INTEGRATED CATCHMENT MANAGEMENT IN AN URBAN CONTEXT THE GREAT AND LITTLE LOTUS RIVERS, CAPE TOWN

Abbott Grobicki

WRC Report No 864/1/01

Water
Research
Commission

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INTEGRATED CATCHMENT MANAGEMENT IN AN URBAN CONTEXT

THE GREAT AND LITTLE LOTUS RIVERS, CAPE TOWN

By

Abbott Grobicki (Pty) Ltd
34 Shortmarket Street
8001 Cape Town

WRC Report No : 864/1/01
ISBN No : 1 86845 686 2

O limpid mirror of God
You bind and gather
All people together

Out of you clouds
Come streaming, winds
Take wing from you, dashing
Rain against stone;

And ever-fresh springs
Well from you, washing
The evergreen globe.

Hildegard of Bingen, *Symphonia*, "Sequence for the Holy Spirit"

ACKNOWLEDGEMENTS

The authors of this report are:

Grobicki, A. (project leader), Males, R., Martinez, I., Matika, S. and Archibald, S.

This study has been funded by the Water Research Commission, whose support is gratefully acknowledged.

Thanks are also due to the local authorities who have co-operated and assisted in the successful completion of the work. These are:

The Cape Town City Council (CCC), now the Cape Town Municipality (CTM); and
The Cape Metropolitan Council (CMC).
The Scientific Services Department of the CCC, now part of the CMC, carried out the laboratory analyses of the water samples.

The Urban Management Research Group in the Department of Civil Engineering at the University of Cape Town has provided access and support for the use of their high-level GIS system, Microstation Graphical Environment (MGE).

The Freshwater Research Unit in the Department of Zoology at the University of Cape Town provided laboratory space and facilities for carrying out macro-invertebrate counts.

We are also very grateful to the following individual academics for their assistance and insight:

Professor John Abbott (UCT)
Mr Neil Armitage (UCT)
Mr Michael Blackmore (Peninsula Technikon)
Professor Bryan Davies (UCT)
Professor Andre Gorgens (Stellenbosch)
Dr Richard Knight (UWC)
Mr Alvin Lagardien (Peninsula Technikon)
Professor Albert Rooseboom (Stellenbosch)

EXECUTIVE SUMMARY

The catchment area of the Great and Little Lotus Rivers presents a microcosm of South Africa's urban development, within a population of some 380 000 people. Communities in the catchment range from the fast-growing but desperately poor informal settlements, through low and middle-income communities with high levels of crime and gangsterism, and the economically important horticultural area of Philippi, to a high-income community around the shores of the lake itself. The legacy of apartheid is strongly apparent in the make-up of these communities and to some extent in the political and social structures representing them.

The overarching vision of the Lotus River project was to create a vehicle whereby people from these very diverse communities could come together with a common desire to improve the environment and quality of life within the catchment in which they live. The end result would be to restore the downstream water body, Zeekoevlei, as a recreational amenity for people from all communities in Cape Town to enjoy, as well as to enhance quality of life within the catchment as a whole. Furthermore, the Lotus River project proposed to develop a "blueprint" for managing urban catchments at a local level, based upon sound multi-disciplinary research, which could then dovetail with the work of the much larger Catchment Management Agencies as set out in the National Water Act of 1998.

The aims and objectives of the Lotus River project were set out as follows:

- To establish a blueprint for urban catchment management in South Africa, focusing upon water quality and ecological stability and improvement, as well as upon hydraulics and flood control
- To identify major sources of pollution in the catchment, both point and non-point sources
- To carry out a detailed flow gauging study and a water quality sampling programme
- To study the ecology of the river systems, including riverine and benthic invertebrates, and macrophytes
- To develop rehabilitation strategies aimed at improving water quality by instream measures, decanalisation, and the creation of wetlands
- To identify all major stake holders in the catchment and to develop a working model for community management of the catchment.

In the original project proposal, a major objective of much of the research would have been to build a GIS-based urban run-off model. Urban catchment management of the future will be based upon such models. Due to the limitations of time and funding, however, this was removed from the original list of aims and objectives. Indeed, it was found that much of the information necessary to carry out this task would not have been available. However, the work of the project continued to be underpinned by its Geographical Information System and the development of methodologies for the use of GIS in urban catchment management. Secondly, a major modification to the aims of the research, which was introduced during the course of the project, was in terms of the ecology of the river systems. The macro-invertebrate communities were found to be so impoverished, and the biodiversity of the river channels in general so low due to extensive canalisation, that having collected the base SASS data the focus of the project then shifted to looking at the ecological management of the catchment as a whole.

The Lotus River project focused from its inception upon creating a positive working relationship with the local authority structures. At all stages, "buy-in" to the project on the part of the local authority was considered to be essential. This was necessary in order to ensure the sustainability of the project objectives in the long term. Sustainability in this context would be demonstrated after completion of the project, by the major stake holders continuing to further the aims of the project and to manage the catchment effectively, with a focus upon water quality and ecological stability and improvement, as well as upon hydraulics and flood control. Furthermore, this management would be carried out in a manner that is inclusive and participatory, working with the full range of stake holders and communities in the catchment.

The development of GIS-based methodologies for Urban Catchment Management

The GIS-based approach discussed in this report provides tools for the analysis and assessment of catchment data in an integrated manner. In addition, the GIS database framework has been designed for a multi-scale approach involving the interaction of metropolitan/regional, catchment level and local level databases. The proposed software configuration has been selected to facilitate an effective co-ordination and integration of data from multiple data sources. The proposed database content and analytical capabilities of the software can be used to address the issues of distribution of costs and benefits amongst all stake holders and to define the roles and responsibilities and accountabilities of the stake holders.

The key advantages of a GIS-based approach may be summarised as follows:

- More accurate parameter estimations
- More rapid parameter estimations
- Facilitates potential for utilising existing public databases
- Facilitates potential for grid-based distributed hydrologic modelling
- Facilitates an integrated analysis of the various data sets through the spatial overlay capability
- Facilitates a more realistic representation of data
  - Raster backdrops to vector data
  - Thematic representation of data
- Facilitates effective communication medium
- Facilitates wide spread diffusion of information
- Facilitates spatial analysis for planning
  - Simplified spatial analysis tools
  - Complex spatial analysis tools.

The primary objective of the GIS component of the Lotus River project was to integrate existing and acquired geo-spatial data on the catchment onto a single platform. The data collation process was carried out in such a manner as to include data from as many of the key role players in the ICM process as possible. This was for two reasons. Firstly, it helped to determine the practical limitations of "real data sets" on a GIS-based ICM approach. Secondly, by basing the methodology on locally acquired data, it would be possible to ensure that the resulting database design would be compatible with existing local authority databases.

A major constraint on using GIS for a catchment situated in a developing country is the patchy nature of digital data. While South Africa is relatively advanced in having digital cadastral data available for the metropolitan areas, there remain large gaps in this cadastral database, which correspond to the informal settlement areas. This is accompanied by an absence of physical infrastructure data for informal areas, while only a limited amount of subsurface infrastructure data is available for the formal areas. Where paper-based maps are available for the stormwater drainage network in former township areas, these maps tend to be unreliable and out of date. Secondly, the organisational structure within the local authorities is not geared up to the needs of integrated projects, and hence data acquisition becomes very difficult.

Two methodologies were tested for capturing the land use data. The first was a cadastral-based approach, while the second was based on mapping the land uses from digital orthophotos. The cadastral-based approach was followed for a selected sub-catchment and a number of land use parameters were estimated. In practice, the method proved far too time consuming to carry out on a catchment-wide basis. As a result, a more rapid method had to be developed. The merits of rapid land use mapping approaches have been very clearly shown in other non-catchment-based studies. The Rapid Land Use Assessment (RLA) methodology developed by the Planning and Development Corporation (PADCO) in the Philippines has proved to be an efficient approach to land use mapping. This methodology relied on the use of satellite imagery for the mapping process. In the case of the Lotus River catchment, 1:20 000 aerial ortho-photo imagery was used in the mapping process. This was available for the years 1983 and 1996.

A comparison of the mapping detail utilised in the production of maps for other recent catchment studies with the land use maps drafted for the Lotus River catchment study (which can be see on the accompanying CD) reveals that the latter are far more detailed with regard to:

1) the number of classes mapped for each sub-catchment,
2) the total number of classes mapped throughout the catchment, and
3) the size of the smallest land use zone mapped in the catchment.

Whereas previous modelling exercises tend to homogenise sub-catchment areas, the land use analysis mapping component of the present study attempted as far as possible to retain the degree of sub-catchment heterogeneity visible on the aerial photography. The use of high-resolution digital orthophotography (at 0.5 m pixel resolution) enabled land use classes useful for development of GIS-based vegetation management and rehabilitation strategies to be mapped.

Catchment characteristics

The Lotus River catchment is a dynamic, fast developing area situated on the Cape Flats, a flat, sandy tract of land connecting the Cape Peninsula to the mainland of South Africa. Being so flat, the catchment boundaries are now to a large extent artificially defined. Although the Lotus Rivers (both Great and Little) drain south into Zeekoevlei, and ultimately into False Bay, large sections of the catchment drain northwards. Hence the urban run-off from this area could equally well have been routed towards Table Bay. In the longer term, the Cape Flats catchment areas all need to be reassessed as part of a wider metropolitan water management system. However, in the short term the Lotus River catchment makes an excellent case study of a highly impacted urban system, demonstrating the whole spectrum of land uses, socio-economic variations and housing types found in South African cities. It also exhibits acute ecological stress, highly polluted water bodies and significant loss of biodiversity.

The catchment area of the Great Lotus has been analysed in more detail, as this river is much larger and carries a greater pollution load than the Little Lotus. The latter runs primarily through areas of middle-income, formal residential housing, and the resulting water quality problems are not as severe. The Great Lotus catchment area, on the other hand, displays the wide variation in land use mentioned above, and is 4816 hectares in extent. 26% of this catchment is currently cultivated farmland, which is heavily fertilised. Over the 13 years from 1983 to 1996, the impervious area of the catchment grew from 17% to 34% of the entire catchment area, as a result of rapid urbanisation.

The Great Lotus catchment is now home to nearly 380 000 people, only 72% of whom are formally housed. Approximately 24% or 90 000 people reside in informal settlements, while 4% live in informal housing in the site and service areas. The figures for informally housed people exclude those living in backyard shacks within the formal housing areas, who are counted within the formally housed population. Informal settlements are a phenomenon, which is characteristic of cities in the developing world, but due to the former policy of influx control it was relatively unknown in South Africa until the late 1980s. The informal population of the Greater Lotus River catchment is growing especially quickly, due to its desirable location near to job opportunities, and large areas of "municipal open space".

Hydrological and water quality studies

Much of the drainage pattern on the Cape Flats was historically undefined, with high levels of infiltration through the sandy soil and many seasonal wetlands, which evaporated in the dry summer months. To combat increased runoff due to urbanisation, the original Lotus Rivers (both Great and Little) were extended to newly developing areas as excavated canals. Further upgrading brought about concrete lining, which is efficient in rapidly transporting water yet ignoring problems of water quality and reduced ecological habitat. The Great Lotus River now exists as a multi-stage channel with concrete lined trapezoidal low flow section and grass lined

high flow section. The section flowing through the Philippi Horticultural Area is an enlarged earth lined canal, permitting groundwater interaction. Throughout the redesign and upgrading work carried out historically, no flow measurements were ever undertaken to verify the event-based stormwater model for the catchment.

Water quality testing carried out by the municipality was restricted to concentration analysis for selected sites. Without any accompanying flow measurements, no source apportionment or annual loading calculations could be undertaken. Because of these shortcomings in the historical monitoring, a combined water quantity/quality sampling program was thus required aimed at carrying out a detailed flow gauging study and attempting to identify pollutant sources to the canal. Significant tributary inflows were selected for discrete sampling. A continuous datalogger/automated sampler was installed at the Springfield Road culvert, 8.5 km from the source. The probe measurements included flow velocity, pH and dissolved oxygen, and results were logged every 10 minutes. The sampler was also utilised to capture rain events producing runoff over a threshold flow, which allowed the estimation of annual pollutant loading for the various parameters.

A once-off analysis for protozoan parasites detected *Giardia* oocysts in the samples, but no *Cryptosporidium*. This is sufficient to constitute a health risk with respect to *Giardia*. Heavy metal analyses of both water and sediments, and analyses of volatile organic compounds (VOCs) in the water were also undertaken as a baseline assessment. These parameters were present in the Great Lotus canal within accepted guidelines. The VOCs were found to be mainly saturated hydrocarbons, characteristic of fuels and solvents e.g. diesel, motor oil, and kerosene. The Great Lotus River catchment is characterised by few industries and no wastewater treatment plants discharging into the canal. Most pollution contributions are therefore from "non-point" or diffuse sources ie. highway run-off, urban residential pollution entering the canal through the stormwater network and dumping, and the agricultural area contributing groundwater and surface water from drainage ditches.

The Great Lotus River is characterised by very poor water quality, with high nutrient loading, as well as very high faecal coliform counts. This is due to raw sewage effluent overflowing from blocked sewers into the stormwater drains, occasional sewer pump overflows, as well as the inadequate or non-existent sanitation characteristic of the informal settlement areas. Despite recent efforts by the local authorities at sewer upgrading, the microbial counts in the stormwater do not appear to be dropping. Table E1 summarises the water quality data obtained over the sampling period for the main parameters analysed.

Table E1 Water quality data for the years of sampling 1997 and 1998, at the point closest to the outflow of the Great Lotus River

1997	Min	Max	Mean
Total Nitrogen (mg N/l)	4.684	15.9	10.991
Total Phosphorus (mg P/l)	0.405	1.304	0.664
Soluble Reactive Phosphorus (mg P/l)	0.317	1.21	0.54
COD (mg O/l)	29.8	84.15	51.188
TSS (mg/l)	4.5	55.5	13.646
Conductivity (mS/m)	94.6	196	148.4
PH	7.35	7.98	7.815
Faecal coliforms (count/100ml)	1.3e3	3.9e7	5.01e6
1998	Min	Max	Mean
Total Nitrogen (mg N/l)	3.272	17.332	9.323
Total Phosphorus (mg P/l)	0.421	0.741	0.588
Soluble Reactive Phosphorus (mg P/l)	0.094	0.594	0.365
COD (mg O/l)	39	107.9	58.642
TSS (mg/l)	6.2	36.85	17.33
Conductivity (mS/m)	52	170	125.564
PH	7.72	8.67	8.192
Faecal coliforms (count/100ml)	4000	4.7e7	5.28e6

Since sampling was carried out along the length of the Great Lotus River, it was possible to construct profiles of the pollutant concentration (in mg/l) and pollutant mass flux (in mg/s). The effect of each major tributary inflow was found by sampling 20 metres upstream and downstream of each tributary, and also where possible in the tributary itself, together with a flow measurement. Carrying out a mass balance calculation on the pollutant mass flux then enabled the accuracy of the sampling method to be assessed.

Table E2 Percentage contributions to Total Nitrogen (TN) and Total Phosphorus (TP) mass flux in the Great Lotus River, from diffuse and tributary sources with different land uses (01/09/97)

Distance from source	Contribution	TN : % flux contribution	TP : % flux contribution
0.5 – 2.4 km	Diffuse source contributions from Barcelona, New Rest and upper part of Nyanga/Guguletu	17.15	1.39
~2.4 km	Tributary source at NY3 stormwater pipeline draining most of Nyanga and Gugulethu	22.5	7.9
	Total contribution of Nyanga, Guguletu, and Barcelona	***35.8***	***11.57***
~4.8 km	Tributary source draining Crossroads, Philippi East, Philippi West and Brown's Farm	16.01	2.88
~5.3 km	Vygekraal detention pond draining subcatchment of Philippi Horticultural Area	6.1	5.48
~5.3 to 7.3 km	Unlined section along Lansdowne Road permitting groundwater flow	2.32	13.0
~7.3 to 10 km	Unlined section through Philippi Horticultural Area permitting groundwater flow	8.52	21.06
~10 km	Tributary source from Lansdowne-Wetton Corridor	5.74	3.17
~10 to 11.8 km	Diffuse sources from residential area of Ottery and Philippi Horticultural Area	6.66	25.32
~11.8 km	Tributary source from subcatchment of PHA	5.94	10.95
~11.8 to 12.9 km	Diffuse sources from Lotus River residential area	3.64	2.66

As the numerical analysis in Table E2 shows, the largest contribution to the nitrogen loading came from the poor residential areas in the north of the catchment, which have a high proportion of informal housing, giving a total of 35.8% of the nitrogen flux. On the other hand, these areas contributed only 11.6% to the phosphorus flux, while the largest contributions came from subcatchments in the Philippi Horticultural Area. Also, groundwater flow played a more important role in the transport of phosphorus, in the unlined sections. In the lined sections of the canal, through the built-up residential areas, as expected, there was little groundwater contribution to flow.

To investigate the sources of total phosphorus (TP) coming from the Philippi horticultural area, a subcatchment investigation revealed that TP concentrations for channels adjacent to irrigated fields with intensive cropping are significantly higher than elsewhere in the subcatchment, despite the prevalence of calcareous soils. The ratio of uncultivated to cultivated P concentrations was 0.411, ie. the concentration of phosphorus in drainage ditches adjacent to cultivated lands is more than double than that measured adjacent to uncultivated land. This shows that the agricultural lands contribute high TP concentrations to the underlying subsoil water, through the application of fertiliser. TP concentrations in irrigation ponds were found to be relatively low, compared to values for the drainage ditches, indicating sedimentation taking place.

Storm event monitoring of the main stem channel revealed that both TP and TN mass flux increased during significant events. Maximum flux occurs around flood peak, indicating a seasonal variation in nutrient loading, with most of the load transported during the winter rainfall season. Combined EMC, total storm load (mass) divided by the total runoff volume, for selected storms multiplied by annual runoff at Springfield Road results in a annual TP load at Springfield Road of approximately 5300 kg/a. This is 10% higher than the interpolated load from the discrete sampling program for the same point, indicating that proportion of the load (contributed by

winter storms) that is not captured by the discrete sampling programme. Assuming that the relationship between EMC and interpolated load calculation for Springfield Road holds for 7th Avenue, the annual TP load at 7th Avenue (and thus into Zeekoevlei) is approximately 7400 kg/a.

Ecological management of the catchment

The Lotus River Catchment is a highly modified environment. It has recently become intensively urbanised, and even the remaining vegetated areas and wetlands are very disturbed. Drainage patterns have been highly modified; many of the vlei and marsh areas have been filled in or destroyed, and storm-water canals have been engineered. Nutrient additions to farming areas and urban run-off have increased the nutrients in the aquatic and terrestrial systems 10-fold, compared to base levels which could be expected in the pristine environment. In addition to this, introduced Australian acacia species have become highly noxious invasive weeds, spreading into all open areas and eliminating the natural vegetation. The aims of this ecological assessment therefore move beyond identification and conservation of the remaining semi-natural/pristine areas of the catchment, towards a more dynamic, positive approach to the environment in an urban context. Rare and threatened habitat types such as seasonal vleis and sandplain fynbos need to be valued and managed, but this has to be done together with the people who live around these areas and bearing in mind the future development of the catchment. Above all, the major focus of ecological management in the catchment is rehabilitation.

Specific aims for the ecological management of the catchment can therefore be summarised as follows:

- Increasing the biodiversity of the catchment, both in terms of species richness and habitat diversity
- Conserving unique species and features
- Increasing the sustainability of the ecological systems in the catchment, through reinstating functioning ecosystems
- Improving water quality
- Improving the quality of the available open space (both for human use and in terms of habitat quality for the fauna/flora)
- Ensuring a sufficient representation of habitats and habitat types in the subcatchment (enriching the urban environment)
- Enhancing access by communities to the environmental resources of the catchment.

The open areas in the Lotus River catchment can be classified into three categories, namely formally conserved areas, areas with potential for multiple land use, and degraded/unutilised areas. There are very few existing conservation areas and these are not actively conserved, eg. the Edith Stevens Nature Reserve. On the other hand, Varkensvlei forest reserve, while not officially conserved, is in private ownership and has not been disturbed. It is important that these areas be integrated into plans for the rest of the open space. They are both surrounded by open areas, which are of lesser conservation value but have high rehabilitation potential. The benefits involved in managing the reserves and the surrounding open space together are manifold:

- Active rehabilitation of the areas outside reserves, which are ignored and under-utilised at present, would be encouraged
- Core areas could be protected while still allowing people access to the open areas for recreation
- Managing these areas as a single unit would increase both the range of habitats available and the size of the reserves
- If planned correctly it would be possible to create biological corridors and improve dispersal by joining together areas of high conservation value with areas of low conservation value.

Three types of wetland open space in the catchment area with potential for multiple land use and rehabilitation include: detention/retention ponds; farm irrigation ponds; and the river corridor itself. It is important to realise that detention and retention ponds could be examples of a habitat type that is highly threatened on the Cape Flats, ie. seasonal wetlands. They are the urban equivalent of the natural ponding areas that existed prior to urbanisation. Degraded as they are, any plans for improvement or rehabilitation of these areas do not need to be non-destructive. The areas could be engineered to be more accessible to people; water could be diverted into them to encourage

nutrient uptake by the plants; possibilities exist for their use for the cultivation of high-value aquatic plants. Their function as detention storage need not be impaired by attempts at rehabilitation, if they are correctly redesigned.

Farm dams are designed purely for water storage; however, a few simple changes could also turn these numerous dams into valuable wetland resources. On a physical level changing the design of the dams so that they have gentle slopes (even just on one side) rather than steep banks would improve the habitat immensely. This would provide a gradient of wetland conditions (wet-dry) and allow for the establishment of aquatic vegetation. Another step, which could be taken, would be fencing off a portion of the wetland to prevent disturbance and trampling from cattle. Further rehabilitation possibilities involve actively planting wetland vegetation. The current use of farm dams does not necessarily clash with their potential to provide acceptable habitat. If this could be implemented then the Philippi horticultural region would contain of a series of islands of suitable wetland habitat scattered within the matrix of an intensively farmed area. Financial subsidy of some kind may be necessary to encourage the farmers to create such areas; this activity would offset to some extent the ecological damage caused by intensive fertilisation.

Participatory Urban Catchment Management

Within the notion of participatory development there are two important components. The first is the participation component and the second the development project, which should be two distinct, yet integrated processes. This implies that there should be two sets of objectives, one for the project and the other for community participation. As for any project, there should be clear goals and objectives for the process of participation, which are distinct from those of the project. The goal and objectives of the community participation process provide the basis on which to build and develop a community participation strategy.

The institutional models and mechanisms envisaged to translate the participation strategy into action would be informed by the objectives of the community participation process. The nature of these institutional models and mechanisms finally established should be influenced by the local context, that is, the project environment and the nature of the project. This is because every project environment has unique features, specific to that particular environment or situation, such as the social patterns, inter-community relations, social stability, socio-cultural and power relations in that environment. These features are very important because they provide key indicators of the nature of structures and mechanisms that are likely to be durable, sustainable, effective and acceptable to the local people.

One of the major objectives of the Lotus River Project was to identify all major stake holders in the catchment and to develop a working model for community management of the catchment. The community participation strategy was designed to involve identified community-based stake holders and representatives of the relevant local government departments directly in the process of developing a model for community involvement in urban catchment management. It was important to bring the community sector to an appropriate level of understanding of the concept, the process and the key components of Integrated Urban Catchment Management, to enable them to negotiate with the local authorities and other stake holders. The specific objectives to the strategy were as follows:

- To identify all stake holders who had an interest in the development of the Lotus River
- To develop a database of these stake holders
- To introduce ICM to the community sector and their representatives
- To facilitate discussions and co-operation between stake holders
- To identify key issues of importance to stake holders in relation to ICM
- To identify the level of decision making at which the issues would considered
- To gain acceptance of the broad principles of community management
- To explore appropriate mechanisms of community input in the decision-making process.

The strategy was divided into three phases consisting of the database development, local interests and needs analysis and platform building phase. The process started with the identification of organised community groups such as civic organisations, local and school based environmental groups, RDP forums, local Councillors and

influential individuals such as business and church leaders in the Lotus River Catchment area. The strategy was implemented through an on-the-ground approach consisting of:

- One-on-one discussions with community representatives
- Group tours to important sites in the catchment and along the river corridor
- Workshops to identify stake holder related interests and needs relevant to the ICM process
- Series of open meetings involving community and local government representatives to discuss issues of principle in terms of community involvement in the ICM process

What makes integrated projects such as ICM important is the inherent ability of such projects to pull together divergent views, needs and interests into generic categories and explore solutions that would address these needs and interest in a holistic manner. During the implementation of the community participation strategy, it was possible to develop specific categories that accommodated the needs and interests that were identified by the different stake holders. These categories are:

- Integrated service delivery and management: stormwater management should be linked to other services such as street cleansing, solid and liquid waste collection and disposal, environmental conservation and improvement. This requires that the planning and implementation of services and functions related to the achievement of a healthy and clean environment should be integrated, through decentralised mechanisms of planning and implementation such as area management
- Integrated development planning and implementation should also facilitate and promote an environmental ethic and sense of ownership. This could be effected through the following:
  (1) Linking environmental education and management programmes to social and economic development projects such as the provision of housing and appropriate infrastructure, promoting income generation opportunities (short and long-term), and supporting organisational development and skills transfer. The programmes must be designed to broaden the philosophy of environmental conservation and management to include socio-economic and physical elements and to assist people to gradually internalise and understand the connections between the biophysical and the economic elements of development.
  (2) Catering for the needs and interests of farmers while addressing the impact of their activities on the environment. The plan would therefore have to facilitate the development of appropriate farming systems approach to promote efficient and environmentally sustainable farming methods.
  (3) Developing long-term environmental awareness programmes that are linked to implementation projects related to local needs and interests. These programmes should be aimed at reaching learners in local schools, people in local organisations, environmental advocacy groups and the general public.
- The existence of urban informal settlements must be acknowledged and upgrading programmes implemented. Any process that is meant to promote an environmental ethic in poor communities will simply fail if people continue to live in squalid conditions, without decent housing and services.
- Community participation and integrated service delivery are two sides of the same coin. Participation should be supported through meaningful capacity building and skills development programmes. It is very important to note that community representatives have constantly raised the issue of tangible benefits resulting from people's participation in ICM, by implementing local projects that improve the physical environment, open opportunities for local employment, and provide capacity building and skill transfer opportunities to local organisations and individuals. Examples include:
  (1) Outsourcing special services like the collection of garden waste, building rubble and dead pets to local entrepreneurs. Such services are currently not provided in some areas of the catchment.
  (2) Providing public sanitation and waste disposal facilities in areas such as informal settlements, trading and sport areas, and public transport interchanges.

Conclusions

The future for urban catchment management in South Africa is full of opportunities:

- With advances in modelling, it will be possible to move towards forecasting a range of scenarios with visual GIS-based representation, allowing urban catchment committees to make real choices with regard to stormwater infrastructure. Advanced technology will make it easier, not harder, for non-technical people to understand the consequences of various choices, by being able to see the outcomes represented visually.
- As the concept of catchment management becomes more widely known and accepted among urban professionals and the general public, catchment committees will become able to influence the urban fabric more fundamentally through decisions on land use changes, and through creating multiple land use opportunities.
- With changes in institutional structures, urban catchment management risks losing its financial base, where water supply and wastewater treatment services increasingly become fragmented and privatised. Stormwater management alone has a less secure financial base. Achieving long-term sustainability for urban catchment management can be assured by linking more strongly with quality-of-life considerations, especially the provision of recreational amenities and the conservation and restoration of biodiversity. Here, community-based catchment initiatives as in the example of the USA are crucial to success.
- Conversely, where water services become more integrated institutionally, catchment management can be linked with land care, wastewater reuse and demand minimisation in an overall approach to urban water management. An example of this is the creation of the Sydney Catchment Authority in Australia (July 1999), which owns the water resources for Sydney, has responsibility for 11 catchments, and has strong referral powers with regard to undesirable developments.
- Perhaps the most important recognition to make in catchment management, especially in the urban context, is that social and institutional processes should take precedence over purely technical decisions. This has been shown over and over again in successful catchment management projects worldwide.

The concluding chapter of this report provides some recommendations and guidelines for urban catchment management. The first section of this chapter presents the top 10 lessons learned from watershed protection initiatives in the USA, as summarised by the US Environmental Protection Agency. These provide extremely valuable general pointers for the set-up phase, and for the social and institutional process of urban catchment management. Access to many useful Internet resources is provided in this section. Secondly, best management practices (BMPs) for stormwater management are outlined, together with an analysis of their effectiveness, drawn from international sources. This discusses the importance and priority which should be given to non-structural or "soft" BMPs, and provides a state-of-the-art list of structural or "hard" BMPs to be used in urban catchment management. Thirdly, some general guidelines for GIS-based urban catchment management are presented, which have been drawn from the experiences of the Lotus River project. The final part of the chapter presents specific recommendations for the management of the Lotus River catchment, which have arisen from the work carried out in this project.

GLOSSARY

AGNPS	Agricultural Non-point Source Pollution Model
ARC	Agricultural Research Council
BHE	Base Hydrological Element
BMP	Best Management Practices
BSU	Basic Spatial Unit
CCC	Cape Town City Council (up to 30 June 1997)
CIR	Colour Infrared
CMA	Cape Metropolitan Area
CMA	Catchment Management Agency
CMC	Cape Metropolitan Council
CMD	Catchment Management Department
CN	Curve Number
CTM	Cape Town Municipality (from 1 July 1997)
DEAT	Department of Environmental Affairs and Tourism
DEM	Digital Elevation Model
DTM	Digital Terrain Model
DSS	Decision Support System
DWAF	Department of Water Affairs and Forestry
EIA	Environmental Impact Assessment
EMC	Event Mean Concentration (mg/l)
EPA	Environmental Protection Agency
GIS	Geographic Information System
GOAL	Graphical Object Programming Language
GUI	Graphical User Interface
ICM	Integrated Catchment Management
INFRUITEC	Institute for Soil, Climate and Water
KSAB	Keep South Africa Beautiful
LP	Linear Programming
MGE	Microstation Graphical Environment
MLC	Metropolitan Local Council
NDH	National Department of Housing
NGO	Non-Government Organisation
NRWA	Nashua River Watershed Association
PADCO	Planning and Development Corporation
PHA	Philippi Horticultural Area
PICC	Projet Informatique de Cartographie Continue
RBA	Rapid Biological Assessment
RLA	Rapid Land Use Assessment
SASS	South African Scoring System
SRP	Soluble Reactive Phosphorus (mg P/1)
TIN	Triangular Irregular Network
TKN	Total Kjeldahl Nitrogen (TKN)
TN	Total Persulphate Oxidisable Nitrogen (mg N/1)
TP	Total Phosphorus (mg P/1)
TWQR	Target Water Quality Range
UCT	University of Cape Town
USLE	Universal Soil Loss Equation
VOC	Volatile Organic Compounds
WRC	Water Research Commission
WWTP	Waste Water Treatment Plant

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND TO THE LOTUS RIVER PROJECT

In 1996, when this project was first proposed, there was a great deal of local concern in Cape Town over the highly polluted state of Zeekoevlei, a large (256-hectare) urban lake which was popular for water sports. However, the catchment area for Zeekoevlei fell into three different local authority structures, and there was no structural mechanism by which to tackle the severe water quality problems of the urban rivers (the Great Lotus and the Little Lotus) flowing into Zeekoevlei. At that time, local authority responsibility with regard to urban rivers was focused solely upon flood control. Furthermore, the relationship between the hydrogeology of the area and issues relating to lake management were not well understood, as the catchment was not being viewed holistically.

At the same time, there were developments at the national level, which were creating a policy focus for the new national water legislation, looking at the creation of Catchment Management Agencies. This work came to fruition in the National Water Act of 1998. It was clear, however, that urban catchments have specific problems, which can have a serious impact upon their receiving waters, and that these issues would have to be managed at the local government level. Policy developments at national level were too broad to cover details of structures to manage urban catchments in an integrated way. Also, the catchment management areas proposed for the new agencies were very large, necessitating work to be done on a different scale to that needed in urban catchments. Hence the Lotus River project proposed to develop a "blueprint" for managing urban catchments at a local level, based upon sound multi-disciplinary research, which could then dovetail with the work of the larger Catchment Management Agencies.

The catchment area of the Great and Little Lotus Rivers presents a microcosm of South Africa's urban development, within a population of some 380 000 people. Communities within the catchment range from the fast-growing but desperately poor informal settlements, through low and middle income communities with high levels of crime and gangsterism, and the economically important horticultural area of Philippi, to a high-income community around the shores of the lake itself. The legacy of apartheid is strongly apparent in the make-up of these communities and to some extent in the political and social structures representing them. The overarching vision of the project was to create a vehicle whereby people from these very diverse communities could come together with a common desire to improve the environment and quality of life within the catchment in which they live. The end result would be to restore Zeekoevlei as a recreational amenity for people from all communities in Cape Town to enjoy, as well as to enhance quality of life within the catchment as a whole.

This catchment therefore offered an ideal starting point for the development of urban catchment management principles, which could be applicable more widely in South African cities. Furthermore, in the local authority transformation process in 1996 and 1997, an opportunity presented itself for members of the project team to influence the powers and duties of the Cape Metropolitan Council. Hence, when the Council officially took up the reins on 1 July 1997 after the first democratic local government elections, it became the first metropolitan area in South Africa to have a Catchment Management Department specifically charged with the duties of urban catchment management. At the time of writing, it remains to be seen however whether this department will survive the next imminent transition in local government to the "unicity" system.

1.2 AIMS AND OBJECTIVES OF THE PROJECT

The work of this research project was carried out over 2 years and 3 months, from 1 January 1997 to 31 March 1999. The aims and objectives of the Lotus River project were set out in the research proposal as follows:

- To establish a blueprint for urban catchment management in South Africa, focusing upon water quality and ecological stability and improvement, as well as upon hydraulics and flood control
- To identify major sources of pollution in the catchment, both point and non-point sources
- To carry out a detailed flow gauging study and a water quality sampling programme
- To study the ecology of the river systems, including riverine and benthic invertebrates, and macrophytes
- To develop rehabilitation strategies aimed at improving water quality by instream measures, decanalisation, and the creation of wetlands
- To identify all major stakeholders in the catchment and to develop a working model for community management of the catchment.

In the original project proposal, a major objective of much of the research would have been to build a GIS-based urban run-off model. Due to limitations of time and funding, however, this was removed by agreement from the list of aims and objectives. Indeed, it was found that much of the necessary information to carry out this task would not have been available. However, the work of the project continued to be underpinned by its Geographical Information System and the development of methodologies for the use of GIS in urban catchment management.

Secondly, the major modification to the aims of the research, which was introduced during the course of the project, was in terms of the ecology of the river systems. The macro-invertebrate communities were found to be so impoverished, and the biodiversity of the river channels in general so low due to extensive canalisation, that having collected the base data the focus of the project then shifted to looking at the ecological management of the catchment as a whole.

In addition, the project team was involved to some extent in lake management at Zeekoevlei, although the majority of project resources were dedicated to researching the river systems and the catchment area. In terms of lake management, the project team supported the Zeekoevlei Environmental Management Team, by assisting in formulating a strategy for periodically dropping the level of the lake, and subsequently developing a Drawdown Action Plan for assessing the full effects of the drawdown. This action plan has subsequently been implemented by the local authority concerned.

1.3 SIGNIFICANT MILESTONES AND OUTCOMES

The Lotus River project focused from its inception upon creating a positive working relationship with the local authority structures. To this end, bi-monthly meetings were organised under the auspices of the project, for the purpose of bringing together the project team with the relevant officials in the departments of Stormwater Engineering, Parks and Recreation, Environmental Management, Water and Waste, etc. Please see Appendix A containing details of major meetings organized and attended.

With the changes in local authority structure, adjustments had to be made constantly to ensure that the relevant players were on board. Furthermore, officials from the local authority were also invited to the research project's annual Steering Committee meetings. At all stages, "buy-in" to the project on the part of the local authority was considered to be essential. This was necessary to ensure the sustainability of the project objectives in the long term. Sustainability in this context would be demonstrated after completion of the project, by the major stakeholders continuing to further the aims of the project and manage the catchment effectively, with a focus upon water quality and ecological stability and improvement, as well as upon hydraulics and flood control. Furthermore, this management would be carried out in a manner that is inclusive and participatory, working with the full range of stakeholders and communities in the catchment.

Initial local authority contacts were developed by the project's involvement with the Zeekoevlei Environmental Management Team. Driven by the award-winning conservation group, the Zeekoevlei Environmental Forum, this team represented an early attempt by the Cape Town City Council (as it was prior to 1997) to work with residents in formulating responses to environmental problems. The Lotus River project's main contribution was to show that, contrary to the prevailing scientific opinion, implementing a drawdown of the lake would be beneficial, not harmful. This beneficial effect would be brought about by the inflow of groundwater from the Cape Flats Aquifer, which is far less polluted than the water in the Lotus

Rivers. The first drawdown of Zeekoevlei took place in 1997, and has been repeated every year thereafter, since water quality was indeed greatly improved by the drawdown. The drawdown also had other benefits, in allowing physical access to the lake shores to remove litter and water hyacinth. However, the Zeekoevlei Environmental Management Team had no formal basis to its existence, and after the re-drawing of local authority boundaries the management of Zeekoevlei passed from Cape Town to the South Peninsula Municipality.

The fragmentation caused by the multiplicity of local authority structures was overcome to some extent by the creation of the Catchment Management Department of the Cape Metropolitan Council, on 1 July 1997. This department convened an initial Lotus River Committee meeting on 22 July 1997, bringing together officials from various municipal departments and sub-structures, to meet with project team members. Subsequently, local authority officials met formally with the project team on 22 October 1998 and 2 December 1998, to discuss the Zeekoe Drainage System.

A parallel process was set in motion by the project team through numerous individual meetings with community groups and other stakeholders, farmers, NGOs, environmental groups, schools and educational bodies. A series of workshops and catchment tours were organised. A weekend was set aside on 27 and 28 June 1998 for catchment tours, in which some 55 representatives from a number of communities participated.

A significant milestone was reached on 19 January 1999, when community members involved in the community participation process and local authority officials came face to face in a discussion around the problems of the catchment, and the way forward. This meeting reached agreement that community members would be henceforth represented on the to-be-formed Catchment Committee, and that negotiations would continue on the structure and powers of this committee. This was the last public meeting to be convened under the auspices of the Lotus River project. On 3 February 1999 the Catchment Management Department of the Cape Metropolitan Council formally convened a Catchment Committee including a range of stakeholders from the various communities and other groups.

Specific outcomes, which can be ascribed to this project, are as follows:

(1) **Community participation.** The most significant outcome of this project has been that the Catchment Management Department has replicated the process of forming catchment committees in most other catchments of the Cape Metropolitan Area. In each of these, problem areas are identified by the residents and other stakeholders in the catchment, and in many cases funds have been made available to design and implement solutions. These processes have taken place with a greater or lesser degree of consultation with communities. Due to the relatively small powers of these Committees, however, community groups from disadvantaged areas frequently lose interest in the discussions, if immediate benefits are not seen to be forthcoming for their community. The problem of the lack of participation is magnified by poor choice of venue, and level of accessibility of information. The greatest barriers to the involvement of poor communities are invariably the physical barrier of transport to attend meetings, and the communication barriers of language and concepts.

(2) **Integrated river management; river and wetland restoration.** A second outcome has been the general acceptance of the principle that flood alleviation is not sufficient as a function of local government, where urban stormwater is concerned. Water quality and environmental issues are as important, and hence the involvement of environmental scientists as well as stormwater engineers in urban river design and maintenance has been taken on board. Hand in hand with this has gone a move away from the use of concrete linings in canalisation, and the recognition of the need for more natural river forms and the multiple uses of vegetation in the urban river corridors and river channels. River maintenance has become a more environmentally conscious activity, although at the time of writing it is apparent in many cases that this has yet to filter through from the abstract level of intention (as mediated by the Catchment Management Department) to the level of contractors' actual on-site activities. The principle of the conservation, preservation and, in some cases, re-creation of urban wetlands as a necessary component of the urban landscape has also been accepted. A follow-up project is now underway, investigating the use of high-value aquatic plants for income generation from degraded urban wetlands (WRC project no K5/1054).

(3) **Monitoring and flow gauging.** A third, more specific outcome has been the coupling of flow gauging to water quality sampling. While an extensive historical database of water quality was kept and updated on urban rivers in Cape Town, no flow gauging had been undertaken, until it was shown in the course of this project how useful the calculation of pollution loads can be in management decision-making. The Catchment Management Department has now undertaken an extensive programme of monitoring and flow gauging in all the urban rivers within the Cape Metropolitan Area.

(4) **The use of GIS (Geographical Information Systems) in urban catchment management.** While GIS is becoming ever more widespread, a number of techniques were tested and new approaches pioneered in the course of this project. This is an essential component of urban catchment management, as geo-spatial data and information on all aspects of the catchment can be presented in a truly integrated fashion, to give an overview of the state of the catchment for management and decision-making purposes.

(5) **Research and education.** The Lotus River project has contributed to the studies of a number of postgraduate and undergraduate students. It was a major component of one Masters thesis, and one PhD thesis, as well as providing information to a number of other researchers (see below). At the undergraduate level, three final-year civil engineering projects and a number of teaching assignments have been based upon the project. At the level of schools, the project team interacted with a number of school groups, and tried to bring the concepts and practical application of catchment management into Curriculum 2005, through working with the Western Cape Education Department. On a broader level of public education, the project has been shared with a range of community groups, discussed on the radio, and presented to gatherings of hydrogeologists, aquatic scientists, civil engineers, and urban planners. Two thousand full-colour brochures were printed and distributed in the course of the community participation process. Finally, papers drawn from work done in the course of the project have been presented at a number of local and international conferences.

PhD:

Martinez, I. A. (1999) The development of a bi-level GIS database model for informal settlement upgrading. University of Cape Town.

MSc:

Males, R. (2000). Hydrological modelling of the Lotus River catchment using PC-SWMM (final title not yet decided). University of Stellenbosch, Department of Civil Engineering.

4th year theses prepared in partial fulfillment of the requirements for the degree in BSc Civil Engineering, University of Cape Town:

(1) B.Petersen, "Solid waste management for low income areas"
(2) S. Evans, "Geographic information systems in catchment management"
(3) T.S.Maseng, "Stormwater management within the Lotus River catchment"

Final year undergraduate students from Roskilde University, Denmark:

Pia Jorgensen, Mette Sorensen, Christina Otzen and Ole Emmik Sorensen, "Phola Park: waste management in dense settlements"

Course no. 05-662: Water pollution control planning; University of Guelph in Ontario, Canada:

Simone Lyons and Caroline McGahey

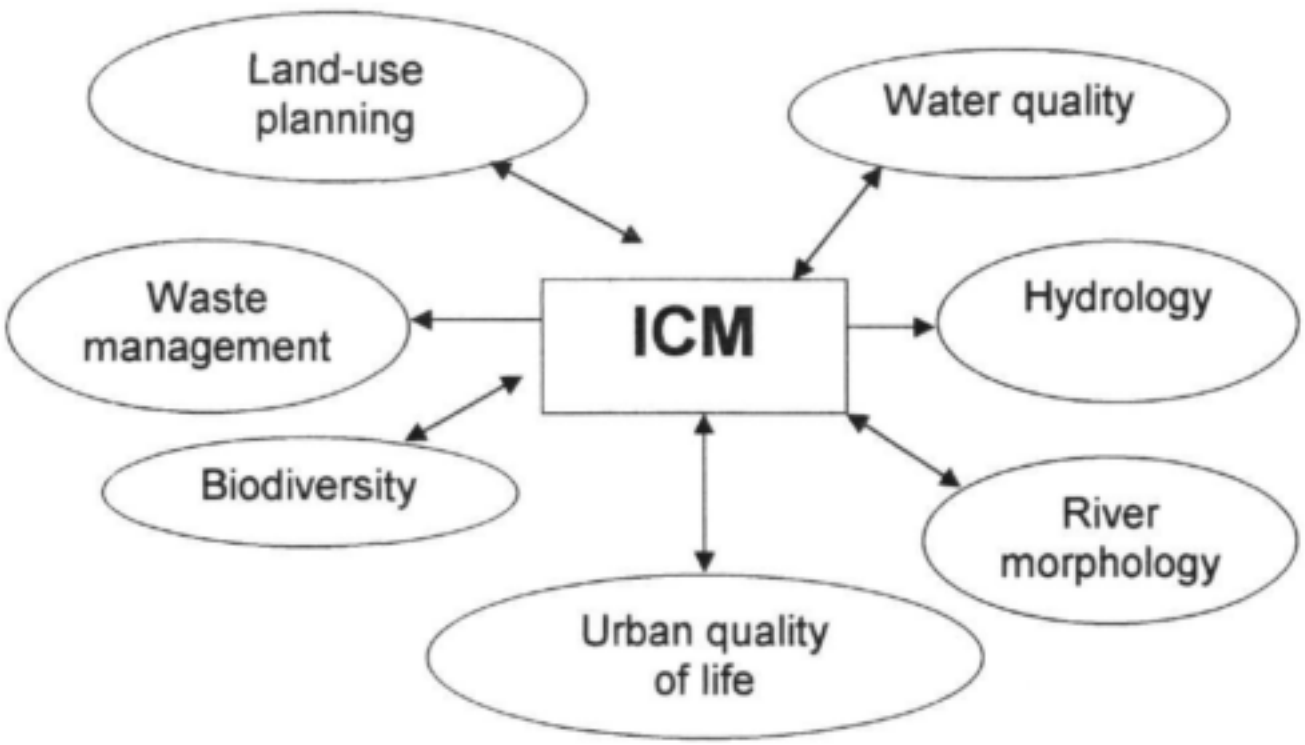
1.4 INTEGRATING ACROSS DISCIPLINES: PROGRESS TOWARDS URBAN CATCHMENT MANAGEMENT

Perhaps the most interesting and challenging aspect of urban catchment management is the necessity for professionals and scientists from a wide range of disciplines to work together. On the management side, the gap between the perceptions of people from different disciplinary backgrounds is widened by the administrative and departmental structures of local government. Frequently there is little or no communication between personnel in different departments, even though they may be working on different aspects of the same problem, eg. river maintenance and the maintenance of public open space. The former would be carried out through Stormwater Engineering, for example, and the latter through Parks & Recreation (or the equivalent departments). The former would be managed by civil engineers and engineering contractors, and the latter by urban planners, horticulturalists, and landscaping contractors. Through urban catchment management structures, it becomes possible for these groups to work together to achieve a common aim, which is the improvement of the river corridor.

Similarly, in the academic world the deep divides between disciplines and the specific world-views associated with each branch of learning create situations where people may have quite opposite perceptions of the same situation. For instance, a civil engineering training specialising in hydraulics may produce people prepared to constrain and canalise rivers in such a way as to avoid flood risk. Conversely, an ecological background produces people who perceive the environmental damage and loss of biodiversity associated with channelisation and canalisation, but may have difficulty in hearing a community's concerns regarding safety, flood security and land values. Even among ecologists, usually a holistic discipline, it is possible to find groups where zoologists and botanists, for instance, do not work together because their research interests are quite different.

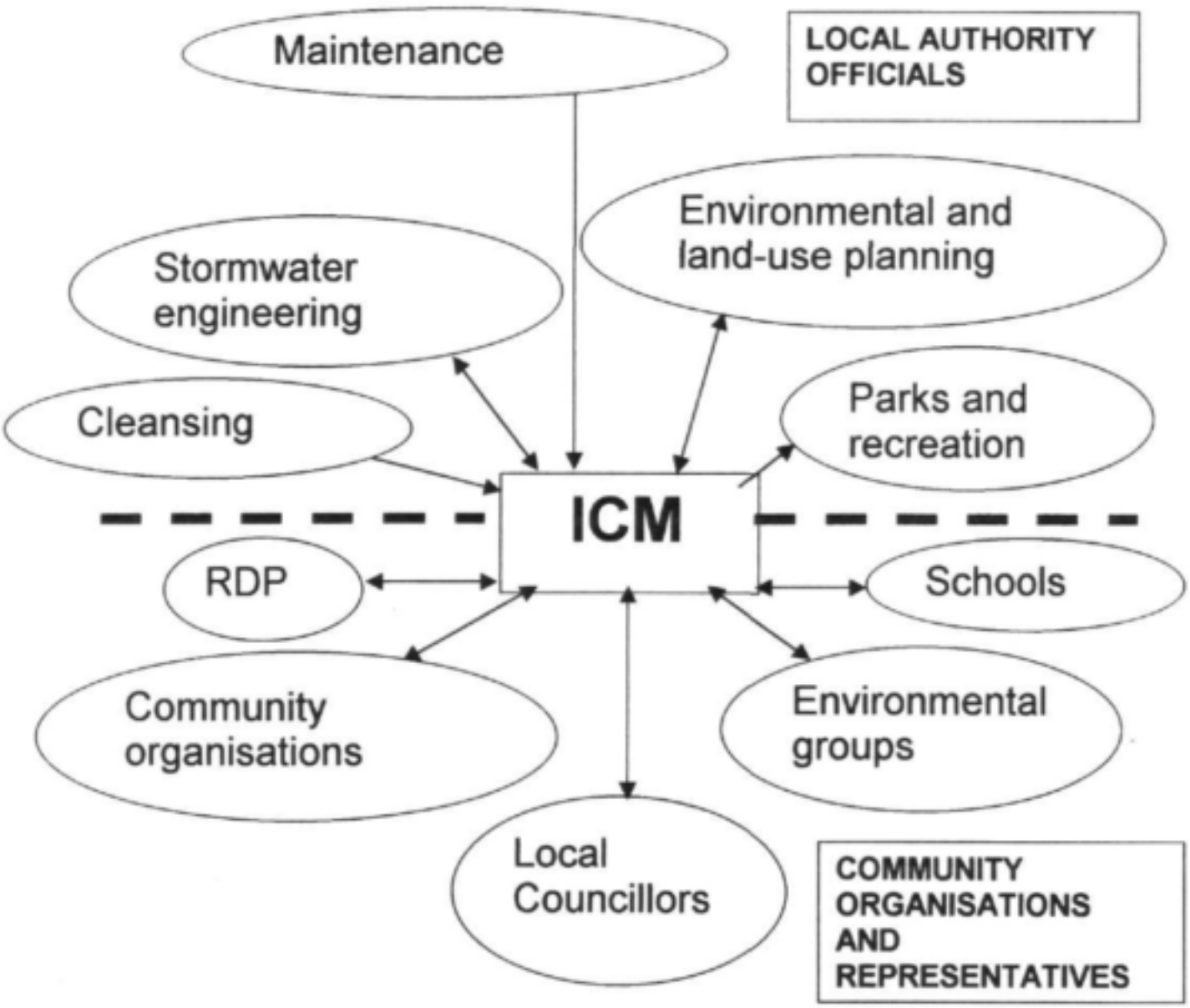
In consulting it is becoming much more the norm to find multi-disciplinary teams working together on the same project. Conventional engineering firms have been expanding their environmental capabilities rapidly in recent years, while environmental consultants generally work with a wide range of groups, including engineers and developers. The introduction of the requirements for Environmental Impact Assessments (EIAs) has intensified this process. Thereby the groundwork has been laid for a multidisciplinary approach to activities such as river channel modification, which is now a listed Schedule 1 activity in terms of the Environmental Conservation Act.

Figure 1.1 Issues and disciplines involved in Integrated Catchment Management in urban areas



The challenge of a multi-disciplinary research project such as the Lotus River project is in finding the right mix of people from various disciplines to tackle the many and varied aspects of the project. The Lotus River team was fortunate to include at different times and to various extents the participation of civil engineers, hydrologists, hydrogeologists, chemical engineers, social scientists, botanists, zoologists, environmental scientists, microbiologists, and GIS and information technology experts. From this experience, it appears that the minimum disciplinary requirement for successful urban catchment management are at least that of a stormwater engineer, an environmental scientist, and a community worker (not necessarily a qualified social scientist). In urban areas of South Africa, the real need is for people who are able to communicate in the vernacular languages in use in the catchment, and who have a human understanding of living conditions in the catchment.

Figure 1.2 Groups who should be involved in Urban Catchment Management.



1.5 THE STRUCTURE OF THE REPORT

This report is designed to show the integrated nature of urban catchment management. Much of this integration is achieved through the bringing together of geo-spatial data within a geographical information system. Hence Chapter 2 on the development of the GIS system provides the foundation for the information provided in the rest of the report. Chapter 3 then describes the characteristics of the Lotus River catchment. Chapters 4 and 5 discuss hydrological aspects and ecological aspects respectively, while Chapter 6 deals with community participation. General readers may find the general discussions of more interest than specific details of the Lotus River catchment area, so a guide to the contents of a general nature is provided below. Finally, Chapter 7 presents conclusions and recommendations, as well as a review of best management practices internationally.

1.5.1 General topics

Much of the information in Chapter 2 is of a general nature, and not specific to the Lotus River catchment, although obviously the examples provided and the techniques discussed were from this catchment. Section 2.1 provides definitions of integrated catchment management, a conceptual framework for the use of GIS in urban catchment management, and objectives and strategies developed in this project. Section 2.2 then provides a review of GIS-based techniques employed, including remote sensing and hydrological modelling. An extensive literature review is included. This section also discusses the problems associated with the use of existing municipal data, which may prove applicable to other areas in South Africa.

Chapter 3 specifically covers the characteristics of the Lotus River catchment. The only aspect of a more general nature is the breadth of information on the catchment, which is considered relevant to integrated catchment management. This includes the historical background (in terms of hydrological changes, urbanisation, and administrative systems); socio-economic data; population distribution; land use changes; geology and soil type; hydrogeology and surface water quality; and service provision in terms of waste management.

Chapter 4, on the hydrological and water quality studies, and Chapter 5, on ecological management, both contain a great deal of detail on the Lotus River catchment interspersed between discussions of a general nature. It is recommended that readers interested in more general aspects should read through the methodologies which were employed, while skimming over the detailed results obtained. Chapter 4 also contains a general discussion on the use of hydrological modelling in urban catchment management.

Much of Chapter 6 on the participatory framework for catchment management is of a more general nature, with some specific discussion of the process undertaken in the Lotus River catchment included. Starting with an outline of the objectives and the participation strategy employed, the chapter discusses the role that integrated catchment management should play in urban areas. The role of communities and the point of entry into communities are analysed in general terms. Also, in the evaluation of the community participation strategy employed, some broad lessons and pointers are found.

In terms of conclusions from the project, Chapter 7 is divided into three sections, of which the first (7.1) brings together conclusions and guidelines from the Lotus River Project which are of a general nature. The second (7.2) gives a review of Best Management Practices (BMPs) in urban catchment management internationally; while the third (7.3) draws specific conclusions for the Lotus River catchment area.

1.5.2 Topics specific to the Lotus River catchment

Readers who are particularly interested in the Lotus River catchment may read Chapter 3, which gives an overview of information related to the catchment which is relevant for the work of urban catchment management. Also of interest is the accompanying CD, which contains bitmaps of the maps and figures generated. The methodology used in developing and generating these maps is discussed in Chapter 2. Much specific information is also contained in the Appendices to the report.

Chapter 4 describes the Lotus River corridor, reach by reach, and gives specific details of the results of the hydrological and water quality studies carried out on the Lotus Rivers, over 1997 and 1998. Similarly, Chapter 5 discusses the ecological management of the catchment, region by region.

Chapter 6, on participatory urban catchment management, is of a more general nature, but contains sections which give details of the institutions and organisations involved in the process used in the Lotus River catchment, as well as the actual methodology, and the outcome thereof. What is of specific interest for the Lotus River catchment is the results of the intensive community workshops which were held. These workshops included local residents from a range of groups who had undergone a tour of the catchment, and were therefore able to deal with the range of issues which needed to be grappled with. This report is included in the Appendices.

In the conclusions in Chapter 7, management proposals for the Lotus River catchment emanating from the project are set out in detail.

CHAPTER 2 DEVELOPMENT OF GEOGRAPHIC INFORMATION SYSTEM (GIS)-BASED METHODOLOGIES FOR INTEGRATED CATCHMENT MANAGEMENT

2.1 INTRODUCTION

This section introduces the concepts of Integrated Catchment Management (ICM) and Geographic Information Systems (GIS). This is followed by a brief description of the conceptual framework for GIS-based ICM which has been developed in this study. The section ends with a discussion of the objectives, strategy and modifications to the strategy that has been followed in this work.

2.1.1 Definitions

2.1.1.1 Integrated Catchment Management

Current discussions on Integrated Catchment Management (ICM) focus predominantly on conceptual and philosophical issues. The definitions for ICM tend to be broad and all-encompassing. For example Görgens et al (1998) define ICM as follows:

"ICM in its widest sense is simultaneously a philosophy, a process and an implementation strategy to achieve a sustainable balance between utilisation and protection of all environmental resources in a catchment, and, through consensual management techniques, to develop a sustainable society."

Another example of this philosophical focus to ICM research is the 1996 DWAF / WRC report entitled: "The philosophy and practice of integrated catchment management: implications for water resource management in South Africa." Some of the key phrases used to elaborate on the definition and requirements of ICM are as follows (p20, p21: DWAF, 1996):

- An integrated or systems approach
- An adaptive management approach
- An active partnership approach and joint strategic planning
- Analysis of aspects of the catchment system
- Assessment of the prevailing environmental, economic and social values
- Monitoring of environmental conditions and related socio-economic factors

Other requirements, which are of particular relevance to the present study, are the following:

- A sustainable balance at local and regional levels between resource use and resource conservation
- Achieving effective co-ordination and integration of water and other natural resource policies to focus on common goals and objectives at a catchment level
- Focusing planning and management actions and activities at a sensible regional and local scale which is strongly related to natural systems, and which can better accommodate local and regional community needs and desires, as well as national objectives
- Ensuring an equitable distribution of costs and benefits amongst all stakeholders
- Defining the roles and responsibilities and accountabilities of each individual involved in implementation of the management plan.

These studies provide an invaluable conceptual and philosophical reference for the development of ICM methodologies. However, within the current literature, very little is written on how these principles and objectives can be obtained in practice. Nothing has been written on the technological issues which must be considered to arrive at these objectives. The current study contributes to this field by providing practical guidelines for the development of a database to enable the implementation of the principles discussed in the previous work.

2.1.1.2 Geographic Information Systems (GIS)

In this section the concept of Geographic Information Systems is examined through a number of definitions which were laid down in the early 1990's. Concepts such as the definition, functionality and purpose of GIS are explored. This is followed by a brief discussion of these concepts in the light of recent technological advances and with respect to its functionalities in terms of Integrated Catchment Management (ICM).

According to Rhind (1989, p28), a GIS is defined as:

"A system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modelling and display of spatially referenced data for solving complex planning and management problems."

The functionality of GIS has been defined as the data collection, storage, manipulation, analysis and presentation operations carried out by this computer technology (Maguire and Dangermond, 1991). These functionalities are discussed in detail by Craglia (1993).

The purpose of GIS can be considered firstly in terms of the potential range of applications and secondly in terms of the extent to which the system represents a management information system (MIS) or a decision support system (DSS) (Craglia, 1993). The wide range of potential applications of GIS (Department of Environment, 1987), indicate that many different types of systems can be found both in terms of size (large/small), of complexity of operations (basic CAD to complex analyses and modelling), and organisational arrangements (from departmental, to organisation-wide, to multi-agency) (Craglia, 1993). These differences imply in turn that there are considerable differences in terms of accuracy of data required, size and number of connected databases etc.

Technological advances over the last five years have led to the development of powerful and easily affordable Internet-based software tools. These advances have led to a shift in the architectural design of current GIS systems. Furthermore, there has been a trend to develop simplified user interfaces and desktop products which are perhaps less analytically powerful than high-end software platforms (eg ArcInfo, Intergraph MGE suite etc), but are far more effective and functional within the user environment. This trend can be seen from the multitude of desktop products which have flooded the market (eg MapInfo, ArcView, Geomedia etc). Manufacturers of GIS products today emphasise simplified user interfaces and Internet capabilities. These technological advances enable one to extend the present definition of GIS to include its functionality as a tool for negotiation. It is in this context that the conceptual framework for GIS-based ICM has been laid down in this work.

2.1.2 A conceptual framework for GIS-based ICM

2.1.2.1 GIS for Integrated Catchment Management

The GIS-based approach discussed here provides tools for the analysis and assessment of catchment data in an integrated manner. In addition, the GIS database framework discussed for ICM in section 2.3 has been designed for a multi-scale approach primarily involving the interaction of metropolitan, catchment and local level databases. Given that the formation of Catchment Management Agencies (CMAs) is proceeding as set out in the National Water Act of 1998, such databases must also interact with the regional and national databases which will ultimately co-ordinate the activities of CMAs. The proposed software configuration has been selected to facilitate an effective co-ordination and integration of data from multiple data sources. The proposed database content and analytical capabilities of the software can be used to address the issues of

distribution of costs and benefits amongst all stakeholders and to define the roles and responsibilities and accountabilities of the stakeholders.

In defining a GIS-based methodology for ICM there are a large number of technical issues which must be considered. These issues can be grouped into issues relating to:

1. a definition of the process
2. criteria describing the process
3. a definition of the system
4. an evaluation of the process or system.

The definition of the process involves an identification of the steps involved and a placement of these steps into a specific order. Criteria describing the process include a definition of the requirements of the process. These requirements refer to the accuracy and time, data inputs and outputs, hardware and software, costs constraints and collaborative requirements. The definition of the system deals with database characteristics such as the structure, content, linkages and applications. The evaluation of the process or system measures the effectiveness and feasibility, the applicability and the advantages and disadvantages of the methodology. The focus of the current work lies in the definition of the system (see section 2.3).

2.1.2.2 A multi-level approach

One of the principle functionalities of GIS with respect to ICM should be the integration of a multitude of data sources. Ideally each stakeholder involved in the ICM process should have a role to play in the development and use of the database. The discussion on GIS above has highlighted a number of differences, which will always exist between different GIS systems. In particular it can be seen that any conceptual framework designed for GIS-based ICM applications must follow a multi-scale approach. Yet there are limitations in terms of the number of scales that should be considered. As the number of working levels incorporated in the design of the database increases, so does the complexity of the database structure. Ideally one wishes to incorporate the minimum number of levels, which suffices at least the basic needs of all stakeholders.

Most GIS databases developed for urban catchment management applications tend to be designed for single level applications (see review section 2.3). Such applications can be treated in essence simply as some of the components of a broader multi-scale GIS database for ICM. Some exceptions to this single level based approach are the GIS initiatives developed by Belyaeva et al (1993), Schaller (1993) and Grossman (1983). These initiatives followed a multi-scale approach and are discussed in section 2.3. The multi-scale GIS database framework proposed in this study for urban catchment management consists of three key levels:

- The metropolitan level
- The catchment level
- The subcatchment level

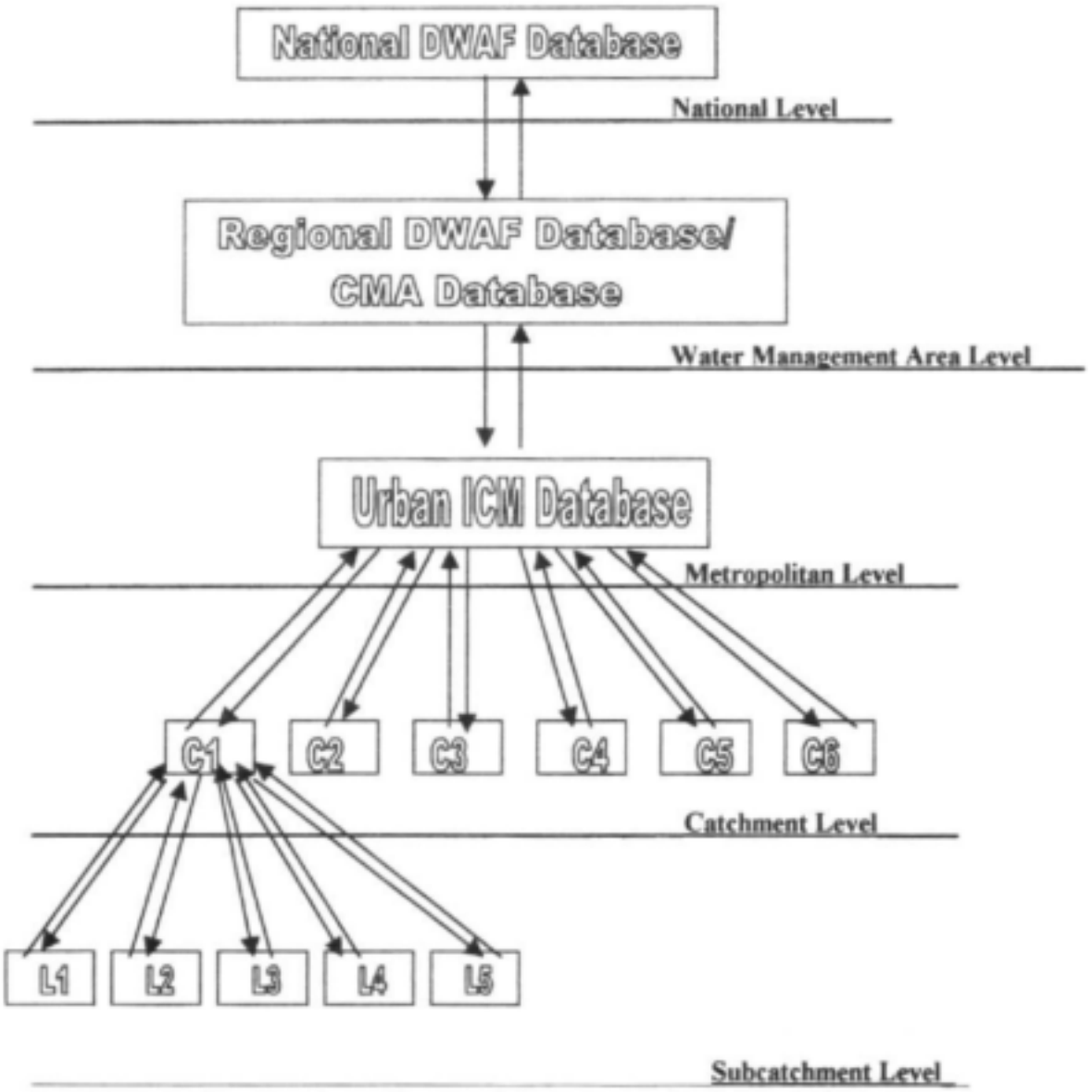
Each level has a specific functionality and several potential users associated with it. The metropolitan level is envisaged as a strategic level analysis and management tool. More specifically it can be used to address water resource and demand management issues on a metropolitan level. Potential users of this level are institutions such as the CMC, in interaction with DWAF and the Water Management Area or CMA.

The catchment level of the database is envisaged as a management and planning tool for the Catchment Management Forum, project-specific committees, and other institutions involved in catchment level projects. This level of the database can be used for constructing lumped parameter hydrological models. Other applications could include water quality monitoring and site selection for source control applications.

The subcatchment level of the database would include highly detailed land-use mapping, vegetation mapping for conservation purposes, and stormwater networks. At this level the database could be used for urban planning, informal settlement upgrading, environmental impact assessment for new developments, and local-level mobilisation around specific projects and issues.

The nature of the proposed database framework is such that all the stakeholders involved in the ICM process are also involved in the database building process. Different institutions are involved to varying degrees in the development of each level. For example at the metropolitan level, community representatives for multiple communities are envisaged, whereas at the subcatchment level, representatives from individual communities are envisaged. The involvement of other institutions is summarised in Table 2.9. The concept of the multi-scale approach is illustrated schematically below (Fig.2.1). C1 - C6 represent a number of catchment level GIS databases, while L1 - L5 represent a series of subcatchment level databases. The linkages and content of each level of the database are discussed in detail in section 2.3.

Figure 2.1 The multi-scale GIS database framework for urban catchment management



2.1.2.3 Importance of GIS in ICM

In addition to its functionality as a mechanism of integrating multiple data sources associated with all the stakeholders of the ICM process there are several other ways in which GIS can contribute to ICM. The Digital Elevation Model (DEM) and land use database components are key advantages of a GIS-based approach for developing hydrologic modelling applications. DEMs include topographical data useful for building slope and aspect maps, determining catchment properties and delineating water-path networks. The

land use data enables detailed subcatchment characteristics to be described. In addition, the grid structure utilised in many GIS software packages is coherent with the grid structure of distributed hydrologic models.

The advantages of GIS from a communication tool point of view are highlighted by Makropoulos et al (1998). He concludes that GIS has a significant potential as a tool for site-specific source control implementation, analysis and quantification, not only due to its inherent spatial information handling capabilities, but also due to "its 'human readability' because it provides a common language between specialists and non-specialists (ie local authorities)" (Makropoulos: p59). However, the importance of GIS in terms of facilitating communication through clearer visual representations of reality is only one aspect of this issue. The communication related issue is that certain GIS software packages have excellent Internet capabilities. This factor on its own places the GIS platform as a medium by which information can be diffused throughout a wider user community. The key advantages of a GIS-based approach may be summarised as follows:

- More accurate parameter estimations
- More rapid parameter estimations
- Facilitates potential for utilising existing public databases
- Facilitates potential for grid-based distributed hydrologic modelling
- Facilitates an integrated analysis of the various data sets through the spatial overlay capability
- Facilitates a more realistic representation of data
  - Raster backdrops to vector data
  - Thematic representation of data
- Facilitates effective communication medium
- Facilitates wide spread diffusion of information
- Facilitates spatial analysis for planning
  - Simplified spatial analysis tools
  - Complex spatial analysis tools

2.1.2.4 Cost constraints

With respect to the cost constraints facing the methodology, in order to facilitate the development of multiple databases at the catchment level, the selected software should be low in cost. For this reason the primary software for GIS-based ICM framework proposed in this work should be a front-end viewer GIS package with advanced Internet capabilities. The cost of such software products lies at about R10 000 (eg GeoMedia). This is extremely cheap in comparison to high-end software platform suites such as the Arc/Info or MGE Intergraph platforms, which require a considerably greater investment before one can actually carry out any work. This is because the architecture of such high-end platform systems requires a minimum number of core modules. For example in the case of the MGE suite at least three basic MGE modules must be purchased: Nucleus, Administrator, Mapper. Furthermore, Microstation is also required. Even with these four products the user cannot perform a number of key operations such as basic image processing (which requires MGE Base Imager) and basic overlay analyses (which requires MGE Analyst). Thus the most basic high-end platform software configuration could easily cost somewhere between R50 000 and R100 000.

2.1.3 Objectives and strategies

2.1.3.1 Original objectives and strategy

The primary objective of this work was to explore the potential for utilising Geographic Information System (GIS)-based techniques to develop a tool for Integrated Catchment Management (ICM). Secondary objectives were to develop a GIS database for the Lotus River catchment in particular and to apply this database to estimate parameters for the stormwater runoff modelling discussed in Chapter 4. The original strategy focused initially on collating all the data available for the Lotus River catchment and on reviewing GIS-based developments in fields associated with ICM (ie remote sensing based approaches and hydrological modelling applications). The data collation process was carried out in such a manner as to include data from as many of the key role players in the ICM process as possible. This was for two reasons. Firstly, it helped to determine the practical limitations of "real data sets" on a GIS-based ICM approach. Secondly, by basing the methodology on locally acquired data, it would be possible to ensure that the

resultant database design would be compatible with existing local authority databases. Part of the database building process and of the review involved an investigation of two other issues. The first issue was an investigation of the potential for using the cadastral database produced by the Cape Town Metropolitan Council (CMC) in the parameter estimation process. The second issue was an investigation of the potential for carrying out the stormwater runoff modelling within the GIS environment.

2.1.3.2 Modifications to strategy

One of the key data categories for GIS-based stormwater runoff modelling applications is land use data. Two methodologies were experimented with for capturing the land use data. The first was the cadastral-based approach described above. The second was based on mapping the land uses from digital orthophotos. The cadastral-based approach was followed for a selected subcatchment and a number of land use parameters were estimated. In practice, the method has proved far too time-consuming to carry out on a catchment-wide basis. As a result, a more rapid method has had to be developed. The merits of rapid land use mapping approaches have been clearly shown in other non-catchment-based studies. The Rapid Land Use Assessment (RLA) methodology developed by the Planning and Development Corporation (PADCO) in the Philippines has proved to be an efficient approach to land use mapping. This methodology relied on the use of Soviet KVR satellite imagery for the mapping process. In the case of the Lotus River catchment, 1:20 000 aerial photography orthophoto imagery (instead of satellite imagery) has been implemented in the mapping process.

The applicability of such rapid land use mapping methods for ICM is determined by whether the accuracy of the resulting land use parameter estimates are sufficient for stormwater runoff modelling applications. A brief inspection of the land use maps utilised in other recent catchment studies (Adinarayana et al, 1994; Schmitz & de Villiers, 1997) was conducted. Attention was paid to the degree of detail of the land use mapping carried out. The following factors were considered:

- the number of classes mapped for each subcatchment
- the total number of classes mapped throughout the catchment
- the size of the smallest land use zone mapped in the catchment

A comparison of the mapping detail utilised in the production of the maps for these studies, with the land use map drafted for the Lotus River catchment study reveals that the latter is far more detailed. Similarly a comparison with the image processing methods and scale of orthophoto imagery utilised by Lo and Shipman (1990) indicates that the results of the land use change study conducted here has been far more sensitive to reality. Whereas previous modelling exercises tend to homogenise subcatchment areas, the land use analysis mapping component of the present study has attempted as far as possible to retain the degree of subcatchment heterogeneity visible on the aerial photography. The accuracy of the land use analysis method used here suffices the needs of the SWMM modelling software (see Chapter 4). Furthermore, the land use analysis involves the use of high resolution digital orthophotography (0.5 m pixel resolution), which enables land use classes useful for development of GIS-based vegetation management and rehabilitation strategies to be mapped. The user can thus use the imagery to map features at a resolution of 0.5 m or less - depending on the application and time constraints. In contrast, the highest resolution obtainable using processed LANDSAT imagery lies at 10 m (Ouma, 1998; Zech & Escarmelle, 1998).

One question that arises from the above reference to the satellite imagery-based RLA methodology, is whether the application of satellite imagery (as opposed to aerial photography) is sufficient for the development of GIS-based ICM applications. While the application of satellite imagery can contribute meaningfully to catchment studies by providing useful ecological information (vegetation indices), the application of this imagery type alone is insufficient to meet the demands of ICM as a whole. Zech & Escarmelle (1998) have shown that while the best ground resolution of satellite imaging systems lies at 10 m (which is the resolution provided by SPOT images in the panchromatic band), a resolution of 5 m is needed for the development of urban hydraulic models. Essentially the resolution of today's readily available satellite imagery is not sufficient to meet all of these demands.

In addition to the issues already listed above, there were three other factors that influenced the methodology that has been followed. These are:

- The fact that the Lotus River catchment represents a largely urban catchment as opposed to a rural catchment.
- The large size of the Lotus River catchment (8437 ha) in comparison to sizes of catchments which have been analysed using high resolution automated mapping methods (11 to 125 ha) and methods based on detailed topographical and cadastral databases (12 km^2) (Frankhauser, 1998; Greene et al, 1995) (see section 2.2.2).
- The restrictions imposed on the methodology by being designed for a catchment situated in a developing country as opposed to a catchment situated in a developed country.

The methodologies employed for stormwater runoff modelling in rural catchments are often based on relatively coarse grid-type models (1 km by 1km; Holden, 1992). For such areas, the mapping outputs of coarse resolution imagery (eg fused Landsat images with a resolution of 10 m) may enable the estimation of input parameters (such as the percentage area impermeable) of an acceptable accuracy for stormwater runoff modelling. However, the greater heterogeneity encountered in the land use variations in urban catchments requires that the imagery used for land use mapping be of a far greater resolution than satellite imagery. As mentioned already above, Zech & Escarmelle (1998) have shown that a 5 m resolution is required. In addition to meeting the stormwater runoff modelling requirements, the imagery and associated vector data must be of high enough resolution to pick out the spatial features and land use variations required for ICM.

The ideal working resolution is also determined by the size of the catchment. While the urban setting of the Lotus River catchment demands that a higher resolution approach be followed, the size of the catchment places a restrict on the practical resolution that can be implemented. The decision to shift from a cadastral data base approach to a digital orthophoto base approach has already been discussed above. The primary reason for this was the considerable time involved in following a cadastral based approach for the whole catchment.

The main restriction imposed on the methodology by the fact that it is being designed for a catchment situated in a developing country is the lack of several types of digital data. While South Africa is relatively advanced in having digital cadastral data available for the metropolitan areas (when compared to other developing countries) there remain large gaps in this cadastral database. These gaps correspond to the informal settlement areas. In addition, there tends to be absolutely no subsurface infrastructural data available for the informal settlement areas and only a limited amount of subsurface infrastructural data available for the formal areas. Where paper base maps are available for the stormwater drainage network in former township areas, these maps tend to be unreliable and out of date.

Finally, with respect to the main modifications to the strategy that was followed, there remain two comments to be made. Where as it was initially hoped that the hydrological modelling would be carried out within the GIS environment, it soon became apparent that the GIS would only be able to provide a means of estimating a number of input parameters for the modelling process. This is mainly attributable to the time and funding limitations of the project. Secondly, with respect to the development of an integrated catchment management (ICM) methodology, a conceptual framework has been developed for the implementation of GIS-based ICM techniques.

2.2 Review of GIS-based techniques employed in urban catchment management

2.2.1 Introduction

The following discussion consists of three key sections. The first focuses on the use of remote sensing in catchment management. The second section deals in general with the technical aspects of the current GIS systems employed in hydrological modelling and more specifically with applications which have been developed for modelling non-point pollution sources in urban catchments. This section ends with a summary

of the implications of this discussion on the database structure of the Lotus River Project GIS system. The final section reviews the status of two fields of research that are particularly relevant to the conceptual framework discussed in section 2.5.

2.2.2 The use of remote sensing in catchment management

2.2.2.1 Airborne remote sensing

Elgy et al (1998) describe an airborne remote sensing technique based on the application of a line scanner that scans continuously while the aircraft flies forward recording 11 bands of the electromagnetic spectrum. The imagery collected in this manner is first processed with an edge detector to create "approximately homogenous polygons". The polygons are then classified into roofs, paved areas and permeable land. A number of problems are associated with this technique. Georectification of the line scanned imagery is very difficult and only recently has a method been presented to rectify the line scanned images to existing aerial photography. In addition there are still problems preventing the imagery to be registered precisely with the aerial photography. These problems are related to shifts in aircraft altitude and to the presence of considerable noise in the data. This methodology is clearly under development and is not readily available in South Africa. In addition, the four classes are insufficient to meet the demands of ICM.

2.2.2.2 Digital Orthophotos

Frankhauser (1998) argues that the determination of impervious areas in urban regions is the most labour-intensive part of data acquisition for rainfall-runoff modelling in urban hydrology. In an attempt to shorten this time-consuming process he has presented an automatic determination method of imperviousness from aerial photographs. The colour CIR (colour infrared) aerial photographs and orthophotos used have a ground resolution of 25 to 75 cm. A maximum likelihood classification algorithm was applied to assign each pixel to a surface category. The classification results were then overlaid with the subcatchments to determine the imperviousness of each subcatchment. The accuracy of the estimated imperviousness for the entire catchment areas was within 10 %. The deviations for individual subcatchments were much higher.

It should be noted firstly that the areas to which the technique has been applied range from 11 to 125 ha in size (Frankhauser, 1998). The range of sizes lies significantly below the size of the Lotus River catchment (8437 ha). It must be remembered that when high resolution cell-based methods are used, the size of the catchment has a considerable influence on the processing time involved. Secondly, although between 11 and 15 classes were selected as training samples for the classification procedure, only two classes were finally presented. Since many of the impervious classes were similar in colour, many pixels in the image were misclassified. Therefore, all impervious and pervious classes were combined into two classes; ie "pervious" and "*impervious*".

A comparison of the classification results with manual digitisation procedures revealed an overestimation for the imperviousness calculated using the colour image, and an underestimation using the CIR imagery. In addition the differences between the individual subcatchments were far greater than for the entire catchment area. The greatest differences between the impervious area estimated by manual digitisation and impervious area estimated by classification is for subcatchments in the size range of 0.5 to 1.5 ha (see Figure 3, p324 in Frankhauser, 1998). The main reasons for these deviations are as follows:

- Differences in the data sources: manual digitisation was performed on an older black-and-white orthophoto, whereas the maximum likelihood classification used more recent colour orthophotography.
- Correctly identified shadow on pervious surfaces as all shadow areas were supposed to be pervious.
- Correctly identified trees on impervious surfaces. Manual digitisation did not take the trees into account. Neither approach is correct. The trees influence the surface runoff by interception and infiltration losses.
- Pervious areas without vegetation that were classified as impervious because of their colour eg gravel paths, railways area etc.
- Errors made during manual digitisation or through manual assignment of surfaces to catchment areas.
- Misclassified pervious pixels on roofs. (taken from p325, Frankhauser, 1998)

Other problems include errors such as pervious pixels within impervious surfaces or vice versa. Frankhauser (1998) comments that further research is required to improve the post-processing of the classifications result and achieve a more homogenous image. Other airborne thematic mapping based techniques have been applied by Reid & Roberts (1989) and Bayer & Hilz (1997). Blagojevic et al (1994) have also used airborne videography as data source with a ground resolution of approximately 2m.

2.2.2.3 Satellite-based methods

The results of previous studies have shown that it is possible to obtain an automatic identification of impervious areas by remote sensing techniques (multispectral classification algorithms) from satellite images (Deguci & Sugio, 1994; Leiss, 1992; Frankhauser & Jancarkova, 1993; Frankhauser: 1994, 1998). Halounova (1994) used Landsat TM satellite images of 30 m ground resolution to determine the surface characteristics of Prague. Despite these studies, the applicability of satellite imagery to rainfall-runoff modelling remains debated (Zech & Escarmelle, 1998). The limitations facing satellite-based techniques are discussed in the following section.

In addition to providing information on the impervious areas for hydrologic work, satellite imagery has been used to provide data for ecological applications. A series of vegetation indices may be determined using slope-based and distance-based models (Thiam & Eastman, 1997). **Slope-based models** comprise models that are simple linear combinations of the visible red and near infrared bands. The vegetation indices, which are determinable for this group, include:

1) Ratio
2) Normalised Difference Vegetation Index (NDVI)
3) Ratio Vegetation index (RVI)
4) Normalised Ratio Vegetation Index (NRVI)
5) Transformed Vegetation Index (TVI)
6) Corrected Transformed Vegetation Index (CTVI)
7) Thiam's Transformed Vegetation Index (TTVI).

The second group of models (ie **distance-based models**) uses the same bands as the first group as well as the intercept and the slope of the background soil line. The vegetation indices in this group are as follows:

1) Perpendicular Vegetation Indices ((PVI, PVI1, PVI2, PVI3)
2) Difference Vegetation Index (DVI)
3) Ashburn Vegetation Index (AVI)
4) Soil Vegetation Index (SAVI)
5) Transformed Soil-Adjusted Vegetation Indices (TSAVI1, TSAVI2)
6) Modified Soil-Adjusted Vegetation Indices (MSAVI1, MSAVI2)
7) Weighted Difference Vegetation Index (WDVI)

A number of Landscape Ecology Indices may also be applied. These techniques have been used to interpret savanna ecosystem patterns in the Sabi Sand Game Reserve, Mpumalanga Province (Fortescue, 1997). Landscape Ecology Indices have also been used to prioritise conservation areas in the Transkei coastal region (Kumi, 1997). Such indices include (Meffe & Carroll, 1997):

- relative richness
- diversity
- dominance
- fragmentation.

One manner in which to obtain a higher resolution satellite image is to evaluate a hybrid 10 m SPOT image fused with 25 m LANDSAT image which results in a 10 m resolution multispectral image. This innovative technique is currently employed in the Department of Land Surveying at UCT (Ouma, 1998), and has been applied in this project in order to obtain a higher resolution image than would otherwise be possible.

2.2.2.4 Limitations facing orthophoto and satellite GIS-based techniques

The limitations facing orthophoto and satellite GIS-based techniques are briefly discussed below.

Frankhauser (1998) concludes his discussion on the automatic determination of imperviousness in urban areas from digital orthophotos with a list of the disadvantages facing the technique. These disadvantages include the following:

- The method does not provide a detailed description of the surface but merely an estimation of the imperviousness. For example roofs are not distinguishable from roads.
- The borders and shape of the surfaces are not as accurate as by manual digitisation.
- The surfaces are clusters of pixels and not vector polygons. Therefore, corrections and reclassifications of surfaces have to be carried out pixel by pixel by image-processing software.
- The heterogeneity of the classification image does not allow a vectorisation of the surfaces.

Zech & Escarmelle (1998) argue that public databases from satellite imaging are not yet adequate for developing distributed urban hydraulics models using GIS. These models require high-resolution data. From a previous study at the Catholic University of Louvain, which involved the development of a GIS-based distributed model (Zech et al, 1994), it was concluded that for an accurate representation of urban areas, the available database meshes were too coarse. The best ground resolution of satellite imaging systems was 10 m (SPOT in the panchromatic band) whereas it was concluded that the needed resolution was 5 m.

2.2.3 GIS and hydrological modelling

In a review on contemporary approaches in urban drainage, Marsalek et al (1994) state that the collection and processing physiographical data for drainage modelling and presentation results are greatly simplified by GIS. Further more, Marsalek et al argue that these systems can be used in conjunction with distributed hydrologic models to compute runoff hydrographs comparing well to those produced by conventional models (Zech et al, 1993). Ross et al (1993) identify the key advantages of the GIS as the provision of spatial / analytical functions, georeferencing and spatial overlays, and as a mechanism to link surface-water and groundwater codes. Other key advantages include minimization of user subjectivity in parameter selection and a reduction in the costs of analysis due to time savings.

GIS applications which have been designed for hydrologic analyses fall into four categories: 1) calculation of input parameters for existing hydrologic models; 2) mapping and display of hydrologic variables[1,2]; 3) watershed surface representation[3]; and 4) identification of hydrologic response units (Greene & Cruise, 1995). The majority of the current applications fall into the first two categories. Examples of these applications include a utilisation of GIS to: produce input parameters for the HEC-1 model (Moeller, 1991), determine time area curves (Sicar et al, 1991) and to display the spatial distribution of hydrologic variables (Loucks et al, 1985). The majority of these models follow a lumped parameter approach that does not incorporate the spatial variation of watershed characteristics in the modelling.

More recently, a model designed by Greene et al (1995), for a 12.2 km^2 area, enables the impacts of proposed land-use changes on the runoff to be predicted. In contrast to previous methods, the co-ordinate values defining the location of features were used to include the spatial heterogeneity of the drainage basin characteristics in the modelling process. In essence this model is based on detailed topographical and cadastral GIS data. This base data is used to identify lots and / or polygons as hydrologic response units.

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[1] DeVantier et al(1993) summarise general indices which are frequently displayed mapped on terrain maps. These indices deal with imperviousness, natural land cover, watershed delineation and stream networks.

2 Adinarayana et al (1994) discuss the use of multi-temporal satellite imagery, from different agricultural seasons, to produce land-cover maps for the catchment, using knowledge-based re-classification. The drainage network, elevation and other topographic and thematic data were digitized from maps. In addition various additional land use classes were developed. These included: wastelands and appropriate preventative measures.

3 An example of a watershed surface representation model is provided by Schaller (1993). In this case, a triangular irregular network (TIN) cascading calculation is conducted to combine flow direction vectors with calculated soil losses and matter transportation related to the surface water flows.

Subsequent to a series of co-ordinate geometry transformations, the GIS data for a particular street block may be converted into a routing schematic.

2.2.3.1 Previous use of existing municipal data

Zech & Escarmelle (1998) describe the use of existing data, captured specifically for cartography, for urban-catchment characterisation in GIS-based distributed hydrological models. The data that used was data that had been captured for the digital cartography program (PICC: Projet Informatique de Cartographie Continue) initiated by the Ministry of Equipment and Transportation (Belgium).

The main difficulty with using such data is the necessity to use a refined mesh (5m) to reach the accuracy required by distributed models. A number of other key disadvantages are associated with using cartographic data. These disadvantages are related to the structure of the database which has been designed specifically for cartographic purposes. For example if a line is a common limit of two distinct areas, this limit will appear in only one of the concerned feature types. Missing contours on one level may be present as footpath limits on another layer. A second problem is that hydrologic models generally define area data (rasterisation) which is not a difficulty if the original data is a polygon. If this is not the case, the conversion from separate vectors to closed polygons is a very time consuming task, as it is a manual digitisation process. Notwithstanding these two issues, a land use map produced by rasterising an existing cartographic vector data file may suffer from other problems. For example roads may be no longer continuous as a result of the automatic conversion, due to the fact that some paths are too small for the set grid size which is typically greater than 5 m. A more critical failing is the absence of underground data, which means that the sewer network must be separately captured.

2.2.3.2 Cell-based modelling approaches and digital elevation models (DEMs)

The application of raster-based digital elevation models (DEMs) for stormwater runoff modelling has been dealt with by Smith and Brilly (1992), Moore et al (1991), VanBlargan et al (1990), Zech et al (1994)[4] and others. The digital terrain model (DTM[5]) developed by Zech et al (1994) incorporated both the undeveloped and urbanized areas of the catchment. This has required some modification of the conventional DTM employed.[6] The discussion by Meyer et al (1993) highlights the suitability of raster systems for urban watershed analysis, particularly for the calculation of slope values. A sensitivity analysis of the runoff model parameters indicates that the most sensitive parameters required by the modelling process may be derived from the GIS. The parameters in order of declining sensitivity are as follows: overland flow length, average sub-basin slope and percent impervious area. Meyer et al (1993) also list possible raster-based encoding formats for reducing errors due to uncertainties in the point region. Further details on the application of cell-based techniques for surface runoff modelling are discussed by Vieux (1993), Smith et al (1992) and McKinney et al (1996).

2.2.3.3 Hydrologic parameter estimation in urban areas

Many rainfall / runoff simulation models (eg. HEC-1, TR-20, SWMM and PSRM) employ the SCS runoff curve number (CN) method to determine initial rainfall losses (infiltration, depression storage and interception) and runoff. The manner in which a GIS catchment model may be implemented to arrive at estimates for the CN value is discussed by DeBarry & Carrington (1990). By overlaying land use and hydrologic soil group maps, composite SCS runoff curve numbers may be generated on a sub-watershed basis. These values may then be entered directly into simulation models. In addition to estimating the pervious and impervious curve numbers, the GIS may be used to determine the percentage of the sub-area that is impervious. By using the (X ; Y) co-ordinates of the locations of rain gauges and sub-basin centroids, also determined from the GIS, the runoff model may be used to determine the weighting for each rain-gauge

[4] A comparison between a distributed model using GIS and other models sensitivity analysis is discussed in Zech et al (1994). The digital terrain model (DTM) developed for this work incorporated both the undeveloped and urbanised areas of the catchment. For each cell of the DTM grid, a water budget is calculated. The model was compared with the SWMM and WALLRUS models, and proved to be the most accurate.

[5] A DTM is a digital representation of the ground levels at each node of a fixed regular grid. (Zech et al, 1994, p: 164).

[6] The adaptation of the DTM involved the representation of houses and buildings by an artificial increase in the elevation of the corresponding nodes, avoiding flow throughout the habitations.

station for each sub-basin. Campana et al (1995) provide estimates for the curve number (CN) from recorded data and by remote sensing for the Dilúvio Basin in the Porto Allegre region, Brazil. A plot of the CN value derived from the Landsat imagery and the same value derived from rain-runoff events shows a good correspondence in some of the slightly impervious urban areas.

2.2.3.4 Drainage utility implementations

Drainage utility applications have been discussed by DeVantier et al (1993), who argue that the database for such applications need not be as extensive as for other applications as no runoff modelling is performed. One application has utilized GIS as means for fee assessment, based on the percent of impervious area of the property (Allen, 1991; Williams & Rosengren; 1991).

2.2.3.5 GIS / urban runoff model linkages

The options which exist for the development of a decision support system (DSS) for urban stormwater management are outlined by Meyer et al (1993) as follows: 1) integrated system development, 2) internal GIS modelling and 3) Model/GIS data file linkage. Integration via the first option requires the programming intensive production of customised program interfaces. This approach has been followed by Shea et al (1993)[7] and Ross et al (1993)[8]. The option of internal GIS modelling is complicated by the fact that most GIS systems do not support the required analytical functionality. Programming languages within the GIS environment typically constitute tools for developing graphical user interfaces and other interactive control interfaces, rather than for processing the numerically intensive iterative processes associated with runoff simulations. The third option is the easiest and most cost effective method for data file transfers and is typically for integrating GIS. Meyer et al (1993) outlines in detail the steps involved in linking the GIS and runoff modelling through this option. (p208-210, Fig 1). In this instance, a raster-based GIS package, IDRISI (Eastman, 1990), is interfaced with a physically based spatially distributed urban watershed model RUNOFF (Labadie et al, 1984). The RUNOFF model is similar to the RUNOFF block in SWMM (Huber et al, 1983).

2.2.3.6 Possible data formats

GIS data is typically represented in vector or raster format. The vector-based approach has been criticized for the limitations present systems suffer from, with respect to the analysis of data errors and uncertainties. Raster systems on the other hand offer specialized spatial analysis operations for distance, overlay, connectivity and neighbourhood calculations via the Map Algebra and Graphical Object Programming Language (GOAL) facilities. Further details on the triangular irregular network (TIN) and on the vector- or contour-based line networks are discussed by DeVantier et al (1993).

2.2.3.7 Limitations facing GIS-based urban hydrology studies

A key limitation facing previous GIS-based studies is the highly focused nature of these studies. Studies involving distributed hydrological modelling are typically highly focussed. The databases developed for these studies contain only the main information layers useful for urban hydrology: land use models describing the soil cover at each location and Digital Elevation Models (DEMs) giving the spatial distribution of elevations. In developing such highly focussed databases, one of the key advantages of a GIS-based approach is discarded - ie. the ability to integrate multiple data sources. In addition, such models have little meaning in an informal settlement area context, where elevation data is usually unavailable anyway.

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[7] A combination of systems was employed by Shea et al (1993). This incorporated: a computer aided design package (CAD), a database management system, and a raster based software package. The HEC-1/HEC-2 models were linked to those packages through customised programming.

[8] Ross et al (1993) have developed a system which integrates GIS, public-domain surface-water and groundwater hydrological models and a specially written evapotransporation code.

2.2.3.8 GIS-based non-point source nutrient loading models for assessment of land development scenarios and water quality variations

The assessment of nonpoint source loads within large and diverse watersheds is typically an obstacle to the development of pollutant loading budgets required for water quality models (Heidtke et al, 1993). This discussion summarizes some of the latest GIS-based approaches which have been followed in this field.

1) A multi-scale system approach

Belyaeva et al (1993) discuss how GIS may be used for water quality management in the Upper Volga River Basin. The key aspect of the conceptual model which has been developed for this application is that data are managed at three levels depending on the scale and detail (ie. regional, watershed and local). Level I (Upper Volga River Basin) contains basic information for a large region (scale >1:1000000). Level II contains data useful for resource management applications in catchment areas (scale: 1:100000 to 1: 1000000). Level III contains information for small areas such as individual problems, causes and solutions for nonpoint pollution sources (scale < 1: 100000)[9]. A multi-scale system approach has also been followed by Schaller (1993) in the development of a GIS-based ecosystem model for watershed management in the Berchtesgaden area, Germany. In this case, the Hierarchical Systems Method[10] proposed by Grossman (1983) was adopted.

Two alternative examples of large-scale modelling of urban nonpoint source pollution using GIS are provided by Kim & Ventura (1993) and Horn & Grayman (1993). The work by Horn & Grayman (1993) focuses on the Reach File system and on the Routing and Graphical display System (RGDS) developed by the Environmental Protection Agency (EPA). Together, these two systems function as a specialised network-orientated GIS for water quality modelling and other surface-water analyses. Kim & Ventura (1993) utilised updated land use coverage to record pollutant loadings for each land use polygon. Storm sewer basins and sub-basins, mapped from storm sewer maps, were overlaid by the pollutant loadings in order to calculate the pollutant loadings for major sewer outfalls. This information was subsequently used to locate areas' excessive pollutant loadings and to evaluate the effectiveness of the Best Management Practices (BMPs) in these areas.

2) Optimisation modelling

The potential for utilizing GIS to evaluate economic and environmental problems associated with an agricultural watershed is illustrated by Xu et al (1993). This work outlines the development of a GIS-based optimisation model for broiler litter utilisation in the Missouri watershed. The optimisation model is used to select management practices that maximize total net returns to the land, and estimates the economic value of litter as a fertilizer substitute for an agricultural watershed. The GIS is used to determine land application rates based on crop nutrient requirements, fertilizer source and litter cleanout schedule. This work illustrates how the GIS can be used to implement a linear programming (LP) model in which total net return to land and management in the watershed is maximized subject to a set of eight constraints. The database was developed on an ARC/INFO platform and holds information on the land use, soil type, and slope amongst other landscape attributes. The LP model is used in assessing the choice of fertilizer, the litter value, the effects of litter price on litter use and the potential negative water quality effects of applying litter based on the crop nutrient requirements.

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[9] The key findings of this work indicated that the global contribution of diffuse pollution is about one third of the total loads generated. Urban diffuse loads constitute an average of 6% of the total nitrogen and total phosphorus loads generated. Bendoricchio et al (1993) estimates that a drastic reduction in the nitrogen (70%) levels is required to restore the lagoon to trophic equilibrium. In view of the intensive urbanisation and high land prices, which prevents remedial solutions involving buffer areas and detention ponds, Bendoricchio concentrates on identifying options for reducing agricultural diffuse loads.

[10] The hierarchical systems method employed by Grossman (1983) distinguishes two principal "functional domains" of ecological systems: the process domain (reality level) and the regulation and control domain (or strategic and dynamic levels).

3) A universal soil loss equation (USLE) GIS-based approach

Heidtke et al (1993) highlights the problems associated with applying complex nonpoint source simulation models (eg HSPF, AGNPS, ANSWERS) and unit loads (or export coefficients) based approaches (Heidtke et al, 1986, 1992) to evaluate basin wide nonpoint point sources (Heidtke et al, 1993: p596). The method employed by Heidtke et al (1993) involves the application of the Universal Soil Loss Equation (USLE)[11] and urban runoff loading functions to derive total phosphorus unit loads representative of local watershed conditions. The GIS database employed in this study involved seven land use categories, three soil texture categories and three surface slope categories. This database was used to construct a land use - soil texture - surface slope attribute matrix for each sub-basin in the watershed.

Each cell within the matrix represents an area of the sub-basin exhibiting a unique combination of attributes. The phosphorus load contributed to a lake by any given sub-basin is subsequently obtained as the product of 1) the appropriate attribute matrix, 2) a corresponding matrix of unit loads, and 3) a "delivery ratio" which reflects the fraction of the sub-basin load reaching the lake. Heidtke argues that the Universal Soil Loss Equation (USLE) is an effective approach for calculating representative unit loads for rural land. The model is applied to illustrate the long-term trends in total phosphorus loading in response to hypothetical development patterns within the watershed. Heidtke concludes his discussion by identifying the need for his model to be extended by interfacing the simulated TP load data output with a simple water quality model.

4) Grid cell-size considerations

Grid-based approaches are often not followed as the accuracy of such methods is limited by the grid cell-size, which in turn is dependent on the available hard-drive storage (DeBarry & Carrington, 1990). Nevertheless, many nonpoint pollutant source models have been developed in a cell-based GIS environment. Vieux & Needham (1993) investigate the effects of cell size selection through a sensitivity analysis of input parameters for the nonpoint-pollution model, Agricultural Nonpoint Source Pollution Model (AGNPS), for a small watershed. The model parameter data base was compiled for grid-cell sizes of 1-, 2-, 4-, 8-, 12- and 16-ha resolution. The sediment yield was found to be most affected by the grid-cell sizes. With respect to the model devised by Zech et al (1994), a dense grid of 5 x 5 m squares is required to ensure that the model does not miss houses. For the case of informal settlement areas in the CMA, this resolution may have to be reduced to identify shacks (typically 3 x 3 m in size).

5) The Lagoon of Venice[12]

Nutrient discharges into the Lagoon of Venice from its drainage basin directly affect the growth of microalgae and have resulted in hypertrophic conditions in the confined areas of the lagoon. Associated with these hypertrophic areas is the occurrence of flooding. The simulation of diffuse loads generated in the Lagoon of Venice watershed has been dealt with by Bendoricchio et al (1993). In this case, a GIS of the watershed has been integrated with two models simulating respectively urban and agricultural diffuse pollution. The diffuse loads are compared with the corresponding point sources to evaluate their relative pollutant contributions with reference to time and space variability of the loads. The data included in the GIS consists of land geography, hydrography, population and land use, water pollution and interventions and remedial actions. The results of the pollution generation models are also inserted in the GIS. These data include: sewer network efficiency; municipal waste load distribution; industrial waste load distribution; livestock waste load distribution; diffuse urban pollution loads (runoff and overflows) and agricultural diffuse pollution loads. Typical outputs of the lagoon GIS include: an analysis of the land use distribution in the watershed and a comparison of the calculated annual loads of nitrogen and phosphorus generated by the

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[11] The USLE was originally developed by the U.S. Department of Agriculture and the Soil Conservation Service (SCS) for assessing gross soil erosion in agricultural areas. Details of the equation are outlined in Heidtke et al (1992) and given by Mills et al (1985).

[12] It should be noted that the Venice catchment (1880 km^2) is much larger than the Lotus River catchment (80 km^2). Nevertheless, this work provides: a first indication of what data should be incorporated into the Lotus River GIS (Bendoricchio et al, 1993: Table 2, p73), a template for potential GIS outputs with respect to pollutant modelling applications and the theoretical background for conducting a similar application for the Lotus River catchment.

point (municipal, industrial, feedlots) and diffuse (agricultural, urban) pollution sources under three different hydrologic conditions (dry, average, wet).

2.2.3.9 Evaluating the potential of the various approaches for the development of the Lotus River GIS database model

The following section discusses several issues that have been considered for the development of the Lotus River catchment GIS database. Some of these issues include an identification of attribute table templates for the Lotus River database and hydrological models, which were initially considered for this work. The applicability of the various approaches discussed above is evaluated in terms of the catchment size and the local data availability. Case studies providing a useful source for future modelling comparisons are also identified. Finally, a number of local constraints facing the issue of a GIS-hydrological model linkage are discussed.

A series of potential attribute database table templates have been identified from the surveyed literature. The discussion by Meyer et al (1993) provides a template for designing a raster attribute GIS database for runoff applications (p220 - 221). Ross et al (1993) provide examples of sub-basin and grid characteristics files (p134-135). In addition, Campana et al (1995) provide a template for potential soil data table formats.

The size of the basin considered in the Dilúvio Basin study Campana et al (1995), which covers 80 km^2, suggests that a Landsat imagery-based approach may be applicable to the Lotus River catchment. However, the availability of detailed topographical and cadastral data for parts of the Lotus catchment suggest that a more accurate land use mapping approach may be followed for a number of subcatchments within the Lotus River catchment. It seems appropriate that an approach, similar to the multi-scale approaches adopted by Belyaeva et al (1993) and Schaller (1993) in the development of GIS watershed database structure, should be followed for the Lotus River catchment database.

The status of digital data availability in the study area is conducive to the development of local level of databases for subcatchments excluding informal housing areas. The discussion by Greene et al (1995) utilizes a detailed topography - cadastral database for a 12.12 km^2 area. The availability of detailed topography and cadastral data from the Cape Town City Council (CCC) and the willingness of the Drainage and Sewerage branch of the CCC, to capture stormwater drainage network data for the Lotus River catchment (80 km^2) suggests that such an approach could be followed for a selected subcatchment.

With respect to Belyaeva et al (1993) case study, two environmental factors are of interest. Firstly, the need is recognized by Belyaeva et al (1993) to include geological data on groundwater aquifers in the database. This is particularly important for the Ivankovo Reservoir watershed where groundwater in the lowlands adjacent to the reservoir is close to the surface, and seasonal fluctuations of 0.5 to 3 m causes nutrient flushing from the soil root zone. The second point of interest deals with the fact that over the last decade the reservoir experienced an 8 - 10 fold increase in algal concentrations. This has been attributed to the increase in inefficient use of fertilizer. Clearly the structure of the Lotus River catchment should be designed to facilitate local investigations along similar lines of research.

The development of a catchment level GIS database should also take into consideration the hydrologic model that has been selected to interface with the GIS or to be integrated into the GIS. The locally developed integrated catchment water quality model developed by Reid et al (1998) for the Amatole water resources system was initially investigated for developing a hydrological model within the GIS environment. Using this model as a basis would have the key advantage of local support with respect to the methodology involved in estimating parameters required for the hydrologic modelling process. Parts of the Reid et al (1998) integrated catchment model utilize or are based on other existing software packages. These include: the multi-reservoir planning model (WRPM), the WQT salinity model and the Impoundment Management and Planning Assessment Model (IMPAQ).

The package which was finally selected for the hydrological modelling of the Lotus River catchment was SWMM (see Chapter 5). Clearly, as the section on: *GIS / URBAN RUNOFF MODEL LINKAGES* suggests, it is important to investigate the possibility of having an interface developed for the selected hydrologic

package and the GIS software.[13] GIS-hydrologic model interfaces have been developed for the following hydrologic modelling packages: Q-ILLUDAS (Haness et al, 1997), SWMM (Carter et al, 1997; Barbe et al, 1997, Univ. of Nevada-Reno, 1997), HEC-1, HEC-5Q (Terstriep et al, 1997). In particular, the SWMM Runoff Block has been integrated with ARC/INFO and AutoCAD (Huber et al, 1991; Curtis et al, 1993).

As the discussion on modifications to strategy indicated (section 2.2.3), it was decided to not carry out the hydrological modelling within the GIS environment for several reasons. However, the development of such an application should ideally be investigated in future work. The paper by Reid et al (1998) provides one of many possible hydrological model templates. This integrated catchment model is comprised of four key modules: 1) a catchment export module, 2) a point source module[14], 3) a river transport module and 4) a reservoir module. The multi-scale database structure proposed here for the Lotus River catchment would support the modelling of hydrological processes at both the catchment / reservoir level and the point source / river level. In the first instance, the four modules suggest that at least four attribute tables need to be created to cater for the input and output requirements of each module. Future work in this area should investigate the feasibility of replicating the modelling functionalities of each module individually within the GIS[15]. This would require an analysis of 1) the calculation procedures followed in each model and 2) the GIS system's capacity for coping with these types of procedures.

The discussions by Bendoricchio et al (1993) and Heidtke et al (1992) provide a good background for developing analogous pollutant loading applications for the Lotus River catchment. A problem with following the USLE GIS- based approach defined by Heidtke et al (1992) is that this model does not incorporate the effects of the urbanized environment within the watershed on the stormwater runoff. In addition, the results of the model calibration procedure, which entails comparisons between the measured load and model estimates (Heidtke et al, 1993: Table 3, p600), does not suggest a particularly great degree of correspondence between the measured and simulated loads. Irrespective of these problems, this work provides some ideas for the manner in which the processed attribute data for the various subcatchments in the Lotus River catchment could be presented on the Geomedia platform. It is interesting to note at this point that the locally developed hydrologic model Reid et al (1998) employ an extension of the USLE equation to simulate sediment load. The extended equation provides monthly estimates of sediment yield from a subcatchment using an approach proposed by Mills et al (1985).

For ideas on a cell-based modelling approach, Vieux & Needham (1993) should be inspected. This work provides a concise listing of the model parameters that must be incorporated into the database for each grid cell (p 146 - 147). A clear discussion is also provided on the manner in which the various coverages should be featurised. In essence, the database must be such that each map feature may have several attributes that are the model parameters (Vieux & Needham: p 151). This work also provides a good indication of what format the model output for the cells should follow.

The review of non-point source pollution modelling applications indicates that a cell-based approach is usually followed in the case of catchments facing a phosphorus pollution problem as a result of fertilzer application. The nature of the water pollution problems facing the Lotus River catchment area suggest that the GIS-based non-point source pollution models employed in the case of Owasco Lake and the Venice Lagoon (Bendoricchio et al, 1993; Heidtke et al, 1992; Belyaeva et al, 1993; Xu, F, 1993) should be investigated further. These papers may given an indication of useful queries to construct on Lotus River GIS database, which resides within the Geomedia environment.

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[13] In fact, the software suppliers should be approached to establish which Stormwater Drainage departments throughout the world have selected to work an Intergraph system. There seems to be a good chance that the required interfacing coding may already exist.

[14] The municipal "end-of-pipe" discharges information required for the point source module can be obtained from the CCC Drainage and Sewerage Branch. According to Nicolson, B (pers. comm.) there are four key pollution point sources situated along the Lotus River canal which are being controlled, with respect to the allowed discharges, by the CCC.

[15] It should be noted that complex differential equations are generally solved by iterative numerical methods. If it is possible acquire the simplified numerical solutions to the hydrologic equations employed by the existing customized modelling software packages, the process of simulating the hydrologic modelling within the GIS environment will be greatly facilitated.

2.2.4 Other issues of direct relevance to the conceptual framework proposed in this work

The issues reviewed in this section fall into three areas. The first deals with developments on Internet-based group decision-making support systems for urban catchment management. The second deals with catchment level GIS database applications. In particular, a source control site suitability mapping application is discussed. The third section focuses on subcatchment level GIS database building approaches and applications. All three issues are directly relevant to the work carried out within the Lotus River Project.

2.2.4.1 Internet-based group decision making support systems for urban catchment management

Ostrowski & James (1998) discuss the requirements and possible approaches for group decision - making using computer networks like the Web for urban catchment management. Ostrowski & James (1998) argue that there is a tendency towards decentralised systems. Associated with decentralised urban drainage solutions (such as integrated optimum individual solutions on the house or neighbourhood scale) is a more complicated planning process. "Transparency and continuous information are compulsory for its acceptance." Furthermore, "…. the introduction of locally and regionally optimum solutions, however, requires the participation of citizens and citizen groups concerned." (p569, Ostrowski & James: 1998)

A number of definitions for DSS are listed. The discussion by Lemons & Brown (1997) argues that in order to ensure sustainable development, the DSS must be designed with a focus towards meeting the needs of the scientific community.[16] The UN-Programme on Integrated Water resources Development and Management argues that DSS designed for catchment management requires "the application of new technologies such as GIS".[17] Osmond (1997) and Olsen & Courtney (1992) state more general and computer network based definitions of DSS respectively.

Ostrowski & James (1998) have designed a GDSS called STEEL for sustainable development. "STEEL" refers to "the working title of the GDSS under design, summarising its major fields Science, Technology, Ecology, Economy and Law under the umbrella of sustainability" (p571: Ostrowski & James, 1998). It consists essentially of six information modules. These are: Public Opinion and Awareness Module (POAM), Information System (INSYST), Educational Modules (EDMOD), Stormwater Best Management Practices collection (STORMBMP), Modelling Expert System (MEXSY) and Evaluation and Decision-making Module (EVADEM). Factors affecting decision-making necessitate the use of GIS.

The STEEL system has apparently been designed "as a participatory system involving the public", in which the medium for interaction is supposed to be the Internet. However, Ostrowski & James (1998) does not discuss in much detail how exactly the public can participate in the decision-making process. The POAM and EDMOD modules address the needs of the community to a limited extent.

For the Public Opinion and Awareness Module (POAM) the use of a list server is recommended. Interested individuals are supposed to be able to subscribe to the module, screen opinions and form sub-groups. Ostrowski & James (1998: p572) continue: "Necessarily those professionally involved in the urban water system considered must subscribe to POAM to be continuously informed about ongoing discussion. They should not be able to argue that they do not know public opinions."

The usefulness of the Internet for disseminating public information has already been highlighted (Courteau, 1996): "Also crucial are questions of information, communication and information dissemination. The Internet can become a strategic tool for consolidating these functions." With respect to the INSYST module,

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[16] Recommendations by Lemons and Brown (1997) include: the creation of regional scientific co-operatives, strengthening of scientific advice to decision-makers and improvement of dissemination of scientific research results."

[17] In a discussion on the definition of DSS systems the UN-Programme on Integrated Water resources Development and Management reads as follows: "The development of interactive databases, forecasting methods, and economic planning models appropriate to the task of managing water resources in an efficient and sustainable manner will require the application of new technologies such as GIS and expert systems to gather, assimilate, analyse and display multi-sectorial information and to optimise decision making. "

the data layers listed by Ostrowski & James (1998) need to be analysed. The following items are contained in the INSYST module:

1) Bibliography
2) Related laws and comments
3) GIS
4) Hydro-meteorological data and statistics
5) STORMBMP

The relevance and extent of each section is debatable. Here only the GIS component will be considered. As a start Ostrowski & James (1998) list the topography, demoscopy and technical infrastructure as elements that should be incorporated in the GIS. Ostrowski & James (1998) stress that the education component (EDMO) must contain modules for all stages within the pre-school, school and university systems as well as adult education as environmental education is a life-long process.

Development of the evaluation and decision making module (EVADEM) is still in its primary stages. Ostrowski & James (1998: p573) argue that it is not the information technology which presents a problem, but rather "the missing interest in the direct linkage of private and public affairs and the inability of real interdisciplinary co-operation."

The GIS platform provides a medium for co-ordinating information diffuse amongst users at a regional level. For ICM the transfer of resources between local boundaries must be considered at the same time. Wastewater and stormwater emissions from a single community may not be critical, however, "the accumulation of several communities along a small or medium size river might still cause manifold downstream problems...it seems compulsory to establish integrated watershed management plans. Local micro-scale impacts can be integrated and averaged and be input to meso-scale GDSS. Although some approaches have been developed much work needs to be done to build up meso-scale GDSS." p576.

2.2.4.2 Catchment level GIS database applications

Source control site suitability mapping

The discussion by Makropoulos et al (1998) which deals with the use of GIS analysis methods for evaluating the suitability of urban areas for source control applications provides a convenient framework for evaluating the analysis potential of the current Lotus River catchment database.

"...Source control application, viewed as an important intervention in the effort to control and minimise water inflow to urban drainage systems and thus reducing its adverse effects on downstream environment is considered as one of these more "sustainable", low energy water management techniques. Although there is a considerable effort to quantify the phenomena involved in source control (ie. infiltration, retention, detention etc) and produce guidelines for its application, there is still lack of reliable, site specific implementation methodologies." (Makropoulos et al, 1998: p59)

In the "source control" approach the aim is to reduce and attenuate the storm flows before the reach the drainage network and to improve water quality by allowing natural treatment to take place. The concepts of source control and downstream control are discussed in detail by Makropoulos et al (1998:p60.) Here it is sufficient to note that local disposal (infiltration techniques, porous pavement etc), inlet control (rooftop storage) and on site detention (ponds and basins) can be classed as source control methods.

The methodology employed by Makropoulos et al (1998) involved the development of a database containing the primary information of the criteria which can be applied to identify areas where source control can be more successful. These layers included data such as the soil type, slope, income, imperviousness, depth to groundwater, soil moisture, structure of the ground surface, connectivity etc. The methodology relied on the built-in analysis functions of the grid-based IDRISI (windows version 2) software. In particular the "Fuzzy sets" and "Multi-Criteria-Evaluation" methods were applied to create a suitability map. These methods are described in detail by Eastman (1997) and briefly by Makropoulos et al (1998). To identify areas for

evaluation through the multi-criteria process a suitability matrix was created (Table 2.1).[18] Using this matrix three suitability maps were created for the three types of source control: infiltration techniques, porous pavements and detention basins. In conjunction with Table 2.1, a second table (Table 2.2) was produced in which each criterion was assigned a weight indicating its relative importance in the characterisation of an area as being suitable or not.

Table 2.1 Categorisation of catchment characteristics for analysis of source control suitability (Source: p62, Makropoulos et al, 1998)

PRIMARY LAYERS (parameters affecting infiltration)	Category 1 (less applicable)	Category 2 (intermediate)	Category 3 (more applicable)
LAND USE	Urbanised (impervious areas > 66 % of the total area)	Semi - urbanised (33 % < Impervious < 66 %)	Non - urbanised (Impervious < 33 % of the total area)
SOIL TYPES	Impermeable (ie. clay, fo=3*10-4)	Semi - permeable (ie. sand)	Permeable (ie. Gravel, fo = 2*10-2)
SLOPE	Steep (S > 20 %)	Medium (3 % < S < 20 %)	Mild (S < 3 %)
LAND PRICE	High	Medium	Low
INHABITANTS INCOME	Low	Medium	High
DEPTH TO WATER TABLE	Small (d<3m)	Medium (3m < d < 10m)	Large (d > 10 m)
DISTANCE FROM OUTLET	From near	To medium	To long
VEGETATION COVER	No cover	Lawn	Natural
DEPTH TO BEDROCK	Small (d<2m)	Medium (2m < d < 10m)	Large (d > 10 m)
STORM DRAINAGE SYSTEM	Buried pipes > 70 %	30 % < Buried pipes < 70 %	Buried pipes < 30 %
AVAILABILITY OF OPEN SPACE	Availability < 33 %	33 % < Av < 66 %	Av > 66 %
CONNECTION OF IMPERVIOUS AREAS TO SS	Connectivity > 70 %	30 % < Con < 70 %	Con < 30 %

Table 2.2 Weights assigned for various source control applications (Source: p63, Makropoulos et al, 1998)

LAYERS USED	WEIGHTS for Infiltration Techniques	WEIGHTS for Porous Pavements	WEIGHTS for Detention Facilities
SOIL PROPERTIES	0.25	0.225	0.05
URBANISATION		0.25	
SPACE SUITABILITY	0.2		0.25
SLOPE	0.2	0.15	0.2
GROUNDWATER	0.2	0.25	0.05
LAND PRICE		0.1	0.25
DISTANCE FROM NETWORK			0.15
CONNECTIVITY	0.1		
DISTANCE FROM OUTLET	0.05	0.025	0.05

[18] The terminology used in this table is defined in footnotes 2 - 7 in Makropoulos et al (1998:p62-63).

2.2.4.3 Subcatchment level GIS database building approaches and applications

A discussion by Rodriguez et al (1998) provides some initial background on the potential application of subcatchment level GIS data applications. Rodriguez et al (1998) analyse an urban catchment on the basis of two spatial elements which are consistent with the structure of urban databases: 1) the property block considered as the base hydrological element, and 2) the stormwater drainage map representing the urban runoff network. The key element of the Rodriguez et al (1998) discussion is that the methodology employed has been designed to utilise existing urban data. This approach has certain merits but also drawbacks when considered in the context of the Lotus River catchment project.

Rodriguez et al (1998) comment that GIS can be used in the following ways: 1) to collect all of the data in numerical form, 2) to organise the computer-aided database management, 3) to allow easier data processing, and 4) to create maps (Pomon, 1992). The basic idea consists in using "existing" urban data banks, not specifically built for hydrologic purposes. In this perspective, an urban catchment is composed of a group of Base Hydrological Elements (BHE) defined from property blocks (p334, Rodriguez et al, 1998).

The discussion by Rodriguez has relevance in terms of the first methodology employed in this study for land use analysis. The GIS database layers extracted from the urban database for the hydrologic application were as follows: property blocks, houses, streets, rain sewer network and rivers, topography. The methodology has been applied to a small catchment of about hundred hectares.

The study assumes that the hydrological characteristics of an urban area can be described by two urban elements (Rodriguez et al, 1998):

1) The Base Hydrological Element which includes a geographic zone composed of a property block, a house and a street portion, adjacent to the property block. Each BHE is connected to the street network.

2) The stormwater drainage map which regroups the street network superimposed to the storm sewer system, in order to connect BHEs to the outlet of the catchment.

The approach developed by Rodriguez et al (1998) has had three applications:

Firstly it has been used to produce data on the impervious fraction of subcatchments for sewer design tools such as CANOE (INSAVALOR and SOGREAH Ingenierie, 1997). Secondly it has been used to delineate catchment boundaries automatically. A third application has been the determination of the transfer function for the catchment. The development of a physically based model, based on GIS information is placed as future research (Rodriguez et al, 1998).

Discussions by Hora et al (1998) and Pryl et al (1998) provide an indication of some of the data types that may be encountered in local level stormwater runoff GIS databases. Hora et al (1998) list the following data types:

- Topological data
- Urban development plan
- Hydrological data
- Hydraulic data
- Measurements (discharges, water levels, rainfalls)

The development of detailed stormwater runoff GIS databases requires extensive resources to be dedicated to data digitisation and data checking. The data checking procedure involves series data control and analyses steps. The data control and analyses steps include:

- Perfection of data digitisation (visual comparison with map sources)
- Regularity of node - pipe connection (visual comparison with map sources)
- Pipe orientation (upstream and downstream)
- Top and bottom elevations control (top under bottom)
- Non-connected nodes control

- Double named nodes control
- Longitudinal profiles validity control
- Detail structure description control

It can also be seen from the above list of data checks required, that additional data is required such as pipe orientation, pipe elevations etc. For such detailed information sewer pipe plans of 1: 1000, 1: 750 and 1: 500 and technical drawings of 1: 25 are also required. Such plans do not exist for informal settlement areas. Again this approach is thus restricted to the formal areas, unless consultants are involved in mapping the sewer network systems in the informal areas.

The discussion by Pryl et al (1998) also sheds some light on what data types are useful to incorporate at the subcatchment level. This paper describes a database system (AQUABASE) which was designed to meet the data processing and design requirements for capturing the urban drainage Master Plans in Prague. In this system information is attached to a number of different node types including manhole nodes, basin nodes, outlet nodes and artificial nodes. Detailed information is attached to each of the node types. In addition to the node name, information on the covers, pumping, overflow, repair work, break down and hydraulic data are kept.

The potential applications arising from adopting the database contents described above have been discussed by Rodriguez et al (1998: p337). Essentially these applications include:

1. Description of the water budget: The out puts of the GIS utilising this type of data have sufficient accuracy for utilizing sewer design tools at a local level
2. Automatic delineation of an urban catchment: Unlike the methodology employed in this present study, the above database contents configuration would enable the catchment boundaries to be directly deduced from the stormwater drainage map.
3. Transfer function: Rodriguez et al (1998) comment that this application is still in progress. Essentially the transfer function calculated is based on the flow paths and on Manning's equation. (see Rodriguez et al (1998) for further details).

The applications arising from a database designed for evaluating sewer network system developments were as follows (Hora et al, 1998):

1. Transfer of the sewer network evidence from paper into digital form.
2. Development of a hydrodynamic model.
3. Monitoring campaign for the whole catchment.
4. Calibration and verification of the hydrodynamic model.
5. Evaluation of the current hydraulic capacity of sewers.
6. Feasibility studies of alternatives of the sewer network development.

2.3 GIS methodologies and database management strategies for the Lotus River catchment

This section consists of three parts. The first part summarises the system parameters, structure of the database and database contents implemented in the development of the Lotus River catchment database. The second part deals with a series of database management strategies proposed for the development of a GIS-based ICM database for the Cape Town Metropolitan region. The third part discusses the specific GIS techniques employed in the development of the Lotus River catchment database.

2.3.1 The Lotus River catchment database

2.3.1.1 System parameters

The system parameters, which have been utilised for the Lotus River catchment database, are as follows:

Co-ordinate system:
Transverse Mercator

Co-ordinate system parameters:
Longitude of origin: 19:00:00:00.000 dms
Latitude of origin: 0:00:00:00.000 dms
False Easting: 0
False Northing: 0
Scale Reduction Factor: 1

Geodetic Datum:
User defined (non-standard)

Ellipsoid:
User defined (non-standard)

Ellipsoid parameters:
Equatorial radius: 6378249.145 m
Polar radius: 6356514.966 m
Eccentricity: 0.082483216588798
Flattening: 0.00340754619495265
Flattening inverse: 293.466307655998

2.3.1.2 Database structure

The database, which has been created for the Lotus River catchment essentially, resides on two software platforms. The first software environment, which is the MGE project environment, has been used primarily to capture vector data from images which have been georeferenced, and to obtain area measurements for the land use classification analysis work. The second platform, Geomedia has been used to archive the data onto an easily accessible and user friendly system. The various data types listed below have been placed into individual database warehouses within the Geomedia environment.

2.3.1.3 Database content

A list of the types of data which have been collected for the Lotus River catchment database are shown in Table 2.3.

2.3.1.4 Database location

The database resides on two platforms. Firstly it exists as an MGE project on the Urban Management GIS system at UCT. Secondly, selected portions of the primary data source have been imported into Geomedia Warehouses residing on a computer at AGM Consulting.

2.3.1.5 Database linkages

Currently, the primary database is not linked to the Internet. It is also not directly linked to the AGM warehouses. The secondary database on the other hand resides on an Internet linked network.

Table 2.3 Types of data that have been collected for the Lotus River catchment database.

Data type	Coverage of data
Detailed cadastral	Nyanga-Gugulethu Lansdowne Wetton Corridor Project
Parcels	Lotus River Catchment
Elevation	
0.5 m contours	50m corridor of data along the proposed Lotus River bicycle track
5 m contours	Table Mountain
10, 20 m contours	Metropolitan area
Stormwater drainage	Nyanga-Gugulethu, Crossroads
Roads	Philippi, Nyanga-Gugulethu
Land use	
1996, 1983	Lotus River Catchment
1938	Ikapa
Hydrological	Lotus River Canal
Groundwater	Cape Flats Aquifer
Soil	Lotus River Catchment
Waste	Lotus River Catchment

2.3.2 GIS methodologies employed in the development of the Lotus River catchment database

The methodologies employed in the development and use of the Lotus River Catchment GIS database can be discussed under the following set of issues:

- Data capturing methodologies
- Parameter estimation methodologies
- Data visualisation methodologies
- Applications of land use data

Different methodologies have been employed to capture the different data sets constituting the database. These methodologies are described in the first category. The section on parameter estimation methodologies describes the manner in which a number of input parameters for the SWMM model have been estimated. "Data visualisation methodologies" deals with the steps required to produce various map outputs for the project. "Other applications" discusses how the various parameters estimated from the land use data were calculated. The database organisation issue is discussed with respect to the structure, content, location and linkages of the database. The system parameters are also discussed under this section.

2.3.2.1 Data capturing methodologies

This section discusses the manner in which the stormwater drainage network, subcatchment boundaries and land use data were captured.

1) Capture of stormwater drainage network data

The drainage system information required some pre-processing (see Chapter 5) before the data could be digitised. For the Nyanga and Gugulethu areas, the key drainage map features were initially extracted from a number of stormwater infrastructures and drainage maps produced by Stewart Scott & Orrie-Welby-Solomon. These features were subsequently drawn onto a 1:5000 scale master plan of the drawings. This simplified representation of the drainage network was used in conjunction with existing parcels information on the system to effectively draw in the drainage features. The resultant drainage map appears in Appendix B. It is clear that methodology employed in the stormwater drainage mapping process will vary with the level and nature of the database application. For example, the construction of a stormwater drainage map for the subcatchment level application described by Rodriguez et al (1998) (see below) involves a far more detailed data capturing methodology. In this case, the following three elements were incorporated into the stormwater drainage map: the sewer map linked streets and unlinked street segments.[19]

2) Utilising GIS to debate the delineation of subcatchment boundaries

The proposed drainage map drawn by Hill, Kaplan and Scott was used to obtain a preliminary map of the Lotus River subcatchment boundaries. These boundaries have undergone numerous modifications resulting from overlay comparisons with detailed (1997) cadastral vector data acquired from the Cape Town Metropolitan Council (CMC), comparisons with previous studies (Taylor, 1994; Chapter 5 in this study), and from discussions with other members of the Lotus River project team. The vector subcatchment boundaries have also been corrected to the May 1996 (1:20000) National Department of Housing imagery which has been used for the land use analysis in this study. The finalisation of these subcatchment boundaries has enabled a number of key input parameters to be estimated for the SWMM model.

3) Land use classification techniques employed

Two techniques were employed in the land use mapping process. The first methodology involves the use of detailed cadastral data. The second is based on digital orthophotography. The second methodology proved to be much quicker than the first and was used to collect all of the land use data for the Lotus River project. Furthermore, the second methodology yields results similar to the first methodology. The results of the two methods are compared in section 2.4.3.

4) The cadastral data-based land use analysis methodology initially employed

The first land use analysis methodology employed was based on the application of existing cadastral data acquired from the Cape Town Metropolitan Council. Table 2.4 shows the type of features which have been collected into the Lotus River catchment database. This data suffered from the lack of polygon elements for several area-based features. In particular, the formal and informal houses and other buildings were represented as linear elements. This required manual linestring (or polyline) to polygon conversions for area measurements. Similarly the road data required pre-processing before road areas could be measured. The implementation of this methodology was eventually terminated as it proved to be far too time-consuming to carry out on a catchment-wide basis. The methodology employed is described here, as it has relevance for ICM GIS work at the subcatchment level.

[19] In the production of a stormwater drainage map, Rodriguez et al (1998) have defined street segments which are associated with sewer segments as "linked street segments". Street segments which are not associated with a sewer segment, but which can be associated with a linked street segment have been included as "unlinked street segments".(p336, Rodriguez et al, 1998)

Table 2.4 Features present in the cadastral database captured by the CMC

Access	Factory	Platform	Steps	Patio
Bridge	Fence	Public building	Substation	Pipes
Building	Flats	Rail	Swimming pool	Plant
Canal	Foot	Religious	Track	Gravel
Canopy	House	River	Transport	Sport fields
Construction	Hydrant	Road	Water tank	Pylon
Electricity box	Marsh	Ruin	Wall	Ramp
Electricity pole	Manhole	School	Parcels	
Embankment	Nation	Shack	Bollard	
Express	Out building	Sluice	Dam	

It should be noted that none of these features have been captured for the informal settlement areas. In addition, where data is available, it has been captured in a manner that requires a great deal of manual data conversion for area calculations.

The land use analysis methodology described here was carried out on one of the subcatchments in the Nyanga - Gugulethu area. The subcatchment, which was selected (110), occurs in the Ikapa area to the south of Barcelona and to the west of Mahobe Drive and Boy's Town. In the first instance the design file acquired from the CMC was clipped so that only the data for this area was worked with. Each of the feature types was then separated out into individual layers. Where possible, areas were converted from linearly represented features into complex shapes. The initial land use analysis results for this subcatchment are shown in Table 2.9.

The total area comprised of buildings was determined by zooming in on building clusters and using the Microstation area measuring tool. These building clusters are shown in Figure 2.2 (see Appendix D). In one case (cluster H) a "polygon within polygon" situation was observed. It is not sure if this represents a second floor or an error. Total area comprised of tracks was determined by calculating the difference between inner and outer track areas (Figure 2.3). The total informal housing area is comprised of areas that conform to the road layout (magenta) and higher density housing areas that do not conform to any layout (green) (Figure 2.4). For the values shown above, boundaries were simply placed around these two different informal housing area types. The areas measured using these boundaries thus contain open spaces between the shacks. A similar approach, which did not take into account the open spaces between the houses, was followed for the formal housing areas. Once rapid estimates were obtained for all the land use types, an attempt was made to obtain more accurate area estimates, which excluded the open spaces between the formal houses. Figure 2.5 illustrates the methodology that was initiated. Essentially it was recognised that within the formal housing areas, three basic counting units could be applied. The first is a rectangular arrangement of four buildings (A). The second is simply a string of shorter buildings (B). The third represents four of the shorter buildings in an X - type arrangement. By accurately measuring the areas of the buildings within each unit, the counting units can be used to more rapidly obtain area estimates, which take into account the open spaces within the housing areas. Another experimental approach involved measuring the total area (including the open spaces) of a housing area, and subsequently summing up the areas of individual buildings within that housing area. Using these two area estimates for the same housing area a coefficient can be calculated to correct for the open areas included in the approach which has been followed here.

The road surface area was calculated by subtracting the polygon areas of other land use types within the subcatchment boundary from the total subcatchment area (Figure 2.6). In addition to the cemetery and to the informal housing areas (magenta), five other polygon-bearing regions were identified. Each region consisted typically of less than 20 street blocks. In this manner the area for each street block polygon was systematically subtracted from the remaining subcatchment area. In order to carry out this process, the linear street vectors had to be manually converted into street block polygons. As commented by other authors who have attempted to use existing urban data bank data sets for hydrological modelling, this conversion process can be very time consuming.

In addition to the time demands associated with this approach, this methodology was abandoned for two other reasons. The first dealt with an MGE-IDRISI project environment set up compatibility problem. The second dealt with the lack of suitable stormwater drainage data for the Nyanga-Gugulethu area at the time. This lack of data and the poor quality of the limited available data, as well as other problems associated with the use of the existing stormwater drainage data is discussed in detail in Chapter 5.

With respect to the first issue, the ultimate aim of implementing this approach was to provide an accurate land use analysis by which to calibrate the results of a remote sensing based approach using Landsat imagery. With time it was found that there was a data compatibility problem between the GIS work carried out in MGE and the work carried out in IDRISI. This arose due to the fact that the IDRISI project environment was based on a pseudo co-ordinate system which had been set up previously in IDRISI. No transformation or projection system information had been employed when the IDRISI database was initially created. Conversion of the correctly positioned MGE data (eg the subcatchment boundaries) into IDRISI environment proved unattainable within the given time frame set for the task.

5) The second land use classification methodology employed

The land use classification analysis procedure employed in this study required some initial image processing procedures. This was followed by the definition of which classes should be mapped for each set of images. Once these two issues were finalised, the land use data was mapped within the MGE project environment using the Microstation digitization tools.

A number of land use classification maps were produced for the Lotus River catchment based on 1996 (*1:20000*) (Figure 3.2), 1983 (*1: 30000*) and 1938 (*1:18000*) aerial photography imagery (see Figures 3.4 - 3.6). In the case of the 1996 data, high resolution (0.5 m pixel size) digital ortho-rectified colour imagery which had been previously acquired from the National Department of Housing (NDH) was moved into position within the MGE Advanced Imager (MAI) module. In the case of the 1983 and 1938 imagery, contact prints were acquired from the Surveyor General and scanned in at 100 dots per inch. These images were subsequently warped into position by selecting control points on the georeferenced 1996 imagery.

With respect to the 1996 imagery, the following classes have been applied: formal, informal, serviced site, open and not vegetated, vegetated by grass, dense vegetation (including grass and shrubs), cultivated, industrial/built-up areas, agricultural buildings, parking lots, rail, detention ponds, dry ponds and wet ponds. Examples of these classes have been extracted from the imagery used and are shown in Figure 2.7. The following classes have been applied in the 1983 and 1938 imagery analyses: vegetated, not vegetated, formal, informal, relocated, industrial / built-up areas and agricultural buildings.

2.3.2.2 Parameter estimation methodologies for the SWMM model

1) Primary input parameters

The primary parameters, which will be estimated via GIS for input into SWMM, correspond essentially to the topographical data requirements of the model. These requirements include the following parameters: subcatchment area (ha), % imperviousness, subcatchment width (m) and the overland slope (m/m).

The area and length parameters have been determined in the Intergraph MGE project environment using Microstation tools. The average slope for each subcatchment has been determined by referring to orthophoto imagery (1:30000) produced by A.O.C. SYSTEMS (Pty). Attached to this imagery (which has been saved as a pyramid format file) is an accompanying spot height model. This model is in the form of an encoded x, y, z co-ordinate grid file. Both the imagery and the spot height data are encoded in formats, which can only be accessed through the Orthodraw software developed by A.O.C. This limitation severely inhibits an automated integration of the data captured by AOC with the Lotus River catchment data already on the MGE and Geomedia platforms.

2) Secondary input parameters

Initially it was intended to utilize GIS to estimate a number of secondary input parameters for the hydrological model which would be used. A number of hydrological models employ the SCS runoff curve number (CN) method to determine initial rainfall losses (infiltration, depression storage and interception) and runoff. By overlaying land use and hydrologic soil group maps, composite SCS runoff curve numbers may be generated on a subcatchment basis. These values may then be entered directly into the hydrological model. In addition to estimating the pervious and impervious curve numbers, the GIS was intended to be used to determine the percentages of the subcatchments that are impervious.

In practice, the SWMM modelling technique which has been employed (see Chapter 5) has not required the input of composite SCS runoff curve numbers. Furthermore, it remains to be verified whether the existing soil data for the catchment would enable the SCS runoff numbers to be calculated. The soil data that has been acquired covers only the Philippi farming area. In addition, the data distinguishes only between calcareous and non-calcareous soils.

In view of the change in the selected SWMM modelling technique and the limited soil data coverage, the GIS was used only to obtain estimates for the percentages of the subcatchments that are impervious.

2.3.2.3 Data visualisation methodologies

1) Coupled raster-vector-based methods

In order to create raster backdrop images to vector data and to produce plots from the original imagery, a number of re-sampling procedures were required. Each of the images acquired from the NDH ranged from 290 to 320 MB in file size. Large imagery file sizes such as these are often difficult to plot and to manipulate on software, which is not designed for image processing. The Lotus River catchment is covered by five images. In order to enable all the images to be viewed simultaneously on the Geomedia platform each of the images were re-sampled at a resolution of 5 m. This reduced the file sizes to 2.4 MB each and enabled the images to be viewed easily. In addition, to create a number of large A1 plots from the imagery, the original files were re-sampled as 8-bit colour images to retain less colour information. The result was a series of images with little loss in colour resolution, no loss in pixel size resolution, and a reduction in the file size from about 300 MB to about 92 MB.

2) Thematic mapping

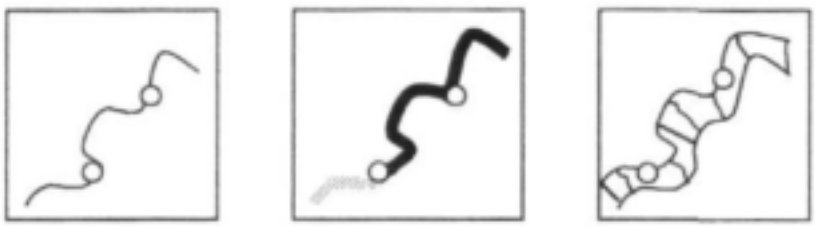
A series of thematic maps was constructed for the hydrological data collected for two dates (15/09/97 and 05/08/97) (Figures 3.16 - 3.25, Chapter 3). This data included measurements for the following variables: TPON, TP, SRP, COD, TSS, TVS and EC. A number of options were considered for the thematic representation of the hydrological data variables. In the first instance it is important to note how the field measurements relate to 21 sample data value sets collected for this project (see Chapter 5). The raw data is associated with single stand alone sample points (eg. N2) and with outlet samples (eg. NY3 outlet). In the case of the outlet samples data has also been collected above and below the outlet sample (ie. above NY3 and below NY3). Where the flow at the outlet was very low the outlet value was calculated as a function of the values measured above and below the outlet. Thus the issue addressed here revolves around the thematic representation of a series of isolated sample point values which required a great deal of pre- and post-measurement considerations.

The sample number labels were initially attached as a text attribute data type to point elements representing the sample locations. To simply illustrate the sample point location a point-based basic spatial unit (BSU) (see the catchment level discussion on ICM for a definition of this concept) is sufficient. However, to illustrate the variation in the hydrological variables along the canal in a manner that is easily compared with land use and population density data for the area adjacent to the canal a different BSU is required. For this purpose a line segment or polygon element is a better choice. After a series of trial and error plots it was decided that the polygon approach provided the best visual result. In order to implement a thematic representation of the data based on polygons, a polygon thematic map template was constructed in Microstation and subsequently imported into Geomedia. This template was later modified so as to represent

the polygon width as a function of the flow velocity for two sampling dates. The polygon width was calculated simply by multiplying the measured flow width by a factor of a thousand. Thus a location with a flow velocity of 0.112 m^3/s was represented within the MGE system by a polygon with a width of 112 m. Polygon widths were subsequently determined for the inter sample and inter kink polygons along the canal in a manner similar to that of calculation procedure followed for the interpolated sample values described below.

As already mentioned data was only available for 21 sampling points. In order to assign attribute values to the polygons between sample locations, each inter-sample section of the canal was subdivided into a number of polygons of a standard width. Thus the number of polygons between consecutive sample points is dependent on the distance between the sample points. In total 103 polygons were created for the Lotus River and 24 polygons were created for the Little Lotus River. The Excel spreadsheet program was then used to interpolate values for the polygons in between the sample point polygons. For this purpose each inter-sample section was treated as having a "start" and an "end" sample point values. The values for the intermediate polygons were calculated simply as a function of the start and end sample point values for each section. The number of polygons in each section was used to calculate a coefficient so that by incorporating the distance from the start polygon, values could be calculated so that they would increase incrementally towards the end sample point. The results of the thematic mapping process are visible on a large number of figures in Chapter 3 (Figures 3.16 - 3.25).

Figure 2.8 Three possible ways of illustrating the hydrological data monitored along the Lotus River canal



2.3.2.4 Applications of land use data

The 1996 land use data enabled the subcatchments in the Lotus River catchment to be grouped into regions (see section 2.5). In addition the land use data enabled estimates for the following parameters: population density, land use heterogeneity, land use change and the degree of urbanisation. The definition and the manner in which each of these parameters were estimated are briefly discussed here.

1) Population data

The total population for each subcatchment has been estimated as sum of the population residing in the formal, serviced sites and informal settlement areas (see Figure 3.26). The population residing in each of these housing types for each subcatchment was calculated using the following relation:

Population in $\underline{x}$ = Ax x Hdx x Hsx

Where:

x = housing type "x"
A = area (ha)
Hd = housing density (households/ha)
Hs = household size (people/household)

In the case of the informal settlement population, shack counting data obtained from a concurrent project (Martinez, 1998) was used to calculate the informal settlement population in each subcatchment.

Thus the total population for each subcatchment was calculated as follows:

Total population $= (Af \times Hdf \times Hsf) + (Ni \times Hsi) + (As \times Hds \times Hss)$

Where:

f	=	formal housing
N	=	number of shacks
i	=	informal housing
s	=	serviced sites

Values for the housing density per hectare were estimated empirically from the land use data. For the serviced site areas and the formal housing areas the housing density has been estimated at 0.005 and 0.008 respectively. The household size estimates (persons/du) used for the serviced sites (3.6), formal areas in Nyanga and in all the remaining formal areas (4.9), was obtained from Van Zyl (1995). Where informal settlements are divided by subcatchment boundaries, previously defined informal settlement boundaries had to be modified and the shack counting data had to be recaptured for the new sub-settlement groupings. Once the total population values had been calculated, the population density values (people / hectare) were calculated by dividing the total subcatchment population figures by the subcatchment areas (see Figure 3.27.).

2) Land use heterogeneity

The variation in land use heterogeneity is an important parameter to consider as it is a first order approximation of the variation in the obstruction to overland hydraulic flows across a catchment region. There is a need to obtain appropriate hydraulic coefficients to incorporate these land use variations into the overland flow modelling process.

3) Degree of urbanisation

The values calculated in this study for the percentage area of each subcatchment, which is impervious, represents a summation of the hydrologically effective and ineffective impervious areas. These values are more appropriately defined as a measure of the amount of urbanisation or the percentage of hardened surfaces comprising each of the subcatchments. The land use change detection analysis of the three land use data sets collected was limited to a calculation which reflected the change in permeability value calculated for the following periods: 1983 - 1996 (see Figure 3.29), 1933 - 1983 and 1933 - 1996. In the case of most subcatchments the estimated permeability has declined. The "change in permeability" parameter has been calculated to emphasise this decline in permeability. This has been done by subtracting the older percentage permeable value from the younger percentage permeable value - so that one arrives at a negative value in most cases.

2.4 Results

This is followed by a description and a comparison with the land use classification methodology employed in this study with methodologies employed in previous studies.

This section discusses the following issues:

- regional subcatchment groups identified via the GIS
- degree of urbanisation
- a comparison of the two land use classification techniques implemented
- a comparison with previous land use data
- a comparison with previous permeability estimates.

2.4.1 Regional subcatchment groups

The 1996 land use mapping data enabled the subcatchments in the Lotus River catchment area to be grouped into five regions (see Figure 3.3). These are:

1) a western formal-industrial-vegetated region (155a, 155b, 167a, 167b, 165a, 165b, 169a, 189, 170a, 170b, 180a, 180b, 185a, 185b, 195a, 195b)

2) a central cultivated land-agricultural buildings-vegetated region (190, 175, 140, 135, 169c, 167c, 160, 150b, 150a, 145, 134a)

3) a north eastern formal-informal-open region (131a, 131b, 130b, 126a, 120, 115, 127, 110, 105)

4) an eastern informal-open region (134b, 126b, 125, 130a, 126a)

and

5) a northern industrial-open region (101).

2.4.2 Degree of urbanisation

In the case of most subcatchments the estimated permeability has declined. For example, for subcatchment 101 the estimated permeability for 1983 was 95%. In 1996 this value had declined to 67.7%. The comparisons for the 1933 calculations are restricted to the following subcatchments: 101, 105, 110, 115 and 120. By comparing the 1933 - 1983 and 1933 - 1996 "change in permeability" data sets (Appendix C), it can be seen that in three of the subcatchments (101, 105, 110) most of the development occurred after 1983. For two of the subcatchments (115 and 120), it can be seen that a great deal of development had already occurred by 1983.

2.4.3 Comparison of land use classification methods

The land use analysis results for this subcatchment based on the first land use analysis methodology that was used (cadastral-based) is shown in Table 2.5. The results of the second land use classification procedure (based on orthophotography) employed appear in Appendix C.

Table 2.5 Results of land use analysis for subcatchment 110 using a cadastral based land use analysis method.

Land use	Area (m^2)	Percentage of subcatchment (%)
Cemetery	296325	16
Open land (minimum)	32878	2
Road surface (maximum)	187666	10
Buildings	16119	1
Formal housing	808628	44
Informal housing	475007	26
Tracks	20920	1
Total subcatchment area	1837543	

In the land use analysis of subcatchment 110, a subcatchment area of 1837543 m^2 has been used in both methodologies. The results of the two methods compare favourably. Despite this favourable comparison, there are a number of reasons why the second digital orthophotography based technique has been followed in this study. In terms of the results of the methodologies, the largest difference lies in the estimate of the formal housing areas. Method 1, which is based on the cadastral data, enables the road and track areas to be calculated. These land uses do not get estimated in the second methodology. A second difference is that

although the open land is underestimated in both methodologies, in contrast to the second methodology, the cadastral-based approach would facilitate the correction of the housing area values to exclude open areas between the houses and shacks. The largest technical difference between the two techniques is that the first methodology is far more time consuming. In addition, unlike the second methodology, which can be applied to the whole catchment, the first methodology can only be applied to certain subcatchments, as detailed cadastral data does not exist for the entire catchment.

Table 2.6 Comparison of the results of the two land use mapping methodologies for a selected subcatchment.

Land use	Method 1 (%)	Method 2 (%)
Cemetery	16	-
Vegetated (mixed)	-	-
Grass	-	9
Shrubs, trees and grass	-	10
Unvegetated open land	2	3
Road surface (maximum)	10	-
Buildings	1	2
Formal housing	44	-
Formal housing (including road surface)	-	52
Informal housing	26	22
Industrial	-	1
School	-	1
Tracks	1	-
Total percentage	100	100

With respect to the treatment of the road surface area measurements, it should be noted that most of the road surfaces occur within the formal housing areas. Method 2 did not enable a direct measurement of the road surface area due to time constraints. However, it should also be noted that the formal housing area measurement using method 2 includes the area of roads within these areas. Considering 1) that the data has been collected to estimate the total effectively impervious area and 2) that both the road and formal settlement areas are treated as effectively impervious surface types in this study, it seemed feasible to use a lumped estimation of these parameters in Method 2.

2.4.4 Comparison with previous subcatchment land use data

The subcatchment boundary and land use allocations in previous stormwater runoff modelling applications for the Lotus River catchment (eg. Taylor, 1994), are faced with certain limitations. The catchment was previous subdivided into 25 subcatchments. These subcatchment boundary definitions disregarded numerous variations in the slope across sub-areas divided by the Lotus River canal. Previous land use allocations have tended to be designed so as to simplify or homogenise subcatchment land use definitions for the purposes of stormwater runoff modelling. Single land use allocations have been assigned to the majority of the subcatchments considered. In addition, the presence of other key land use features, potentially useful for integrated catchment management applications (eg. informal settlements) or for investigating rehabilitation possibilities (eg. small dry or wet ponds scattered throughout the agricultural region) have been completely ignored. Examples of these simplified classification schemes include the Pinetown and the Palmiet River studies. The land use categories in the Pinetown study included: parkland, commercial, high density residential, medium densities, industrial. In the Palmiet river catchment (20 km square) study the following land use categories have been considered: open spaces, industrial areas, commercial areas and residential areas (Schmitz & de Villiers, 1997).

In the previous land use based permeability estimates, areas were assumed as homogenous "residential" (110, 120, 127, 167, 169, 170, 180, 185, 195) or "agricultural" (175, 190, 160, 150, 145, 140, 135) areas. Graphs of percentage land use data for subcatchments previously placed into one of these categories show significant variations from one subcatchment to another within a single category. The graphs indicate that simplified land use allocations [which imply 1) that subcatchments can be treated in a homogenous manner and 2) that

a standard permeability can be allocated to subcatchments within a specific category] approach can result in a grouping of subcatchments that are in actual fact very different from one another in terms of the land use percentage data (see Figures 3.7 and 3.8).

The formal component of a previously "residential" subcatchment grouping varies from 0 (167b) to 89% (180a). Similarly the nature of the hydrologically pervious component within the same category varies from 73% shrubs (195b) to 77% cultivated (167c). Parking lot areas vary significantly reaching up to 20% in some subcatchments (167a). Similarly, subcatchments with the so-called "agricultural" subcatchment category are composed of variable combinations of cultivated, grass and shrub bearing areas. The percentage cultivated land use varies from 24% (150a) to 82% (160). The percentage of shrub bearing areas varies from 4% (160) to 40% (150). In addition, parking lots can reach up to 12 % of the subcatchment (145).

2.4.5 Comparison with previous permeability estimates

The study by Taylor (1994) lists values for the percentage of a subcatchment which is impermeable for the following five land use combinations: sportsfields / agricultural (0%); agricultural / residential (10 %); residential / light industrial / Spoornet (37 %); residential & grassed / industrial, institutional & residential (48 %) and industrial / residential (60 %). The approach adopted in allocating a permeability value for a subcatchment involved categorising the subcatchment in terms of one of these land use type combinations, thereby enabling a "standard" percentage impermeable value to be employed. Instead of retaining information which would reflect the heterogeneity of the subcatchments there is a clear tendency to homogenise the land use descriptions of the subcatchments under consideration. In the majority of the cases only one land use category has been assigned to a subcatchment. It is clear that no attempt was made to incorporate an area-weighted estimation of the various land uses within a subcatchment, in the process of obtaining an estimate for the impermeability of the subcatchments. The tendency to ignore significant slope variations across individual subcatchments dissected by the Lotus River canal has already been mentioned.

The percentage hardened areas calculated in this study lie between 2.7 and8 % for subcatchments within the agricultural region which were previously allocated a percentage impervious value of 0%. Large variations between the percentage hardened surface and the percentage imperviousness exist for subcatchments containing informal settlements, and for subcatchments which have been further subdivided due to intra-subcatchment heterogeneities (see discussion below).

Furthermore, informal housing areas are not considered within conventional hydrological modelling (eg. Taylor, 1994). Previous studies have also ignored inter-subcatchment land use variations. This can be seen from the variation in the percentage hardened surfaces comprising a number of subcatchments which were all previously allocated a 60% impervious value: 101 (32.2%), 115 (90.4%), 120 (75.4%), 126 (57.2 - 4.8%), 127 (51.8 %), 130 (82.8 - 65.7%) and 131 (57.5 - 68.8%). Thus previous studies are lacking in that no consideration of the variation in the percentage hardened surfaces are taken into account. Secondly extreme heterogeneous nature of land use distributions within individual subcatchments are often overlooked. Examples of where significant intra-subcatchment land use variations have been ignored are as follows (predominant land use listed in brackets): 130a (informal) versus 130b (formal); 126a (informal, parking lot, industrial) versus 126b (grass and shrubs); 195a (formal, industrial) versus 195b (open vegetated), 169a,b (formal, open, industrial) versus 169c (open grass and shrubs); 167a,b (industrial, parking lot) versus 167c (cultivated); and 134a (grass and shrubs) versus 134b (open not vegetated).(The land uses which have been incorporated into the hardened land use category include: industrial, parking lot, formal, informal, school, site and service.)

2.5 Discussion

This section discusses the following issues:

- potential applications of the Lotus River database
- limitations facing the methodologies employed in the present work
- future work.

2.5.1 Potential applications of the Lotus River database

With respect to the spatial analysis of the database compiled for the Lotus River catchment project, time constraints have prevented this process from taking place. As a consequence, the following section is a discussion of the potential spatial analyses that could be carried out on the existing database rather than a description of analyses which have been conducted. The discussion by Makropoulos et al (1998) provides some initial ideas for how the data in the existing Lotus River database could be analysed. Within the Geomedia environment similar criteria can be implemented in a far simpler manner to select areas suitable for source control. Using the buffering, spatial overlay and spatial query capabilities of Geomedia.

2.5.1.1 Buffer zones

The "distance from outlet", "distance from network" and "connectivity" can be incorporated in the form of buffer zones. Once the buffer zones have been created they can be treated as features in their own right.

2.5.1.2 Spatial overlays

Spatial features must first be created which satisfy the criteria required for each source control technique. These features can then be overlain within the same Geomedia Geoworkspace environment using the spatial overlay capability of the software. The advantage of carrying out the overlays on the Geomedia platform is that the display sequence and style of each feature can be very rapidly and easily manipulated to aid the analysis.

2.5.1.3 Spatial queries

Once the appropriate spatial features are overlain the simplified suitability analysis can be carried out by setting up spatial queries.

The key advantage of this approach is that it is technically much easier to implement than a methodology which relies on Fuzzy set theory and multi-criteria-evaluation procedures using black-box methods. It would also be far easier to explain the results of an analysis using the simplified methodology to a public audience. This is crucial for integrated catchment management applications where the results of analyses must be submitted to a large number of interested parties (local authorities, community leaders, research funding committees, NGOs, etc) who may not know anything about GIS at all. A second important advantage is that since the database resides on a software package with highly evolved Internet capabilities, other Geomedia users who access to the Internet can easily access and analyse the data. It should be noted that the Internet capabilities of IDRISI are extremely poor when compared to Geomedia.

2.5.1.4 Boundaries of "changeability"

Boundaries of "changeability" can be defined based on land use and land ownership data. With respect to the suitability maps for various source control applications Makropoulos et al (1998) comments that " the resulting maps are an indication of suitability and no sharp boundaries actually exist." (p63)[20] A second interesting point to note is that through this methodology the only constraint that was applied was the catchment boundary.

2.5.1.5 Potential wetlands adjacent to the canal

In order to identify potential wetlands adjacent to the canal a number of contour data sets were obtained from the local authorities. The only contour data that is available on a metropolitan wide level is the 1: 20 m data. The extent of the 1: 10 m and 1: 5 m contour data sets is restricted to the Table Mountain area. In addition to these data sets (which are essentially useless in terms of ICM in the Lotus River catchment) there is a very

[20] The boundaries on the suitability maps are a function of the weights assigned for various source control applications. The values for these weights are variable and a large number of combinations can be drawn up. The application of different combinations would shift the boundaries and the exact suitability ratings on the suitability map (Makropoulos et al, 1998).

limited amount of contour data contained within the Lansdowne Corridor and the Lotus River bicycle track data sets. Of these two data sets only the latter has been partly analysed, as it is far more closely associated with the Lotus River, which is a significant feature, as potential wetlands should be closely situated to the river. In practice the 50 m wide restriction on this corridor of data makes the identification of potential wetland areas difficult. The use of imagery has been made to identify open areas adjacent to the canal. In most cases these open areas were found to coincide with school grounds. This finding is significant in supporting the potential role of schools in the ICM process.

2.5.1.6 Evaluation of potential sites

It should be noted that in the evaluation adopted by Makropoulos et al (1998) there is only a limited element of the ICM concept. This element is embodied in the land price and inhabitants income parameters. One of the primary parameters in Table 2.1 should include the community's opinion on the selection of an area for the implementation of source control practices.

2.5.2 Limitations facing the methodologies employed in the present study

A number of limitations have been found to face a series of potential GIS-based applications for the Lotus River catchment. These are as follows:

- Limitations facing GIS-based non-point source pollution modelling
- Limitations of height data for catchment
- Limitations facing development of spatial queries.

The limitation facing GIS-based non-point source pollution modelling is the lack of suitable agricultural activities data. Since most of the non-point source pollution arises from the application of fertilisers in the Philippi farming area, data on the type and frequency of farming activities in this area are required. Specifically the crop planting and fertiliser application activities need to be quantifiable for the part of the farming area within the catchment. In practice obtaining this type of data from the local farmers has proved unsuccessful.

The limitations of height data for catchment have prevented accurate slope estimates for the catchment. In order to estimate slopes of the various subcatchments, a surface model (triangular irregular network, TIN) must be constructed. The availability of spot height data for the catchment area is largely restricted to the northern extreme of the catchment and along the Lotus Canal. The 5, 10 and 20 m contour data sets available from the CMC are useless with respect to detecting elevation differences across the catchment. In addition to the detailed topographical data (spot heights) available for the Nyanga-Gugulethu region, the only detailed elevation data available for the catchment occurs along two very narrow proposed development zones. These include: the Gugulethu to Strandfontein bicycle and pedestrian path project and the Lansdowne Corridor project data sets acquired from the CMC. Thus the high accuracy data which is available is very sparse and scattered with respect to the catchment as a whole.

The main limitation facing the development of spatial queries is time. Initially there was a lack of the required data types for the development of useful spatial queries. Presently, however, the database has been developed to such an extent to enable queries for source control site selection and for the allocation of management responsibilities to be addressed.

2.5.3 Other areas for research

Four areas for future research can be identified from the present study. These are as follows:

- Conversion of the hydrological parameter thematic mapping process into an effective catchment modelling tool

- Land use mapping based on supervised classification of orthophoto imagery

- Identification of potential spatial queries for the assessment of land development scenarios and water quality variations

- The implementation of the multi-level ICM database proposed in this study

The conversion of the hydrological parameter thematic mapping process into an effective catchment modelling tool requires research in two areas. The first is to establish the extent to which the required digitisation procedures can be automated within Microstation. The possibility of constructing customized dialogue boxes which prompt the user simply for the location of hydrological data files to be plotted needs to be investigated. Associated with this dialogue box would be a series of macros designed to take the information in the hydrological data file and create a polygon based thematic map along the canal as has been done manually for this study. Currently the thematic maps require the use of Excel based interpolation programs and the digitising of flow volume proportional polygons in Microstation for each sampling date. The extent to which this process can be automated will depend on the customization potential of Microstation.

The second area of research involves experimentation with the customisation potential of Geomedia. The Geomedia software contains a Spatial Engine Building facility, which is designed specifically for programming Geomedia workflows. Maps that have been produced for the catchment characteristics chapter in this study often involve the overlay of different types of thematic maps such as the variation of a specific hydrological variable along the canal over the population density variation in the catchment area. Within the Geomedia environment the production of each thematic map requires a series of steps to result in the output of a visually suitable thematic map. Once it is decided what map formats (colour range definitions, scales, etc) and what overlay sequences are required, the visualization process can be automated using the Spatial Engine Building facility. An automation of these processes would enable the visualization procedures, which have been discussed in the present study to start forming part of an effective GIS-based ICM system.

The second area, which requires research, is land use mapping based on a supervised classification of digital orthophoto imagery. The supervised classification procedures used to date have resulted mainly in the distinction of permeable and impermeable areas. One task that should be carried out is a supervised classification of the existing ortho-rectified imagery which has been used in this study. This imagery has a pixel resolution of 0.5 m. Whether or not the required results will be achieved has yet to be seen. Previously, brief investigations using 12 classes in a supervised classification procedure were carried out on this imagery for a separate project. The result was a series of "agglomerated globules" for distinctly separate shack features - which was totally unacceptable. Due to the time limitations no further attempts were made to try and improve the results of this method.

With respect to the identification of potential spatial queries, a large amount of data has been collected - again it is simply a question of time limitations, which prevent the construction queries. Two types of queries can be carried out. Firstly, the existing database can be used for source control site selection applications. Secondly, by utilising the land use data (specifically the distribution of the formal and informal settlements) one can arrive at a first impression of the potential maintenance responsibilities of individual subcatchment populations.

The fourth area for future research is essentially to test the implementation of the multi-level ICM database proposed in this study. This process would require an identification of what Internet linked databases could be linked to the present Lotus River catchment database. The success of such a task would be greatly dependent on the willingness of the key stakeholders to co-operate, collaborate and negotiate.

2.6 Database management strategies for a GIS-based ICM database for the Cape Town Metropolitan Area

The experience of ICM via the Web discussed by Ostrowski & James (1998) is based on the status of GIS and Internet infrastructures within developed countries. The discussion by Ostrowski & James (1998) indicates that ICM through the Internet is a feasible scenario for a developed country. However, modifications are required to facilitate the implementation of these concepts to a catchment in a developing

country such as South Africa. The following section takes the ideals described by Ostrowski & James (1998) and evaluates the feasibility of applying such an approach within a developing country context. The system requirements for converting the proposed Internet based ICM approach into a functional reality for the Lotus River catchment are also highlighted.

2.6.1 A database model for Integrated Catchment Management

Any database model designed to aid the implementation of integrated catchment management in the Cape Town area must consider database management issues at both the catchment and metropolitan levels at least. A third level, the subcatchment level, also needs to be considered when local level implementation work is to be carried out. In addition the model must facilitate the exchange of spatial and other (e.g. educational) types of information amongst various parties such as: the Cape Metropolitan Council (CMC), the Metropolitan Local Councils (MLCs), other government organisations, and non-government organisations such as: planning and development agencies, engineering consultancies, environmental groups and community groups. In this section the potential contributors to such a database are identified, the appropriate structure and data types for such a database are also investigated.

2.6.1.1 Key role players

The CMC recently established a new department (Catchment Management Department) to co-ordinate the management of riverine systems in the Cape Metropolitan area. This department recognises the need to integrate ICM related initiatives between all the key role players (ie. CMC, MLCs, community groups, other authorities, other private sector groups). " To assist in the achievement of the goals of Integrated Catchment Management, the CMC: Catchment Management Department is in the process of establishing broadly representative Catchment Committees, which will co-ordinate activities within the individual catchments. These committees will be tasked with the development of Catchment Management Plans **through consultation and negotiation**." (p24, CMC, 1998)

The development of an appropriately designed Internet-based ICM database would be one way of accelerating information flows between the key role players involved in ICM. In addition to increasing the effectiveness of communication between the different parties, it could extend the capacity of non-governmental groups by facilitating access to spatial data captured by or for local authorities. Such data, which is often referred to as "public domain data" is not available in a form that is easily accessible by the public.

A list of some of the potential contributors to the development of an ICM database for Cape Town is shown in Table 2.7. The organisations that have contributed to the development of the Lotus River catchment database, are keen to contribute (ie. schools), or that have contributed information which has yet to be incorporated into the database (South African Police Service), are shown in bold.

Table 2.7 Potential contributors to an ICM database for Cape Town

Cape Town Metropolitan Council	Water and Waste
	Protection Health & Trading Services
	Directorate of Information Services
	Survey and Land Information Department
Metropolitan Local Councils	South Peninsula
	Helderberg
	Blaauwberg
	City of Tygerberg
	City of Cape Town
	Oostenberg
Other Government Organisations	**Chief Director of Surveys and Mapping**
	Department of Agriculture
	Department of Water Affairs and Forestry
	Department of Environmental Affairs and Tourism
	Provincial Administration of the Western Cape
	Water Research Commission
	South African Police Service
	Agricultural Research Council
Non-Government Organisations	Portnet
	Wildlife and Environment Society
	Victoria and Alfred Waterfront
	Cape Nature Conservation
	False Bay Forum
Private Sector Organisations	**Abbott Grobicki (Pty) Ltd**
	Ninham Shand
	Watertek (CSIR)
	A.O.C. Holdings
Educational Service Groups	**Schools**
	University of Cape Town
	University of the Western Cape
Community Groups	**Civics**
	Development Forums
	Councillors

2.6.2 Catchment level database management strategies

2.6.2.1 Database structure

At a catchment level there are essentially two ways of attaching the attribute data to the spatial features. The attribute information can be attached either to subcatchment polygons or to municipal area polygons. The selection of which spatial element should be used in order to structure the database will depend on a number of factors such as: the availability of certain data types, the dominant application of the database, etc. Ultimately it is determined by the primary focus of the organisation conducting the database building process.

In the case of the Lotus River catchment there are about twenty municipal area polygons to which the data could be attached. These polygons have been digitised by placing boundaries to individual municipal area-based parcels files provided by the CMC. The number of subcatchments is slightly higher (about 30). The definition of the subcatchment polygons has been carried out utilising digital orthophotographs and previous maps, and has also involved ground truthing by a hydrologist (see section 2.2.4 for further details).

A limited amount of socio-economic data is available for the Lotus River catchment. It would be worthwhile to consider using the municipal area polygons as the key spatial feature for the attribute information if the available census data covered the whole catchment area. However, this data is limited to the westernmost extreme of the catchment. No census derived socio-economic data is available for the vast majority of the catchment population. The available data, which covers formal settlement areas, is also in no way indicative of socio-economic conditions for the majority of the catchment population, which live mainly in informal settlements. In addition, the available data covers less than a third of the catchment area as a whole.

In addition to the issue of data availability, the concept of a "basic spatial unit" is useful when deciding upon the database structure to apply. A basic spatial unit (BSU) can be simply defined as the smallest spatial area feature to which attribute data is attached in a database. This should logically be selected as the smallest spatial unit at which heterogeneities need to be detected. Clearly for ICM applications at the catchment level, heterogeneities, as one moves from one subcatchment into another subcatchment, need to be visible. The discrepancies between the municipal area boundaries and the subcatchment boundaries are such that these heterogeneities would not be detectable if a municipal area based BSU were to be applied. Municipal areas often contain a number of subcatchments. In the case of the Lotus River catchment, the majority of the municipal areas contain between 2 to 12 subcatchments. For example, if one uses the current subcatchment boundary definitions for the Lotus River catchment, the subcatchments falling within some of the municipal areas are as follows: Lotus River (180a,b;185a,b), Montague Park (170a,b), Nyanga (110,115), Philippi East (126,125), Brown's Farm (131, 130) and Philippi (190, 175, 135, 169, 167, 160, 145, 160). Clearly a great deal of information would be lost if one were to decide upon a municipal area BSU in this case.

Two other reasons exist for avoiding the use of municipal areas as the BSU. Firstly the municipal areas often extend beyond the catchment boundary. In the case of the Lotus river catchment, between about 5% and 70% of the following municipal areas actually lie within the catchment boundary: Lansdowne, Hanover Park, Sand Industria, Gugulethu, Wynberg, Philippi, Grassy Park. Thus from a database management point of view, in order to reduce the amount of data in the database which does not lie within the catchment, a subcatchment BSU is more appropriate.

The second issue is that from the start the database development process, one of the key functions of the GIS has been to provide primary and secondary parameter estimates for the hydrological modelling of the catchment. Parameters such as slope variations, concentration times, subcatchment widths, the percentage impervious area etc, need to be estimated on a subcatchment basis. Again, from a hydrological modelling point of view, it makes more sense to utilise the subcatchment polygon as the BSU.

2.6.2.2 Database contents

The key data types, which are essential catchment level database applications, are as follows:

- Subcatchment and catchment boundaries
- Municipal area boundaries
- Land use data
- Stormwater network data
- Road network data
- Elevation data
- Groundwater data
- Soil data
- Hydrological data
- Ecological data

The need for the subcatchment, catchment and municipal area boundaries is self-evident and has been discussed in some detail above. The subcatchment and catchment boundaries are needed for the hydrological modelling process and to delineate the boundaries of the GIS database. The municipal area boundaries are needed to identify which areas of the catchment fall under which municipalities. This has wider implications when the database starts being used to issue maintenance responsibilities to local authorities and communities. The land use, stormwater and road network data are schematic in nature and can be obtained from imagery and existing schematic maps. Relying on automated digital mapping methods to arrive at low resolution map (> 5 m) which distinguishes between permeable and impermeable areas is unsuitable. Such a solution may be rapid but it does not provide the land use classes required for ICM. On the other hand utilizing the detailed municipal cadastral data (> 0.5m) to estimate hydrological parameter inputs based on land use data has proven ineffective chiefly for three reasons. Firstly the data sets are large and cumbersome to manage on a catchment wide-level. For example the parcel boundary data layer alone is 50 MB for the Lotus River catchment. This represents only one of the cadastral data layers. There are approximately 50 layers in total. The majority of these layers are much smaller in file size, however there are at least another four or five very large data layers such as: roads, formal houses and informal houses. Secondly, there are large gaps in the cadastral data. These usually correspond to the informal settlement areas. Thirdly, the large file sizes and the graphics processing (eg line to polygon feature conversion process) required before the data can be used to estimate hydrological parameters for each subcatchment, make the use of this data for catchment wide hydrologic analysis applications extremely time consuming and ineffective.

For these reasons it is more effective to implement a simplified land use classification scheme based on manual digitizing of digital orthophotos. The land use classification scheme should incorporate at least the following classes: vegetated, not vegetated, cultivated, industrial / commercial buildings, formal housing and informal housing. If the database is being constructed with a view to identifying sites for rehabilitation and source control applications, then the vegetated class should be sub-divided if possible. For example it is usually possible to distinguish on 1:20 000 digital orthophotography between grassy areas with: no covering, grassy areas with a low density covering of trees and shrubs, and grassy areas with a high density covering of trees and shrubs.
Makropoulos et al (1998) have taken the simplification process further. The land use classification used in this paper involved only three classes:

- Urbanised: Impervious areas > 66 % of the total area
- Semi-urbanised: 33 % < Impervious areas < 66 % of the total area
- Non-urbanised: Impervious < 33 % of the total area.

Even if these land use types are used in conjunction with the some of other data types required by Makropoulos et al (1998) (see below) this scheme for the land use data may be sufficient (ie. availability of open space and vegetation cover). For the purposes of ICM it is essential to know the location of the informal settlements and industrial / commercial areas for example.

The absence of detailed digital stormwater network data makes it impossible to incorporate such data into the catchment level of the database without a considerable financial investment for data capturing. Assuming that such funds are not available, stormwater network data at this level should represent a simplified impression of the real drainage. Only the key drainage features should be captured. Although the parcel boundary data is awkward to manage on a catchment-wide basis (and should therefore not be incorporated as a permanent component at this level), it is useful to have access to this data to facilitate the stormwater drainage data capturing procedure.

The situation with respect to the groundwater, elevation and soil data is similar to that encountered for the availability of stormwater network data. The limitations of the elevation data are discussed in a later section. It is sufficient to say that the cost that would be involved in capturing these data types at a high resolution would be extremely high. At a catchment level only a schematic representation can be incorporated into the database. The soil data should distinguish at least between the permeable and impermeable layers. Makropoulos et al (1998) distinguish between impermeable (ie. clay), semi-permeable (ie. sand) and permeable (ie. gravel). In the case of the Lotus River catchment this has required that only the calcareous and non-calcareous soils be differentiated.

The hydrological and ecological data requirements are discussed in detail elsewhere in this report. The hydrological data is based on samples taken from the rivers in the catchment and thus have a highly restricted spatial distribution. There are about 25 points for the Great and Little Lotus River catchments together. While the ecological data can be of a similar nature (ie. based on ecological observations at sample sites), it can also have a catchment-wide representation. This is possible if remote sensing based ecological mapping techniques are implemented to determine the variation in vegetation indices across the catchment.

The above database contents listing covers the majority of data types required for source control site selection analyses. The data types required for this work are listed by Makropoulos et al (1998) (see section 2.3).

Of the data types listed by Makropolous et al (1998), the following data types have already been listed and discussed above: land use, soil type, vegetation cover, storm drainage system. In the case of the Lotus River catchment, the elevation data is insufficient to enable areas to be prioritized on the basis of slope variations. Makropoulos et al (1998) seeks slope variations in the following three categories: $S > 20$ %, $S < 3$ % and $3 < S < 20$ %. The slope parameter for the entire catchment is usually far below 3 %. The land price and inhabitants' income data are also difficult, if not impossible, to acquire for informal settlement areas in the catchment. One way of treating these data types is by approximating a value for the data type on the basis of the land use data. For example, areas with formal settlements will be characterized by higher land prices and inhabitants' income values than areas with informal settlements. Further research must be done on the availability of the land price data. The depth to water table data layer and depth to bedrock (or "sediment thickness") represent only two of the potential groundwater parameters to consider (see previous description of groundwater data collected for the Lotus River catchment.) With respect to vegetation cover Makropoulos et al (1998) proposes the following differentiation: no cover, lawn and natural. For the Lotus river catchment a similar classification was employed (see above).

2.6.2.3 Database location

It is envisaged that a number of catchment databases will exist within the metropolitan area – essentially at least one for each catchment that is being managed. Furthermore, one would expect that a number of organisational committees, such as the catchment management committees referred to in the *1997 False Bay and Table Bay Water Quality Committee Annual Report* (CMC, 1997: p18), would have stewardship of these catchment databases. The catchment management committees would determine the location of the catchment databases. In some cases, a database could reside in a consultancy or in another key organisation carrying out the bulk of the ICM related projects for a specific catchment. Thus a single catchment database could have warehouses distributed amongst a number of organisations working on the same catchment. Each catchment database would be updated to keep track of the developments and needs of the catchment. Other information, such as the results of subcatchment level hydrological models should also be incorporated.

2.6.2.4 Database linkages

There are essentially three types of database linkages that are associated with the catchment level database. Firstly there are the linkages with other databases situated on the catchment level (ie. catchment warehouse – catchment warehouse connections). For example, three different consultancies and a project team within the Catchment Management Department (CMD) who are working on the same catchment, could all share information on the same catchment via a series of warehouse connections. Secondly, there are linkages between the catchment level database and the metropolitan level database situated at the CMD. Through these catchment warehouse – metropolitan warehouse connections information collated locally on suggested proposals and needs can be written to the metropolitan database, and information on development proposed by the metropolitan authorities can be read off the metropolitan database. The third type of linkage, which can be constructed, is that of catchment warehouse – subcatchment warehouse connections. For each catchment level database there can exist a number of connections to subcatchment databases within the specific catchment.

2.6.2.5 Database applications

Through the catchment warehouse – subcatchment warehouse linkages, information can be collated on subcatchment level problems and requests. The developers of the catchment level databases have the responsibility of reorganising subcatchment level information in a manner which can be easily accessed by the metropolitan level database developers.

2.6.3 Metropolitan based ICM database management strategies

2.6.3.1 Database structure

At a metropolitan level attribute data could be attached either to polygons defined by the Metropolitan Local Council (MLC) boundaries or to polygons defined by the various metropolitan catchments. There are six MLC areas. The distribution of the catchments with respect to these MLC areas is summarised in Table 2.8.

Table 2.8 The distribution of the catchments with respect to MLC areas

Metropolitan Local Council	Catchments within MLC
South Peninsula	Disa / Hout Bay Rivers
	Cape Point to Hout Bay
	Simons Town to Cape Point
	Sandvlei Canal to Simons Town
	Kyser & Westlake
	Diep & Sand
	Little Lotus & Lotus River
Helderberg	Eerste River
	Lourens River
	Sir Lowry's Pass River
	Steenbras River
Blaauwberg	Melkbosstrand to Milnerton
	Modder River
	Sout River
	Diep River
	Melkbosstrand to Bokbaai
City of Tygerberg	Diep River
	Elsieskraal
	Jakkelsvlei
	Kuils River
	Mitchell's Plain
City of Cape Town	Diep River
	Elsieskraal
	Jakkelsvlei
	Black
	Liesbeek
	Hout Bay to Green Point
	Disa / Hout Bay Rivers
	Little Lotus & Lotus River
	Mitchell's Plain
Oostenberg	Diep River
	Kuils River
	Eerste River

From Table 2.8 the consequences of applying either approach may be investigated. It can be seen that several catchments lie within the area boundaries of a number of Metropolitan Local Councils (MLC). To address catchment analysis related applications, the database management approach which should be adopted is one

that ensures the most homogenous database structure for the spatial data sets which are to be analysed. In other words the attribute data should be attached to catchment databases as opposed to MLC databases.

2.6.3.2 Database contents

A large number of different types of cadastral and topographical data can be acquired from the Directorate of Information Services (within the CMC). However, in order to not overburden the system with data the initial data contents proposal for this level of the database should be kept to the required minimum. The "skeleton" vector coverages, which should be present, are as follows:

- Catchment boundaries
- LMC boundaries
- Built-up areas
- Main drainage system
- Service areas
- Informal settlement areas
- Formal areas
- Main roads

In addition it is envisaged that the database should be designed to cater for the display of four types of data. These are:

1. Development proposals
2. Proposed service schedules
3. Development needs
4. Requested service schedules

2.6.3.3 Database locations

The metropolitan level database should be situated within the Catchment Management Department at the CMC. The Catchment Management Department (CMD) would have the responsibility of collating and converting information from other departments within the CMC (eg. Stormwater and Drainage, Cleansing etc) and placing this information into the metropolitan level database.

2.6.3.4 Database linkages

Linkages should exist between the metropolitan database and any existing catchment level databases within the metropolitan area. In addition to placing the internal data on proposed development plans and services schedules onto the metropolitan database, the CMD would be responsible for creating linkages to catchment level warehouses. From the catchment level database warehouses, the CMD would be able to import data on development needs and requested services schedules. The key authorities in the metropolitan area (MLCs) should have linkages to the database as well. In this manner the authorities with funding and development responsibilities will be able to access information on local needs and opinions.

2.6.3.5 Database applications

The proposed database contents and linkages would enable the metropolitan database to serve as a **platform for negotiation**. The database provides a platform 1) for internal CMC departments to display proposed service schedules and development plans, and 2) for information on locally requested developments and services (which has been collated and negotiated by the developers of the lower level databases). By placing both types of information on the same system the needs and the proposals can be compared on a regular basis.

2.6.4 Subcatchment based ICM database management strategies

2.6.4.1 Database structure

The complexity of the database structure will vary with the number and type of applications the database is designed for. Unlike the metropolitan and catchment level where only one basic spatial unit may be sufficient for the required analyses, at the subcatchment level the number of basic spatial units will vary with the number and type of applications. At the subcatchment level the "database" will comprise a series of interacting database warehouses. Some of these warehouses may include: a detailed cadastral database, a specialized sewer design system database, a local level informal settlement upgrading database etc.... In the case of a specialized sewer design system database, detailed data is required for various elements of the sewer network. Data needs to be attached to the pipes and nodes of the system. Thus the required basic spatial units will be the "pipe" line element and a "node" point element. The types of data are discussed below. In the case of a local level socio-economic database a "shack" polygon will be used as the basic spatial unit. For the database approach followed by Rodriguez et al (1998) a "base hydrological element" is used. This base hydrological element includes a geographic zone composed of a property block, a house and a street portion, adjacent to the property block. Thus the scenario can arise where a GIS user may construct a Geoworkspace in Geomedia where a number of basic spatial units of different morphologies (point, line or polygon) are simultaneously displayed.

One of the weaknesses facing the application of existing urban data banks as suggested by Rodriguez et al (1996) is that municipal data banks within the developing countries are characterised by large gaps corresponding to informal settlement areas. Three of the five key elements required for hydrological purposes are typically missing from the GIS databases for informal settlement areas. In particular very little or no sewer network and elevation point data exist for the informal settlement areas. In addition, parcels are often not defined or not adhered to by the population in these areas. The definition of street is also unclear in these areas. The absence of a DTM prevents the application of the Base Hydrological Element (BHE) approach (Rodriguez et al, 1998) in these areas.

2.6.4.2 Contents of the hydrological database component

Initially, the contents of the subcatchment level database can follow the guidelines implemented by Rodriguez et al (1998). The following features were incorporated in the database for the Rodriguez et al (1998) study:

- Property block
- Houses
- Street segments
- Street sections
- Elevation data
- Sewer segments and rivers
- Base hydrological element
- Roads
- Surface flow path
- Pipe flow path

This methodology can be employed where detailed cadastral data is available from the local authorities. In practice this means that the methodology can only be applied to subcatchments comprised of formal settlements, cultivated land, open land or industrial commercial land uses. Additional data will have to be captured for subcatchments containing informal settlement areas. Each base hydrological element BHE is connected to the sewer network. The methodology employed by Rodriguez et al (1998) to capture the sewer network data has been discussed elsewhere. It should be noted that the street segments are lines versus the street sections, which are areas. The main advantage of working with higher accuracy data at the subcatchment level is that it can be used to guide local level interventions. The main disadvantage is that it is far more time consuming and practically impossible on a catchment-wide basis.

The above database contents list can be extended if or when it is certain that the database will be used to evaluate the sewer network for future development. The database contents for such local level applications are discussed by Hora et al (1998) and Pryl et al (1998).

2.6.4.3 Contents of the non-hydrological database component

In addition to the hydrological database contents component, there must be an additional database component at the local level to ensure that ICM is a reality. It is here where the principles outlined by Tomalty and Pell (1994) (Table 2.4) can be incorporated into the ICM database model. The non-hydrologic database component is essentially a modified version of the socio-economic local level database designed for upgrading informal settlements in Belo Horizonte (Martinez, 1998; Abbott et al, 1998).

2.6.4.4 Database locations

The locations of the following two key databases need to be considered:

1. the subcatchment level hydrologic database
2. the local level socio-economic database

The subcatchment level hydrologic database should reside in a local authority. The local level socio-economic database should reside within the community undergoing upgrading, or within an institution which isfacilitating the upgrading process.

2.6.4.5 Database linkages

The number and nature of linkages at the subcatchment level changes to accommodate the different types of data sources. At this level the majority of the data sources will not be in a computer format. Thus computer-based and non-computer-based database linkages are envisaged. Computer-based linkages may exist between the subcatchment database and the nearest MLC system. This depends whether the subcatchment database is linked to the Internet. The same is true for the subcatchment database – local level upgrading database linkage. If Internet connections are not available, the information will simply have to be manually transferred from one database to the other. Non-computer based linkages are also envisaged between the subcatchment database and several institutions within the subcatchment. These institutions include schools, police stations, community groups, NGOs and DFAs. Inputs should include the results of other ongoing water related community projects. For example, the results of local development programs as discussed by Schoeman (1997) should be incorporated into the database.

2.6.4.6 Database applications

The database linkages and information inputs described above can facilitate a number of essential applications. For example, the database can be used for local quality of service monitoring. Specifically the community can input into the database by delivering information on local problems such as blocked pipes, inadequate garbage removal services etc.

At the subcatchment level the database contents starts to become more intricate. The time involved in setting up databases at this level is considerably greater than at the previous two levels. The potential utility of the GIS database at this level (ie. subcatchment level stormwater drainage network upgrading integrated with the operation and management tasks) can be further extended to a true ICM approach if the hydrologic database is linked to a local level socio-economic database designed for informal settlement upgrading. The potential applications arising from detailed subcatchment level database designs for stormwater runoff modelling have been discussed by Rodriguez et al (1998) and Hora et al (1998).

2.6.4.7 Implementation

The selection of an area for local level implementation should be done in such a manner to overlap, if possible, with other existing informal settlement upgrading projects. This would enable any data (particularly socio-economic and water quality related data) by another project to be incorporated into the local level database for mutual benefit.

2.6.4.8 Developing country context

The definitions of DSS designed for ICM discussed by Lemons & Brown (1997) and Ostrowski & James (1998) reveal two issues. Firstly, that GIS is an essential component to ICM. Secondly that even though community participation is listed as a requirement the manner in which this may be achieved is not discussed. Instead the focus of the system seems to lie in serving the scientific and planning communities specifically. This is evident from the discussions of Lemons & Brown (1997) and Ostrowski & James (1998).

Ostrowski & James (1998) emphasise the need for the transparency of the system: " It is necessary to keep the complete system as transparent as possible. No security reasons can be seen so far to exclude any party from single components. It seems likely, however, that some parties involved would not desire complete transparency from the beginning. Especially political decision making processes and economic data from communities and water companies are sometimes considered secrets." (p572: Ostrowski & James, 1998)

Ostrowski & James (1998) reproduce a table initially published by Tomalty and Pell (1994) which lists the requirements for planning process for community based sustainable development. The same table has been reproduced here in order to identify issues that must be incorporated into the design of an ICM DSS for a catchment situated within a developing country (Table 2.10). The key issues have been placed in bold type.

Table 2.9 A framework for GIS-based ICM in the Cape Town area

ICM database level	Envisaged utility & potential users	Conceptual functionality	General applicability	Institutions involved
Metropolitan level	A management tool for the CMC and DWAF.	Strategic level analysis and management.	Water resource and demand management.	MLC, LMC, WRC, DWAF Consultancies, NGOs & Multiple Community representatives.
Catchment level	A planning tool for project specific committees and team members.	Lumped parameter hydrologic modelling.	Water quality monitoring and site selection for source control applications.	MLC, LMC, Consultancies, NGOs & Individual community representatives
Subcatchment level	An implementation tool for local level pilot project team members.	Distributed parameter hydrological modelling.	Implementation of intervention strategies.	LMC, LA, Consultancies, multiple representatives from individual communities.

Table 2.10 Requirements for planning process for community based sustainable development (source: Tomalty and Pell, 1994)

Principles	Requirements
Community	**Is the decision process explicitly community-based?** **What ongoing consultation with community residents has been included?** **Does the planning process address community concerns?** **What rationale is there for the process in the stated concern of community residents?** **How does the process include consideration of identified social issues?**
Equity	Is the process democratic? Does the process promote equality of opportunity? Does it clarify or make explicit its basic values and beliefs? Are those values and beliefs consistent with a sustainability perspective?
Self-determination	**Is the process open and accessible to those who will be affected by it?** **Does it promote self-management at a local-level?**
Integration	Is the process systematic in orientation? Is the process synergistic, taking into account a variety of perspectives? Does the process acknowledge and account for inter-dependencies among social, environmental and economic well being?
Balance	Is the process cyclic and reflective?□Does it include ecological principles, such as geographical boundaries, cross-general timeliness, and social and physical carrying capacity?
Diversity	Is the process inclusive? Can it embrace apparently opposing views, such as persistence and change? Does it anticipate and expect divergent points of view? Does it provide mechanisms for achieving consensus or otherwise resolving disagreement in situations where differences of opinion occur?

2.7 General recommendations

The issues that have been discussed in this chapter enable a number of recommendations to be made on the applicability of GIS to ICM. The recommendations can be discussed under the following topics:

- Internet connectivity
- Limits of data integration
- Level of detail required
- A multi-scale approach
- Utility of GIS

2.7.1 Internet connectivity

The appropriate software for ICM must be such that the principles embodied in ICM can be carried out. In other words the software must be capable of facilitating:

- effective communication through the Internet medium
- at least simple spatial analyses.

All the other procedures such as data capturing, image processing and complex spatial analyses can be carried out on specialised software. For example in the case of the Lotus River catchment database the bulk of the data was initially captured in the Microstation and MGE software environments. In the case of the

work by Rodriguez et al (1998), MapInfo was implemented to develop a database for hydrologic analysis for the city of Nantes catchment. The main reason this software was selected is that the accompanying MapBasic software facilitates the programming of hydrologic subroutines. The classification and overlay analyses carried by Frankhauser (1998) were based on the use of the raster-based IDRISI software. While such specialised packages have been customised to accelerate the data capture process, and to arrive at specific hydrologic analysis solutions, these capabilities are required by only a number of the database developers. Such specialised capabilities are not the key requirements the majority of the ICM database users. Instead the principle functionality of the software should be to ensure effective communication between all the stakeholders. For this the software must have extensive Internet capabilities such as: GIS database read - write capabilities (ie. two-way warehouse communication links), multiple warehouse linkage capabilities, on-the-fly projection transformations, "smart-maps" and other facilities. These facilities are only encountered in the most advanced Internet GIS user platforms such as Geomedia.

2.7.2 Limits of data integration

The extent to which the data integration process can take place is dependent on the degree of compatibility of the databases involved. Unless the project parameters of various database sources have been set up in an identical manner, data integration can be time consuming, if not impossible at times. A classic example of the problems that can be encountered was experienced when the groundwater data was incorporated into the Lotus River database.

2.7.3 Level of detail required

The need to map the subcatchments at a scale, which reflects land use heterogeneity variations across the catchment to a greater extent than previous work, is essential for several reasons. Firstly it seems clear that variations in the degree of heterogeneity of individual subcatchments will affect the overland flow through these areas. Secondly, although it may not be possible to incorporate the detailed land use variations within single subcatchments into the stormwater runoff modelling process, it is clear that a minimum land use mapping resolution is required if integrated catchment management applications or river restoration potentials are to be investigated within a GIS database environment. "Integrated catchment management" implies that not only the physical / hydrological components of the system need to be catchment model, but also the socio-economic components such as the population distribution, the location of the formal and informal housing sectors. These data types are essential if the database is to be used for examining the potential river maintenance related responsibilities of individual subcatchment populations. A second reason for striving to obtain detailed land use mapping representations for catchment related studies, is that such data provides a valuable spatial reference frame for analysing the variations in water quality parameters (TPON, TP, EC etc) monitored along a canal or river. Coupled with the need for detailed land use mapping are the needs to:

1. adopt a less homogenising approach to stormwater runoff modelling, and
2. map land use variations in greater deal than previously.

2.7.4 A multi-scale approach

The results of the present study reveal that the ICM database building process needs to be carried out on three levels. These levels include:

- the catchment level
- the metropolitan level and
- the subcatchment level

The principle reasons for a multi-scale approach are:

- the variable nature of the data coverage
- the different requirements of database users and
- the different requirements of lumped and distributed parameter models.

2.7.5 Utility of GIS

The utility of GIS for ICM has been shown in a number of ways. GIS provides an effective medium for:

- the visual representation of ICM data
- the applicability of GIS as a communication mechanism for ICM
- integrating the inputs and outputs of the various role players.

CHAPTER 3 CATCHMENT CHARACTERISTICS

3.1 INTRODUCTION

The Lotus River catchment is a dynamic, fast developing area situated on the Cape Flats, a flat, sandy tract of land connecting the Cape Peninsula to the mainland of South Africa. Figure 3.1 shows the geographical situation of the catchment, lying between Table Bay and False Bay. Being so flat, the catchment is largely artificially defined. Although the Lotus Rivers drain south into Zeekoevlei, and ultimately into False Bay, large sections of the catchment drain northwards. Hence the urban run-off from this area could equally well have been routed towards Table Bay. In the longer term, the Cape Flats catchment areas all need to be reassessed as part of a wider metropolitan water management system. However, in the short term the Lotus River catchment makes an excellent case study of a highly impacted urban system, demonstrating the whole spectrum of land uses, socio-economic variations and housing types found in South African cities. It also exhibits acute ecological stress, highly polluted water bodies and significant loss of biodiversity.

The main purpose of this chapter is to summarise and put in context information regarding the entire catchment area, prior to developing more detailed discussions of the hydrology and ecology of the catchment. Hence Chapter 4 contains detail of the rivers themselves, reach by reach, while Chapter 5 presents ecological information. Figure 3.2 shows the catchment area, with subcatchment boundaries demarcated, superimposed upon 1:20000 aerial photography of the area (taken in 1996). This shows how the catchment is situated between Cape Town International Airport to the north, and Zeekoevlei to the south.

The catchment area of the Great Lotus has been analysed in more detail, as this river is much larger and carries a greater pollution load than the Little Lotus. The latter runs primarily through areas of middle-income, formal residential housing. The Great Lotus catchment area, on the other hand, displays the wide variation in land use mentioned above. Of the total catchment area of 4816 hectares, 26% of the catchment is cultivated farmland. Over the 13 years from 1983 to 1996, the impervious area of the catchment grew from 17% to 34% of the entire catchment area. The Great Lotus catchment is now home to nearly 380 000 people, only 72% of whom are formally housed.

The following section of this chapter is a general historical background to the catchment, which deals with both the hydrological aspects and with the changes in the administrative system of areas within the catchment. Section 3.3 then gives a discussion of the entire catchment in terms of: socio-economic data, population distribution, land use changes, geology and soil type, hydrogeology, surface water quality, waste management and cleansing. Given the tremendous variations across the catchment, it can be subdivided into six distinct regions, each of which is relatively homogeneous. Figure 3.3 illustrates the location of these six regions, namely Airport Industria, Nyanga / Gugulethu, Philippi East / Crossroads, Philippi Horticultural Area, Grassy Park/Lotus River/Ottery, and the Little Lotus catchment.

Figure 3.4 provides a land use analysis based on 1996 photography, which shows clearly the different characteristics of the six regions. Section 3.4 of this chapter characterises each region in detail, and calculations such as detected land use changes and the rate of urbanisation are also discussed. These calculations are based on the differences in land use between 1996 and 1983 (the land use analysis for the latter is shown in Figure 3.5). Figure 3.6 shows the land use map for a portion of the catchment based on 1933 photography, for historical interest. Please note that the land use designated "industrial/commercial" includes farmhouses, barns and warehouses as used in the Phillipi Horticultural Area. The GIS methodology used in these land use analyses was discussed in Chapter 2 above. The last two sections of Chapter 3 deal with present and future proposed development projects such as the Metropolitan Spatial Development Forum, the Wetton-Lansdowne Development Corridor, the Integrated Serviced Land Project, the Olympic Cycle Track, the Airport Extension, R300 Extension and Philippi Horticultural Area Redevelopment Proposals. Finally, the conclusions are summarised, which may be drawn with respect to the regional variations in the Lotus River catchment.

3.2 HISTORICAL BACKGROUND

3.2.1 Hydrological aspects

The Lotus River system is comprised of the Great and Little Lotus rivers and their associated tributaries. It drains a catchment area of approximately 80 km^2, made up of a variety of land use types. These include formal and informal residential areas, light industrial areas, agricultural areas and municipal open space.

The Great Lotus River rises at Bottelary (adjacent to the Cape Town International Airport) and flows through Nyanga, Gugulethu, Philippi, Ottery, Grassy Park and Lotus River before draining into Zeekoevlei. The river and its catchment area therefore fall into three separate substructures of the Cape Metropolitan Region: the Tygerberg Municipality, the Cape Town Municipality and the South Peninsula Municipality. The Little Lotus River flows from the Royal Cape Golf Club through Grassy Park into Zeekoevlei, i.e. through the Cape Town and South Peninsula Municipalities.

The topography of the catchment is generally quite flat with drainage being ill defined. Before urban development, the Lotus River system catered for seasonal runoff. Surface depressions and seasonal vleis collected rainfall and allowed water to infiltrate the underlying aquifer. The runoff that did occur resulted in two clear water, sandy bed seasonal rivers with ecosystems adapted to these conditions (Snaddon, 1996). At this time both the Great and the Little Lotus Rivers were much shorter in length and were sustained by a groundwater baseflow.

Post Second World War urbanisation, however, saw an increase in runoff. Development of the land surface for agriculture, infrastructure, housing and industry resulted in an altering of drainage patterns. Surface depressions and vleis were "connected" and engineered, essentially converting the small natural river into an extended drainage canal. This was exacerbated by the large-scale removal and flattening of dunes for mining and agricultural purposes. The development of the Cape Flats resulted in a "hardening" of much of the catchment (the covering of ground with impermeable surfaces) thereby reducing groundwater infiltration. This greatly increased runoff, resulting in the rivers changing from seasonal to perennial systems and increasing the flood risk of land adjacent to the rivers.

From the 1940s onwards, the Lotus River system has been regularly "upgraded" to control flooding. This upgrading entailed the construction of concrete and earth lined canals. The canal has largely been designed as a multi-stage channel. Low flows are accommodated by a concrete-lined trapezoidal section, whilst flood flows are conveyed in an enlarged section with grass-lined overflow side banks. To facilitate the upgrading, numerous studies were undertaken on the system. These studies were commissioned by the Divisional Council of the Cape, the Western Cape Regional Services Council and finally the Cape Metropolitan Council. A list of these various consultants' reports is given in Appendix E. The hydrological simulations of the catchment areas carried out to date has been extremely coarse. Using historical rainfall and storm duration data for Maitland, which is outside the catchment, flood peaks were calculated for the 1 in 2 and 1 in 50 year rainfall events. It must be stated that these calculations were never validated by actual flow measurements. There is thus no historical record of flow measurements in either of the rivers.

A historical database of water quality parameters was however maintained by the Scientific Services branch of the Cape Town City Council (now part of the Cape Metropolitan Council). This database extends over the past 25 years, due largely to the concern of the aquatic sports community about the noticable deterioration of water quality in Zeekoevlei, which used to be a popular resort area for sailing, rowing and swimming. The Great and (to a lesser extent) Little Lotus Rivers both suffer from poor water quality. The concrete lining reduces habitat and species diversity and thus hinders the river's natural ability to reduce pollutant loadings. The poor water quality is mainly due to polluted urban and nutrient-rich agricultural runoff flowing into the river.

In the urban runoff, high faecal coliform counts and significant amounts of gross litter have been found. In addition, organic analysis of water samples indicated the presence of low concentrations (lower than water quality standards for recreational use) of saturated hydrocarbons, compounds mainly characteristic of fuels and solvents eg. diesels, motor oils, and kerosene. These compounds are frequently dumped in the stormwater system and from there flow into the canal.

The agricultural runoff is high in phosphates and nitrates/nitrites from traditional fertilising techniques and livestock effluent. Depending on the type of cultivation both organic fertiliser (in the form of manure) and inorganic fertiliser are applied. These fertilisers produce high concentrations of phosphate and nitrate in the surface waters draining the agricultural area into the canal. The phosphate loading is especially significant in that it promotes eutrophication and therefore contributes to the currently hypertrophic status of Zeekoevlei. Chapters 4 and 5 provide detail on the hydrological and ecological aspects of the catchment area.

3.2.2 The administrative systems of areas in the catchment

The Lotus River Catchment Area is mostly urban in nature, in terms of population. It is largely constituted by the African and Coloured population groups, in addition to a significant number of the White population group in the smallholdings in the Philippi horticultural area and in the Zeekoevlei residential area.

The overwhelming majority of the African population group that resides in the catchment occupy the eastern parts of the catchment area upstream of the Lotus River. This area includes the former Black Local Authority Town Council areas of Ikapa and Crossroads, in addition to Lower Crossroads (Philippi East) and Brown's farm. Service provision in these areas is poor and the socio-economic and environmental status is low. This status is related to the legislation passed to provide for the control and administration of Africans in urban areas. Before 1971, Ikapa and Nyanga (Crossroads transit camp was part of Nyanga) were administered and serviced by the Cape Town City Council (CCC) and the Divisional Council of the Cape, (DCC, precursor to the Regional Services Council (RSC) and subsequently CMC) respectively. They were then taken over after 1971 by the provincial administration and administered by Bantu Affairs Administration Board (BAAB) under the Bantu Affairs Administration Act of 1971. This scenario changed in 1979 when these townships were proclaimed as Community Town Councils and subsequently becoming Black Local Authorities in 1982, with some political decision-making but still no executive authority (Shubane, 1991: 65).

Since the BAAB and the subsequent political institutions had no administrative and operational capacity to provide services to these areas, they were only directly responsible for the political aspects of these areas and the payment of the bulk services provided to these areas. The BAAB's purpose was to serve the government policy in regard to influx control and the provision of funds for the homelands by diverting surplus income collected in the African areas (Elias, 1983: 67). The CCC and DCC continued to provide services to these areas on an agency basis. Consequently this affected the level of services. Apart from the establishment of New Crossroads and a few houses in Nyanga, virtually no family dwellings, commercial/retail and social facilities for Africans have been built and no upgrading effected to the existing infrastructure to cater for their growth in the Peninsula since 1973 (ibid.: 32). This was a conscious decision by the government because these areas were only designed to cater for the labour demands of white business in the region and were just dormitory suburbs, separate and away from white and Coloured areas, far from jobs, shopping centres and recreational opportunities (CMC, 1995: 2). This was the case until the establishment of Khayelitsha in 1985, when it became apparent that it was expensive and virtually impossible to control African urbanisation.

The Coloureds and Indians reside in the Greater Grassy Park area (Grassy Park, Lotus River, Ottery East, Parkwood and Fairways), west of the horticultural area and downstream of the river corridor. Housing and services in these areas and their local administrative system, though based on the same framework of racial domination, division and capital accumulation, reflected the intermediate position that these groups came to occupy in the racial division of labour and specific regional dynamics of accumulation (Grest, 1988: 92). It was the intention of the government to win their political allegiance and prevent the formation of alliances with Africans. The government's goal revolved around creating separate but relatively better serviced areas and better jobs for these population groups. Their local administrative structures were sufficiently attractive to co-opt credible participants from these communities.

After the Group Areas Act of 1950, management committees for Coloureds and local affairs committees for Indians were established in most coloured areas of the Western Cape. These management committees were linked to CCC and had only a consultative role (ibid.: 93). Since the process was based on gradually increasing the political stakes and providing the incentives for coloured participants, the process culminated in their inclusion in the tri-cameral system and the creation of RSCs in the early 80s. However, the falling

level of services and the political legitimacy crisis was also experienced by the Indian and Coloured population, though in relation to levels of services, the crisis was not as acute as in African areas.

In relation to the white population group, the WLAs had traditionally operated as 'democratic' structures answerable to a racially exclusive electorate. They had also benefited from the apartheid style financing system that ensured that white ratepayers enjoyed a high level of services based on jealously guarded revenue accounts. To the extent that they remained responsive to a racially exclusive electorate, they [did] not suffer from the acute fiscal and legitimacy crisis experienced by the majority of other local authorities (Grest, 1988: 110). Hence the Cape Town City Council maintained a high level of infrastructure and services to the WLAs.

The Philippi farming area is rural in nature and has been administered, until recently, by the Regional Services Council's Cape Rural Council. There is therefore no stormwater drainage and waterborne sewerage system in the area and a few holdings are provided with potable water by CCC water mains. The white population group farms most of this area and a large number of Coloured people (80% of 6715 residents) and a small number of Africans (10%) reside and work in these smallholdings (Census, 1991). The Philippi rural area is about 4 500 hectares (Urban Studies, 1995) and most of it is farmed by approximately 80 vegetable farmers (CMC, 1995). The area is reserved for agricultural purposes and the exploitation and refining of sand by the glass industry. Due to uncertainty arising from the broad interpretation of the reservation and the term agriculture, and the absence of a planning framework to identify issues and co-ordinate development, this land is constantly under pressure. This pressure emanates from speculative rezoning applications, urban encroachment, illegal dumping, water pollution, squatting, lack of services and maintenance and a general deterioration of the physical environment.

The first truly democratic local elections in 1997 resulted in the election of councillors to the Cape Metropolitan Council (CMC), an integrated structure with responsibility for decision-making and policy within the entire Cape Metropolitan Area, as well as six sub-structures, or municipal local councils. The Lotus River catchment now spans three of these municipal areas, namely Tygerberg, the Cape Town Municipality, and South Peninsula Municipality. All these bodies came into being on 1 July 1997 and hence have been finding their feet and meeting enormous challenges of restructuring and integration. However, there is now hope for catchment-based policy-making under the umbrella of the CMC, although implementation of projects would still fall under three separate administrative bodies.

3.3 CATCHMENT CHARACTERISTICS USED

In this section, an overview of the catchment with respect to various characteristics is given. These characteristics are socio-economic characteristics, total population, population density, heterogeneity of the land use distribution, land use changes for the periods 1983 - 1996 and 1933 - 1983, degree of urbanisation, geology, hydrogeology and surface water quality, and municipal levels of service with regard to waste management and cleansing. All figures referred to in the text can be found on the accompanying CD (as bitmaps). Table 3.1 below lists the figures with their captions.

Table 3.1 List of Figures as bitmaps on CD

FILE	DESCRIPTION
Figure3_1	Location of the Lotus River catchment with subcatchments.
Figure3_2	Aerial photography used to map subcatchment boundaries and land uses within the Lotus River catchment.
Figure3_3	The five subcatchment regions comprising the Great Lotus River catchment.
Figure3_4	Land use map for the Lotus River catchment based on 1996 photography.
Figure3_5	Land use map for the Lotus River catchment based on 1983 photography.
Figure3_6	Land use map for the Lotus River catchment based on 1933 photography.
Figure3_9	Variation in the sandthickness (m) across the Lotus River catchment.
Figure3_10	Variation in the groundwater level (m above mean sea level) across the Lotus River catchment.
Figure3_11	Variation in the saturated thickness (m) across the Lotus River catchment.
Figure3_12	Variation in the salinity (TDS in mg / l) across the Lotus River catchment.
Figure3_13	Variation in the transmissivity (sq m/d) across the Lotus River catchment.
Figure3_14	Variation in the borehole yields (l / s) within and adjacent to the Lotus River catchment.
Figure3_15	Variation in soil type in the Philippi region of the Lotus River catchment.
Figure3_16	Variation in the total phosphorus (mg / s) along the Lotus River and the Little Lotus River for the high flow date (05/08/97).
Figure3_17	Variation in the total phosphorus (mg / s) along the Lotus River and the Little Lotus River for the low flow date (15/09/97).
Figure3_18	Variation in the total oxidizable nitrogen (mg N / s) along the Lotus River and the Little Lotus River for the high flow date (05/08/97).
Figure3_19	Variation in the total oxidizable nitrogen (mg N / s) along the Lotus River and the Little Lotus River for the low flow date (15/09/97).
Figure3_20	Variation in the soluble reactive phosphorus (mg P / s) along the Lotus River and the Little Lotus River for the high flow date (05/08/97).
Figure3_21	Variation in the soluble reactive phosphorus (mg P / s) along the Lotus River and the Little Lotus River for the low flow date (15/09/97).
Figure3_22	Variation in the chemical oxygen demand (g COD / s) along the Lotus River and the Little Lotus River for the high flow date (05/08/97).
Figure3_23	Variation in the chemical oxygen demand (g COD / s) along the Lotus River and the Little Lotus River for the low flow date (15/09/97).
Figure3_24	Variation in the total suspended solids (g / s) along the Lotus River and the Little Lotus River for the high flow date (05/08/97).
Figure3_25	Variation in the total suspended solids (g / s) along the Lotus River and the Little Lotus River for the low flow date (15/09/97).
Figure3_26	Variation in the total volatile solids (%) along the Lotus River and the Little Lotus River for the high flow date (05/08/97).
Figure3_27	Variation in the total volatile solids (%) along the Lotus River and the Little Lotus River for the low flow date (15/09/97).
Figure3_28	Variation in the electrical conductivity (m S / m) along the Lotus River and the Little Lotus River for the high flow date (05/08/97).

Figure3_29	Variation in the electrical conductivity (m S / m) along the Lotus River and the Little Lotus River for the low flow date (15/09/97).
Figure3_30	Variation in the total population per subcatchment across the Lotus River catchment.
Figure3_31	Variation in the population density per subcatchment (people / hectare) across the Lotus River catchment.
Figure3_32	Land use map for the Great Lotus River catchment (based on 1983 photography) superimposed with 1996 informal settlement boundaries.
Figure3_33	Land use map for the Great Lotus River catchment (based on 1933 photography) superimposed with 1996 informal settlement boundaries.
Figure3_34	Variation in the degree of urbanization (unit: % change in effectively permeable area) across the Lotus River catchment.
Figure3_35	Variation in the total phosphorus (mg / s) along the Lotus River and the Little Lotus River for the low flow date (09/03/98).
Figure3_36	Variation in the total oxidizable nitrogen (mg N / s) along the Lotus River and the Little Lotus River for the low flow date (09/03/98).
Figure3_37	Variation in the total oxidizable nitrogen (mg N / s) along the Lotus River and the Little Lotus River for the high flow date (01/09/97).
Figure3_38	Variation in the total phosphorus (mg / s) along the Lotus River and the Little Lotus River for the high flow date (01/09/97).
Figure3_39	Position of cleansing depots responsible for the Lotus River catchment.
Figure3_40	Location of dumping sites in the Boquin area.
Figure3_41	Location of dumping sites in the Grassy Park area.
Figure3_42	Location of dumping sites in the Hanover Park area.
Figure3_43	Location of dumping sites in the Lotus River area.
Figure3_43a	Location of cleansing depots and the type of collection systems used in the Lotus River catchment.
Figure3_44	Location of dumping sites in the Pelikan Park area.
Figure3_45	Location of dumping sites in the Philippi East area.
Figure3_46	Location of dumping sites in the Sand Industry area.
Figure3_47	Levels of service by domestic ton per month depots service areas.
Figure3_47a	Municipality service areas and the collection systems used in these areas.
Figure3_48	Commercial recycling facilities found within the Lotus River catchment.

3.3.1 Socio-economic characteristics

Apartheid policies have profoundly influenced the location and the socio-economic characteristics of the different racial groups, and the physical structure and spatial/land use relations in the Cape Metropolitan Region (CMR). These policy measures were an attempt to control the entry of the people of colour in Cape Town and the relationship between the population groups, and by the mid-1980s the city had a more comprehensive set of influx controls and segregation measures than any other metropolitan area in the country. This control mentality originated from the ideology of racial separation and the planning-based belief that large cities have negative consequences and that their growth should be controlled. These two beliefs reinforced each other over the decades and politicians have been seen evoking planning rhetoric to justify racially based controls on city growth (UPRU, 1991: 2)

These policies not only dictated the location, growth and relationship between population groups in the region, but also determined the nature of the services they were to receive, the types of jobs and training they were entitled to, how and by whom these areas were to be administered (Elias, 1983). The impact of these measures is not only reflected in the geographic location of the different population groups. It is also felt in the form of low skill and income levels amongst the African population and to a lesser extent amongst the Coloured population, including the chronic levels of residential overcrowding in African and Coloured areas (Dewar and Watson, 1990: 11-12). Thus there is a direct relationship between these policy measures and the current development status of the different racial areas, to a large extent the position that these groups have come to occupy on the socio-economic ladders of society, the current land use patterns and physical structure of the region. The Lotus River catchment area is a microcosm of the region that reflects these kinds of relationships.

Hence in the six subregions of the catchment which have been defined (see Figure 3.3), socio-economic characteristics are very different and distinct. This is discussed in more detail for each region in section 3.4 below. For the catchment as a whole, a variation can be seen from average annual incomes per households of below R10000 in Crossroads, Philippi East and Brown's Farm, rising to over R52000 in Zeekoevlei. The largely urban regions of the catchment are populated by African and Coloured people, while a small number of the White people own the smallholdings and farms in the Philippi horticultural area, which is the 'rural' portion of the catchment. This rural portion contributes significantly to the nutrient load of the stormwater drained by the Lotus River canal and Zeekoevlei. The Lotus River eventually flows into Zeekoevlei, which is utilised by local groups for recreational purposes. Though not physically within the catchment area, a significant number of the White population group reside in Zeekoevlei and form part of the local groups who use the vlei for recreational purposes and are therefore directly affected by developments in the catchment. Thus this group and the farmers have interests in developments in the area and need to be part of any process designed to effect a holistic management approach to the catchment area.

A characteristic of major importance is the fact that approximately 90000 of the people in the catchment area reside in informal settlements. This excludes the people living in informal housing in the site and service areas, and in backyard shacks within the formal housing areas. Informal settlements are a phenomenon which are characteristic of cities in the developing world, but due to the policy of influx control it was unknown in South Africa until the late 1980s. They therefore pose profound challenges to policy-makers. Socio-economic data gathered in these areas indicate that they are characterised by extreme poverty. For the Crossroads, Phillipi and Brown's Farm area, 39% of households survived on about R150 per month, 33% survived on income between R150 - R650 per month and 13% on income between R651 – R1000 (Urban Studies 1997). Informal settlement dwellers tend to have the least education. Education level data indicate that 52% have standard 5 education or less, 32% have standard 6 or standard 7 and about 13% have standard 7 or 8 and only 4% with a certificate or diploma (WCCHT, 1996). On average the standard passed in the Phillipi and Brown's Farm area is standard 6, indicating a very low level of formal education (Urban Studies, 1997).

3.3.2 Population data

From data from the CCC Urban Studies Unit, the Wetton-Lansdowne Corridor Project and the Provincial Administration it may be estimated that the number of people in the catchment in 1995 was close to 380000. The African section of the catchment area accounts for approximately 79% (300000) of this number, while the agricultural and the Greater Grassy Park area accounts for about 2% (7650) and 18,6% (71000) respectively, and Zeekoevlei for only 0,35% (1350 people). These estimates are based on projections made using the 1991 Census data and a number of other project-based studies (van Zyl, 1995; WLCP, 1998; Urban Studies unit, 1995) related to the catchment area.

From the GIS work carried out for this project, using methodology as discussed in Chapter 2 above, the total population for the catchment has been calculated at 379 380. This figure includes a population of 272057 in the formal housing areas, 17394 in the serviced site areas and 89929 in the informal settlement housing areas. Figure 3.26 illustrates the actual number of people in each subcatchment, to within 10000 people. Figure 3.27 then shows the population density found in each subcatchment. The highest population densities (ranging from 113 to 356 people / ha) are encountered in the Nyanga-Gugulethu region. The lowest population densities (people / ha) are observable in the Philippi (0 to 112) area, undeveloped parts of Philippi

East, and the Airport region (0). The size of the Gugulethu/Nyanga/Crossroads area is about 1060 hectares and densities range between 100 – 300 people per hectare. The size of the Philippi East/Brown`s Farm area is 1000 hectares and densities here range between 60 – 250 people per hectare. The Lotus River/Grassy Park area is about 1100 hectares in size and densities range from 55 to 200 people per hectare. Zeekoevlei is about 493 hectares in size and has a population density of about 3 (CCC Urban Studies, 1995).

3.3.3 Land use heterogeneity

The variation in land use heterogeneity is an important parameter to consider as it is a first order approximation of the variation in the obstruction to overland hydraulic flows across a catchment region. There is a need to obtain appropriate hydraulic coefficients to incorporate these land use variations into the overland flow modelling process. In this chapter, the discussion on this aspect simply highlights this need, while Chapter 4 provides detail of the modelling process.

In previous hydrological modelling reports, single land use allocations were typically assigned to the majority of the subcatchments considered (Taylor, 1985). In addition, the presence of other key land use features, potentially useful for integrated catchment management applications, (eg. informal settlements) or for investigating river rehabilitation / restoration possibilities (e.g. small dry or wet ponds scattered throughout the agricultural region) were completely ignored. Taylor (1985) defines a large number of subcatchments in the Lotus River catchment as homogeneously "residential" (110, 120, 127, 167, 169, 170, 180, 185, 195) or "agricultural" (175, 190, 160, 150, 145, 140, 135) areas. Graphs of percentage land use data for subcatchments previously placed into one of these categories show significant variations from one subcatchment to another within a single category (see Figures 3.7 and 3.8). The simplified land use allocations used by Taylor (1985) imply, firstly, that subcatchments can be treated homogeneously, and secondly that a standard permeability can be allocated to subcatchments within a specific category approach. The land use graphs in Figures 3.7 and 3.8 indicate that such an approach can result in a grouping of subcatchments that are in actually very different from one another in terms of the land use percentage data. The formal component of a previously "residential" subcatchment grouping varies from 0 (167b) to 89% (180a). Similarly, the nature of the hydrologically pervious component within the same category varies from 73% shrubs (195b) to 77% cultivated (167c). The percentage of land used for parking lots varies significantly reaching up to 20% in some subcatchments (167a). Similarly, subcatchments with the so-called "agricultural" subcatchment category, are composed of variable combinations of cultivated, grass and shrub bearing areas. The percentage cultivated land use varies from 24% (150a) to 82% (160). The percentage of shrub bearing areas varies from 4% (160) to 40% (150). In addition, parking lots can reach up to 12% of the subcatchment (145).

The variation in the land use distribution in the Nyanga-Gugulethu region is **more homogeneous** than the Lotus River region and **less homogeneous** than the Philippi region. The Philippi region is the most homogenous in terms of the land use distribution. It is comprised of cultivated, grassy, shrub-bearing areas in varying proportions.

3.3.4 Land use changes

Two land use change detection analyses were conducted. The analyses were carried out on-line by overlaying the 1983 and 1996 land use maps and by noting the changes in the land use on a per subcatchment basis. The first analysis focused on detecting changes during the period 1983 to 1996 for the entire catchment. In this section, we discuss the most notable characteristic, namely the growth in informal settlements. A further land use change detection analysis involved a visual comparison of the 1938 and 1983 land use maps for the main informal settlement bearing area in the catchment (Ikapa). This area includes Nyanga-Gugulethu, Airport and a portion of the Philippi East -Brown's Farm regions of the Lotus River catchment.

The areas of the subcatchments and of informal settlements within the subcatchments have been calculated. These have been used to calculate the percentage of areas of the subcatchments comprised of informal settlement areas, for the whole catchment. Results show that informal settlements in the region constitute 6.6% (331 ha) of the total Lotus River catchment area (5043 ha). The density of informal settlements in this area ranges from 286 - 13 dwelling units / ha (μ = 143.9). The total population living in informal settlements

in the catchment is estimated as 89929. A comparison with the latest previous shack counting study (Van Zyl, 1995) enabled an approximate annual growth rate, with respect to the increase in the number of shacks, to be calculated for each of the settlements in the catchment. The highest annual growth rates were calculated for the Sweet Home (266%) and Barcelona (50.4%) settlements. Figure 3.28 shows the boundaries of the informal settlements as mapped from 1996 photography, superimposed upon the land use map from 1983 photography. This shows very clearly how and where informal settlements were established on previously open space.

The land use changes which occurred during the period of 1983 to 1996 are predominatly a reflection of the increase in urbanisation which took place throughout the catchment. These changes involved increases in the areas of formal housing[1] (NG, PBF, P, LR), informal housing (NG, PBF, P), parking lots (A, NG, PBF, LR) and industrial / agricultural building (A, P, LR). Another result of the urbanisation process has been a net decrease in the total area of open vegetated land (A, NG, PBF), and open non-vegetated land also declined (P).

Similar trends in the change in land use are observable in the period of 1938 to 1983. There was an increase in the formal housing (NG), informal housing (NG, PBF), and agricultural buildings / industrial development areas (NG, PBF). Decreases occurred in open vegetated space (NG, PBF) and in the open non-vegetated areas (A, NG). Some of the land use changes observable for this period may also be attributed to the relocation policy which was being applied at the time. This is observable in the decrease in informal housing areas and in the replacement of previous relocation areas by formal housing developments which has occurred in the Nyanga-Gugulethu region.

3.3.5 Degree of urbanisation

The second land use change analysis carried out focused upon detecting changes during the period 1983 to 1996. The land use data collected for these two dates were used to calculate the percentage increase in urbanisation. The change in the percentage of urbanised areas within the individual subcatchments can be illustrated by mapping the difference in the hydrologically impermeable areas for 1996 and 1983. The values calculated for the percentage area of each subcatchment that is impervious represents a summation of the hydrologically effective and ineffective impervious areas. These values are more appropriately defined as a measure of the degree of urbanisation or the percentage of hardened surfaces comprising each of the subcatchments. The degree of urbanisation has been quantified by subtracting the percentage of impermeable area measured on the 1996 photography from the percentage of impermeable area measured on the 1983 photography.

Using this calculation, the degree of urbanisation found in each subcatchment has been mapped in Figure 3.29. This shows that subcatchments on the 1996 imagery, which illustrate that a great deal of urbanisation has occurred since 1983, will be characterised by very low negative values (eg.-80) for the degree of urbanisation, i.e. the lower the negative value, the higher the degree of urbanisation. Four classes can be designated based on this difference for the degree of urbanisation which has occurred: very high (-100% to -75%), high (-75% to -50%), intermediate (-50% to -25%) and low (-25% to 0).

Considering the catchment as a whole, 26.8% of the subcatchments illustrate a very high degree of urbanisation. The subcatchments, which display a very high degree of urbanisation, occur primarily in the Philippi East - Brown's Farm and in the Lotus River regions. The remainder of the subcatchments are evenly distributed between the high, intermediate and low degree of urbanisation categories (24.4% in each case). Some parts of Philippi as well as one subcatchment in Philippi East show no change in the degree of urbanisation.

[1] The following abbreviations have been used for the various subcatchment regions:
NG=Nyanga-Gugulethu, P=Philippi, PBF=Philippi-Brown's Farm, A=Airport, LR=Lotus River.

3.3.6 Hydrogeology

The Lotus River lies on the western periphery of the Cape Flats aquifer. The Cape Flats aquifer is a shallow, unconfined aquifer located in the sand deposits which form the Cape Flats. The aquifer occupies 630km^2 and pinches out against impermeable boundaries to the east, west, and north while the False Bay coastline between Muizenberg and Macassar serves as the southern boundary (Wright, 1995). It consists of recent deposits of predominately high quality silica sand and is underlain by essentially impervious Malmesbury Shales or Cape Granite (Tredoux, 1984). The maximum saturated depth of the aquifer, about 50m, is achieved near the False Bay coastline. Groundwater data distributions for the Cape Flats aquifer (for 25/8/97) were obtained from Watertek (CSIR). The mapped variables include: sand thickness, groundwater level, saturated thickness, salinity, transmissivity and borehole yields. This data has been integrated with the existing Lotus River catchment database to characterise the individual subcatchments.

Mean annual rainfall for the Cape Flats is between 500 and 800 mm, occurring mainly in the winter and early spring. Due to the characteristics of the Cape Flats sand unit, recharge occurs over almost the entire area of the aquifer, with little surface runoff. Evapotranspiration losses are high. Previous investigations have estimated the losses in excess of 80% of the annual rainfall. This translates to aquifer replenishment of 36 x 10^6 m^3 per annum. (Wright 1995) The presence of perched water tables on calcrete and clay lenses increases evapotranspiration rates locally. Subsequent work by Vandoolaeghe (1989) confirmed that net groundwater recharge in the South-Western Cape varies between 15% and 37% of annual rainfall. Exploitation of the aquifer however is carried out in the Philippi agricultural area which pumps an estimated 13 x 10^6 m^3 p.a.

The sand thickness, shown in Figure 3.9, is greatest (35 to 45 m) in the southern portion of Philippi. Low sand thickness values (15 to 20 m) occur along the canal. The lowest sand thicknesses (5 to 10 m) occur in the Nyanga-Gugulethu area. The groundwater level in metres above sea level, shown in Figure 3.10, declines gradually from the mounding in the north east across the catchment, and is lowest (5 to 10 m) in the Lotus River region. Hence, the groundwater within the Lotus catchment flows predominately in a westerly to southwesterly direction. However, given the region's topography, the water table is close to the surface. Borehole monitoring conducted by the Department of Water Affairs and Forestry reveals that within the Philippi agricultural area, the water table generally remains between 2 and 4½ meters below ground level (mbgl). The Philippi region is characterized by groundwater abstraction for irrigation, which amplifies the natural seasonal variation in groundwater levels. In the areas of the catchment where groundwater abstraction does not take place, fewer fluctuations occur in the water table elevation. These areas are characterized by less than one-meter variations in the water level over the year. The saturated sandthickness, shown in Figure 3.11, is lower in the Lotus River and Nyanga-Gugulethu regions and higher (25 to 45 m) in the central parts of the Philippi region.

The salinity, shown in Figure 3.12, exhibits the greatest variation. The main part of the Cape Flats aquifer has a low salinity (250 to 1000 mg TDS/l). Areas of elevated salinity often occur as a result of high evaporation rates where the water table is at, or near, ground level (i.e. seasonal vleis), and as a result of concentration due to evaporation of perched water tables. The Philippi area exhibits the highest salt concentrations (over 2 750 mg TDS/l) and this has been shown to be the result of irrigation practices (Wright, 1995).

The hardness of the groundwater in the Cape Flats aquifer ranges from hard to very hard, averaging 309 mg/l as $CaCO_3$ (Edwards, 1989). The groundwater's hardness can partly be attributed to the abundance of shelly material throughout the aquifer. Hardness, along with high alkalinity, is also indicative of "young," or recently charged, groundwater. This is consistent with the high infiltration rates and broad areas of recharge which characterise the Cape Flats aquifer. Other measured water quality variables within the aquifer were relatively low. However, elevated nitrate and potassium concentrations were found locally and are attributed to agricultural practices, particularly the application of approximately 400 tons of fertilizer per annum in the Philippi area (Wright, 1995).

Most of the borehole yield data available lies to the south of the catchment area. The transmissivity, as shown in Figure 3.13, declines northwestwards, and in much of the catchment, particularly near the Lotus River, transmissivity is relatively low. The highest values occur in the Philippi area (100 to 200). However, in more central regions of the Cape Flats aquifer, near Mitchell's Plain for example, transmissivities are above 400 m/d. Significant borehole yields occur only in the southeastern portion of the catchment, with the best yields occurring to the south of the catchment (Figure 3.14). Borehole yields within most of Philippi itself are low and falling (I.Rix, pers.comm., 1999). A number of well fields for exploiting the Cape Flats Aquifer have been proposed in the region directly south of the Lotus River catchment, although at present this resource is not viewed as a high priority for supplementing water supply to the Cape Metropolitan Area.

3.3.7 Geology and soil type

Soils in the Lotus River catchment are comprised of Recent (Witzand Formation) and Pleistocene (Langebaan Formation, Springfontein Formation) sediments. The Airport, Nyanga - Gugulethu and Philippi-Brown's Farm regions are comprised entirely of sediments from the Langebaan formation. This formation consists of calcrete and very fine to fine calcareous sands. The Philippi region contains sediments from the Langebaan, Witzand (comprised of very fine to very coarse calcareous sands with abundant small shells and shell fragments) and Springfontein (fine to medium quartzose sand, with localised calcareous clay and peat lenses) formations. The Lotus River region is characterised by Springfontein formation sediments.

Recent soil data was obtained for the Philippi region from the Institute for Soil Climate and Water (Agricultural Research Council). This data characterises the calcareous or non-calcareous nature of the subcatchments in this region (Figure 3.15). It was obtained in order to determine whether there would be a high background concentration of phosphorus to be found in surface water, leached from the soil. The soil type in a number of subcatchments in the western half of the Philippi region is predominantly non-calcareous. Subcatchments in the eastern half of the region display a combination of calcareous and non-calcareous soil types. This study is discussed in more detail in Chapter 4.

3.3.8 Surface water quality

Thematic maps illustrating the variation in the water quality parameters monitored along the Lotus River canal have been produced for two dates. These dates were selected to represent water quality variations typically associated with a high flow volume (05 / 8 / 97) and a low flow volume (15 / 9 / 97). The points where major tributary inflows occur are indicated by arrows. It must be noted that the water quality data is presented in terms of mass flux rather than concentration, as the mass flux data allows us to see exactly where increases or decreases in the amount of the pollutant entering or leaving the river system occur. The width of the river is proportion to the flow. The thematic maps are shown in the following figures:

Figure 3.16 Variation in Total Phosphorus (mg/s) (high flow)
Figure 3.17 Variation in Total Phosphorus (mg/s) (low flow)
Figure 3.18 Variation in Total Persulphide Oxidisable Nitrogen (mg/s) (high flow)
Figure 3.19 Variation in Total Persulphide Oxidisable Nitrogen (mg/s) (low flow)
Figure 3.20 Variation in Chemical Oxygen Demand (g/s) (high flow)
Figure 3.21 Variation in Chemical Oxygen Demand (g/s) (low flow)
Figure 3.22 Variation in Total Suspended Solids (g/s) (high flow)
Figure 3.23 Variation in Total Suspended Solids (g/s) (low flow)
Figure 3.24 Variation in Electrical Conductivity (mS/m) (high flow)
Figure 3.25 Variation in Electrical Conductivity (mS/m) (low flow)

The flow volume ranges and maxima differ significantly for these two dates. The thematic maps were analysed with three objectives: 1) to determine whether there was a steady downstream variation, and if so to verify where the maximum values occurred, 2) to determine the location of anomalies and 3) to determine the land use in the subcatchments adjacent to the anomalous values.

A number of variations in the water quality monitored along the Lotus River have been detected adjacent to three of the regions. Variations adjacent to the Nyanga-Gugulethu region (observable in the SRP, COD, TSS, TVS, EC, TP and TPON data) may be associated to high population densities and the presence of informal

settlements in these areas. Variations (in the SRP, COD, TSS, TVS, EC and TPON data) north of the Philippi region and south of Lansdowne Road may be associated with farming activities in the area. Variations (in the EC, TVS, TSS and TPON data) along the Lotus River region may be associated with the formal residential and industrial land use activities. The low flow TPON data set shows a decline downstream, increasing again where inflows occur from the agricultural area. This decline may be attributed to assimilation or infiltration into the groundwater system. Declines may also be noted for the data sets for total suspended solids and electrical conductivity, at both high and low flows. In the case of TSS, such declines are attributable to sedimentation which occurs in certain stretches of the Great Lotus River. The data on electrical conductivity, however, which is not a mass-based parameter, may show declines occurring due to dilution at major tributary inflows.

3.3.9 Waste management and cleansing

Waste management in the Lotus River catchment is the responsibility of three different local authorities, with different levels of service and levels of efficiency (B Petersen, 1998). North of the N2, subcatchment 101 lies within the City of Tygerberg. This industrial area is serviced by a private waste management company, but there are major problems with dumping and littering. The municipality is responsible for removing dumped material which is found on municipal land.

Within the area, which falls under the City of Cape Town, four different depots are responsible for waste management (Klipfontein, Athlone, Bonteheuwel, and Claremont). River cleansing is, however, undertaken by the Maitland Industrial Waste Department. Within the area serviced by the South Peninsula Municipality, three depots (Skaapkraal, Wynberg and Muizenberg) are responsible for both waste management and river cleansing. Figure3_39 shows the position of the depots responsible for the Lotus River catchment.

Other figures on the CD which have information related to waste management in the catchment are as follows :

Figure3_40	Location of dumping sites in the Boquin area
Figure3_41	Location of dumping sites in the Grassy Park area
Figure3_42	Location of dumping sites in the Hanover Park area
Figure3_43	Location of dumping sites in the Lotus River area
Figure3_43a	Location of cleansing depots and the type of collection systems used in the Lotus River catchment
Figure3_44	Location of dumping sites in the Pelikan Park area
Figure3_45	Location of dumping sites in the Philippi East area
Figure3_46	Location of dumping sites in the Sand Industry area
Figure3_47	Levels of service by domestic ton per month depots service areas
Figure3_47a	Municipality service areas and the collection systems used in these areas
Figure3_48	Commercial recycling facilities found within the Lotus River catchment

Levels of service found in the residential areas of the catchment vary between the different local authorities, and also with the type of housing. The main systems used are as follows:

(1) The bag and bin system: this is a kerbside system, collecting the waste from individual formal dwellings, in a labour-intensive way. This is considered to be a high level of service, and is correspondingly more expensive. This system is widely used by South Peninsula Municipality, and to a lesser extent by the City of Cape Town.

(2) The skip system, which is a form of communal collection. The servicing of the skips may be done by the municipality, or may be contracted out to a private company. This is a low level of service, which gives rise to severe littering problems in the vicinity of the skips, and is a low-cost service. This system is used by the City of Cape Town to service the informal settlements and semi-formal residential areas in Gugulethu, Nyanga and Brown's Farm.

(3) The octabin system is another form of kerbside collection, where the bins are 240 litres in capacity, and can be emptied into the compacting truck by hydraulic arms. Although the same crew is required for each truck as in the bag-and-bin system, their work is safer and less strenuous. This is the system used by the City of Cape Town in the formal housing areas.

(4) The KSAB system (Keep South Africa Beautiful) is a form of waste collection being used in the informal settlements, whereby the municipality contracts a single person to collect domestic waste and litter manually from a given area. This system can be highly cost-effective, but is difficult to manage and implement. It is being used by the City of Cape Town in the informal areas of Gugulethu, Nyanga, Phillipi East and Crossroads.

Tables 3.2 and 3.3 give details of the collection systems, collection frequency, and average figures for the amount of domestic and street refuse collected per month in each residential area. As the figures for the City of Cape Town show, very high levels of street refuse are generated by dumping, which are removed from time to time by the municipality. The level of littering and dumping is extremely high and completely uncontrolled, and in fact visual inspection rapidly reveals that the municipality is not keeping pace with the level of waste generated. This is particularly the case in the vicinity of the semi-formal and informal housing areas. This indicates the need for many more skips and "controlled" dumpsites in these areas of the catchment.

In the areas serviced by South Peninsula Municipality, littering and dumping are also wide-spread. The difference is however the problem is not intensely concentrated in certain areas as it is within the City of Cape Town, since there is far less informal housing in the southern part of the catchment. The municipality in fact does not take responsibility for removing street refuse. One depot manager commented, when interviewed, that they frequently remove dumped material, in order to "use it as fill" in depressions and wetlands, or other areas "needing to be lifted". While the domestic waste is taken to landfill, the street waste is not.

River cleansing services are undertaken by heavy machinery, commonly by digger-loaders. These remove the waste in the canal, as well as any sedimentation and vegetation growth in the canal. Frequently, the material removed from the canal is dumped on the banks on either side. The only litter traps currently maintained on the river system are on the outlets of the Great and the Little Lotus Rivers, where they flow into Zeekoevlei. These are simple wire litter traps (two on each river) which are regularly cleaned and maintained by the Skaapkraal depot. The removed material is taken to the Coastal Park landfill site.

Table 3.2: Cape Town Municipality levels of service

Depot Name	Klipfontein						Athlone	Bonteheuwel		Claremont
Sweeping cycle (weeks)	6						8	4		8
Inspectors present	yes						yes	yes		yes
Drop-off facility provided	no						no	no		yes
River Cleansing	yes						yes	yes		no
Landfill	Swartklip						Swartklip	Swartklip		Coastal Park
Residential Area Name	Gugulethu	Nyanga	B's Farm	Phillippi	Phillippi E.	Cross Rds	Hanover	Manenberg	Sand Ind.	Lansdowne
Domestic Refuse (ton/mth)	789	400	315	69	38	42	235	225	0	289
Street Refuse (ton/mth)	603	500	366	0	140	180	84	109	0	
Collection System										
formal areas:	Octabin	Octabin	-	-	-	-	Octabin	Octabin	-	Octabin
semi-formal areas:	Skip	Skip	Bin&Bag	Bin&Bag	-	-	Bin&Bag	Bin&Bag	-	-
informal areas:	KSAB	KSAB	Skip	-	KSAB	KSAB	-	-	-	-
industrial areas:	-	-	Private	-	Private	Private	-	-	Bin&Bag	-
Collection Frequency (/wk)										
formal areas:	1	1	-	-	-	-	1	1	-	1
semi-formal areas:	0.5	2	0.5	-	-	-	2	2	-	-
informal areas:	1	1	0.5	-	1	1	-	-	-	-
industrial areas:	-	-	varies	-	varies	varies	-	-	1	-
Vehicle days (/wk)	2.5	4	1	0	1	1	3	3	1	1
No. of Vehicles	4	3	3	1	1	1	2	2	1	3
Vehicle days (/mth)	32	24	24	8	8	8	16	16	8	24
Garden Refuse	on req.	on req.	-	on req.	-	-	Wednes	on req.	-	Fridays

Table 3.3: South Peninsula Municipality levels of service

Depot Name	Skaapkraal						Wynberg		Muizenberg
Sweeping cycle (weeks)	8						8		8
Inspectors present	yes						yes		yes
Drop-off facility provided	yes						yes		no
River Cleansing	yes						yes		no
Landfill	Coastal Park						Coastal Park		Coastal Park
Residential Area Name	**Wetton**	**Ottery**	**Grassy P.**	**Lotus R.**	**Zeekoevlei**	**Montague**	**Fairways**	**Parkwood**	**Pelican P.**
Domestic Refuse (ton/mth)	62	98	151	121	65	95	94	56	59
Street Refuse (ton/mth)	-	-	-	-	-	-	-	-	-
Collection Method									
formal areas:	Bag&Bin	Bag&Bin	Bag&Bin	Bin&Bag	Bag&Bin	Bag&Bin	Octabin	Bin&Bag	Bag&Bin
semi-formal areas:	-	-	-	-	-	Bag&Bin	-	-	Bag
informal areas:	-	-	-	-	-	-	-	-	-
industrial areas:	-	-	-	-	-	-	-	-	-
Collection Frequency (/wk)									
formal areas:	1	1	1	1	1	1	1	1	1
semi-formal areas:	-	-	-	-	-	1	-	2	-
informal areas:	-	-	-	-	-	-	-	-	-
industrial areas:	-	-	-	-	-	-	-	-	-
Vehicle days (/wk)	1	1	1	1	1	2	1	3	1
No. of Vehicles	1	2	3	2	1	1	1	1	1
Vehicle days (/mth)	8	16	24	16	8	8	8	8	8
Garden Refuse	with refuse	with refuse	with refuse	with refuse	with refuse	with refuse	with refuse	with refuse	with refuse

3.4 REGIONAL CATCHMENT VARIATIONS

3.4.1 Introduction

On the basis of the 1996 land use distribution variations, hydrological modelling considerations, and variations in the rate of urbanisation, the Lotus River catchment has been subdivided into five regions: 1) Airport (A), 2) Nyanga - Gugulethu (NG), 3) Philippi East - Brown's Farm (PBF), 4) Philippi Horticultural Area (PHA) (P) and 5) Lotus River (LR). Each of these regions is comprised of one or more subcatchments, which may be characterised by predominant land use combinations, as shown in Table 3.4. In the discussion that follows, the socio-economic characteristics, total population, population density, heterogeneity of the land use distribution, land use changes for the periods 1983 to 1996, and 1938 to 1983, degree of urbanisation, geology and hydrochemistry of each region is discussed.

Table 3.4 Subcatchments within the Lotus River catchment

Subcatchment Number	Area (square meters)	Total Population	Predominant Land use	Percentage (%)
101	1610.2	0	no vegetation	41
105	60.2	9299	informal housing	77
110	183.8	21924	formal housing	54
115	162.3	14009	formal housing	79
120	153.0	12966	formal housing	69
125	391.3	14878	shrubs	54
126a	106.5	5076	parking lot	24
126b	92.0	94	shrubs	83
127	183.4	17569	no vegetation	31
130a	65.7	6881	informal housing	70
130b	44.5	2938	formal housing	63
131a	152.9	15683	informal housing	38
131b	135.3	8777	serviced sites	56
134a	44.5	1289	grass	36
134b	188.1	6174	no vegetation	59
135	411.3	119	cultivated	45
140	403.8	0	cultivated	64
145	42.5	35	industrial	28
150a	59.4	259	shrubs	40
150b	45.5	29	cultivated	71
155a	31.0	2610	formal housing	78
155b	20.6	799	formal housing	57
160	328.6	13	cultivated	82
165a	196.0	4481	formal housing	39
165b	62.7	1867	grass	42
167a	25.6	562	formal housing	31
167b	19.6	0	industrial	61
167c	54.5	116	cultivated	77
169a	36.0	376	industrial	44
169b	37.4	1041	grass	38
169c	20.9	230	grass	55
170a	21.1	948	formal housing	56
170b	36.8	992	grass	50
175	297.5	64	cultivated	73
180a	44.5	3128	formal housing	89
180b	70.1	3839	formal housing	68
185a	31.9	1955	formal housing	83
185b	40.6	1840	formal housing	59
190	378.8	876	cultivated	57
195a	19.0	857	formal housing	63
195b	40.0	403	shrubs	73

3.4.2 Airport Industria

The Airport region lies in the northernmost part of the catchment and is comprised of one subcatchment (101). This area, adjacent to the Cape Town International Airport, is bounded by Borchards Quarry Road, Airport Approach Road and the N2 national road. It is an area of approximately 1610,2 ha and is characterised by light industrial and commercial activity land use areas, and open areas. This area has undergone significant recent development resulting in hardening of the subcatchment. Two detention ponds are located in the area catering for flow from the Boquinar South Industrial Area (outlet restriction of 0.7 m^3/s) as well as the Cape Town International Area (outlet restriction 0.1 m^3/s). The combined flow from these areas is thus restricted to 0.8 m^3/s into the Great Lotus River canal. Upgrading proposals for the airport, discussed elsewhere, are expected to increase the runoff from the Airport area into its detention pond.

The dominance of industrial concerns in this region has resulted in an absence of formal and informal settlements. The vast majority of the working population in this region reside elsewhere. Consequently this region is characterised by a population density value of less than 1 person per hectare. A high degree of urbanisation has taken place in this region.

The land use changes which occurred during the period of 1983 to 1996 reflect an increase in the number of industrial concerns in the region. Accompanying (and resulting from) this change was an increase in the total area utilised for parking lots and a reduction in the total area of open vegetated land. The 1938 to 1983 analysis showed a net decrease in the area of open non-vegetated land - which is again attributable to urbanisation.

3.4.3 Nyanga and Gugulethu

3.4.3.1 Land use heterogeneity

The Nyanga - Gugulethu region, 559 hectares in extent, lies in the north eastern part of the catchment and is comprised of five subcatchments (105, 110, 115, 120, 127). This region is **more homogenous** than the Lotus River region and **less homogenous** than the Philippi region. Within the Nyanga-Gugulethu region, the heterogeneity in the land use distribution increases northwards (110) with increases in the informal, vegetated and non-vegetated open areas. The southern subcatchments are more homogenous and are comprised almost entirely of formal (120, 115) areas.

3.4.3.2 Socio-economic and population data

Prior to local authority restructuring of 1995, Nyanga and Gugulethu were managed by the Ikapa Town Council. It is an area composed of primarily formal and informal residential areas. The area was historically disadvantaged in terms of the provision of adequate sanitation and sewer/stormwater infrastructure. This is especially pertinent to the informal settlement areas where shack dwellers had, and continue to have, no access to sanitation and the only means of water supply are standpipes. This has had a negative impact on the water quality of the Lotus River canal, which is used as a waste removal system, as well as an open sewer.

Until the introduction of the Discount Benefit Scheme within the new housing policy after 1994, the apartheid laws prevented or made it virtually impossible for Africans in Gugulethu, Nyanga, Crossroads and indeed in the entire Peninsula to own any property. The CCC therefore provided and owned the bulk of housing stock within these areas. There was, however, provision within the Native Location Amendment Act of 1905, which permitted Ownership to Africans in these locations 'subject to such terms and conditions as the Governor deem expedient' (Elias, 1983: 7). An insignificant number of housing schemes were built and provided to Africans in Gugulethu under this measure in the mid-80s by some employers and the Urban Foundation. There were no such schemes in Nyanga.

The Nyanga-Gugulethu region contains the second highest percentage (37.8%) of the total informal settlement population in the catchment. The informal settlement population distribution within the various subcatchments in this region is as follows: subcatchment 105 (Barcelona, Miller's Camp) holds 9299 people, 110 (KTC, Tambo Square, Black City, Miller's Camp) holds 13993, 115 (Mkhonto Square, Mpetha Square, Mahobe Drive) holds 4712 and 120 (Phola Park, Mahobe Drive) holds 6034 people.

The highest population densities are observable for the main informal and formal settlement bearing subcatchments (110: KTC, Tambo Square, Black City, Miller's Camp, 288 people/ha; 115: Mkhonto Square, Mpetha Square, Mahobe Drive, 273 people/ha; 120: Phola Park, Mahobe Drive, 232 people/ha) in the region. Lower densities are observable in the subcatchments which lack formal settlements and which have only recently undergone a growth in informal settlements (105:Barcelona: 154.5 people/ha).

The average household size in these areas is 3.6 (Urban Studies, 1997; WCCHT, 1996). Average annual income in Gugulethu is about R14 000 per household and R10 000 per household in Nyanga (CCC Urban Studies, 1995). According to 1991 Census data, about 86% of households in Gugulethu have income levels that fall within the low-income strata (R0 – R18000), while for Nyanga the number is about 90%. More detailed household income data, including the areas of Philippi East, indicate that 60% of households were earning less than R800 per month, 18% were within the R800 – R1500 income bracket and 14% within the R1501 – R2500 income bracket (WCCHT, 1996).

The education levels in these areas point to the fact that until the abolition of the labour preference policy, some skilled jobs were reserved for particular groups. Consequently, there was no incentive for Africans in urban areas to further their education. Even technical education bursaries offered by the CCC for Africans were redeemable in the former homelands institutions. Those candidates who successfully completed these courses were supposed to work in the homelands, thereby forfeiting their rights to be in the urban area (Elias, 1983: 111). Until 1990, there were only four high schools serving the population of Gugulethu, Nyanga, Crossroads, Philippi and Brown's Farm. According to Census 1991 data, there were only 3857 matriculants in Gugulethu and 2387 in Nyanga and Crossroads. In the same period there were 1229 individuals who completed a degree or a post matric diploma in Gugulethu, and 446 in Nyanga and Crossroads.

3.4.3.3 Land use changes

The land use changes which have taken place in this region of the catchment clearly reflect a high degree of urbanisation. The most obvious changes which have resulted from this trend include a net increase in the formal housing (110, 130b), informal housing (105, 110, 115, 120, 130a) and parking lot areas (130a), and a net decrease in the open vegetated land area (105, 110, 120, 130a, 130b). Where areas have been cleared for further development, an increase in the open unvegetated areas (129, 130a) is observable. The data indicates that significant land use changes had already occurred in this region as early as 1938 because of the urbanisation process. As with the 1983 - 1996 comparison, net increases in the in the formal housing (115, 120, 110), informal housing (115), and industrial development (120, 115) areas, and net decreases in the open vegetated space (115) and open non-vegetated areas (110) took place.

3.4.3.4 Degree of urbanisation

The degree of urbanisation varies across the region from very high to low values as follows: 25% of the subcatchments show a very high degree of urbanisation, 25% show a high degree of urbanisation, 25% show an intermediate degree of urbanisation, and 25% show a low degree of urbanisation. The variation in the degree of urbanisation increases gradually towards Barcelona (105) in the north.

3.4.3.5 Sewers

The poor water quality has historically been affected by overflows of the sewer systems into the stormwater infrastructure. This can be seen especially at two stormwater inputs (point sources) into the Great Lotus River in the area. These two sources contribute high concentrations of faecal coliform bacteria, up to 1.6×10^7 and 4.0×10^7 counts per 100ml respectively.

A number of possible causes have been suggested for these overflows. Sewer overflows have historically occurred at sewer pump stations. The Cape Town Municipality maintains records of these pumpstation overflows including location of overflow and duration of overflow. Of more difficulty in tracking are the overflows from the sewer pipes themselves. These are frequently caused by blockages due to the introduction of sediment and gross litter into the sewers. The blockages cause a backing up and surcharge at manholes with the accompanying overflow being routed into the stormwater system. Coupled with this is an overburdened sewer system infrastructure underdesigned for the present load with a lack of maintenance leading to pipe breakage. This area is characterised by a significant increase in population. In addition to the formal residential areas, informal settlements as well as an increasing number of backyard shacks in the area are causing an overloading of the existing sewer infrastructure.

The Ikapa Town Council, historically under whose responsibility the area fell, maintains records of blockages in the sewers. Unfortunately these blockages were not recorded with any corresponding overflows. Hence it is not possible to determine from these records when overflows resulted from blockages. The records have rather been used to isolate problem areas requiring either cleaning or upgrading. Significant upgrading has been undertaken on the sewer network in these areas yet the counts still remain high.

An additional source of faecal coliform bacteria in the canal is the poor sanitation conditions characteristic of the Nyanga - Gugulethu informal settlement areas. At present the means of sanitation in these areas is the "bucket" system, effectively a "long drop", that is provided approximately per every four households. This system relies on continual maintenance which the local authorities frequently do not have the capacity to undertake. Local residents thus utilise the canal for sanitation due to the lack of any suitable alternative thereby constituting a diffuse source of the coliforms to the canal. It constitutes a significant health risk and any attempt at an improvement of water quality in the Great Lotus canal must address this social sanitation concern.

3.4.3.6 Hydrochemistry

Variations in the hydrochemical variables monitored along the canal adjacent to the Nyanga - Gugulethu region may be associated to high population densities and the presence of informal settlements in these areas. High value anomalies are observed in the TPON, TP, SRP, COD, TSS, TVS and EC data variations adjacent to the following subcatchments: 105, 110 and 115. Lower values in this region are found for TPON and TP adjacent to subcatchment 120.

3.4.4 Philippi East / Crossroads

The Philippi East - Brown's Farm region lies in the eastern part of the catchment and is 1171 ha in extent. It is comprised of seven subcatchments (125, 126a, 126b, 127, 130a, 130b, 131a, 131b) and is characterised by informal settlement areas and open areas. This is the most rapidly urbanising region of the entire catchment.

3.4.4.1 Population data

Intermediate to high population densities are observed in the subcatchments which are undergoing urbanisation. These subcatchments are characterised by having experienced a recent growth in informal settlements (Brown's Farm area: 131a: 123.3 people/ha; 130a: 117.7 people/ha; Klipfontein, Glebe and Crossroads: 127: 157.3 people/ha) or by having been provided recently with serviced-sites (131b: 96.7 people/ha; 130b: 263.7 people/ha; 126a: 47.7 people/ha). The lowest population densities are observable for the subcatchments which have undergone the lowest degree of urbanisation (126b: 1 person/ha) or subcatchments which have retained the greatest amounts of open vegetated areas since 1938 (125: 38.0 people/ha).

The Philippi East - Brown's Farm region holds 55% of the total informal settlement population in the catchment. The informal settlement population distribution within in each of the subcatchments in this area is as follows: subcatchment 127 (Boy's Town, Crossroads, Klipfontein Glebe) holds 14677 people, 125 (Klipfontein Glebe, Lower Crossroads) holds 9234, 126a (Vietnam) holds 5076, 126b (Philippi West) holds

94, 130a (Brown's Farm) holds 6664, 130b (Vietnam) holds 680, and 131a (Brown's Farm) holds 13028 people.

Crossroads, Lower Crossroads (Philippi East) and Brown's Farm is rapidly developing under the integrated Serviced Land Project (iSLP), a Presidential Lead Project for housing undertaken within the new housing policy. The project originated from the old Provincial Administration eight years ago. In the last three financial years, about ten thousand serviced sites have been provided to African households or at least been completed. It is estimated that 80 to 90% of these sites were or will be provided under the full subsidy band (ie R15000) (iSLP 1998). This indicates that up to 90% of these households have a combined income of less than or equal to R800 a month, which is within the low income strata (R0 – R18000 a year). This points to average annual incomes for households of below R10000 (less than or equal to R9600) in Crossroads, Philippi East and Brown's Farm. (CCC Urban Studies 1995). According to Census 1991 data, there were only 270 matriculants in Philippi and Brown's Farm. Not surprisingly, there were no individuals who had completed a degree or a post matric diploma living in Philippi and Brown's Farm, in the same period.

3.4.4.2 Land use heterogeneity

This region is less homogenous than the Philippi region and more homogenous than the Nyanga - Gugulethu region. Subcatchments in the central parts of the Philippi East - Brown's Farm region are highly homogenous as they are predominantly comprised of single land use types (130a, 130b, 126b) (Fig.2). The majority of the subcatchments are less homogenous and are comprised of at least two predominant land use types (134b, 131a, 131b, 125, 127). The most heterogeneous subcatchment in the region is 126a, which is characterised by the presence of roads and parking lots.

3.4.4.3 Land use changes

The land use changes observed during the period of 1983 to 1996 (Fig.2, Fig3) are the result of this urbanisation process. These changes involved net increases in the formal housing (131a, 131b), informal housing (131a, 131b, 134b, 126a, 125) and road/parking lot areas (126a, 125, 131b, 131a), and a net decrease in the vegetated space for all subcatchments in this region (134a, 131a, 131b, 136a, 126b and 125). The older imagery indicates that significant urbanisation had already occurred in subcatchment 127 of this region by 1983 (Fig.3, Fig.4). This is indicated by increases in the informal housing and agricultural building / industrial developments areas, and by a decrease in the open vegetated space.

3.4.4.4 Degree of urbanisation

This region of the catchment has been the most affected by the urbanisation process. The degree of urbanisation varies across the region as follows: 50% of the subcatchments show a very high degree of urbanisation, 25% show a high degree of urbanisation, 12.5% show an intermediate degree of urbanisation, and 12.5% show a low degree of urbanisation. The greatest increases in urbanisation (ie. the most negative degree of urbanisation values) are observed in the south eastern portion of the region (subcatchments: 130a, 130b, 131a, 131b).

3.4.4.5 Hydrology

This area is targeted as an area of rapid development, for low-cost housing as well as new industrial/commercial activity. Historically, the Philippi East area was open unutilised land that did not contribute any runoff to the Great Lotus River canal. The northern parts of the area were not serviced and no drainage infrastructure was provided. Drainage thus occurred as seepage into the Cape Flats aquifer. The southern part of Philippi East largely does not provide runoff to the Great Lotus canal either. This was since the topography of the land was sloping south-east away from the Great Lotus canal. Large-scale earthwork activity has graded the land so that runoff would be channelled towards the Lotus River canal. Serviced sites have been provided for residential development. Stormwater infrastructure including minor and trunk pipework and stormwater detention ponds have been provided or are proposed for development.

3.4.5 Philippi Horticultural Area

The Philippi region lies in the central part of the catchment. While the entire Philippi area is approximately 3500 ha in extent, the part which drains to the Great Lotus River is 2279 ha in extent and is bounded by Vanguard Drive, Lansdowne Road, Strandfontein Road and Strandfontein Village. It consists of twelve subcatchments (190, 175, 140, 135, 169c, 167c, 160, 150b, 150a, 145, 134a, 134b) characterised predominantly by the presence of cultivated land and agricultural buildings, as well as vegetated open areas.

3.4.5.1 Population data

The lowest population densities in this region occur in the central subcatchments, which have undergone a low degree of urbanisation since 1983. These relatively unchanged, low population density subcatchments include: 150b, 160, 175, 140, 135. The marginal subcatchments of the Philippi region, which have undergone higher degrees of urbanisation are characterised by slightly higher population densities (167c: 10.4 people/ha; 150a: 4.4 people/ha; 145: 4.0 people/ha; 134a: 29.0 people/ha; 134b: 32.8 people/ha). The Philippi region holds the second lowest total informal settlement population distribution in the catchment (6.3%). In this region the informal settlements are small but significant, occuring in the following subcatchments: 134b: Samora Machel (1289 people), 134a: Sweet Home (3938), 150a: Ottery (259), and 150b: Ottery (29 people). Clearly, in most cases where a higher population density is observed, this attributed to the presence of an informal settlement.

The African and Coloured sections of the catchment area are generally characterised by poverty, low levels of income, standard of education and skills, and high unemployment. These demographics are at an extreme level for the members of the same group who reside within the Philippi rural area (CMC 1995). It is estimated that 55% of workers in this area are illiterate, 24% of mothers are malnourished, 47% of children are born underweight and almost all the workers are totally reliant on their employers for their livelihood (ibid. 6). About 50% of residents in this area are not economically active, and of those who are economically active, about 40% are employed in the farming industry and about thirty workers in the sand industry.

3.4.5.2 Land use heterogeneity

The Philippi region is the most homogenous in terms of the land use distribution (Fig.2). It is comprised of cultivated, grassy, shrub-bearing areas in varying proportions. The most heterogenous subcatchments (the eastern parts of: 190, 175, as well as the following subcatchments: 169c, 167c, 150c, 145, 134a) in this region lie adjacent to the formal settlement bearing areas. The heterogeneity in these areas is increased by the presence of formal, agricultural buildings and informal settlement land uses. These subcatchments are also characterised by increased amounts of uncultivated vegetated land (134a, 190, 175, 145).

3.4.5.3 Land use

The area is composed mainly of smallholdings with horticulture being the primary land use. Almost all of the arable land is considered to be man-made through the filling of low-lying areas and the levelling of calcareous/non-calcareous dunes. These low-lying areas are frequently old vleis that were covered with dune sand. The land is privately owned or leased by both tenant farmers and sand mining operators. Absentee land-lordism is however common (CMC 1995). Property sizes vary between two to twenty two hectares, with larger landowners holding several such properties. However, there are also larger areas of state-owned land, with the CMC occupying the most publicly-owned land.

Horticulture in the area mainly consists of intensive vegetable farming. These include cabbages, beetroot, potatoes, carrots, spinach and lettuce that are marketed to local street traders, markets and supermarkets and restaurants. While horticulture remains the predominant land use in the area, the proportion of land use for vegetable cultivation has diminished over the last decade (CMC 1995: 6). In the late 1970s about 70% was used for horticulture. Current estimates indicate that only about 38% of land is used for this purpose. Horse breeding and stabling is also becoming a major activity, together with other opportunistic land uses.

This decline in horticulture can be attributed to a number of reasons including the present state of economic conditions, uncertainty in the current land use reservation, the lack of effective or strongly enforced

development regulations, attitude and behavioural changes. There is increasing vacant or unattended land, land speculation, absentee landlordism, illegal land use and a perceived lack of local authority administration. Land on the boundary of the PHA is subject to theft of agricultural produce, equipment and vandalism of farm property, a situation that promotes a sense of insecurity amongst landowners on the periphery. This leads to these owners either selling their land or abandoning horticultural production, a situation that leads to opportunistic land uses and urban encroachment. Thus land that is still actively cultivated is largely located in the centre of the PHA. The decline in the area of cultivated land has not led to a corresponding decline in produce volume, however, which suggests that there has been a substantial increase in productivity in the remaining parcels of land. This is due to more intensive farming practices and the application of organic (manure) and inorganic fertilisers (superphosphate).

The other predominant land use is sand mining and this occurs mainly in the southern portion of the study area. Soils of the area are primarily wind blown sand. Geological studies of the area have shown that the sands are of a high quality silica content making it suitable for glass making. Mining of this sand occurs mainly in the southern portion of the area. Since mine operators are obliged to retain the top soil and rehabilitate the areas they have levelled and stripped for mining, these rehabilitated areas are made accessible for the potential extension of horticulture.

Other land uses include horticultural activities like nurseries and some landscaping companies cultivate plants and seedlings for the local markets. There are also a few farmers who supply cut flowers to local florist and street traders. While current regulations prohibit the keeping of livestock, this land use existed before the introduction of these regulations. Lack of effective policing has resulted in an increase in the scale of this land use and an increasing number of livestock being raised in the area, especially in terms of horse breeding. This has potential ramifications in terms of livestock manure polluting drainage channels and increasing phosphate concentrations. There are also four farm stalls and a co-operative located within the PHA. Industrial and commercial undertakings are concentrated along Lansdowne and Strandfontein roads.

Large tracts of land are presently either vacant or under-utilised and this situation contributes significantly to uncertainty, land speculation, opportunistic land use and environmental decay. A number of rezoning proposals have been raised for the area. These proposals are addressed elsewhere in this report.

3.4.5.4 Degree of urbanisation

This region of the catchment has been the least affected by the urbanisation process. The degree of urbanisation varies across the region as follows: 8.3% of the subcatchments show a very high degree of urbanisation, 8.3% show a high degree of urbanisation, 42% show an intermediate degree of urbanisation, and 42% show a low degree of urbanisation (Fig. 25).

As a result of the limited amount of urbanisation which has taken place, the land use detection analyses for the Philippi region showed the least number of land use changes when compared to the other regions of the catchment. Associated with the limited amount of urbanisation which has taken place are a number of minor increases in formal housing developments (145, 175, 190, 169c, 167c), informal housing (134a) and agricultural building areas (175, 134a, 150). The completion of road developments (eg. Vanguard Drive) may be associated with a reduction in the open non-vegetated land in a number of the subcatchments (175, 190, 140, 135, 134a).

3.4.5.5 Hydrology

Drainage in the area was historically ill-defined with the dune ridges containing and ponding stormwater. The increase in horticulture and removal of dunes increased flooding in the area with ruined crops posing a horticultural problem. Due to the flat nature of the area topography, the alteration of catchment boundaries through earthmoving activities and the excavation of furrows significantly affected this flood risk. The existing drainage system is comprised of constructed channels and drainage ditches with piped road crossings. These channels are maintained by farmers and frequently have had their discharge capacity reduced through infilling or inadequate maintenance.

The soil type in a number of subcatchments in the western half of this region is predominantly non-calcareous (150a, 150b, 145, 160, 167c, 169c). Subcatchments in the eastern half of the region display a combination of calcareous and non-calcareous soil types (175, 190, 135). It may be noted that phosphate levels in the surface water are very high, and are the subject of a detailed investigation in Chapter 4.

3.4.6 Grassy Park/Lotus River/Ottery

The Lotus River region lies in the western part of the catchment and covers 678 hectares. It consists of sixteen subcatchments (155a, 155b, 167a, 167b, 165a, 165b, 169a, 189, 170a, 170b, 180a, 180b, 185a, 185b, 195a, 195b) characterised predominantly by the presence of formal residential housing, industrial and commercial areas, as well as vegetated areas.

3.4.6.1 Population data

Because of the Coloured Labour Preference Policy of the Western Cape, a number of housing schemes were designed to provide housing to this group either on an ownership or rental basis. The CCC undertook a large number of these schemes. Even though current housing policies encourage ownership as opposed to council owned rental stock, a significant number of houses in the Greater Grassy Park area are still currently occupied on rental basis due to the economic hardship experienced by a significant section of this group (CCC Urban Studies).

Historically the White population group has been encouraged to be economically independent such that they could provide for their housing needs, although there was flexibility in tenure options. The White population group owns most of the housing stock in Zeekoevlei and the surrounding area is developing quite rapidly.

The population densities observed for the Lotus River catchment region varies from very high to very low. The highest population densities correspond to subcatchments which are predominantly comprised of formal housing areas (195b: 49.4 people/ha; 185a:300.3 people/ha; 185b:300.3 people/ha; 180a: 344.5 people/ha; 180b: 268.5 people/ha; 170a: 220.4 people/ha; 155a: 355.7 people/ha). The lowest population density areas correspond to subcatchments which are comprised significantly of open vegetated areas (195b: 49.4 people/ha; 170b:132 people/ha; 169a: 51.2 people/ha) or of industrial and parking lot land use areas (167b: 0 people/ha; 167a: 107.7 people/ha; 165a: 112 people/ha). Less than 1% of the total informal settlement population of the catchment resides in the Lotus River region. This fraction (804 people) resides in subcatchments 155a: Ottery (455 people) and 185b: Pelican Park (349 people). Again the influence of the presence of informal settlements on the overall population density of a subcatchment (i.e. informal settlement bearing subcatchments tend to have higher population densities) can be seen.

The socio-economic data for the Lotus River/Grassy Park area indicates that about eight years ago there were 6589 people who had completed their matric in this area and there were 2474 who completed a degree or a diploma. In the case of Zeekoevlei for the same period, the data indicates that there were 310 individuals who completed matric and 119 who completed a degree or a post matric diploma. The data indicates that education levels in the Greater Grassy Park area are poor as compared to the Zeekoevlei area (9,7% completed matric and 3,6% completed post matric studies in Greater Grassy Park compared to 23% and 9,1% for Zeekoevlei). Further, comparing the education status of the Grassy Park area to the same for the African area (4.2% - about 155300 people - completed matric and 1% completed post matric studies) of the catchment for the same period reveals a striking divide within the catchment area.

It is estimated that 60% of households in the Greater Grassy Park/Lotus River area have household incomes that fall within the low-income strata. The average annual household income in Parkwood and Fairways is R15000, R24000 for Lotus River, R29000 for Grassy Park, and R52000 for Zeekoevlei.

3.4.6.2 Land use heterogeneity

Within this region, the heterogeneity in the land use distribution increases northwards (Fig.2). Subcatchments in the south are predominantly formal (180a, 180b, 185a, 185b, 195a). Increased amounts of industrial land use and grass-bearing areas occur in the central to northern areas (170a, 155b, 170b, 169a, 169b). The heterogeneity is also increased by the presence of parking lots (167a, 167b). The northern industrial area is the most heterogeneous area and is comprised of a mixture of parking lot, industrial, shrub-and-grass bearing and open land areas.

3.4.6.3 Degree of urbanisation

A predominantly high to very high degree of urbanisation has occurred within this region. This region of the catchment has been the least affected by the urbanisation process. The degree of urbanisation varies across the region as follows: 31.3% of the subcatchments show a very high degree of urbanisation, 31.3% show a high degree of urbanisation, 18.8% show an intermediate degree of urbanisation, and 18.8% show a low degree of urbanisation. The results of the high degree of urbanisation which has taken place is observable in increases which have occurred predominantly in the northern subcatchments of this region (Fig.2, Fig.3). These increases are observable in the formal housing (167a, 155a, 155b, 165b), industrial land use (165a, 169a, 169b, 167a, 167b), and parking lot areas (167a, 167b, 170a, 170b, 185b).

3.4.7 Little Lotus River catchment

3.4.7.1 Land use heterogeneity

The Little Lotus River catchment is highly homogeneous in comparison to the Lotus River catchment. It is comprised predominantly of formal settlements (55%) interspersed with widespread open vegetated and industrial areas. The homogeneity declines northwards, towards the north-easternmost portion of the catchment which is comprised entirely of industrial land uses.

3.4.7.2 Degree of urbanisation

The degree of urbanisation experienced in the Little Lotus River catchment area from the period 1983 to 1996 can be characterised as high (-27.2). As with similar high urbanisation areas in the Lotus River catchment, the land use changes, which have taken place as a result of the urbanisation process, are an increase in the formal settlement areas (12%) and a decrease in the vegetated land (14%). In addition, the 1983 imagery showed a number of small open unvegetated areas, however all of these areas had disappeared by 1996.

Unlike the high urbanisation areas in the Lotus River catchment, these areas characterised by the absence of informal settlements. The Little Lotus River canal passes through Montague's Gift, Lotus River and Grassy Park and drains sections of these suburbs in addition to Fairways and Parkwood. The 1995 estimates indicate that these areas have a total population of 75000 people. This entire population resides in formal residential housing areas and is distributed throughout the catchment at population densities ranging from 64 to 100 people / hectare.

(Note: The north-westernmost portion of the Little Lotus River catchment was not mapped for 1996 as the imagery for this area was not readily available. The 1983 imagery revealed that this area was predominantly comprised of open vegetated (70%), industrial (20%) and unvegetated areas (10%).)

3.4.7.3 Hydrology

The Little Lotus River, whilst forming part of the entire Lotus River system, has received relatively less attention than the Great Lotus. It is characterised by significantly lower flows and is less polluted than the Great Lotus, as it flows through formal residential areas. The canal is a concrete trapezoidal channel of varying widths. It drains almost exclusively through the residential areas of Grassy Park, Montague Park, and Ottery with the headwaters being adjacent to the Royal Cape Golf club and draining into Zeekoevlei. The canal caters for stormwater runoff from these residential areas through stormwater pipes draining into the canal. Upgrading projects are currently under way in certain sections to cater for housing areas which were experiencing problems with flooding and standing water.

3.5 CURRENT DEVELOPMENT OF THE CATCHMENT

3.5.1 The Metropolitan Spatial Development Framework

The Metropolitan Spatial Development Framework (MSDF) originated in 1991 out of the need for co-ordinated planning and development in the Cape Metropolitan Region (Region constituted by the CMC and Winelands District Council Areas). The Western Cape Economic Development Forum, a forum consisting of key stakeholders in the metropolitan region including government departments, community representatives, the public and the private sector initiated the process to develop this plan. This process was subsequently taken over by the CMC when it came into being after the 1995 elections. It culminated in the production of this framework and its endorsement by the CMC in April 1996.

The main purpose of the framework is to guide the form and location of physical development in the CMR. This is done by providing direction for physical growth, private and public sector investments, spatial direction to RDP projects, and a framework for co-ordination between public, private and community sectors. It is a basis for the development of policies and programmes at local level that would intensify development, link people and residence to economic opportunities, integrate the divided city to curb urban sprawl and energy inefficient urban form. The framework gives spatial form to these ideals/goals through identifying four basic structuring elements, namely; Metropolitan Urban Nodes, Metropolitan Activity Corridors, Metropolitan Open Space System, and Urban Edges.

Three nodes that already exist and about seven activity corridors in the Metropolitan area have been identified. The Philippi East and Wetton-Lansdowne Corridors have been identified and proposed in the MSDF as a new major urban node and a major activity corridor respectively. The Lotus River Catchment Area constitutes a major portion of this node and Corridor. A number of projects, some of which are discussed in the following sub-sections, were identified to provide content to the Philippi East node of this framework. Some of these projects are currently being implemented.

If all or some of the ideas in this node and corridor could be implemented, they have the potential to redefine the face of the catchment area, change its physical and social form and influence the environmental elements of the river corridor and the False Bay coastal waters.

3.5.2 The Wetton-Lansdowne Development Corridor

The Wetton-Lansdowne Corridor Development Programme (WELD) was conceived as a process with the aim of developing a spatial and development framework (Master Plan) and strategies for the corridor, and designing an implementation plan to make this programme a reality. The plan identifies the nature and attempts to influence the direction of development, assist in prioritising local, metropolitan, provincial and national investments and serves as a guide for future private sector investment. (Corridor Section CCC, 1997).

The framework has identified three nodes for development in the corridor, namely the Eastern, the Central and the Western node. The nature of development in these nodes includes transportation, stormwater drainage, potable water infrastructure, and commercial/industrial facilities, housing and social/recreational infrastructure. Beside the Airport industrial section of the catchment area, the area identified as the Eastern

node corresponds almost exactly to the area of the catchment largely populated by African people. The central and western nodes include parts of the Philippi rural area and the Lansdowne section of the river corridor, and Ottery East respectively. Thus, the process established to implement integrated urban catchment management would have to take account of the master plan and projects.

Further, the Lansdowne Road-Philippi Local Structure Plan, a local specific component of this programme, has been proposed for implementation in combination with other development proposals. This structure plan is perceived as a mechanism that could provide a physical barrier to the urban encroachment pressures that are threatening the viability of the Philippi Horticultural Area (PHA). The PHA is a source of affordable food for the entire region and particularly for the local low-income communities. The PHA will be discussed in detail in one of the later sections.

3.5.3 The integrated Serviced Land Project (iSLP)

The iSLP is a Presidential Lead Project undertaken by the Western Cape Province Housing Department that is aimed at responding to the low-income housing needs for Africans. The iSLP project area was identified as the area of Ikapa, Crossroads and Greater Philippi. It was particularly designed to provide housing on a site and service or upgrading basis for the occupants of the informal settlements and back-yard shacks in these areas. However, due to pressure caused by the progressive environment within which the project operates, it has been extended on an ad-hoc basis to also benefit the Coloured population group. The relocation sites for the site and service part of the project occur in a much wider area than the project area.

About 10000 sites have been, or are in the process of being developed in Philippi East, Brown's Farm and Crossroads. More than sixty five percent of these sites have been completed and have been occupied. Interestingly, this occupation rate does not correspond to the clearing of the original informal settlement areas from which these occupants were drawn. In fact, recent surveys reflect that in some of these settlements, the densities have actually increased. This scale of development and population growth would inevitably increase the physical area of the catchment, its population and its stormwater catchment capacity. This implies more stakeholders to contend with, a greater geographical area to cover and increased runoffs into the canal. This could affect the environmental status of the river corridor and the False Bay coast.

A number of potentially negative impacts have been identified for this project. This includes potential effects on the Philippi Horticultural Area. According to the guidelines dictated by the MSDF the horticultural area should be excluded from urban development. It is, therefore, intended to limit access to the link whilst providing agricultural underpasses. The proposed route would cut through the Varkensvlei wetland and reduce the size of the Varkensvlei Forest Reserve, an uncultivated area containing several rare species of fauna and flora. Independent environmental consultants were appointed to assist in the planning and scoping stages of the project and to assess the impacts of alternative road alignments. One of the major recommendations has been to create wetland areas alongside the road reserve and in the interchange areas, in order to make up for the loss of wetland areas to road construction, especially through the Philippi section (Rosenthal, 1998).

3.5.4 Zoning of the Philippi Horticultural Area

Agriculture, and particularly horticultural production, is one of the industries in the Western Cape that shows the greatest potential for growth in the regional economy and amongst the various agricultural sectors. This is because of exceptionally high population and growth linked to the vegetable market that is dominated by local consumption (50% local demand and 80% CMR purchases) (CMC, 1995: 3). Secondly, expenditure on food, as a proportion of income is 29% and 37% in Coloured and African households respectively. Since the number of these population groups is growing rapidly, the demand for vegetables is likely to increase faster.

Local farmers estimate that at least 50% of their produce is sold directly to street traders, local supermarket chains, residents, and restaurants and the remainder is sold to the Epping Market (ibid. 7). The PHA supplies about 80% of the vegetables, such as carrots, cauliflower, lettuce and cabbage, that are sold at the Epping Market. Thus, although the area of horticultural production in the PHA has diminished over the last few years, there has not been a decline in volume of produce from the PHA sold at the market. This suggests a substantial increase in productivity on the remaining pieces of land.

However, despite this positive situation, the PHA has been, for several decades, and is still under pressure from urban encroachment. Urban population growth has been the major contributor to this pressure, particularly the rapid growth of the surrounding suburban and informal settlements and the land demands for low cost housing that is close to urban opportunities. Furthermore, large tracts of land in the PHA are presently either vacant or under-utilised. A co-ordinated urban development plan and strategy in the CMR is lacking. This factor contributes to uncertainty and physical decay.

Farmers begin to lose their political, economic, social status and ability to preserve their farmland as they become outnumbered by people with different economic and political interests, even if they are economically successful. This pressure increases if international agencies like the World Bank begin to suggest that the PHA should not be retained for agriculture and should rather be used for housing as it is better to transport food than people (CMC, 1995: 14). This has lead to under-utilised farmland, fragmentation of farms and private land banking, land speculation, increases in the value of land, and the proliferation of incompatible land uses.

Related to this, is the pressure contributed by the spillover effect. Urbanisation offers new opportunities for many farmers that are not doing very well in farming and farm workers who are facing seasonal unemployment or low-income potential. The approval of commercial and industrial undertakings in close proximity would attract these workers off the farms into the factories.

This situation has led to a proliferation of alternative development proposals for the PHA. There is a proposal to urbanise the PHA completely. The justification is that the area is well located and could easily accommodate approximately 140000 households or 560000 people. This could make a big dent in the current shortage of land suitable for low-cost housing and in turn a large proportion of the current housing demand could be met. This proposal could also provide an impetus to integrate Strandfontein Road into the network of activity routes, construct various public transport linkages like the extension of the R300 freeway and the rail link from Philippi East westwards through the PHA to Southfield Station.

Clearly, the proposal could affect the vegetable supply for the region and compromise the sand mining related glass production and the building sand industries. This would lead to a net loss of fertile land in a country that possesses only 13% arable land and the loss in vegetable production is likely not to be made up by other vegetable producing areas in the region. The overall consequence would be a steep rise in the cost of vegetables in Cape Town, which would disproportionately affect poor people. Alternative sources of building sand are located about 70 kilometres from the PHA and this could affect the cost of building material.

Further, due to the high water table in this region, there would be a need to fill large portions of this land before the actual building takes place. Besides adding to building costs, access to the Cape Flats Aquifer would be further inhibited, as much of this access has already been lost to urbanisation. The pollution and total loss of this resource would have serious implications for the long-term water supply for the region, which is currently facing a water shortage. This development would also increase the stormwater runoff and flows into the False Bay, which could dramatically increase pollution levels and reduce water quality of groundwater, the stormwater canals and seawater.

There are alternative proposals under consideration, the major one being the retention for this productive land for horticulture purposes. The success of this is premised on the approval of the Lansdowne Road-Philippi Local structure plan that could provide about 214 hectares of land for various forms of commercial and industrial undertakings. This area could form a hard physical barrier (urban edge) between urban development and the PHA.

The third proposal is a compromise between the two. This one calls for the development of the PHA as a mixed 'green' area, a scenario that refers to the co-existence of urban, recreational and agricultural rather than horticultural land uses only. The basis is the interdependence of urban areas and to their agricultural hinterlands. The interdependence is especially important for low-income communities, as the price of food is directly related to the degree of access people have to food wholesalers. If the middle-man is eliminated between consumers and producers, commodity prices are lower. Since food is the most common commodity

sold by informal traders in the low-income areas within the catchment and close areas, this sector provides the most efficient distribution network to transfer food to low-income communities at lower prices and in small quantities, although on a large scale. The existence of the PHA to provide access to cheap food has important implications for the well-being of the low-income group.

There are four roles that have been associated with this proposal. These are the control of urban sprawl by defining an urban edge, providing opportunities for space extensive activities like public green open spaces, parks and sports fields, provision of service required by urban development, and conservation of important natural systems such as river catchments, wetlands and aquifer recharge. These roles would facilitate and promote the following elements of the proposal:

- Urban edge around the PHA
- Small scale market gardens
- Other agriculture related activities like on-farm packaging and keeping of animals
- Access to land and farming opportunities by emergent farmers
- Retaining and supporting the productive elements of horticulture
- Conserving urban wetlands
- Creating Open Space Interconnecting Systems between the urban edge and the PHA

The first of these proposals, namely rezoning Philippi for low-cost housing, would pose major implications for the catchment area and the entire region. However, indications are that the PHA will continue to be zoned for horticulture in the foreseeable future, while in practice it will effectively become more of a mixed-use area, with various other activities taking place on the open space, but with no appreciable level of urbanisation.

3.6 FUTURE DEVELOPMENT OF THE CATCHMENT

This section discusses possible future developments which could have considerable effects with regard to the river corridor or to major areas of the catchment, if implemented.

3.6.1 Olympic Bid cycle track

In May 1997 the Cape Metropolitan Council: Directorate of Transport appointed consultants to design and implement a pedestrian path and cycle route on the Public Open Space along the Lotus River Canal between Gugulethu and Strandfontein/False Bay. This was to create a viable transport and recreational system through this area and simultaneously upgrade and develop Public Open Space.

The budget for the project was part of a budget that was earmarked for bicycle and pedestrian facilities as part of the total budget allocated for Olympic Transport Priority Projects. Through a process incorporating transport and planning issues together with the integration of existing initiatives in the area, local community involvement and the principles of Integrated Environmental Management, it was intended to produce an infrastructure that would provide benefits long after the Olympic Bid phase was over.

Budget constraints on the project meant that a continuous route could not be provided. It was decided therefore that several priority areas would be identified for implementation, the strategy being that it would give an indication of what could be achieved within the canal space. Areas that were selected were Gugulethu (Klipfontein Road to Duinefontein Road), Manenberg to Hanover Park (along Lansdowne Road), Ottery (Lansdowne Road to Ottery Road) and Lotus River (Ottery Road to Zeekoevlei).

For each area relevant planning policies and projects were identified as well as the existing landscape, transport conditions and electrical provisions. Environmental impact assessments were undertaken and recommendations made. A detailed GIS map of the river corridor in each section was drawn up

Unfortunately, due to the Olympic Bid being unsuccessful, no funding exists presently to implement this project. Although it may prove to be a viable project if initiated, it has been shelved pending alternative funding sources.

3.6.2 Airport Extension

The Airports Company of South Africa (ACSA) is undertaking an initiative to establish a development framework for land not required for aviation purposes at the Cape Town International Airport. In terms of the stormwater drainage system a number of proposals have been identified for the handling of these services for the short and long term.

The project entailed the establishment of the current drainage patterns of the site as well as a preliminary design of the drainage system both for the current developments and future complete airport development. Development is proposed for both the airport itself, as well as commercial, industrial and residential uses attached to airport activities.

The existing system is of an intermediate capacity. It consists of a network of stormwater pipes feeding into a stormwater detention pond. This pond has a limited outflow of 0.1 m^3/s and is designed to cater for 1 in 5 year storms. The present drainage capacity is thus fully committed and no additional drainage can be routed into it. To cater for storms of a 1 in 50 year frequency, therefore, a future drainage system has been proposed. This includes the creation of increased onsite detention, to avoid excessively large pipes/culverts, as well as the enlarging of existing detention facilities and culverts. The future drainage system is expected to produce a flow of 1 m^3/s and when combined with the Boquinar industrial pond outflow of 0.7 m^3/s will contribute 1.7 m^3/s to the Great Lotus River canal. This has major implications for the capacity of the canal downstream to cope with peak flows.

3.6.3 R300 Extension

This section is largely taken from the Project Brief and Identification as received by the Cape Flats Consortium.

Analysis of traffic patterns in the Cape Flats region shows that there is a high demand for east-west travel from Mitchell's Plain and Khayelitsha to employment opportunities between Wynberg and Retreat. Unfortunately, the present routes are circuitous and overutilised, with farm roads through Philippi used to reduce distances and travel times. It has been proposed that the Kuils River/Cape Flats Freeway (R300) presently terminating at the intersection with Vanguard Drive, would greatly reduce costs to metropolitan and regional traffic if extended to Prince George Drive. The proposed routes for the R300 traverse the Philippi Horticultural Area, which at present forms a barrier to metropolitan traffic due to the lack of high-order roads traversing the area.

The project is in the preliminary design stage with the objective being to finalise a road corridor for the extension between Vanguard Drive and the future Princess Vlei Parkway. It is in the context of the Metropolitan Spatial Development Framework (MSDF) with the design to satisfy planning requirements of the Integrated Metropolitan Transport Plan

A number of potentially negative impacts have been identified for this project. This includes potential effects on the Philippi Horticultural Area. According to the guidelines dictated by the MSDF the horticultural area should be excluded from urban development. It is therefore intended to limit access to the link whilst providing agricultural underpasses. Also, the proposed route would cut through Varkensvlei and the Varkensvlei Forest Reserve, uncultivated areas of the PHA which support several rare species of fauna and flora (see Chapter 5 for details). Independent environmental consultants were appointed to assist in the planning and scoping stages of the project and to assess the impacts of alternative road alignments. One of the major recommendations has been to create wetland areas in the road reserve, in order to make up for the loss of wetland areas to road construction, especially through the Philippi section.

CHAPTER 4 HYDROLOGICAL AND WATER QUALITY CATCHMENT STUDIES

4.1 DESIGN PHILOSOPHY

The aim of the catchment studies done in the Lotus River project is to integrate water quality issues with "water quantity" or narrowly hydrological issues. This entails a reconceptualisation of the stormwater design philosophy, upon which the engineering of the river system has been based.

Stormwater can be defined as the water that flows over or near the surface of a subcatchment during and after a rainfall event and contributing to flows in the rivers within a subcatchment (Tarboton and Schulze, 1992). Increasing urbanisation within a subcatchment results in greater stormwater runoff volumes in addition to higher peak discharges. This results in an increase in the flood risk with associated loss of life, destruction of property and the need for large sums of public money to be spent on alleviating hardship (Neilson, 1997).

In order to prevent the above Neilson, (1997) submits that the goals for stormwater management include:

- The protection of life and property from flood hazards
- The improvement of the quality of life of a community
- The preservation of the natural environment.

These goals can be transferred into *Objectives:* (Corin, 1991)

- To provide a stormwater drainage system for the convenience of the community and the protection of property from damage by the run-off from frequent storms
- To prevent loss of life and reduce damage to property by the runoff from severe storms
- To prevent land and watercourse erosion
- To protect water courses from pollution
- To preserve natural water courses and their ecosystems
- To restore degraded urban watercourses
- To achieve the foregoing objectives at optimal total cost.

Unfortunately, the above objectives are frequently not all met with equal consideration. In an urban context the protection of life and property are often considered more significant than the prevention of erosion and pollution and the protection of water courses and their ecosystems. This results in the design and construction of substantial concrete lined culverts and canals to cater for extreme events with defined recurrence intervals, to the detriment of water quality and aquatic ecosystems.

Traditionally stormwater design has been based on permissible return period and the selection of a corresponding design rainfall. The return periods were not chosen in relation to the actual detrimental effects, but based on a tradition from the days of limited computing capacity (Harremoës, 1994) (not flooding, but pipe full capacity; not pollution, but number of overflows per year). Return periods and relations to design rainfalls were set by rules chosen in professional committees and given regulatory certainty by authorities (Harremoës, 1994). Consultants and municipal engineers were relieved from responsibility if rules were applied according to the scripts.

It is axiomatic that to avoid flooding, one does not develop in the floodplain. The question this begs is *where* in the floodplain? Conventional engineering wisdom is to stay out of the 1:50 year *floodplain*, which in an insurance, assurance, or purely probabilistic understanding, implies safety from flood damage during the storm events with an average return period of *once in fifty years* over the long term. Establishing the so-called *1:50 year floodline*, itself a probabilistic, and not entirely reliable, undertaking, calls for examination of upstream catchment characteristics that interact with infiltration/run-off relationships operating during the 1:50 year return period event, routing its hydrograph through the catchment to estimate peak flow resulting in the receiving stream channel, and applying one or other of

the hydraulic models of open channel flow, to estimate associated flow width. Development within the wider floodplain context may furthermore impact locationally on the 1:50 year floodplain.

Protection outside the 1:50 year line comes from conventional drainage works that currently comprise a minor system of conduits capable of accepting the peak flows of minor events, 1:2 years to 1:5 years, with an associated major system designed according to road and site topography, capable of draining overflow from the minor system, for up to the 1:20 years to 1:50 years, event.

As development proceeds, development densities and runoff rates increase and pressure for further intrusion into the floodplain becomes stronger. This rapid urbanisation, coupled with infilling and inappropriate floodplain development, leads to increased runoff, as well as increased nutrient and heavy metal concentrations from different sources. These sources include "point sources" - a source that discharges through a pipe at a known location, such as from an industry or municipal wastewater treatment plant, as well as "non-point sources" (or diffuse sources), which refers to pollutant sources from flow distributed over the land surface (Huber, 1993).

(With regard to the above definitions for point and non-point sources, this can lead to ambiguities in urban situations for, say, stormwater inputs into a river. These can be considered as point source discharges having diffuse source origins. For the purposes of this report it is assumed that flow from a single location, ie. a factory or wastewater treatment works is termed a *point source*, contribution whilst stormwater collected over a catchment and discharged into a river via a pipe, is a *tributary source* to that river. Tributary sources are thus strictly outlets for diffuse source contributions)

The traditional solution was to accept these intrusions and, in addressing the increased runoff, to engineer an 'improved' channel cross section capable of carrying a greater flow in a smaller cross-section (Neilson, 1997). Various technical innovations in recent decades have assisted situations where insufficient river passageway is available. These include the construction of flood attenuation ponds to reduce the flood flow of the lower reaches of the river. A more recent innovation is the development of BMPs (see section 7.1) for stormwater management in urban catchments.

The conventional design of the Great and Little Lotus Rivers can be seen clearly in light of the above discussion. This system has been extensively designed as a stormwater removal facility. Increased urbanisation of the catchment had resulted in greater surface runoff and the associated flood risk. In order to protect property from flooding the canal was modelled and designed to cater for the 1:50 year flood (Taylor, 1994). This design included the construction of large concrete lined culverts and dissipation structures for the rapid removal of floodwaters. In order to prevent the structures from becoming excessively large and therefore expensive, detention ponds were constructed along the length of the canal to reduce outflows (Taylor, 1994).

In terms of flood control, this approach is partially successful but frequently inadequate in dealing with other needs that may arise. It can be thought of as a re-active approach looking at the river itself and concentrating mainly on the passage of flood waters without due consideration to the broader aspects of the river, particularly ecological, recreational and aesthetic needs (Neilson, 1997), as well as water quality. A more pro-active approach is required that focuses on the holistic needs of the river and its surrounds. This is tending towards viewing the river with a multi-objective floodplain management strategy with flood hazard reduction thus being seen as only one component (Neilson, 1997).

4.2 LITERATURE SURVEY OF OTHER ICM INITIATIVES

Somlyódy (1995) states that water and its deteriorating quality may be the most severe stress on the growing human population in the next century. Water related issues are becoming increasingly complex and there is a necessity for efficient integration across various disciplines, sectors etc. Water quality management can be seen to be at the interface of water resources management and environmental management, drawing from hydrology, biology, chemistry, ecology, engineering etc. He submits that we must be prepared to realise the desired integration in theory and practice.

In attempting to provide guidelines for Integrated Catchment Management, (Görgens et al. 1998) went further stating in Guideline 1.4 that "Catchment Management should address all components of the water resource and all elements of the hydrological cycle which may relate to each issue". Effective management must therefore address all facets of the catchment such as water quality and quantity, as well as the processes involved in the hydrological cycle.

The notion of ICM is gaining momentum within the South African context. This follows the international trend towards ICM based on an holistic approach to managing water resource use and human activity in river catchments. It is enshrined within the new Water Act of 1998, which deals with the development of catchment strategies for the "protection, use, development, conservation, management and control of water resources within its water management area".

On a national scale a number of catchment management initiatives have been proposed or are underway.

The Kruger National Park Rivers Research Programme (KNPRRP) is a program of multi-disciplinary research focusing on six regional perennial rivers (Crocodile, Sabie, Olifants, Letaba, Shingwedzi and Luvuvhu) flowing through the Kruger National Park. The fundamental basis of the KNPRRP is an innovative consultative management process in which interaction between stakeholders, managers and researchers is facilitated (Bestbier and Rogers, 1997). The diversity of socio-economic situations, as well as the physical and ecological characteristics of the rivers, interact to present a challenge to managers and researchers to develop an interactive, consensus-building management environment (Bestbier and Rogers, 1997).

A primary focus of the KNPRRP is to develop an interface between research and management through a Decision Support System (DSS). The DSS, operating under the umbrella of ICM, provides, operates and maintains a range of tools to service the interactive management and research processes.

The KNPRRP has also provided the impetus to the development of a unique inter-organisational, inter-disciplinary endeavour to create a public domain Integrated Catchment Information System (ICIS) specifically tailored to the needs of the South African situation (Jewitt et al. 1997). Following international trends in environmental information systems, the ICIS presents the user with a map-based Graphical User Interface (GUI), time series plots, multi-media, on-line hyper-text help facilities, seamless links to remote databases over the Internet and the ability to run simulation models from the GUI. This enables the remote interaction of a target market of stakeholders over water issues of common concern in a catchment (Jewitt et al. 1997).

ICIS has also been used in other rivers including the Umgeni River. Here DWAF and Umgeni Water have jointly initiated and funded a catchment management plan for the Umgeni River (DWAF and Umgeni Water, 1996d). The high level of development in the catchment has resulted in increased water quality problems and flood risks in the lower reaches. The objective of the management plan is to mitigate existing problems thus preventing further catchment deterioration, to enable the sustainable management of water resources thereby providing for basic needs whilst supporting healthy functioning of the natural environment. Based on the database of grab samples maintained by Umgeni Water (Pillay and Howard, 1998), water quality and quantity problems and sources are identified with strategies suggested to provide a framework for individual actions to be developed by the responsible parties. These are combined into an Action Plan for Implementation.

Whilst the above two projects are ICM initiatives, they are concerned primarily with large river systems with largely rural catchments incorporating agriculture, forestry and grasslands. In terms of urbanised catchments, a number of studies have focussed on water quality and the effects of high-density urban development.

In the Buffalo River, Eastern Cape, O'Keefe et al (1994) compiled a situation analysis of water quality using existing data. This was to define water quality guidelines for different users, to design a water quality monitoring system and to make management recommendations to reduce the impacts of pollution in the river. Of relevance to the Lotus River Project, a second set of aims was to assess the effects of

diffuse runoff from different types of townships in the catchment on the water quality and to derive a phosphate budget for the catchment to identify the major sources of input.

Phosphate sources increase due to point contributions from Waste Water Treatment Plants (WWTP) and diffuse contributions from urban catchments (O'Keefe et al, 1994). The nature of the catchment is such that the nutrients tend to reach the river intermittently in large amounts during high flows. As will be shown for the Lotus River catchment, phosphate appears to be the main limiting nutrient in the Buffalo River and as such is the variable that needs to be managed as the main priority in order to limit eutrophication.

The report concludes that water quality problems are ultimately a consequence of overpopulation and inappropriate development in a relatively small catchment with inadequate water resources(O'Keefe et al, 1994).

Similar conclusions were made by (Wright et al. 1993) in a study focusing on the hydrological processes occurring within the urbanised catchment of Khayelitsha [Khayelitsha being a township residential development with a combination of formal housing (permanent housing), serviced sites (shacks with waterborne sewerage and stormwater) and informal shacks (communal water supply and bucket latrines)]. This was an attempt to identify the role of each process in contributing to the contamination of the stormwater runoff, with special emphasis on microbial contaminants.

The study found that runoff was highly polluted in terms of microbiological and nutrient concentrations with sources composed of gross litter and faecal contaminants. Low heavy metal concentrations were found due to the lack of significant industrial and vehicular activities. As in the Lotus River, high population density, poor living conditions coupled with a general lack of environmental awareness ensure ongoing pollution (Wright et al, 1993). Unfortunately, priorities in such settlements do not place any value on the environment. Environmental education in itself will not produce any improvement in pollution unless it is in combination with an improvement in social conditions, including sewer and stormwater infrastructure, as well as regular refuse removal.

This view is reinforced by Schoeman (1998) in researching water pollution in informal settlements. She contends that "it is clear that a program focussing on the promotion of environmental awareness and a conservation ethos (in a first world sense) is bound to be unsuccessful in combating pollution in developing communities if it ignores the environmental problems that must be seen in the context of the developing communities".

She continues, suggesting that because informal settlements are effectively residential with little commercial or industrial activities of a formal nature, coupled with the lack of infrastructure and poor sanitation, it results in a shift in emphasis when considering potential contaminants. Toxins such as heavy metals, pesticides and herbicides become less important whereas organics, nutrients, bacterial and pathogenic microorganisms become significant. The major source of pollutants must undoubtedly be litter and faecal contamination from humans and domestic animals. Although regular refuse collection occurs, there is still extensive litter and informal illegal dumpsites throughout the catchment. Schoeman concludes that "unfortunately untidy, unclean and unhygienic conditions limit opportunities for increased living standards and have a desensitising effect. It then becomes more difficult to change attitudes toward the dumping and littering".

4.3 GREAT LOTUS RIVER MAIN-STEM CHANNEL DESCRIPTION

The discussion below provides a brief description of the various reaches of the Great Lotus River canal. Design schematics of the cross sections of each reach are included in Appendix F.

4.3.1 Airport Industria to Miller Road

The Great Lotus River canal starts to the west of the Cape Town International Airport and flows south west through the adjacent Airport Industria area (this area has seen significant redevelopment and is included as one of the identified development proposals in Chapter 3). Detention ponds limit the flow to the N2 to 0.8 cumecs. The river is unlined with large quantities of algae. The canal, after flowing under the N2, flows through the informal settlement area of Barcelona. The canal is earth lined with steep banks resulting in a channel up to 5 metres deep, a base width of approximately 1 m, and is approximately 1.6 km long. The lag time (defined for base flow conditions) is of the order of approximately 6 hours. This reach is choked with litter and suffers from a poor visual appearance. The canal servitude is used extensively as a pedestrian access and for livestock grazing. The canal leaves Barcelona and flows into Nyanga-Gugulethu. Here it cuts through a waste disposal site upstream of Klipfontein Road before flowing underground through a 900 ∅ pipe to Miller Road.

4.3.2 Miller Road to New Duinefontein Road

For the rest of the reach within Nyanga-Gugulethu the canal consists of a 2.88 km long concrete lined trapezoidal channel (depth average = 0.8 m, base width = 1.2 m to 2.04 m) with a small grass-lined high flow channel. Photo 1 gives an indication of the Great Lotus River as it flows through Nyanga and Gugulethu. Stormwater pipework enters the canal at frequent intervals with a number of large stormwater pipes (>1000∅) draining the area contributing year round flow. The max 50 year flood is calculated to be approximately 21.4 m^3/s (Taylor, 1994) whilst the base flow lag time is approximately 2.4 hours.

The river corridor is well utilised as a pedestrian thoroughfare, as well as recreation and the grazing of livestock.

Electrical lighting along selected sections of this reach was upgraded during a recent municipal project attempting to "green" the corridor.

Towards the downstream end of this reach, the canal flows past an informal settlement area (Phola Park/Waterfront).

Residents dwelling in shacks in a narrow corridor adjacent to the canal utilise the canal, its servitude and the adjacent open land as a means of sanitation and refuse removal. This can be clearly seen in Photo 2.

Together with sewer overflows into the stormwater network, it results in a poor water quality in the canal with unpleasant odours, evidence of raw sewage and general organic and inorganic litter.

4.3.3 New Duinefontein Road to Vygekraal Road

The canal between New Duinefontein Road and Vygekraal Road was upgraded as a multistage channel approximately 810 m long. It consists of a 3 m wide bottom width concrete lined trapezoidal low-flow channel 0.5 m deep with a wide grassed high flow section (Taylor, 1994). All of the available canal servitude was utilised to create a high flow channel wider than that required to handle the 1:50 peak flow of 27.8 m^3/s (Taylor, 1994). This is to provide additional flood detention storage. Water quality is poor and gross litter is severe. The baseflow lag is approximately 1.75 hours. A major stormwater pipe draining the light industrial area of Philippi East feeds into the canal in this reach.

A number of detention ponding areas are present in this reach. They collect runoff from the northward draining Weltevreden Agricultural Area. The eastern pond is a natural ponding area and has been retained through the canal upgrading. This pond incorporates the Edith Stevens Nature Reserve and drains into the canal through stormwater pipes under Lansdowne Road. This nature reserve is labelled as an *Isoetes* vlei and is characterised by fauna/flora. The western detention pond (Vygekraal Road Detention pond) serves as a flood attenuation facility in addition to collecting flows from the Weltevreden Agricultural Area to the south.

In order to create a natural ponding area the pond was excavated with curvilinear banks. Islands were constructed to provide habitat for aquatic birdlife (Taylor, 1994). Photo 3 shows the detention pond with the constructed islands.

The pond attenuates floods due to the limited capacity of the Vygekraal Road culvert. The efficiency of the system was increased by the construction of an entrance weir to the pond.

Flood flows backing up the channel due to the culvert constriction (13.5 m^3/s) are routed over the weir into the pond.

A series of one-way metal gates were built into the weir to prevent silt, polluted low flows and the first-flush flood flows from entering the pond. As the flood flow diminishes the gates permit draining of the pond when the level is below that of the weir crest. Inspection of this entrance weir reveals, however, that the gates have been removed and the entrance is frequently choked with litter and other rubble. Discussions with the Cleansing Department revealed that this is cleaned only on an annual basis prior to the winter rains. It remained choked with litter for the duration of the winter months (see Photo 4), posing a potential flood risk.

It was only through a letter of complaint from the research team that this, and other litter-accumulated sites, was cleared by the relevant cleansing department.

4.3.4 Vygekraal Road to Heins Road

Downstream of Vygekraal Road, the canal is an enlarged earthlined channel approximately 6 m wide and 2 m deep catering for the design 1:50 year flood of 13.5 m^3/s. The reach is 950 m long with a base flow lag of approximately 3.75 hours. The channel and the banks are characterised by aquatic and terrestrial vegetation, providing increased ecological habitat, with the river appearing to undergo a visual improvement in water quality. Upstream of Heins Road there is a small offline wetland adjacent to the canal. This is a *Typha* dominated wetland supporting wetland birds and is separated from the canal by an earth berm.

4.3.5 Heins Road to Lansdowne Road

The canal reverts to a concrete lined low trapezoidal channel, 1.02 km long with a 3 m base width and grass-lined banks. The design 1:50 year flood flow is 13.5 m^3/s and the base flow lag is approximately 1 hour.

This reach is the most recent of the Lotus River Canal phased upgradings and attempted to incorporate more environmentally friendly design features (Taylor and Duffy, 1996). Instead of the usual straight canal excavation, this reach was excavated with a curvilinear shape to approximate limited river meandering. The concrete lined low flow section was reduced with the remaining section lined with Armoflex® for a total depth of 0.5 m. The high flow section is also overlain with Armoflex® and grassed with a 1 vertical to 3 horizontal slope.

Whilst functioning as an erosion protection mechanism, the Armoflex® provides limited connectivity with the underlying subsoil and allows for vegetative growth through its blocks. This serves to increase habitat diversity with a corresponding increase in biota. The use of curvilinear design and Armoflex®, coupled with local community attempts at increasing amenity value, contribute to reducing the "drain-like" appearance of the canal.

4.3.6 Lansdowne Road to New Ottery Road

This reach is characterised by an enlarged earth lined channel approximately 2.5 km long. The cross section consists of a bottom width between 3 and 6 m with 1 vertical to 2 horizontal grassed sloping grass banks. The design 1:50 year flood is 13.5 m^3/s (Taylor, 1994) and the base flow lag is approximately 7 – 8 hours.

This reach flows through a predominately agricultural area, the Philippi Horticultural Area (see rezoning issues in 3.5). This area is characterised by smallholdings with intensive vegetable cropping. Farms adjacent to the canal abstract water for irrigation purposes. Photo 5 is of the Great Lotus River adjacent to the Springfield Road. It is possible to note the aquatic and bank side vegetation, as well as the irrigation pipes leading to the adjacent farm.

Drainage in the adjacent agricultural area results in a diffuse contribution to flow and pollutants in the canal.

This diffuse contribution will be shown to be significant in terms of phosphorus loading from the area. The role of the groundwater is significant for this reach and depending on the time of year, either contributes or reduces flow in the canal. During the winter rainfall months, the watertable is high with subsurface flow augmenting flow in the canal. During the drier summer months however, the watertable drops, with a resulting decrease in flow in the canal.

The Springfield Road culvert is characterised by a significant drop off on its downstream side and a concrete stilling basin was constructed to minimise channel and bank side erosion. Below New Strandfontein Road the canal remains an earthlined channel up to 8m wide and flows through a middle income residential area. The canal is characterised by aquatic and terrestrial vegetation. This vegetation increases habitat diversity whilst serving to trap litter where overgrown. There appears to be a visual improvement in water quality when compared to the upstream reaches and the riverine corridor appears utilised for pedestrian access.

Historically the Drainage and Sewerage Department of the old Cape Town City Council operated a diversion of the Great Lotus River in this reach. The diversion, at Strandfontein Road, diverted the summer low flows in the canal into a trunk sewer for treatment at the Strandfontein Wastewater Treatment Works adjacent to Zeekoevlei. This practice has subsequently ended due to costs of treatment and disagreement between the various substructures as to who should finance the treatment costs. Following pressure from local Zeekoevlei community forums to improve the Zeekoevlei water quality, it appears that the diversion option is again being considered as a management option.

4.3.7 New Ottery Road to Ottery Road

4.3.7.1 New Ottery Road to CTM Ottery Canal Confluence

This short reach of 150 m consists of an 11.6 m top width concrete lined trapezoidal low flow channel, 1.2 m deep with base width of 8 m. The design 1:50 year flood flow is 13.6 m^3/s and the base flow lag is approximately 15 minutes. The cross section also includes a wide grass-lined high flow channel sloping at 3% towards the lined channel. Flow tends to be shallow and sedimentation occurs. Although the canal is concrete lined this sedimentation permits the establishment of aquatic channel vegetation. The flow pattern becomes braided and the vegetation increases habitat diversity. Flow in the canal is augmented by the Woodlands canal at CTM Ottery Canal Confluence. This canal drains part of the Lansdowne-Wetton Road Corridor (see section 3.5).

Photo 1: Great Lotus River in Nyanga, Gugulethu

Photo 2: Great Lotus River canal adjacent to informal settlement of Phola Park

Photo 3: Lansdowne Road Detention Pond

Photo 4: Entrance Weir to detention pond

Photo 5: Great Lotus River – unlined canal adjacent to Springfield Road, PHA

Photo 6: Great Lotus River flowing past Sunset Park Detention Pond, Grassy Park

Photo 7: Litter trap upstream of Zeekoevlei

4.3.7.2 CTM Ottery Canal Confluence to Ottery Road

This reach, whilst remaining a concrete lined trapezoidal canal, is reduced in cross-section and flows for a length of approximately 430 m. Because of higher shear velocities, this reach is self-scouring. The cross-section consists of a 5 m wide top width channel 1.22 m deep with a base width of 2.21 m. This, together with a grass-lined high flow section within the canal servitude, is designed to cater for the design 1:50 year flood of 18.7 m^3/s (Taylor, 1994). The base flow lag is approximately 15 minutes.

The reach flows through a commercial area bounded by Pick 'n Pay and SAB. Historically, natural flood ponding occurred in these low-lying areas and a formal detention pond was thus incorporated into the design of the Pick 'n Pay parking area.

4.3.8 Ottery Road to Klip Road

This reach, characterised by a similar concrete lined trapezoidal cross-section as above, is approximately 1.32 km long with a base flow lag of approximately 1.2 hours. The design 1:50 year flood flow is 19.4 m^3/s (Taylor, 1994).

Historically, the reach was characterised by a natural low-lying flood area. This flood area was filled by private developers during a development proposal. To offset this loss in flooded area, it was recommended that an additional pond be excavated by the developers.

The resulting detention pond is situated at Sunset Park and, when operating efficiently, attenuates the peak flood in the canal from 19.4 m^3/s to 15.1m^3/s (Taylor, 1994). As the flood level rises it overtops the canal along a length of reduced height and into either side of the detention pond.

Photo 6 shows the overflow wall for this detention pond. Once the floodwaters have passed, the accumulated water in the detention ponds is released back into the canal through outlet stormwater pipes.

4.3.9 Klip Road to Seventh Avenue

As above, this reach consists of a concrete-lined trapezoidal section. The reach is 1.1 km, has a design 1:50 year flood flow of 23.9 m^3/s at Seventh Avenue (Taylor, 1994) and a base flow lag of approximately 30 minutes.

Minor flooding outside of the canal servitude is expected for 1:50 year floods and where the level is above property floor levels, flood levees were constructed. Downstream of Seventh Avenue a drop structure and energy dissipater was constructed. This is the beginning of an unlined section of canal to Zeekoevlei and was constructed to provide sufficient hydraulic gradient and minimise channel erosion.

4.3.10 Seventh Avenue to Fisherman's Walk

This reach, approximately 500 m long, drains into Zeekoevlei and is thus the outlet of the Great Lotus River. It is an enlarged earthlined channel, with a varying base width of 10.4 m to 14 m, excavated with a curvilinear profile. The design 1:50 year flood flow is 28.2 m^3/s. The water level of Zeekoevlei is such that it causes a backwater effect to flood this channel thereby masking the end of the Great Lotus and beginning of Zeekoevlei. For the purposes of flow measurement, to offset the variation in flow regimes for this reach, it was decided to utilise the 7th Avenue culvert as the downstream point of the Great Lotus River.

Upstream of Fisherman's Walk, a litter trap in the form of a fence across the river, serves to collect gross litter and prevent water hyacinth from moving upstream (see Photo 7).

During periods of drawdown, this fence is exposed and is cleaned by local authorities.

4.4 HISTORICAL DATA FOR THE LOTUS CATCHMENT

4.4.1 Historical flow monitoring

Although much engineering work has been done on the Lotus Rivers, actual flow characteristics and chemical loadings in the system have never been quantified. As support to an ICM process, it is therefore important to carry out a thorough flow gauging study and a water and sediment sampling program. (A list of the consultant reports on development and upgrading of the canal is available in Appendix E.)

Detailed design flood calculations were performed for the Great Lotus River by HKS using synthetic rainfall and storm duration data. Flood peaks were calculated for the 1:2 and 1:50 year rainfall events with these discharges used in the design of the canal upgrades. The above calculations were event simulations with no validation through actual flow measurements.

4.4.2 Historical water quality monitoring

Historically, water quality sampling has been undertaken since 1981 in both of the Great and Little Lotus Rivers, as well as in Zeekoevlei. Sampling in the Great and Little Lotus Rivers occurs at one site on each river at 5th Avenue (reach between Klip Road and Seventh Avenue in section 4.3.9 above). This sampling is done by the Scientific Services Branch of the Cape Metropolitan Council. Samples are taken monthly and analysed for both physical and chemical parameters. The results are stored on computer, the parameters of which are listed below:

Total Kjeldahl nitrogen	Water temperature
Total persulphate oxidisable nitrogen	Dissolved oxygen
Dissolved ammonia nitrogen	Oxygen saturation
Dissolved nitrate + nitrite	Secchi disk transparency
Total phosphorus	Electrical conductivity
Dissolved total phosphorus	Total suspended solids
Dissolved reactive phosphorus	Total alkalinity
Dissolved reactive silicon	Phaeophytin a
Chlorophyll a corr for phaeophytin	Faecal coliforms

Limitations of this sampling program are that it only occurs on a monthly time interval basis and does not include any stream discharge observations. The sampling program does, however, provide a database of the long-term water quality trends for the Lotus Rivers and Zeekoevlei and thus provide an indication of the variables of concern for the system. The variables of concern are those aspects of water quality in the river, either natural or anthropogenic, which actually or potentially exceed the regional water quality guidelines or users requirements and therefore need to be managed if water quality requirements are to be met (O'Keefe et al. 1994).

In order to place the water quality concentrations in context it is first necessary to detail the water quality guidelines to be followed. Zeekoevlei is used extensively for boating and other aquatic sports and as such the water quality levels for both aquatic ecosystems and recreational usage are assessed. These guidelines, as put forward by DWAF, are to ensure that the quality of water resources remains fit for recognised water uses and the viability of aquatic ecosystems is maintained (DWAF, 1996c).

The guidelines for aquatic systems are essentially a specification of the water quality required to protect fresh water aquatic ecosystems, as well as the qualitative and quantitative criteria for toxic, non-toxic constituents and trophic status for nutrients (DWAF, 1996c). For the purposes of this appraisal, the Target Water Quality Range (TWQR) is detailed. This is compared to the long-term average from 1981 to 1997, as well as the 95 percentile, the concentration value that should not be exceeded for more than 5% of the time.

Table 4.1 DWAF water quality guidelines for aquatic systems compared to Great Lotus River long term average

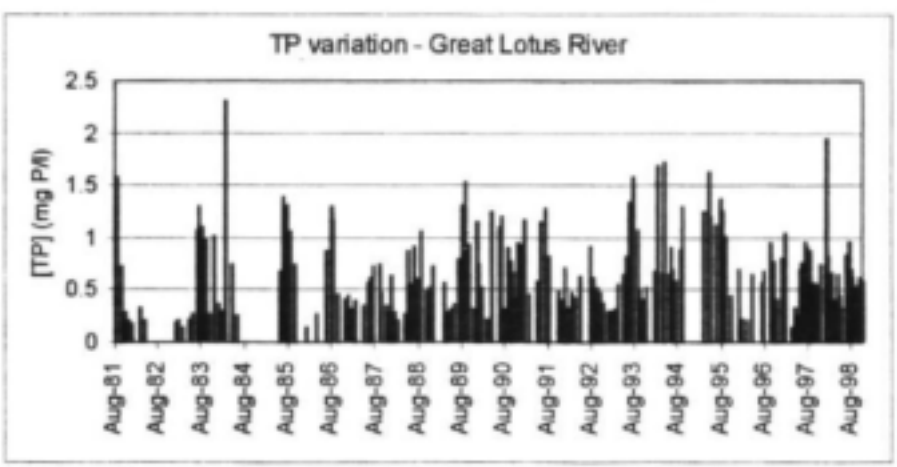
Parameter	DWAF TWQR (mg/l)	Great Lotus (5th Ave) (mg/l)
Ammonia	≤ 0.007	Min = 0.0039 95 percentile = 0.0112 Mean = 0.77 Max = 5.42
Total Nitrogen (Inorganic)	< 0.5 (oligotrophic)	Min = 1.25 95 percentile = 1.346 Mean = 6.49 Max = 21.7
	0.5 – 2.5 (mesotrophic)	
	2.5 – 10 (eutrophic)	
	> 10 (hypertrophic)	
Total Phosphorus (Inorganic)	< 0.005 (oligotrophic)	Min = 0.14 95 percentile = 0.2114 Mean = 0.703 Max = 2.31
	0.005 – 0.025 (mesotrophic)	
	0.025 – 0.25 (eutrophic)	
	> 0.25 (hypertrophic)	
Total Suspended Solids	< 100	Min = 1 95 percentile = 0.0112 Mean = 32 Max = 400

(Scientific Services, 1981-1997 and (DWAF, 1996c)

The above table highlights the variables of concern for the Great Lotus River canal. The canal can be seen to be nutrient-rich with phosphorus and nitrogen concentrations in the hypertrophic range. Given that the concrete lining of the Great Lotus results in pollutants all effectively being transported to the receiving water body, it is not surprising that Zeekoevlei, itself, is hypertrophic (Harding, 1996).

The figure below is an indication of the variation of TP concentration as measured by the Scientific Services Department at 5th Avenue. This point is approximately 1 km from the start of Zeekoevlei and thus provides a fairly representative picture of the pollutants transported to Zeekoevlei.

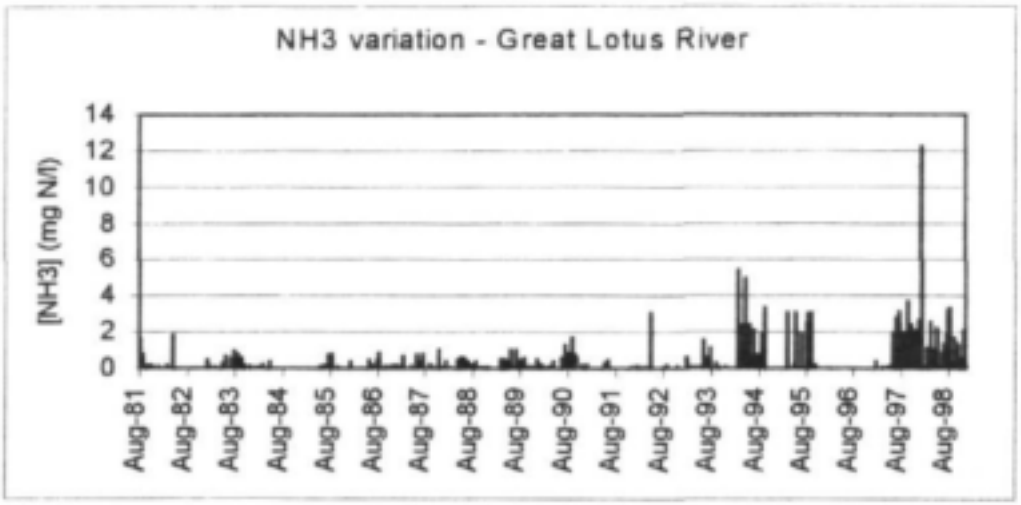
Figure 4.1: Total Phosphorus concentration in Great Lotus (5th Ave)



Analysis of the above plot of Scientific Services data for 1981 to 1998 shows that it is difficult to draw any significant conclusions about the variation of TP for the period. Although there appears to be a seasonal variation with higher concentrations during the higher rainfall season, the trend is not consistent for the entire period. Comparison with mean annual rainfall figures for the catchment for 1990 - 1998 (see following section 4.6.1) shows that no significant relationship seems to exist between the rainfall and resultant TP runoff concentrations either. (An assessment of TP sources and relative contributions is made in section 4.6.3.2.)

The above uncertainties are possibly due to the extent to which data is missing from the collected database. These omissions create uncertainty in estimating the seasonal trends, as well as, in all likelihood, underestimating the peak concentrations. The plot below, for the same period, is of the variation in ammonia for the Great Lotus River (TN analysis began January 1996, thus ammonia is selected to show long term annual trends).

Figure 4.2: Annual variation in Ammonia concentrations – Great Lotus River



Analysis of the above plot again shows the large omissions in data. It is impossible to draw any convincing conclusions as to any seasonal variation in concentration. What is apparent, however, is the significant increase that can be noticed from 1994 onwards. This is possibly due to the relatively recent growth in semi-formal and informal settlements, with corresponding increases in polluted runoff. (Section 4.6.3.1 discusses sources of nitrogen in the Great Lotus River catchment.)

Because the downstream receiving water body, Zeekoevlei, is extensively utilised for aquatic sports including boating and angling, it is necessary to evaluate the water quality guidelines in terms of recreational water usage. These guidelines differentiate between a range of impacts due to water quality changes including health impacts, human safety, aesthetic impacts and economic impacts. Scientific Services have maintained a record of indicator organisms including Faecal coliform bacteria (primary indicator of faecal pollution) and *Escherichia coli* (specific indicator of faecal pollution originating from humans and warm blooded animals).

Table 4.2 Bacteriological counts of the Great Lotus River as compared to DWAF guidelines

Organism	TWQR (counts/100ml)		Great Lotus
	Domestic Use[a]	Recreational Use[b]	
Faecal coliform	0	0 – 1000	Mean = 1.78 e 06 Min = 3 e 03 Max = 47 e 06

(Scientific Services, 1995 – 1998, a – (DWAF, 1996a), b – DWAF, 1996b)

Analysis of the above table shows that both indicator organisms are significantly higher than the accepted guideline. The levels correspond to those of raw sewerage and, as such, constitute a significant health risk for any interaction with the water. Although the values obtained in the Great Lotus for the two indicators are similar, the data is not identical but shows that *E coli* is the major component of the faecal coliform count. Given the urbanised nature of the catchment this is consistent with research that shows *E coli* comprise up to 97% of the coliform bacteria of human faeces (DWAF, 1996b).

The variables of concern for the Great Lotus River are therefore seen to be:

- Total Nitrogen (TN)
- Total Phosphorus (TP)
- Indicator organisms (Faecal coliforms, *E coli*)
- Ammonia

In concluding the discussion on the historical water quality database, it is noted that the Scientific Services sampling program does not include any flow measurements. There have thus been no attempts to relate any of the above pollutant concentrations to flow. It will be shown in the following sections that a comprehensive water quality programme requires that flow measurements be undertaken in conjunction with sample analyses. In addition to estimating the relative contributions of each source, relating concentration to flow thus enables actual chemical loadings to be calculated for the system from the supplied data.

Furthermore, in assessing the Scientific Services database, there are frequent gaps in the sampling data or even complete omissions. This is the case for parameters such as total alkalinity and dissolved total phosphorus, which were last measured in November and March 1995 respectively (Scientific Services Records 1981-1997). As discussed, the omissions create uncertainty in estimating seasonal trends, as well as potentially underestimating peak concentrations. In addition to the need for pollutant loadings, the above sampling omissions justify the development of a detailed project sampling programme for the Great Lotus River.

Table 4.3 summarises the significant data for the sampling period between July 1997 and September 1998.

Table 4.3 Physico-chemical water quality data from sampling programme on the Lotus River – 1997/1998

	1997					
	Springfield Road			7th Avenue		
	Min	Max	Mean	Min	Max	Mean
Total Nitrogen (mg N/l)	8.1	12.18	10.08	4.684	15.9	10.991
Total Phosphorus (mg P/l)	0.482	0.997	0.707	0.405	1.304	0.664
Soluble Reactive Phosphorus (mg P/l)	0.282	0.856	0.546	0.317	1.21	0.54
COD (mg O/l)	44.8	74.6	61	29.8	84.15	51.188
TSS (mg/l)	3.4	20.85	9.9	4.5	55.5	13.646
Conductivity (mS/m)	83.7	142.8	107.223	94.6	196	148.4
PH	-	-	-	7.35	7.98	7.815
Faecal coliforms (count/100ml)	1.1e4	9.3e6	1.52e6	1.3e3	3.9e7	5.01e6

	1998					
	Springfield Road			7th Avenue		
	Min	Max	Mean	Min	Max	Mean
Total Nitrogen (mg N/l)	5.725	11.749	9.289	3.272	17.332	9.323
Total Phosphorus (mg P/l)	0.583	1.257	0.894	0.421	0.741	0.588
Soluble Reactive Phosphorus (mg P/l)	0.372	0.976	0.704	0.094	0.594	0.365
COD (mg O/l)	56.5	79.9	67.5	39	107.9	58.642
TSS (mg/l)	4.7	22.85	11.78	6.2	36.85	17.33
Conductivity (mS/m)	76.8	125.3	94.7	52	170	125.564
PH	-	-	-	7.72	8.67	8.192
Faecal coliforms (count/100ml)	3000	5.2e5	9.98e4	4000	4.7e7	5.28e6

4.5 METHODOLOGY

Hydrological objectives of the Lotus River Project include:

1) To identify all sources of pollution in the catchment under consideration, both point and non-point sources.
2) To carry out detailed flow gaugings, including the mapping of surface drainage paths.

In order to address these objectives, a detailed sampling programme was undertaken in both the Great and Little Lotus Rivers. Flow measurements were carried out concurrently with the water quality sampling program to determine accurate pollution loadings for the system. This programme was carried out for 14 months (July 1997 - September 1998). Although this period is insufficient to establish historical trends for the river, it will identify tributary and non-point pollution sources and provide sufficient data regarding pollutant loads for individual stretches of the river.

4.5.1 Water quality and flow data

In order to identify pollutant sources, the sampling program entailed sampling at all tributary inflows. The sample points were selected based on a review of the engineering hydrological documentation and site visits. Significant tributary inputs to the Great Lotus River were found to include inflows ranging from stormwater input from urban subcatchments to agricultural runoff from the Philippi and Weltevreden Horticultural areas. The majority of tributaries to the Lotus River canal are stormwater inputs, dry for significant periods of the year and contributing minimal flows for the remainder. It would

be prohibitively expensive and impractical to sample all stormwater inputs. The above selected sample points thus refer to significant tributary inflows relative to the flow in the canal.

4.5.1.1 Discrete sampling

The discrete sampling entailed collecting water samples for chemical analysis, as well as recording flow characteristics at each sample point. Samples were taken on a weekly basis for the winter rainfall period of 1997 and then scaled back to a monthly basis for the summer base flow situation (September 1997). The winter period of 1998 was also sampled more frequently, on a fortnightly basis, until the end of the sampling period in September 1998. The analytical results obtained are summarised for the Great Lotus River and the Little Lotus River in Appendix G.

Samples for analysis were taken 20 metres upstream and downstream of the inflow, as well as in the tributary flow itself. Average stream velocities were obtained using a propeller-type velocity meter (OTT model C2 small current meter) with readings taken at 0.6 of the depth of the canal. At each point, three measurements of the velocity and flow depth were taken, and an average flow calculated at each point using the Area-velocity method with knowledge of the canal cross section.

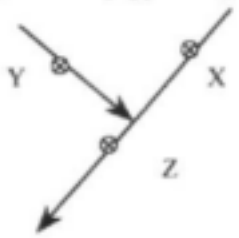
In order to ensure the downstream sampling site provides a reliable estimate of the water quality at that site, it is important that the point be located beyond the minimum distance required for complete mixing to take place. This distance, depending on flow conditions, can be calculated using the equation of Thomann and Mueller (1987) to approximate the minimum distance from the influent point to the point of complete mixing:

$$L_m = 8.6 * \frac{U \times B^2}{H}$$

where L_m = distance to complete mixing (m)
U,B = average stream velocity (m/s) stream width (m)
H = average stream depth (m)

Where tributary flow measurement was impossible due to practical physical constraints, the flow calculation was through consideration of the continuity equation. The mass balance equation is then used to check the accuracy of the data collection.

Figure 4.3: Schematic of tributary inflow [Y] joining main flow [XZ]



The continuity and mass balance equations are as follows with Q_x and Q_z measured at X and Z respectively:

$Q_x + Q_y = Q_z$ and $C_x . Q_x + C_y . Q_y = C_z . Q_z$

where Q = discharge at point (m^3/s)
C = pollutant concentration (mg/l)

The table below shows the location of the discrete sampling points, as well as the distance of the point from the source. The Great Lotus contributes the majority of flow and pollutant loading to Zeekoevlei and is thus treated in more detail.

Table 4.4 Sample points of the Great and Little Lotus rivers

Sampling number	Distance from source	Location – Great Lotus River
SP 1	0.49	Below N2 culvert
SP 2	2.43	Above NY3A culvert
SP 3	-	In NY 3A stormwater inflow
SP 4	2.46	Below NY 3A culvert
SP 4a	4.34	Downstream of Nyanga-Gugulethu
SP 5	4.83	Upstream of Philippi East/Crossroads inflow
SP 6	-	In Philippi East/Crossroads inflow
SP 7	4.88	Below Philippi East/Crossroads inflow
SP 8	5.27	Upstream of Vygekraal Road detention pond
SP 9	-	In Vygekraal Road detention pond
SP 10	5.31	Downstream of Vygekraal Road detention pond
SP10a	7.35	Upstream of Lansdowne Road culvert
SP 11	8.51	Springfield Road culvert – **datalogger**
SP 12	10.00	Above CCC confluence
SP 13	-	In CCC confluence
SP 14	10.04	Downstream of CCC confluence
SP 15	11.77	Above PHA outflow (2) (Klip Road)
SP 16	-	In PHA outflow (2)
SP 17	11.81	Below PHA outflow (2)
SP 18	12.89	Upstream of 7th Avenue culvert

Sampling number	Location – Little Lotus River
SP 19	Upstream of Seventh Avenue culvert – Little Lotus
SP 20	Upstream of Klip Road culvert – Little Lotus
SP 21	Adjacent to Robin Road – Little Lotus

Sample points 4(a) and 10(a) above, were selected after an initial set of samples were taken. SP 4(a), situated below Gugulethu, enables the total contribution of the formal and informal residential areas of Nyanga and Gugulethu to the pollution loadings to be calculated. Sanitation and domestic waste collection services are inadequate or non-existent in this area, with severe implications for the water quality in the river channel. SP 10(a) was selected as it is at the start of a 2.5 km stretch of unlined canal, and the data from this point may therefore be used to gauge the assimilatory capacity of this unlined section in reducing pollutant concentrations.

The discrete samples were collected in 500 ml HDPE sample bottles and transported to the Scientific Services Branch of the Cape Metropolitan Council for laboratory analysis. The samples were analysed for the following parameters:

- Total Oxidisable Nitrogen (TN)
- Total Phosphorus (TP)
- Dissolved Reactive Phosphorus (SRP)
- Chemical Oxygen Demand (COD)
- Total Suspended Solids (TSS)
- Total Volatile Solids (TVS)
- Conductivity (EC)

4.5.1.2 Philippi Horticultural Area subcatchment study

An assessment of the data for variation in TP flux revealed that a significant contribution to the flux appeared to be diffuse sources in the Philippi Horticultural Area (see section 4.6.3.2). As previously discussed, this area is intensively cultivated with vegetables and flowers in addition to livestock farming practised to a lesser extent.

Initial investigations revealed that a major source of TP flux was thought to be due to fertiliser rich runoff percolating into the channels draining the subcatchment. It was thus deemed necessary to attempt to assess the potential sources of the TP flux in this area.

The Institute for Soil, Climate and Water (INFRUITEC) of the Agricultural Research Council (ARC) has undertaken extensive soil sampling within the area. Samples were assessed to indicate the degree of calcareousness / non-calcareousness, as well as soil texture. In addition to broadening the understanding of the catchment, it will provide insight into the degree of soil leaching and therefore inferences as to ambient levels of phosphorus in the area. A map detailing the extent of calcareousness is included in Chapter 3. This also indicates the locations of collected soil samples. Additional subsoil samples, collected and stored by INFRUITEC, were analysed for micro-element analysis to assess, inter alia, concentrations of TP, K, pH etc. This was to determine the relative concentrations of phosphorus in the soil solution.

In addition, a survey was conducted of five co-operating farmers in Philippi. This was to assess the types of cultivation and the types (and amounts) of fertiliser applied per growing season. Because of the mechanisms of phosphorus transport into the groundwater and lateral subsurface flow into drainage channels, a sampling programme was thus devised focussing on the drainage channels and irrigation ponds of the area. This was to determine the effects of cultivation and to test the hypothesis that the drainage channels adjacent to cultivated lands would contain relatively higher concentrations of TP. This was not an attempt to assess the efficiency of fertiliser application (method of application) nor was the aim to draw conclusions on whether the amounts of fertiliser applied were excessive. This was, unfortunately, not within the project resources but should nonetheless be a focus of further research within the catchment.

A representative subcatchment draining into the Great Lotus canal was selected for sampling during October 1998. This is subcatchment 140, which drains into the Vygekraal Detention pond and thence into the Great Lotus River at the Lansdowne Road culvert. This detention pond contributes flow with a high TP concentration to the Great Lotus during the winter rainfall months (months characterised by increased surface runoff and higher water tables). Although the subcatchment is largely cultivated, it contains an area that is relatively undisturbed. This area, containing natural vegetation, should provide an indication of more ambient phosphorus levels. Sampling took place after a period of rainfall with water in the drainage channel appearing to be the top of the water table.

4.5.1.3 Continuous measurement

In addition to the grab samples at the selected sites, flow was monitored continuously in the Lotus River at one point. A continuous data logger was installed in July 1997 on the Great Lotus River at the Springfield Road culvert. The site is isolated from populated areas and was selected to diminish the

threat of vandalism. The culvert is box shaped and characterised by a large drop-off into a downstream concrete lined stilling basin. This drop-off ensures that no downstream backwater effects will influence the data measurement.

The datalogger consists of an automatic sampler (ISCO® 6700) with an interface module for various sensing probes. It contains an Area Velocity Flow module with a probe that continuously measures flow velocity and flow level. The module measures average velocity using ultrasonic sound waves and the Doppler effect ((ISCO, 1996). Flow level in the culvert is measured by an internal differential pressure transducer. The difference in pressures exerted by the flow and the atmosphere is recorded as the hydrostatic pressure. Because pressure is proportional to stream level, the module thus calculates stage from the hydrostatic pressure (ISCO, 1996).

The logger is housed in a secure stainless steel box securely mounted above the culvert. The probes are mounted on a bracket bolted to the concrete base of the canal. Level and flow measurements are taken on a ten-minute interval resulting in a continuous database of the flow. The data is stored by the logger and downloaded to a portable notebook computer using Flowlink® software (ISCO, 1995). Analysis of the data is undertaken using Flowlink.

Since installation of the instrument, large fluctuations in the recorded flow velocity have been observed. This rendered the Area Velocity method of flow calculation inaccurate. A theoretical stage discharge relationship was thus established for the culvert using Manning's equation (with knowledge of the dimensions and physical characteristics of the culvert) whilst considering stream drawdown effects due to the downstream drop-off. The stage-discharge relationship is as follows, the accuracy of which was verified using the Ott velocity meter and Area-velocity calculation of discharge:

$$Q = 11.418 * h^{1.6306}$$ where Q = flow (cumecs), h = stage (m)

Flows are thus calculated using level measurements with the probe situated in the middle of the culvert to minimise entrance effects.

The datalogger has collected a detailed flow record at ten-minute intervals. By relating rainfall to the continuous flow measurements, rainfall-runoff relationships can be investigated together with an analysis of the catchment dynamic response. Examples of the data recorded in the data logger, in monthly reports, are shown in Appendix H.

4.5.1.4 Storm event sampling

In order to obtain an understanding of storm related river water quality processes, the automated sampler was programmed to capture storm events greater than a certain threshold flow. Internationally, research has found that highest pollutant loads are generally transported during flood events with maximum mobilisation around the flood peak (Huber, 1993; Chiew and McMahon, 1998). The automated sampler was thus programmed on a flow volume proportional basis rather than a fixed time interval to ensure maximum samples are taken at the peak. In effect, the greater volume rate transported during the flood peak, results in maximum sample frequency around the peak. As the flow drops off, so does the rate of sample frequency.

In order to program the sampler effectively, it was thus first required to gain some understanding of the flow regime of the Great Lotus River. As discussed in Chapter 3, no previous flow measurements had ever been made. Through a comparison of the return period of rain events with the corresponding runoff volume monitored by the datalogger, it is possible to determine the storm event most desired to capture, the threshold flow from which to begin sampling, as well as the volume interval at which the sampler would take samples.

The monitored discharge from a storm event with a return period of 1 in 6 months was selected initially as a desirable event to capture. The accumulated runoff volume obtained from the datalogger for this event

was divided by 24 (the number of bottles in the sampler) to obtain a sample frequency with the threshold flow was set just above the winter base flow condition.

Samples were collected within 2 days of the storm event and analysed by the Scientific Services Department for non-reactive contaminants: TN, TP, TSS, TVS, pH and EC. This was to offset the possible error through reactive contaminants undergoing transformations whilst stored in the automated sampler and resulting in an inaccurate representation of the actual storm event.

A total of six storm events were captured with only three being of sufficient duration to enable adequate samples to be taken. The results and plots of pollutant variations during an event are shown in the results section.

4.5.2 Heavy metal and sediment analysis

The Lotus River catchment includes a variety of land use types including Industrial, Light Industrial and Agricultural areas. Significant transport corridors are located within the catchment including a national freeway, as well as major arterial roads. A number of farms along the length of the river abstract water for irrigation purposes.

Included within the baseline assessment it was thus deemed necessary to assess potential heavy metal concentrations in the Lotus River. These were undertaken quarterly on sediment and water samples and analysed for:

- Cadmium (Cd)
- Chromium (Cr)
- Cobalt (Co)
- Copper (Cu)
- Iron (Fe)
- Zinc (Zn)
- Lead (Pb)
- Manganese (Mn)
- Nickel (Ni)

Samples were collected at five points in the Great Lotus (three sites unlined, two sites concrete lined) on two separate occasions, once towards the end of winter (September 1997) and once in summer (February 1998). The table below shows the location of the sample points that are adjacent to significant transport corridors, below the informal settlement area and in the Philippi Horticultural Area.

Table 4.5 Sample points for heavy metal analysis

Sampling number	Distance from source (km)	Location Great Lotus River
1	0.49	Below N2 culvert
2	4.34	Below Gugulethu
3	7.35	Below Lansdowne Road culvert
4	8.51	Above Springfield Road culvert
5	12.89	7th Avenue stilling basin
6	-	Fisherman's Walk (Little Lotus River)

Samples 1, 3 and 4 are located in unlined sections of the canal and sediment cores up to 0.75 m deep were taken. Sample points 2, 5 and 6 are in concrete lined sections that are characterised by significant sediment build up. In an attempt to assess the heavy metal concentrations at these points, the sediment was scooped up into jars. For the water column, samples of 2 litres were collected at each site.

The samples were analysed by the Scientific Services branch of the Cape Metro. The analysed concentrations were compared to the DWAF water quality guidelines for aquatic ecosystems to assess the level of heavy metal pollution within the catchment.

4.5.3 Organic compounds

Due to the intensive agricultural activities within the Great Lotus catchment, it was deemed necessary to conduct an identification of possible Red List substances and pesticides in the system. Samples were collected on a particular day (18/08/97) and organically screened by the Building Technology Division of the CSIR (Pretoria). Discussions with CSIR revealed that a significant proportion of the Red List

substances are unavailable in South Africa and are thus unlikely to be found within the Great Lotus catchment. The organic analysis was thus undertaken for chlorinated and non-chlorinated hydrocarbons and phenolic compounds.

4.5.4 Protozoan parasites

Additional samples were collected and analysed for protozoan parasites principally, *Giardia* and *Cryptosporidium parvum*. These species are recognised as important pathogens causing diarrheal disease in humans and animals. They generally occur in low numbers in water environments; however a minimal infectious dose may be as low as a single cyst (*Giardia*) or oocyst (*Cryptosporidium*) (Grabow, 1996).

Collection sites corresponded to two stormwater pipes in Gugulethu known to contribute high faecal coliform counts to the Great Lotus River (Scientific Services Data, 1998), as well as Springfield Road in Philippi Horticultural Area and 7th Avenue, considered the downstream point of the Great Lotus River.

Ten litre samples were collected at each point in the Great Lotus River on the 27/08/97 and analysed by the Water, Environmental and Forestry Technology Division of the CSIR.

4.6 RESULTS AND DISCUSSION

4.6.1 Precipitation in Great Lotus River catchment

A number of organisations are involved in the collection of meteorological data for the catchment. The Cape Town Weather Office, situated at the Cape Town International Airport, thus monitors rainfall for the headwaters of the catchment. In addition to this, there are a number of automatic rainfall gauges in the catchment monitored initially by the Cape Town Municipality (CTM) and now under the jurisdiction of the Catchment Management Department of the Cape Metropolitan Council (CMC).

The CMC gauges are generally of the tipping bucket type and thus facilitate the determination of short interval 5 or 10 minute rainfall periods. This is significant given the dynamic nature of a hardened quick response urbanised catchment. In order to accurately determine rainfall runoff relationships for these catchments it is imperative that short interval rainfall periods are available.

Data from three of these gauges has been collected for the period of discussion. The extent of the catchment which they cover was determined through the use of Theissen polygons and is listed below:

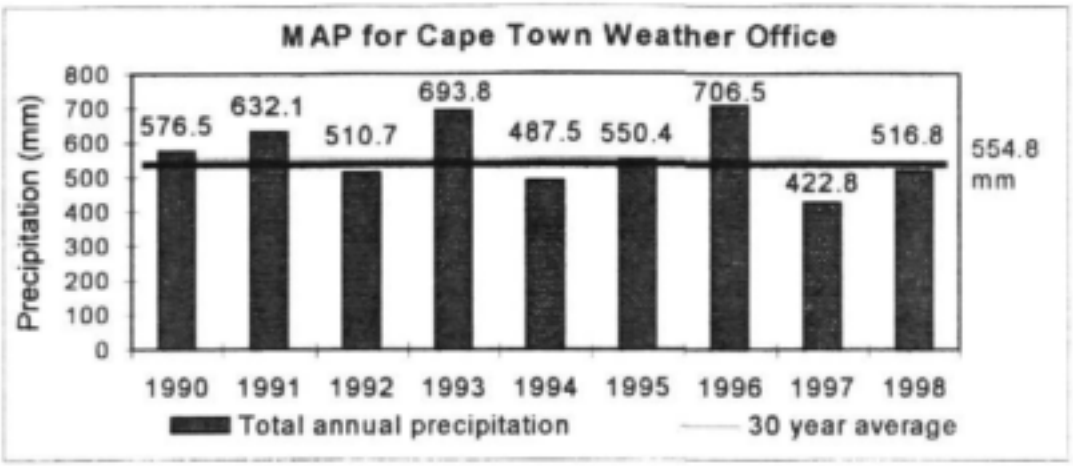
Table 4.6 Precipitation gauges in the Lotus River catchment

Rain gauge	Catchment Area	% of Total Area
Cape Town Weather Office	28.068	49%
Groenvlei	27.026	48%
Strandfontein	1.666	3%
Mitchells Plain	-	-

(Morrison, 1998)

Analysis of the records showed that a total of three weeks data was missing for the Groenvlei gauge for 1997. The rainfall was estimated for this period based on interpolation of the three other gauges. The figure below depicts the Mean Annual Precipitation (MAP) as measured at the Cape Town Weather Office at Cape Town International Airport.

Figure 4.4: MAP for Cape Town Weather Office

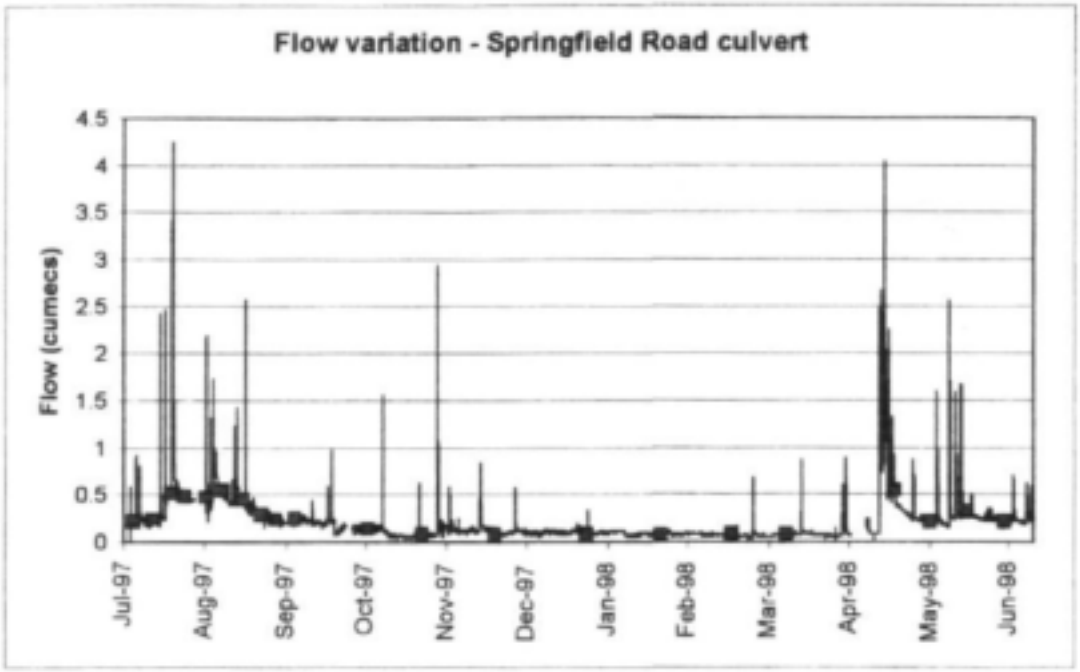


The figure depicts the MAP for the period 1990 to 1998. In addition, the 30-year average of 554.8 mm for the Weather Office is plotted to place the rainfall in context. Analysis of the precipitation records, show that 1997 was characterised by approximately 30% less rainfall than the long-term 30-year average. This has implications for the pollutant washoff characteristics of the catchment during the study period. It was thus imperative that the water quality and flow gauging sampling programme be maintained for another season in order to be able to make reliable recommendations based on the collected data. Records for 1998 revealed that the MAP was just under 10% less than the 30 year average and thus is a far more characteristic representation of the annual rainfall as experienced in the catchment.

4.6.2 Flow data

The graph below depicts the variation in flow, plotted on a 10-minute interval, as recorded by the Springfield Road datalogger. The period depicted is for a year of runoff beginning in July 1997, the start of the sampling program. The highlighted blocks indicate the days on which discrete grab samples were taken at the site.

Figure 4.5: Flow variation – Springfield Road, Great Lotus River canal



The winter period ending September 1997 was sampled intensively on a weekly basis. This was then scaled back during the summer base flow conditions to a monthly interval. Although the peak flood flows fell between the discrete sampling days, the sampling program nonetheless managed to obtain a fairly representative picture of the higher winter baseflow situation. Of interest to note are the storm events during October and November of 1997. These events are highly unseasonal and were characterised by high peak flows but low total runoff volume. This will be discussed in more detail in the following section assessing the annual catchment runoff.

As stated previously, a principal aim of the sampling program was to identify the major point and non-point contributions to the Great Lotus River. These terms can be defined as follows:

- "point source" - a regulatory term meaning a source that discharges through a conduit at a known location such as from an industry or municipal wastewater treatment plant.
- "non-point source" (or diffuse source) refers to a source from flow distributed over or through the land surface (Huber, 1993).

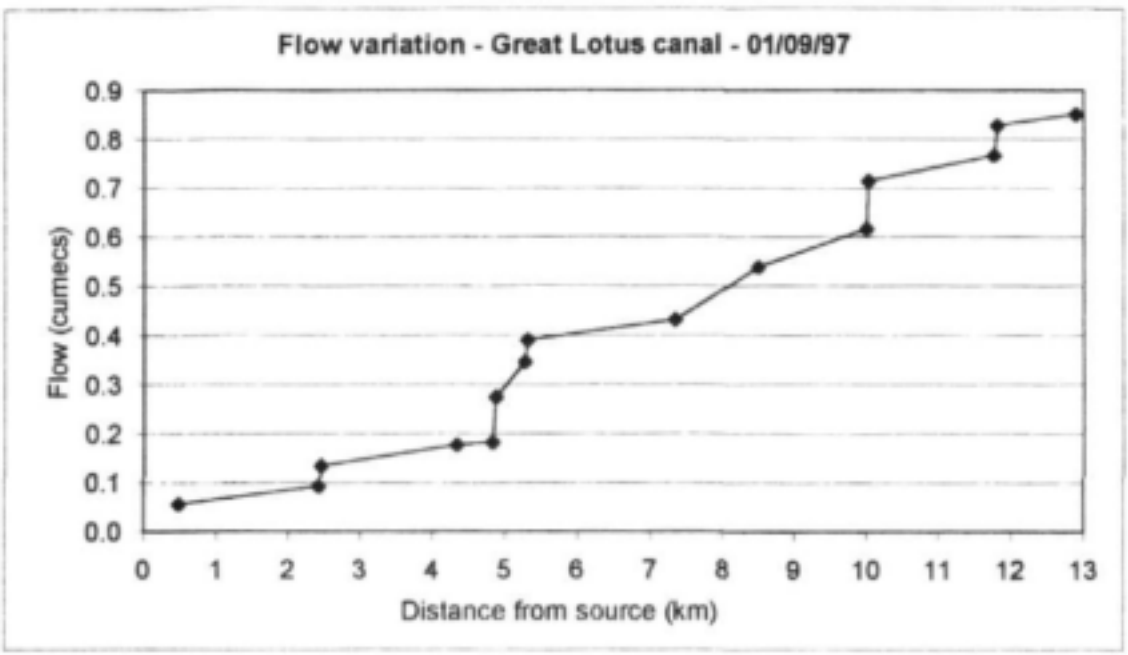
This is echoed by (Chiew et al, 1997) who submit that "point sources are those where the polluted water is discharged at a single location – such as a factory or WWTP. Diffuse sources, on the other hand, are those where polluted water is generated from a large area and flow into the drainage system at more than one point."

As previously mentioned, for the purposes of this report, it is assumed that flow from a single location, ie. a factory or wastewater treatment works is termed a *point source* contribution whilst stormwater collected over a catchment and discharged into a river via a pipe, is a *tributary source* to that river. Tributary sources are therefore strictly outlets for diffuse source contributions with the following land use types being regarded as having non-point source contributions: urban, agricultural, mining and undeveloped (Huber, 1993).

The Great Lotus River catchment is characterised by few industries and no wastewater treatment plants discharging into the canal. The majority of pollution contributions are therefore from non-point or diffuse sources, ie. urban residential and agricultural areas that enter the canal as tributaries. These non-point sources originate principally from rain events and follow the temporal and spatial characteristics of rainfall to a large degree (Huber, 1993).

In order to assess the relative contributions to the Great Lotus canal, data from the discrete sampling programme is selected and plotted longitudinally. Analysis of the above annual runoff plot indicates that the discrete sampling taken on the 01/09/97 is after a period of sustained rainfall and should thus provide a good indication of the locations of the various tributary sources. As discussed, the sample locations were selected at significant stormwater inlets and agricultural channels.

Figure 4.6: Flow variation – 01/09/97 – Great Lotus River



The above flows correspond to a relatively high flow situation. Step changes in flow are due to tributary contributions whilst gradual increases are due to diffuse sources. Significant sources are thus at:

Table 4.7 Flow contributions to the Great Lotus River

Distance from source	Contribution	% flow contribution
0.5 – 2.4 km	Diffuse source contributions from Barcelona and upper part of Nyanga-Gugulethu	4.77
~ 2.4 km	Tributary source at NY3 stormwater pipeline draining significant portion of Nyanga and Gugulethu	5.9
2.4 – 4.3 km	Diffuse source contributions from Nyanga-Gugulethu and Phola Park	5.3
	Total contribution of Nyanga, Gugulethu, Barcelona	*16*
~ 4.8 km	Tributary source draining Crossroads, Philippi East, Philippi West and Brown's Farm	11.8
4.8 – 5.3 km	Diffuse source along Lansdowne Road	8
~ 5.3 km	Vygekraal Detention pond draining PHA subcatchment 140	5.1
~5.3 to 7.3 km	Unlined section along Lansdowne Road permitting groundwater influence	5.15
~7.3 to 10 km	Unlined section through PHA and Turfhall Estate permitting groundwater and subsurface irrigated flow	23.8
~10 km	Tributary source from Lansdowne-Wetton Road Corridor	12.2
~10 to 11.8 km	Diffuse source from residential area of Grassy Park	6.66
~11.8 km	Tributary source from subcatchment of PHA	7.7
~11.8 to 12.9 km	Diffuse source from Lotus River residential area	2.9

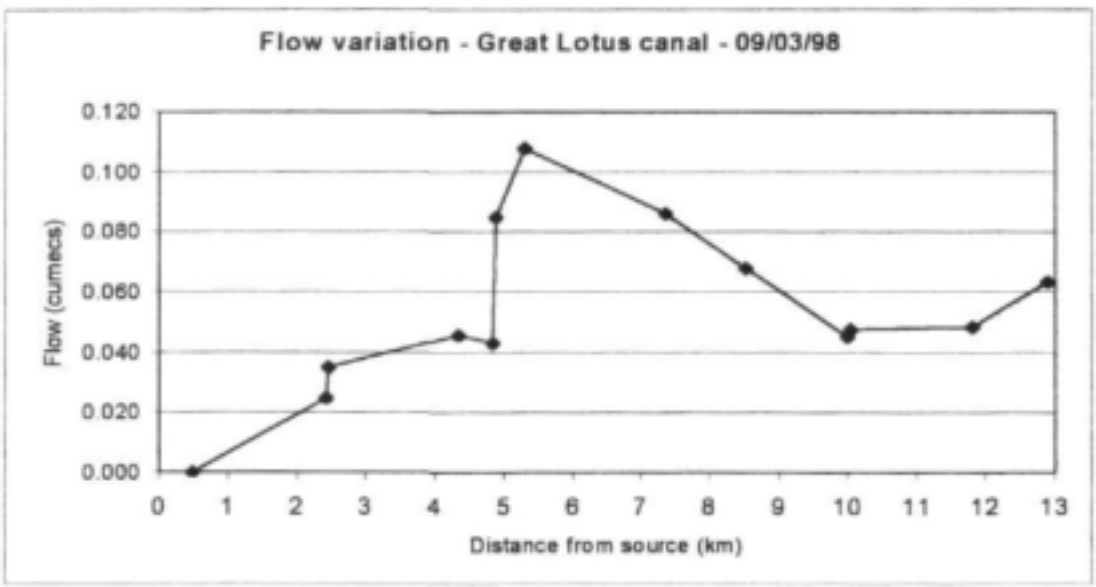
The Cape Flats is characterised by sandy soils and flat topography. The water table exhibits a high seasonality with water level varying between 2 and 5 m below ground level. Depression areas are often inundated with open standing water during the winter months. For the unlined sections of the canal flowing through the Philippi Horticultural Area, this results in the groundwater augmenting flow in the canal during the high water table winter months. This can be seen in the above plot of the longitudinal flow variation with diffuse contributions especially between ~ 7.5 km and 10 km.

Surface runoff to the Great Lotus appears to be mostly from the urbanised catchments. Although the residential settlements of Nyanga and Gugulethu exhibit low hydraulic effectiveness (gutters connected to the stormwater system) these areas are characterised by hardened impermeable surfaces and baked calcrete open ground. This results in a high surface runoff component from these areas. The agricultural area of Philippi, on the other hand, is characterised by a drainage network frequently clogged with vegetation and suffering modification through infilling and excavation. Surface runoff is evident only during significant rainfall events coupled with a high water table. The contribution to the Great Lotus is thus frequently in terms of groundwater seepage during high winter water table levels.

The above table shows, for a high flow situation, that the upper township developments of Barcelona, Nyanga, Gugulethu, Crossroads and Brown's Farm together account for just under 30% of the total flow into Zeekoevlei for this particular day. The Philippi Horticultural Area, on the other hand, through diffuse contributions as well as tributary sources, accounts for just over 40% of the flow. The remainder of flow is thus from the more formalised residential areas of Ottery, Lotus River, as well as Lansdowne and Wetton.

It is of interest to contrast these conditions with a typical baseflow situation. The graph below represents flow measurements taken on the 09/03/98.

Figure 4.7: Flow variation – 09/03/98 – Great Lotus River



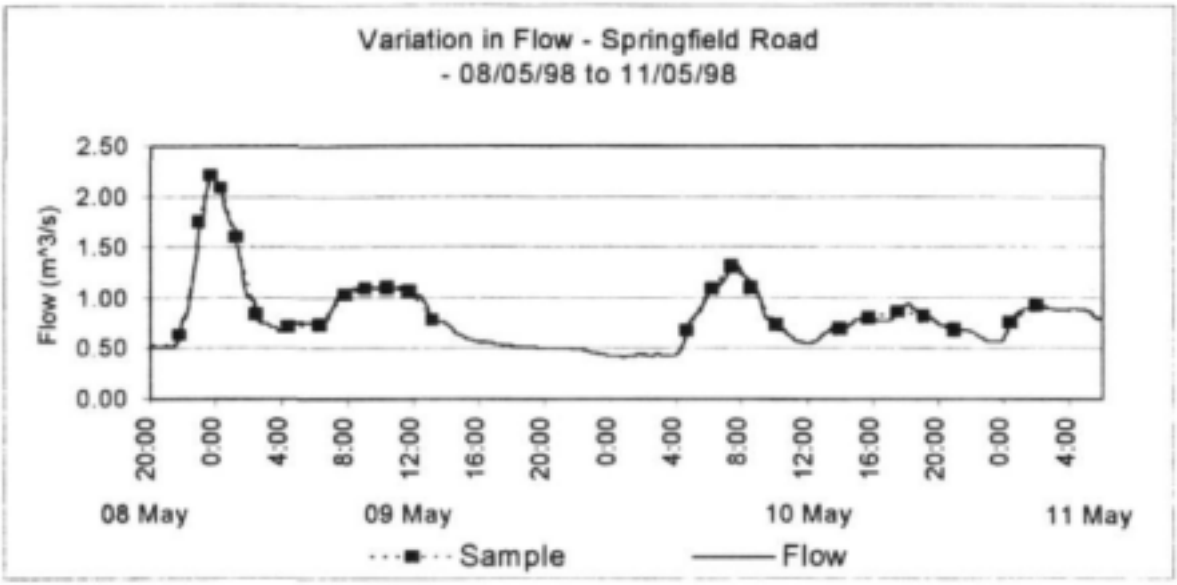
The urbanised sections of the catchment are still contributing to the flow. This is at ~2.4 km (NY3), ~ 4.8 km (Crossroads, Philippi East, Brown's Farm). This results in a max flow of 0.108 cumecs (at ~5.3 km) before the start of the unlined sections of the canal. With the low water table characteristic of the summer months, there appears to be a loss of flow into the groundwater where unlined sections of the canal occur. These unlined sections occur between 5.3km and 10 km with an almost 60% loss of flow for this particular day.

This interaction of the river with the underlying groundwater is approaching that of a normal river system with implications for the increase and reduction of pollutants in the canal.

4.6.2.1 Storm event monitoring

The graph below depicts hydrographs obtained by the datalogger for two storm events captured for analysis.

Figure 4.8: Storm event hydrographs – Springfield Road – Great Lotus River



As discussed in the sampling methodology, the sampler was programmed to begin sampling after flow had risen past 0.5 m^3/s with a sample being collected every 8000 m^3. This frequency enabled the above events to be captured fairly successfully. The table below indicates the total runoff of each event.

Event No.	Begin Date	Total Runoff (m^3)
1	08/05/98	56690
2	10/05/98	20836

The samples were analysed by the Scientific Services, the results of which are shown in section 4.6.3.2 below.

The table below compares monthly precipitation (Cape Town Weather Office), monthly evaporation (DWAF) with monthly runoff as recorded by the datalogger at Springfield Road. This is for the period of the flow gauging study from 21 July 1997 to 30 September 1998.

Table 4.8 Monthly comparison of precipitation, flow and evaporation data

Month	Evaporation (mm/month)	Precipitation (mm/month)	Flow volume (m^3/month)
July 1997	19.9	8	197517
August 1997	44.9	74.8	1420785
September 1997	132.4	6.8	723889
October 1997	183.1	18	423725
November 1997	230.7	45.8	313989
December 1997	247.2	10.4	319167
Total	858.6	163.8	3399072
January 1998	280.6	9.2	267877
February 1998	231.6	0	197017
March 1998	149.3	12	186402
April 1998	91.1	33.8	201692
May 1998	37.7	109.6	1099692
June 1998	36.4	46.2	749714
July 1998	Not Available	99.8	**410133**
August 1998	Not Available	41.6	734984
September 1998	Not Available	28.2	479083
Total		380.4	**4326594**

___ - underestimated due to missing flow data

4.6.3 Water quality

Analysis of the historical database maintained by the Scientific Services Department of the Cape Metro has shown that the water quality variables of concern are:

- Total Nitrogen (TN)
- Total Phosphorus (TP)
- Indicator organisms (Faecal coli, *E. coli*)

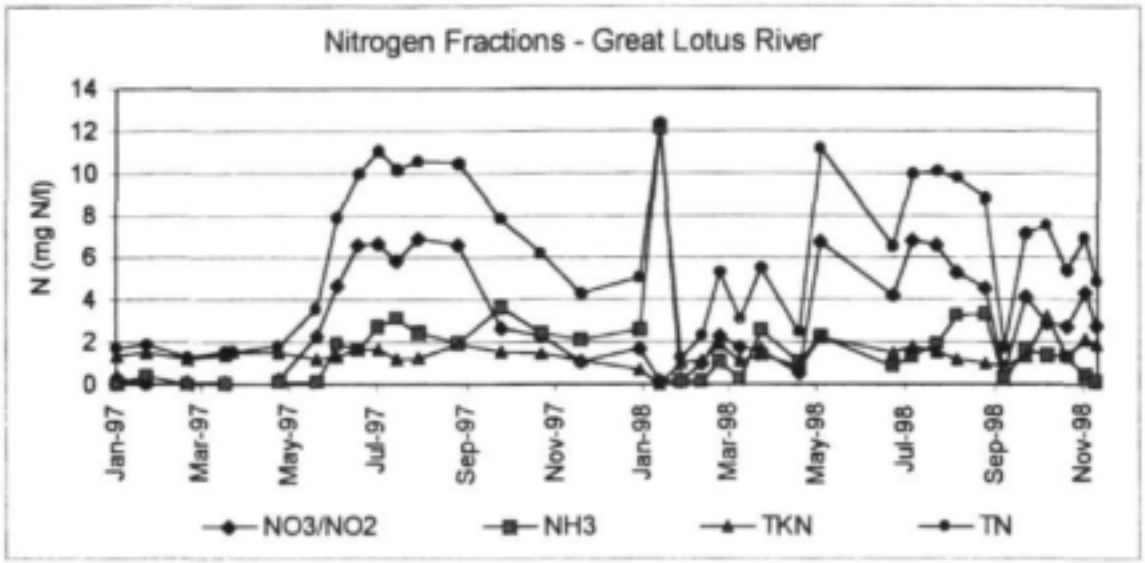
As discussed, sampling of the indicator organisms is undertaken by the Scientific Services on a monthly basis. The results of this sampling are discussed.

In terms of the TN and TP, a detailed sampling program was utilised to determine sources and relative loadings.

4.6.3.1 Total Nitrogen

Total Nitrogen is composed of organic nitrogen, ammonia, nitrite and nitrate but excluding nitrogen gas. Sources of nitrogen in streams include agricultural runoff and industrial activity point sources. Nitrogen is also contained in municipal wastewaters discharged into streams as well as in atmospheric deposition (McCutcheon et al, 1993). Figure 4.9 below depicts the fractional breakdown of nitrogen for the Great Lotus River at 5th Avenue. This data was obtained from the Scientific Services Department of the CMC.

Figure 4.9: Fractional composition of Total Nitrogen – Great Lotus River



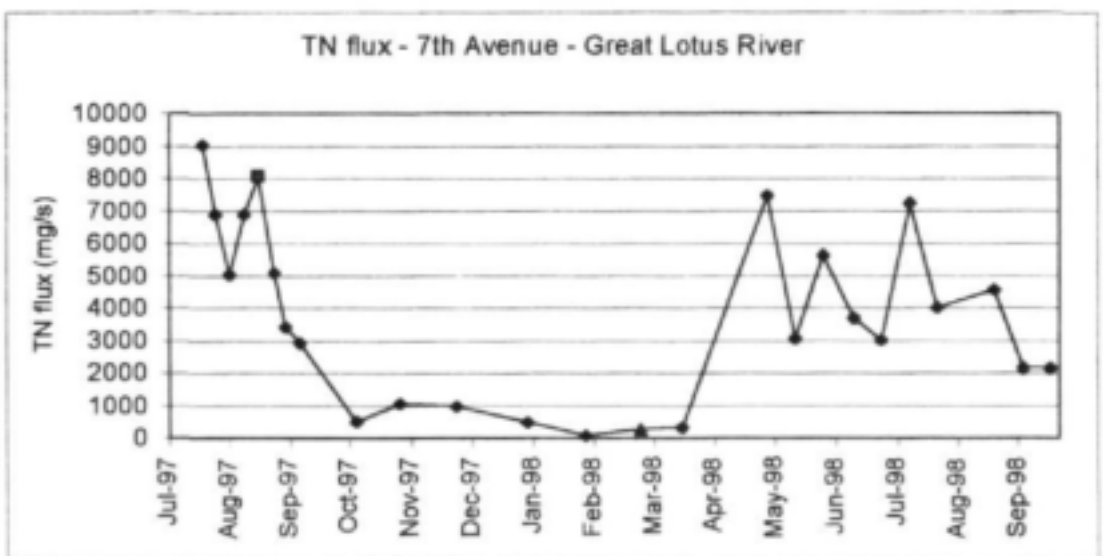
(Scientific Services, 1998)

The above plot, selected for the period January 1997 to December 1998, reveals the varying composition of total nitrogen. It is apparent that a seasonal variation occurs in the concentration of TN with highest concentrations generally occurring during the winter higher rainfall period. This will be discussed in more detail in the following sections. For the winter period, it appears that both the ammonia and nitrate/nitrite concentrations increase with the TKN concentration remaining relatively constant.

Furthermore, the nitrate/nitrite concentration seems to constitute the dominant part of the total TN concentration for the winter period. Because of the high historical levels of Nitrogen, it was required to assess the sources of this pollutant. This will be discussed further in the following sections. Figure 4.10 below provides an indication of the variation in TN flux at the downstream point, 7th Avenue.

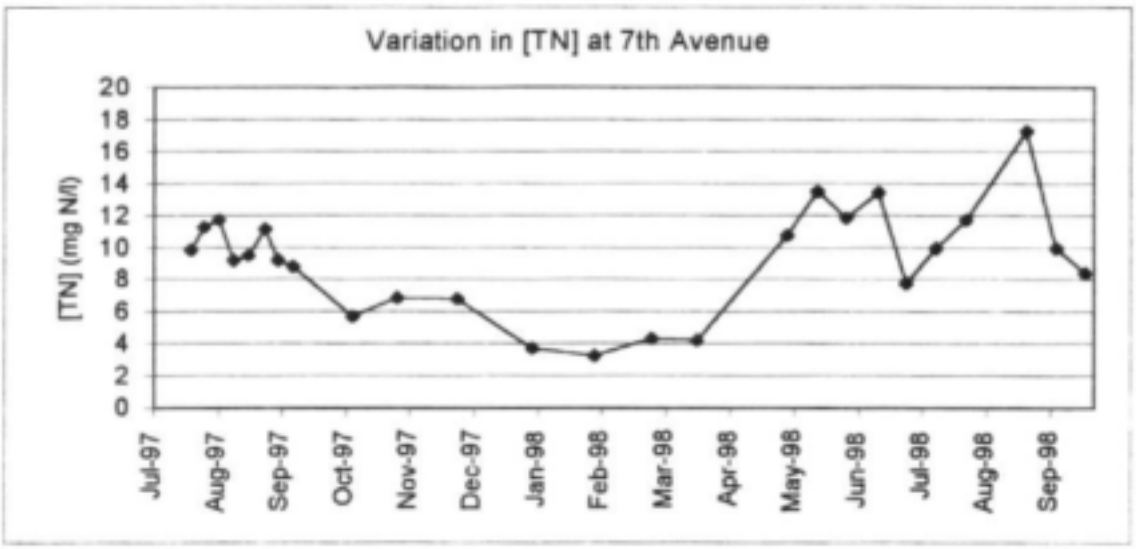
It is immediately apparent that the highest TN loading rate (flux) occurs during the winter rainfall months (seen here for 1997/1998). For the period between the end of September 1997 and beginning of April 1998, however, the summer baseflow conditions result in relatively low loads being transported. This seasonal variation is not surprising given that the flux is in terms of flow with seasonal flow variation thus having a dominant effect on the load.

Figure 4.10: Seasonal variation of TN flux – Great Lotus River



It is of interest to assess seasonal effect on TN concentration. Figure 4.11, below, is the variation in TN concentration for 7th Avenue for the same sampling period.

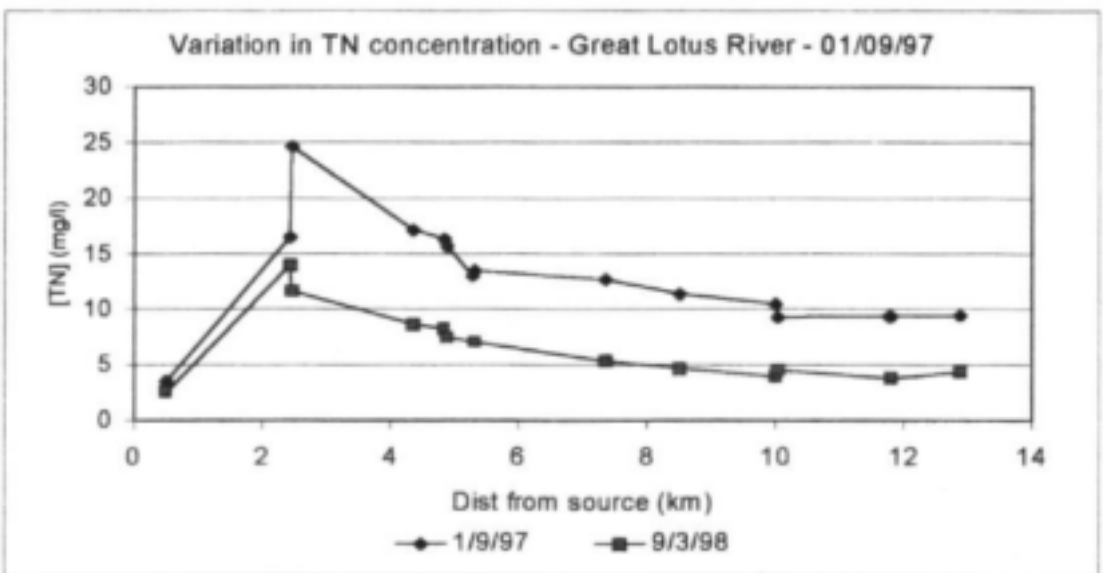
Figure 4.11: Seasonal variation - Total Nitrogen concentration at 7th Avenue



Analysis of the above plot shows a similar seasonal trend for the concentration data. From the above two plots it can thus be concluded that for TN, both the concentration and loading display a similar seasonal variation with the higher contributions during the winter rainfall season. This is in agreement with the literature (Chiew and McMahon, 1998; Huber, 1993; Wright et al, 1993) etc who found that the highest pollutant loads occur with rainfall events.

In order to assess the sources of TN to the Great Lotus River, dates from the sampling program are selected for analysis. To contrast the seasonality of the catchment a high flux situation (01/09/97) and a low flux situation (09/03/98) are selected. These dates also correspond to the dates analysed as high and low flow situations respectively.

Figure 4.12: Total Nitrogen concentration for selected dates - Great Lotus River



The above plot details the variation in TN concentration along the Great Lotus for both a high and low load situation. Given that the dates refer to high and low flow situations, the similarity in the longitudinal

variation of TN for the Great Lotus River is surprising. The concentration profiles are fairly similar with the high flow profile appearing to approximately double the low flow concentration profile.

For both of the selected dates there is a steady increase in the TN concentration leading up to ~2.4 km from the source. This diffuse source contribution can be attributed to the informal settlement of Barcelona as well as the residential areas of Nyanga and Gugulethu. At this point, there is a significant jump in concentration corresponding to the tributary source contribution at the stormwater pipe at NY3 draining a large part of Nyanga and Gugulethu. From this point onwards the concentration decreases for both the high and low flow situations. This is due to possible dilution and assimilation. Analysing the concentrations alone does not give a clear indication of the relative contributions of each source. It is thus necessary to assess the variation of TN flux depicted in Figure 4.13 below.

Figure 4.13: Total Nitrogen flux for selected dates - Great Lotus River

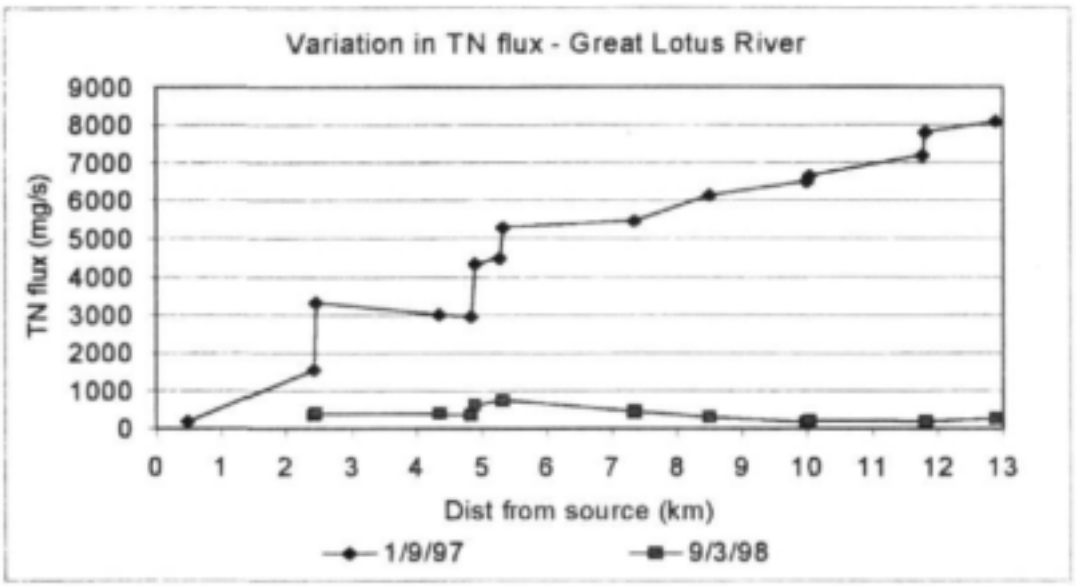


Figure 4.13 dramatically highlights the notion of the highest pollutant flux occurring during the high rainfall periods. As discussed, the selected high flow date (01/09/97) occurs after a period of sustained rainfall with the accompanying washoff characteristics.

Referring to this high flow situation in Figure 4.13, above, it is possible to identify the dominant contributors to the flux. For this selected date, significant sources are shown in Table 4.9 below:

Table 4.9 Contributions to TN flux during 01/09/1997

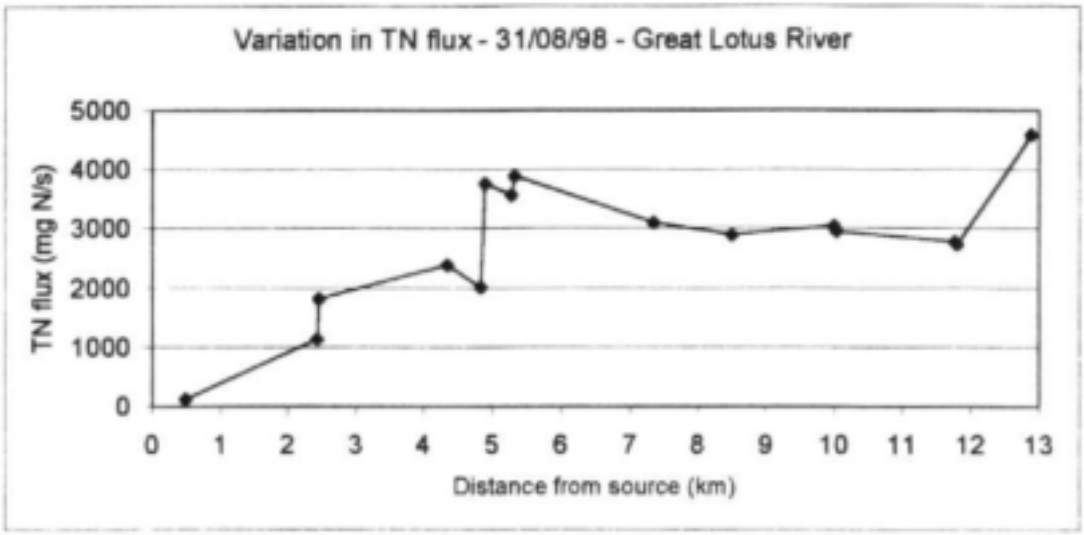
Distance from source	Contribution	% flux contribution
0.5 – 2.4 km	Diffuse source contributions from Barcelona and upper part of Nyanga-Gugulethu	17.15
~ 2.4 km	Tributary source at NY3 stormwater pipeline draining significant portion of Nyanga and Gugulethu	22.5
	Total contribution of Nyanga, Gugulethu, Barcelona	*35.8*
~ 4.8 km	Tributary source draining Crossroads, Philippi East, Philippi West and Brown's Farm	16.01
~ 5.3 km	Vygekraal Detention pond draining subcatchment of PHA	6.1
~5.3 to 7.3 km	Unlined section along Lansdowne Road permitting groundwater influence	2.32
~7.3 to 10 km	Unlined section through Philippi Horticultural area permitting groundwater and subsurface irrigated flow	8.52
~10 km	Tributary source from Lansdowne-Wetton Road Corridor	5.74
~10 to 11.8 km	Diffuse source from residential area of Grassy Park	6.66
~11.8 km	Tributary source from subcatchment of PHA	5.94
~11.8 to 12.9 km	Diffuse source from Lotus River residential area	3.64

The predominately formal and informal settlements of Barcelona, Nyanga, Gugulethu, Crossroads and Brown's Farm draining into the Great Lotus canal up to ~ 4.8 km cumulatively contribute just over 51% of the total flux of TN into Zeekoevlei. The two stormwater pipes (NY3, Brown's Farm) together contribute 39% of the flux for the selected day. This is possibly due to the inadequate sanitation and cleansing services offered to these areas.

From this point downward, contributions are mainly diffuse sources from the Philippi Horticultural Area (23%) as well as the residential subcatchments of Ottery, Grassy Park and Lotus River. The relative contributions to the flux for these areas are significantly less and it can be concluded that the township settlements are the major source of TN loading to the Great Lotus River.

Consideration of the concentration variation at 7th Avenue, in Figure 4.11, reveals a significant jump in TN concentration for the date 31/08/98. This corresponds to a relatively average TN load and is significant in terms of the potential sources. Figure 4.14 below depicts the variation in TN flux for the Great Lotus River for this date.

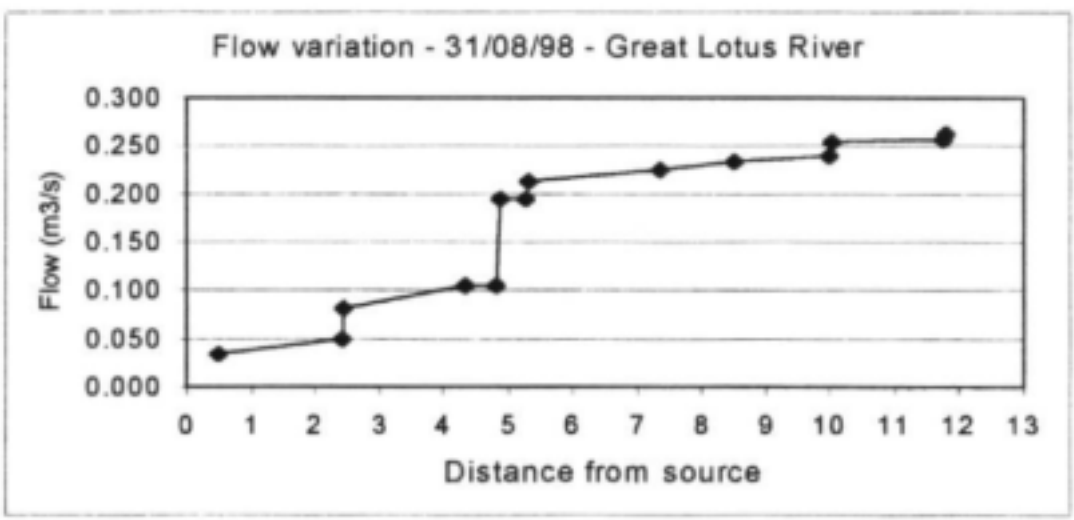
Figure 4.14: Variation in Total Nitrogen flux – 31/08/98 – Great Lotus River



Step increases occur at ~2.4 km (NY3) and 4.8 km (Philippi East) as for the dates discussed above. Of significance for this particular date, however, is the dramatic increase in TN flux between 11.8 and 12.8 km. This reach corresponds to the Lotus River residential area and thus constitutes a diffuse urban source. The increases in TN flux thus all correspond to urbanised sections of the catchment. In contrast to this, the TN flux appears to decrease for the unlined sections of the canal (between 5.3 and 10 km).

Assessment of the flow variation for this particular day, shown in Figure 4.15 below reveals that increases of flow occur not only at the same tributary points but also from diffuse sources along the unlined sections. This indicates some form of nitrogen assimilation. The above results also seem to support the notion that the principal sources of TN in the Great Lotus River are the urbanised areas of the catchment, composed principally of formal and informal residential areas.

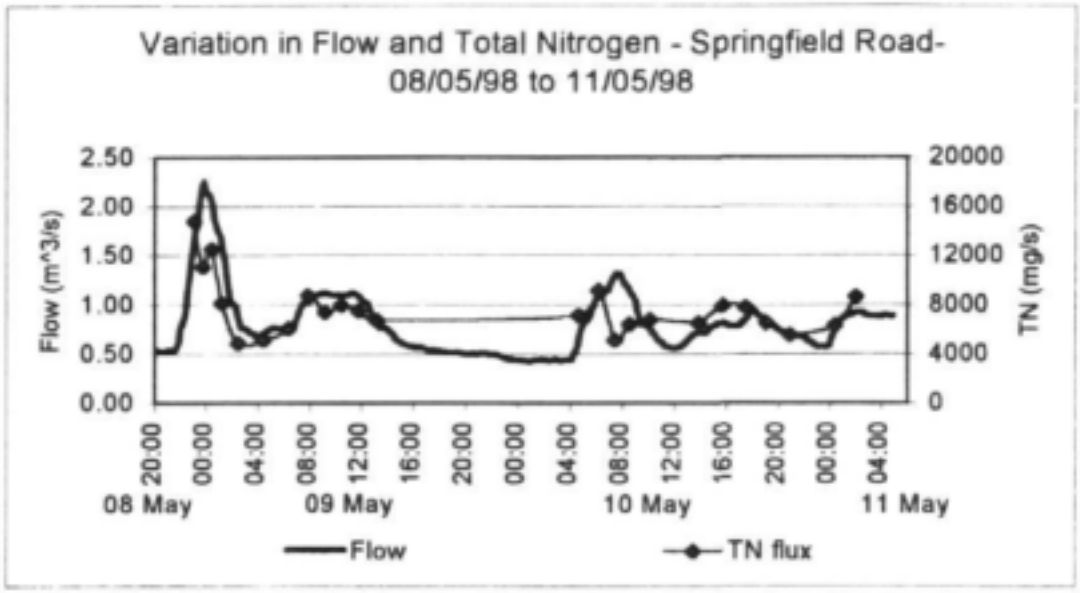
Figure 4.15: Flow variation – 31/08/97 – Great Lotus River



4.6.3.2 Storm event monitoring

Figure 4.16 depicts the effects on Total Nitrogen flux under storm conditions. These events correspond to the events discussed in section 4.6.2.1 above.

Figure 4.16: Event TN pollutograph – Springfield Road – Great Lotus River



It is of interest to note the effect the peak flow has on TN flux. The rising limb of the hydrograph is characterised by an increase in flux with the peak TN flux leading the peak flow for each event. As the flow reaches its peak, however, there is a corresponding slight drop in flux, followed by an increase in flux as the peak passes. For the falling limb of the hydrograph, the TN flux decreases. The flux variation shown in Figure 4.16 above conforms to the literature with maximum loading occurring during flood events (Chiew and McMahon, 1998; Huber, 1993).

4.6.3.3 Total Phosphorus

Phosphorus can be divided into dissolved and particulate phosphorus, each with organic and inorganic components. The phosphorus cycle is principally composed of organic P and inorganic P in the form of orthophosphate where orthophosphate is soluble and considered to be the only biologically available form of P (ie. SRP) (McCutcheon et al. 1993). Since P strongly associates with solid particles and is a significant part of organic material, sediments influence water column concentrations and are an important component of the phosphorus cycle in streams.

The major sources of phosphorus in streams are natural organic material, organic and inorganic phosphorus in wastewaters and nonpoint sources and phosphorus detergents in wastewaters (McCutcheon et al. 1993). Agricultural lands are an especially significant diffuse source of phosphorus (Oenema and Roest, 1998).

Phosphorus can be the limiting nutrient that prevents additional biological productivity from occurring (McCutcheon et al. 1993). This implies that phosphorus is a limiting nutrient for eutrophication. In this way phosphorus enrichment can cause algal blooms, ecological changes due to changes in the food chain, recreational amenity loss and dissolved oxygen loss (Herricks, 1995).

In terms of the Great Lotus catchment, the downstream water body, Zeekoevlei, is severely hypertrophic with "increased *Microcystis* growth being linked to the increased concentrations of biologically available Phosphorus (SRP) following the winter rains" (Harding, 1996). Harding continues by stating that "attenuation of external (phosphorus) loading could have a positive effect on the severely impaired trophic state of the lake" (Harding 1996). This attenuation brought about through the control of P in sewage, industrial wastewaters and diffuse pollution is, therefore, critical. Similar findings were reported in research conducted on the Buffalo River where phosphate appears to be the main limiting nutrient in the Buffalo River. It was found to be the variable needing to be managed as the main priority in order to limit eutrophication (O'Keefe et al. 1994).

Figure 4.17: Variation in TP concentration at 7th Avenue, Great Lotus River

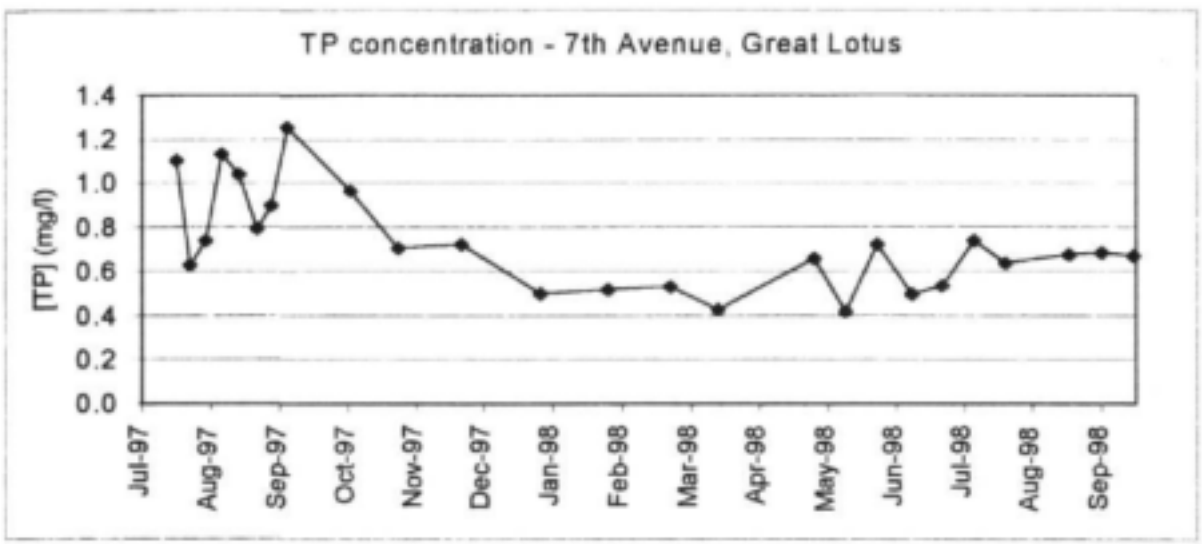
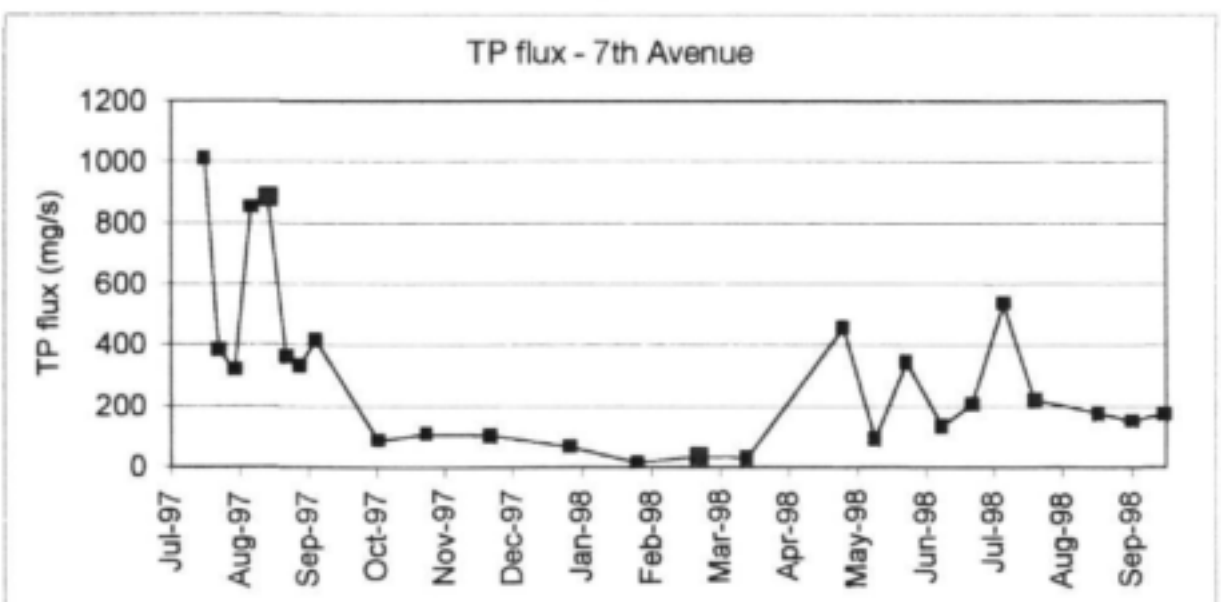


Figure 4.17 above depicts the variation in Total Phosphorus concentration at the point upstream of Zeekoevlei, 7th Avenue for the duration of the sampling period. This plot shows a marked seasonal variation with higher TP concentrations evident during the higher rainfall months with a corresponding decrease during the summer drier months. This seasonal variation is shown even more strongly when considering the variation in TP flux at the same point for the same interval in Figure 4.18 below.

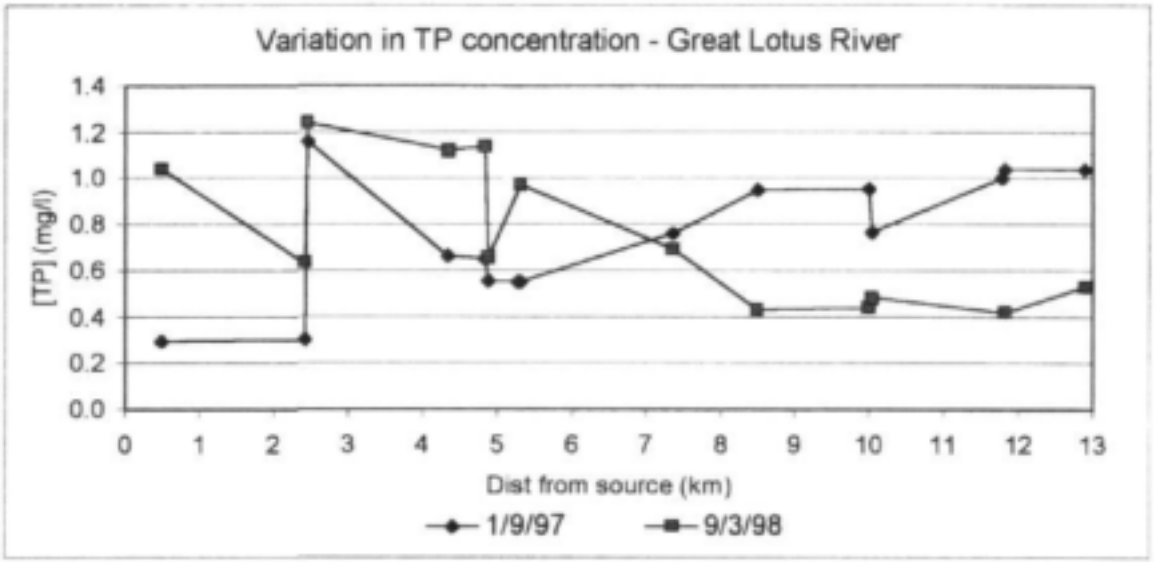
Figure 4.18: Variation in TP flux at 7th Avenue, Great Lotus River



Again the rainfall season is characterised by higher TP fluxes. The drier summer period between October and April displays a baseflow condition resulting in comparably lower fluxes being transported. Of interest to note is the magnitude of both the concentration and flux being relatively less during the rainfall season of 1998 than the similar period of 1997. This may be accounted by the interval of sampling being greater (fortnightly for winter 1998 as opposed to weekly for winter 1997) during 1998 with the result of more storm events occurring between sample points. Analysis of the Mean Annual Rainfall, as measured by the Cape Town Weather Office, reveals that although 1998 received just over 22% more rainfall than 1997 (1997 : 422.8 mm versus 1998 : 516.8 mm) (Cape Town Weather Office Climate Records, 1999) the months of June and August were relatively drier during 1998 when compared to the same months for 1997. Storm intensities were low with less washoff during the period.

In order to assess the sources of TP for the Great Lotus River it is necessary to review a longitudinal plot of the variation in TP concentration and flux along the length of the canal. Two dates are selected from the sampling programme, a high flow/flux situation and a low flow/flux situation.

Figure 4.19: Variation in TP concentration for selected dates



A number of conclusions can be drawn from an assessment of Figure 4.19 above. Both the low and high flow situations are characterised by a significant jump in concentration at ~2.43 km. This again refers to the stormwater pipe draining parts of Nyanga and Gugulethu and flowing into the canal at NY3. (The relatively high concentration measured at the N2 (~0.5 km) is due to a high organic content at this point due to cleared aquatic vegetation not being removed and choking up the canal.) A decrease in concentration is then evident to the point just below the Nyanga-Gugulethu settlements. This is due to diffuse sources contributing flow to the canal with lower concentrations and producing a dilution effect. Further dilution occurs at the sample point at ~4.9 km. This point corresponds to the stormwater pipe draining Crossroad, Philippi and Brown's Farm. Although these are residential settlements the stormwater is routed through a number of detention ponds resulting in possible assimilation and a lower concentration of TP.

From this point onwards, the low flow and high flow situations diverge in their characteristics. The high flow situation is seen to have a gradual increase in TP concentration whilst the corresponding low flow situation experiences a decrease in concentration. This reach of the canal coincides with an unlined length of the canal and thus opens up the possibility of interaction of the river with the underlying groundwater. Thus, as previously discussed, the gradual increase/decrease can possibly be attributed to a varying water table contributing nutrient rich agricultural groundwater flow during winter and causing transmission losses during the summer months.

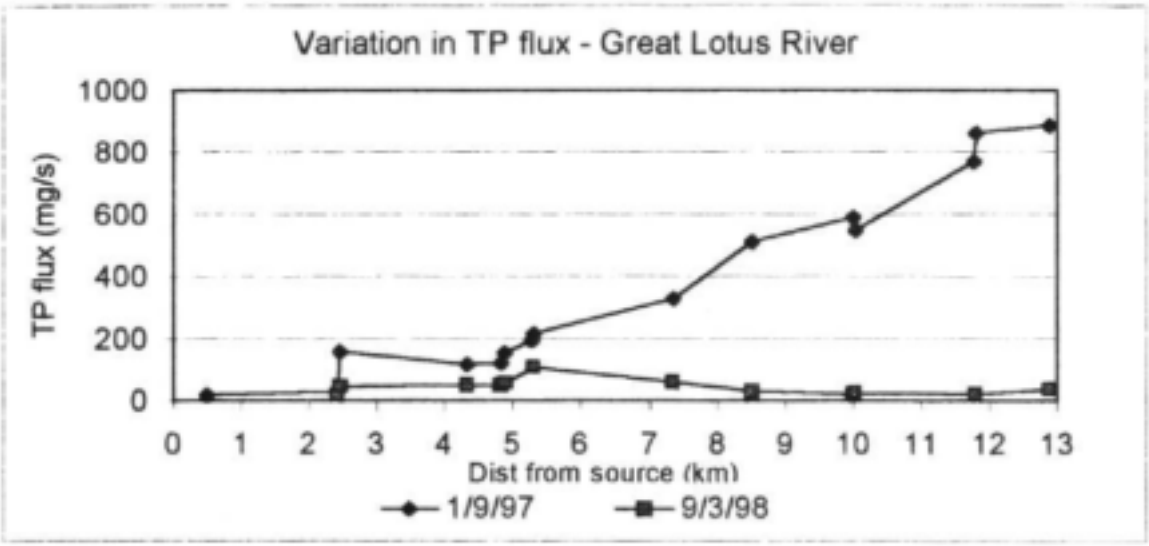
The canal continues to be unlined between ~8.5 km and ~10 km. This corresponds to a more urbanised residential area with traffic corridors crossing the canal. The concentration remains fairly constant for

both the low and high flow situation. In order to assess the implications of this, it is required, however to contrast the variation in flux with the above concentration variation. This may detail the extent to which the groundwater plays a role for this reach.

The remainder of the canal flows through formal residential areas with a small tributary source from the Philippi Horticultural Area contributing flow during the winter rainfall season.

In order to compare relatively the various contributions, it is necessary to view the concentrations in terms of flow, ie. a TP flux variation shown below in Figure 4.20.

Figure 4.20 Variation in TP flux, Great Lotus River



It is immediately apparent from analysis of the above Figure 4.20 that there is a significant seasonal variation evident for TP fluxes in the catchment. As far as ~5.3 km the contributions to the flux remain fairly small. From this point onward, however, the groundwater begins to play a more significant role. With the high water table characteristic of winter, there appears to be a significant contribution to the flux up to ~10 km. As discussed, this is presumably due to nutrient rich agricultural groundwater and, to a lesser extent surface water, augmenting flow in the canal during the unlined sections. For the high flow situation, this accounts for almost 43% of the total TP flux into Zeekoevlei. As in the case of the TN flux plot above, the low flow situation appears to result in a loss of TP from the canal for the corresponding reach of the canal. This is due primarily to the loss of flow to the groundwater as well as possible vegetative assimilation during the longer retention periods of the summer base flow conditions.

Table 4.10 below represents a summary of the significant sources and percentage contributions each source make to the total flux at high flows (01/09/97)

Table 4.10 Contributions to TN flux during 01/09/1997

Distance from source	Contribution	% flux contribution
0.5 – 2.4 km	Diffuse source contributions from Barcelona and upper part of Nyanga-Gugulethu	1.39
~ 2.4 km	Tributary source at NY3 stormwater pipeline draining significant portion of Nyanga and Gugulethu	7.9
	Total contribution of Nyanga, Gugulethu, Barcelona	*11.57*
~ 4.8 km	Tributary source draining Crossroads, Philippi East, Philippi West and Brown's Farm	2.88
~ 5.3 km	Vygekraal Detention pond draining subcatchment of PHA	5.48
~5.3 to 7.3 km	Unlined section along Lansdowne Road permitting groundwater influence	13
~7.3 to 10 km	Unlined section through Philippi Horticultural area permitting groundwater and subsurface irrigated flow	21.06
~10 km	Tributary source from Lansdowne-Wetton Road Corridor	3.17
~10 to 11.8 km	Diffuse source from residential area of Ottery	25.32
~11.8 km	Tributary source from subcatchment of PHA	10.95
~11.8 to 12.9 km	Diffuse source from Lotus River residential area	2.66

The above table shows, for a high flow situation, that the upper township developments of Barcelona, Nyanga, Gugulethu, Crossroads and Brown's Farm together account for just under 15% of the total TP flux into Zeekoevlei for this particular day. The Philippi Horticultural Area, on the other hand, through diffuse contributions as well as tributary sources, accounts for just over 50% of the TP flux into Zeekoevlei. The remainder of flux contribution is thus from the more formalised residential areas of Ottery, Lotus River, as well as Lansdowne-Wetton.

Present literature partitions phosphorus for stormwater and sewage. McCutcheon et al. (1993) submit that particulate P accounts for supposedly 95% of the total P in most cases of urban stormwater runoff. This is echoed by Abustan and Ball (1998) by apportioning 85% of TP to inorganic particulate P. Table 4.11 below provides an indication of the principle fractions of phosphorus in both sewage and stormwater:

Table 4.11 Total Phosphorus fractions in stormwater and sewage

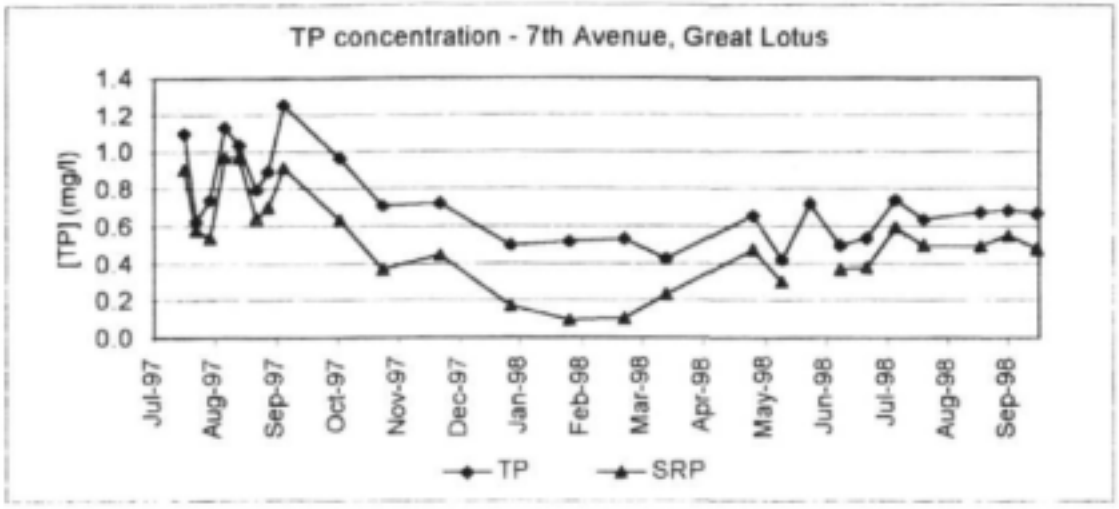
	Soluble P	Particulate P	
		Organic (%)	Inorganic (%)
Sewage	83	17	0
Stormwater	4.2	11.6	84.2

(Waller and Hart, 1985)

It is therefore of value to assess the fraction of P that is either soluble or particulate. This can be seen in Figure 4.21 below which compares the soluble fraction to the total P concentration.

Assessment of Figure 4.21 shows that, in fact, the SRP is the major constituent of the TP concentration principally during the winter rainfall months. For the summer base flow conditions it appears that the particulate form of P becomes more significant. (Findings reported by Gerdes and Kunst (1998) show that a high content of particulate P causes a low bioavailability, ie. SRP content) The major proportion of phosphorus transported in surface waters from agricultural soils is generally in particulate form (Oenema and Roest, 1998) with Sharpley and Rekolainen (1997) reporting particulate values between 60 and 90% of the total P load. Because the Lotus River has a high SRP component of the total TP concentration, this seems to suggest that the principal diffuse solutions from the agricultural areas are subsurface influences. In light of the above table, this is augmented by urban stormwater affected by sewer overflows and inadequate sanitation of the upper parts of the catchment.

Figure 4.21: Fractional composition of TP – Great Lotus River

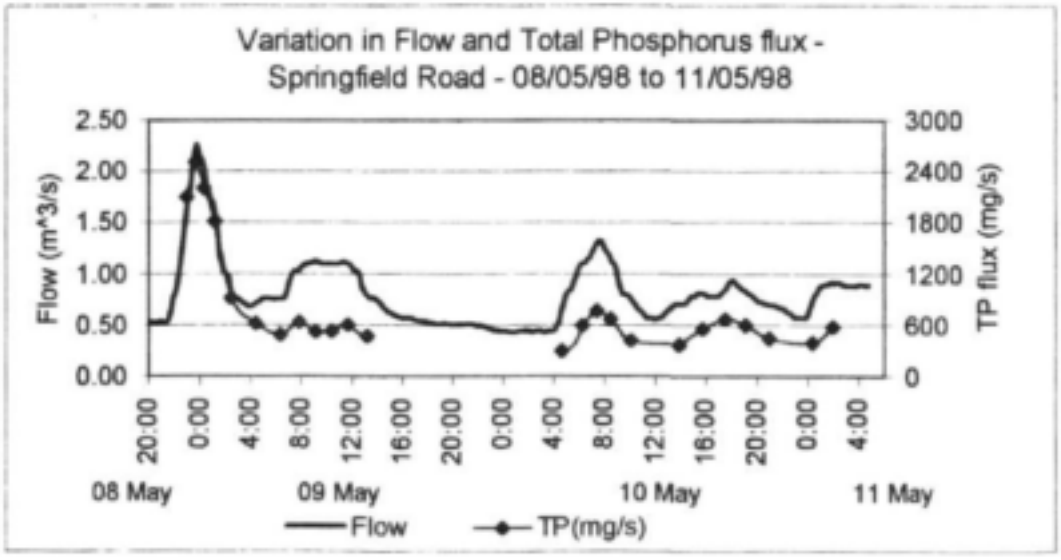


For the summer months, however, it appears that the particulate fraction is more dominant. These are periods characterised by low groundwater levels (flow in the canal appearing to be actually lost to the groundwater during these periods). The agricultural influences on the TP flux are thus reduced and the major sources appear to be urban sources including possible sewer overflows and diffuse contributions through inadequate sanitation runoff.

4.6.3.4 Storm event monitoring

The plot below depicts the variation for TP flux for the sample events discussed in section 4.6.2.1 above.

Figure 4.22: Event TP pollutograph – Springfield Road – Great Lotus River



As with the TN storm related variation in section 4.6.3.1 above, the highest TP flux occurs during peak flow. In the case of the TP flux in Figure 4.22 above, the peak TP flux matches the flow hydrograph more closely than for the TN variation with no lag evident between peak flow and peak flux. The rising limb is characterised by an increase in TP flux with the falling limb exhibiting a decrease in TP flux. This again confirms the notion of increased loads being transported during storm events.

4.6.3.5 Philippi Horticultural Area subcatchment study

As discussed, an assessment of the above high flow data for TP flux reveals that a significant contribution to the flux appears to be diffuse sources in the Philippi Horticultural Area. It was thus deemed necessary to attempt to assess the potential sources of the TP flux in this area.

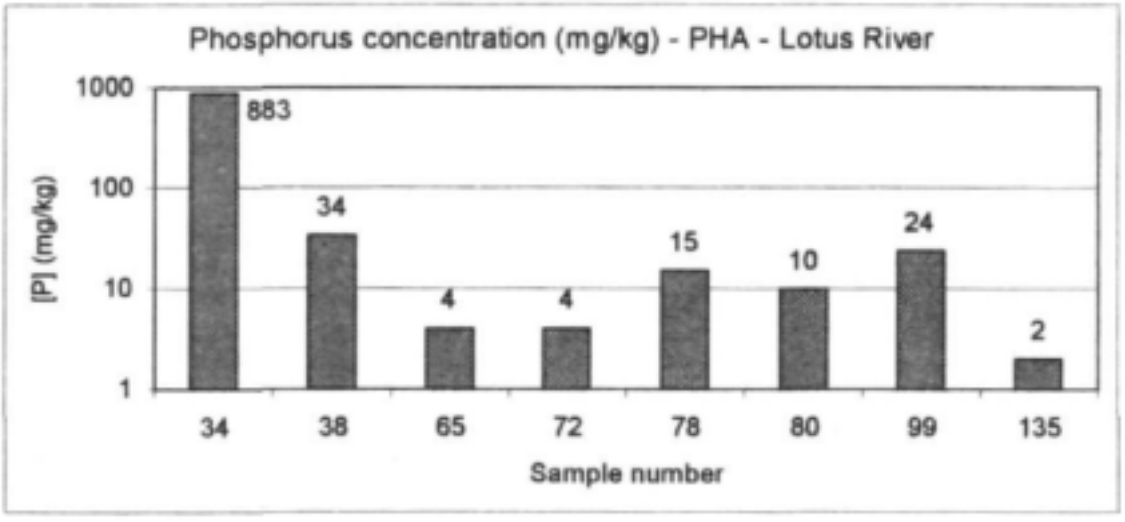
To obtain an indication of typical fertiliser application rates for the area, a limited survey was conducted of five collaborating farmers in Philippi. The survey showed that, due to the low ambient nutrient content of the Cape Flats sands and, depending on the type of plant cultivated, a combination of organic and inorganic fertiliser is applied during cultivation. Organic fertiliser, in the form of pig and chicken manure and sewage sludge, is readily available in the area and regularly applied (fortnightly in some cases). Discussions with an agronomist from a local fertiliser supplier revealed that as much as 20t/ha of manure is applied per growing season (Du Plessis, 1998). This manure contains relatively low concentrations of nitrogen and phosphorus (N = 1.5 – 3%, P = 1 – 1.5%, Du Plessis, 1998) hence the need for significant amounts of application.

In addition to the organic manure, various inorganic fertilisers are also applied. These fertilisers, containing varying ratios of nitrogen, phosphorus, calcium and potassium are generally expensive and applied far more sparingly. Of significance, N is applied at a rate of about 150 kg N/ha and P ~ 80-120 kg/ha (Du Plessis, 1998). This inorganic phosphorus application is through Maxiphos, a concentrate of 20% P.

Soil samples were collected and analysed by INFRUITEC for soil depths varying between 300 and 1600 mm. The samples were collected along subcatchment 140 in the Philippi Horticultural Area.

Figure 4.23 below depicts the TP concentration for each sample with the concentration axis plotted to a log scale.

Figure 4.23: Subsoil P concentrations – PHA, Great Lotus River



Sample 34 in Figure 4.23 above, taken on a small holding in subcatchment 140, has a disproportionately high concentration of phosphorus and is indicative of a recent fertiliser application. Discussions with INFRUITEC revealed that maximum ambient concentrations of P are usually between 20 – 30 mg/kg with reasonable P concentrations in agricultural areas being of the order of 30 mg/kg (Woolridge, 1998). The remaining soil samples in Figure 4.23, above, therefore display relatively low P concentrations.

The soils of the area are generally sandy and were largely deposited by sea-action (Stehr and van Huyssteen, 1998). It is to be expected, therefore, that the natural, unworked soils would have a high degree of calcareousness due to shell fragments. This can be seen in the southern parts of the area where a high degree of calcareousness occurs (see figure 3. of the previous chapter - map depicting degree of

calcareousness of Philippi). Through attempts at cultivation, dunes were levelled and low lying vlei areas were filled. Continuous irrigation resulted in large scale leaching of the sands removing the calcareousness content of the soil. Analysis of figure 3..again shows that, in fact, the majority of the Philippi area is non-calcareous and can be considered man-made (Stehr and van Huyssteen, 1998). This leaching would in all likelihood, also remove any natural phosphorus concentrations and produce the acidic, low nutrient concentration, sandy soils characteristic of the Philippi area.

Of interest to the Great Lotus are the processes involved in the transportation of P from the cultivated lands to the river. Precipitation dissolves the fertiliser and through infiltration into the subsoil, renders the dissolved nutrients available to the plant roots for take-up. Drainage channels act as collectors taking lateral subsurface flow. Any dissolved nutrients not utilised or adsorbed onto soil particles thus seep into the drainage channels and irrigation ponds.

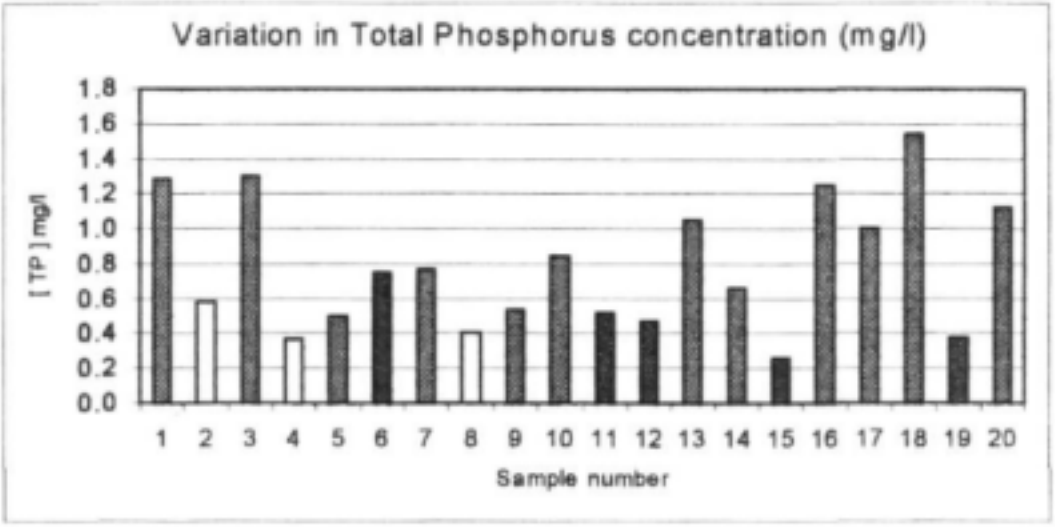
Oenema and Roest (1998) state that for poorly drained sandy soils, heavily laden with phosphorus containing fertilisers and animal wastes, phosphorus concentrations in shallow groundwaters are expected to be high. This is due to a low capacity of these soils to adsorb phosphorus from the percolating soil solution. Once the phosphorus adsorption front reaches the groundwater level, its discharge into surface water accelerates. Such soils can contribute a 100 times more than well-drained soils with a phosphorus poor subsoil. These soils consequently act as hot spots as point sources of surface water enrichment.

Because of the mechanisms of phosphorus transport into the groundwater and lateral subsurface flow into drainage channels, the sampling programme initiated in October 1998 thus focussed on the drainage channels and irrigation ponds of the area.

Figure 4.24, below, depicts the variation in Total Phosphorus concentration along the length of the subcatchment 140. Samples were taken in the drainage channel draining the subcatchment, as well as the irrigation ponds along this channel. These irrigation ponds are generally large excavations dug to below the summer water table levels and are filled by seeping groundwater.

In Figure 4.24, below, bars with diagonal crosshatching refers to samples taken from the drainage channel adjacent to irrigated cultivated fields. Plain white bars denote samples from the excavated irrigation ponds whilst the bars with dotted fill pattern are samples taken where drainage channel flows through an uncultivated or undisturbed area.

Figure 4.24: TP variation in PHA subcatchment 140



Assessment of Figure 4.24 reveals a number of trends:

- TP concentrations in the irrigation ponds are relatively low when compared with values for the drainage ditches. These concentrations (average = 0.45 mg P/l), when contrasted with the water quality guidelines, are all indicative of a hypertrophic status however.
- TP concentration for channels adjacent to irrigated fields are significantly higher than elsewhere (average = 0.99 mg P/l). Samples 1, 3, 16, 17 and 18 are especially high (average = 1.3 mg P/l) corresponding to areas of intensive cropping and irrigation. This lends support to the notion of the agricultural lands contributing high TP concentrations to the underlying subsoil water and is in agreement with the discussion of Oenema (1998) above based on phosphorus losses from sandy soiled agricultural areas.
- Samples 16,17,18 and 20 are just upstream of the Vygekraal Road detention pond draining into the Great Lotus River. With significant rainfall events it appears as if this high concentration would thus be transported into the pond.
- Sample 6, whilst appearing as an uncultivated point, is adjacent to a grazing pasture with the concomitant likelihood of manure rich flow seeping into the channel. The remainder of the uncultivated sample points 11, 12, 15 and 19 display lesser concentrations (average = 0.407 mg P/l)
- The ratio of cultivated to uncultivated P concentrations is therefore 1:2.43, ie. the concentration of water in drainage ditches adjacent to cultivated lands is more than double that measured adjacent to uncultivated land.

4.6.4 Microbial data

Analysis of Scientific Services data reveals that both faecal coliforms and *Escherichia coli* are found in high concentrations in the Great Lotus River. As suggested, this is due to a number of reasons, including raw sewage effluent overflowing from blocked sewers into the stormwater drains, as well as the inadequate or non-existent sanitation characteristic of the Gugulethu and Nyanga residential areas. An additional source appears to be due to the ingress of stormwater into deteriorated sewers. During storm events this results in surcharging of the sewers with overflows occurring at the sewer manholes and thence into the stormwater system.

Figure 4.25: Concentration of faecal coliforms in Great Lotus River

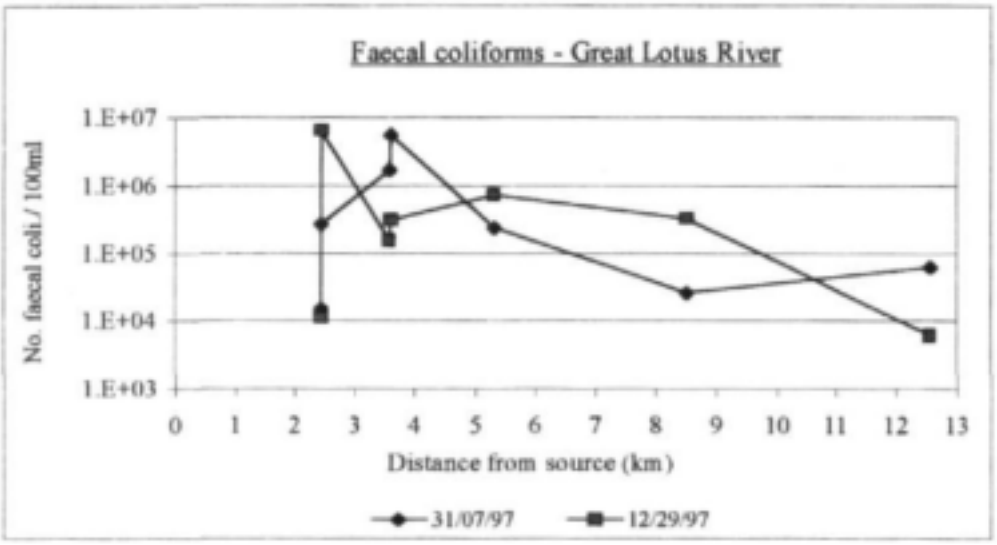


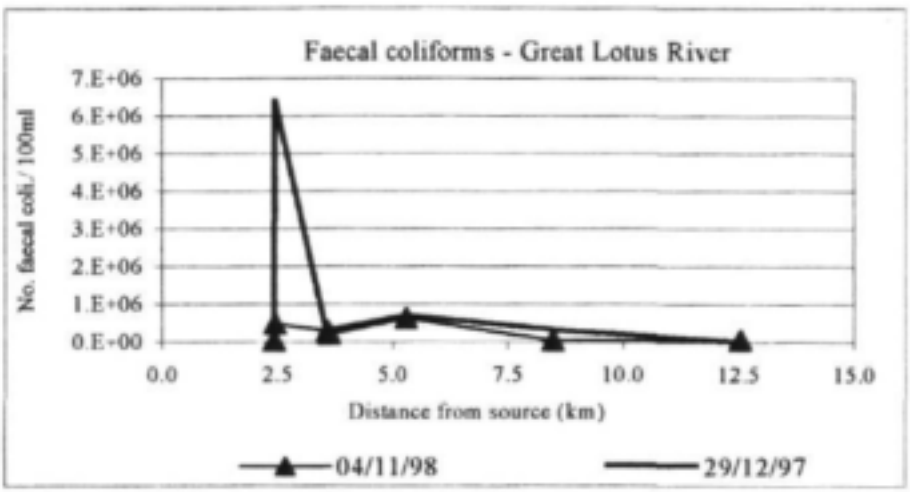
Figure 4.25 above (with y-axis plotted to log-scale) depicts the extremely high faecal coliform counts in the Great Lotus River. These counts originate principally from two stormwater outlets at NY 3 (~2.4km) and NY 3A (~3.6km) in Gugulethu. These increases can be seen as step changes at the stormwater inlet due to samples being taken upstream and downstream of the inlet. The gradual increase is due to a diffuse contribution of faecal matter, principally from the informal settlements adjacent to the canal in Gugulethu. Further downstream, at Springfield Road (~8.5km) and 5th Avenue (~12.5km), dilution and possible bacteriological die off in the unlined reaches of the canal result in decreased counts.

Because of these sources, the Drainage and Sewerage Branch of the Cape Town City Council historically diverted the entire summer base flow to the Strandfontein Treatment Works adjacent to Zeekoevlei. This practice has subsequently ended due to costs of treatment and disagreement between the various substructures as to who should finance the treatment costs. This option is supposedly in the process of being reinvestigated (see section 4.9)

In order to combat the overflowing of effluent into the stormwater system at NY3, the Cape Town Municipality initiated an extensive upgrading project. This project entailed the relaying of the entire trunk stormwater line, along NY3, draining into the Lotus in an attempt to repair the overflow points.

Figure 4.26 below depicts the faecal coliform count following the completion of the project in September 1998 with the y-axis in terms of actual concentrations. This sample taken on the 04/11/98 is contrasted to a sample taken during the similar base flow conditions of 1997.

Figure 4.26: Concentration of faecal coliforms in Great Lotus River



Note the concentration at ~2.5 km (the inlet of the upgraded stormwater pipeline) in Figure 4.26 is significantly lower for the sample taken post construction (4.8e5 counts/100 ml compared to 6.5e6 counts/100ml). This corresponds to a decrease of just over 90% of the faecal coli count. Thus whilst the faecal coli count is still excessively high, the upgrading of the stormwater pipeline appears to have limited the ingress of sewer effluent into the Lotus canal. In order to assess whether overflows have been completely eradicated, it remains to analyse the counts at this point over a longer period, especially during high flow situations.

4.6.5 Heavy metal analysis

4.6.5.1 Water samples

Interaction of inhabitants within the catchment with water in the Lotus River includes both abstractions for irrigation, as well as a potential source of water and disposal system for waste. It is thus necessary to assess the concentrations of selected heavy metals in terms of acceptable levels for agricultural irrigation and domestic usage.

Table 4.12 below provides an indication of the average heavy metal concentration at selected sample points in the Great Lotus River compared to the Target Water Quality Range (TWQR) of the DWAF Water Quality Guidelines for Irrigation and Domestic Use. The uppermost value of the range is quoted below. Note that the irrigation water uses of the above guidelines refer to application to commercial crops and to sustain suitability of irrigated soil, whilst domestic water use refers generally to human health as well as aesthetic effects in certain cases.

Table 4.12 Suspended heavy metal concentrations - Great Lotus River

Constituent (µg/l)	TWQR (µg/l)		N2	Gugulethu	L'downe Road	Spring-field	7th Ave
	Irrigation[1]	Domestic[2]					
Cadmium (Cd)	10	5	1.975	2.075	2.605	2.56	2.46
Chromium (Cr)	100	50	1.135	2.265	1.475	2.18	1.93
Cobalt (Co)	50	-	7.99	39.14	9.645	9.815	8.78
Copper (Cu)	200	1000	4.555	9.56	6.265	4.805	6.38
Iron (Fe)	5000	100	51.89	211.43	86.415	63.645	122.57
Lead (Pb)	200	10	13.49	24.755	22.41	20.43	22.04
Manganese (Mn)	20	50	9.09	26.975	14.7	20.04	24.08
Nickel (Ni)	200	-	10.39	10.7	8.18	9.85	9.7
Zinc (Zn)	1000	3000	24.77	129.11	49.005	110.98	5.28

([1]) - (DWAF, 1996b); ([2]) - (DWAF, 1996a)

From Table 4.12, it can be seen that the concentrations of heavy metals generally fall below the limit concentrations as dictated by DWAF. What are noticeable, are the relatively higher concentrations of Iron and Lead. These values typically exceed the accepted values for domestic human usage. Because of the high nutrient and microbiological values of the water, however, the water is unlikely to be used for domestic purposes. In terms of the agricultural usage of the water, therefore, the iron and lead contents are well within the accepted guidelines for irrigation.

4.6.5.2 Sediment samples

Table 4.13 below provides an indication of the heavy metal analysis undertaken on the sediment samples. Where sediment cores were taken, an assessment of the historically accumulated solids in the system can be obtained.

Table 4.13 Sediment heavy metal concentrations – Great Lotus River

Constituent (mg/kg)	N2	Gugulethu	L'downe Road	Spring-field	7th Ave
Cadmium (Cd)	1.3	0.83	0.19	0.21	0.26
Chromium (Cr)	16.17	4.995	2.925	7.53	2.73
Cobalt (Co)	6.24	1.655	0.745	0.565	0.44
Copper (Cu)	13.125	10.705	2.605	1.83	2.52
Iron (Fe)	3851.54	1341.52	594.465	1932.14	1266.63
Lead (Pb)	48.39	77.975	9.275	11.45	8.32
Manganese (Mn)	28.64	22.215	5.92	4.505	6.54
Nickel (Ni)	8.56	4.35	1.25	1.14	0.87
Zinc (Zn)	103.26	155.485	17.79	14.925	21.12

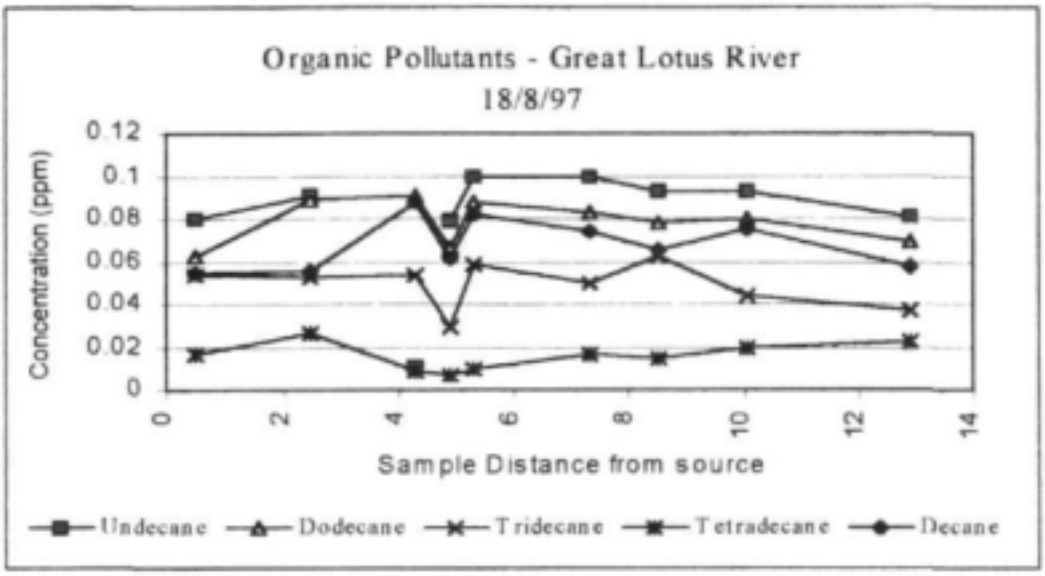
Analysis of Table 4.13 reveals that heavy metal concentrations in the sediments of the Great Lotus River are also relatively low. As for the above water sample concentrations, the concentrations of iron and lead, whilst exceeding the values for domestic use, are still within the target range for agricultural usage.

An evaluation of water quality parameters for the Great Lotus River system thus reveals that the principal pollutants are in terms of nutrients and microbiological organisms and not heavy metals.

4.6.6 Organic analysis

Figure 4.27, below, depicts the concentrations of the identified organic compounds for a selected day in the Great Lotus River. These compounds are saturated hydrocarbons, more specifically, linear alkanes. They are present in low concentrations. They are insoluble in water or alcohol and are compounds mainly characteristic of fuels and solvents eg. diesels, motor oils, kerosenes (Neckers and Doyle, 1977). These linear chains are essentially non-toxic and therefore pose more of a fire hazard.

Figure 4.27: Organic concentrations for Great Lotus River



From analysis of Figure 4.27, a general increase in concentrations can be noted from the source up to 4 km. This corresponds to the informal settlement areas of Nyanga/Gugulethu. Burning of fuels and disposal of oils into the stormwater system are potential sources of these compounds. The decrease in concentrations after this point corresponds to the tributary inflow from Philippi East with low concentration flow diluting the concentrations in the Lotus. The subsequent rise in concentration corresponds to a developed linear commercial area along Lansdowne Road. This area is characterised by high traffic volumes and commercial/industrial activity. Between 7 and 10km, the canal is unlined, flowing through the agricultural area of Philippi with a corresponding decrease in compound concentration.

4.6.7 Protozoan parasites

Analysis of the samples taken on a particular day revealed in the table below represents the results of a protozoan analysis undertaken on 27/08/97 for the Great Lotus River.

Table 4.14 Protozoan parasites in Great Lotus River

Location	*Giardia* cysts	*Cryptosporidian* oocysts
NY3	ND	ND
NY3A	ND	ND
Springfield Road	100	ND
7th Avenue	50	ND

Table 4.14 above shows that neither *Giardia* nor *Cryptosporidian* were detected in either of the stormwater pipes discharging into the Great Lotus River at NY3 and NY3A. This is in spite of these tributaries being identified as sources of faecal coli. No *Cryptosporidian* oocysts were detected for the remainder of the river. In terms of *Giardia*, however, 100 cysts were found at Springfield Road, and 50 at 7th Avenue. This number is in excess of that required to produce adverse health effects and, as such, constitute a significant health risk for any interaction with the water.

4.7 DATA ANALYSIS

4.7.2 Pollutant loading

A principal objective of any stormwater management study focussing on runoff pollution is to calculate an annual pollutant load into the downstream water body. In the case of the Lotus River Project, this downstream water body is Zeekoevlei. Zeekoevlei has been shown to be a self-sustaining hypertrophic system (Harding, 1996) with the phosphorus loading being the limiting factor regarding the eutrophic status of the vlei (Harding, 1996) and (McCutcheon et al, 1993). This is a characteristic of impoundments fed by nutrient rich runoff affected by urban and agricultural land uses (Wiechers et al, 1996)

Because phosphorus is the limiting nutrient affecting eutrophication in Zeekoevlei, any management recommendations must address the sources of this pollutant (Harding, 1996). Harding further suggests that "attenuation of external loading could have a positive effect on the severely impaired trophic state of the lake". It is therefore necessary to estimate the annual Total Phosphorus (TP) load into Zeekoevlei as recorded during the study.

The pollutant load washed off the catchment depends on runoff volume and concentration of pollutant (Chiew and McMahon, 1998). An initial estimate of the load can be determined for 7th Avenue on the Great Lotus River. This is the most downstream point on the Great Lotus before the water level of Zeekoevlei begins backing up into the Great Lotus. It is based on interpolation of grab sample data and would thus underestimate the actual load.

4.7.2.1 Total Phosphorus Loading – Springfield Road

It has been shown in international literature as well as in water quality analyses of the Great Lotus River, that the majority of pollutant loading occurs during storm events. Reliable estimates of pollutant loads can thus be more accurately obtained through the monitoring of several storms in the catchment (Chiew and McMahon, 1998) with an average storm pollutant loading being obtained. This is most efficiently done with an automated sampler programmed to take samples on a flow weighted basis and results in an understanding of the storm related effects on pollutant loadings in the catchment.

From the monitoring of storm events it is possible to derive an event mean concentration (EMC). This EMC is defined as the total storm load (mass) divided by the total runoff volume

$$EMC = \bar{C} = \frac{M}{V} = \frac{\int C(t)Q(t)dt}{Q(t)dt}$$

where C(t) is the time variable concentration and
Q(t) is flow measured during the runoff event.

The EMC results from a flow weighted average, not simply a time average of the concentration (Huber, 1993). Thus multiplying the EMC by the annual runoff volume will provide a more realistic estimate of the loading to a receiving water body.

It must be noted that just as instantaneous concentrations vary within a storm, so does the EMC vary from storm to storm and site to site. It is thus necessary to obtain a site median EMC to obtain an overall description of the runoff characteristics of a constituent for a catchment(Huber, 1993). This implies the need to capture a number of storms during different periods of the year to obtain a realistic average of the storm-induced pollutant loading. Unfortunately, budgetary constraints as well as a lack of any historical flow data with which to program the sampler, resulted in only 3 storm events being captured during this project. The approach taken, therefore, to obtain the annual loading should thus be seen as an example of the methodology that could be employed. An accurate annual loading calculation using the EMC approach would need many more captured storms to allow the eventual catchment average EMC value to be representative.

Table 4.15 below summarises three storms captured during the monitoring period by an automated sampler. The sampler was programmed on a flow basis to begin sampling above 0.5 cumecs with the highest frequency of sampling around the flood peak.

Table 4.15 Captured storm events – 1998 – Great Lotus River

Event No.	Begin Date	Total Runoff (m^3)	TP Load (kg)	EMC (mg/l)
1	21/04/98	5690	6.028	1.06
2	08/05/98	56690	46.477	0.82
3	10/05/98	20836	11.53	0.55

Analysis of the Table 4.15 reveals that although the first event (21/04/98) was characterised by a relatively small event load when compared to the other events, the EMC is high. This event proved to be one of the first storms of the season and provides evidence of a first flush event for the catchment. An average EMC of 0.81 mg/l TP is obtained from these storms and utilised for annual load calculations. Again, as discussed above, this average EMC should be based on further storms for a more accurate estimate of the total load.

Given the flow record recorded at Springfield Road it is thus possible to calculate an annual load by multiplying the daily runoff with the EMC for the period between 22 June 1997 and 30 June 1998.

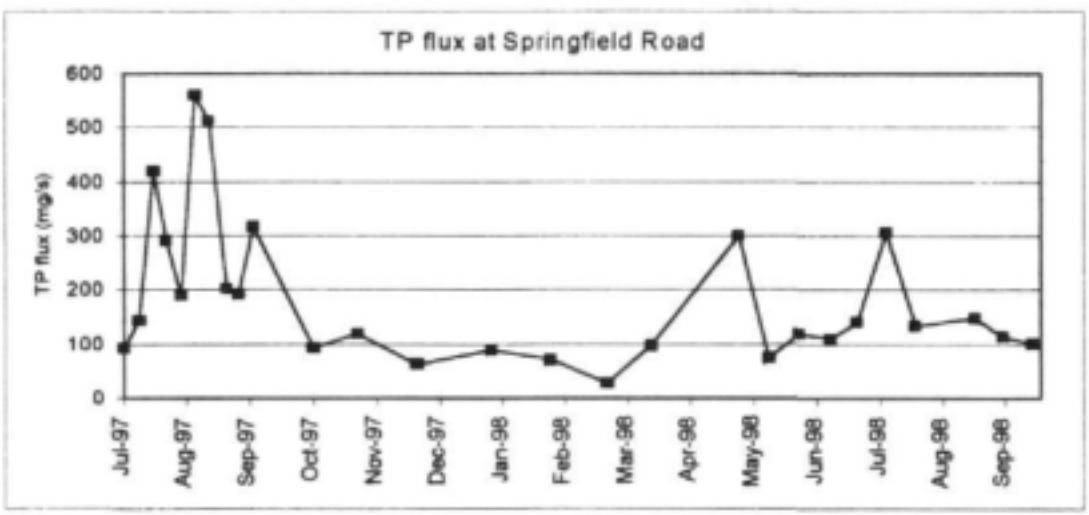
$$Load(kg/a) = \sum (EMC(mg/l) \times Q(m^3/a)$$

$$\therefore Load(kg/a) = 0.81 \times 6541000$$

$$Load \sim 5300\, kg/a$$

(this load is slightly underestimated due to 20 days of sampler inactivity)

Figure 4.28 TP Flux at Springfield Road – Great Lotus River



Based on a year of collected grab samples it is possible to calculate an annual loading through a linear interpolation of the flux variation curve shown in Figure 4.27 above:

$$TPLoad(kg/a) = \int \Phi(t)dt$$

where Φ (t) is flux (mg/s) at time (t)

From the above equation the interpolated load is calculated to be **4860 kg/a**. The interpolated load calculation thus produces a result within 10% of the EMC derived annual TP load. The similarity of the readings could be indicative of the grab sampling programme obtaining a fairly representative picture of conditions experienced in the catchment in the sampling period. This is further influenced by climatic conditions and the characteristics of the catchment itself.

A high seasonal rainfall variability is experienced in the Western Cape. Precipitation is generated mainly through winter frontal systems that occur on a fairly frequent basis. Pollutant concentrations remain high with continuous runoff due to extended periods of unrelenting frontal precipitation. Analysis of the flow duration curve for Springfield Road, with the grab sample dates highlighted in red, reveals that although many of the samples were taken during the base flow situation, samples taken in the tail of the major storms displayed higher pollutant concentrations than base flow situations. The weekly sampling period during winter was thus able to obtain a fairly representative picture of the catchment pollutant loading characteristics over the annual time period.

4.7.2.2 Total Phosphorus Loading – 7th Avenue

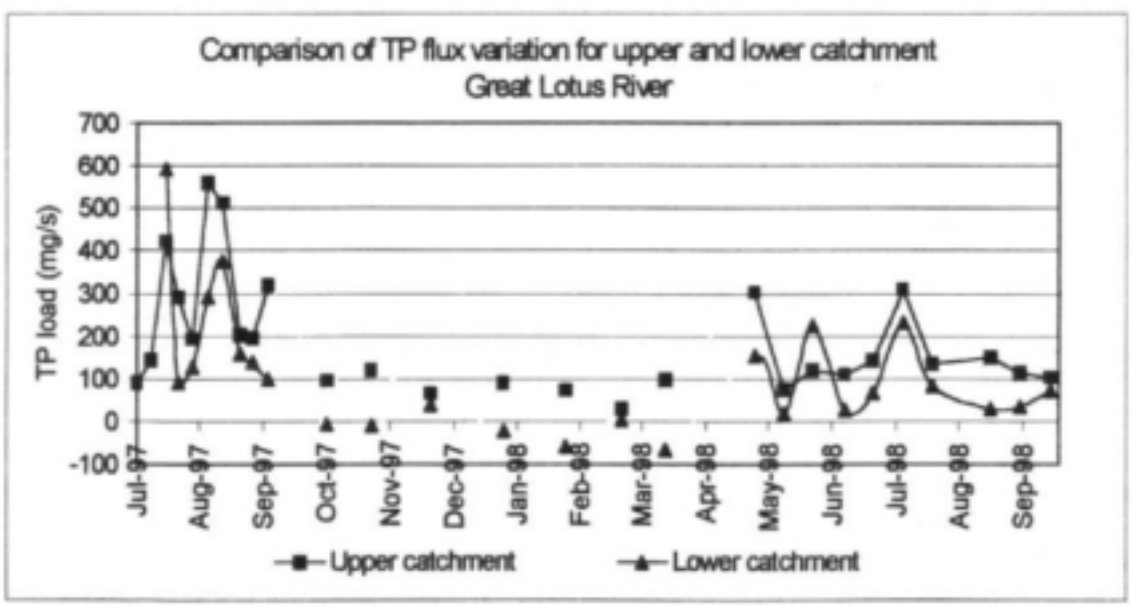
Figure 4.18 shows the TP flux at 7th Avenue over the recorded time interval. Integrating under the flux plot results in an annual load of approximately **6710 kg TP/a** flowing into Zeekoevlei.

Grab water samples provide an indication of pollutant concentrations during baseflow conditions as well as the study of long term water quality trends. Referring again to Figure 4.18 it is immediately evident that the flux is significantly higher over the winter rainfall months. This is due to most of the pollution flux being generated during storm events (Chiew and McMahon, 1998), (Huber, 1993). Because most pollutants are transported during heavy storms the above interpolated load calculation, in all likelihood, therefore underestimates the actual load into Zeekoevlei.

In order to determine whether the relationship between interpolated loads and EMC derived loads for Springfield Road holds for 7th Avenue, it is required to assess the similarity of the response of the upper and lower parts of the catchment. (Springfield Road is situated to receive approximately two thirds of the total catchment contribution and is assumed to be representative of the upper majority of the catchment. Between this point and 7th Avenue, it is assumed the lower catchment contributes the difference in loads)

Given that the majority of the pollutant loading is transported during winter rainfall period, and given that assimilation and loss of load occurs during summer, the similarity of loading characteristics is assessed for the winter period. Figure 4.29 below is an indication of the flux variation for the upper and lower parts of the Great Lotus River catchment.

Figure 4.29: Comparison of TP flux for upper and lower parts of Great Lotus River catchment



Assessment of Figure 4.29 above shows that there is a fairly similar load relationship between the upper and lower catchment (flux values below 0 for the lower catchment sources correspond to periods of

nutrient loss or assimilation between Springfield Road and 7th Avenue). Whilst the magnitude of the differences varies, the loading patterns are similar and is possibly due to the majority of load and flow being contributed to the canal before Springfield Road and the transport of such loads occurring in a concrete lined canal preventing any assimilation. In addition, the lower catchment is composed of similar landuse types with diffuse agricultural sources flowing into the canal through tributary sources as well as the stormwater inputs of the residential areas of Grassy Park and Lotus River.

Assuming that the relationship between interpolated loads and EMC derived loads for Springfield Road holds for 7th Avenue, it is thus possible to determine an annual load for 7th Avenue. Correcting the interpolated load by 10% produces an annual TP load at 7th Avenue of approximately **7400 kg/a**.

In obtaining this annual load, it is recognised that the EMC value is based on 3 storms from largely first flush events and that to be entirely representative a number of additional storms through the rest of the season should be monitored. In addition, as discussed, the annual flow at Springfield Road is slightly underestimated also resulting in the annual load being underestimated. (These constraints should produce conflicting results and an overestimation and underestimation of the load thus producing a cancelling effect.)

4.7.2 Annual runoff

In order to calculate the annual runoff for the sampling period, it is required to find a correlation between flows continuously monitored at Springfield Road with those at 7th Ave. Correlating the flows recorded through the grab-sampling programme produced a correlation of 0.978 between the two sites. This is to be expected given the canalised nature of the Lotus River and the short lag time between the points. A regression equation was thus set up to relate the flows. This resulted in a flow duration curve for 7th Avenue. To offset the error due to lag time, daily flows were calculated at Springfield Road and related to 7th Avenue through the regression equation. For the period of August 1997 to July 1998, an annual runoff was thus calculated to be approximately 9700 Ml. Given periods of sampler inactivity (~20 days), this value is thought to slightly underestimate the actual volume.

Analysis of the annual volume calculated above resulted in various runoff indices being calculated. One such index is termed the Q75 index. It refers to daily flows extracted from the flow duration curve that are exceeded 75% of the time respectively ((Smakhtin and Toulouse, 1998). This is a low flow estimation technique developed for some southern African countries and approaches the concept of "normal flow" as used in the South African Water Law (Smakhtin and Toulouse, 1998). Although this is an index derived principally for natural river systems, the Q75 index flows are calculated for various points in the Lotus River and are as follows:

For Springfield Q75 ~ 22000 m^3/d
For 7th Ave: Q75 ~ 33000 m^3/d

Analysis of the flow duration curve for 7th Avenue show that this normal flow situation occurs during the summer months as expected from roughly the end of September to the beginning of May for the period recorded. Of interest to note are the unseasonal rainstorms during this period. Whilst high event discharges were recorded the storms were of a shorter duration than the frontal winter storms and produced a correspondingly lower total daily runoff than expected. This is possibly due to the rapid response of the urbanised subcatchments without the groundwater influence of the agricultural subcatchments prolonging the flow.

4.7.3 Conclusions to annual load calculation

Although a total annual load has been calculated for the Great Lotus River, there are a number of assumption uncertainties regarding the possible accuracy of this load.

- Calculating the total annual TP load at 7th Avenue based on grab samples underestimates the actual value due to the missed storm events and the corresponding higher loads transported during these events.
- A more accurate means for calculating the annual load uses the concept of the Event Mean Concentration. The theory shows that this captures the effect of higher storm flows and would thus produce a more realistic value for the TP load. Unfortunately this EMC has been calculated on a small number of storms (3) and only at Springfield Road.
- In accepting the relationship between calculated EMC and interpolated load for Springfield Road, it is questionable whether the same relationship holds of 7th Avenue (i.e. whether the similarity in loading characteristics for the upper and lower catchment seen from the grab sample program holds for significant events)
- A good correlation exists between the two stations in terms of the recorded grab sample flows. This results in a regression equation being calculated. These readings were, however, recorded most frequently during normal flow conditions and it is uncertain if the same relationship holds for flood flows.

4.8 HYDROLOGICAL MODELLING

The original objectives of the Lotus River Project included the development of a GIS-based catchment runoff model. Subsequent budget restrictions prevented this objective from being realised. What has been developed is the modelling philosophy to be followed, the preferred choice of model for urban catchment management applications, and the input data in terms of hydrological parameters required by the model, generated from the GIS of the catchment area (as detailed in Chapter 2 above). Some preliminary work has been done on modelling the upper portion of the catchment where detailed data on the stormwater system was more readily available. A continuous runoff model of the entire catchment forms part of future research to be carried out (Males, in prep), which may subsequently be used as part of a decision support system for catchment management.

Catchment management can be seen on one level to be concerned with the implementation of management actions in a catchment, thereby addressing critical water resource problems in an integrated manner, based on a thorough understanding of the cause and effects of those problems (Görgens et al, 1998). Current trends in catchment management and the desire of the community for an enhanced aquatic environment require information about the water environment within the catchment (Ball and Powell, 1998). This understanding of catchment resources and their interactions is fundamental to sound decision making and is obtained through a combination of detailed assessment of available information and catchment water resource modelling (Görgens et al, 1998).

Mathematical models can be seen as a quantitative expression of a process or phenomenon one is observing, analysing or predicting (Overton and Meadows, 1976). (Hughes, 1991) in attempting to review classifications of models observed that it is possible to suggest as many classification schemes of models as actual models themselves. At extreme ends are empirical lumped (black box) and physically-based distributed (white box) models.

Physically-based distributed models (white box) follow a deterministic approach based on reductionist philosophy and attempt to relate all underlying physical, chemical and biological laws of nature to a set of partial differential equations that govern an engineering application (Harremoës and Madsen, 1998). It assumes that a system or process operates such that the occurrence of a given set of events leads to a uniquely definable outcome (Preti, 1996). Deterministic distributed models include SHE (Abbot et al, 1986), SWMM (Huber and Dickinson, 1992), WITWAT (Green, 1984) etc.

Although any deterministic model is based on understanding the physics of the modelled system it, however, includes empirical components (Hughes, 1991). This is due to all models being an approximation of reality and thus subject to simplifying assumptions and errors. Empirical (black box) models require a trial and error stochastic approach involving calibration against a recorded database from which to optimise model assumptions. Stochastic models presuppose that the outcome of the modelling exercise to be uncertain and are structured to account for this uncertainty. Stochastic models are often simple models yet since they contain elements that describe elements in terms of distribution functions or random variation, statistical approaches can be used for identifying model structure, estimation of model parameters and model validation (Harremoës and Madsen, 1998). Of significance,

however, is that black box models relate inputs to outputs through arbitrary functions and therefore have no physical significance. Examples include regression models (linear) and transfer models (ARMAX)

Between the above extremes, a number of grey box models exist combining the above deterministic and stochastic approaches (Harremoës and Madsen, 1998). They represent a compromise between limitations of available data, sound conceptualisation and model formulation (Hughes, 1991). This approach makes it possible to combine information in terms of physical, chemical and biological knowledge with information embedded in available databases. They frequently use subcatchment distribution systems (SWMM - Huber, 1992 and WITWAT - (Green, 1984)) and the model algorithms are based on a mixture of physically measured and empirically based parameters (Hughes, 1991).

Significant work has been undertaken by the Water Systems Research Group of the University of Witwatersrand on catchment hydrological modelling. One such investigation resulted in a series of reports being published on the effects of urbanisation on catchment water balance (Stephenson et al, 1992b). Two topographically similar catchments were considered, one virgin and one urbanised. In order to distinguish between different effects, runoff was modelled through a realistic distributed parameter model (Stephenson, 1992a).

This model, WITSKM, based on physical laws and measurable parameters attempted to minimise calibration effects and to thus represent all observable effects (physically distributed white box model). Because of subsurface parameters having to be estimated, however, this model is a grey box model of the above type. The study thus focussed on the estimation of significant parameters as well as an assessment of the significance of these parameters (Stephenson, 1992a).

The choice of model is dependent upon desired level of complexity with the appropriate level of analysis dependent upon: (Yen, 1994)

- Objective and approach taken – continuous vs. event based analysis
- Information needed – design discharge or runoff hydrographs
- Accuracy required
- Available data – sewers, junctions, catchment, rainfall (spatial and temporal)
- Tools available – computer capability and numerical techniques
- Flow conditions – network, catchment properties, roughness, Froude numbers

Effective solutions thus require understanding, proper selection and application of hydraulic analysis. For a particular modelling application it is thus necessary to define the desired complexity and information required based on available data.

For modelling purposes in the Great Lotus River, a continuous model was required able to relate, historically, rainfall data with collected runoff data. (Past modelling in the catchment was concerned specifically with design purposes and thus was based on an event modelling approach) Continuous modelling is used for ICM purposes as a means of decision support for catchment managers. It, therefore, should be of sufficient accuracy to determine, say, effects on runoff quantity or quality of catchment landuse changes.

The Stormwater Management Model (SWMM) was selected as a model comprising a semi distributed physically based approach with varying levels of complexity. This model, written in Fortran and developed in 1971, has evolved through the decades to be capable of simulating urban stormwater runoff and CSO on a continuous and event basis. The model has undergone extensive improvements in this period including the adaptation to personal computers and the development of user-friendly Windows interfaces for ease of use.

PCSWMM'98 (an interface to SWMM version 4) developed by Computational Hydraulics Inc (CHI), Canada, was written as a decision support system for SWMM and provides a large array of file management, data file creation, output interpretation and model calibration (James and James, 1998). It was written specifically for the web and the extensive user group facilitates queries to be addressed and answered.

Complex interactions between the meteorology and hydrology of an area can be simulated with SWMM being run for an unlimited number of timesteps. This implies a simulation resolution of daily, hourly or even 10-minute intervals. In this way an overall assessment of urban runoff problems can be performed or critical events from a long period of simulation can be selected for detailed analysis. These all being issues to be considered in an ICM application.

Primary input into the model is long term precipitation data. Outputs consist of hydrographs and pollutographs over an event at a specified interval of time steps. Utilising rainfall and basin characteristics as inputs, SWMM calculates stormwater quantity and quality. The model consists of four components: RUNOFF, TRANSPORT, EXTENDED TRANSPORT and STORAGE.

- RUNOFF simulates quantity and quality runoff phenomena for a drainage basin and the routing of flows and contaminants to the major sewer lines. It represents each basin by an aggregate of idealised subcatchments and gutters or pipes (James and James, 1997).
- Routing through the sewer system is accomplished in the TRANSPORT block. This includes routing of quantity and quality parameters, estimating dry weather flow, infiltration and storage (Huber and Dickinson, 1992)
- Extended TRANSPORT (EXTRAN) was developed for complex systems where the assumption of steady flow cannot be made. It is thus a dynamic flow routing module solving the full St Venant equations for gradually varied flow (Roesner and Dickinson, 1992).
- STORAGE simulates the routing of flows and pollutants through storage/treatment plants having detention or non-detention characteristics (Huber and Dickinson, 1992).

Although SWMM was designed principally for urban stormwater runoff problems, the subsurface flow routing module incorporating infiltration, evapotranspiration, interflow and percolation enable the pervious rural subcatchments of the multi landuse type Great Lotus River catchment to be sufficiently modelled.

Through the process of ICM, the understanding obtained of the catchment should be synthesised and captured on an accessible and dynamic information system to support future decision-making (Pegram, 1998). This is thinking in terms of Catchment Management Information systems and is done most effectively on a Geographic Information System (GIS). GIS provides the basis for spatially referenced data and should be linked to databases of other types of data. This is especially significant when operating data intensive physically based runoff models, requiring a large amount of catchment physical data to be collected, collated and stored before input into the model. The present state of the art of physically based runoff models includes direct linkages with GIS systems. This allows seamless integration of model and GIS system thereby representing geospatial data for both model input and output.

As discussed above, the time and budget allocated for the Lotus River Project prevented hydrological modelling within the GIS environment. The GIS was therefore used to provide a means of estimating a number of input parameters for the modelling process. Apart from estimation of input parameters, GIS offers many other advantages for catchment runoff modelling as a decision support tool. These advantages are discussed in detail in Chapter 2 and will not be repeated here suffice to say it results in:

- More accurate parameter estimations
- More rapid parameter estimations
- Facilitates potential for utilising existing public databases
- Facilitates potential for grid-based distributed hydrologic modelling
- Facilitates an integrated analysis of the various data sets through the spatial overlay capability
- Facilitates a more realistic representation of data
- Facilitates effective communication
- Facilitates wide spread diffusion of information
- Facilitates spatial analysis for planning

4.8.1 Results of modelling of Great Lotus River

As discussed, although completion of a model was beyond project resources, the development of a detailed stormwater model was initiated for the Great Lotus River catchment. This is to be a continuous simulated model capable of being utilised as a catchment management decision support system (DSS).

The discussion below broadens the description of the SWMM modelling process. Descriptions of the model are from User Manuals written by (Huber and Dickinson, 1992) and (James and James, 1997). The discussion also includes the difficulties found in determining the initial input parameters. At this time only the water quantity aspects of the model have been investigated. The extensive water quality components of the model detailing pollutant build up and wash off is part of further research.

4.8.1.1 RAIN

Precipitation is the principal driving input into SWMM. RAIN reads long term precipitation records, performs optional storm event analysis and generates a precipitation interface file for inputting into RUNOFF ((James and James, 1997).

The Department of Environmental Affairs and Tourism (DEAT), as well as the Cape Metropolitan Council (CMC) are involved in the collection of meteorological data for the catchment. A DEAT gauge, at the Cape Town International Airport, monitors rainfall for the headwaters of the catchment. In addition to this, there are a number of automatic rainfall gauges in the catchment monitored initially by the Cape Town Municipality (CTM) and now under the jurisdiction of the Catchment Management Department of the Cape Metropolitan Council (CMC).

Unfortunately only data from DEAT was consistent and without gaps. One of the gauges maintained by the CMC in the catchment, Groenvlei, is outdated and prone to breakdowns (Page, 1997). Monitoring of the gauges is on a monthly basis with any breakdowns thus resulting in significant gaps in the data. The Catchment Management Department of the CMC is in the process of taking responsibility for these issues, and developing a monitoring strategy and this should lead toward a more efficient service in the future.

Requests for data resulted in supply of daily and monthly rainfall figures. For a dynamic catchment with a hardened quick response this is insufficient resolution to drive an intensive run. Raw rainfall data was thus requested and read into SWMM.

In order to assess the spatial variability of rainfall across the catchment, precipitation data for four gauges was collected for the Great Lotus River catchment (SWMM caters for up to 10 gauges). To accurately determine rainfall hyetographs complete rainfall datasets are required. This resulted in the patching of missing data for the Groenvlei gauge through the inverse squared distance weighted method using distances to the other three gauges with complete datasets. Precipitation intensity files with 10-minute intervals were thus produced as interfaces to the RUNOFF module. Given the dynamic nature of a hardened quick response urbanised catchment this short rainfall interval allows more accurate determination of rainfall runoff relationships for these catchments.

Evaporation data was obtained from the same sources. It is input either as monthly values or as a time series. It is considered as a "loss off the top" and is subtracted from rainfall before infiltration.

4.8.1.2 RUNOFF

RUNOFF forms the origins of flow generation in SWMM. Precipitation files generated in the previous module are read in as input hyetographs with RUNOFF making a step by step accounting of infiltration losses in pervious areas, surface detention, overland flow and channel flow. This leads to the calculation of a number of inlet hydrographs and pollutographs (which may be placed on the interfacing file for input into subsequent modules).

Input data for this module requires two tasks:

- discretisation of physical drainage system
- estimation of subcatchment coefficients

Subcatchments are described as subareas either: impervious with or without depression storage and pervious. Overland flow is generated from each subarea by approximating them as non-linear reservoirs, spatially lumped, with uniform slope, constant roughness, depression storage and infiltration parameters. (The width is considered a calibration parameter and used to adjust predicted to measured hydrographs).

Infiltration is either through the modified Horton (empirical) or Green Ampt (physically based) approaches. Losses from infiltration may optionally be routed through a subsurface pathway first into unsaturated zone storage then to a saturated zone form which baseflow into an inlet or channel pipe may be generated.

Discretisation of the catchment begins with the identification of drainage boundaries through topographical drainage maps. For the Great Lotus River, subcatchment data was obtained from City of Cape Town 1993 spotheight data. Subcatchments were divided with homogenous land use types.

Subcatchment boundaries determined by consultants for the event based model were deemed to be inappropriate. This is due to the event model determining 1:50-year flood levels that have the road network as primary flood input (stormwater pipes are presumed to be surcharged with the excess flowing along road corridors). For a continuous simulation, however, overland flow generated off subcatchments is routed through gutters and pipes. Stormwater pipes are also considered as non-linear reservoirs in SWMM flow routines (coupling of Manning equation with continuity equation). Exceedance of pipe capacity results in a surcharge with the water being stored at the upstream end until the pipe can accept it. Of the subcatchment impervious areas, an estimate of the effective imperviousness was made. This approximates runoff from impervious surface areas that are directly connected to the stormwater system (e.g. roof gutters leading to channels to road catchpits are considered hydraulically connected)

In order to adequately define the subcatchment boundaries, it is necessary to assess the routes of the subsurface stormwater pipe network. This is also due to the majority of inputs into the Great Lotus River being stormwater inputs. The acquisition of this data proved to be an institutional nightmare.

As discussed previously, the Great Lotus River flows through two separate municipalities: CTM, SPM. Historically there were many changes in local authority jurisdiction of the river. This has had a fundamental effect on the existing data as well as the level of present services offered.

The upper parts of the catchment consist of the previously disadvantaged township areas of Barcelona, Nyanga and Guguletu. In addition to these areas being historically ignored in terms of the provision of water services including both sewerage and stormwater facilities, the problem is further exacerbated in that these services have been improperly documented with no detailed stormwater layout drawings for significant parts of these areas.

In an attempt to rectify this problem, consultants were tasked by the then City Engineer of the City of Cape Town to undertake a preliminary investigation and technical review of the stormwater infrastructure in the Crossroads, Nyanga, Guguletu and Langa areas ((Dachs and Orrie, 1997). It entailed the collation of data from various sources including existing records, previous consultant studies, and the Strategic Management Plan (SMP) Project (this project incorporating cleaning of the stormwater infrastructure). From this collated data, it was then required to assess the critical hydraulic and physical deficiencies in the bulk infrastructure.

Analysis of the report shows that there is a wide disparity in the detail of available information. Although the report compilers collected as many drawings as could be located, the drawings range in detail from very old drawings with no useful information to those of recently completed projects with full detail and in CAD format. These collated records have all been referenced and indicated on a GIS Masterplan for the above areas (Dachs and Orrie, 1997). Examination of this masterplan shows that the area has not been comprehensively covered, rather that individual organisations have completed drawings only for their particular area of interest. As noted before, this has resulted in a wide variation in the information available from these drawings. Furthermore, it also suggests that areas that have not received recent attention are undocumented and there are thus large gaps in the area for which no drawings occur (Dachs and Orrie, 1997).

This has a detrimental effect on the objective of hydrological modelling of the Great Lotus River. A deficiency of subcatchment and stormwater data will result in the unnecessary large scale lumping of the subcatchment physical attributes with the accompanying decrease in modelling accuracy. This is highly undesirable given the high resolution and modelling accuracy required to investigate catchment changes for ICM.

Of the existing data, a further institutional obstacle was the local authority ignorance of data they were in possession of themselves. This necessitated the approaching of individual consultants responsible for stormwater work in the area to collect drawings. As mentioned above however, the plans are patchy, significant areas are lacking of any data or the present data is only in terms of layout without detailed accounts of the stormwater data required to run a data intensive model such as SWMM. This refers to pipe sizes, linkages, slopes, lengths, material etc. From these drawings an overall master drainage plan was put together drawing by drawing and digitised on GIS for rapid access to layout. This layout plan does not have any attribute data attached and is merely a schematic.

- The GIS was additionally utilised in estimating primary input parameters for input into SWMM. These correspond essentially to the topographical data requirements of the model. These requirements include the following parameters: sub-catchment area (ha), % imperviousness, sub-catchment length (m) and the overland slope (m/m).

- The area and length parameters were determined in the Intergraph MGE project environment using Microstation tools. The average slope for each sub-catchment has been determined by referring to orthophoto imagery (1:30000) produced by A.O.C. SYSTEMS (Pty). (See chapter 2)

The above process of data collection was an exhausting and time-consuming process. Within the present project constraints, only the upper township developments were captured in this way. Stormwater pipework of diameter 450 mm and greater was considered to be of a sufficient resolution for modelling purposes. The result was the inputting of all available stormwater and subcatchment data into SWMM and the generation of a first run.

As discussed above, this was performed at a 10-minute interval. (Discussions with SWMM developers revealed that an hourly interval would provide information on annual water budgets and pollutant loads, but given the significant reaction of urban and impervious areas to rain events, viz. property destruction, habitat pollution, flooding killing people, a higher resolution interval is desired. In addition, present computing power results in no significant increase in computing time and the costs of simulation are relatively nothing for higher resolution (James, 1998).

This run entailed routing of overland flow off each subcatchment in Nyanga/ Guguletu to a respective stormwater conduit or pipe. These pipes are linked to an eventual outlet conduit for each subcatchment. Hydrographs are stored for each outlet in an interface file for input into further SWMM modules.

As part of future work, stormwater drainage plans need to be collated for the rest of the catchment and digitised to form a stormwater drainage masterplan for all the urbanised parts of the Lotus River catchment. Local authorities are in the process of digitising uncharted areas of the This is also required for the agricultural sections of the catchment where a design master plan has been created but which has been modified through excavation and infilling on individual properties.

4.8.1.3 TRANSport

Flow routing through the stormwater/sewer system is accomplished in the TRANSport module of SWMM. For the purpose of modelling in the Lotus River catchment, simulation of flow in the Great Lotus River is accomplished in TRANSport. This module has benefits over RUNOFF for flow routing and includes additional elements for channel routing. The Great Lotus River is characterised by multi stage channels with varying cross sections and roughness coefficients as well as irregular earth lined channels. These cross sections can be captured in TRANSport through an option for inputting coordinates of an irregular cross section and the roughness coefficients for each section.

Hydrographs stored in the above RUNOFF module are considered as inputs into the Great Lotus River in TRANSport. These are summed with hydrographs and pollutographs generated at specified points. This is desirable given the need for calibration of simulated hydrographs with those generated by the continuous datalogger. This permits the optimising of model parameters to ensure best fit of simulated to observed.

4.8.2 Concluding remarks

Water resource modelling is vital for the monitoring, assessment and management of the physical environment in support of catchment water quality management. Modelling provides the link between the conceptual understanding of the physical catchment characteristics and the empirical quantification of the hydrological, water quality and ecological response.

It is utilised for the evaluation and prioritisation of water quality issues and the selection and operation of possible management techniques. It also provides the only method of predictive quantification of the impacts of possible management actions and/or future development scenarios. (Pegram et al, 1997) However, water quality modelling is still in a relatively early stage of development compared to the sophistication of the hydrological models now available.

In terms of modelling and monitoring, developments in information and computer technology, electronic communication, remote sensing, control and modelling have had a significant impact on catchment hydrological management (Somlyódy, 1995). Combining databases, models and interfaces (such as the GIS/runoff model interface), in terms of decision support systems, offer excellent opportunities for integration, analysis and consideration of complex water-related issues. Modelling for flood management using rainfall and streamflow monitoring and radar to track storms is a particularly topical issue.

In order to run these detailed models, it is imperative that detailed drainage patterns and stormwater network characteristics (urban conditions) are available for efficient catchment management. It is preferable that this information be obtainable on a GIS platform and needs to be emphasised at local authority level (see Chapter 2). Access to this detailed information is necessary, and if the information itself is lacking, funding should be made available for the rapid acquisition of this information.

It is only with a detailed knowledge of pipe network capacities and catchment response to flood events, that detailed catchment hydrological models can be created enabling catchment management organisations and local authorities, confidently and holistically, to develop effective catchment plans. These are essential for supporting development-related decisions, which may involve moving people off flood plains. All programmes for the upgrading or maintenance of river systems should be preceded by the development of a catchment plan. Finally, the water quality modelling component enables the prioritisation of issues to be tackled when combating pollution in an urban catchment.

CHAPTER 5 ECOLOGICAL MANAGEMENT OF THE CATCHMENT

5.1 INTRODUCTION AND AIMS

5.1.1 Introduction

The Lotus River Catchment is a highly modified environment; people and their activities have been affecting the system for many centuries (Cowling, 1992). It has recently become intensively urbanised - catchment permeability dropped from 83% to 56% between 1983 and 1996 (see Chapter 3). Even the remaining vegetated areas and wetlands are very disturbed. Drainage patterns have been highly modified; many of the vlei and marsh areas have been filled in or destroyed, and stormwater canals have been engineered. Nutrient additions to farming areas and urban run-off have increased the nutrients in the aquatic and terrestrial systems 10-fold. In addition to this, introduced Australian acacia species have become highly noxious invasive weeds, spreading into all open areas and eliminating the natural vegetation. Urbanisation of the catchment is an ongoing process and the catchment is constantly changing.

It is within such a context that an ecological assessment of the Lotus River was attempted: the degraded state of large portions of the catchment and the large numbers of people living in the catchment both mean that traditional conservation measures need to be reassessed and modified. The aims of this ecological assessment move beyond pure identification and conservation of the remaining semi-natural/pristine areas of the catchment into a more dynamic, positive approach to the environment in an urban context. The aim of this assessment was to identify and discuss ways in which the environment of the catchment could be improved for the humans, flora and fauna living there. Rare and threatened habitat types such as seasonal vleis and sandplain fynbos need to be valued and managed, but this has to be done in the context of the people who live around these areas and the future development of the catchment.

Aims for the ecological management of the subcatchment can therefore be summarised as follows:

- Increasing the biodiversity of the catchment, both in terms of species richness and habitat diversity
- Conserving unique species and features
- Increasing the sustainability of the ecological systems in the catchment, through reinstating functioning ecosystems
- Improving water quality
- Improving the quality of the available open space (both for human use and in terms of habitat quality for the fauna/flora)
- Ensuring a sufficient representation of habitats and habitat types in the subcatchment (enriching the urban environment)
- Enhancing access by communities to the environmental resources of the catchment
- Identifying management tools to improve the environment and the functioning of the ecosystems.

To this end it is important to assess:

- The nature of the original pristine ecosystems (ie. what conditions are beneficial for the indigenous animals and plants)
- What fauna/flora are present at the moment
- How much space, and what sort of space is required to fulfill the aims mentioned above (The Rio Convention on biodiversity suggests that countries aim to conserve a minimum of 10% of a habitat/ecosystem. Moreover, seasonal wetlands are variable habitat types which require a wide range of representation in order to be temporally consistent. Space needs to be considered in a broader context as well: the size, shape, and position of areas affect their utility as islands and dispersal corridors for animals and plants).

- The extent of the space available for ecological management. This includes:
  - Formally conserved areas
  - Space used for some other purpose, but which could be multi-purpose (detention ponds, river channels, farmland)
  - Highly degraded areas which have the potential to be improved and become assets in the catchment
- The functioning of the ecosystems: understanding the environmental factors by which they are affected and which need to be controlled (water quality, noise, disturbance, size etc).

5.1.2 Available information on the original ecology of the Cape Flats

The Cape Flats forms part of the Cape Basin, which is a remarkably uniform geographic feature (Deacon et al, 1992). The altitude change from Zeekoevlei to the source of the Great Lotus River is less than 20m. In the past it has been inundated with seawater for long periods of time (in the cretaceous and the Cenozoic). The soils present are the result of many years of weathering and consist mainly of deep old marine limestones and sands (Cowling, 1995). This means that the water (especially standing water) is slightly alkaline (Stephens, 1929).

The previously shifting sands & dunes are now mostly secured by vegetation but the landscape still shows signs of being sculpted by the wind – the numerous depressions and shallow hollows are thought to have been caused by wind erosion. As mentioned, the topography is very flat and drainage has generally been very undefined – characterised by ponding and seepage of stormwater. There were originally no permanently flowing rivers and open, seasonally inundated vlei/marsh areas were wide-spread (Stephens, 1929; Day and King, 1980).

Underlying clay prevented the water from percolating deeply and in winter large expanses of land would be submerged under several centimeters of clear water. There would be many submerged aquatic plants and algae and an astounding diversity of amphibians and crustaceans (Stephens, 1929). In summer the depressions all but dried up and were covered with coarse grass, Crassula and Salicornia species.

The aquatic life was much richer in this region than other areas of the SW Cape (Stephens, 1929) and much richer in the seasonal than the permanent wetlands. There are 12 frog species which occur naturally on the Cape Flats and the life histories of 40% of these are specifically adapted to the seasonal vleis characteristic of the region (de Villiers, 1997). A range of small mammals (mostly rodents) is also recorded to occur here (Erasmus, 1997). Although no ecological appraisal of the seasonal wetlands of the Cape Flats has ever been done they can be considered a threatened habitat (Day and King, 1980; Campbell, 1980).

The original terrestrial vegetation of the area is sandplain fynbos (Spottiswode, 1997). This is described as 'Medium-height proteoid shrubland with a low ericoid and restioid understorey' (Cowling, 1995) and characterised by Leucodendron coniferum (dune conebush) and Thamnochortus erectus (dakriet). This is a vegetation type typical of the Cape Flats, which is fast disappearing due to urbanisation and agriculture and is the focus of much attention from conservationists (Cowling, 1995).

Thus the wetland systems and the terrestrial systems, which are natural on the Cape Flats, are very interesting ecologically, unique to the area, and considered to be threatened habitats (ie. not adequately represented anywhere else). Identification of any examples of these habitat types within the Lotus River catchment is therefore very important in any ecological management plan.

5.2 METHODOLOGIES EMPLOYED

5.2.1 Catchment studies

5.2.1.1 Collation of information on the present status of the catchment

Information on the ecology of the Lotus River catchment was collected from various sources. Numerous specialist reports have been written as part of development plans in the catchment (Cape Flats Freeway

extension, Wetton-Lansdowne Corridor Project). These studies identified areas in the catchment which are of importance for their fauna/flora, gave lists of animals and plants present in these areas, classified them (gave them conservation status) and presented various recommendations.

An extensive vegetation study of the entire Cape Flats area has been (and is being) performed (McKensie and Low, 1991; Rebelo, 1997) (Golding unpublished) with the aim of identifying sites of core floral importance (conservation value) and thus focussing development/conservation plans. The information from this study, which pertains to the Lotus River catchment, was included.

This information has been integrated and complete descriptions of important sites are presented in the catchment description section. As mentioned above, the aims of ecological management presented in this study do not necessarily coincide with strict 'conservation' aims; however, it is important to have an idea of the conservation value of the various sites in the catchment so this information is also presented.

Various field trips into the catchment supplemented this information available on the catchment.

5.2.2 River studies

5.2.2.1 Physico-chemical data

The methods of collection of physico-chemical data at each site are outlined in chapter 4. Data collected over the last 15 years by Scientific Services Department of the CMC was also utilised.

5.2.2.2 Bioassessment

The use of biological indices to assess river health and ecosystem functioning has received much attention over the last 10 years (Uys, 1994; Davies, 1998; Dallas & Day, 1993; Hellawell, 1989). Various rapid biological assessment protocols have been developed over the world based on the theory that the abiotic conditions in a river control which species are able to survive and therefore, inversely, that the species in the river (usually community composition – the types of organisms found) will be an indication of the abiotic conditions in the river.

Biological indicators were used in the Lotus River system in order to:

1: Describe the state of the rivers at present. This can then act as a template against which any rehabilitation measures can be compared.

2: Obtain some measure to demonstrate the effect which various (abiotic) characteristics of urban streams (canalisation, high flow rates, little vegetation, high disturbance, low water quality) can have on the aquatic organisms and the functioning of the river ecosystem.

To this end a program of macro-invertebrate sampling was initiated on the Lotus River system. Invertebrate counts can be used on their own as a measure of the diversity of a community, and also can be used in more sophisticated bioassessment protocols. In South Africa SASS (the South African Scoring System) is one such protocol developed for the bioassessment of water quality in South African rivers (Chutter, 1994; Dallas, 1995; Chutter, 1998).

Site selection

There were 14 sampling sites along the Great Lotus River and 3 on the Little Lotus. Samples were taken upstream and downstream of 4 major confluences on the Great Lotus River so that the relative contributions of tributaries' hydraulic and pollutant loads on biotic diversity would be detected. 13 of the 14 sites coincided with the water quality and flow measurement sampling sites as shown (Table 5.1) and were sampled within 2-3 days of water quality sampling, so that water quality and SASS scores could be compared (Underwood, 1993).

Sampling regime

Sampling was carried out over 1 year (from 22 July 1997 to 23 July 1998). Initially sampling was undertaken every 3 months. This was subsequently changed to monthly sampling, in order to undertake a more detailed assessment of variability in the system (Underwood, 1993). Sampling followed the SASS4 protocol described in Thirion et al, 1995.

Samples were taken from each of the habitat types present at each site (which could generally be divided into vegetation and no vegetation). A "kick" sampling technique was used: the river bed is disrupted using one's feet, with the net (a 180µm mesh sweep net) placed immediately down stream to catch dislodged insects for a specified time period. The invertebrate organisms obtained in this manner were identified to familial level. This data was then summarised as a macro-invertebrate count (indication of the diversity of the aquatic community) for each site.

This data can also be converted into a SASS4 score (a measure of water quality - see section 5.4.2.2 and Dallas, 1995): The unit of taxonomic currency is the family, each of which has a score associated with it. This score represents each family's sensitivity to poor water quality ranging from 15 in sensitive taxa to 1 in pollution tolerant species. The total SASS4 score for each site is the sum of the scores for all families recorded at that site. Thus the lower the SASS4 score the poorer the water quality (Davies and Day, 1998). The Average Score Per Taxon (ASPT) can also be calculated for each site and this provides more information on the sensitivity to pollution of the organisms present.

Table 5.1: Description of macro-invertebrate sampling sites on the Great Lotus River, *with average Habitat Quality Indices, SASS scores and Average Scores Per* Taxon (ASPT) (averaged over 8 sampling events in 1 year, July 1997 – July 1998)

Sampling Site (Site No)	Description of site	Habitat Quality Index	Average SASS4 Score	Average ASPT	Average taxa count
N2 (SP1)	unlined channel slow flowing water vegetation	33	30.50	3.75	9
NY3(up) (SP 2)	lined channel slow flow no vegetation	23	7.37	2.33	3
NY3(dn) (SP 4)	lined channel slow flow no vegetation	23	3.37	1.32	2
Philippi (up) (SP 5)	lined channel medium flow no vegetation	20	4.75	1.99	2
Philippi (dn) (SP 7)	lined channel medium flow no vegetation	20	2.50	1.54	2
Vygekraal (up) (SP 8)	lined channel medium flow no vegetation	21	1.75	1.50	1
Vygekraal (dn) (SP 10)	lined channel medium flow no vegetation	20	2.12	1.29	2
Hein Rd	unlined channel slow flowing water vegetation	23	13.00	2.53	5
Lansdowne Rd (SP 10A)	lined channel (armourflex) medium flow vegetation	20	24.25	3.20	7
Springfield Rd (SP 11)	unlined channel slow flow vegetation	39	23.87	3.31	7

CCC (up) (SP 12)	lined channel fast flow vegetation	37	18.25	3.29	5
CCC (dn) (SP 14)	lined channel fast flow no vegetation	20	7.87	2.73	2
Klip Road (SP 15)	lined channel fast flow no vegetation	20	8.75	2.42	4
7th Avenue (SP 18)	lined channel fast flow no vegetation	20	6.17	2.28	2

5.2.2.3 Ecotoxicology

Introduction

Vertebrate embryos have been used successfully in ecotoxicology for a considerable period of time. The techniques employed in such analyses exploit the sensitivity exhibited by developing vertebrate embryos to their immediate chemical environment. This is because embryonic cells, in the process of intensive replication and division, are particularly sensitive to chemical cues. Perturbations from the norm, or optimal, are usually expressed as aberrant development or even death. In lotic environments, water physiochemistry is particularly important in determining the rates and nature of early embryonic development and lotic vertebrates, such as amphibians, lend themselves well to ecotoxicological analyses. Xenopus (Amphibia), particularly, has been used extensively to assess water and habitat quality within lotic systems. Developmental aberrations, eg. deformed limbs, usually being derived from chemical stimuli such as pesticides; and death or stunting usually being attributed to environmental or physical factors such as temperature and light (Hellawell, 1989).

Materials and Methods

Specimens and Examination

Professor Alan Channing of the Zoology Department of the University of the Western Cape provided a total of 140 Xenopus embryos (Gosner stage 19). The embryos were separated into 4 groups: one control group consisting of 20 individuals and three experimental groups consisting of 6 batches of 20 embryos.

Three samples sites were chosen along the Great Lotus River with 2 replicates per site: one at 4A just below Gugulethu, one at the Springfield Road culvert in Philippi and the last at the 7th Avenue culvert in Grassy Park. Sample sites were chosen such that the runoff contributions of a high-density settlement, an agricultural area and low density housing area could be assessed respectively.

Samples were transferred into cylindrical nylon gauze bags with screw-top lids and secured using 0.2-0.5m of string to the riverbank, vegetation and Gabion mattress reinforcing respectively. Where possible, care was taken to place the receptacles in areas free from potential hazards such as areas of extreme turbulent flow or physical obstacles. Samples were retrieved 5 days after immersion (23 June 1998) and fixed using 8% formalin immediately after removal from the river. These samples were taken to Professor Channing at the University of the Western Cape for analysis on the same day.

Procedure

The test is a modification of the FETAX procedure, which involves scoring mortality and developmental abnormalities using quantitive and qualitative means respectively.

Results

Control

The control batch developed normally, growing from Gosner stage 19 to stage 25. Mortality was low with 19 out of 20 embryos surviving. This is within the range expected.

Site 4A - below NY3 in Gugulethu

Although development showed no clear abnormalities, mortality was high with 8 and 6 embryos surviving. Mean survival rate was 7/20 (35%).

Site 11 - Springfield Road culvert in Philippi

Development appeared to be normal with mortality slightly higher than the control group. 15 and 13 embryos survived. Mean survival rate was 14/20 (70%).

Site 18 - Seventh Avenue in Lotus River

The mortality appeared to be extremely high with only 1 embryo in total surviving (3%).

General

Development of all surviving embryos appeared to be normal, with somewhat more dorsal pigment than the control which may have been attributed to the level of sunlight at the test sites. Variation between the embryos was minimal and within the range expected.

Discussion

The sites below NY3 and at 7th Avenue would appear to have been extremely stressful for the developing Xenopus embryos during the time the test was run. The cause for the increased mortality at these sites was unknown. Even if the Springfield site (SP11) was an internal control, then both sites 4A and 18 posed significant threats to survival.

It must be noted that concrete lining is present at both these sites. Higher velocities at these sites may have affected development, as upon removal, most of the embryos seemed to be aggregated in a corner of the gauze receptacle. The absence of embryo deformities could be indicative of the fact that there were no mutagens (such as pesticides/chemicals) at high enough concentrations in the river at the time. Additional trials of this nature should be performed, particularly during periods of low flow when relative concentrations of mutagens would be higher and the likelihood of embryo damage, as a consequence of high water velocities, would be lessened.

5.2.2.4 Descriptive Data

Habitat quality

A general description of each site is given in Table 5.1. Also at each site a habitat quality assessment (modified by Thirion et al, 1997) was performed in July 1997. The habitat was assessed in terms of the type of river bed, the embeddedness, the habitats available, water velocity, water depth, bank cover, and bank erosion potential (all factors which affect the aquatic organisms present) to give a quantitative habitat quality index (HQI) (maximum possible value 135) which could be used in analysis.

Lists of the macro-invertebrate species, vegetation and amphibian species recorded on the Lotus River were compiled (Appendix I).

5.3 THE LOTUS RIVER CATCHMENT

5.3.1 Conservation value: meaning and applicability of the term

Assessing the conservation value of a site is something that is often required of environmental consultants. Some measure of the value/benefit of protecting the environmental integrity of a site is needed to be able to compare this option with any other development proposals for the site. As such it is assessed according to a range of criteria – from a simple count of the number of different species represented, to more complicated measures of biodiversity and habitat representation.

Saying that a site has low conservation value does not write it off as an environmental asset. However, it does allow for more imaginative management options because there is no need to maintain the integrity of the system as it is at present. Thus rehabilitation measures can include large-scale re-structuring, site engineering, and the site can be considered for multiple land uses, thus allowing for allocation to needs of the people in the area. For ease of comparison specialist reports generally follow an accepted guideline when classifying sites (Table 5.2):

Table 5.2: Explanation of the terms used in classification of areas/habitats.
Classification depends on the flora/fauna present, the extent of degradation of the habitat and the potential for rehabilitation/mitigation (altered from Snaddon, 1997).

Significance of loss of habitat	Description
Very high significance	"red flag" area - should not be touched, cannot be compensated for by simple mitigatory measures
High significance	High ecological value - but could be compensated for if lost by creation of alternative habitats
Medium significance	Moderate ecological value - large areas of similar habitat elsewhere; could be compensated for if lost by creation of alternative habitat
Low significance	Not of direct ecological value, but has elements of a functioning system and rehabilitation measures could improve the habitat
No significance	Very degraded area - total destruction of habitat would not significantly affect the ecological value of the area

This information can be integrated with the needs of the community to identify areas that need to be afforded some sort of conservation status, and areas that are under-utilised and degraded. Some areas are more in need of strict conservation status and management, while others can function very well fulfilling environmental requirements of habitat representation while being used for other purposes as well. Most importantly it helps to identify areas which are in need of rehabilitation. It is in this context that the conservation values of the various open areas in the catchment are discussed.

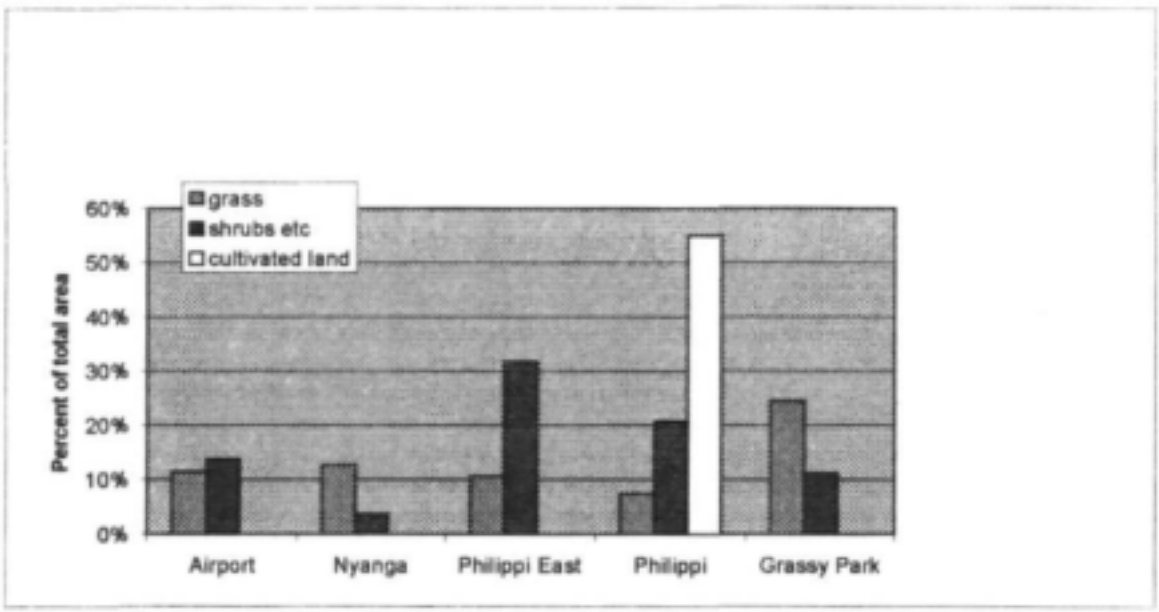
5.3.2 Description of the 5 catchment regions

Table 5.3 below gives details of the areas of each region of the catchment which are vegetated. These areas are classified as grass, shrubland, or cultivated land, from the aerial photography as described in Chapter 2. The areas were calculated from the GIS system as described in Chapter 2. Figure 5.1 compares the proportions of each area that is vegetated, in graphical form. Figure 5.2 is a map (see Appendix B) of the entire catchment showing areas that are of ecological interest.

Table 5.3: Breakdown of the amount of open vegetated land in each subcatchment (hectares and percent of total area).
Information from Appendix C - (calculated from 1996 photography). Shrubland - open areas with some trees (generally alien acacia species). Grass - open areas without trees.

	total area (hectares)	total vegetation (grass and shrubs)		grass		shrubland		cultivated land	
Airport	128.1	32.5	25%	14.8	12%	17.7	14%		
Nyanga	559.2	91.3	16%	70.6	13%	20.8	4%		
Philippi East	1171.6	497.3	42%	126.0	11%	371.2	32%		
Philippi	2279.4	644.7	28%	172.0	8%	472.6	21%	1245.7	55%
Lotus River	678.0	242.6	36%	165.9	24%	76.6	11%		

Figure 5.1: Relative percentages of each subcatchment consisting of open vegetated areas



5.3.2.1 Region 1: Airport Industria

This region consists mostly of the airport and its surrounds. A quarter of the region is open vegetation (Table 5.3, and Figure 5.1) but this value has decreased since 1983 and various upgrading proposals for development around the airport are likely to reduce the amount of open area still further (refer to Chapter 3). The consultants involved in the development around the airport are in the process of implementing an environmental management plan and strategic assessment of the airport region (Brett Lawson, Environmental Partnership pers comm). This would involve an assessment of all areas of conservation value. However, at present much of the open space is highly disturbed, both hydraulically and environmentally.

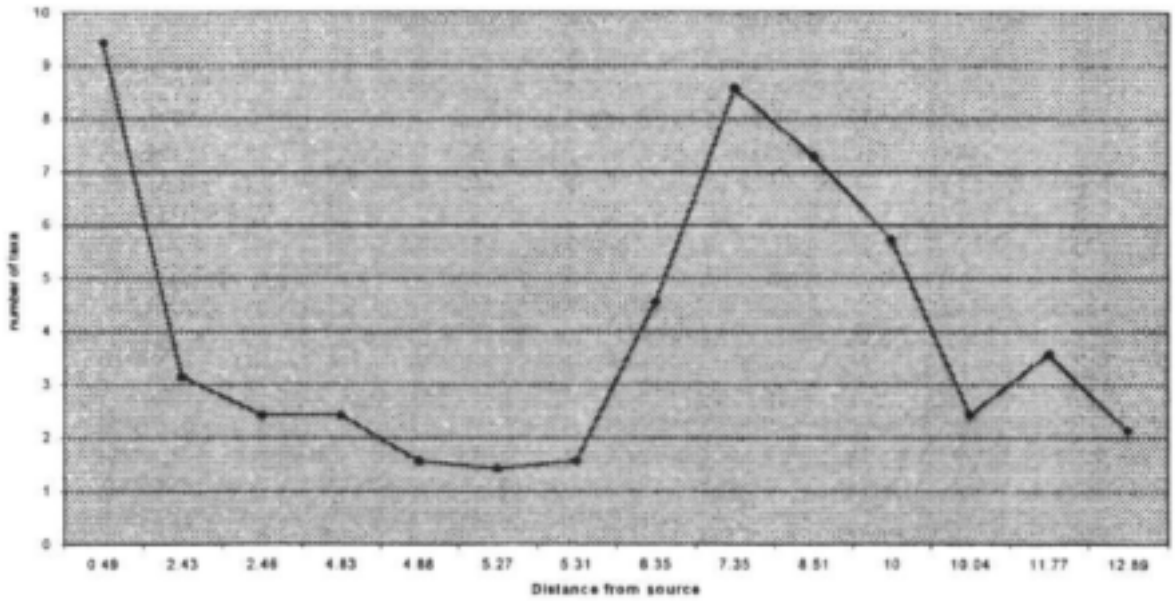
Major wetlands and open areas

There are two main detention ponds in this region (1A-Figure 5.2). These occur in Borchard's Quarry, and are surrounded by industry. Children in the area use the ponds to swim in. There are also a number of smaller, seasonal wetlands drained by the Lotus River (1B-Figure 5.2) which have a greater variety of fynbos plants, and fewer exotics than the two main detention ponds. However these are in the area zoned for development.

State of the Lotus River

The canal here is unlined, the river is slow flowing (but still perennial) with a high algal content (refer to Chapter 4). The fact that the canal is unlined and the slower water velocities in this section mean that the habitat for aquatic organisms is much better than in most of the rest of the river. As regards water quality, the concentrations of phosphorus and nitrogen are at their lowest (SRP= 0.2-0.5mg/l; TON=3-4mg/l) although this is still very enriched (see Figures 4.12 and 4.19 in the previous chapter). The relatively good habitat and water quality is reflected in the biological indices with maximum invertebrate counts in this region (Figure 5.3).

Figure 5.3 Average number of macro-invertebrate taxa at each site along the length of the Great Lotus River



5.3.2.2 Region 2: Nyanga and Gugulethu

Nyanga-Gugulethu has been and is being developed very rapidly. It has the smallest percentage of open vegetated land of the 5 regions (16%) (refer to Chapter 3). The open areas, which do exist, are generally used for grazing of goats and cattle, or are covered with invasive shrubs, or are being encroached by informal housing and dumping. There are, therefore, no areas that are worth considering purely for conservation purposes. However, the high density of people in the region means that there is an urgent need for some sites to be identified and set aside as public amenities and open areas. Areas along the river corridor might be considered for this. One possible area is the open space opposite the Phola Park informal settlement, known as the Phola Park triangle (marked 2 in Figure 5.2). This is earmarked for detention storage and could potentially be rehabilitated.

State of the Lotus River

The river is concrete lined throughout Nyanga-Gugulethu with minimal vegetation. Nitrogen and phosphorus concentrations increase dramatically in this region from both diffuse and point sources (Figures 5.3/4: SRP up to 0.6mg/l TON up to 25mg/l). The macro-invertebrate counts reflect the low habitat and water quality of this section of the river with an average of only 3 species over the whole year - mostly chironomids, but some tubicid worms and lumbriculids (Figure 5.3 - also refer to SASS discussion).

5.3.2.3 Region 3: Philippi East/Crossroads

Although informal settlements are expanding rapidly in this region 42% of the area is still open vegetated space according to the 1996 maps and this is the highest of the 5 catchment regions (Table 5.1). However, as can be seen in Figure 5.1 more than 3/4 of this open space consists of shrubland ie vegetation over-run with

invasive alien acacias (*Acacia saligna* and *Acacia cyclops*). These areas contain very little other vegetation and do not provide suitable habitat for indigenous birds, reptiles and mammals (Barnes, 1996; Griffeth & Erasmus). No core areas for plant conservation have been identified in Philippi East (Rebelo, 1997). At present this region is of no conservation value to birds, and only extensive rehabilitation would improve the situation (Barnes 1996). Like Nyanga-Gugulethu, open recreational space is the most important objective in Philippi East and this would have environmental benefits if it involved the removal of alien *Acacias*.

Major wetlands and open areas

The drainage in this area is largely underground but 5 detention ponds exist, or will be created during development (refer to chapter 4) These provide small areas of seasonal wetland habitat (3A-E Figure 5.2). No investigation into the significance of these wetland areas for birds, amphibians and aquatic fauna has been performed but they contain no rare/endangered plant species (Rebelo 1997). Therefore these areas are likely to be of ecological value mostly because of the habitat they provide - a series of seasonally wet open areas in a part of the Cape Flats which is otherwise highly degraded. However the potential for multiple use of these areas (for cultivation of high-value aquatic plants, for grazing or for recreation) is currently being investigated (refer to section 5.3.3.3).

5.3.2.4 Region 4: Philippi Horticultural Area

This region is different from the others in that a large proportion of cultivated land is included in the total open area count. While 90% of Philippi is permeable (Chapter 3), only 28% consists of open grass and shrubland. 55% of the area is under cultivation, while the balance is open water or seasonally flooded areas. Therefore there is a range of habitats in the region, from relatively pristine wetlands, though fairly undisturbed open areas and wetlands, to highly modified cultivated fields and irrigation ponds. Many of the original vleis have been infilled to make arable land. Because of the use of fertiliser by farmers nutrient enrichment is the most obvious disturbance/threat to the natural systems, and this is something which is hard to isolate and eliminate.

As mentioned in Chapter 3, the drainage system is inadequate at present. However, the fact that the drainage system is unregulated means that there is a wide range of seasonal wetland habitats scattered around the area (many of the cultivated fields also become inundated in winter). Thus the Philippi agricultural area is the only remaining example of the original uncontrolled drainage pattern of the Cape Flats and this is very beneficial to the bird, frog and aquatic fauna of the area (40% of Cape Flats frog species breed in seasonal wetlands (de Villiers 1997). Flamingoes and many other bird species are prevalent. The hydrological benefits of improving the drainage must therefore be weighed up against the environmental benefits of uncontrolled drainage.

There are quite a number of open areas - specifically wetland areas - that have been identified as potentially valuable and in need of conservation. Because parts of this region are affected by development proposals such as the Wetton-Lansdowne corridor development proposal and the Cape Flats freeway extension proposal, numerous specialist reports have been written on the areas of interest.

Major wetlands and open areas

The three major wetland areas in the subcatchment are (refer to Figure 5.2) the Edith Stevens Reserve (4A), Varkensvlei (4D) and Varkensvlei forest reserve (4E). Other areas include the Vygekraal retention pond (4B), Hanover park wetland (a small wetland off Lansdowne Road-4C), and a collection of wetlands in the eastern portion of the Philippi farming area (known collectively as the Vanguard Drive wetlands). There are many other water-bodies in the area, generally excavated farm irrigation ponds, and often low lying areas become inundated in winter.

Edith Stephens Reserve: (3A)

This is the only formally conserved area in the Lotus River Catchment. It is a 3.5ha area established in the late 1950s for the purpose of conserving *Isoetes capensis* (a rare Pteridophyte - fern ally) (Campbell, 1989). It is now the only formally conserved area of seasonal open vlei on the Cape Flats. Besides *Isoetes capensis*

126 indigenous plant species have been recorded on the reserve (Campbell 1989) and it is identified as a core flora conservation area (McKenzie and Rebelo, 1997). However it also contains many alien plant species, some of which are dominant in the plant communities (Campbell, 1989).

Water drained from a large area of Philippi (the Weltevreden agricultural area) runs through this reserve before entering the Lotus River drainage system via an outlet pipe flowing under Lansdowne Road (refer to Chapter 4). No research has been done into the effect which changes in drainage, and fertilisation by farmers in the drainage area, has had on this reserve although this was identified as a concern in the last research report on the reserve in 1978. It is likely that the reserve has become much drier than it was previously (because of the construction of the outlet pipe) and this, as well as altered water quality, might have changed the vegetation characteristics quite dramatically. The eutrophication of the water is difficult to prevent, since the diffuse pollution is caused by the high levels of fertiliser used. This would entail a major shift in farming practices, as outlined in section 7.2.2. however, preventing too much water from draining through the outfalls into the Lotus River would be a relatively straight-forward engineering task. This would raise the level of the water table in the area once again, although without a further detailed study it is not clear whether the water table could be restored to its historical levels.

Besides being of importance for plants, the seasonal pools provide habitat for a variety of fauna: the interesting bird-life present probably relies on it as one of a network of sites in the area (medium significance – Barnes, 1997). It is of high significance for amphibians because of the seasonal wetland habitat (Griffeth & Erasmus). Compared with other sites in the area the water quality and aquatic environment is fairly high (Snaddon, 1997). Various open areas and stormwater detention ponds surround this reserve but it is fenced off from these areas. Therefore over-all the reserve has medium-high conservation value but there is great need for more active utilisation and management of the area. The formal conservation status, which it has had up till now, could well be re-assessed without undermining the conservation value of this reserve. These ideas are encompassed in the management plan for the Wetton-Lansdowne corridor: according to this proposal the fence will be removed, adjacent land will be bought up, detention ponds will be incorporated, and the area will be managed as one unit with recreation and education facilities (Ansa Ferreira pers comm.).

Vygekraal Road detention pond (3B)

This is one of the open areas around the Edith Stephens Reserve. Unlike the reserve it has been excavated and thus consists mostly of a permanent retention pond (which also drains the Weltevreden Agricultural area). As a permanent water body it is of less value to the bird and frog-life of the area (Barnes, 1997; Griffeth & Erasmus, 1997). Children use this detention pond to swim in. As mentioned above, if it were afforded some conservation status and managed together with the Edith Stevens Reserve this area could be a valuable community amenity and provide varied wetland habitat for the indigenous fauna.

Hanover Park wetland (3C)

This is a small seasonal wetland adjacent to the Lotus River off Vanguard Drive. It is highly disturbed and contains mostly common wetland plant species and many exotics. It is classified as being of low significance for fauna because it is so small (Griffeth & Erasmus) but there is great potential for it to be rehabilitated and to have some amenity value for the community (see recommendations in Chapter 7). This area is currently zoned for transport in the Wetton-Lansdowne proposal.

Varkensvlei (3D)

This is a highly degraded wetland in the eastern portion of the subcatchment. It is essentially a 6-hectare grassed depression filled with stormwater (Spottiswode, 1997) and as such has very few wetland plants (Snaddon 1997). Cattle graze in the area, trampling and defaecating in the wetland. Cattle, the presence of algae, and the aquatic plant *Azolla filiculoides* suggest that it is a highly nutrient enriched system. As such it is valuable for birds as a foraging area (medium significance – Spottiswode, 1997) but contains no interesting plant or amphibian species and has very few invertebrate taxa (low significance – Snaddon, 1997; de Villiers, 1997).

However, as mentioned earlier, seasonal wetlands are a threatened habitat and this gives it conservation value. The proposed Cape Flats freeway extension would destroy a portion of this wetland, but there is the possibility of involving the contractors in a rehabilitation programme. Rehabilitation of the remaining wetland (introduction of more indigenous plants, decreasing the amount of disturbance) and the inclusion of redundant land fragments from the freeway development could help to create a larger area of suitable habitat. Thus the impacts of this development could be mitigated, and might even have a beneficial effect on this degraded wetland (Snaddon, 1997; Spottiswode, 1997; de Villiers, 1997).

Varkensvlei Forest Reserve (3E)

This area is very close to Varkensvlei but is a much less degraded system. Some of the wetlands are permanent and some seasonal and vegetated dunes surround the wetlands (Snaddon, 1997). Thus the reserve has a wide variety of habitats.

The wetland vegetation has more indigenous wetland plants than other wetlands in the area, but many exotics are also present (Snaddon, 1997). The terrestrial vegetation on the dunes is typical of the original duneveld habitat of the Cape Flats but the area is also heavily infested with alien trees (70% {de Villiers}) (Spottiswode, 1997). This site is not identified as a core flora conservation site (Rebelo, 1997) but the habitat provided by the indigenous vegetation at this site makes it important for birds (Spottiswode, 1997). The bird community is representative of strandveld but no globally threatened or high priority bird species have been recorded. Because of its probable role as a 'stepping stone' habitat between fynbos habitats the area is judged to be of medium-high significance for birds.

This area is of high significance for amphibians and reptiles because of the variety of habitats available. It provides habitat for 10 of the 12 amphibian species and possibly 2 red data book snakes (de Villiers). The number of aquatic invertebrate taxa is typical for the Cape Flats, but generally consists of common, tolerant taxa. Compared with Varkensvlei the water quality seems to be quite good (Snaddon, 1997).

Overall this site is of medium-high significance and attempts should be made to conserve and rehabilitate the area. However the land is in private ownership (Phillip Rosenthal pers comm.) and is isolated and inaccessible. The proposed freeway extension would result either in a bisection of the Varkensvlei forest reserve, or the loss of the southern portion (de Villiers, 1997). There are a variety of mitigation and rehabilitation measures which could be performed should a portion of this reserve be destroyed during construction of the freeway (Snaddon, 1997; de Villiers; Spottiswode).

Other areas in Philippi

Near Varkensvlei forest reserve there is another area of dune vegetation, which is used as a police training area, but most of the rest of the region has been levelled for farming. Generally the other wetland areas in Philippi are highly modified. A fairly extensive area of wetlands has been identified near Vanguard Drive but these are usually simply depressions in horse paddocks etc, and surrounded either by sand, or by exotic grasses - *Pennisetum clandestinum* (Kikuyu) (Snaddon, 1997). Some of the surrounding dunes support a relatively diverse fynbos plant community. Any one of these modified wetlands would be classified as of low/no significance for birds, frogs, aquatic fauna, and plants. However, collectively these wetlands provide a wide variety of food and habitat requirements and with a little rehabilitation could be very valuable examples of the original seasonal wetland habitat of the Cape Flats (Barnes).

State of the Lotus River

Most of the Great Lotus River is unlined in the Philippi region and here the canal bears more of a resemblance to a river. Macro-invertebrate counts are higher, indicating a slightly more diverse aquatic community (Figure 5.3), despite the fact that nitrogen and phosphorus concentrations are still very high (Figures-SRP=0.5-0.8mg/l TON=11-13mg/l) (refer to section 5.4.2- habitat quality vs water quality).

Functioning river systems have a degree of nutrient cycling/uptake ability (Davies, 1998). There is a significant amount of interaction with groundwater along this stretch of the Lotus River. Phosphorus concentrations increase in this section but this is expected because of fertiliser run-off from Philippi.

Nitrogen concentrations decrease slightly and it is clearly that the uncanalised, well-vegetated river is playing a role in this.

The river corridor in this area is often quite wide but either consists of communities of weedy species (with many exotics), or of grass banks (*Pennisetum clandestinum* - Kikuyu). The area between Heins Road and Lansdowne Road was lined with Armoflex® in July 1997.

5.3.2.5 Region 5: Grassy Park/Lotus River/Ottery

36% of the Grassy Park region is open vegetated land, and it is much less invaded with alien trees/acacias than other catchments. Compare the ratio of shrubland:grass in this subcatchment with that of Philippi East (Figure 5.1). As mentioned in Chapter 3, this region is mostly formal settlements, but there are several open areas which might be of value if some effort were put into rehabilitating them. Two areas have been identified as important.

Major wetlands and open areas

Wetton-Ottery marsh (4A)

This consists of a fairly large area of temporary and perennial wetlands surrounded by more degraded areas where dumping and spread of alien acacias have caused deterioration of the habitat. However the area is not heavily infested with *Acacia* species and the water is clean and clear (Snaddon, 1996). This area has very good habitat for wading and mesic grassland bird species, and is large enough to have some fairly undisturbed areas - shy bird species like Hottentot Teal (*Anus hottentotica*) and Ethiopian Snipe (*Gallinago nigripennis)* have been recorded here (Barnes, 1996). It is therefore of medium significance for birds. As regards fauna the area is of medium-high significance because there is a variety of suitable habitats for amphibians, reptiles and mammals (Griffeth & Erasmus). Although the area is surrounded by residential areas it is under-utilised. An intensive rehabilitation program could be valuable here because the area is big enough to allow for the creation of a well-protected wetland habitat surrounded by buffer zones of more heavily utilised park-like recreational space.

Sunset Park

This area is a detention pond, separated from the river by concrete banks. It is flooded in winter and hosts quite a wide range of wetland plants. While no specialist studies have been done on this park it is likely that it provides habitat for frogs and some bird species. Originally designed as a soccer field it is too wet for playing soccer but there are other possibilities that could improve the amenity value of the site.

State of the Lotus River

In the north of this region the river is unlined with channel vegetation and more diverse invertebrate communities. After New Strandfontein Road the channel is again concrete lined, but quite wide, which allows for lower water velocities and some sediment accumulation and establishment of aquatic vegetation. Quite clean water flows into the river down the Woodlands Canal off Ottery Road (coming from the Wetton-Ottery marsh). From Sunset Park onwards the servitude is grass lined and wide, and this is another example of open space in the catchment which could be improved.

5.3.3 Discussion and recommendations

5.3.3.1 Biological corridors and islands

Island biogeographic theory (MacArthur and Wilson, 1967) has been utilised in an urban context for many years. It deals with the patterns of species richness, which occur on areas ('islands') which are isolated from each other in a 'sea' of inhospitable habitat. It is therefore useful in urban situations where natural habitats are surrounded by developed, inhospitable areas. Stated very simply the theory describes how **size** affects the extinction rates on an island, and **distance** affects the immigration rates to an island. Thus for urban management it is important to ensure:

1. that the individual areas are large enough, and contain a suitable variety of habitats to support a range of floral and faunal species;
2. that the distance between suitable areas be small enough to allow for successful dispersal.

To sustain environmental processes within an urban area there must be enough areas, which are large enough, and varied enough, to support a full range of plants and animals. These areas can be considered as continents from which organisms disperse, or move across the sea of urban environment. Such areas in and around the Lotus Catchment include: Rondevlei, Zeekoevlei, Kenilworth Racetrack, Black River Parkway, Durbanville Racetrack, Khayelitsha wetlands etc.

Next it is important to consider the distance between these areas. If animals and plants are to move successfully between these areas they need to be close enough together. Alternatively they need to be joined by corridors of suitable habitat. Thus it is recognised that movement corridors, or dispersal corridors are essential for maintaining the environmental integrity in urban areas. Rivers are naturally occurring corridors, which often link larger open areas and their value as corridors for movement of fauna needs to be realised. Smaller islands of suitable habitat within inhospitable areas can also be valuable. While in themselves they might not support a very diverse suite of species, they can act as stepping stones for birds and other animals to larger, more hospitable areas.

Thus small islands and corridors of natural vegetation aid in the maintenance of a matrix of a sustainable natural environment operating within an urban environment. There is quite a lot of evidence which shows that birds (especially gulls and ducks) use areas of open space and river corridors to move between different wetlands in the CMC (Turpie, 1993). Similar dispersal patterns are likely to be shown by plants (wind or bird dispersed), mammals and frogs.

5.3.3.2 Seasonal wetlands as a habitat type

As mentioned earlier this is a threatened habitat type and it is one that many indigenous bird and frog species are dependent on. It is therefore important to ensure that seasonal wetlands are represented within the urban environment. However, preserving one very good example of this habitat is not really sufficient - wetlands will dry out at different times and birds and other species will utilise wetlands in turn as shallow water and mud habitats become available. So ideally a range of wetlands needs to be available in an area. The original situation on the Cape Flats consisted of many variable habitats, so at any one time there were likely to be enough suitable areas. This can still be accommodated to a certain extent in the urban situation by providing alternatives to the main wetlands - detention ponds, farm dams, and unused low-lying areas all could be of environmental value in this context. However, many of the wetlands in the Lotus catchment are too degraded to be of environmental value without intensive rehabilitation.

5.3.3.3 Summary of available open space: conservation and rehabilitation options

The open areas in the Lotus River catchment can be classified according to their use/state at present and the possibilities for rehabilitation. The categories discussed below are:

- formally conserved areas
- areas with potential for multiple land use:
  - detention ponds
  - river corridor
  - farm dams
- degraded/unutilised areas

1. Conserved areas

There are very few existing conserved areas and these are not actively conserved. Edith Stephens is an officially conserved site, but not actively conserved. On the other hand, Varkensvlei forest reserve while not officially conserved, is in private ownership and has not been disturbed. It is important that these areas be integrated into plans for the rest of the open space. They are both surrounded by open areas, which are of less

pure conservation value but have high rehabilitation potential. As mentioned earlier, development proposals for both these reserves are concerned with more integrative management (section 5.3.2.4).

The benefits involved in managing the reserves, and the surrounding open space together, are manifold.

- It would encourage active rehabilitation of the areas outside the reserves which are ignored and underutilised at present.
- It would mean that core areas could be protected while still allowing people access to the open areas for recreation.
- A study on the Black River wetlands showed that number of bird species correlated with wetland size and diversity of micro-habitats. Managing these areas as a single unit would both increase range of habitats available and increase the size of the reserves.
- If planned correctly it might be possible to create biological corridors and improve dispersal by joining together areas of high conservation value with areas of low conservation value.

One option for using the redundant land fragments from the R300 freeway extension in Philippi would be to incorporate them into a corridor of wetlands and indigenous vegetation along the road (Rosenthal 1998). This would have a number of advantages; it would increase the detention ponding area of the catchment as well as creating an important dispersal corridor for fauna, and could be very valuable in raising of the environmental value of the fragments of redundant, underutilised, degraded areas. It is important to note here that allocating the land for this purpose is the first, easiest step in the process. Any rehabilitation plans would be very costly, and require intensive management and monitoring. At present the funds are unlikely to be available for such an exercise. This is the situation with many of the rehabilitation proposals for the catchment. However, the potential is there and it is important to follow it through and search for possible funding in the future.

2. Multiple land use

Detention ponds and retention ponds

Detention and retention ponds are well represented in the catchment area, since nearly all the subcatchments have some of these stormwater engineering facilities. These areas have not been given much attention from an ecological perspective, since their function was simply seen as flood amelioration. It is important, however, to realise that these ponds could be examples of a habitat type which is threatened on the Cape Flats, namely seasonal wetlands. Generally these are not pristine systems; many are artificially excavated and are maintained annually. These disturbances mean that the vegetation which is present does not contain rare or threatened species, and the ponds are not large enough to support a diverse fauna. This, however, represents an opportunity, since any plans for improvement or rehabilitation of these areas do not need to be non-destructive. The ponds could be engineered to be more accessible to people; at low flows water could be diverted into them to encourage nutrient uptake by the plants; or they could be used for cultivation of economically desirable plants. Their function as retention ponds need not be impaired by attempts at rehabilitation. This is, therefore, a good example of the benefits of multiple land use. This proposal is now the subject of a current WRC research study entitled "Cultivation of high value aquatic plants in restored urban wetlands for income-generation in local communities" (WRC project no. K5/1054).

Irrigation dams - Philippi Area

At the moment these are of limited value to flora and fauna of the region; they have been designed as water-holding facilities with nothing else in mind. However, a few simple changes could turn these numerous dams into valuable wetland resources. On a physical level changing the design of the dams so that they have gentle slopes rather than steep banks would improve the habitat immensely. This would provide a gradient of wetland conditions (wet-dry) at one site and allow for the establishment of aquatic vegetation. Another step, which could be taken, would be fencing off half of the wetland to prevent disturbance and trampling from cattle. Further rehabilitation possibilities involve actively planting wetland vegetation. Possible wetland plants, which would flourish in these areas under these conditions (on a gradient from dry to wet), would be (Dalton Gibbs pers comm.):

Carpobrotus edulis
Crysanthemoides incana
Senecio halimifolius
Passerina paludosa (red data book species)
Nidorella foetida
Zantedescia aethiopica (Arum lily)
Chondropetalum nudum
Chondropetalum tectorum
Paspalum dilatatum
Scirpus nodosus
Juncus kraussi
Typha capensis (potentially invasive)
Phragmites australis (potentially invasive)

These changes could be brought about through giving economic incentives to the farmers (giving a certain amount of money for each dam that fulfils criteria of gradient, fencing and vegetation). Implementation of this programme could possibly be done through the Catchment Forum. The main problem lies in obtaining the indigenous vegetation - there is the possibility of involving nurseries that grow indigenous plants and Rondevlei nature reserve might also be a source of some plants. This programme may have the additional benefit of changing the farmers' perceptions of catchment management activities and the importance of their own involvement.

Like detention ponds the current use of farm dams does not necessarily clash with their potential to provide acceptable habitat. If this could be implemented then the Philippi horticultural region would consist of a series of islands of suitable wetland habitat scattered within the matrix of an intensively farmed area. This would ensure a choice of wetland habitats, as was identified as necessary for this habitat type (section 5.3.3.2), and would promote dispersal of birds and mammals across the Cape Flats to larger wetland areas in the north and west (Kenilworth Racetrack, Black River Parkway, Durbanville Racetrack etc).

The river corridor

The other main type of open space identified is that along the river corridor. Large sections of the Lotus River have grass-lined servitudes which cannot be built on because of the flood risk, but which are at present under-utilised and of limited ecological value. This is a valuable asset which has not been utilised. As mentioned above, many bird species use rivers as flight paths to move between different wetlands (Turpie, 1994) and the river provides a natural corridor through some otherwise highly developed areas. However at present, because it consists almost entirely of Kikuyu grass (Pennisetum clandestinum) it is of no value as a biological corridor for birds, frogs or mammals. It is also not a particularly attractive area for people and is little used for recreation. Potential for rehabilitating these areas is very high. However it would require a very intensive rehabilitation process (extensive re-planting and perhaps a re-engineering of the servitude). While to a certain extent the fauna of the region require indigenous plants it is suggested that the vegetation planting not be limited to this – large trees such as poplars can greatly improve the recreation value of the area, and they are utilised for roosting and perching by birds (Black River Parkway).

3. Degraded areas

Other degraded wetlands (such as that at Hanover Park) which are at present of low conservation value can also be subject to the imaginative management proposed for detention ponds. While degraded they still have several assets: open space and readily available water. Therefore cultivation programmes, or sculptured recreational wetlands, are two options for this type of area, which both make better use of it than dumping. In many of these situations simple prohibition of dumping and removal of alien trees would improve the areas immensely. As mentioned earlier, connecting these areas to more pristine, valuable environments would help to prevent further deterioration and perhaps provide valuable links between habitats.

5.4 THE LOTUS RIVER

5.4.1 Biological description of the Lotus River

Appendix I gives a list of the macro-invertebrates recorded in the Lotus River system from 1997-1998. A total of 31 macro-invertebrate families were recorded over the sampling period. These were generally pollution-tolerant taxa, and were present in large quantities. The chironomidae were the most abundant taxon with populations estimated at more than 100 per sample. Tubificid worms and snails (gastropods) were also very abundant at most sites. Most of the species present are tolerant of pollution, and particularly of low oxygen levels associated with organic enrichment: Molluscs respire atmospherically (Thirion et al, 1995), leaches and annelids have low metabolic rates and are indifferent to low oxygen levels (Dallas and Day, 1993), many hemipterans and coleopterans can carry air bubbles of atmospheric oxygen. Crabs were also recorded on the river. Organisms which are particularly susceptible to low oxygen levels are fish (which respire with gills), mayflies (ephemeroptera), stoneflies (plecoptera) and caddisflies (trichoptera). These organisms are totally dependent on dissolved oxygen for respiration and they were only occasionally noted on the Great Lotus River. Their absence indicates that oxygen concentrations are often unacceptably low in this river.

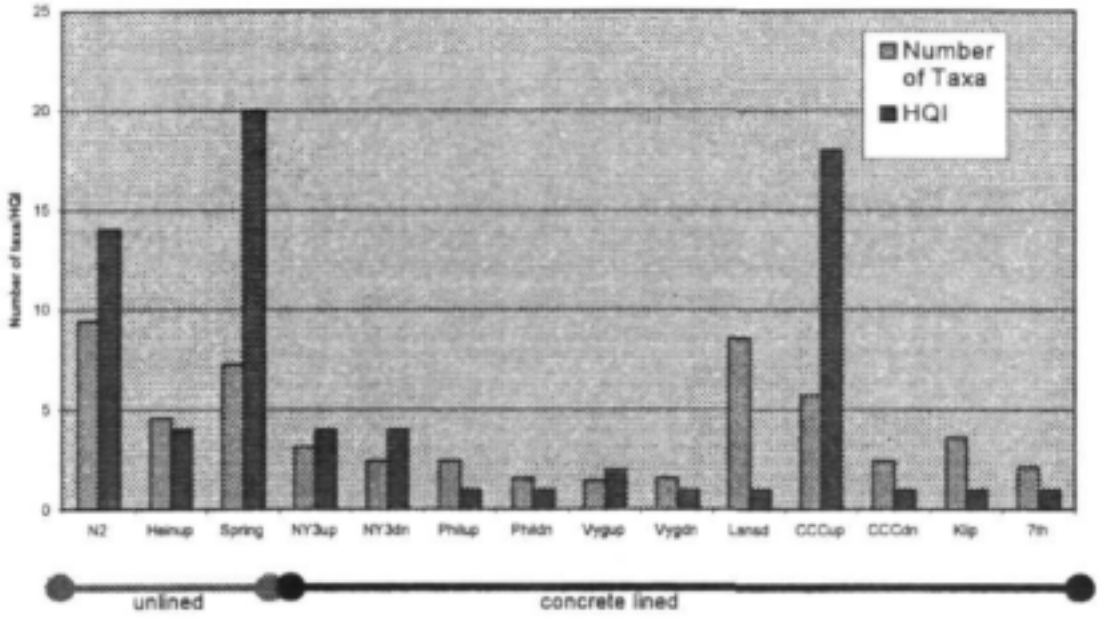
The type of food available in the Great Lotus River also controls the organisms present: high nutrient conditions favour algal, bacterial and fungal production so hardy grazers and saprophytic detritivores dominate the biotic assemblages of the river. Concrete canals also limit the organisms that are present. Only those, which are adapted to very high water velocities, can maintain themselves in concrete canals (ref section 5.4.2.1)

It is generally accepted that healthy aquatic systems support a diverse macro-invertebrate community (many different species), and poor conditions have low diversity but large abundances of the few tolerant species which are present (Metcalfe-Smith, 1991 in Dallas, 1995). Conditions in the Great Lotus River are therefore indicative of poor conditions.

The aquatic vegetation recorded on the river was not very diverse (Appendix I). It consisted of common aquatic plants and exotics. The concrete lined sections are an acceptable substrate only for filamentous algae, but in the unlined sections Potamogeton pectinatus dominated the plant community. Invasive plants do not seem to be much of a problem on this river (compared with problems on the Kuils River) because of the high shear velocities, and regular maintenance which is undertaken by the local authorities. All vegetation, as well as accumulated rubble and waste, is removed from the river channel on an annual basis. However, Azolla filiculoides, an alien invasive fern, is present on all backwaters and slow-flowing areas. Zeekoevlei itself has a problem with excessive growth of many wetland plants, particularly Eichhornia crassipes (water hyacinth), phytoplankton (sometimes toxic blue-green algae), and Typha capensis (Davies, 1998) but these problems do not reach up-stream.

Figure 5.4 Habitat quality indices and average macro-invertebrate counts for 15 sites on the Lotus River

[These sites are not in longitudinal order along the river, but arranged to demonstrate the difference between lined and unlined sites]



Because the Lotus River is a highly impacted, totally engineered river system there is no satisfactory reference with which it can be compared. Having a reference condition against which an aquatic system can be rated is very important when attempting to assess the ecological integrity of a river (Underwood, 1993; Thirion, 1995). When describing the Lotus River it is not applicable to talk about such things as ecological integrity and degree of impact, because there is no natural state towards which we are aiming. However, it is still possible to discuss the Lotus in terms of river functioning, and comparative indices developed for the whole of South Africa (SASS, HQI) can help to put the biology of the Lotus River in context.

The habitat of the Lotus River for biotic communities is very bad. Habitat Quality Indices (HQI's) for the various sites ranged from 20-39 out of a maximum of 135. According to general guidelines any value under 40 is an indication of a very poor condition, unsupporting of biotic communities (Thirion, 1995) (see section 4.2.2).

The SASS4 and ASPT scores also reflect this. No sites had SASS4 scores higher than 70 (poor water quality is considered to be anything less than 85 (Dallas, 1995)), and ASPT was also very low (most ASPT values were less than 4 and anything less than 6 implies poor water quality). This data implies that the sites all have very poor water quality and that the aquatic fauna is dominated by species that are tolerant to pollution.

5.4.2 The Lotus as a river ecosystem: factors affecting functioning

The Lotus River is a totally unnatural phenomenon - a permanent river in an area which used to consist of very undefined seasonal drainage. It was engineered solely for the purpose of stormwater removal and the entire catchment lies within an urban area. However, this does not mean that it cannot become an environmental asset. Rehabilitation of the Lotus River into a functioning riverine ecosystem is a real possibility - there are many examples of successful river rehabilitation programs in Europe (Grobicki, 1998) and within the CMC the rehabilitation program on the Liesbeek River is already having a positive effect (Davies, 1998; Luger, 1998) - so it is important to discuss the Lotus River in this way.

The ecological functioning of the Lotus River is likely to be affected by a range of things. These can be broadly divided into habitat quality factors and water quality factors. These will be discussed in the context of the Lotus River.

5.4.2.1 Habitat quality

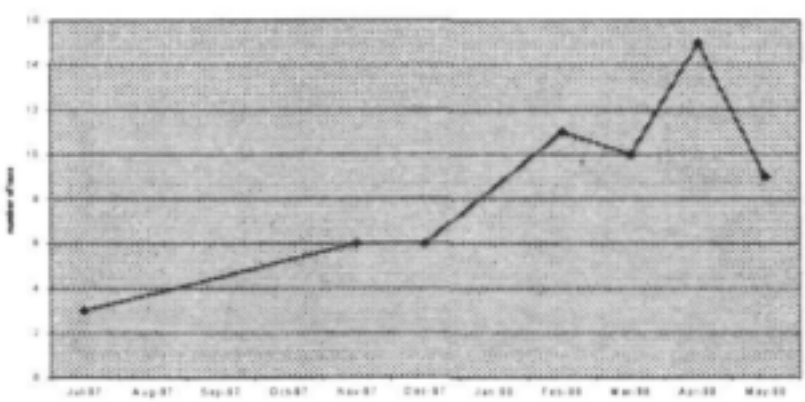
Much has been written on the effect which canalisation has on all aspects of river functioning (Luger, 1998; Davies and Day, 1998; Lewis and Williams, 1991). Basically lining a river canal with concrete affects four major factors in aquatic habitats: substrate availability, growth of aquatic vegetation, current velocity, and access to the hyporheos.

1. Substrate availability and the importance of vegetation

Functioning (unlined) rivers generally consist of many different substrates along their reaches: anything from pebbles to cobbles to sand to mud. These substrates provide a variety of habitats in themselves, and they also allow for the growth of aquatic vegetation, which supplies another range of habitats. These natural substrates are also permeable (allow water and aquatic organisms to penetrate to the hyporheos). Canalised rivers, on the other hand, generally have only one habitat type (cement) which does not allow for growth of vegetation or access to the hyporheos.

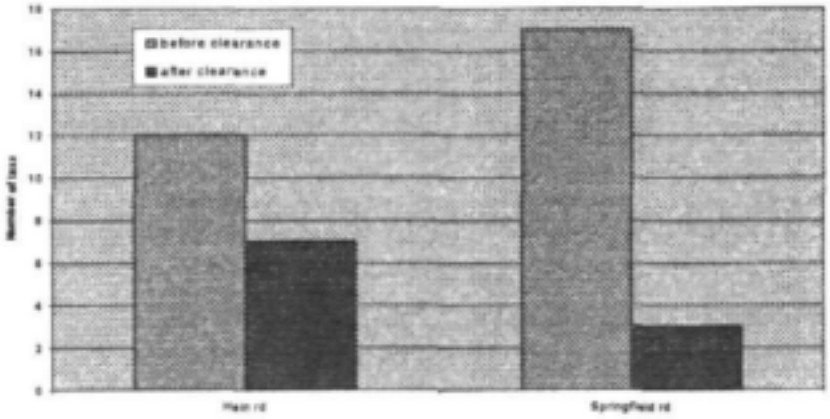
The difference between lined and unlined canals is clearly demonstrated on the Lotus River: unlined reaches have better habitat quality indexes, more aquatic vegetation and a more diverse macro-invertebrate community (Table 5.1, Figure 5.4). The exceptions to this are site 15 (CCC up) (which has a very wide, slow flowing canal in which large sand bars build up allowing extensive vegetation growth), and site 10A (Lansdowne Rd), which was lined with armoflex just before the habitat assessment was done (low HQI) but a lot of vegetation has grown back since then. This points to the importance of vegetation as a beneficial habitat affecting the aquatic community on the Lotus River. Looking at the macro-invertebrates present at the Lansdowne site shows this clearly (Figure 5.5): as mentioned the site was lined with armoflex in July 1997 (when the biological community was completely destroyed). The number of invertebrate families present increased with time, as the river became re-vegetated.

Figure 5.5 Changes in invertebrate counts over time at Lansdowne Rd site



Because aquatic communities are so dependent on the availability of acceptable habitat, annual clearing of the aquatic vegetation also impacts negatively on the functioning of the river. Figure 5.6 below shows how the diversity of the biotic community decreases dramatically following clearing at two sites on the Lotus River. This is due to a number of factors, including the necessity for a rapid change in food source following clearing, a change in the temperature regime as shading vegetation is lost, and as well as a drop in the habitat diversity. Environmentally-friendly methods of clearing the channel, such as hand-cutting rather than machine-scraping, would therefore be a step towards improving the biodiversity of the river.

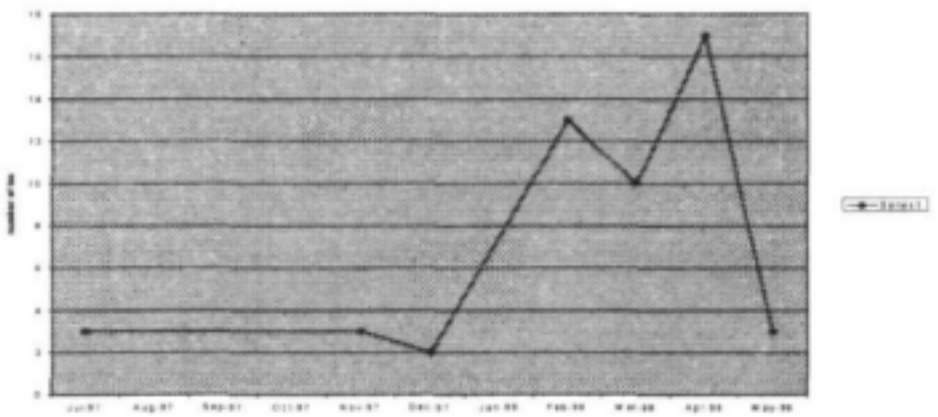
Figure 5.6 The effect of clearance on the diversity of the aquatic communities at two sites on the Lotus River



2. Water velocity and access to the hyporheos

Concrete lined rivers also have very high water velocities (this was the whole point of canalisation in the first place), and at the same time, a cement bottom prevents aquatic organisms from utilising the hyporheos as a refuge and shelter during periods of high flows (Davies, 1998). Thus the only species that can survive are ones which are adapted to living in fast flowing waters and most organisms are washed downstream when flow rates are high. On the Lotus River macro-invertebrate abundances were observed to increase in the summer months (low flows) and decrease in winter (high flows).

Figure 5.7 Macro-invertebrate counts at Springfield Road over one season



As well as affecting the abundance of aquatic organisms, the effect which high flows can have on reducing the community diversity of the Lotus River is illustrated in Figure 5.7 above. Counts of invertebrate taxa more than halved during the winter when very high flows were often recorded and must have scoured out the aquatic communities on the river.

5.4.2.2 Water quality

1. Biological indicators of water quality

As mentioned in section 5.4.2.1, SASS4 scores for the Lotus River illustrate that it is a very degraded system with poor water quality. However, these values are also influenced by the fact that the habitat in the Lotus River is also of such a poor quality. Much work has been done on the difficulty of isolating the effects of these two variables (Chutter, 1994; Underwood, 1993; Parsons, 1996). It is apparent that in the context of the Lotus River it is other assessments of water quality that are required (refer section 5.4.3).

2. Physico-chemical measures of water quality

Many aspects of water quality affect the aquatic community. The most important to consider are dissolved oxygen, pH, Suspended solids, temperature and conductivity. As well as this, it is important to consider nutrient concentrations and toxic substances. An urbanised catchment can affect all of these water quality factors. The table below shows summarised values as given in the City Engineers Report, while summarised values from the Lotus River Project may be found in Table 4.3.

Table 5.4: Physico-chemical data for the Lotus River 1995-1996
(Data from City Engineers Report 1996)

	mean	min	max
Temperature	17.6	11.6	28.8
Dissolved Oxygen	11	5.2	18.0
Oxygen Saturation	110	54	210
COD*	63.6	39	107.9
TSS	15	6	52
pH	8.4	7.7	9.8
Conductivity	102	74	126
Total Nitrogen	5.4	3	10
Ammonia	0.59	0.05	3
Nitrate	0.57	0.01	7.3
Total phosphorus	0.643	0.213	1.38
Soluble Phosphorus	1.06	0.869	1.25
Soluble Reactive Phosphorus	0.321	0.036	0.955
Faecal Coliforms/100ml 50%	39000		

Conductivity, pH and TSS

Data from CMC (Table 5.4 above) show that conductivities on the Lotus River are low, and unlikely to negatively impact the flora and fauna. The pH ranges from 7.3-9.8, which is very alkaline, however, as mentioned earlier, the waters of the Cape Flats have always been alkaline because they run through limestone, so these values are considered normal. However, at high pH values the proportion of ammonia relative to other forms of nitrogen becomes higher, which can be a problem as ammonia is toxic to many organisms (Brown, 1998).

The maximum temperature recorded on the Lotus is 28.8 degrees, which is about 4 degrees higher than the Liesbeek River, and the real maximum is likely to be higher. It is probable that the concrete lining is increasing the temperatures. In the range of temperatures above 28°C conditions start to get difficult for many aquatic organisms (Dallas and Day, 1995). The mean Total Suspended Solids (TSS) values are generally acceptable (over 20mg/l is considered unacceptable), but maximum values are much higher than this. High turbidities (high TSS) can be detrimental to aquatic organisms for a number of reasons.

Dissolved Oxygen

As discussed above, the amount of oxygen available to organisms is very important in riverine ecosystems. This can be measured in various biologically meaningful ways. Dissolved oxygen shows how much oxygen is available in the water. Oxygen saturation expresses this as a percentage of the maximum dissolved oxygen concentration possible by diffusion alone (ie., when this is over 100% active photosynthesis is occurring in the water).

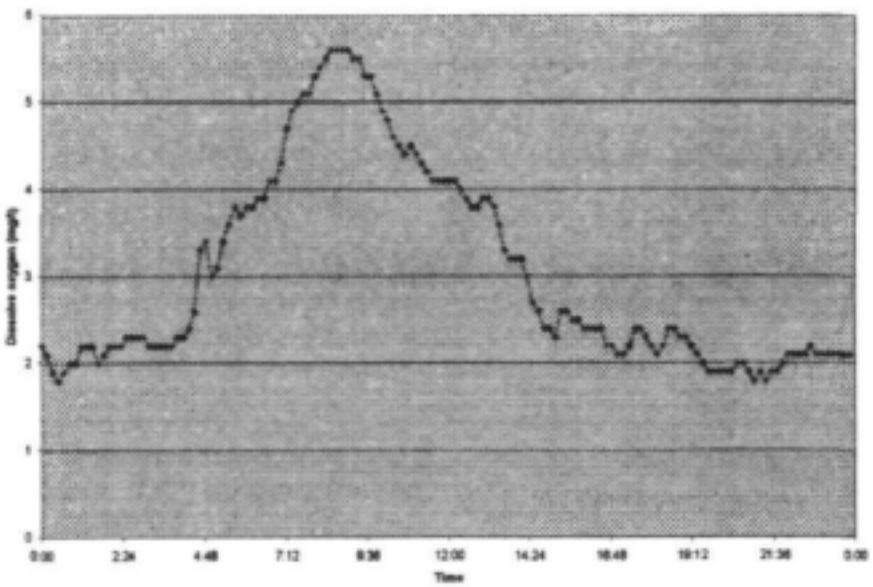
Measures of dissolved oxygen at the Springfield Road sampling point over one day are shown in Figure 5.8 below. The increase in dissolved oxygen during the day indicates that some degree of photosynthesis is occurring on the river (oxygen is less soluble at higher temperatures, so if no photosynthesis was occurring one would expect the dissolved oxygen to be lower during the day). However, the concentrations are fairly low ranging from 1.8mg/l to 5.6mg/l. The recommended minimum value for maintaining biological integrity

in South Africa is 4-5mg/l, and in Australia it is greater than 6mg/l. Therefore the water chemistry data supports the inferences made from biological sampling that dissolved oxygen concentrations are low, and are a limiting factor for organisms in the Lotus River.

The reasons for this are likely to be due to the large amount of organic enrichment from sewage overflows and informal settlements on the river. When oxygen is being used by micro-organisms to break down organic waste, less is available for the other macro-invertebrates and fish present. The average Chemical Oxygen Demand is 63.3mg/l which is in the range found in raw sewage (15-75mg/l), and therefore very high. This is an indication that the biological oxygen demand is likely to be very high.

The high oxygen demand is exacerbated by the fact that generally on the Lotus River there is little aquatic vegetation, ie. very little oxygen production. As can be seen in Table 5.4 the dissolved oxygen concentrations measured by Scientific Services at a different site are much higher (average 11, ranging from 5.2-18mg/l). The difference in the two measurements is quite striking. The two methods of measurement are similar (both used the membrane electrode method). The most probable explanation for the high oxygen concentrations at the Scientific Services sampling point (7th Avenue) is that at this sampling site there is always a large amount of Potamogeton pectinatus in the river. Photosynthesis by this aquatic plant is likely to increase the dissolved oxygen concentrations. As can be seen the oxygen saturation is very high at this site (averaging over 100%).

Figure 5.8 Dissolved oxygen measurements over one day at Springfield Road in May 1998



This information makes it clear how processes on the Lotus River can be active in improving the quality of the stormwater run-off: photosynthesis by aquatic vegetation is instrumental in supplying the oxygen which is required for the decomposition and cleansing of organically enriched waters. However, there is a limit to this process, where septic conditions prevail, and the inputs and processes need to be monitored closely.

Nutrients

Chapter 4 gives information about the nitrogen and phosphorus characteristics of the water in the Lotus River. The water is eutrophic - Nitrogen and Phosphorus values range from 4mg/l TON and 0.2mg/l SRP to 25 mg/l TON and 1mg/l SRP. As mentioned above, it is difficult to find an acceptable reference for comparison with the Lotus River, but values found in other rivers in the CMA are usually a factor of 10 lower than this (City Engineers Report 1996).

Table 5.5 Comparison of average nutrient concentrations in three urban rivers in Cape Town

	Great Lotus River	Keysers River	Liesbeek River
avg SRP (mg/l)	0.32	0.029	0.033
avg TON (mg/l)	5.3	1.3	0.2

Increased nutrients can result in excessive nuisance growth of aquatic vegetation. This is expensive to clear. Moreover, some forms of nitrogen (Nitrite - NO3 and Ammonia -NH3) are toxic to fish and too many invertebrates at high concentrations. As can be seen in Table 5.5 Ammonia concentrations are very high, high enough to have an inhibitory affect on many aquatic organisms (Dallas and Day 1995) and well above the accepted current standard in the USA, Australia and the UK (0.03mg/l).

Trace metals

The data in Chapter 4 all indicate that the concentrations of trace metals in the Lotus River are well below the accepted minimum level in South Africa.

5.4.3 Water quality assessment in an urban river

5.4.3.1 Applicability of SASS4 sampling on the Lotus River

Rapid biological assessment protocols such as SASS4 are not really suited to investigations of water quality in urban, degraded streams. They were developed for identifying the effects of pollution in otherwise unimpacted rivers where habitats are relatively untransformed, and as such they are valuable (Dallas 1995). However, in urban situations the habitat is often so hostile that the only organisms which can survive are ones that are incredibly tolerant of poor conditions, and this makes any fine-scale assessment of water quality differences, using biological indicators, very difficult.

For example on the Lotus River the SASS4 data was not useful in identifying the effects of major stormwater inputs. Statistical tests were performed on SASS4 scores up-stream and down-stream of various stormwater inputs and the only site which showed a significant difference was the one up-stream and down-stream of CCC (Mann-Whitney U test U=4, z=2.62 p=0.0088 n=7). The site upstream of CCC has a much better habitat quality than the one downstream (although it is concrete-lined, sandbars had built up through sedimentation and much vegetation was present – see Table 5.1). The more varied habitat, rather than a decrease in water quality, is the most probable explanation for the significant difference observed in this one instance. In fact, a study by (Brown, 1998) on the effect of sewage effluent on urban rivers did not even attempt a SASS assessment when the rivers were concrete-lined because there were not enough biotopes to sample.

However it is important to have some understanding of the water quality of urban rivers and other methods need to be investigated.

5.4.3.2 Alternative indicators of water quality for urban rivers

1. Physico-chemical measures

One can take measurements of certain biologically meaningful physico-chemical water characteristics. These are important in any situation because they give a broad idea of the environment experienced by the aquatic organisms (refer to section 5.4.2.2). However, there are various limitations to pure physical measurements, which caused people to try to develop other methods in the first place.

Firstly it is time consuming and expensive to get detailed physico-chemical data: a regular sampling procedure needs to be undertaken. While some things like temperature, pH and conductivity are easy to measure, others are more difficult and expensive. In order to have a complete picture of the pollution in a river many things need to be measured:

- nutrient concentrations
- hydrocarbons
- herbicides/insecticides
- litter
- accumulation of trace metals

Secondly, water quality samples are, by nature, instantaneous measures and thus do not give any information of the history of pollution at a site. They do not reflect the true variability of conditions that organisms are exposed to, and most importantly, it is extremely unlikely that they will pick up a brief disturbance or pollution event.

2. Other bioassessment techniques

Other biological indicators of water quality are not subject to the same limitations as SASS. One of the major problems with SASS is that it is difficult to isolate the effect of the variable of interest (water quality as opposed to habitat quality) (Parsons & Norris, 1996). One alternative is to investigate the effects that various pollutants have on individual organisms rather than biological communities (Dallas and Day, 1993).

These investigations can be undertaken under more controlled conditions, either in a laboratory, or in a controlled field experiment, and thus there is more certainty about the variables involved. Field experiments (tagging, measuring, releasing, recatching, remeasuring) have an important advantage which SASS scores also have: the results reflect the complete range of conditions experienced by an organism from one sampling period to the next. Laboratory work does not have this benefit, but it is valuable because it is possible to identify the effect of individual water quality variables on individual organisms (tolerance testing).

Various traits, which are influenced by pollution, can be measured – growth rate, age to maturity, fecundity, survival rate (Dallas and Day 1995). In the context of the Lotus River it is suggested that it would be valuable to carry out field-based ecotoxicological tests on organisms such as fish or frogs, as discussed in section 5.2.2.3 above, or on macro-invertebrates.

3. Photosynthesis : Respiration ratio (P:R ratio)

Measuring ecosystem processes can also be helpful in gaining a broad understanding of the functioning of a riverine ecosystem (Davies 1998). Measurements of photosynthesis and respiration in a river and the ratio between them will provide valuable information on the type of system represented – whether it is a productive system (taking up nutrients and creating organic matter) or a decompositional system which is breaking down material brought in from terrestrial systems. Urban streams are receiving a great deal more input than most natural rivers – increased run-off, less infiltration, and organic enrichment are all characteristics of urban rivers. An urban river is therefore likely to be characterised by decompositional processes (low photosynthesis to respiration ratio).

All of these methods for describing rivers only give half the picture. They were developed to assess whether the effect which various pollutants have on a river is detrimental to ecosystem processes in the river, and are always compared against a reference basis of a pristine river system (Dallas 1995, Underwood 1993, Chutter 1994). As mentioned earlier, in an urban river such as the Lotus, there is no really meaningful reference state. The focus is more on what factors most need to be changed so as to improve the situation. It is necessary to have information on the state at present because this will act as a reference point to assess the improvement after rehabilitation measures have been attempted.

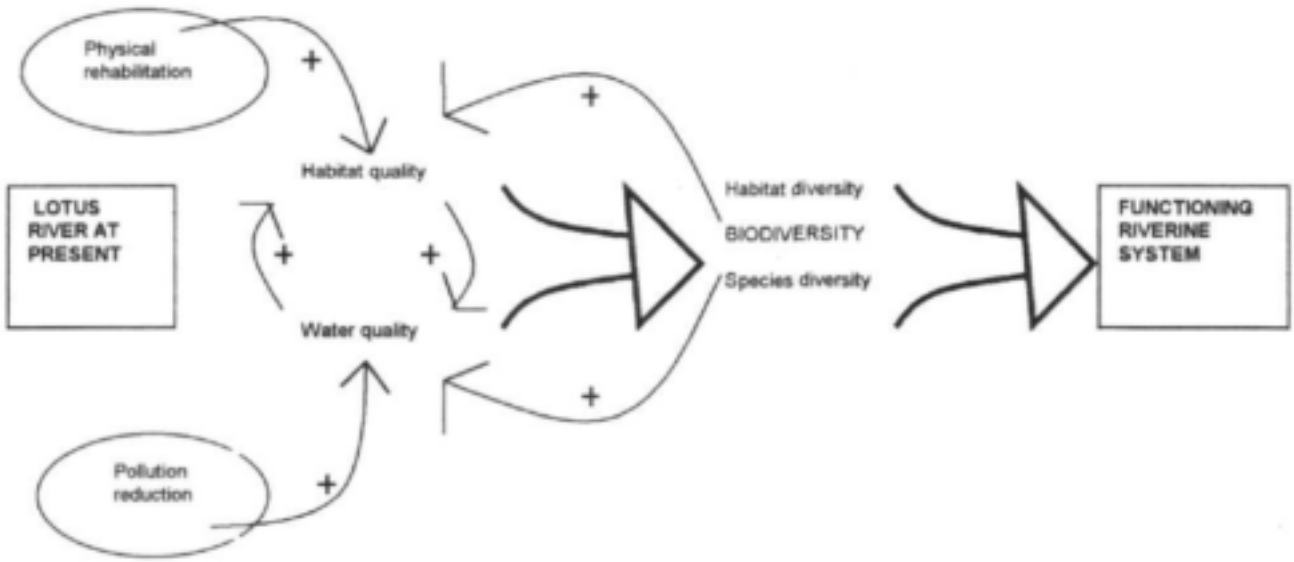
5.4.4 River Rehabilitation

5.4.4.1 Ecological understanding behind river rehabilitation

Madsen (1995) states that the provision of suitable habitat is the primary constraint behind the re-establishment of biotic diversity at a site, and that habitat provision supercedes water quality as a limiting criterion.

Generally the data collected for the Lotus River supports this statement. The strong relationship between habitat quality and average macro-invertebrate counts, as shown in Figure 5.4, makes it apparent that the lack of suitable habitat is the factor most limiting the presence of aquatic invertebrates, and that the poor water quality (found throughout) is subsidiary. However, through rehabilitation efforts a positive feedback loop can be established between these two factors. Improved habitat quality aids nutrient cycling and oxygenation, and mediates temperatures. On the other hand, better water quality conditions allow for a greater diversity of vegetation and habitats. Therefore any re-habilitation strategy needs to address both issues.

Figure 5.9 Diagrammatic representation of the interactions between water quality, habitat availability, various rehabilitation measures and the riverine ecosystem



The aim is to move the riverine ecosystem from its present state (degraded, with limited processes and limited types of organisms), to a more useful, viable and healthy state. Better water quality, improved habitats, and a wider range of habitats result in more species (biodiversity), and a more complete range of processes – photosynthesis, respiration (decomposition), nutrient uptake, nutrient cycling. This in turn will have many other benefits in a range of contexts.

This is the vision for the Lotus River. The means to this end are therefore two-fold:

1) intensive input into physical rehabilitation (removal of concrete, active planting of vegetation), and
2) pollution reduction, especially from diffuse sources (legislation, education, provision of the necessary services, and filtering of wastes before they reach the river - eg Edith Stevens Reserve and Wetton-Ottery marsh).

This two-pronged approach will result in positive feedback loops being established, bringing about a change from the present degraded state of the river.

5.4.4.2 River rehabilitation measures

There are a number of river rehabilitation measures, which have been well documented. Some of these techniques are as follows:

(1) Restoring **meanders** to straightened rivers, or creating meanders and natural-looking curves for canals. This can only be carried out if there is open space on either side of the existing river, and the river is decanalised.

(2) Enhancing redundant river channels, by creating **backwaters** and bays. Where meanders have been created, the old channel should only partially be backfilled, allowing the unfilled lengths to be used to create backwaters, which are connected to the downstream leg of the new meanders. These backwaters provide a range of habitats for aquatic life, and attract bird-life. Flow into the backwater can be maintained by incorporating a gravel lens into the backfill.

(3) Enhancing straightened river channels by the use of current deflectors, ledges and riffles, in stretches where it is not possible to introduce meanders.

Current deflectors
Where the channel is uniformly trapezoidal, and there is no diversity in the shape of the channel or the banks, this can be introduced by building a series of low level structures in the channel, which intermittently narrow the channel. These cause variation in flow currents and localised pockets of erosion and deposition. The structures can be built using logs, and are small-scale to avoid creating scour of the banks or impeding flood flow.

Aquatic ledges
These are used to introduce desirable habitats along the banks, and improve the visual aesthetics of the channel. They also narrow the normal flow channel, introducing velocity variations in the flow. Ledges can be built from logs and coir matting, adding fill from the river bed and surrounds, and planting plants on the ledges. Silt accumulates on the plants and builds up the ledge, while the coir matting and the logs will degrade over time, by which time the plants will have become established.

Stone and gravel riffles
An artificial riffle may be designed as a low weir, in order to minimise scour effects. The riffle consists of two semi-elliptical shoals, one slightly downstream of the other, linked by a shallow sloping weir built of a densely graded rock mixture. During low flows, only the weir is submerged, but shoals quickly drown as flows increase. In a flood, the whole structure is "drowned out" at an early stage.

(4) Revetting and supporting river banks by the use of spiling, mattressing, or other soft revetments.

Spiling
This technique is suitable for steep river banks which require both support and erosion protection. It utilises a densely graded rock matrix which lines the bank below water level, having first excavated the river bed to a designed level to provide room for the rock. The rock forms a shelf at the water's edge, behind which wooden stakes are driven. Flexible indigenous plant material (eg. Cape willow, palm leaves) is then woven between the stakes (spiling), and a geotextile is placed behind the spiling to help stabilise the soil backfill. This provides what is essentially a vertical retaining wall. The upper bank should then be graded back to a safe slope that is un-revetted. (Osier willow is used for spiling in the UK, since it produces long, slender, flexible shoots. The use of Port Jackson shoots or other alien acacias could be considered for spiling in the South African context, as they are available in large quantities through the Working for Water project. The shoots are flexible, and do not pose a threat as these aliens reproduce only from seed.)

Mattress revetment
This can be used to stabilise a newly graded river bank which is not too steep. Crushed rock is used to line the channel, then netting is placed over the rock above ground, with a length extending towards the river. Soil fill is added on top of the netting. Poles are placed horizontally on the soil, after which the

netting is pulled back and stapled onto the poles, and finally the ends of the netting are secured to stakes driven well back in the fill. This forms a secure mattress. Finally, the upper bank is created with a soil fill at a safe slope (covering the stakes), and coir pallets or plant rolls are placed along the water's edge and planted with aquatic plants. Plant rolls can be made out of dense coir matting, which is pre-grown with selected marginal aquatic species, eg. reeds.

Other types of "soft" revetment
Many other types of soft revetment, utilising combinations of logs, geotextiles, wooden stakes, and plant rolls have been used on various river restoration projects.

(5) Enhancing outfalls to rivers.

Surface water outfalls
Outfalls discharging into the river above water level are often very unsightly, with ugly concrete headwalls. Outfalls with grills are frequently cluttered with litter. Redesigning the outfalls to locate them below water level where possible allows for a far more attractive and pollution-free riparian environment. The new outfall should incorporate an underground chamber, which is a silt and oil trap. This outfall chamber needs to be cleaned by means of a suction unit at regular intervals. The outfall pipe lies on a concrete apron, which reduces scour during high flows, and is turned to face downstream so that the river draws the discharge. This reduces the risk of blockages. In addition, a gabion is installed upstream from the outlet in order to reduce the risk of pipe damage from floating objects. Alternatively, outfalls can be designed to flow into backwaters [see (1) above] if the river has been re-meandered, which can allow for the natural filtration of the discharge through a reedbed.

Farm ditches and drains
Reedbeds may be planted adjacent to the river, taking the flow from the tributary into a series of longitudinal furrows (running parallel to the main stream) which are planted with reed species such as *Typha*, *Scirpus* or *Phragmites* (which are common species in South Africa). In this way, a buffer zone is created which helps to intercept agricultural pollutants before they reach the main stream. Reed beds also provide additional habitat diversity to the riparian environment.

Details of the use of the techniques above in a number of existing river restoration projects are given in the excellent Manual of River Restoration Techniques (Vivash, 1999) which is available from the River Restoration Centre in the UK. A great deal of information on river restoration can also be accessed from their web-site at:

www.qest.demon.co.uk/rrc/rrc.htm

It must be stressed, however, that river restoration techniques should be developed or amended to suit site-specific conditions.

5.4.4.3 River rehabilitation: social and hydrological consequences

This ideal state for the rehabilitated river (the final state in Figure 5.9 above) has numerous environmental benefits as mentioned above. However, river rehabilitation needs to be considered in the context of three different agendas: social, environmental and hydrological. Table 5.6 summarises the benefits and disadvantages of these changes to the various stakeholders. Often the needs of people for clean water and an attractive river corridor are complementary to the environmental requirements.

However it is important not to compromise the engineering and hydrological requirements of an urban river. For example, removing concrete and planting vegetation will reduce the river's velocity and a greater area will be needed for flood alleviation. In a nutrient-enriched system such as the Lotus there is bound to be nuisance growth of vegetation in an uncanalised channel, requiring more frequent clearing. Clearing of vegetation in uncanalised rivers is more difficult and expensive, and if it is to fit into the environmental vision for the river it needs to be done in an environmentally-sensitive manner. These are compromises which must be made. There are benefits as well – bank stabilisation and nutrient uptake – and the

disadvantages can be minimised by good design techniques, as well as by defining an efficient and labour-intensive maintenance programme.

Table 5.6 The positive and negative effects which river rehabilitation can have in the hydrological, ecological and social context of the river

	Hydrological	Ecological	Social
Benefits	Bank stabilisation	Improved water quality	Improved water quality
	Nutrient uptake	Biodiversity : habitat diversity and species richness	Recreation value
		Functioning ecosystem : nutrient cycling, nutrient uptake, decomposition and photosynthesis	Decreased health risk
		River corridor : movement *corridor for animals*	
Disadvantages	Increased flood risk / more space required		Possible flood risk
	Excessive vegetation growth - increased maintenance		
	Potentially decreased bank stabilisation		

CHAPTER 6 PARTICIPATORY URBAN CATCHMENT MANAGEMENT

6.1 THE PARTICIPATION STRATEGY AND OBJECTIVES

One of the important questions that usually arise in development projects that seek to implement community participation is what are the key elements constituting the participation process that makes the process meaningful to the community? The basis for providing an appropriate answer to this question is the understanding of the notion of participatory development. Within this notion there are two important components. The first is the participation component and the second the development project, which should be two distinct yet integrated processes. This implies that there should be two sets of objectives, one for the project and the other for community participation. As for any project, there should be clear goals and objectives for the process of participation, which are distinct from those of the project.

The goal and objectives of the community participation process provide the basis on which to build and develop a community participation strategy. This requires a serious consideration of the role of the community participation process before the development project actually begins. There are a number of roles that community participation can play in a development project. These roles can be translated into objectives ranging from just informing the beneficiaries of the project about the project and how it will be implemented, consultation of the community leadership about important elements of the project, negotiation with the community, to community control of the project, etc.

The institutional models and mechanisms envisaged to translate the participation strategy into action would be informed by the objectives of the community participation process. The nature of these institutional models and mechanisms finally established should be influenced by the local context, that is, the project environment and the nature of the project. This is because every project environment has unique features, specific to that particular environment or situation, such as the social patterns, inter-community relations, social stability, socio-cultural and power relations in that environment. These features are very important because they provide key indicators of the nature of structures and mechanisms that are likely to be durable, sustainable, effective and acceptable to the local people. A community participation strategy that utilises civic association-based institutions of decision-making, for example, would not be appropriate in rural areas that still subscribe to the traditional system of decision-making based on chiefs and indunas.

While the local context and the project environment are critical to consider, the importance and the need for that community participation strategy to be grounded within a clear conceptual framework cannot be over-emphasised. This is very important because such a framework would provide a mechanism for evaluation, review and to relate it to other processes and similar situations elsewhere. Without a framework, there would be no mechanism that would allow that strategy to be monitored, documented and evaluated in terms of its success or failure in achieving its goals and objectives and there would be no basis of developing a methodology that would be replicable for such programmes. This is also true for Integrated Catchment Management (ICM).

Thus this chapter does not focus only upon providing the details of the strategy and documenting the activities that were part of the community participation process in the Lotus River Project. It also provides a conceptual framework for this component of the project. This conceptual framework is the basis of the methodology adopted to undertake the community participation component in this project and to develop an appropriate model for community participation in integrated urban catchment management in South Africa. Therefore this chapter also highlights key issues and principles that influenced and informed the model, providing insight into practical constraints that determined the structure of the methodology and the model.

One of the major objectives of the Lotus River Project was to identify all major stake holders in the catchment and to develop a working model for community management of the catchment. This objective is the basis of the discussion in this chapter. The translation of this major objective provided a focus on a

number of specific objectives for the community participation strategy adopted. This assisted in defining the work programme necessary to achieve the major objective. These specific objectives were defined as follows:

- To identify all parties that have an interest in the development of the Lotus River
- To identify the nature of the decisions to be made, and the level of complexity of the decisions
- To identify the community input most appropriate to the different levels of complexity of decision-making process
- To gain acceptance, from all the parties involved, of the broad principles of community management

The Participatory Rapid Appraisal (PRA) technique was initially envisaged to pursue the achievement of these objectives. Due to reasons that were provided in the penultimate meeting of the Steering Committee, this methodology was subsequently substituted by an action-based, on-the-ground approach, organised and implemented through a series of workshops, local meetings and catchment tours involving the community leaders and representatives. The justification for adopting this approach was to enable community representatives, within the time limitation, to assist in defining key issues and principles that would underpin a working community participation model. It also provided local communities with an opportunity to identify practical constraints, limitations, strengths and opportunities that could influence or assist in the implementation of community participation in integrated urban catchment management in future.

However, the PRA technique, as will be shown later, would be a valuable technique to utilise in relation to the various projects that would constitute the implementation phase of integrated urban catchment management at local level. Presumably these projects would be planned and implemented with the involvement of the local communities. It is at this level that the technique would become suitable and valuable due to issues such as the identity of the community, local stability, power relations, its size and relative homogeneity in terms of local interests and needs.

6.2 THE ROLE OF INTEGRATED CATCHMENT MANAGEMENT IN URBAN AREAS

6.2.1 Integrated Catchment Management: A conceptual framework

Integrated Catchment Management (ICM) is about establishing, supporting, promoting and becoming a sustainable society. Sustainability implies attaching more importance and value to integrating the natural (ecological), physical, economic and social elements in development processes. In developing countries, people and their needs dominate (Abbott, 1996: 12). This implies that the integration and participation of people should be the core component of any integrated catchment management process. The process should seek to understand and preserve or re-establish functioning ecosystems and hydrological processes (Grobicki, 1997: 11-12), facilitate the understanding of the functioning of human systems, as well as incorporate people's needs and interests.

The integration of the people can be done through establishing institutions and mechanisms that reduce conflict, negotiate and resolve differences, address local needs, respect people's inputs, facilitate initiative while encouraging individual and collective responsibility. It is, therefore, not solely about managing water resources, or natural resources management or even about controlling hydrological processes (ibid. 11). Partnerships between the people and the public sector in the process of governance become the basis of sustainability in developing countries. The aim is not to ignore the importance of the natural environment, but to recognise that the needs and interests of the poor majority, coupled to limited skilled, technical, physical and financial resources places the process of setting priorities and allocating resources at the centre of sustainable development.

ICM should therefore be "simultaneously a philosophy, a process and an implementation strategy to achieve a sustainable balance between the utilisation and protection of all environmental resources in a catchment and to grow a sustainable society through stake holder, community and government partnerships in the management process" (WRC 1998: 2). It is a process that takes the river basin/catchment as a basic unit,

establishes a management and implementation strategy that balances the short-term needs and interests of individual people or communities with the wider and long-term needs of the society. It is a people-centred and needs-driven process, and establishes the river corridor and resources within the catchment as both a unifying force and resource for all, as well as a basis for evaluating the success of the process.

This approach to ICM assumes a fundamental relationship between the community on the one hand and the resources within the catchment area on the other, and implies a substantial role for the community in the process of integrated catchment management. This relationship between the people and the catchment area is governed mainly by and based on the needs of the people within that catchment. Gasson (1995) provides a very powerful way of conceptualising the relationship between people's needs and the environment. While this conceptualisation was used for defining such a relationship in urban environment, it can be modified to apply for entire catchment areas.

Gasson (1995) contends that the relationships between social systems or human settlements and the natural environment everywhere are a direct reflection of certain survival needs of their inhabitants (Gasson, 1995: 1). He then divides the needs into four categories. The first need being the extractive needs for the resources from the environment (clean air, water, food, fibre, mineral and energy). The second being the absorptive need for the return to and disposal in nature of urban wastes (solids, liquid, gases, and heat). The third being the expansive need for well-located and suitable land on which to accommodate the growth of homes, businesses and other facilities. The fourth being the existential (sense of place, pride and ownership) need for psychological and emotional security and well-being (ibid. 1).

The first two categories of needs can be classified as catchment metabolism, the third as the catchment footprint and the last one as catchment presence. Conceptualised this way, this relationship provides a basis for developing an ICM model that is based on the needs of the people and their impact on the environment (see Figure 6.1). However, there is a need to recognise that there should be an inter-relationship between the people, the government, the environment and the resources, because any attempt to exclude some of these elements and focus on only two will affect the sustainability of the ICM process. Therefore, the role of ICM should be the structuring of an appropriate relationship between these elements to achieve sustainable development.

In relation to rural catchments the relationship would prioritise the quality of the environment, focusing on concerns such as the preservation of bio-diversity and reducing the depletion of natural resources, while seeking to incorporate the needs and interests of the poor majority in a sustainable way. This is appropriate because in rural areas, even the poor are directly dependent on the environmental system for their survival. In relation to urban areas, the priorities are different. This is not to ignore the natural environment, but simply to recognise that there are a different set of priorities and a different process of setting them (Abbott 1996: 12). "Cities are a creation of people, and in this environment people and their needs dominate. The key relationship is that between the management structure and the people. However, the majority of the population of cities in the South is poor. Hence the key relationship in the South has to be that between the management structure of the city and its poor. Otherwise there is a serious danger that these cities will continue to deteriorate" (ibid. 12).

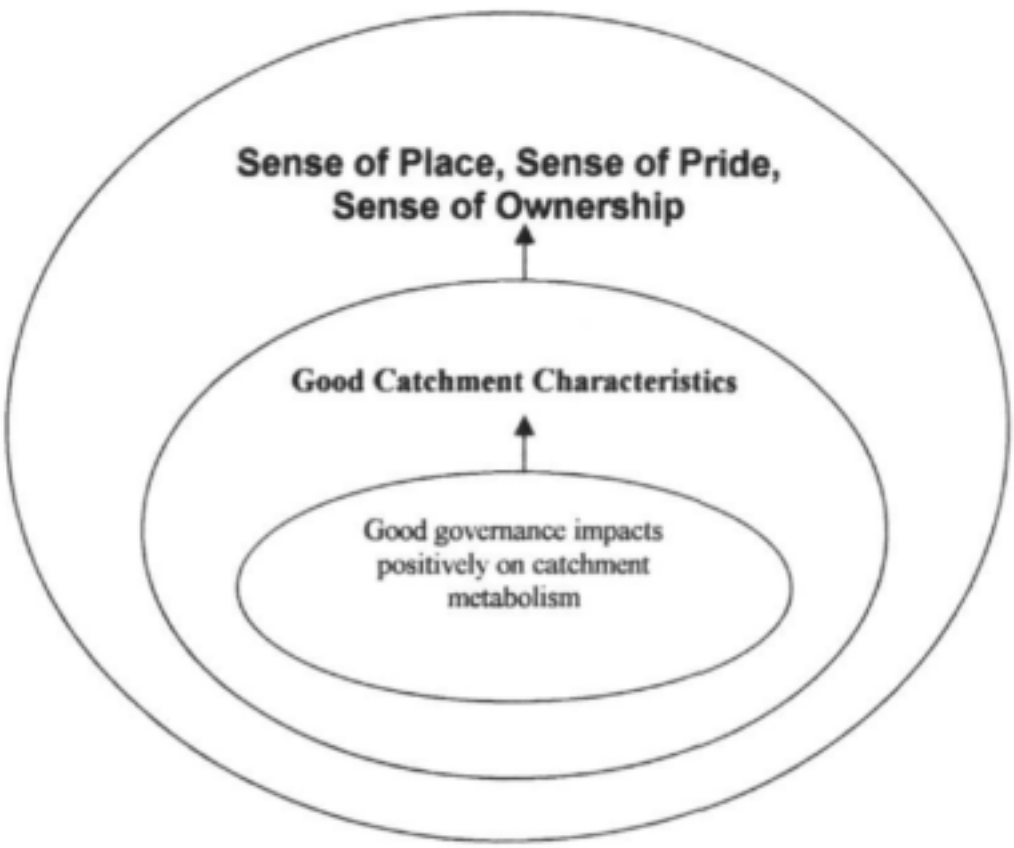
The key point here is to recognise that in developing countries, there is a different set of priorities and the key issue is one of access to resources. It would not be sustainable to invest large amounts of resources into programmes that ignore the needs of the majority, and focus on preserving the environment. In developing countries sustainability implies an approach that assists the poor to develop an active interest in the quality of the environment and recognise the consequences of their actions on the environment through a process that addresses their needs. This would require a new approach in terms of how the government views the process of governance at local level. This needs a commitment by government to integrate the poor in the process of governance. This implies effective partnerships, between the poor and the government, that would be based on the allocation of resources and also focus on assisting the poor to internalise the relationship between the sustainable fulfillment of their basic needs and the quality of the environment.

People would not begin to appreciate and understand this relation until they begin to reap tangible material benefits from participating in processes such as integrated development and catchment management. Community participation and integrated development are therefore two sides of the same coin. People must

perceive themselves to be, and indeed be, part of the process of governance (refer to Figure 6.1). Their existential needs must be fulfilled. This implies that the process of governance should result in the community feeling a sense of ownership for the environment, ownership of the decisions from the governance process, understand the rationale and accept the consequences of these decisions. Since the poor would not have the capacity to and would find it very difficult to dedicate protracted time for participating at the levels where broader issues of ICM and governance are negotiated, the process of governance should also be duplicated at local level.

Thus the needs-based conceptual framework can only translate into a working model only if in urban areas, the relationship between the poor and the government is central to the urban catchment management process. This is not only because the needs of the people dominate, but also the economic disparities in urban areas are reflected in terms of developed and underdeveloped geographic areas. These areas also reflect race divisions as the consequences of race-based planning. Consequently, in order to reduce the tension between such areas, the implementation of integrated urban catchment management has to be undertaken through a process based on negotiation between the government and urban poor. Therefore community participation is central to integrated urban catchment management.

Figure 6.1 The role of good governance in ICM: A conceptual model



NB: Good Governance implies an appropriate relationship between the community and the government, which results in an integrated and sustainable process of development. It implies ideal ICM

6.2.2 Participation: Key issues in agricultural/rural catchments

Rural catchment areas or watersheds are usually defined by a large river system that form a thread through many municipal, provincial and even state jurisdictions, and usually runs through large rural, agricultural, residential townships and industrial areas. Everybody in the catchment is directly or indirectly dependent on the river and its catchment area for their production needs, and the river is affected directly or indirectly by

human activity within the catchment. "All people living in a particular catchment are united by the river, whether they know it or not" (Auerbach, 1997). Abbott (1997) notes that the land/physical environment is part of a landscape, and that landscape is moulded primarily by water (Abbott, 1997: 16). Water is the lifeblood of the environment, and the water in a rural environment would provide a range of multi-functional activities that impact upon all people in the area. These activities would be economic, environmental, and social in nature.

South Africa places a high value on water and natural resources management as far as rural catchments are concerned (Water Act 1998). Water is a scarce resource in South Africa and rivers are the only source potable. Without appropriate ecological preservation, environmental management and sustainable environmental practices, these rivers gradually die off and the water becomes very expensive to treat to a level of quality suitable for human consumption. The river looses its resource potential and becomes more of a liability. Therefore the major role of catchment management becomes environmental conservation (promotion and preservation of bio-diversity - plants, insects, animals, birds), management (promoting sustainable land use and practices) and sustainability (promoting sustainable use of natural resources), with the purpose of preventing their depletion.

While the major concern is natural resource management, the catchment management process has to address a myriad of other issues related to the needs of all the stake holders. There are political issues such as the inter-governmental and departmental relations in terms of co-operation, jurisdiction and responsibilities. There are inter-community conflicts based on access to land and water, allocation, rights and ownership. There are also environmental conservation and protection agencies with their objectives and programmes. The needs of the community and other stake holders are frequently in conflict with the objectives of the government and environmental agencies. The major environmental issues are water quality, provision of reserves to support ecological systems, inter-basin water transfers, soil erosion caused by overgrazing, unsustainable agricultural and farming methods, urban and agricultural encroachment, industrial pollution and social practices that impact on the integrity of the environment.

Integrated rural catchment management has to confront the demands placed on the natural resources based on the needs and interests of the stake holders in the catchment. All these demands can be categorised under two key issues. These issues are related to water and land use.

6.2.2.1 The role of water and land use in rural catchment management

Dams

Water in South Africa is a scarce natural resource and there should be co-operation between the government, private and community sector to find sustainable ways of managing this resource. Large rivers are currently the only source or potential source of water. Dams are constructed to collect and treat river water to ensure that water of acceptable quality continues to be available for recognised water uses, such as urban, industrial, agricultural, recreational and environmental conservation uses. Dams are also increasingly being used for other functions such as providing facilities for fishing, sports, boating, rowing, education, etc. It is, therefore, not unusual for a river to be dammed a number of times before it eventually flows into the sea or joins another river.

One of the important implications of dams is their impact on the natural balance of the river and the river corridor. Dams affect water flow and quantity downstream. This in turn affects and sometimes destroys the natural habitats and the ecological balance in the immediate vicinity of the dam and the habitats below it. The river's natural ability to support riverine life and wetlands in areas downstream is sometimes permanently destroyed. This has resulted in the adoption of the principle of reserve in managing rivers, which refers to both the quantity and quality of the water resource and has two fundamental components. One is the basic human needs reserve, which "provides for the essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene" (Water Act 1998: Chapter 3). The other is the ecological reserve, which relates "to the water required to protect the aquatic ecosystems of the water resource" (ibid. Chapter 3).

Land use

While they do affect the natural balance of riverine environments, dams are themselves affected by land use activities within the catchment environments. These land use activities can sometimes lead to their decommissioning as a source of potable water. Siltation is one of the major problems faced by those who manage dams. This is caused by activities such as sand and gravel quarrying, overgrazing, inappropriate farming practices and methods and the burning of fields during winter. All these land use activities, which provide economic and job opportunities to and support the productive needs of the people in the catchment, can result in the loosening of the soil and, in turn, soil erosion. Soil and soil residue, together with other solid matter is washed into the river and collects at the bottom of dams. These and other pollutants can render the dam out of commission.

Industry and agriculture are the major contributors to environmental pollution. Agro-chemicals, such as fertilisers and pesticides, industrial effluent such as oils, dyes and paints residue, end up in the river stream through groundwater run-off, heavy irrigation and the stormwater drainage system. Inappropriate fertiliser application, together with heavy irrigation practices, results in fertiliser residues such as nitrates and phosphates seeping into rivers. These nutrients stimulate the rapid and uncontrollable growth of water hyacinth and other weeds, which invade and affect indigenous and beneficial plant species in riverine environments. Pesticides and these industrial residues poison the river and the riverine ecosystems. While such ecosystems can withstand small concentrations of such poisons, they are overwhelmed if high concentrations of such poisons are introduced continuously into the environment. This can sometimes lead to major ecological disasters, with effects that are sometimes difficult to reverse.

There is also the problem of poor service delivery in most black townships of South Africa. This affects the environment. By the late 1980 and early 90s, many Black Local Authorities were experiencing a collapse of their administration and the provision of services became chaotic. Many communities suffered extreme hardship and exposure to public health risks as a result of the collapse of infrastructure – particularly cleansing, sewers, stormwater and water. The environment, in many cases, was adversely affected due to faecal pollution of stormwater systems, uncollected refuse and the emergence of informal settlements. Hundreds of kilometres of sewers and stormwater drains have collapsed as a result of lack of maintenance. Blockages of sewers and stormwater drains occur frequently and in some cases nearly permanently because of the theft of manhole covers which, in turn, allow large quantities of debris and solid waste into the system (McConkey, 1996: 24).

As a result of lack of sanitation services in informal settlements, sewerage infrastructure failure, raw sewage is deposited or spills into the stormwater system, which in turn ends up in the river. Uncollected refuse in the streets of the township accumulates in the river system, causing major pollution effects. Faecal and refuse pollution turns the river into a public health risk and it becomes unfit for water uses such as swimming, washing, drinking and water related sports activities, fishing and bathing to continue. This kind of pollution does adversely affect living organisms in the riverine environment, which can contribute to improved water quality. Water hyacinth and other alien weeds, which propagate easily in such polluted environments, gradually replace indigenous plant species, suffocate and invade the riverine environments, rendering these environments unhealthy and dysfunctional.

The effects of pollution are usually more visible in areas where there are dams. Dams are adversely affected because the water becomes unfit and too expensive to treat for human consumption. The water hyacinth invades the surface of the dam, preventing the penetration of sunlight and depleting the dam of its oxygen content, thereby affecting the natural ability of biological species in the water to survive and contribute to water improvement. In its life cycle some of the water hyacinth dies and sinks on the bottom of the dam. This adds to the solid sediments and siltation of the dam. The rotting process of the hyacinth, the sewage and other pollutants cause the release of foul smells from the dam.

Some communities and riparian farmers in rural areas depend on the river as a source of water for drinking, washing, agriculture, cleaning, recreation and income generation related activities. Most of the time it is not apparent to these communities that the water they are using is polluted until fish and other organisms in the water begin to die and the water begins to smell or changes colour. In such situations, such communities continue to use the river because they are either ignorant of the health risks or simply do not have an

alternative source of water. The cost implications in terms of reversing the environmental damage and for public health care are enormous.

Commercial tree planting or afforestation, clear-felling of timber and overgrazing, harvesting of indigenous and rare plant species for herbal use and the use of bore-holes for irrigation are other land use activities that impact on the integrity of the environment and water quality in rural catchments. The plantation of water hungry tree species such as pines, wattles and gum trees affect the river flow. Indigenous species are also affected because during periods of draught, they cannot compete for water with the alien species. Plantation rows provide wind channels that promote soil erosion. Clear felling of timber and overgrazing remove the organic material that holds the soil together and, consequently, these activities contribute to soil erosion.

In remote rural areas, most people depend on traditional medicines for medical care. Traditional herbalists obtain the herbs that they use in their medical mixtures through harvesting indigenous plants from the environment. They sometimes hunt for these herbs in environmentally sensitive areas, and harvest plant species that are rare or are on the endangered list. This destroys the local botanical heritage and effectively reduces the chance of investigating the medicinal properties of such plant material. Bore-holes used for irrigation effectively reduce the water table and the chance of wetland formation. This in turn can contribute to the drying out of the river-beds during low rainfall periods, and can affect the integrity and fertility of the soil.

6.2.2.2 The role of Integrated Catchment Management in rural areas

ICM in rural areas is centred on water resource and environmental management. The key issues would be the management of water and land use activities as far as they affect the integrity of the environment and the water resources. Activities that would characterise the ICM process would be those designed to prevent or reduce negative impacts on the water resources and the environment. Depending on the nature of land use, these activities would include the following:

- Integrated and participatory land use planning, management and development
- Preventing, reducing and monitoring pollution
- Promoting sustainable farming methods and practices
- Designing ecological farming and forestry processes
- Farming system, hydrological and water quality research
- Riverine re-vegetation and combating invasive alien weeds
- Wetland re-establishment and conservation
- Establishing parks and community open spaces linked to dams
- The management of dams and rivers
- Establishing co-operatives and other income generating activities
- Environmental education and awareness and establishing conservation groups
- Forming and capacitating negotiation platforms and subcatchment structures

6.2.3 Integrated Catchment Management: An urban context

The needs of individual people or communities are usually different. Communities have different needs on the environment based on their life-style and they produce different categories of stress on the environment. In relation to water needs, some people may need just a few litres of water per day for basic domestic use, while some would need larger volumes to satisfy their opulent life-styles and some may require even larger volumes for commercial use. In an urban context, such water needs would not be satisfied directly by the urban river. Local authorities or special parastatal water institutions would provide potable water for the above needs. Thus the major issue in integrated urban catchment management is not centred on water resources management as in agricultural or rural catchments.

While the basic unit of integrated catchment management in urban as in rural areas is the river basin/catchment area, one of the key points of difference between urban and rural areas is that the river corridors are not viewed as a resource. Urban rivers, particularly in the Cape Metropolitan Area (CMA) are man-made public water canals designed to get stormwater away from the built environment as soon as possible (Adams, 1996: 19). For example, the Lotus River canal does not follow a natural drainage course

(Taylor, 1996: 29). It drains a total of fifty square kilometres on the southern Cape Flats from the Cape International Airport to False Bay via Zeekoevlei (refer to Chapter 3 for land use and other characteristics). The canal is basically an urban stormwater drainage system. The Lotus River canal is therefore currently not viewed as an important water resource that can be beneficial for domestic or commercial use except by some riparian commercial farmers in Philippi who abstract water from it for irrigation purposes during the dry summer months.

This attitude has been caused by two important factors. The first factor is that while the form and function of world cities such as London, Paris and Cairo are based on major rivers (Thames, Seine and Nile), the natural elements that shape Cape Town's structure are primarily its magnificent mountains and beautiful coastlines (Tomalin, 1996: 10). These physical features have been successfully promoted internationally over the years as the symbols that define the natural beauty and heritage of Cape Town. The other factor is related to the effects of urbanisation. Urbanisation is a social phenomenon in all developing countries, and despite past political interference has steadily taken place in South Africa albeit in an unplanned manner. Its rate has risen over the years and with the new political dispensation, it can be expected to increase considerably (Adams, 1996: 18).

Consequently, many problems associated with urbanisation and urban development have increased. Demands for land to establish residential and industrial areas and to provide infrastructure have increased. The consequence of addressing these demands is increased run-off peaks due to increased roofed areas, concrete and bitumen pavement areas and other impervious surfaces. This in turn results in natural streams and unlined water channels not coping with the increased run-off. Due to inappropriate planning approaches, and because of the factors mentioned above, these natural water channels, floodplains and valuable wetland areas have been compromised to provide for urban development pressures. Natural streams have been redeveloped into urban stormwater drainage system. Because of hydrological factors, the urban stormwater systems have been lined with concrete to facilitate high water flows to reduce the risk of flooding built areas. These channels play no other role in urban areas, such as an ecological role, and have little if any social and economic value. Frequently, they are perceived as having a highly negative impact through attracting dumping and criminal activities.

Integrated urban catchment management is, therefore, centred on environmental management. In relation to the Lotus River Corridor, there are multi-functional land use activities that impact on the environmental status and consequently the environmental quality of canal. The Lotus River canal is one of the most polluted canals in South Africa. There are two main sources of pollution, namely, point source and diffuse pollution. Point source pollution relates to the discharge of effluent or pollutants from a single point. An example would be a manufacturing factory discharging effluent into the canal. This type of discharge is easy to manage because it is normally known where it comes from and who is responsible.

The second is very difficult to manage by local authorities, particularly if it is managed without the involvement of the broader community. Diffuse pollution is the result of many activities in an urban area which, when washed down by the rainfall, cause a deterioration in the rivers and streams. It occurs in all urban areas and the level of pollution is directly related to the activities within that area. To successfully manage this type of pollution requires partnerships between local authorities and the community.

There are a number of different land use activities in urban areas in a particular catchment that could contribute to pollution. About seventy percent of informal settlements in the entire Cape Town Municipal area occur in the Lotus River catchment area. People residing in areas with low levels of municipal services utilise the river as a sewage and waste disposal system. This is particularly so in areas where the watercourse passes through or near an informal settlement. In the townships of the former BLAs (Black Local Authorities), where there are poor or inappropriate levels of service delivery and deteriorating infrastructure, sewage spillage and the accumulation of uncollected refuse or litter into the stormwater canal is a common occurrence.

The Great Lotus River flows through an agriculture and farming area that is altogether about 3500 hectares in extent, including parts of the area which are not in the Lotus River catchment. Riparian farmers in the Philippi Agricultural Area extract water from the Lotus for irrigation purposes. The Lotus River canal has a problem of high water concentration of nitrates and phosphates, which seep into the canal from the Philippi

Horticultural Area. A lot of fertiliser is being applied in the horticultural area, followed by heavy irrigation to improve production. A significant amount of fertiliser, which is not assimilated by the soil, is introduced into the canal through groundwater run-off seepage. These nutrients affect the natural balance of the river because they promote the growth of a range of weeds particularly the water hyacinth.

Due to the high bacteriological counts, high levels of nutrients, together with litter and solid waste in the Lotus River canal and the Zeekoevlei, the lake has been labelled as the most polluted coastal lake in the world. This has affected community health and has impaired the use of the lake and the canal by the downstream water users. People in Zeekoevlei and elsewhere, as well as religious groups in the Metropolitan area, use the Lotus River and the Zeekoevlei for recreational purposes and religious baptising purposes. Since the Lotus River is not a potential resource for potable water, the impacts of these land use activities are approached from an environmental and to a limited extent, recreational perspective. Thus, Integrated Urban Catchment Management (IUCM) would be centred on service delivery, particularly the upgrading and provision of infrastructure, decent housing and maintenance, land use management, and ecological farming systems.

What is common in both rural and urban catchments is that there is usually a multitude of poor communities, interspersed with opulent areas and a rich commercial and industrial core. In agricultural areas this would be reflected by a majority of small-scale subsistence farmers, with poor rural and peri-urban communities interspersed by rich commercial farmers (such as the sugar cane farmers in KwaZulu Natal), large scale manufacturing industries (sugar cane, commercial forestry and other). The relationships between stake holders would be characterised by inequity in terms of access to resources such as land and water. Such relationships would usually favour the richer communities in such catchment areas.

In urban areas the relationship is reflected in the form of racially divided areas. The historically disadvantaged areas are poor, with no industrial and commercial tax base, characterised by high rates of unemployment, high incidences of crime, poor service delivery, limited environmental ethic, low income, poor education and lack of skills. These areas would be interspersed by opulent suburbs, near rich central business districts and in the case of Lotus River catchment area, a commercially viable agricultural area control by a few rich resident farmers or absentee landlords.

However, the principle of community participation also underpins integrated catchment management in urban areas. The role of participation, the local structures and mechanisms of decision-making may differ from similar processes in rural contexts. This is because the nature of these processes and structures is determined by the nature of the local context. The mechanism of democratic structures based on civic association and development forums may not be feasible on a context based on the traditional way of decision-making. Similarly, the nature of the category of stake holders may not coincide with that in an urban context.

6.3 COMMUNITY PARTICIPATION

6.3.1 The conceptual framework

This component of the project is based on the model of community participation for urban management that has been developed by Abbott (see Lotus River Project - Progress Report May 1997). The model is constructed from the basic premise that process of participation is multi-faceted and operates on different levels. These levels reflect the relationships between the stake holder needs/interests and the nature of the decisions to be made to address those needs. This relationship gives an indication of the appropriate levels at which those decisions would be taken and therefore the level at which those relationships would operate. This takes into account the category of stake holders involved and their role in the decision making process. Analysing the nature of the decisions and the role of the stake holders, reflect that there are two levels at which the relationship between the stake holders can operate in terms of integrated urban catchment management.

Abbott (1996) refers to these levels as the arena of inclusion and consensus. "The general view of community participation is that it is built around the community. This is a simplification which does not take

account of the wider implications of community-based decisions on other actors, or in this case, on other elements of the catchment management model. In the arena of inclusion community needs dominate, and the whole of the participatory process is focused at a community level. This community focus can only be achieved, however, if the decisions that are being taken are situated in the lower levels of systems hierarchy where the impact of the decisions are largely contained within the community. In the arena of consensus, the nature of the decision-making is such that decisions have a wide impact across a range of actors and more than one element of urban management. The purpose of the participatory process in this situation is to ensure that the community has a right to participate in the wider decision-making process. Hence the arena of consensus and the arena of inclusion work together and should be seen as inter-linked and inter-dependent" (WRC 1997: 29-30).

If the key issues in Integrated Urban Catchment Management is urban development and environmental management, and it is accepted that community participation is central to the process, then the role of community participation process in IUCM should be negotiated development. This negotiated development process would operate within the two-dimensional framework mentioned above. This implies that the differences between the arenas of consensus are such that there would be different community participation strategies. Hence an understanding of the actors and the nature of the decision that has to be confronted is paramount.

The most important difference between the two arenas in relation to the strategy is in terms of the role of the community participation process. In the arena of consensus the objective of the participation process would be negotiating with other stake holders to reach consensus on the vision of the catchment, the objectives of the integrated catchment process, a catchment management plan, the strategy for implementation, including capacitating appropriate institutions for implementation. The role of the participation strategy would therefore be the mobilisation and capacitation of the community sector to effectively engage in this decision-making process, getting the necessary mandates and establishing report-back mechanisms. This is a process of negotiation that has to take into account local needs and interest and balance them with wider needs and resources.

The objective of the participation process in the arena of inclusion is the participatory planning and implementation of local projects that flow from the catchment programme developed from the arena of consensus. The role of the participation strategy in the arena of inclusion is the development of durable local institutions and establishing appropriate mechanisms for planning and implementing the local projects. This would entail gathering relevant information for the projects, assessing and accessing technical support for project implementation, financial management, analysing local needs and interest, resolving conflicts related to the project, information dissemination, capacity building and training, job allocation, etc. Here the needs of the local community dominate. It is, in effect, the translation of the programme into local implementation projects that are undertaken by the community in partnership with the local authority. Figure 6.2 shows the conceptual model for this process.

These two arena are inter-linked and the one feeds on the other. The inter-relationship between these two levels can be facilitated through the use of decision-making support tools such as the GIS, which can also assist in integrated planning and implementation at both the local and wider levels through the integration of the technical, economic and social data (see section 2.2.2). This tool can be effectively used to manage and manipulate the information related to the local project and to create user friendly imagery in the form of thematic maps.

In relation to Figure 6.2, sustainability is dynamic and is a result of the interaction between the four elements of Urban Management (The Government, Community, Urban Resources, and the Environment). The stake holders (Government and Community) interact with the local environment and that interaction produces stress (Risks) on the environment, which can be minimised or solved through the application of effective solutions (Efficacy) using Urban Resources (Science, Technology, Skills, Money). However, for these solutions to be sustainable, both the government and the community must perceive the solutions as their own (Ownership). This can be done through the establishment of planning and implementation partnerships between the community and the government, with the provision for capacity building and training for the community sector. In the arena of consensus, the interaction process is about the development of an

integrated catchment programme and at the arena of inclusion, which is characterised by a focus on local needs; the interaction is about the planning and implementation of local projects.

6.3.2 Implementation strategy

6.3.2.1 The methodology: Key principles

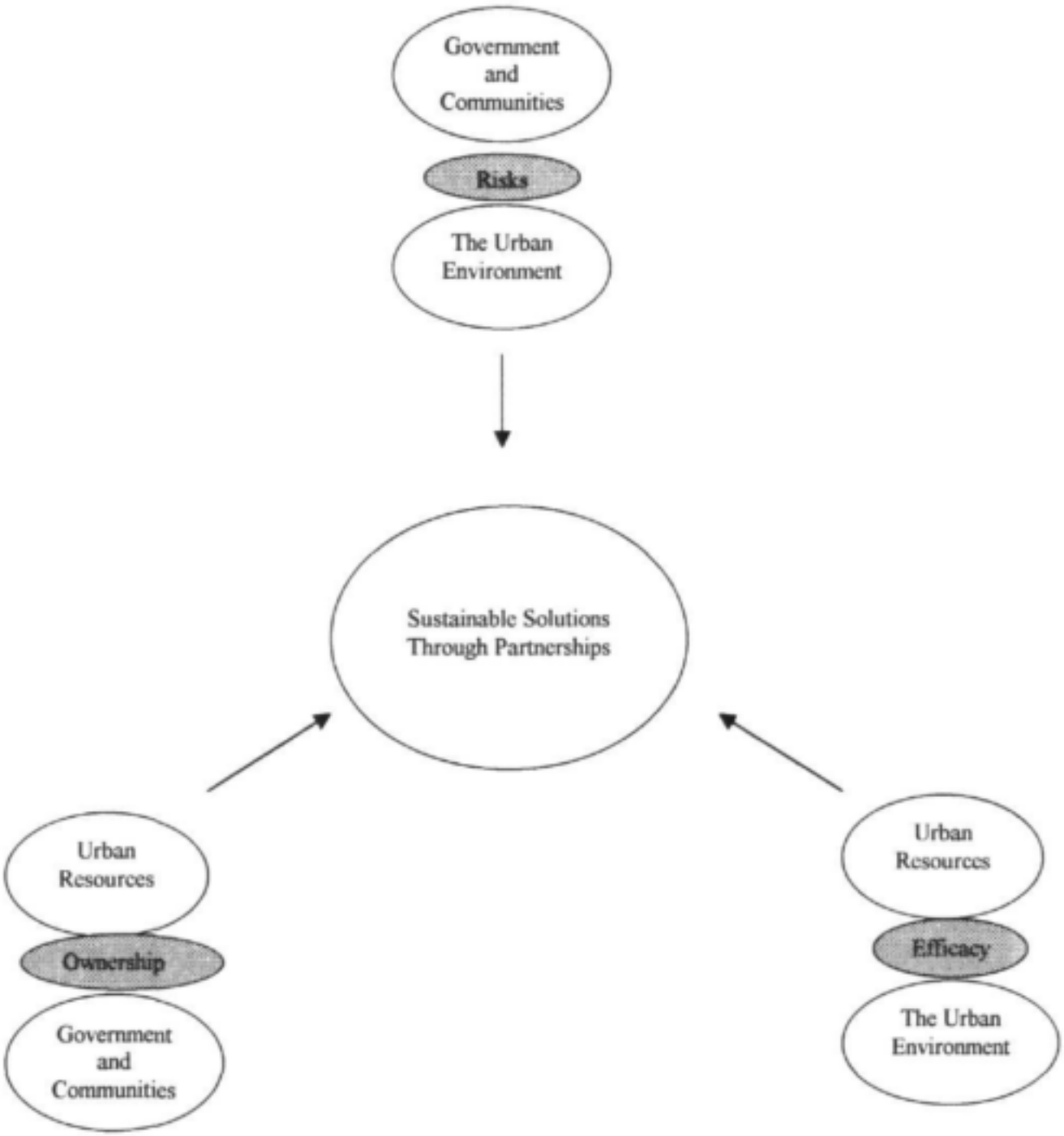
Ideal ICM is a process that has to evolve from the interaction of all stake holders that have an interest in the development of the catchment. These stake holders have to take into account environmental sustainability, technical and financial viability and social acceptability of the solutions suggested within the ICM programmes. This process begins with the establishment of inclusive vehicles that allow the generation of programmes and projects. It includes the establishment of an appropriate institution to implement the programme at local level and involves the gradual devolution of implementation responsibilities to the local levels as the capacity of the local institutions develops. This evolution process is based on the following two key principles:

- Meaningful Community Participation
- Integrated Participatory Planning, Design and Implementation

The first major implication of the first principle is that the process will take into consideration the capacity and the skill of the community relevant for playing an effective role in the process. Therefore, there would have to be the assessment of the strength and weaknesses of the community sector in terms of local skills and the capacity of local institutions. These will have to be a programme and resource allocation to address this limitation.

The second major implication is that the process must establish trust between the community and the government, which is the basis of the success of the process. This implies that there must be transparency in the process and the community sector must be given opportunities of responsibility rather than being just spectators whose responsibility is to consult and advise the process.

Figure 6.2 Interaction process at the arena of consensus and inclusion: A conceptual model



The second principle establishes the basis of sustainability. This implies that the process of planning and implementation must be undertaken through community participation. Integrated development and community participation are two sides of the same coin. The planning and implementation process will consist of spatial planning, environmental planning, community development, physical development (Decent Housing and Infrastructure), and economic development (Job creation and training). However, it should be noted that this is an evolutionary process and while it is in the development stages, there should be ad-hoc projects implemented at local level to address emergencies and to keep the interest of local communities in the process. It should be acknowledged that this is a new concept and approach to communities and their continued participation in the development of ideal ICM must be sustained and rewarded by the implementation of development projects at local level.

6.3.2.2 The methodology: Key elements

The methodology of ICM implementation is based on two components, namely, the process and the projects. The process has four key elements, namely, an extensive community development and support service, an education and information programme, a capacity building and training programme, an interactive planning and implementation process, and the institutional transformation to enable local authorities to implement integrated management systems.

The projects focus on two components, namely, socio-economic and physical development. Socio-economic development component involves the use of accessible technologies to facilitate local involvement in implementation and management, rapid appraisal techniques to gather preliminary information about the local environment and important local needs, and comprehensive social and economic analysis in partnership with the local community. The physical development component involves site design and planning based on the information gathered, and construction using labour-intensive techniques where possible.

6.4 THE ROLE OF THE COMMUNITY

6.4.1 Point of entry into the community

In the period of transition there has been much speculation concerning the future role that civic associations and other local structures will play in the emerging frameworks of governance and development (FCR 1994: 3). The speculations are increasing in particular in relation to the role of civic organisations, reconstruction and development forums, and other organised local interest groups in community participation in urban development projects. The major question in this regard currently is centred on the nature and the extent of their role as far as participatory development is concerned and their relationship with popularly elected representatives of the people and legitimately constituted local government institutions (ibid. 26).

It is mainly the role of civic organisations in the history of resistance against the previous oppressive regime in South Africa, that links civics to reconstruction and development. This history is unique because it effectively integrates politics and development. Other local structures, such as the well-known RDP forums, do not have such history, are relatively new, having been formed after the establishment of the new dispensation. Other organisations such as NGOs and other service groups, suffer from their sectoral focus, having been interested in addressing the needs of a section of the community (eg women, youth, children), or the needs of a particular development sector (eg environment, health, social grants, prisoners' rights etc). In African and Coloured communities, these organisations cannot claim to be broadly representative to the extent of civic organisations.

There are a number of reasons that have caused civic organisations to assume such a status. Firstly, the fact that extreme levels of impoverishment are experienced by the majority, and this situation existing within a nation historically capable of providing a first world existence to whites, makes the reduction of social and physical disparities through development as important as the constitution of full political rights. As a consequence of the apartheid government using development interventions in impoverished historically disadvantaged areas as an instrument for demobilisation, there arises a need for development institutions to legitimise their interventions into these communities through participation (ibid. 31). Narsoo (1993) notes that:

> **"Development is a greatly contested political issue in South Africa . . . The State employed its resources to distribute patronage through a variety of institutions such as the DBSA to win political patronage. The grassroots organisations used their political influence among the 'beneficiaries' to block this, but . . . could not respond by launching their own initiatives. One result was that genuine development was obstructed along with patronage. This created an environment in which development resources are inevitably seen as a political weapon to be controlled rather than shared" (Narsoo, 1993: 6).**

This created the need for subsequent and genuine development intervention into impoverished areas to be blessed through the participation of representatives of the people to reduce the development of counter-productive perceptions and suspicions. Secondly, even with legitimate local government, it is generally accepted that for development solutions to be sustainable, these solutions must have been the result of genuine interaction and negotiations with affected communities (Baskin, 1994: 8). Sustainable delivery depends on whether the initiators and beneficiaries of development are involved in all stages of its planning and implementation (Heymans, 1993: 3). A question that arises then is who are the authentic representatives of the people and/or which mechanisms would ensure that those who attempt to implement participatory development do so through representative local structures and reach the majority of the beneficiaries?

This question is related to the issues of the point of entry to the community. Clearly, meaningful negotiations have to be conducted through organisations that are somehow embodiments of local aspirations, capacities, the thinking of the bulk of any given community and the mediators or advocates of local issues (Baskin, 1994: 8). Naturally, as a consequence of and their role in the history of resistance, and the fact that there are no other established and proven alternative local institutions to take this role, civics have assumed this role.

The problem arises at project level when this is translated into the exclusion of the beneficiary households in the decision-making process. The exclusion of the rank and file community members in the participation and consultation process is usually justified on the grounds that the civics which serve on development committees are representative, without any attempt being made to determine whether or not this is true (Bekker et al, 1995: 9). Clearly, such participation procedures create shortfalls of information at grassroots level and this creates gaps that can be exploited, rightly or wrongly, by influential parties such as NGOs, interest groups and individuals to question or derail the delivery process (ibid. 9). More importantly, they exclude many components and sectors of the community from participating directly in the development process.

Obviously, there are very important questions to consider related to this assumed role or status for civic groups. These questions include their role in terms of the notion of community and community representation, the relationship between civil society and civic organisations, and whether the organisational and operational capacity of civics could effectively fulfil the requirements of the role of community participation. While these questions are very important, it is very important to note that it is not the use of existing structures such as civic organisations or such-like structures in community participation strategies that cause these strategies to fail. As the historical representatives of communities, civic organisations rightly seize any opportunity of participation that they come to know of. The critical problem is the weakness of design in terms of the community participation strategies that causes problems to emerge in development projects (ibid. 14). These problems create feelings that develop into perceptions within the broader community that they are being marginalised in local projects.

Since civic associations have assumed the role of and substituted local government in African and to a limited extent in Coloured urban areas during the resistance era, they have tended to carry this stigma over and had demanded a role even after the advent of popularly elected local government. Due to their unquestionable struggle credentials, and the fact that the principles of participation have been entrenched through the Constitution as far as local government and development is concerned, it is common to see community participation strategies developed with the purpose of just utilising civic associations for the community participation process. These strategies assume that civics are the be-all and end-all of community representation and participation in terms of local development interventions, particularly those from the public sector. This view clearly sets them up for failure in a number of development projects.

Firstly, it should be noted that civic associations are not ubiquitous. They do not exist in all contexts, and particularly those rural areas that are remote from urban areas. They also do not exist in the same form even in urban areas and the local context usually shapes their areas of interest. Some may even prefer to play a local role based on parochial interest. Even if they wanted to engage in wider development interventions, some may be limited by their organisational capacity. Furthermore, many communities have only new, emergent or weak leadership and others have authoritarian leaders who are not accountable to constituencies (Bekker et al, 1995: 12). Historically such organisations are under-institutionalised, with the development of such civil society organs having been frustrated by past policies (ibid. 11).

Secondly, there is a need to define clearly the appropriate role for civic association in development, drawing on lessons from the wealth of local development projects in various contexts in South Africa. Just because effective and sustainable development depends to a considerable degree on whether the implementers and beneficiaries of development are involved in all stages of its planning and implementation does not imply uniformity (Heymans, 1993: 30). In fact, this implies institutional diversity and the creation of a space for the diverse beneficiaries to debate their differences and reach consensus (ibid 3). Development is not likely to be sustainable if development agencies simply substitute civics for the beneficiaries.

There is a need to analyse the development contexts in terms of the nature of the development interventions or projects, the objectives and the strategies adopted for participation, the role of civics and other local structures and how these structures have or are interacting and managing these local interventions. This approach would provide an opportunity to focus on project environment contexts, the nature of and the key elements of the project, local institutions, the beneficiary communities and the performance of existing community based institutions. This would provide the answers that could assist in designing appropriate participation strategies that can penetrate below the level of the local leadership and provide space to the poor to debate differences, needs, aspirations and facilitate meaningful participation. This would provide an indication of the level at which civic organisations and emerging local institutions should play a role for participation to be meaningful.

There are two issues that must be borne in mind in terms of participatory development. One is the issue of the relationship between access to urban resources and community participation, coupled to the need to address the development duality of South African cities. If participation is the key tenet of urban governance, then organisations representing the urban poor are going to have to play a vital role in development projects given the limited resources of the state and the failure of state-led development projects in other countries (Narsoo, 1993: 5). The second issue is the unquestionable importance of civics in development. In most cases, and particularly in urban black communities, civic associations have been viewed as the embodiment of what is commonly known as civil society (FRC 1994: 2). The question of the role civic associations will play in the era of reconstruction is closely tied up with the assessment of what they are and have been for the underdeveloped communities. The FRC (1994) notes that:

> **"a very specific form of local organisation has emerged from the anti-apartheid struggles known as civic associations. Civic Associations have been historically constituted with a complex political and development role. Theoretically a 'civic' should mediate relationships between a heterogeneous network of established groups and institutions in a local civil society with larger structures of power and authority. A mucky history whereby an apartheid state engineered black communities into being often nothing more than dormitories of surveillance has meant that civic associations have had to embody the entirety of civil society. Additionally, these associations have acted to compensate for the many of the functions otherwise serviced by legitimate local political authorities" (ibid. 3).**

Notwithstanding the limitations of civics and other existing organisations, development politics require relatively credible, broadly representative and identifiable partners to represent the highly diverse interests of the recipient community and pave the way for the flow of resources (ibid. 113). Therefore, just as the current local government institutions are used to effect development, albeit their limitations, civics and the emerging organisations are an entry point to most local communities. They will continue to play a significant role in defining the initial participatory frameworks for local projects where they exist (Hindson and Swilling, 1994: 16). Their focus on bread and butter issues links them to development.

6.4.2 Broadening the participation process

What needs to be borne in mind in participatory project management is that the local leadership is not identical to the community. There is a specific role for local leadership that includes negotiating with the initiators of development the appropriate community participation mechanisms that have a chance of broadening the involvement of the community to include the beneficiary households. The initial relations between the leadership and development agencies must evolve into sophisticated institutions and mechanisms that respond appropriately to local dynamics.

It is obvious that processes like the development of catchment management into integrated catchment management process could effectively be negotiated at catchment level. This does not, however, have to ignore the fact that some decisions affect local communities directly. The negotiating strategies have to accommodate such aspects and devise institutions and mechanisms at sub-municipal level. Such institutions would focus on negotiating on local issues, and therefore techniques like the Rapid Appraisal methods could always be utilised. Clearly, the nature of these institutions would conform to the realities of the local context and the key elements of the project in which communities and households have to be involved directly.

6.5 INSTITUTIONAL FRAMEWORK

6.5.1 The role of the CMC and MLCs

The division of function and duties between the CMC and the MLCs is based on the principle that the CMC should not perform a function that can be better performed by MLCs (MRF 1995). The interpretation of this principle resulted in the CMC being responsible for metropolitan wide planning and provision of bulk services and the MLCs being responsible for local planning and service delivery to the public. Metropolitan planning and bulk services include the development and co-ordination of the Metropolitan Spatial Development Framework (MSDF), Metropolitan Open Space System (MOSS), catchment management, bulk water supply, wastewater treatment, etc.

The core business of the CMC's catchment management department is to manage the quantity and quality of water in drainage routes and receiving bodies and to co-ordinate the management of riverine open spaces in the CMA in an environmentally responsible and consultative manner (Catchment Management Department 1998). The core business is based on integrated catchment management (ICM), which seeks to integrate the needs and interests of the community and other stake holders, in ensuring that rivers become a community asset rather than liabilities (CMC Catchment Management Department 1999). The CMC's plan is driven by the need to provide safe, healthy, and sustainable river environments based on the process of ICM. They are on four key functional areas:

- Overall planning of drainage systems
- Co-ordination of catchment management in the CMA
- Funding of operational activities on major watercourses
- Monitoring of rainfall, flows and water quality.

According to the Metropolitan Restructuring Forum (MRF) agreement in 1996, the relationship between the CMC and the MLCs as far as catchment management would be informed by the following roles:

- The CMC shall be responsible for overall planning which includes catchment analysis, determination of strategic options and integrated urban drainage management policies/plans and co-ordination of implementations thereof, rainfall, flow and water quality monitoring and establishment of relevant legislation.
- The MLCs shall participate and assist with the above activities and be responsible for policing and application of legislation.
- The CMC shall, in consultation and negotiation with and assisted by affected MLCs, identify major watercourses, water bodies, wetlands and associated infrastructure according to rational criteria which will be developed in due course.
- The CMC shall, in consultation and negotiation with and assisted by the affected MLCs, determine integrated strategic management frameworks for major watercourses, water bodies, wetlands and associated infrastructure and may provide discretionary funding for improvements and maintenance thereof.
- The MLCs shall be responsible for the detailed planning, improvements and maintenance of all watercourses, water bodies, wetlands, infrastructure and stormwater systems in compliance with the overall management policies and strategic frameworks described above.

In terms of the powers and duties agreement between the CMC and the MLCs, the CMC is also required to ensure the preparation of and compliance with an integrated metropolitan environmental management strategy. This strategy will inform environmental management targets and objectives, direct the implementation of plans and programmes as part of an environmental system for the CMC and allow for ongoing monitoring and review of environmental performance across the CMA. The strategy would operate within an integrated metropolitan environmental policy framework, which is guided by the following principles:

- The policy will be based on a holistic and integrated understanding of the term environment, which includes both the biophysical and socio-economic components
- To provide an overall framework within which detailed local and sectoral policies can be formulated
- Reflect and influence CMC and MLC functions and activities
- Implementation and monitoring of EMS will feed back to policy review
- Public participation is essential to both the credibility and effectiveness of an environmental policy
- Policy formulation process and the EMS will use existing forums and structures wherever possible.

The CMC has begun a process of setting up catchment management committees to begin discussions about the role and relationships between the CMC, the MLCs and the community in relation to the implementation of urban catchment management. These committees will also co-ordinate catchment management activities, provide a forum for communication between all role players and identify opportunities that can be exploited within each catchment area. A catchment management committee was established on the 3rd February 1999 for the Lotus River Catchment. All these committees will be co-ordinated by the CMC. The CMC has also begun developing its environmental policy and the environmental management strategy.

6.5.2 The role of the Department of Water Affairs and Forestry

Sustainability and equity are identified as central guiding principles in the protection, use, development, conservation, management and control of water resources in South Africa (DWAF 1998). Water resources are defined as any watercourse, surface water, estuaries and aquifers, including rivers, springs, natural channels, wetlands, lakes, dams and any other collection of water as declared by the Minister to be a watercourse. This definition and the principles recognise and imply that water resources include any form of water that can be used beneficially to promote social and economic development. National government, through the Ministry of Water Affairs and Forestry, is responsible for the achievement of these fundamental principles in accordance with the constitution (National Water Act 1998: 15). The national Water Act has been enacted to achieve the purpose of the act.

The purpose of the Act is to ensure that all water resources, are protected, used, developed, conserved, managed, and controlled in a way that addresses the promotion, planning, implementation of water resources related conditions and practices, seeking to meet basic human needs, promote equitable access and address past imbalances. These conditions and practices include promoting efficient, sustainable and beneficial use of water resources, facilitating economic and social development, planning for growing demands for water, protecting aquatic, associated ecosystems and bio-diversity, preventing pollution and degradation of water resources and managing flooding and droughts.

The Act would achieve this through a National Water Resource Strategy that would contain strategies, objectives, plans, guidelines and procedures of the Minister and set out the nature of institutions and mechanisms to ensure the achievement of the purpose of the act. The strategy would consist of the following:

- Classification System for water resources
- Set of objectives in respect of water quality to be achieved through the classification system
- State water quantity available and provide a system for Inter-basin Transfers
- Establish water management areas and procedures for catchment management strategies
- Set principles relating to water conservation and demand management
- Determine the inter-relationship between institutions involved in water resource management.

Contents of a Catchment Management Strategy (CMS) will be formulated and implemented through a catchment management agency (CMA), which will be responsible for a water management area (WMA).

The strategy would have to consider the class of water resources, reserve requirements and resource quality objectives as they apply to the water resources in their jurisdiction, and set out the strategies, objectives, plans, guidelines, and procedures that would apply to the WMA. It will contain water allocation plans, promote and facilitate integrated catchment management and community in managing water resources. Therefore the CMA must consult any organ of state, any person and/or representative organisation, which/who has an interest in the content, effect or implementation of the CMS and whose activities affect, or might affect, water resources with the WMA. The CMS will also consider the following:

- Consider needs and expectations of water users
- Physical, environmental, social, technical features of the WMA
- Development plans in terms of the Water Service Act (1997 – ensure that everybody has access to basic water supply, sanitation, sewerage and waste water services necessary for human health and well-being), other regional and national plans related to WMA
- Establish institutions to carry out the strategy.

The classification system provides guidelines and procedures, prescribed by the Minister, for determining different classes of nation's water resources, related resource quality objectives and state the geographic area in respect of which the classes and objectives will apply. In respect of each class of water resource, the system will establish procedures for determining the reserve; procedures designed to satisfy water quality requirements of water users without significantly altering the natural quality characteristics of the resource. The system will set out water uses for instream or land-based activities, which activities must be regulated or prohibited in order to protect water resources.

The quality objective will relate to the reserve, the instream flows, the water levels, the presence and concentration of particular substances in, characteristic and quality of, the water resource, the characteristic of instream and riparian habitats, the distribution of aquatic biota. The objectives will focus on measures for pollution control and prevention, and the regulation and prohibition of instream or land-based activities that may affect the quality of the water resource, including measures to encourage reductions in waste, and provide incentive for effective and efficient water use. The water uses are defined as follows:

- Taking water from a water course
- Storing water
- Impending or diverting the flow
- Engaging in stream flow reduction activity (eg afforestation or planting of trees)
- Engaging in controlled activities (such as irrigation with waste) that affect water quality
- Discharging waste or water containing waste into a watercourse
- Disposing waste in a manner that will impact on the watercourse
- Disposing waste water from industrial and power generation process
- Altering bank, bed, course, or characteristic of watercourse
- Using water for recreation purpose
- Removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people.

The Act indicates that any person who owns, occupies, controls and/or uses land on which any activity that is, or is likely to, or has caused pollution of a water resource must take reasonable measures to prevent any such pollution from occurring, continuing or recurring. The CMA has powers to direct any person/s who fail to take the measures required to prevent pollution to do so within a specific timeframe. Should that person fail to do so, the CMA must take measures it considers necessary to remedy the situation and recover costs incurred as a result of taking such measures from the person or persons who directly or indirectly contributed to pollution or the potential pollution. These persons may be owner/s, controller/s, user/s, occupier/s of the land where such pollution occurred or may occur. Measures include:

- Ceasing, modifying or controlling any Act or process that causes pollution
- Containing or preventing the movement of pollutants and eliminating any source of pollution
- Remedying any effects of the pollution
- Remedying the effects of any disturbance to the bed and banks of a watercourse.

Funding for carrying out the purpose of the Act will be through water use charges, and can be supplemented by money appropriated by parliament and money obtained lawfully for the purpose of the Act. The details of funding will be contained in a pricing strategy that will be established by the Minister. The pricing strategy will provide the basis for establishing water use charges, provide charges to be paid by water management institution or by consumers directly. It will contain measures to finance the provision of water resource management as well as financial and economic measures to support the implementation of strategies aimed at water resource protection, conservation of water, the development and beneficial use of water, and to achieve equitable and efficient allocation of water. In terms of water resource management, this will include costs related to the research, monitoring water resources and their use, controlling water resources, protecting water resources and reserves, water conservation, preventing the discharge of waste, and the development and operations of waterworks, including planning, design and construction.

Clearly, the CMC and the Department of Water Affairs would have to begin discussions in terms of their roles and the relationship that would be conducive for the implementation of their respective functions and duties. The Water Act does not distinguish between urban and rural catchments. The Act covers a broad range of issues, including the management of water resources, land use activities and the environment as far as these affect the quality and quantity of water resources. Urban catchment management is focused on flood control and environmental management, and would address any land use activity that impacts on the quality of water and the environment. Clearly, there is a huge overlap because in terms of the mandate from the water act, urban catchments are included in the functions and duties of the Water Affairs. This is implied from the following:

- Urban rivers would have to be managed according to the classification system
- Water Management Institutions in terms of the Act include "any person (legal) who fulfils the functions of a water management institution in terms of the Act. This would include institutions such as the CMC
- Urban rivers would have to be managed to achieve specific water quality objectives prescribed through the provision of the Act
- Urban rivers would have to be monitored in terms of their impact on major receiving bodies, and measures have to be taken to address any negative impacts
- There is an overlap in terms of the communities to be involved in carrying out the purpose of the Act and the role of the CMC in terms of Catchment Management
- The Department of Water Affairs has proposed that CMA fall under the Berg Water Management Areas which, if finally adopted, would include:

    - The Berg and Steenbras River Catchment Area
    - Urban River Systems draining into Table Bay and False Bay, such as the major catchments like the Diep, Eerste, Salt, Zeekoevlei, Sand, Lourens, Sir Lowry's Pass, Noordhoek, Hout Bay, Sout, and the minor catchments like the City, Mitchell's Plain Khayelitsha, South Peninsula and West Coast.

While there would clearly be a role for the CMC and integrated urban catchment management in terms of the provisions of the act, what is not currently clear is how the two institutions would formally relate to each other and the provisions in terms of funding. In terms of the relationship between the two institutions, what would be the role of the CMC and what kind of relationships would be established to accommodate it in the Catchment Management Agency responsible for the Berg water management area? There is the issue of how the overlapping roles in relation to carrying out the catchment management strategies in terms of the Act within the Cape Metropolitan Area as far as the provisions of the strategy overlap with the functions and duties of the CMC would be funded. If the CMC contributes a significant amount of funding in relation to its responsibility in terms of catchment management, would this translate into proportional powers within the Catchment Management Agency? This needs to be addressed within the pricing strategy.

6.6 PROJECT ACTIVITIES

6.6.1 Stake holder identification (database) and interaction

The goal of community participation was to develop, with the participation of the community and consultation with other stake holders, an appropriate community participation model for the integrated management of the Lotus River. The original strategy, which was to be used to achieve this goal, was based on the adaptation of the Rapid Rural Appraisal technique for the urban context. This was to be undertaken through applied research, combining research with implementation. The purpose was to analyse the technique and its surrounding context, and identify key elements of the technique that would have to inform its adaptation to conform to an urban context. The research component was to be undertaken in parallel to the broad assessment of the project context, the local dynamics, the development of a stake holder database and the introduction of the concept and philosophy of ICM to community representatives.

The intention was to use the adapted version of the rapid appraisal technique to identify key issues of importance to local communities in relation to ICM and the river corridor, do an analysis of local needs, interest, skills and organisational capacity relevant to the catchment management process. However, due to time constraints it was decided that a new strategy should be adopted if the goal of the community participation component of the project were to be achieved within the original timeframe.

The new community participation strategy was designed to involve identified community-based stake holders and representatives of the relevant local government departments directly in the process of developing a model for community involvement in catchment management. The strategy was implemented through an on- the-ground, hands-on approach consisting of:

- One-on-one discussions with community representatives
- Group tours to important sites in the catchment and along the river corridor
- Workshops to identify stake holder-related interests and needs relevant to the ICM process
- Series of open meetings involving community and local government representatives to discuss issues of principle in terms of community involvement in the ICM process.

The major objective of the new community participation strategy was to bring the community sector to an appropriate level of understanding of the concept, the process and the key components of Integrated Urban Catchment Management, to enable them to negotiate with the local authorities and other stake holders. The specific objectives to the strategy were as follows:

- To identify all stake holders who had an interest in the development of the Lotus River
- To develop a database of these stake holders
- To introduce ICM to the community sector and their representatives
- To facilitate discussions and co-operation between stake holders
- To identify key issues of importance to stake holders in relation to ICM
- To identify the level of decision-making at which the issues would be considered
- To gain acceptance of the broad principles of community management
- To explore appropriate mechanisms of community input in the decision-making process.

The strategy was divided into three phases consisting of the database development, local interests and needs analysis and platform building phase. The process started with the identification of organised community groups such as civic organisations, local and school-based environmental groups, RDP forums, local Councillors and influential individuals such as business and church leaders in the Lotus River Catchment area. The major intention was to develop a database and to establish networks through which the project could share, disseminate information and communicate with stake holders, with the purpose of bringing as many stake holders as the project could identify onto the project database. This was an on-ongoing process that was designed to overlap with the other phases. Three major categories of stake holders were identified, based on the analysis of the impact of their involvement or non-involvement in the success of the ICM process. The categories are:

The Community-Based Stake holders such as:

- Civic Organisations
- Development Forums
- Environmental Bodies
- School-based Groups
- Local Councillors

Local Government (CMC and MLCs) departments such as:

- Stormwater and Roads
- Urban Development Planning
- Environment Planning

National Government Departments such as:

- Department of Water Affairs
- Department of Environmental Affairs
- Department of Education

The Business Sector, in particular:

- The Philippi Farmers

NGOs and Research Institutions such as:

- Environmental and Water Quality NGOs
- Academic Institutions
- Agriculture/Farming Research Institutes

Soon after the first phase was started, the project began with comprehensive discussion with the identified stake holders. This was the interest and needs analysis phase, and was undertaken through a process of visiting, on an individual basis, all the known organised community groups, Councillors and other leaders operating within the catchment area. There was a set of two workshops organised for the community sector to bring them together and to share their views and to develop common positions related to the role of community participation in ICM. The first set of workshops was preceded by a tour of important sites in the catchment and along the Lotus River. The purpose of the visits, the tour and the workshops in this phase was to:

- Introduce and explain the objectives of the Lotus River Project
- Introduce and explain the meaning of Integrated Catchment Management
- Explain the implications of ICM in terms of the role of communities
- Engage stake holders in discussions about local interest, needs and perceptions about the Lotus River and how these relate to ICM
- Identify key issues and needs of stake holders related to the success of ICM implementation
- Provide opportunities for stake holders to understand the needs and interests in other areas
- Provide opportunities for the community sector to develop common positions in relation to the role of the community in the ICM process
- Engage stake holders in discussions about their perceptions and needs in relation to community participation in development projects and their role in this process.

The workshop was attended by a number of community representatives within the catchment area, from the formal and informal areas of Ikapa, greater Philippi, greater Grassy Park and Lotus River, Hanover Park and Zeekoevlei areas. The first set of workshops began with a tour of the Great Lotus River and catchment area, followed by the workshop at the Zeekoevlei Yacht Club. The tour started at one point of the canal opposite Phola Park, an informal settlement in Gugulethu. The tour then moved to the site of the datalogger in Philippi farming area, finally concluding with the Sunset Park Detention Pond in Grassy Park. The purpose

of the tour was to provide an opportunity for the workshop participants to get a general view of the river corridor and its potential, particularly in relation to its physical, environmental and socio-economic features so that they could engage in the workshop deliberations from an informed position.

The workshop began with a short presentation on the meaning and the implications of implementing integrated catchment management in urban areas. This presentation also highlighted the key role players that would have to be involved in the process of integrated catchment management, including negotiating on aspects like the nature of catchment management structures, their role and responsibility and other operational issues. Participants were then divided into three groups. The groups were given an hour to discuss, in detail, a number of questions (see Appendix J) related to community participation and catchment management and were asked to report on the outcomes of these discussions. The participants were however not restricted to these questions only. They were also encouraged to consider any other issues that they felt were important to their areas in relation to this subject.

Each group was given a set of flip-chart sheets to write down the group's response to all the questions and issues considered. Each group chose a person amongst them to report to plenary. Members of each group were given an opportunity to add to the leaders' report during the report back session. A short discussion was allowed at the end of each group report. The report back session and the open discussions that follow each report back were recorded. The workshops were conducted in Xhosa, Afrikaans and English with translation where necessary.

The third phase consisted of a series of meetings involving the community groups, NGOs, and local government and representatives of the Department of Water Affairs. The original purpose of this phase was to achieve an agreement from all parties on the principles of community participation that must guide the process of ICM. These were principles related roles and responsibilities, appropriate structures, capacity building, training and other socio-economic issues such as job creation and local security. Due to limitations related to time, operational fragmentation, lack of an integrated institutional framework and a common vision in terms of ICM within local government, the objective of this phase was toned down to conform to the realities of the current limitations.

The CMC Catchment Management Department (1999) notes "catchment management is a relatively new concept which is in the process of being translated into practical action. In the light of these realities it became clear that it was highly unlikely that the process of negotiation on the key principles and the vision in terms of community participation could be finalised within the timeframes of the Lotus River Project. This phase was reduced to a series of meetings designed to set up a forum or committee to negotiate the details of the ICM process. On the 3rd February 1999 the Lotus River Catchment Management Forum was formally inaugurated, with participants from the CMC, MLCs, NGO, CBOs and the Department of Water Affairs. The role of the Forum is to develop a catchment vision, consider interim management needs and develop a catchment management plan.

6.6.2 Issues and principles in Integrated Catchment Management

There were a number of issues raised by the stake holders during the implementation of the participation strategy that indicated that the success of the integrated catchment management process depends on the kind of role the communities will play in the process of conceptualising, developing and implementing a catchment management plan. If there is genuine commitment to ICM, then it must be coupled to the recognition that local communities have to play a major role in the development and implementation of the process. This role must be proportional to the role local communities are playing in shaping the current physical features and the environmental status of the catchment.

One of the major problems within the Lotus River catchment is diffuse pollution in the form of liquid and solid waste. The form of pollution is very difficult to manage by local authorities, particularly if it is managed without the involvement of the broader community. Diffuse pollution is the result of many activities in an urban area which when washed down by the rainfall cause a deterioration in the rivers and streams. It occurs in all urban areas and the level of pollution is directly related to the activities within that area. To successfully manage this type of pollution requires partnerships between local authorities and the

community. This places community participation on top of the list of key principles that have to inform the catchment management process.

The major sources of diffuse pollution in the Lotus River Catchment area are the former BLA townships and the Philippi Horticultural Area (see socio-economic characteristics in Chapter 3). In the black townships, there are poor or inappropriate levels of service delivery and deteriorating infrastructure. If the role of service delivery and infrastructure is to support the maintenance of a healthy and clean environment, then such a state would clearly affect water and environmental quality of the Lotus River. About seventy percent of informal settlements in the entire Cape Town Municipal area occurs in the Lotus River catchment area. The Lotus canal plays a sewerage disposal system in areas where it passes through unserviced informal settlements. Due to the state of service delivery and infrastructure in the area, sewage spillage and the accumulation of uncollected refuse or litter into the stormwater canal is a common occurrence.

All the issues that were raised by the stake holders during the participation process fell into a category related to infrastructure, service delivery, and environmental management. The following are major issues raised and the major perception that shaped the stake holder's attitudes and actions in relation to the river corridor. There are two major perceptions in relation to the role of urban rivers that provide an indication of the major focus of the main categories of stake holders: These perceptions are the following:

6.6.2.1 Major perceptions

A stormwater management role

Urban Rivers are viewed as just engineering utilities designed to provide a stormwater management and flood control service in built-up areas of the Catchment. This view is the major determinant of the current physical features of urban rivers and is the basis of current planning and design approaches and operational frameworks in terms of local government. The basic planning and design responses from local authorities over the years were based on the provision of technically effective flood control infrastructure. Consequently, urban rivers are characterised by concrete canalisation.

Implications of canalisation are:

- A river corridor with a limited social and economic functions
- A river corridor which is aesthetically displeasing
- A river corridor with a lot of environmental risks (unhealthy and dangerous for children, sanctuary for criminal activities, poor and polluted waters).

Consequently, some sectors of the community have suggested that some sections of the canal, which are sensitive in terms of the above-mentioned environmental risks should be buried underground or fenced off.

An opportunity for an integrated role

The other approach is to view the corridor as an opportunity to adopt and implement an integrated approach to service delivery, and provide much needed local recreation and education facilities and facilitate integrated service delivery and development, promote an environmental ethic and awareness. Approached this way, a stormwater management system can be designed to serve multi-functional services and provide beneficial facilities to local communities. The drainage system can play the following functions:

- Technical function – to serve a stormwater management function within an integrated services delivery process
- Social function – to provide spaces for public parks, public open spaces/green areas, sports and other recreational functions
- Environmental function – recreate wetlands to support bio-diversity, and to enhance environmental quality and local aesthetics
- Educational function – natural biophysical and biochemical laboratories for use by local schools

6.6.2.2 Major interests and needs

The needs and interests of the different categories of stake holders in all projects would inevitably differ. However, the importance of integrated projects such as ICM is the inherent ability of such projects to bring together divergent viewpoints, and to force people to listen to other people's needs. Furthermore, such projects explore the integration of divergent needs and interests into generic categories and lead people to find solutions that address these needs and interest in a holistic manner. During the implementation of the community participation strategy, it was possible to develop specific categories that accommodated the needs and interests that were identified by the different stake holders. These categories are:

- Integrated service delivery and management

  Stormwater management should be linked to other services such as street cleansing, solid and liquid waste collection and disposal, environmental conservation and improvement. This requires that the planning and implementation of services and functions related to the achievement of a healthy and clean environment should be integrated. This implies exploring decentralised and integrated mechanisms of planning and implementation. Area management is one possible approach.

- Integrated development planning and implementation should also facilitate and promote an environmental ethic and sense of ownership. This could be effected through the following:

  (1) Linking environmental education and management programmes to social and economic development projects such as the provision of housing and appropriate infrastructure, promoting income generation opportunities (short- and long-term), and support organisational development and skills transfer. The programmes must be designed to broaden the philosophy of environmental conservation and management to include socio-economic and physical elements and to assist people to gradually internalise and understand the connections between the bio-physical and the economic elements of development.

  (2) An Integrated Catchment Management plan implies that the plan should also contain a component that caters for the needs and interests of farmers while addressing the impact of their activities on the environment. The plan would, therefore, have to facilitate the development of an appropriate farming systems approach to promote efficient and environmentally sustainable farming methods.

  (3) Develop long-term environmental awareness programmes that are linked to implementation projects related to local needs and interests. These programmes should be aimed at reaching learners in local schools, people in local organisations, environmental advocacy groups and the general public.

The time has come to acknowledge the existence of urban informal settlement and to develop settlement management and upgrading programmes. Any process that is meant to promote an environmental ethic in poor communities will simply fail if people continue to live in squalid conditions, without decent housing and services. See Table 6.1 for informal settlement growth trends in the CMA. These statistics show that informal settlements are growing in the CMA, despite the existence of the iSLP, which is also nearing its saturation.

Table 6.1 Shack count and growth in the Lotus River catchment

Name of Settlement	Total Count 1998 (1996)	Average Densities (Shacks/Ha)	Population Estimates (S x 3.6)	Growth 1996-98 (%)
Barcelona (CTM)	2220 (2105)	52.98	7992	5
Black City (CTM)	291 (507)	97.00	1048	-23
Boy's Town (CTM)	2981(2475)	117.4	10731	20
Brown's Farm (CTM)	7481(5125)	111.32	26931	46
Crossroads (CTM)	1652(1457)	36.63	5947	13
Kanana (CTM)	1515(868)	82.29	5454	75
Klipfontein Glebe (CTM)	1268(1003)	21.86	4565	26
KTC (CTM)	2101(2324)	115.44	7564	-10
Lower Crossroads (CTM)	1049(853)	66.39	3776	23
Mahobe Drive (CTM)	29(369)	8.92	104	-92
Miller's Camp (CTM)	929(1089)	127.26	3340	-15
Mkonto Square (CTM)	442(722)	105.23	1591	-39
Mpetha Square (CTM)	198(483)	86.09	713	-59
Mpinga Square (CTM)	64(239)	32	230	-48
New Rest (CTM)	1250(1214)	79.57	4500	3
Phola Park (CTM)	1356(1416)	186.49	4882	-4
Samora Machel (CTM)	333(1094)	25.42	1199	-70
Sweet Home (CTM)	886(373)	184.58	3190	54
Tambo Square (CTM)	382(445)	115.76	1375	-7
Vietnam (CTM)	1796(1711)	72.71	6466	5
Ottery (SPM)	141(137)	37.10	507	3
Pelican (SPM)	64(69)	71.11	230	-8

Source: Abbott and Douglas 1999; "Informal settlements in the CMA – Status and Trends Report 1998"

- Community participation and integrated service delivery are two sides of the same coin

  (1) Integrated Development and Catchment Management is not possible without Community Participation at Catchment and Subcatchment level. Participation should be supported through meaningful Capacity Building and Skills Development Programmes

  (2) It is very important to note that community representatives have constantly raised the issue of tangible benefits resulting from people's participation in ICM. Tangible benefits have been explained as the implementation of local projects that improve the physical environment and open opportunities for local employment, and provide capacity building and skill transfer opportunities to local organisations and individuals.

- Explore Outsourcing Special Services like the Collection of Garden Waste, Building Rubble and Dead Pets to Local Entreprenеurs. Such services are currently not provided in some areas of the catchment.

- Public Sanitation and Waste Disposal Facilities must be provided in areas such as informal settlements, trading and sport areas, and public transport interchanges

- Upgrade deteriorating sewers to prevent spillage into stormwater canal

6.6.2.3 Key principles

These are the key principles identified by stake holders, which must guide the development of an Integrated Catchment Management process:

- Capacity building, skills development and job creation can be implemented through meaningful participation between the community and local government
- The urban stormwater drainage system should be utilised to facilitate the environmental, social and economic development of local areas – an integrated and holistic approach
- Informal settlements should be acknowledged as permanent features in cities of the developing world. Local authorities have to develop holistic management and upgrading programmes for informal areas
- The principles of Integrated Catchment Management should not be compromised. Interim management measures should be established
- Appropriate institutional frameworks, funding, management systems and tools to facilitate community participation, research and the implementation of ICM must be urgently considered.

6.6.3 Establishing negotiation platforms

In the light of the current realities in terms of the institutional (local government and community structures) framework and operational capacity, it would be impossible to implement ideal integrated urban catchment management (IUCM) in the short-term. While the implementation of the ideal state of IUCM is long overdue, there is a need to acknowledge the current institutional limitations and the operational capacity of the major stake holders to achieve the objectives of IUCM within a very short space of time. It should be recognised that IUCM is not an event, but an iterative and dynamic process, a state of management that responds effective to a dynamic environment guided by the commitment to achieve sustainability.

Through the implementation of the Lotus River Project, these limitations became obvious and it has been realised that achieving IUCM would have to be through a gradual, experiential process that is conducted through negotiations and that also develops appropriate frameworks and implementation institutions. The most important and the major step to initiate this process is to set up the necessary negotiation platforms to begin what in South Africa has come to be known as 'talks about talks'. Fortunately, the CMC, being one of the major stake holders and the current responsible authority for catchment management, has already committed itself to set up and co-ordinate such structures. The major difference between the Lotus River Project recommendation and the CMC view of such structures is in the role of such structure.

The CMC currently views these structures playing more of a consultative role. The interpretation of this role may differ but a consultation role is normally taken to be centred on the sharing of information between parties and the consideration of external views, without the commitment by the responsible agency to negotiate on contentious issues such as policy, institutional structures, operational approach, powers and functions, etc. The chance of the Lotus River Project's recommendations being implemented depend on whether all parties are open to negotiating the shape and all the elements of the IUCM process. These are the Project's recommendations:

- Establishing inclusive Catchment Management Forums, with appropriate task teams both at catchment and subcatchment with the following basic roles:

    1. Negotiate on the process and appropriate structures to conduct negotiation related to IUCM

    2. Establish the process and its elements to begin negotiating on a common catchment vision and a Catchment Management Plan (vision, objectives and plan)

    3. Negotiate, define and develop an appropriate catchment management institutional framework, structures and/or sub-structures, roles and responsibilities and transfer responsibility to these structures as their capacity develops

4. Facilitate the involvement of all stake holders in the catchment management process, particularly at local level

5. Develop a capacity building programme for local/community structures

6. Identify further research needs and priority projects for immediate implementation

7. Monitor current catchment management plans and other development proposals

8. Study recommendations of the Lotus River Project and formulate and/or integrate into, action plans

9. Facilitate and support school-based environmental groups and promote the integration of ICM into the school curriculum.

6.6.4 Potential projects

6.6.4.1 Understanding and re-establishing urban wetlands

Grobicki (1997) notes that South Africa's urban rivers are effectively stormwater drains, designed and controlled to avoid flooding of built areas (Grobicki, 1997: 4). Wetland areas are drained and developed for further housing, and consequently resulting in increased runoff, which in turn need further canalisation of the rivers (ibid. 4). Canalisation severely reduces the assimilatory capacity of rivers, and ensures that water quality problems accumulate along the length of the canal until the point of final discharge, where the water quality is often extremely poor (ibid. 7). Canalisation also increases the irregularity of water flow, as the response time to rainfall events drop, requiring further engineering responses. There is increasing international recognition that decanalisation and river restoration could reverse these problems (ibid. 7).

The process of decanalisation and river restoration needs to occur within the framework of integrated catchment management. This is because every catchment is unique, in terms of its hydrology, its ecology, its land use characteristics, its communities and the major stake holders (ibid. 1). The behaviour and the characteristics of the river depend on all these factors. It is, therefore, critical that the studying of hydrological and ecological processes, and the understanding of the role of wetlands and their re-establishment occur within the context of an integrated catchment management process. The Lotus River Project has identified a number of potential sites along the Lotus River to begin this process. The CMC has also indicated some support for this process, through reviewing its river management policies. No pilot projects are currently being implemented on the Lotus River system, however, although three wetland projects were proposed in detail, regarding Sunset Park, Brown's Farm, and the Hanover Park wetland.

The Sunset Park project was proposed as a pilot to achieve the re-establishment of wetlands and river restoration. Wetlands restoration projects have relatively low construction costs, reduced need for daily attention and maintenance, passive mode of effluent treatment and aesthetic appeal render them as highly suitable urban runoff treatment facilities. The Sunset Park retention pond, south of the Ottery Hypermarket, was proposed to be redesigned as a pilot scale project to investigate its ability to remove various nutrients and sediments from flow in the Lotus River. These include phosphates, nitrates, COD, suspended solids and heavy metals.

The river at the Sunset Park retention pond is a trapezoidal concrete lined canal with overflow berms, and the pond itself is characterised by open grassy areas on either side of canal. These grassed areas have excavated earth banks and are used for attenuation of 1 in 50 year flood peaks. Unfortunately, due to a defect in construction (a faulty outlet), the pond is inundated for much of the winter and hence cannot be used for football games. Because of the physical problems, it does not have a social amenity as an open space, but neither can it effectively serve its intended function as a retention pond. In addition, local residents have complained about the potential danger or risk posed by the steep-sided open canal for small children. The proposal was meant to address both the potential social value of this area, and its potential function for treatment of urban run-off at low flows. The objective was the creation of a permanent wetland system and "water park", using aquatic and shoreline vegetation for nutrient removal. Following discussions with the South Peninsula Municipality, the implementation authority for this area, the project was, however, shelved.

The other spin-off resulting from the work of the Lotus River Project is the project on high value aquatic plants. The objectives of the project is to study the growth and potential economic benefits of planting high-value aquatic plant species along urban rivers, with the twin purpose of generating income for low income communities and the contributing to wetland restoration and water filtration. Initial attention has focused largely upon arum lilies, which are indigenous to the Western Cape, although a database of aquatic plants for use in other areas of South Africa is in preparation (WRC Project No K5/1054 on "The cultivation of high-value aquatic plants in restored urban wetlands, for income generation in local communities"). A feasibility study was conducted to identify potential sites and assess the marketability of arum lilies, as well as the potential financial returns. Two suitable sites in the Lotus River catchment were proposed for the cultivation of arum lilies, namely the excavated detention pond at Brown's Farm, and the natural wetland at Hanover Park, which is currently cut off from the Lotus River by earth berms. Unfortunately, neither of these projects is being implemented, through difficulties in accessing municipal land. The wetland at Hanover Park is currently zoned for transport, and the municipal planning approach is to fill it and develop a taxi interchange on the site. It is, however, unlikely in the long term to pass the required Environmental Impact Assessment for this development.

6.6.4.2 Designing ecologically sustainable farming systems

The Philippi Horticultural Area (PHA) has a predominantly rural nature in terms of its social, economic and physical characteristics (see Chapter 3). There is no stormwater drainage and waterborne sewerage system in the area and a few holdings are provided with potable water by CCC water mains. The PHA is about 3 500 hectares and most of it is farmed by approximately 80 vegetable farmers (CMC 1995 - Rezoning pressure on the PHA). The area is reserved for agricultural purposes and the exploitation and refining of sand by the glass industry. Due to uncertainty arising from the broad interpretation of the reservation and the term agriculture, and the absence of a planning framework to identify issues and co-ordinate development, this land is constantly under pressure. This pressure emanates from speculative rezoning applications, urban encroachment, illegal dumping, water pollution, squatting, lack of services and maintenance and a general deterioration of the physical environment.

Yet this area has shown incredible growth in vegetable production over recent years. Local farmers estimate that at least 50% of their produce is sold directly to street traders, local supermarket chains, residents, and restaurants and the remainder is sold to the Epping Market (ibid. 7). The PHA supplies about 80% of the vegetables, such as carrots, cauliflower, lettuce and cabbage, that are sold at the Epping Market. Thus, although the area of horticultural production in the PHA has diminished over the last few years, there has not been a decline in volume of produce from the PHA sold at the market. This suggests a substantial increase in productivity on the remaining pieces of land.

However, despite this positive situation, the PHA has been, for several decades, and is still under pressure from urban encroachment. Urban population growth has been the major contributor to this pressure, particularly the rapid growth of the surrounding suburban and informal settlements and the land demands for low cost housing that is close to urban opportunities. A major onslaught has also begun from the environmental front. The Lotus River Project has shown that most of the nutrient loading experienced in the Lotus River emanates from the PHA. This is due to outdated and environmentally inappropriate farming practices such as over application of agro-chemicals and heavy irrigation. A lot of these chemicals end up in the water through groundwater runoff. The farmers have therefore come under fire from environmentalist and local authorities.

Attempts to involve them in the ICM process through the community participation strategy have so far had limited success. Farmers are more interested in increasing production levels and in safeguarding their land use interests. Since they have come under fire recently, they are very suspicious of any external approaches, particularly those from the local government and private sector. Yet, for the success of the ICM process, they have to be brought on board. The only system that could work to achieve this purpose is a farming system approach, which is based on recognising and addressing the needs and interests of farmers, while designing appropriate and ecologically sustainable farming methods, through experiential processes. This system has to occur in parallel to considering short-term physical infrastructure measures to ameliorate impacts on the environment.

Individual farmers have shown themselves willing to become involved in environmental initiatives, which if proved successful would then be more readily considered by other farmers and by the association as a whole. There are three issues which, in discussion with individuals, have shown themselves to be viable future approaches:

- Irrigation dams : environmental rehabilitation including sloping of banks, fencing, planting of aquatic vegetation (to enhance biodiversity, see Chapter 5)
- Fertilizer management : there is a willingness to do field trials on organic crops, minimising the usage of inorganic fertilizers
- Concern about water quality in canals used for irrigation: this issue could be used as a *quid pro quo* with farmers whose land borders on the river; eg linking improvements in water quality to the setting aside of riparian strips along the riverbank, and rehabilitating dams

6.6.4.3 Integrating ICM into Curriculum 2005

One of the key principles identified by stake holders during the community participation process was the integration of the concept and practices of ICM into the school curriculum. The major justification for this principle is that a broad-based environmental ethic is dependent on whether or not individuals within the community have been made aware of the basic reasoning behind environmental protection and conservation. Being environmentally conscious is a learned behaviour. This behaviour can be nurtured and spread through all the corners of the community by targeting learners at school. This was the rationale behind the development of the proposal to integrate ICM into Curriculum 2005. This project is one of those that resulted from the work of the Lotus River Project.

The project was designed to operate as an integral part of the whole learning process, rather than as an extra curricular or stand-alone activity. It would be implemented within, and be an integral part of, the normal learning or school's timetable. The major goal of the project would be to develop and implement a Learning Area focussed Learning Programme or Curriculum in all the grades within the senior phase, in parallel with the on-going curriculum development process for the learning areas identified within Curriculum 2005. This project would focus on the Natural Sciences Learning Area.

The project would emphasize two themes, namely the Earth, and the Life and Living Themes, with learning contexts drawn heavily from the environmental discipline. It would emphasize scientific knowledge and principles, the development of skills to acquire this knowledge, and the ability to use this information to respond to real life situations. The Learning Programme would thus involve learners in a real life environmental situation and would be based on practical activities, with the purpose of highlighting the influence of science and technology on development and the relationship between development, people and the environment.

Its specific objectives would be:

- To create a mechanism of constructive engagement between the education and private sector
- To contribute to curriculum planning and development, implementation and support
- To contribute to science teaching, human resources and learning support material development
- To stimulate learners' interest in science, its relationship to decision-making and development
- To facilitate the use of scientific principles for analysing environmental situations or phenomena
- To develop learners' research, creative writing, presentation and communication skills
- To involve learners in water quality and environmental analysis
- To encourage involvement of learners in problem-solving activities
- To facilitate and encourage cross-cultural interaction and teamwork.

This project has received high level interest from the Western Cape Education Department and has been presented to some of the teachers and officials within the Lotus River Catchment area. It has also been submitted to potential funding sources for implementation on a pilot scale in the Lotus River Catchment area. However, the implementation within the regional Department of Education has been delayed due to limited funding and the policy delays from the national Department of Education. Hopefully the project will be implemented in due course, within Curriculum 2005.

6.7 EVALUATION OF THE PROCESS

6.7.1 Strengths and weaknesses of the participation strategy

The commissioning of the Lotus River Project provided a valuable opportunity of, among other aspects, introducing to and discussing the concept, philosophy and implication of ICM with communities and their representatives, and facilitating the serious consideration by local authorities, of the principles of ICM in planning and implementation. These are some of the major successes of the project. However, the Lotus River Project lacks the ability to maintain the momentum gained thus far through to implementation. This is not a limitation directly related to the structure, the focus and the implementation approach of the project.

The Lotus River Project was conceived and was designed as a research project. The methodology of implementation enabled the project to be conducted more than just applied research. The implementation methodology provided the space to enable the project to also lay the foundation for the translation of the key principles that resulted from the research into meaningful action. All the project components encouraged dialogue between the project team and the major agencies and individuals on all the key elements of ICM and issues related to its success in the Lotus River Catchment area. The major shortcoming of research is that there is no guarantee that the recommendations from such work will ever be implemented.

In relation to the participation component of the work, the community participation methodology and ICM model would remain just that until relevant implementation agencies translate the recommendations into implementation action plans. It is unfortunate that the concept of ICM is still new and local institutional capacity is limited; otherwise civic society organs such as civics and related structures could maintain the momentum gained through the project thus far. The major success of this project component is the establishment of a forum involving the CMC and community-based organisations to begin discussing details in relation to the implementation of ICM. Fortunately, as has been mentioned before, all of the major implementation agencies, relevant NGOs, influential individuals and representatives of the community have been part of the project. It is hoped that this is the foundation from which implementation could emerge.

Another major weakness of the project was that it becomes very difficult to extend a research project through to implementation if that research work has not been commissioned by an implementation agency or the commissioning agency has limited influence over implementation agencies. It becomes even more difficult if any suspicion that the recommendations from such work would amount to sharing of some powers with communities outside the conventional construct of administrative control and regulation. Government agencies have not been known to be keen to hand over significant powers and responsibilities to communities. Even if they do, they usually make sure that such situations are within frameworks where such government and local community relationships are still largely under their control.

The other weakness in terms of the participation strategy is the assumption of the strategy, which approached the integration of the farming community as if this sector was similar to the community sector. Farmers are farmers and their major interest is to increase and maintain effective production levels, using any legal means. Unfortunately, some of these means impact negatively on the ecological balance of nature. The Philippi farmers and their association have not responded to the invitations to attend the community workshops or been part of any broad gathering related to the project, even when they were invited by the CMC. However, most individual farmers have welcomed and responded very positively to members of the project team who have visited their holdings for information or assistance. This indicates that given an appropriate approach, the farming community can be part of the process of sustainable development. The strategy to bring them on board must be based on a farming systems approach (see WRC Report No 684/1/97 for details of such systems).

6.7.2 The Catchment Management model

The process of negotiation centred on establishing ideal ICM should focus on three critical components simultaneously. First, the process must identify and support the implementation of strategic local projects that would facilitate the sustained involvement of local communities while addressing the needs of the environment. This is a component that should combine local income generating projects (short- and long-term) with medium- and long-term environmental education programmes that target the community and learners in local schools.

Secondly, the process must take the role of monitoring development projects that are undertaken by the various line departments in terms of their impact on the catchment environment while also making recommendations on the process of establishing an appropriate institutional framework for Integrated Catchment Management. This must include the consideration of the deployment of financial and other resources to these projects and how implementation projects are designed, that is, whether they are guided by the principles of sustainability and conform to the key elements of ICM. Finally, it must begin to define the details of integrated catchment management as it would apply to the catchment, its goals and objects and begin to develop appropriate strategies and institutions for implementation.

The model of the process as seen in Figure 6.3 is based on the principle that the community participation implementation institutions and mechanism finally adopted must emerge out of negotiations with the community. These would be based on the final roles and responsibilities that are allocated to them through the negotiation process. The model recognises that the process would be evolutionary in that the initial roles allocated to communities might change and increase based on their increasing capacity. Therefore, it is critical to allocate resources to support this process of community development.

6.7.3 Conceptual limitations, local priorities and capacity

One of the most important challenges of establishing a functioning ICM process would be to assist people, more so ordinary people, to begin to internalise and relate to the concept of a catchment and integrated catchment management. People's actions are usually governed by their survival strategies, which are driven by basic needs. These needs do not usually conform to the needs of integrated planning and development. Until people begin to understand the value of integrated catchment management, it would remain only a vision shared by professionals, and would be perceived by the poor as an elitist vision, with no tangible meaning or value to ordinary people.

Auerbach (1997) notes that "while a catchment-based approach (would) look attractive to geographers and natural resources managers, it is often seen as very abstract by people who live in a catchment. Usually, people see themselves as part of a community defined in terms of a town, a village, an area, or a faction. If not language, politics or culture, often schools, roads, bus routes or administrative boundaries define communities. In some rural areas, the unit of community is defined by a dependence on a common resource, such as the local spring and in such communities, this can act as a very powerful social unit" (Auerbach, 1997: 51). Thus, while ICM in South Africa has achieved widespread support, implementation is still in its infancy and the approach is not prominent on the agenda of local communities.

Thus the challenge is to establish a process that would be seen to be meaningful to ordinary people in terms of their basic needs in the short term. Only when ordinary people have an economic dependency on the process, will people allocate a value to it. The response and attitude of individual people and communities towards catchment management would be dependent on whether they see the process contributing or having a potential to contribute towards addressing their basic needs. Some value would be allocated to the river or the management of the catchment if and only if people have an economic and/or social dependency on these entities. Sharma (1997) contends that it is not enough to promote the participation of people in projects or programmes if their efforts would not be translated into or generate tangible benefits to the people (cited in Auerbach, 1997).

The issue of building the understanding of the concept can be addressed through long-term educational programmes that target all sectors of the community, particularly women and school going youth. It is a process designed to effect behavioural change and the way people perceive the local and the broader environment. The issue of basic needs can be addressed through a process that combines this education programme with economic development. It is about creating a common view and vision of an environment that is not only there for exploitation for economic benefit but a direct benefit to the health and the general quality of life of all people. Development and management programmes must combine the priorities of ordinary people, which are driven by basic needs as they are being addressed at individual household level, with an appropriate and broader definition of the role of the environment and planning.

This process must consider and promote appropriate household survival strategies while combining this to the building of local institutional capacity for increasing collective action and involvement of the community in planning and implementation. Since the communities have not yet internalised the concept of catchment management and their organisational capacity is still limited, they are therefore not geared up to undertake such a complex task immediately. Further, their immediate priorities currently do not conform to the needs of the Integrated Catchment Management approach and they do not attach any economic value to the environment. This requires that the elitist view of environmental planning and conservation as only based on preserving biological diversity and historic buildings should be discouraged. It also requires the allocation of resources to the process of community development and the training of local structures and individuals.

Environmental education projects and campaigns can only succeed if supported by integrated physical and economic development. If people do not have access to decent housing, reasonable service delivery and income generating opportunities, there is no way that they will respect their immediate environment. The challenge is to combine short-term income generation projects with environmental education to translate these into environmentally sustaining behaviour, awareness and a common vision that is based on shared problem appreciation within local communities (Auerbach, 1997: 13).

6.7.4 Role of ad-hoc projects (committed projects)

It should be remembered that because ICM is relatively new in terms of implementation at local government level, the current catchment management budgets in terms of drainage operation and maintenance are still being deployed on an ad-hoc basis. Funding and operation depends on either a demand from local communities, visible need or emergencies and this is assessed in relation to flood control, maintenance needs and environment factors. There are, therefore, budget allocations from the CMC to MLCs that is currently being used for such projects. Since the basis of catchment management within the metropolitan area is stormwater management and flood control, and the vision of ICM is integrated development and environmental management and improvement, the impact of the ad-hoc projects needs to be monitored in terms of their contribution to the ideals of ICM. This is a role that should be played by the new catchment management committees.

There is also a need to consider strategic opportunities provided by these projects and budgets. These projects and budgets need to be reviewed and redesigned to promote the ideals of integrated catchment management, particularly in terms of integrating the needs and interests of local communities. These projects can contribute significantly in terms of educating local communities about alternative roles for the stormwater canal and the meaning of integrated catchment management. It is critical that local communities are brought into the process of ICM sooner rather than later. The only strategic option immediately available to facilitate this process is through these ad-hoc projects. This can be undertaken through increasing local community involvement through short-term education and job creation projects.

6.7.5 Institutional and social constraints

6.7.5.1 Operational constraints

From the definition of ICM and the preceding discussion, it is clear that ICM is a very complex process. It is a process that would have to be developed gradually through negotiations between all the relevant stake holders. Besides the need for negotiations, there are real and practical constraints that would prevent the immediate establishment of a functioning Integrated Urban Catchment Management process.

The ideal institutional model for catchment management would have to be based on a management system that would integrate all the components of development implementation and management within a catchment area, which also include all stake holders, relevant government levels, departments and institutions. It would need the streamlining of the interrelationships between the operational components of municipalities, effect behavioural change, develop and train human resources capable of operating such a system. Such an operational framework does not exist currently within government institutions. Local government administrations are still trapped within the historical regulation and control culture.

Ideal IUCM is therefore "a long-term ideal, which will only be achieved if it is actively striven for by establishing the building blocks and proceeding towards it in a gradual and phasing manner, with all the capacity contained in the catchment – be it social, economic, legislative, political or environmental energy. Provision should be made for ongoing and phased steps towards a system of integrated catchment management" (WRC 1998: 11).

6.7.5.2 Institutional fragmentation and priorities

The institutional framework of government structures in terms of legal, policy and operational aspects negates the immediate establishment of appropriate institutional models for integrated management. Despite the comprehensive reforms of water and environmental law currently underway, serious fragmentation will persist because the new Constitution renders water management and certain land use-related subjects as central government competencies, while others are rendered provincial competencies.

There is also serious operational fragmentation. Environmental and nature conservation on the one hand and water resource management and forestry on the other hand is managed and operated respectively by the ministries and departments of Environment and Tourism, and Water Affairs and Forestry. Land affairs and energy, for example are central government competencies, while agriculture, nature conservation, rural and urban development are provincial competencies. At local government level, environmental planning is usually under a separate department to water management and urban physical development. These departments and their operational arms usually do not communicate with each other, not because they do no want to but because the institutional framework and financing mechanisms makes it difficult for them to plan and work together. Further, these departments have different operational priorities, which would not necessarily conform to the needs of Integrate Catchment Management planning and development.

Finally, in the demarcation of administrative boundaries for local government, political rather than the functional aspects of the environment takes precedence. Some catchment areas fall under the administrative authorities of a number of local authorities. The Lotus River catchment area falls under the administrative jurisdiction of the Tygerberg, the Cape Town and the South Peninsula municipalities. This makes it very difficult, at both the political and operational level to establish working relationships because of political relations and competition between these local authorities. Thus a process of bringing these components into an appropriate institutional model would have to begin by developing a common vision within government in terms of the wisdom of an Integrated Catchment Management approach. In the short-term, any department that has the responsibility of catchment or integrated environmental management would suffice to kick-start the process.

6.7.5.3 Institutional capacity

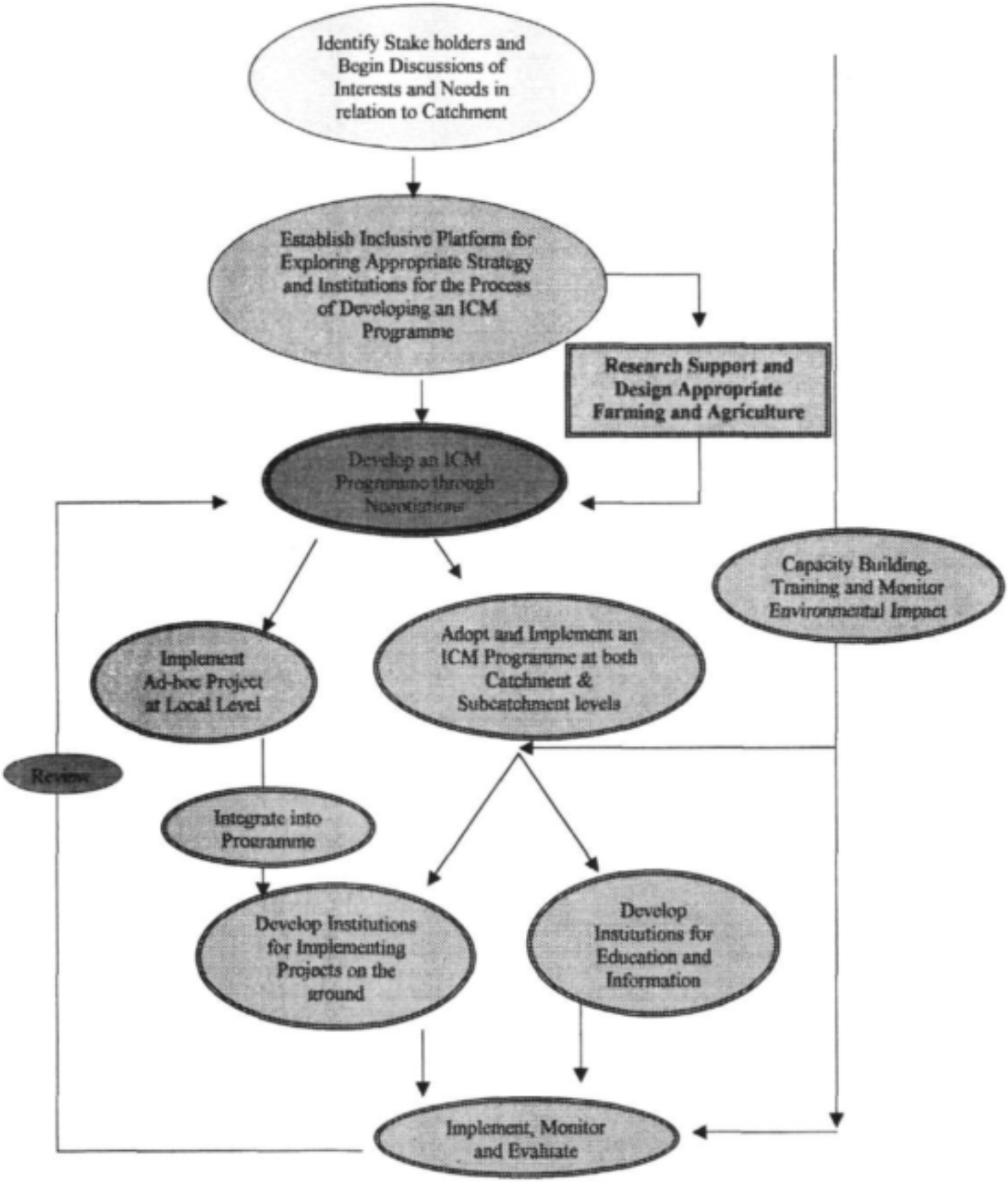
This relates to both the local government management and operational capacity and the organisational capacity of the local community to undertake such a sophisticated task. While there is an abundance of technical skills within the local government structures, particularly in urban areas, most local authorities have not adopted the approach of integrated planning and development on the basis of catchments in undertaking the planning and implementation responsibilities. Consequently they currently do not possess the capacity and have not begun to develop the capacity to maintain such a complex perspective at operational levels.

This applies even to those local authorities where there is abundance of skill and technical capacity. They are also not operationally ready to undertake such a task. Such an operational perspective would overstrain their

limited management capacity, because it would involve so many varied and inter-related activities and disciplines and so many participatory and control bodies, a role for which these institutions are not ready (WRC 1997: 9). Local government institutions are simply not geared to assume such complex tasks immediately. These tasks would involve the development and training of local structures, and the gathering and management of information such that the information and the planning and implementation process is accessible to the poor. Municipal engineers and planners are not experienced in managing such processes.

Thus there is a need to acknowledge these deficiencies, begin to build inclusive and participatory structures that will begin to negotiate about the details of ideal integrated catchment management and gradually establishing and capacitating appropriate institutions that will pursue the achievement of these goals. This process would happen in parallel to, but must monitor and influence the on-going operation and maintenance functions, of local authorities. The immediate and most important requirement is a commitment to a process of negotiations that is inclusive. Structures and processes must be established immediately to facilitate a dialogue between local authorities, government departments and communities about the role of Integrated Urban Catchment Management and begin to explore appropriate structures and mechanisms, leading into detailed discussions about strategies to translate vision into reality.

Figure 6.3 Catchment management model: The process



CHAPTER 7 CONCLUSIONS

7.1 GENERAL CONCLUSIONS AND GUIDELINES FOR URBAN CATCHMENT MANAGEMENT

The Lotus River project has shown that urban catchment management can be approached on an integrated basis. Ecological, hydrological and water quality considerations are linked and balanced through a participatory decision-making process, and supported by a GIS database which makes the spatial data visually meaningful. Limitations on data acquisition and modelling capabilities are rapidly being removed, as the use of GIS becomes widespread and the technology advances. The future for urban catchment management is full of opportunities:

- With advances in modelling, it will be possible to move towards forecasting a range of scenarios with visual representation, allowing catchment committees to make real choices with regard to stormwater infrastructure. Advanced technology will make it easier, not harder, for non-technical people to understand the consequences of various choices, by being able to see the outcomes represented visually.
- As the concept of catchment management becomes more widely known and accepted among urban professionals and the general public, catchment committees will become able to influence the urban fabric more fundamentally through decisions on land use changes, and through creating multiple land use opportunities.
- With changes in institutional structures, urban catchment management risks losing its financial base, where water supply and wastewater treatment services increasingly become fragmented and privatised. Stormwater management alone has a less secure financial base. Achieving long-term sustainability for urban catchment management can be assured by linking more strongly with quality-of-life considerations, especially the provision of recreational amenities and the conservation and restoration of biodiversity. Here, community-based catchment initiatives as in the example of the USA are crucial to success.
- Conversely, where water services become more integrated institutionally, catchment management can be linked with land care, wastewater reuse and demand minimisation in an overall approach to urban water management. An example of this is the creation of the Sydney Catchment Authority in Australia (July 1999) which owns the water resources for Sydney, has responsibility for 11 catchments, and has strong referral powers with regard to undesirable developments.

Perhaps the most important recognition to make in catchment management is that social and institutional processes should take precedence over technical decisions. This has been shown over and over again in successful catchment management projects worldwide. The first section of this chapter presents the top 10 lessons learned from watershed protection initiatives in the USA are given, as summarised by the US Environmental Protection Agency. These provide extremely valuable general pointers for the set-up phase, and for the social and institutional process of urban catchment management. Secondly, best management practices (BMPs) for stormwater management are outlined, together with an analysis of their effectiveness, drawn from international sources. Thirdly, some general guidelines for GIS-based urban catchment management are presented, which have been drawn from the experiences of the Lotus River project. The final part of the chapter presents specific recommendations for the management of the Lotus River catchment, which have arisen from the work carried out in this project.

7.1.1 Top 10 watershed lessons learned in the USA

In the USA, catchment management is termed watershed protection, and is an activity which is pursued largely on a local level, through community-based initiatives, rather than at a federal level. However, the US Environmental Protection Agency has taken an active interest in promoting watershed protection, by providing information and facilitating contacts between various smaller dedicated organisations and networks, because of the wide-ranging beneficial spin-offs to the environment of this approach. In 1998, the EPA published a

document summarising the lessons learned by the numerous watershed protection initiatives taking place around the USA. The full text can be found at http://www.epa.gov/owow/lessons together with a host of other useful contacts and web sites. The following section is summarised from this document, for the benefit of readers in South Africa.

For the past six or so years, EPA, in partnership with many others, has been pursuing a watershed approach to protecting lakes, rivers, wetlands, estuaries, and streams. For a federal agency with a strong regulatory tradition, this is a new way of doing business. Taking on the role of community helper and partner has been a challenge. As with any change of this magnitude, there has been a lot of trial and error, and important lessons have been learned that are worth sharing. This document of Watershed Lessons Learned is an attempt to identify the top lessons and present them in one place.

The target audience is watershed practitioners and those who support them: anyone who is trying to make watershed work happen or support it. This can include concerned citizens, scientists, government employees (on the local, state and federal levels), corporate sponsors, non-profit groups, among others. This document helps readers learn what works and does not work, based on past experience. Second, it will assist people in reaching important resources and contacts that exist across the USA that can help them. The need for such information was pointed out in the conclusion of a presentation made by Robert Nuzum, Manager of Natural Resources, at East Bay Municipal Utility District in Oakland, CA. ***After working on a watershed plan for four years, he said that if he had to do it over again, he would spend more time educating participants on 'what works' and 'what doesn't' prior to beginning his watershed planning effort.***

As for how this list was developed, a focus group comprised of 20 members of the target audience was assembled. This included representatives from River Network, Know Your Watershed, Center for Watershed Protection, Maryland Office of Planning and EPA Regional Offices among others. This group reacted to the idea, refined it, and developed the "top 10" watershed lessons learned. That list was circulated and improved with the insights of approximately 100 watershed coordinators and their supporters across the USA. These practitioners helped to identify the best examples to illustrate each lesson and the resources that have worked for them. Such testimony is very powerful.

Lesson One: *The Best Plans have Clear Visions, Goals, and Action Items*
Lesson Two: *Good Leaders are Committed and Empower Others*
Lesson Three: *Having a Coordinator at the Watershed Level is Desirable*
Lesson Four: *Environmental, Economic, and Social Values are Compatible*
Lesson Five: *Plans Only Succeed if Implemented*
Lesson Six: *Partnerships Equal Power*
Lesson Seven: *Good Tools are Available*
Lesson Eight: *Measure, Communicate, and Account for Progress*
Lesson Nine: *Education and Involvement Drive Action*
Lesson Ten: *Build on Small Successes*

WATERSHED LESSON #1: The Best Plans have Clear Visions, Goals, and Action Items

"I want to be able to see my feet."

- Bernie Fowler

Visions can rally individuals to take action and to focus their efforts on specific goals. The best visions are graphic in their descriptions and relate to human experience. Bernie Fowler, for example, former Maryland state senator and a leading voice on environmental issues, brought instant attention to the problem of sediment in the Patuxent River when he stood chest high in the river and declared: "I want to be able to see my feet." At the very least, visions must be scientifically accurate – represent the facts – and be understandable to the general public.

So how does a watershed group come up with powerful visions? Experience suggests that before a group can develop visions and goals, there must be a clear and widely recognised problem statement. This statement helps to establish a common understanding of the conditions that warrant a watershed protection effort. The term "problem" does not mean that a water body has to be actually damaged before action can be taken. Just the threat of damage in a pristine watershed may prompt a group to take action. Clear visions help watershed groups understand, relate to, and support protection and restoration efforts. When framed well, they can also help the general public, elected officials, business, the press, and community leaders understand.

In addition to visions, groups usually develop goals, objectives, and action items. The difference among them is explained below.

A. **Visions** - general statements of where the effort wants to go and what it will accomplish over a given time span (usually 5 to 10+ years). Visions should be comprehensive enough to capture the thrust of the effort's overall mission.
B. **Goals** - less general than visions, describe what is needed to obtain vision, refer to components of overall effort, sometimes quantifiable.
C. **Objectives** - elaboration of goals, describe types of management or activities and are quantifiable where possible*.
D. **Action Items** - explain who is going to do what, where, and when; they generally articulate how to implement the objectives and should be quantified if possible; benchmarks of existing conditions and/or indicators should be developed for action items.

**Note*: Objectives are optional. Some watershed groups may find that additional level of detail confusing.

These four elements are folded into an implementation plan. It is desirable to obtain commitments to as many of them as possible.

Many watershed groups go through a facilitated workshop process in which they develop their statements. A facilitator, as a neutral party, can help people reach consensus and avoid getting bogged down in arguing among interests. It is important not to quibble over whether a particular statement becomes a goal or an objective. What is important is to get issues on the table. Designating them can come later.

WATERSHED LESSON #2: Good Leaders are Committed and Empower Others

Leadership is a critical factor in making the watershed approach work. Watersheds can be large or small, urban or rural, degraded or pristine. They can have resources of local or national importance, and they can have little or great development pressure on them. Government may be trusted and relied upon or distrusted and feared. Likewise, the leader that emerges in any given watershed varies. He or she can be a farmer or rancher, coal miner, nonprofit organization member, local council person, or a government person from the state, tribal or federal level. Or, leadership can come in the form of a group or entity, such as a local board, State agency, or the Federal government. Essentially, leaders are individuals or groups who care about the watershed and its future.

As for common characteristics of successful watershed leaders, they tend to reflect the values of the community and to know what works there. They generally are good communicators, have the ability to bring about change and set things in motion, and are committed to making their (or a group's) vision a reality. They also tend to know how to engage, respect, and empower others and are able to find new or leverage existing resources.

Because leadership is so important, many seek to encourage and nurture it. Some States offer grants to budding watershed associations. Several nonprofits maintain lists of watershed leaders who are willing to talk to others about their success. Other groups offer training and leadership workshops.

"A Great Leader is One Whose Followers Say:
'We Did It Ourselves'."

- Lao-tzu

WATERSHED LESSON #3: Having a Coordinator at the Watershed Level is Desirable

The watershed approach to protecting our lakes and streams and other water bodies involves many stake holders and, as a result, requires a lot of coordination. A good coordinator is key to a successful watershed protection effort.

Having a coordinator based within the watershed is important because it provides a focal point for the watershed effort and helps to ensure that someone is paying attention to moving group activities along. The coordinator's role varies depending on the needs of the watershed, but generally it includes maintaining contact with members of the watershed group; performing liaison with interested parties beyond the group; celebrating success; calling, facilitating, and summarizing meetings; helping to secure funding and training; and ensuring that watershed plans are developed, implemented, and effective in achieving the desired outcomes.

A coordinator may be a volunteer or a part-time or full-time paid staff person. He or she may be housed in government offices, a non-profit organization, or out of someone's basement. In general, they should be from a group that is trusted and that has the power to make a difference. The ideal coordinator is one who can commit to spending enough time to really make a difference. Part-time and volunteer coordinators have been able to accomplish a lot for watersheds, as have individuals located outside the watershed. As for funds, securing financial resources to support a staff person is not always easy; fortunately, many groups have been creative in establishing multiple funding sources to support watershed coordinators.

WATERSHED LESSON #4: Environmental, Economic, and Social Values are Compatible

At the national conference Watershed '96 held in Baltimore, Jonathan Lash, from the President's Council on Sustainable Development, reported on his team's survey of communities across the nation and approaches they were taking to achieve sustainability. In many instances, his group found watershed management was the approach they were taking. In his remarks, John recognised the watershed work going on across the USA and encouraged more as a means to achieving sustainability. While definitions of 'sustainability' differ, it generally means viewing economic, environmental, and social values as complementary and interdependent and working to sustain all three over time (typically more than one generation).

Too often in the past, environmental and economic and social issues have polarised people, making it impossible to achieve a common vision of sustainability. For the watershed approach to become a reality, there must be widespread recognition in the community that people and nature can coexist within the watershed. This can pave the way for partnerships of diverse interests to form around a sustainable vision.

The Nashua River Watershed Association (NRWA), in its long-range plan, *1995 to 2020 Vision for the Nashua River Watershed*, gives high priority to the need to "support resource-based economic activities, including sustainable farming, forestry and eco-tourism." Residents of the watershed recognize that protecting open space will provide positive economic returns. Through environmental education,

resource-based community planning, and advocacy for resource stewardship, the NRWA attempts to achieve greater sustainability through cooperative management.

Some farming practices can have severe impacts on water quality by causing erosion, sedimentation, and fertilizer and pesticide runoff. Taking a sustainable approach, the NRWA suggests, means encouraging farmers to use integrated pest management and cost effective organic farming. An important goal of the plan is to seek the enlargement of greenway buffers along wetlands and other water bodies. To achieve this end, the NRWA's *2020 Plan* calls for a mix of new incentives to farmers and additional support from the State agricultural department, local conservation districts, and extension services.

WATERSHED LESSON #5: Plans Only Succeed if Implemented

Plans are essential in that they represent the consensus achieved among watershed stake holders. Typical components of a plan include: vision, goals, action items, and time frame (see Watershed Lesson #1). Time frames for plans typically range from 5 to 20 years. The best plans allow for the incorporation of new information, reflect the needs of the watershed, and have the commitment of the community behind them.

The greatest challenge associated with watershed planning is to ensure that the recommendations called for within a plan are implemented and that the plan does not sit on a shelf gathering dust in some office. A key element in implementing a plan is charging an individual or organization with the responsibility to follow through and work with key constituencies to take the actions laid out in the plan (see Watershed Lesson #3). It is also important to break things down to a manageable scale. This often involves a "nested approach" in which broad goals are set for large watersheds but subwatersheds are used to implement and achieve those goals.

An Analysis of Urban Watershed Plans

- Tom Schueler's Insights into What Works and What Doesn't

Tom Schueler, Executive Director, Center for Watershed Protection, interviewed a number of watershed practitioners from a wide cross-section of disciplines (planners, municipal officials, consultants, scientists, and others) and found that most agree that the majority of plans developed in the past have failed to adequately protect their watersheds. A chief reason is that they were drawn up on too large a scale -- 50 square miles or more. Too many subwatersheds and their individual problems had to be consolidated, and the focus of the plans became blurred. As the number of stake holders proliferated, responsibility for implementing the plans became diffused. In short, says Schueler, the planning process got too big, too complicated to be effective. A typical municipality or county might have 10 to 50 subwatersheds to manage.

WATERSHED LESSON #6: Partnerships Equal Power

"Far different from the adversarial emphasis of traditional environmentalism, the focus of the watershed approach is to work cooperatively to build healthy watershed communities."

- Joy Huber, ***River Voices****, Fall/Winter, 1995*

Watershed work is about partnerships. Essential ingredients for effective partnerships include: focusing on common interests, respecting each participant's view point, thanking each other, being willing to learn about others' needs and positions, and building trust. The important thing is to pull together a partnership that is of manageable size, creates synergy, and represents the key interests in the watershed.

No one entity can solve all the issues in any given watershed. Watershed partnerships come in all shapes and sizes, with each partner having a different interest. Some partnerships are loosely structured, while others are quite formal. Some groups are open, while others are closed -- meaning they do not allow anyone else to join. Regardless of how they are structured, making partnerships work is challenging and takes commitment. Common issues that partnerships face include selecting a leader, ensuring that all the right people are involved, and moving beyond any hostility that may exist among members. If a group is able to develop *esprit de corps*, they can be quite effective. To get past the "forming and storming stages," some groups have set ground rules under which individuals can complain for only a certain amount of time, after which they must move on. Some groups have decided to say that issues that are too divisive are not to be discussed.

Partners can include any one who has an interest in the watershed. This ranges from conservation groups, local elected officials, chambers of commerce, environmental education organisations, local military bases, farm groups, students, senior citizen and religious organisations, financial groups, credit unions, and land developers, among others. The important thing is to include all the key interest groups so that you can tap into their strengths, increase your credibility, reduce duplication of effort, and make optimal use of limited funds.

In terms of lessons learned, experienced watershed practitioners say that one-on-one contact is most effective in eliciting support. Further, building partnerships takes time and commitment, and once built they need to be nurtured. However, their benefits are clear as they can lead to wider acceptance and quicker implementation of projects.

Give credit where credit is due.

WATERSHED LESSON #7: Good Tools are Available

Good tools are essential to the success of the watershed approach. Tools are broadly defined to include geographic information systems, "how to" guides, funding sources, regulations (when appropriate), and monitoring and modelling programs. The sources of funds and technical assistance vary widely, from corporate, government, to nonprofit organisations.

In many watersheds, technical advisors are critical to the effort, as watershed residents need a sound, scientifically-based understanding of the resource in order to make good decisions. Some studies suggest that one of the biggest challenges for watershed groups is securing funding. Many states have special funds to support watershed groups, but using creativity in finding other sources is always needed. GIS maps have been very helpful to watershed efforts and have served to educate constituency groups such as town councils and landowners. Fortunately, many tools are available to assist watershed groups.

- ***Project NEMO: Impervious Surface Analysis***

The Nonpoint Education for Municipal Officials (NEMO) Project of University of Connecticut Cooperative Extension is demonstrating the power of using Geographic Information Systems (GIS) to advance watershed protection. And, while NEMO uses GIS and remote sensing (RS) for limited watershed analysis, NEMO Project Director Chester Arnold stresses that the most important -- and most often overlooked -- use of these high-tech tools is for education.

NEMO uses the power of computerised GIS maps to educate busy local land use decision makers on the complexities of the land use/water quality connection. The maps help to graphically and simply illustrate the concept of watersheds, the role of land use in determining water resource health, the relationship between watershed boundaries and political jurisdictions, and the location of key natural

resources. Arnold emphasizes that the maps are not complicated, and are combined with local photographs and computer graphics to make them as simple and understandable as possible. The idea is catching on – adaptations of NEMO are springing up around the country.

One aspect of NEMO that really gets people's attention is the project's analysis of impervious surfaces, which is recognised as a key indicator of watershed health. NEMO conducts an impervious surface "build-out" analysis, which compares current levels to future levels projected from local zoning regulations. The difference is often startling to local officials, and can help direct changes to land use policies and management that are more protective of water resources. In partnership with The Nature Conservancy, the Environmental Protection Agency, and the U.S. Fish and Wildlife Service, the UConn NEMO team has been working on two pilot watershed projects in the lower Connecticut River valley. These projects use additional GIS data layers, like soils and parcel (property line) information, to lend more in-depth educational and analytical assistance to the watershed communities. For instance, GIS is used to target high priority large woodlot and streamside property owners for educational programmes. In addition, maps of priority conservation areas and areas best suited for development are being prepared.

- ***Save Our Streams, Izaak Walton League: Stream Restoration Services for Local Watershed Projects***

Through workshops, guides and a 1-800 number, Save Our Streams (SOS), operating out of Gaithersburg, MD, provides technical assistance on stream restoration and volunteer monitoring techniques to local watershed groups. Training is designed for all ages. SOS maintains a nationwide computer database of roughly 4,000 projects through which groups can coordinate their efforts with others. A typical hotline call might be a water watch group wanting to know techniques and plant types for restoring grass beds, plants that work well in sandy soils, and techniques for planting on steep slopes where the bank can not be graded. Save Our Streams is able to refer the caller to projects across the nation who have tackled and solved similar issues.

SOS encourages local groups to partner with federal and state agencies and private sector sponsors to bring costs down. Some groups are able to get enough outside funding support that they can restore a stream with as little as $500-$1000 of their own money. This partnering can pay off in other ways: in several states, like Virginia and West Virginia, data collected by volunteer monitors has been used in the States' official water quality reports.

The typical SOS workshop lasts one to two days and covers materials developed by SOS and others. For example, besides using the Global Rivers Environmental Education Network's teacher manual, they also use the SOS wetlands assessment handbook that they developed with the aid of citizen's groups.

WATERSHED LESSON #8: Measure, Communicate, and Account for Progress

Having systems in place to measure and communicate progress is a critical part of watershed work. Appropriate measures not only keep watershed issues on people's radar screens, but also, as they are met, allow stake holders to share successes and to highlight new challenges to the watershed.

Progress can be measured in many ways and communicated through meetings, brochures, Internet sites, annual reports, news releases, and other ways. The important thing is to make sure that the appropriate measures of progress (often referred to as indicators) are selected and that information on these indicators is shared with relevant stake holders. Measurements of progress should be associated with achieving goals set for the watershed effort (see Watershed Lesson #1). Depending on the goal, groups may choose water quality measurements (eg. dissolved oxygen, bacteria levels, faecal coliform) or less directly water-quality based results (eg. number of trees planted, number of watershed groups in a State, pounds of trash collected, number of canoe rentals, number of miles protected from erosion). To make

sure that progress does indeed occur, most watershed groups spell out who is responsible for what in their watershed plans. Some go so far as to establish agreements that commit groups to certain actions within certain time frames. Spelling this out can help with accountability.

In terms of groups to whom progress should be communicated, county commissioners, elected local and state officials, watershed residents, and major companies in the watershed are at the top of the list for most watershed practitioners. Over time, as updates on progress are made, practitioners have found that some constituencies will begin to ask for them - a sign that awareness has been raised.

WATERSHED LESSON #9: Education and Involvement Drive Action

Earth Day, 1970, and the resulting actions taken by government demonstrated that public support is the engine that drives protection of the environment. But public support depends upon public awareness, involvement, and education. Watershed awareness campaigns and education programmes can help people who live, work, and recreate in a watershed understand what the problems are and how they can help remedy them. Based on lessons learned by watershed educators, effective watershed communication involves: **understanding one's audience**, **being careful with terms**, and **knowing how the target audience likes to receive its information**. Further, one should be ready to **explain how that particular audience can help remedy the problems - what actions they can take**.

When it comes to creating awareness in the general public, watershed coordinators have used many different mechanisms, including highway signs, bumper stickers, billboards, awards, field trips, newsletters, and newspaper inserts as well as cutting edge approaches such as the internet. A large number of people have also been reached through public service announcements, license plates, storm drain stenciling, peer-to-peer communication, and community events.

Educating a community for the purpose of stimulating voluntary action means targeting groups from all walks of life: farmers, businessmen, school children and teachers, local government officials, homeowners, and the like. Well designed education programmes can lead to tangible results, especially when they get participants out in the field, are delivered in an effective way, and encourage action and reflection. Some local watershed groups have had a lot of success in awarding small contracts to key constituency groups under which they themselves are charged with carrying out education programmes. Such programmes have been quite effective in encouraging the voluntary adoption of best management practices.

Watershed practitioners have learned that who delivers the information is important, as well. In general, peer to peer communication or communication by a neutral source is best. Community members, such as students, are often better received than a government official.

WATERSHED LESSON #10: Build on Small Successes

Small successes fuel future, larger ones. It is important, according to watershed practitioners, to start small and demonstrate success before working on a larger scale. For this reason demonstration projects are often a popular choice in watershed work. In some states, small victories have been instrumental in prompting the implementation of the watershed approach statewide.

Commitment to the watershed is key, and a small group's passion for its improvement can catch fire. Practitioners also say over and over that it's important to "Celebrate Success" as it occurs. Other tips:

- Have the support build up from the community and not be imposed from the outside.
- Focus on manageable issues that are meaningful to people and provide a focal point around which action can occur.
- Over time, other issues can be addressed, after a commitment and networks have been established.

7.1.2 Best Management Practices for stormwater management

The need for pollutant reduction has led to an emphasis on a stormwater management approach that focuses on keeping pollutants out of the receiving bodies of water, by upstream control – attenuation and treatment measures close to where run-off is generated. ***Best Management Practice*** – BMP – is a term describing approaches and engineering devices for the better handling of ***urban*** stormwater. This has resulted in an adaptation of stormwater management to include:

- Securing reasonable levels of protection against damage to property from unexceptional storm events
- Mitigation of damage from exceptional storm events
- Securing mutual compatibility between these objectives and the promotion of good environmental stewardship.

The quality aspect in the maintenance of stream ecology developed into the dominant concern that came to be associated with BMP awareness. As a starting point it lent emphasis to the engineering (ie. structural) approaches, which address environmental imperatives: measures to trap and settle out particulate matter to which pollutants had attached. At a later stage, social and institutional (ie. non-structural) factors were found to be of primary importance in achieving the BMP objective. Non-structural and structural BMPs are now defined as follows:

(1) Non-Structural measures are exclusively concerned with prevention. Success means fewer pollutants from urban sources being discharged onto the landscape, and hence less total load being transported. These BMPs include a variety of institutional and educational practices focussing on land development; public education to modify behaviour contributing to pollutant deposition; the detection of illicit wastewater connections; and the enforcement of ordinances designed to prevent the deposition of pollutants on the urban landscape (Urbonas, 1994)

(2) Structural measures act as a backup to the above non-structural measures, by providing attenuation or treatment facilities before transportation of the water to watercourses as ultimate environmental receptors.

Urbonas (1994), in assessing BMPs, catalogued the essential objectives of BMPs as measures for the improvement of stormwater quality, as follows:

- Prevention – minimisation of pollution of the urban landscape
- Source controls – interception of pollution from run-off (which would embrace physical trapping BMP measures)
- Source disposal and treatment – attenuation of run-off at or near its source
- Follow-up treatment – downstream interception of run-off using structural BMPs to provide follow-up treatment.

Niemczynowicz (1994) went further and suggested that pollution accumulation is a problem, precisely because it is inadequately addressed in present societies. Water management should be integrated with management of other activities such as waste handling, industrial production, and transportation. The most important action must be "prevention at source". Tools for implementation of solutions are legislative and administrative actions coupled with education programmes on all societal levels, and increasing public awareness. The goal is sustainability of the society by resource recovery and re-use. The principles of preventative strategy include:

- Preventative actions at pollution sources – influencing production processes
- On-site treatment and re-use – tailor-made treatment according to content of actual effluent
- Off-site treatment and reuse – as above but more expensive, as requiring transportation

- On-site concentration and storage – partial solution but protects the environment now and allows for future resource recovery
- Treatment at small-scale treatment works using novel, low-technology solutions
- High-technology solutions for end of pipe effluent – expensive, last solution to be utilised, only if above measures are not feasible.

7.1.2.1 Non-structural BMPs

This category of BMPs embraces a number of subsets that address matters of procedure, creating a climate of enlightened awareness and of law enforcement. As discussed, these measures include a variety of institutional and educational practices. Below is a list of measures as identified by Urbonas (1994):

- Adoption and implementation of building and site development codes to encourage or require the installation of structural BMPs
- Adoption and implementation of site disturbance control programs
- Compelling the minimisation of directly connected impervious area in new developments through the use of landscaped areas, grassed buffers and roadside swales instead of the curb, gutter and storm sewer system. This is aimed at reducing the volume of runoff to the stormwater system through on-site storage and percolation.
- Public education on proper use and disposal of household chemicals, paints, solvents, motor oils, pesticides, herbicides, fertilisers etc
- Street sweeping and leaf pickup
- Detection and elimination of illicit discharges of wastewater lines to separate storm sewers
- Enforcement of operation and maintenance requirements of privately owned stormwater management facilities, including structural BMPs and non-structural programmes on site.

Non-structural BMP applications to the development process embrace such issues as the major/minor approach to storm event flood protection, and the identification of flood lines consistent with major system constraints, which reserve space for more physical applications. They extend to measures of controlling site disturbance, and the minimisation of off-site run-off.

Significantly, the introduction of non-structural BMPs requires the involvement and action of large numbers of non-technical people, with the accompanying need for explanation and training. In Wagga Wagga, within the New South Wales Murrumbidgee catchment, a recent edict compels the disconnection of all house roof gutters from the municipal stormwater drainage system, and recommends removal of eaves gutters as a measure to more uniformly disperse undrained roof run-off, in preference to soakaway construction. This involves all house-owners in reducing off-site run-off from their properties. Within the Australian model, the Total Catchment Management Plan provides a legislative framework for the application of the various plan elements and non-structural BMPs, particularly with respect to funding.

Non-structural BMPs reduce the level of pollutant accumulation by townscape elements. In aggregate the non-structural BMPs fall broadly into three groups, which may be termed educational, regulatory, and enforcement measures.

- Educational BMPs are non-specific in the sense that they target no specific phase in the urban development process. They comprise any and all measures devised to sensitize people into a positively oriented awareness of their own role in water quality degradation, and hence in water quality protection and enhancement.

- Regulatory BMPs may be similarly non-specific, eg. vehicle emission controls, prohibitions on use of persistent pesticides, the disconnection of roof gutters from the urban drainage system, etc. However, certain regulatory examples stand out as being specifically targeted on phases of the urban cycle. The declaration of the 50-year flood line in new developments, as being the boundary between activities

dependent on built space and those requiring only open space, focuses attention on the flood protection aspect of urban development. In the redevelopment phase where earlier there may have been no such exclusion, the application of the 50-year flood line may be fraught with compensation complexities.

- Enforcement as a non-structural BMP aligns itself closely with regulation and control. Enforcement measures, which complement regulation and control, are by nature educational and conditioning in their effect on people's mind set. Most important among these is the principle of "*let the polluter pay*", ie. the costs of enforcement should be recovered from detected and convicted offenders.

The enforceability problems for developing countries (including South Africa) are many and complex, however, and they include issues of equity between potential individual offenders and potential corporate offenders. Hence regulation and enforcement need sensitising to their current social context. Fifty-year flood lines can be enforced in formal housing areas, but informal housing often springs up on marginal land, including within the flood plain. Removal of such informal housing needs to be coupled with the provision of formal low-cost housing for that group of people elsewhere, followed by the development of that land either as a public amenity, or for urban agriculture. Without the active utilisation and protection of the land within the floodplain, the likelihood is that the cycle of settlement and removal will be repeated.

Prohibitions on using drainage channels for dumping refuse are also not easily enforced in the developing country context. They need to be coupled with improved solid waste management, and vigorous community education programmes. Enforcement of other prohibitions relating to careless or deliberate misuse of oils and chemicals carries urgent messages to offenders concerning the need to respect the environment. Yet the potential for enforcement is very low. These are matters more amenable to long term improvement through education, and with rigorous sanctions available in those situations where identification of offenders proves possible.

7.1.2.2 Structural BMPs

Whilst the above *non-structural* BMPs often encourage, educate and enforce the use of various devices, it is the devices themselves that are referred to as *structural* BMPs. The early efforts concentrated on the prevention or minimisation aspects of the polluted runoff problem, while the emphasis more recently has been on devices providing some level of treatment.

(1) Run-off minimisation design approaches: non-traditional layouts of urban streets, buildings and parking lots, for example, that are relevant in new development or redevelopment contexts. This refers to the concept of *minimising directly connected impervious areas* and is concerned with the slowing down of the disposal of runoff.

(2) Infiltration enhancement approaches: percolation trenches and infiltration basins, with due consideration to the type of urban land use generating the run-off. These include (Urbonas, 1994):

- Grass swales and buffer strips – lowering overland runoff velocity, thus promoting pollutant removal through sedimentation and tending toward a linear detention basin
- Porous pavements – self-draining pavements, constructed from porous asphalt or concrete paving block.
- Percolation trenches – rock filled percolation trenches temporarily storing stormwater and permitting percolation into the ground (serving small impervious areas of typically two hectares or less).

(3) Treatment approaches: the Australian Co-operative Research Centre for Catchment Hydrology (CRCCH) characterises most structural BMPs as "Stormwater Treatment Measures", STMs, and emphasises the catchment-specific criteria for their selection, proposing a process of assessment that embraces a consideration of catchment size for effective treatment, and of land use (Mudgway et al, 1997). The authors observe that "*many STMs can provide additional benefits for the environment or conversely can impact* (i.e. negatively) *on the environment*", listing the following possible environmental effects:

- Aquatic habitat enhancement
- Wildlife habitat enhancement
- Thermal impact – cautioning against use in situations where ecology is sensitive to temperature change
- Soil contamination
- Base flow augmentation
- Peak discharge and volume reductions
- Stream bank protection (against erosion)
- Water conservation (by reuse eg. for secondary purposes)
- Provision of active recreation
- Provision of passive recreation
- Aesthetic appeal enhancement
- Safety issues
- Nuisance (pests).

A comprehensive list of Stormwater Treatment Measures (STMs) is as follows:

- Filter basins – sand filters in conjunction with upstream detention/settlement structures.
- Water Quality Inlets - Underground masonry tanks, compartmented for enhanced solid and oil separation, and serving relatively small catchments.
- Source trapping devices for solid waste, in respect of which 6 are reviewed in the December 1997 Industry Report 97/11 issued by CRC*.
  - Side entry pit trap (SEPT) – baskets fitted below entrance to drains from road edge gutters
  - Litter control device (LCD) – baskets positioned below point of entry to an inlet pipe
  - Trash rack – vertical or horizontal steel bars typically 40mm to 100mm apart, fitted across stormwater channels of up to 10 metres width
  - Continuous deflection separation (CDS) – a device installed in stormwater channels, diverting solid pollutants into a separation and containment chamber where they are kept in continuous motion during flow and prevented thereby from blocking the screened outlet
  - Gross pollutant trap (GRT) – comprising a large concrete-lined wet basin upstream of a weir protected by a trash rack. Decreased flow velocities encourage sedimentation in the basin with the trash rack at the downstream end retaining gross material. Major and minor GPTs have been developed to cater for small, 2 – 50ha and large 50 – 500ha catchments.

- Floating debris trap (FDT) – effectively a litter boom, multi-cell and partially submerged, which "collects" floating objects in contact with it, i.e. the highly buoyant and less polluting of the gross pollutant load
- Extended detention basins (dry) - the dry type comprising globally the most common type of detention facility. If the basin is to function as a water quality enhancing BMP, with sedimentation as the main treatment process, it requires storage and drainage over an extended period of time - hence the term extended detention basin.
- Retention ponds – may be an infiltration pond (dry) or a wet system with a permanent pool and a surcharge detention volume above this pool. In addition to having the flood attenuating properties of the above detention ponds, retention ponds offer significant additional benefits in terms of water quality. Retention ponds, in their similarity to natural and seasonal wetlands, encourage the development of chemical and bio-chemical activity, together with assimilation through established aquatic and bank side vegetation.
- Wetlands – providing filtering, settling, stabilising, oxygenation and nutrient uptake.

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* These devices, together with a number of additional designs, were investigated in a recent report to the Water Research Commission. In this report Armitage and Rooseboom (1998) surveyed international experience on litter trapping devices. Together with laboratory experimentation, various trapping devices were compared in terms of operating efficiency and cost (installation and maintenance) to make recommendations for the South African context.

At this point it may be useful to clarify the difference between detention and retention as they occur in urban storm drainage systems (Scott, Santos and Argue, 1999). Both types of technologies may be either wet or dry, above ground or underground, and hence they should be distinguished by their effects, as follows:

> "**Detention** refers to the holding of runoff for short periods to reduce peak flow rates and later releasing it into natural or artificial watercourses to continue in the hydrological cycle. The volume of surface runoff involved in this process is relatively unchanged.
>
> **Retention** refers to procedures and schemes whereby stormwater is held for considerable periods causing water to continue in the hydrological cycle via infiltration percolation, evapotranspiration, and not via direct discharge to watercourses."

The environmental benefits of detention technology are limited to sedimentation (improving the water quality of flood peaks and the "first flush" effect), and habitat protection of aquatic ecosystems downstream through amelioration of flood peaks. Wet detention ponds also act as sedimentation basins for base flows. However, the environmental benefits of retention technology are much more wide-ranging, through improving water quality as well as reducing the total volume of surface runoff. Retention technology includes a very wide spectrum of structures and processes, from rainwater harvesting and re-use on individual sites to aquifer storage and recovery schemes. Most projects for the beneficial re-use of urban stormwater provide some form of retention facility.

7.1.2.3 Structural BMP effectiveness

The rate at which pollutants are transported is a function of water depth, velocity and the degree of turbulence. Fine and dissolved pollutants may become attached to suspended solids, with the smaller sizes more implicated on account of their greater surface area relative to larger particles, and with improved ease of transport at lower velocities. Detention storage facilities associated with urban drainage waterways reduce particle-associated pollutants through velocity reduction and subsequent settling, and with efficiency in this accomplishment a function of detention time. Aquatic plants and micro-organisms aid the process. The controlling variables are:

- inflow concentration
- a design index that describes basin geometry and cell composition, and
- upflow rate – a parameter based on annual run-off volume, storage area and catchment area. (CRC Industry Report 97/5, 1997).

For particulate pollutants, inflow concentration and upflow rate are identified as controlling parameters. The design index is more important in the removal of dissolved pollutants. In the case of total phosphorus and total nitrogen, up to 70% removal is found to be achievable in good practice. Crucial to success, therefore, are accurate approximations of run-off and pollutant load, and the CRC Industry report 97/5 suggests three different approaches: simple computation; analysis of data from a good storm event monitoring program; and an appropriate run-off and water quality model.

Reviewing the effectiveness of a number of structural BMPs reveals the need for continued monitoring of performance over time. Some conclusions:

- Minimising drained area: amelioration of peak flow rate and hence volume reduction in the transfer of pollutant material from point sources. The degree of run-off elimination is site-specific, however, and difficult to quantify.
- Grass swales: performance is site-related, flow velocities and hence land slopes needing to be minimal. Whalen and Callum (1988) report suspended solids removal rates in excess of 80%, but this is dependent on soil characteristics, this level of elimination requiring high infiltration capacity.
- Porous pavements: asphaltic monolithic poured surfaces are known to seal over time with the accumulation of trapped solid material (Schueler et al, 1991) but modular block structures perform well (Pratt, 1990).

- Percolation trenches: capable of removing up to 99% of solid particles but are failure prone, with groundwater mounding surfacing within the trench (Schueler et al, 1991).
- Infiltration basins: capable of removing up to 99% of stormwater particulate matter depending on site conditions. Prone also to failure through sealing and groundwater mound build-up (Schueler et al, 1991).
- Water quality inlets: evidence indicates poor performance of sand, silt and oil traps. These devices are expensive and appear to offer little water quality enhancement (Urbonas, 1994).
- Trapping devices have been shown to have performance levels that vary from low for booms, to high for SEPTs and to very high for CDS devices. More detailed comparisons on the effectiveness of litter trapping devices are given in Armitage, Rooseboom et al (1998).
- Extended detention basins: performance is governed by basin size, shape, and inlet/outlet geometry, with removal rates varying between 10% and 90%.
- Wetlands: perform similarly to detention basins in sediment removal; nutrient uptake performance is thought to be dependent on maintenance measures eg crop harvesting.

Significant research has recently been conducted on the design, use and effectiveness of retention and detention pond features as Best Management Practices strategies. Somes et al (1998) discuss the design of constructed stormwater ponds (retention ponds), noting that because ponds are frequently designed as amenity features as well as having assimilation objectives, undesirable flow hydrodynamic conditions are frequently produced. They investigate a number of hypothetical designs focussing on inlet/outlet configurations and pond shape in terms of hydraulic efficiency to produce guidelines for most appropriate design shapes. Duncan (1998) presents an overview of urban stormwater treatment by detention in on-stream storage (ponds and wetlands), identifying relationships between quality improvement performance and a range of explanatory variables using data from international experience. He states that the best performance measure is percentage removal (output concentration as a percent of input concentration). Basin size measure is in terms of mean annual hydraulic loading rate. In terms of pollutants, suspended solids, nutrients (nitrogen and phosphorus), hydraulic loading and input concentrations are the most important explanatory variables. He notes that nutrient removal is poor with hydraulic loading rates greater than 100 m/a, even with good design practice.

Lloyd et al (1998) present a description of an investigation of wet detention basins and wetland systems for reducing sediment bound stormwater pollutants. They found that the removal efficiency of pollutants such as TSS, as well as sediment bound contaminants such as phosphorus is intrinsically related to the sediment characteristics of the sediment inflow into the wetland. These pollutants frequently have an affinity with the finer range of sediment sizes. They conclude that to achieve a high reduction in sediments and thus pollutants, a long retention time is required. Cognisance is also taken of the role wetland vegetation performs in reducing fine sediments, providing improved removal efficiency compared to an equally sized permanent (deep) pool. Of interest is the conclusion that differing sediment characteristics of catchments have important implications for the types of systems selected for pollutant reduction, and the sizing of these facilities. Because of these differing sediment characteristics, the authors call into question the suitability of directly transferring guidelines for appropriate sizes of wetlands for effective removal of pollutants such as TSS, TP and metals.

Table 7.1 summarises the performance of a number of structural BMPs in use in the USA (Colorado S.W.T.F, 1990). The table on the following page (Table 7.2) presents BMP pollutant reduction performance as found by the Centre for Catchment Hydrology in Melbourne, Australia, summarising data abstracted from a number of sources.

TABLE 7.1 Percentage removal ranges for structural BMPs

BMP	TSS	Total P	Total N	Zinc	Lead	BOD	Bact.
Porous Pavement	85-95	65	75-85	98	80	80	-
Infiltration	0-99	0-75	0-70	0-99	0-99	0-90	75-98
Percolation	99	65-75	60-70	95-99	-	90	98
Retention	91	0-79	0-80	0-71	9-95	0-69	-
Detention	50-70	10-20	10-20	30-60	75-90	-	50-90
Wetland	40-94	(-4)-90	21	(-29)-82	27-94	18	-
Sand filters	60-80	60-80	(-1100-0	10-80	60-80	60-80	-

TABLE 7.2 BMP pollutant reduction findings (CRC 1997)

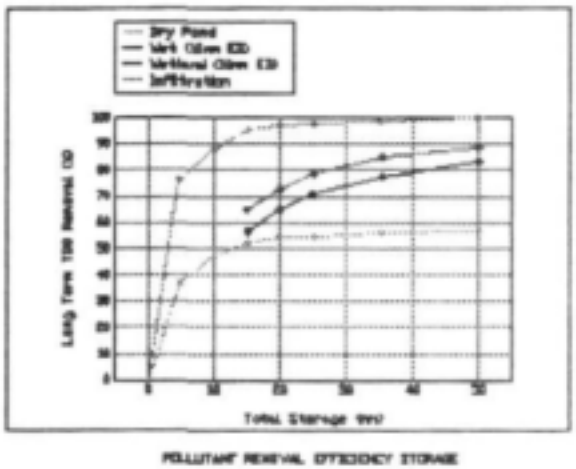
Pollutant concentration reductions (percent of inflow concentrations)																	
Treatment Control	**SS**	**P**			**N**			**Pb**	**Zn**	**Cu**	**Cd**	**Fe**	**BOD**	**COD**	**Bacteria**	**Litter**	**Comments**	**Sample Size**
		TP	**OrgP**	**SolP**	**TN**	**OrgN**	**SolN**											
Extended detention	50-75 64	10-66 18			10-35 19			70-90 83	24-62 45					20-41 30	50-90 70			6 studies
Wet pond	39-98 69	0-80 51	20	70-80 75	30-85 60	14-20 17	24-60 42	9-95 68	0-71 51	40		17	0-69 44	20-70 30	90-95 93			13 studies
Wetland	40-98 81	-33-97 50		0-75 59	-9-43 25	32	13-90 50	6-94 72	-29-97 50	40-99 66	33-99 66	12-62 37	18-34 26				Sol.N = NH_3 for several studies	28 studies 1 ref gives range only
Infiltration Trench	71-99 83	60-75 65			60-70 63			25-99 61	51-99 74				90		98		50% fail within 5 years due to clogging	4 studies 2 refs give range only
Infiltration basin	75-99 87†	50-75 63†			45-70 58†			75-99 87†	75-99 87†	75-99 87†	75-99 87†	75-99 87†	70-90 80†		75-98 87†		50% fail within 5 years due to clogging	2 studies both give range only
Porous pavement	50-95 89	50-71 65			<0-85	29	<0	50-98 86	62-99 85	42-50 46	-33		80	82			Many fail within 5 years	8 studies
Sand Filter	60-90 80	35-80 57			40-70 55		-110-0 <0	65-90 74	10-80 53	20-60 40			60-80 70	35-70 53				3 studies all give ranges only
Filter & buffer strips	5-95 74	50-79 66		62	50-73 62												Grass (including sod & corn-stalk residue)	10 studies
				100			95										Forested	1 study
Grassed swale	80	4-25 15		8-24 16	-4-11 4	-4-13 5	-5-22 9	0-91 80	34-90 70	-14-60 50	20-50 29	3-67 35		25			Sol.N & P often not all of soluble fraction	7 studies
CDS	100*	1‡			1‡											95-100 98		2 studies 1 field, 1 lab study
Floating boom																12-50 24	Tagged litter study	4 trials
Trash rack																5-14 10	Tagged litter study on 2 small traps	2 trials
Filter baskets																65	Fitted to 50% of side entry pits	1 study
Street sweeping	37-50 41	9-28 28		45		12-45 27		5-48 32	45	45	45	13-60 45		34-45 35		95-100 98	Org.N=TKN in some studies; frequent sweeping assumed	5 studies

NOTES: 1. Lower figure in cells is median
2. † values may not be from measured data, and are estimated from mean of range
3. ‡ given vegetative matter contains less than 1% of all TN and TP and all is captured
4. * capture of sediment greater than 1mm in size

Amongst physical BMP systems, performance attributes vary according to the character of the pollutant to be removed and the type of structure. The relevance of suspended solids removal as an indicator of BMP performance is to be found in the sediment associations which many pollutants – metals, oils, greases, and nutrients– share. Figure 7.1 (below) supports four important conclusions:

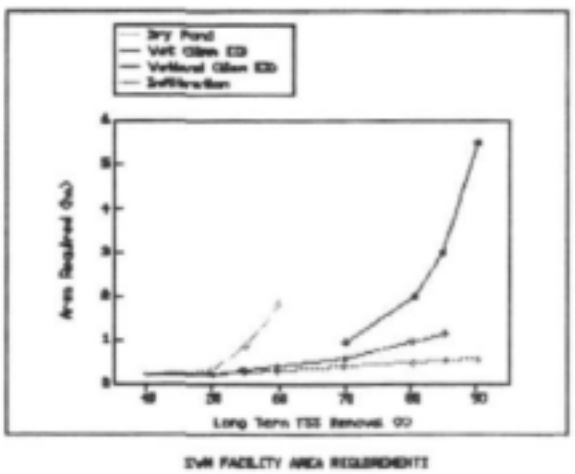
- The permanent pool (in "wet" systems) plays an important role in pollutant removal.
- Storage volume provision encounters diminishing returns (more quickly for dry than for wet systems).
- Infiltration systems outperform other types (but are known to be more failure prone through clogging).
- A wetland is more effective than a wet pond.

Figure 7.1 Pollutant removal efficiency (CRC 1997)



However, Figure 7.2 demonstrates that the area requirement for a wetland is much greater than for a wet pond for similar performance levels. This has significant cost implications in an urban context. Hence, the investment decision-making matrix for structural BMPs must embrace the total benefits potential.

Figure 7.2 Storage facility area requirements



Performance objectives in BMP policy consideration internationally were also summarised, for storage BMP devices (or STMs).

Table 7.3 Performance objectives for storage BMP devices

Location	Water quality		Volume capture	
	Standard	**In relation to**	**Standard**	**In relation to**
Florida, UK, California	TP control			14 day residence time
Washington DC, UK			Max. 2.5 x runoff vol. From mean storm	Capture of all volume of a majority of runoff events
Texas			Runoff from 50mm rainfall	
Auckland			60-75mm from impervious area	Capture 75-90% of runoff events, or capture of sub bank-full events
Maryland	Remove 70% SS	From mean storm		
Auckland	Remove 75% SS	Point of diminishing return against treatment of volume	25mm (3.8 x runoff vol. of mean storm)	Storage device which would capture 80% of rainfall volume
California	Remove 80% SS	Point of diminishing return against treatment volume		Capture of a% of runoff events (infiltration & dry basin) or 2.5 to 3 x runoff from mean storm (wet ponds)
Ontario	Remove 80% SS	Effect on fish habitat in receiving water		
Others			12mm, 25mm or 1 year ARI storm runoff	

Addressing performance requirements as a policy consideration requires developing an approach methodology for which CRC has postulated inclusion of the following four stages (CRC Report No. 97/7)

1. Establishing need for control of stormwater pollution
2. Improving knowledge of processes involved and bringing control within the scope of the urban stormwater engineering mandate
3. Estimating required performance objective
4. Selection

Table 7.4 expands stages 3 and 4 into a stepwise proposal.

Table 7.4 Treatment selection methodology

General	*Detail*
1. Define water quality objectives	• Identify catchment location • Identify receiving waters • Define beneficial uses • Adopt appropriate Victorian SEPP water quality objective values
2. Estimate catchment pollutant concentrations	• Estimate proportions of major land use groups • Estimate mean wet event SS concentration (C_{in}) • Measured EMCs should be used if available for sufficient storms • Factor concentrations to allow for different geology
3. Determine removal requirement	• For C_{in} of SS, estimate mean removal based on storage treatment, for 1% area ratio (C_{out})
	Repeat steps 2 and 3 for TP, TN, Zn and Pb, using appropriate SEPP criteria values (TP & TN criteria are related to prevention of nuisance growth, metals to toxicity thresholds)
4. Determine gross pollutant removal	Gross pollutant removal is independent of storage treatment. Adopt overall removal of gross pollutants (greater than 2mm) of 65%
5. Screen treatment controls – create short-list of feasible treatments	Select appropriate treatment controls according to: • Topography/slope • Soils • Area available and catchment area • Groundwater/bedrock depth • Temperature concerns (relate to water quality criteria) • Water quantity mitigation • Environmental and community amenity
6. Select treatment control	Optimise various treatments based on area, total removal required and mean removals data

The major limitations on treatment selection are identified as:

1 Area served, which has been observed to suffer from wide variation; however, although catchment area may exceed the capability of particular devices, it may be possible for some to be used on a subcatchment, or subdrainage area basis.

2 Land use; examples of land use restrictions include porous pavement where heavy traffic is expected, and grass swales anywhere other than in low density development (Schueler 1987).

The full list of selection criteria for structural BMPs comprises:

Area served
Land use
Slope
Hydraulic head
Depth to water table
Depth to bedrock
Area needed
Need for pretreatment
Usable for treatment
Soil type
Fertility
Nuisance
Water requirement
Maintenance requirement
Initial cost
Aquatic habitat enhancement
Thermal impact
Wildlife habitat enhancement
Soil contamination
Baseflow support
Peak discharge control
Stormwater volume control
Bank erosion control
Water conservancy
Active recreation
Passive recreation
Aesthetic appeal
Safety hazards
Overall value

In sum these 27 criteria address BMP selection policy considerations in the most comprehensive way yet documented. Table 7.5 (CRC Report No 97/7, 1997) brings together findings from around the world on the effectiveness of various STMs under one of these criteria: area served. Under USA the classifications used define "large" as greater than 16 hectares; "medium" between 4 and 16 hectares; and "small" as less than 4 hectares.

Table 7.5 STMs and areas served

STM	*Location (reference)*					
	Washington DC (Schueler, 1987)	*Auckland (ARC, 1992a)*	*Australia (GHD, 1995)*	*California (CD & M, 1993)*	*USA (Novotny, 1995)**	*Other*
Pond	>4-8		>4	Large/regional	Large	
Wetland	>4-8		>4	Large/regional	Med/large	
Dry ext. detention	>7-9		>4	Large	Med/large	
Wet ext. detention	>3-8		>4	Large/regional	Med/large	
Infiltration basin	0-3 to 8-14		12 – 120		Small/med	.2
Infiltration trench	<2-3	<4	<2		Small	<8
Porous pavement	0-1 to 2-7		0.1 – 1		Small/med	
Sand filter		<4	<20	<40	Small/med	
Grass swale	<2-4		<2	Small	Small	
Filter strip	<2-4	<2	<2-10	Small	Small	
Oil/grease trap	<0.5-1		<0.4	Small	Small	
"GPT"			>8			
CDS			Various = no limit?			

7.1.2.4 BMP potential within urban catchment management in developing countries

In South Africa the level of sophistication in terms of leadership, skills and other environmentally relevant resources encourages optimism that sustainable environmental improvement targets are feasible. The political will is there, as evident in existing legislation, signalling a determination that the necessary resources will be allocated a high priority for environmental protection and improvement.

The reality is that improvements in current environmental status will require investment that with today's levels of financial uncertainty, may well be outbid by projects with more immediately measurable benefit streams. What then can be targeted at least cost?

1. The non-structural group of BMPs immediately stands out as least-cost, potentially high return investments for early action. The most promising environmental education programmes are those targeting the youth.
2. Physical BMP trapping systems that can be retrofitted into existing storm drainage installations offer payback by way of source improvements in quality, independent of heavy financial outlays in new attenuation storage.
3. New developments can be made subject to improved policy and procedures requiring investment in physical BMPs at the developers' cost, rather than at the taxpayers'.

It has to be recognised that there exists an urgent need for both structural ("hard") and non-structural ("soft") BMPs. Soft BMPs in many cases can be implemented at minor effective costs, where the necessary infrastructure is already in place, as in the school system. Their payback is significant, depending on their level of success, in terms of the sustainability of the urban environment. The medium to long-term financial rewards of soft BMPs are their effect on decreasing the size of hard BMPs, necessitating lower levels of investment. The outcomes in the case of hard BMPs are subject to conventional cost-benefit appraisal, where benefits are more predictable. The following are the key areas for action on introducing BMPs into urban catchment management in the South African context:

- The need for including pollution control criteria into Municipal Services Guidelines for urban storm drainage and management
- Rehabilitation of highly degraded urban catchments and watercourses
- Setting levels of environmental distress for prioritising action on the above
- Local cost-benefit studies to build into the assessment methodologies that already exist, data for evaluation of trapping/treatment combinations and alternatives, supporting treatment selection strategies

- Close co-ordination of research into the operation of trapping systems, detention and retention storage and wetlands, as well as co-ordination with international research efforts
- Identifying and workshopping soft BMP facilitation, with the relevant stakeholder groups and catchment committees

7.1.3 Guidelines for GIS-based Urban Catchment Management

This section provides general guidelines for implementing GIS-based urban catchment management in South Africa, including setting out a conceptual framework for the GIS. GIS provides an effective medium for:

- the visual representation of catchment management data and queries
- the integration of ecological, hydrological and water quality considerations, together with socio-economic data on the population of the catchment, and the cadaster
- the integration of the inputs and outputs of the various role players
- communication and education.

Prior to setting out the general guidelines, two areas of concern need to be highlighted.

(1) Since urban catchment management relies on a wide variety of data sources, and the resulting spatial information needs to be diffused to a wide range of stake holders, there is now an urgent need to define a standardised format, and a consistent approach in South Africa. The extent to which the data integration process can take place is dependent on the degree of compatibility of the databases involved. Unless the project parameters of various database sources are set up in an identical manner, data integration can be very time consuming, if not impossible at times. It is essential that formats be standardised at the outset, and used consistently thereafter. However, as the level of compatibility between different GIS systems increases, and as municipalities convert more data to digital formats, a standardised system will gradually emerge. Convening workshops at a national level, which bring together urban GIS users with the aim of agreeing on such a standardised format and a consistent approach, could speed up the process.

(2) An even more difficult set of issues arises from the custodianship of the catchment database – where it should be located; and who should have responsibility for keeping it updated and diffusing the updated versions to stake holders. Diffusion is now facilitated by the widespread use of the Internet, so the technical aspects can be readily resolved. However, the social dimension of these questions remains. These revolve around two issues:

- the acceptability of data to all stake holders
- the level of trust in the custodian of the database.

It is essential for the social and institutional processes involved in catchment management are run in parallel, or even ahead of, the technical process, in order to resolve these issues before problems arise.

1. Conceptual GIS framework: a multi-scale approach

The conceptual GIS framework addresses urban catchment management issues at the following three levels: the metropolitan level, the catchment level and the subcatchment level. The database-building process for urban catchment management needs to be carried out on all three levels.

The principal reasons for a multi-scale approach are:

- the variable nature of the data coverage
- the different requirements of database users and
- the different requirements of lumped and distributed parameter models

For each of these levels the potential key role players must be identified and used to design database management strategies that enable the database to be used not only for analysis, but also as a mechanism for negotiation. The database management strategies include recommendations on the following issues for each level of the ICM database:

1. The database structure
2. The database contents
3. The database location
4. The database linkages
5. The database applications

The detailed guidelines on these issues can be found in Chapter 2 of this report.

2. Internet connectivity

The appropriate software for urban catchment management must be capable of facilitating:

- effective communication through the Internet medium
- simple spatial analyses.

All other procedures such as data capturing, image processing and complex spatial analyses can be carried out on specialised software. However, the principal functionality of the software should be to ensure effective communication between all the stake holders in the urban catchment management process. For this the software must have extensive Internet capabilities. The website for the catchment should be simple, functional, and updated frequently.

3. Catchment indicators

(1) Impervious **areas of the catchment: past, current, and future scenarios**

- A detailed map of impervious areas of the catchment is essential to calculating accurately the proportion of the catchment area that is covered by impervious surfaces: a key indicator of the health of the catchment.
- For communicating with community members, a comparison of the impervious areas of the catchment in the past, compared with the current situation, is helpful. It allows people to see concretely how urbanisation has affected the catchment, and gives everyone involved an indication of the scale of the run-off problem, and the rate of change.
- For analysing future land use options and development proposals, the new proposals can then be added into the current map, to create future scenarios showing how the proportion of the catchment that is impervious will change with the various proposals.
- The land use classification can be linked with the typical run-off factor for each type of land use to give a more accurate map, showing degrees of impermeability, if necessary.

(2) Calculation of pollutant mass flux

Whereas the calculation of pollutant loading rates is useful, it can never be more than an estimate, except in those rare instances where the parameter in question is being analysed and logged on line, together with the flow rate. Discrete sampling and analysis is the norm, and is likely to remain so on the grounds of practicality and cost. It is recommended therefore to use the calculation of mass flux (concentration x flowrate) for each parameter of interest, and to generate time series data for this. The estimation of loading rates from this data is possible, but comparisons of the annual load, year on year, are fraught with errors. Estimation of the daily load is more accurate, particularly at base flow. However, comparison of the mass flux at the same point in time, year on year, at the same sampling spot, and especially at the base flow rate, is an entirely accurate representation of the pollution status of the river, and how this is changing over time.

4. Level of detail required for modelling

The work done on the Lotus River Project has shown that in order to utilise the GIS to model an urban catchment effectively, there is a need to

(1) Adopt a less homogenising approach to stormwater runoff modelling, and
(2) Map land use variations in greater detail than in previous catchment studies.

Clearly, variations in the degree of heterogeneity of individual sub-catchments will affect the overland flow through these areas. Previously, stormwater runoff studies have tended to simplify sub-catchment land use descriptions for the modelling process. The approach often adopted in allocating a permeability value for a sub-catchment involves categorising the sub-catchment in terms of one of these land use type combinations, thereby enabling a "standard" percentage impermeable value to be employed to a number of sub-catchments with a similar overall land use pattern. In doing so, information on the heterogeneity of different sub-catchments is lost. The result is that sub-catchments, which are markedly different in terms of the land use distribution, are treated analogously in the modelling process. This is evident from the application of equivalent impermeability values for sub-catchments which differ greatly in terms of land use.

Carrying out a detailed land use analysis based upon remote sensing or high resolution digital orthophotography (0.5 m pixel resolution), then integrating the results with a GIS-linked stormwater modelling programme such as SWMM, will provide the most useful and accurate results for urban catchment management.

5. River and wetland rehabilitation

There is a need to map a wide variety of data types to enable the development of truly integrated catchment management and river/wetland rehabilitation applications. The land use mapping carried out in previous catchment studies tended to focus only on identifying permeable and impermeable areas. "Integrated catchment management" implies that not only the physical/hydrological components of the system need to be incorporated into the catchment model, but also the socio-economic components such as the population distribution, and the location of the formal and informal housing sectors. These data types are essential if the database is to be used for management applications such as examining the potential river maintenance related responsibilities of individual sub-catchment populations, and in identifying potential river restoration projects of different kinds. In this case an overlay of the formal settlement distribution throughout the catchment will help to identify which sub-catchments have the greater likelihood for deriving financial resources from the local population for restoration applications.

In addition, it is clear that from this study that the water quality in a catchment is greatly affected by activities carried out in within informal settlements. If pollution sources are to be identified and incorporated into the management model, informal housing needs to be clearly mapped. Another area where greater detail should be employed in the mapping process lies in the definition of the vegetated areas of the catchment. In previous catchment studies, the vegetated areas distinguished only between agricultural and sports field areas. From the point of view of evaluating different river rehabilitation strategies, it is useful to differentiate between open non-vegetated, grass-bearing, shrub-bearing, and cultivated land uses - at least in the immediate vicinity of the river. Each of these land uses are characterised by different rehabilitation potentials, costs, implementation strategies and other factors that need to be considered during the site selection process. Land ownership data should also be incorporated if possible. In contrast to the other land uses mentioned here, this data would obviously not come from the analysis of aerial photography, but rather from the local authority vector and attribute databases. For the ecological management of the catchment, the same information would be used for the catchment as a whole.

6. Water quality monitoring

The visual representation of changes in water quality along the length of the river is a particularly useful tool for identifying pollution sources. Secondly, a detailed land use map for a catchment provides a valuable spatial reference frame for analysing the variations in water quality parameters monitored along a canal or river. By overlaying thematic maps illustrating the variation in the water quality data onto the land use map, the location of anomalies in the water quality data can be compared with the adjacent and upstream land uses.

The parameters of greatest interest to be monitored are:

1. COD, for the organic pollution level of the water
2. Nitrate and soluble reactive phosphate, for the eutrophication potential of the water
3. Suspended solids, for the level of particulate matter being transported. This is important in terms of measuring:

- the sustainability of land use in the catchment (erosion levels);
- the transport of certain pollutants, such as particulate phosphate, which can have important impacts on the receiving water body, and toxic compounds (eg. PCBs) and heavy metals which typically adsorb to solid particles;
- the geomorphology of the river, with the extent of deposition of sediments which can be expected to occur;
- the riverine ecosystems themselves.

The levels of toxic pollutants in the water can be measured by analysing for VOCs, pesticides, and heavy metals. However, the fast-developing field of eco-toxicology is providing tools for a much more accurate and sensitive way of assessing toxicity, which is preferable to measuring the levels of individual compounds. The use of indicator organisms, if the organisms are available and standardised testing methods exist, is recommended. Similarly, the SASS as a method of scoring the diversity of micro-invertebrate populations in aquatic ecosystems is recommended as a monitoring tool for urban rivers that are being upgraded and rehabilitated. Although scores are too low to be very meaningful while the river is highly polluted and degraded, as this project has shown, the use of SASS is recommended to measure the effects of rehabilitation efforts and other changes in the management of the catchment.

7. Hydrogeology and decanalisation

Effects of catchment development on groundwater quantity and quality must be taken into account in integrated catchment management. The management of surface water and stormwater alone gives only a partial picture of what is happening in the catchment. Groundwater is often depleted in urban catchments, because of the decrease in infiltration, and the higher proportion of precipitation that is allowed to run off. The impact of urbanisation on groundwater quality can also be severe, particularly in the vicinity of informal settlements and landfill sites. Similarly, the intensive use of pesticides, herbicides and fertilisers can pollute groundwater. Allowing the infiltration of polluted stormwater (eg. from motorway drainage or sewer overflows), without adequate provision for treatment, will also affect groundwater quality. The increasing use of techniques such as aquifer storage and recharge in urban water management is raising the awareness of the importance of the hydrogeology of the urban catchment. The GIS database for the catchment should contain all available information on the hydrogeology of the area.

While not all catchments have important groundwater resources to consider, in natural riverine environments there is always interaction between ground and surface waters. Often streams and rivers are sustained by a base flow from groundwater discharge. When the water table is above the bottom elevation of the riverbed, there will be groundwater inflow into the surface water body. Conversely, when the water table is below the bottom of the river or lake there will be seepage from the surface water body to the groundwater. Canalisation alters this natural interaction, artificially interfering with surface-groundwater exchange between the river and the aquifer below. Decanalisation restores this exchange. It is likely that there would be periods of both groundwater inflow into the river, and river water seepage into the groundwater, following decanalisation. Similarly, the recreation of wetland areas within an urban catchment allows for an increase in the infiltration taking place into the groundwater. Decanalisation and the recreation of wetlands are, therefore, not only important tools for the management of surface water quality, and aquatic ecosystems, but also can have a major effect on groundwater within the catchment.

7.2 CONCLUSIONS SPECIFIC TO MANAGEMENT OF THE LOTUS RIVER CATCHMENT AREA

The Lotus River catchment area has a long history of rapid change, of which the two years duration of this project is merely a snapshot. However, there are some pointers for the future resulting from this project, which may be of use to consider. These are presented in addition to the specific recommendations made in the preceding chapters regarding community participation in catchment management, the GIS database, hydrological considerations embracing both water quantity and water quality, and the ecological management of the catchment.

7.2.1 Social and institutional processes

As noted in section 7.1, it is essential for the social and institutional processes to precede the technical process of catchment management. In South Africa at present, the social process is even more important than the institutional process, since the latter is highly fluid and uncertain. Technical and financial decision-making should be subject to a satisfactory social structure, driven primarily by motivated community-based individuals or groups. This is the key to ensuring sustainability of the structure, and of catchment management.

In the introduction given in chapter 1, it was stated that sustainability in this context would be judged by the major stake holders managing the catchment effectively, with a focus upon water quality and ecological stability and improvement, as well as upon hydraulics and flood control. Furthermore, this management should be carried out in a manner that is inclusive and participatory, working with the full range of stake holders and communities in the catchment. At this point, the key stakeholder who has emerged from the social and institutional process undertaken in the catchment is the Catchment Management Department of the Cape Metropolitan Council. Although from a technical perspective, this outcome has enabled the catchment to be managed effectively in interaction with the other relevant local authorities, there are some valid concerns regarding the sustainability of the situation:

- This department of the local authority has responsibility over a large number of very different urban catchments, which inevitably means that there is little focus on a specific catchment at any given time.
- Community and NGO involvement in the catchment committee has fallen, due to meetings being organised from outside the catchment, with little individual involvement.
- The local authorities are once again due to undergo a massive administrative reorganisation, so that the future of the catchment management department is uncertain.
- For the same reason, the funding of catchment management activities in the future is also uncertain.

It is recommended, therefore, that in order to restore some level of sustainability to the process, funding should be set aside from the catchment management budget, which remains, prior to the local authority reorganisation, to institute non-structural BMPs within the Lotus River catchment. This work should be undertaken not by consultants but by the community-based organisations and relevant NGOs, who have been involved in catchment management thus far, and have demonstrated an interest and understanding of the key issues. Such seed money would undoubtedly spark off a remarkable level of voluntary involvement and activity. Some examples of necessary projects, which should be done through CBOs and NGOs, are given below.

(1) Community liaison and environmental education in residential areas. The funding which would be required for this work would be largely for purchasing materials, printing and photocopying. A certain amount could be set aside for a part-time co-ordinator.

- Supporting environmental education work in schools. There are a number of organisations in the catchment that do this, eg. the annual Environment Day outing organised by the Zeekoevlei Civic Association. Using the educational materials on rivers that already exist, these organisations could do a lot more around catchment management if the corresponding expenses were covered, such as photocopying of materials
- Raising the profile of environmental issues and people's responsibility, using billboards, posters in public loos, and bus stops
- Community newsletters

(2) Farmer support - Philippi area. This work is more specialised and would require the involvement of a part-time extension worker, preferably from the Philippi farming community itself, who would need to receive some training. Whereas some subsidy may need to be provided to farmers for aspects of the necessary work, eg. rehabilitating irrigation ponds, there is much in the programme that farmers may be willing to undertake themselves, as they have indicated concern about the water quality in the canal, which is used for irrigation. The farmers as stake holders will become more willing to be involved in

catchment management if they see other stake holders becoming actively involved, and especially if actual improvements in water quality can be made, with regard to bacterial contamination.

- Individual farmer involvement is important with this group of stake holders. The extension worker's task would be to contact each farmer and determine the extent to which they would be prepared to support the aims of the project
- Adapting irrigation ponds to improve biodiversity: sloping, fencing, planting of aquatic vegetation (see Chapter 5).
- Introducing fertiliser management, including soil testing and optimisation of fertiliser use.
- Field trials on growing organic crops.
- Introducing buffer strips along ditches and canal (recommended width 5m), to reduce nutrient content of surface runoff.
- Maintaining drainage ditches in an ecological way.

As noted above, these projects (conforming to non-structural BMPs) could be funded with relatively small amounts of seed money, because there would be a great deal of voluntary involvement. This continuing involvement by a range of stake holders would help to ensure sustainability in the management of the Lotus River catchment.

7.2.2 Technical decision-making

All the recommendations made below have been shared with catchment stake holders during the course of the project. As a result, some are already in the course of being implemented. The following points present a summary of the more urgent needs for adequate management. For details, please refer to recommendations made in specific chapters of this report.

Usage of GIS database and catchment models

The GIS database constructed for the Lotus River catchment has been used to:

1. Evaluate the suitability of two GIS-based land use classification methodologies;
2. Estimate primary input parameters for the PC-SWMM stormwater management model;
3. Aid the visualisation of spatial (eg. land use etc.) and hydrological time series data using coupled raster-vector-based and thematic mapping techniques respectively;
4. Classify the catchment into a number of regional sub-catchment groups;
5. Estimate population density data on a per sub-catchment basis;
6. Estimate the degree of urbanisation that occurred during 1983 to 1996 and from 1933 to 1996.

- The integrated information available, in a series of maps as shown on the accompanying CD, should be put on the Internet for the benefit of all the stake holders in the catchment. The actual database requires to be kept updated, and integrated with the local authority database.
- Continuous modelling of system is necessary as a management tool (ultimately including both flow and water quality modelling). Used to support management decisions on land use changes etc. Present input data sketchy thus model development dependent on above points for data input. State of art of modelling includes GIS model linkages hence there is a great need for digitised input data.
- Event model presently used to determine 1:50 year flood flows was completed in 1994, with limited updates. If to be utilised for assessing land use change effects on flood levels, this model needs to be updated with recent changes in the catchment

Catchment considerations

- Provision of improved services to previously disadvantaged township areas: improved sanitation is necessary in the formal areas, and provision of sanitation in the crowded informal areas should be seen as a priority. Improved waste management will also contribute to preventing gross pollution.
- A detailed investigation of stormwater/sewer infrastructure to assess sewer overflows is necessary, aimed ultimately at reducing negative health aspects of the present situation.

- For management purposes, the stormwater system needs to be surveyed in detail - As-Builts. At present, knowledge of stormwater system in much of the Lotus River catchment sketchy, incomplete, and based on old paper maps. The system needs to be captured onto GIS for ease of access.
- Rainfall data is only available in coarse resolution (or as raw data) from local authorities. Frequently data is missing due to lethargic and inefficient monitoring of gauges. For modelling of rapid response urbanised catchments, finer resolution data must be readily available. Faulty rain gauges producing missing data should be updated to provide complete datasets.
- Borehole study of catchment is necessary to assess nutrient concentrations. Present knowledge and information on aquifer based on outdated borehole readings.
- Land use changes to be assessed in terms of maintaining present channel capacity. Promotes need for on-site detention, especially for new developments, and should consider BMPs discussed above. This is aimed at reducing directly connected impervious areas through the use of porous pavements, routing of roof drainage over pervious land instead of directly into stormwater network, and increased numbers of multi-purpose retention ponds.
- The Philippi farming area requires to be studied with regard to both drainage and groundwater. Farmers are experiencing greater depths for borehole water. The adjacent Edith Stevens nature reserve appears to have dried out over the past decades, as shown by botanical records. Measures to raise the level of the water table should be taken, if this data is confirmed by a borehole study.

River channel

- Delink peak flow design from low flow design – the former is used only for a tiny proportion of the time.
- Lotus canal cross sections only on design drawings. Need for detailed survey including location of all tributary inputs.
- Cape Metropolitan Council has been charged with the maintenance of historical water quality database. However, the present sampling programme is insufficient for any management decision-making applications. Samples need to be taken in conjunction with flow measurements to assess loading.

Maintenance of river channel

- Re-assessment of the maintenance programme is required, since the annual dredging programme in unlined sections of the canal destroys the few ecosystems able to survive in adverse conditions. A more frequent labour-intensive maintenance programme for cleansing is required, especially in the lined sections that are easily accessible. Annual maintenance is insufficient to prevent large-scale accumulation of solid waste (gross pollution) at specific points such as detention ponds and stilling basins. These need cleansing on a more frequent basis, to enable the hydrological system to function as it should.
- Further to above point, reassessment of vegetation management in the river channel. A more sensitive maintenance plan needs to be implemented, taking into account the nutrient assimilation capacity of aquatic vegetation and reducing complete annual removal through dredging. This plan should promote establishment of indigenous species over alien and should consider more detailed, sensitive and labour-intensive harvesting of vegetation.

Decanalisation and river restoration:

- Prevention of any further concrete lining of existing canal. Focus on more aesthetically pleasing earth lined channels. Investigation of earth lined cross section required to maintain similar concrete lined channel capacity. Acquire increased channel servitude if necessary to facilitate construction of earth lined channel with curvilinear flow profile. Requires weighing up of increased costs of construction, land acquisition and maintenance versus benefits of creating aesthetically pleasing, habitat diverse, nutrient assimilative channel utilised by public as recreational and educational amenity.
- Limited decanalisation should be investigated to permit percolation during summer (reducing need for above sewer diversion) to reduce pollutant loading downstream. This would also have significant effects on canal habitat diversity.

- In-stream restoration measures are necessary where decanalisation is not possible, to improve habitat diversity (weirs in lined sections and riffles in unlined sections) whilst avoiding excessive increases in flood risk.
- On-line and off-line wetlands for pollutant removal.
- Above three factors require installation of litter traps, frequently maintained to prevent clogging of in-stream features.
- With every rehabilitation project, the effects need to be monitored.

Decanalisation and river restoration: effects on groundwater and downstream water bodies

Decanalisation would enable the surface-groundwater exchange to take place once more, which has been artificially prevented by the canalisation of the Lotus Rivers. It is likely that there would be periods of both groundwater inflow to the rivers and river water seepage into the groundwater. Importantly, in the dry summer, infiltration would be such that there may be no flow from the Lotus Rivers into Zeekoevlei at all. In the case of river water seepage into the aquifer, the effects in terms of water quality in the aquifer would probably be small and highly localised, due to:

- the small volume of river water relative to the size of the aquifer
- the low transmissivity of the aquifer in that region, and
- the westerly direction of groundwater flow in that region, away from the main body of the aquifer, which further reduces the potential for contamination.

An ongoing groundwater monitoring program is in order, and this would need to be linked to intensive groundwater investigations in the reaches where river restoration and decanalisation is to be undertaken.

Concluding remarks

The Lotus River catchment will continue to develop and change rapidly, but even so it will take many years to become an ecologically sustainable area. With economic growth, a rise in income and living standards, and strong political commitment to improving people's quality of life in the area, there is hope that good catchment management will gradually be instituted. Environmental education and the emergence of community champions for the vision are essential for this to succeed.

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APPENDIX A

MEETINGS OF THE LOTUS RIVER PROJECT

Meetings of the Lotus River Project

The following list gives the major meetings organised or attended by the Lotus River project team, over the life-time of the project, including conference papers presented. There were also numerous smaller meetings, site visits with various people, and discussions with a range of stakeholders which are not included.

1997

13 February :
Zeekoevlei Environmental Management Team meeting (Ania Grobicki)
Introducing catchment management issues to the management of the vlei

19 March :
1st Team Meeting
All team members plus local authority representatives

Welcome and introduction	Ania Grobicki
Hydrology, flow measurement & sampling programme	Ryan Males
Microbial sampling of the Lotus River	Mjiko Vulindlu
Community participation in integrated catchment management	Errol Ally

Steering Committee meeting on 08 May 1997 :
Progress report presented : full Steering Comm plus local authority representatives

05 June :
Zeekoevlei Eco Day - 190 schoolchildren learning about ecology at the outflow of the Little Lotus River. Activities were organised by Mark Lorenz of Abbott Grobicki, working jointly with the Zeekoevlei Civic Association

19 June :
Zeekoevlei Environmental Management Team - the last meeting to be attended under the auspices of CTM, before the team is taken over by SPM. The lake drawdown (24 March to 4 July) was the main item under discussion, and we have undertaken to draw up an action plan for the next drawdown, to take place in winter 1998.

26 June :
Marine Litter Network - presentation focusing on waste aspects of urban catchment management (Ania Grobicki)

30 June :
Environmental Task Team, Planning Department, CTM
Presentation to the task team involved with the Lansdowne-Wetton Corridor Project, to establish co-ordination between ourselves and the LWCP (Ania Grobicki)

03 July :
Masters module in Urban Environmental Management, UCT
Presentation and field trip, including a walking tour of the Great Lotus River from Vygekraal Road Detention Pond to Guguletu NY3 (Ania Grobicki)

22 July :
1st Lotus River Management Team meeting, CMC
First meeting to be held under the auspices of the Department of Urban Catchment Management of Directorate of Water and Waste, CMC; establishing co-ordination between Lotus River project, stormwater engineering projects, and the proposed Olympic cycle track

28 August :
2nd Team Meeting

Summary of developments	Ania Grobicki
Initial results from sampling programme	Ryan Males
Lotus catchment groundwater study	Samantha Salvia
Ecological status of the canal	Mark Lorenz
Progress in community participation	Errol Ally

Items for discussion :
(1) Proposed wetland at Sunset Park
(2) Moving towards a Catchment Management Structure

17 September :
Presentation on the Lotus River Project to the European Centre for River Restoration at Silkeborg, Denmark (Ania Grobicki)

25 September :
Presentation on the Lotus River Project to the UK River Restoration Project at Darlington, UK (Ania Grobicki)

29 October :
Zeekoevlei Environmental Management Team - first meeting under the auspices of the newly created South Peninsula Municipality

17-19 November :
8th South African National Hydrology Symposium (SANC-IAHS), Pretoria
Poster paper presentation : A.Grobicki and R.Males, "Integrated catchment management in an urban context : evidence of point source and diffuse source pollution from the Lotus River Project"

26 November :
Zeekoevlei Environmental Management Team - presentation of Zeekoevlei Drawdown Action Plan prepared by the Lotus River team (Ania Grobicki)

02 December :
Meeting with Cape Town Municipality to identify strategic sites for restoration along the Great Lotus River

04 December :
Presentations by Ryan Males and Mark Lorenz to academic members of the team, attempting to define integrated ecohydrological approach (Andre Gorgens, Bryan Davies, Neil Armitage, John Abbott)

1998

24 January :
CMC/SAICE/WISA Symposium on Catchment Management
Paper presentation : A.Grobicki, "The Lotus Catchment study : practical application of integrated catchment management"

9-11 February :
Integrated Environmental Management in South Africa (CEMSA '98), East London
Paper presentation : A.Grobicki, "Integrated catchment management in an urban context : the Lotus River Project, Cape Town"

Steering Committee meeting on 07 May 1998 :
Progress report presented to full Steering Comm plus local authority representatives. Reports by Ania Grobicki, Siviwe Matika, Iuma Martinez, Ryan Males, and Mark Lorenz

18 May : Presentation on the Lotus River Project by Ania Grobicki to the Board of the Water Research Commission (at the University of the Western Cape)

05 June : Zeekoevlei Eco Day - 200 schoolchildren learning about ecology on the Eastern shore of Zeekoevlei. Activities organised by Abbott Grobicki (Pty) Ltd, working jointly with the Zeekoevlei Civic Association

27 June : Community workshop : catchment tour, slide show and workshop for 30 community representatives from Guguletu, Nyanga, Crossroads, Philippi East and Hanover Park

28 June : Community workshop : catchment tour, slide show and workshop for 25 community representatives from Grassy Park, Lotus River, and Zeekoevlei

29 June - 1 July :
Conference on the National Rivers Initiative (SASAQS 1998), Pietermaritzburg
Paper presentation : A.Grobicki, "Urban catchment management and the integrated development and management of urban rivers"

Numerous meetings with stakeholders in community participation process for remainder of the year.

1999

19 January : Meeting to bring together all interested stakeholders into a formal catchment management structure

03 February :
1st meeting of the "Zeekoe Catchment Committee" held under the auspices of the Cape Metropolitan Council's Department of Catchment Management

09 February :
Swedish International Programme on Management of Groundwater for Urban Areas, CSIR, Stellenbosch
Presentation : A.Grobicki, "Urban catchment management : case study on the Great and Little Lotus Rivers, Cape Town"

19 March :
2nd meeting of the "Zeekoe Catchment Committee", now re-named the "Zeekoe Catchment Forum", held under the auspices of the Cape Metropolitan Council's Department of Catchment Management – the last with the formal involvement of the project team

25-26 March :
S.Matika and A.Grobicki, "Participatory Urban Catchment Management and its role in urban development", paper presented at the Institute of Commonwealth Studies Conference *South to South : urban-environmental policy and politics in Brazil and South Africa*, London, March 1999.

Final Steering Committee meeting on 06 May 1999 :
Draft report presented to Steering Committee plus local authority representatives.

07 May :
Seminar presentation to the Department of Chemical Engineering, UCT :
A.Grobicki, "Urban catchment management : case study on the Great and Little Lotus Rivers, Cape Town"

01 June :
Seminar presentation to the Department of Environmental and Geographical Sciences, UCT :
A.Grobicki, "Urban catchment management : case study on the Great and Little Lotus Rivers, Cape Town"

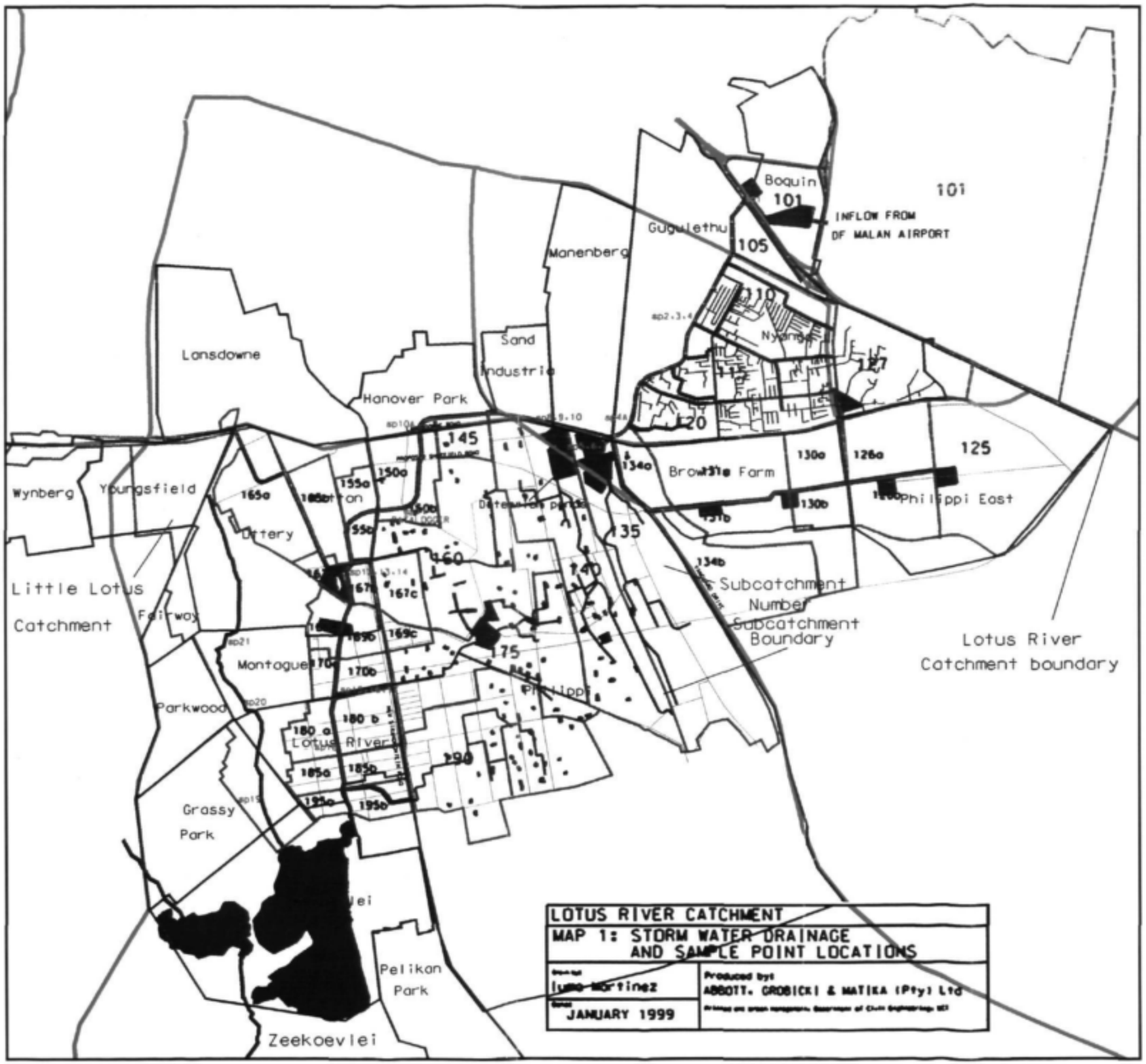
2000

3 - 7 July :
1st World Congress of the International Water Association (IWA)
Paper presentation : A.Grobicki, "Urban catchment management in a developing country : the Lotus River project, Cape Town, South Africa" (4 July)

APPENDIX B

1. LOTUS RIVER CATCHMENT MAP OF STORMWATER DRAINAGE AND SAMPLE POINT LOCATIONS

2. FIGURE 5.2 – ECOLOGY MAP


Boquin
101
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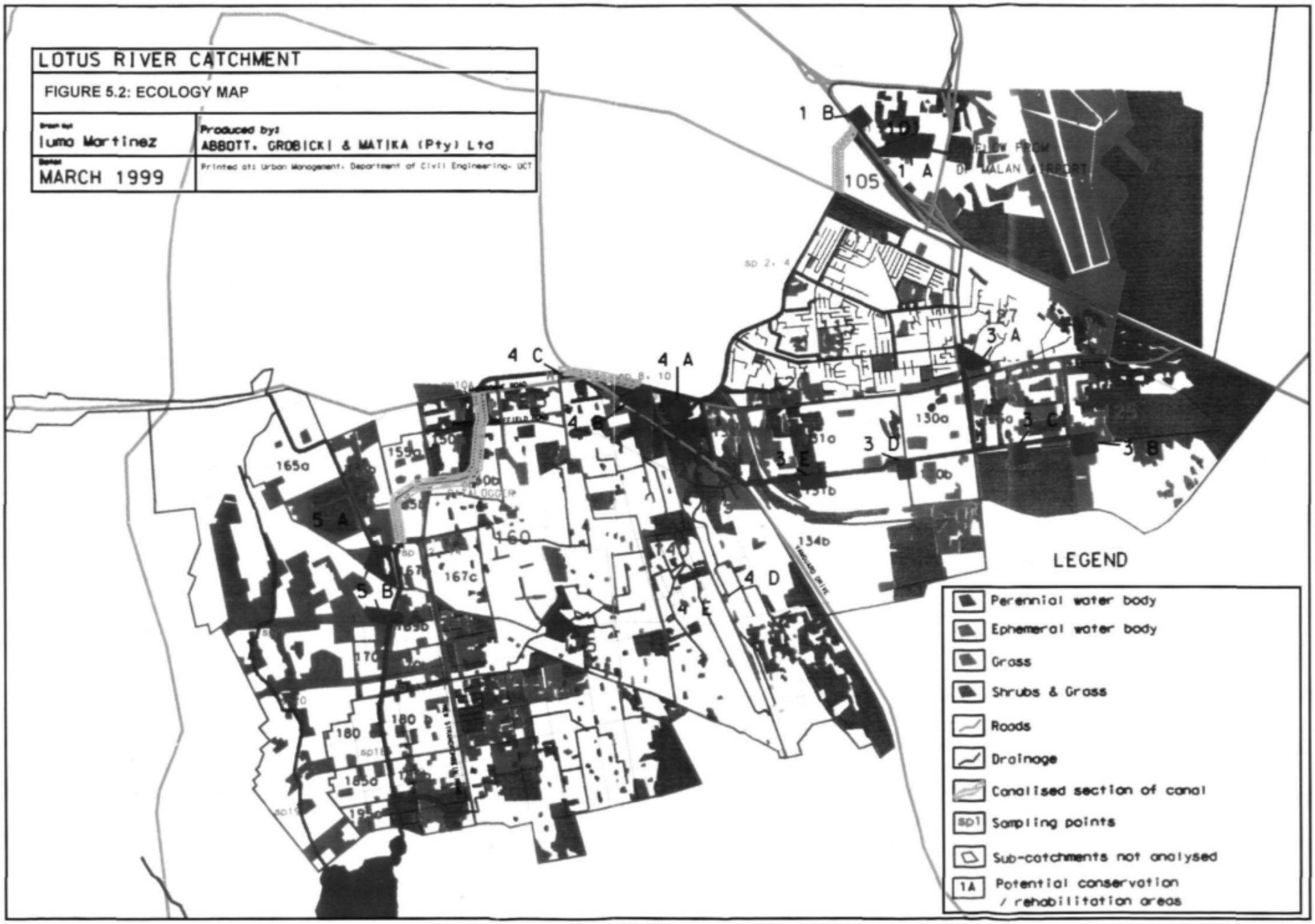
INFLOW FROM
DF MALAN AIRPORT
Gugulethu
Manenberg
105
110
Nyanga
115
120
127
Sand
Industrie
Hanover Park
Lansdowne
145
150a
155a
165a
Wynberg
Youngsfield
Ottery
Brownlee Farm
130a
126a
125
Philippi East
130b
135
140
160
Little Lotus
Catchment
Fairway
Montague
170
170b
175
Parkwood
180 a
180 b
Lotus River
185a
185b
190
Grassy
Park
Pelikan
Park
Zeekoevlei
Subcatchment
Number
Subcatchment
Boundary
Lotus River
Catchment boundary
LOTUS RIVER CATCHMENT
MAP 1: STORM WATER DRAINAGE
AND SAMPLE POINT LOCATIONS
Drawn by
Isabel Martinez
Produced by:
ABBOTT, GROBICKI & MATIKA (Pty) Ltd
Date
JANUARY 1999

LOTUS RIVER CATCHMENT

FIGURE 5.2: ECOLOGY MAP

Drawn by:	Produced by:
Iuma Martinez	ABBOTT, GROBICKI & MATIKA (Pty) Ltd
Date: MARCH 1999	Printed at: Urban Management, Department of Civil Engineering, UCT



APPENDIX C (1-3)

RESULTS OF LAND USE CLASSIFICATION ANALYSIS OF SUBCATCHMENTS IN THE LOTUS RIVER CATCHMENTS

APPENDIX C1

BASED ON 1996 PHOTOGRAPHY

RESULTS OF LANDUSE CLASSIFICATION ANALYSIS OF SUBCATCHMENTS IN THE LOTUS RIVER CATCHMENT BASED ON 1996 PHOTOGRAPHY

Note 1 Total area values indicated by an 1 is a summation of areas for which imagery was available.
Note 2 Total area values indicated by an 2 is the total subcatchment area.
Note 3 Percentages have been calculated using total1.
Note 4 Where the cultivated land constitutes the major area of a subcatchment,
this value has been calculated as a balance of total1 and total2.
Note 5 The "industrial" category includes farming buildings in the predominantly farming subcatchments
includes industrial aswell
Note 6 The no vegetation category refers to open vacant land which
bears no vegetation or or land uses.

Subcatchment 101

	Square meters	Percentages
detention pond	17760	1
grass	147679	12
shrubs	177454	14
no vegetation	524736	41
industrial	168882	13
parkinglot	244538	19
total1	1281048	100
total2	1281048	100
total pervious	867628	67.7
total impervious	413420	32.3

Subcatchment 105

	sqmeters	Percentages
grass	133948	22
shrubs	5900	1
informal	461978	77
total1	601826	100
total2	601826	100
total pervious	139848	23.2
total impervious	461978	76.8

Subcatchment 110

	sqmeters	percentages
grass	157018	9
shrubs	192198	10
no vegetation	47952	3
formal	984141	54
informal	415875	23
industrial	25809	1
school	14550	1
total1	1837543	100
total2	1837543	100
total pervious	397168	21.6
total impervious	1440375	78.4

Subcatchment 115

	sqmeters	percentages
grass	126648	8
no vegetation	29040	2
formal	1277489	79

informal	90553	6
industrial	31351	2
parkinglot	14977	1
school	52919	3
total1	1622976	100
total2	1622976	100
total pervious	155688	9.6
total impervious	1467288	90.4

Subcatchment 120

	sqmeters	percentages
grass	288020	19
shrubs	9474	1
no vegetation	79168	5
formal	1052169	69
informal	75103	5
industrial	20567	1
parkinglot	1497	0
school	3768	0
total1	1529765	100
total2	1529765	100
total pervious	376662	24.6
total impervious	1153103	75.4

Subcatchment 125

	sqmeters	percentages
grass	273619	7
shrubs	2120980	54
no vegetation	843002	22
informal	216773	6
industrial	102295	3
parkinglot	47589	1
site and service	309222	8
total1	3913481	100
total2	3913482	100
total pervious	3237602	82.7
total impervious	675880	17.3

Subcatchment 126a

	sqmeters	percentages
grass	214259	20
shrubs	221284	21
no vegetation	19826	2
informal	205801	19
industrial	147268	14
parkinglot	256155	24
total1	1064593	100
total2	1064593	100
total pervious	455369	42.8
total impervious	609224	57.2

Subcatchment 126b

	sqmeters	percentages
grass	89875	10

shrubs	763365	83
no vegetation	22096	2
informal	31148	3
industrial	6774	1
parkinglot	6595	1
total1	919852	100
total2	919852	100
total pervious	875336	95.2
total impervious	44517	4.8

Subcatchment 127

	sqmeters	percentages
grass	199409	11
shrubs	118078	6
no vegetation	566584	31
formal	358894	20
informal	486737	27
industrial	88242	5
parkinglot	14450	1
school	1125	0
total1	1833518	100
total2	1833518	100
total pervious	884070	48.2
total impervious	949448	51.8

Subcatchment 130a

	sqmeters	percentages
grass	46836	7
shrubs	7718	1
no vegetation	58547	9
formal	27026	4
informal	460307	70
industrial	25226	4
parkinglot	25763	4
school	5509	1
total1	656931	100
total2	656931	100
total pervious	113100	17.2
total impervious	543831	82.8

Subcatchment 130b

grass	60548	14
no vegetation	92194	21
formal	280190	63
industrial	12446	3
total1	445379	100
total2	445378	100
total pervious	152742	34.3
total impervious	292636	65.7

Subcatchment 131a

	sqmeters	percentages
grass	178724	12
shrubs	366645	24
no vegetation	104412	7

formal	100732	7
informal	587019	38
site and service	100937	7
industrial	86705	6
parkinglot	3760	0
total1	1528934	100
total2	1528935	100
total pervious	649781	42.5
total impervious	879153	57.5

Subcatchment 131b

grass	197085	15
shrubs	114329	8
no vegetation	111065	8
formal	137224	10
site and service	757699	56
industrial	11589	1
parkinglot	24403	2
total1	1353394	100
total2	1353393	100
total pervious	422479	31.2
total impervious	930915	68.8

Subcatchment 134a

	sqmeters	percentages
grass	160627	36
shrubs	118873	27
no vegetation	36505	8
rail	42997	10
informal	52761	12
industrial	33407	8
total1	445170	100
total2	445170	100
total pervious	359002	80.6
total impervious	86168	19.4

Subcatchment 134b

	sqmeters	percentages
grass	40348	2
shrubs	459897	24
no vegetation	1105011	59
rail	134699	7
site and service	122472	7
industrial	18547	1
total1	1880975	100
total2	1880974	100
total pervious	1739956	92.5
total impervious	141019	7.5

Subcatchment 135

	sqmeters	percentages
wet pond	13913	0.3
dry pond	2505	0.1
cultivated	1834214	45
grass	402035	10

shrubs	1578812	38
no vegetation	37855	0.9
industrial	215647	5
parkinglot	27690	0.7
total1	4112672	100
total2	4112671	100
total pervious	3869335	94.1
total impervious	243337	5.9

Subcatchment 140

	sqmeters	percentages
detention pond	82608.9	2
wet	13042.5	0.3
dry pond	12151.1	0.3
cultivated	2564917	64
grass	91646	2
shrubs	585219	14
no vegetation	74274	2
industrial	588543	15
parkinglot	45154	1
total1	4037556	100
total2	4037556	100
total pervious	3403859	84.3
total impervious	633697	15.7

Subcatchment 145

	sqmeters	percentages
dry pond	1580.31	0.4
cultivated	111319	26
grass	21080	5
shrubs	112162	26
no vegetation	6054	1
formal	4299	1
industrial	117611	28
parkinglot	51064	12
total1	425168	100
total2	425168	100
total pervious	140876	33.1
total impervious	172973	40.7

Subcatchment 150a

	sqmeters	percentages
wet pond	326	0.1
dry pond	284	0.05
cultivated	139906	24
grass	84809	14
shrubs	236908	40
no vegetation	36877	6
industrial	51015	9
parkinglot	43786	7
total1	593912	100
total2	593912	100
total pervious	499110	84.0
total impervious	94802	16.0

Subcatchment 150b

	sqmeters	percentages
wet pond	782.1	0.2
cultivated	322456	71
grass	15072	3
shrubs	70473	15
industrial	34671	8
parkinglot	11739	3
total1	455193	100
total2	455193	100
total pervious	408783	89.8
total impervious	46410	10.2

Subcatchment 155a

	sqmeters	percentages
grass	60473	20
formal	241768	78
informal	4849	2
parkinglot	2535	1
total1	309625	100
total2	309626	100
total pervious	60473	19.5
total impervious	249152	80.5

Subcatchment 155b

grass	56953	28
formal	117275	57
industrial	31789	15
total1	206017	100
total2	206016	100
total pervious	56953	27.6
total impervious	149064	72.4

Subcatchment 160

	sqmeters	percentages
wet pond	24266	1
dry pond	18764	1
cultivated	2682497	82
grass	148260	5
shrubs	145033	4
formal	1647	0
industrial	265927	8
total1	3286394	100
total2	3286394	100
total pervious	3018820	91.9
total impervious	267574	8.1

Subcatchment 165a

	sqmeters	percentages	
grass	181118	13	
shrubs	281913	20	
formal	556051	39	
industrial	392522	28	
total1	1411604	100	
total2	1960399	548794	missing imagery

total pervious	463031	32.8
total impervious	948573	67.2
Subcatchment 165b		
	sqmeters	
grass	266266	42
shrubs	115248	18
formal	231612	37
industrial	12065	2
parkinglot	2147	0
total1	627338	100
total2	627339	100
total pervious	381515	60.8
total impervious	245824	39.2
Subcatchment 167a		
	sqmeters	
grass	56123	22
formal	79761	31
industrial	50078	20
parkinglot	69820	27
total1	255781	100
total2	255781	100
total pervious	56123	21.9
total impervious	199658	78.1
Subcatchment 167b		
	sqmeters	
grass	50927	26
industrial	119532	61
parkinglot	25276	13
total1	195736	100
total2	195736	100
total pervious	50927	26.0
total impervious	144808	74.0
Subcatchment 167c		
	sqmeters	
wet pond	784	0.1
dry pond	2076	0.4
cultivated	450132	77
grass	29991	5
shrubs	35588	6
formal	14381	2
industrial	48101	8
parkinglot	3957	0.7
total1	585010	100
total2	585010	100
total pervious	518570	88.6
total impervious	66439	10.7
Subcatchment 169a		
	sqmeters	
grass	148344	41
formal	46705	13

parkinglot	5174	1
total1	359966	100
total2	359966	100
total pervious	148344	41.2
total impervious	211623	58.8

Subcatchment 169b

	sqmeters	
grass	141142	38
shrubs	23781	6
formal	139221	37
industrial	69843	19
total1	373986	100
total2	373987	100
total pervious	164923	44.1
total impervious	209064	55.9

Subcatchment 169c

	sqmeters	
grass	113778	55
shrubs	64431	31
formal	28545	14
industrial	1811	1
total1	208565	100
total2	208565	100
total pervious	178209	85.4
total impervious	30356	14.6

Subcatchment 170a

	sqmeters	
grass	52398	25
shrubs	7093	3
formal	117571	56
industrial	33568	16
total1	210630	100
total2	210631	100
total pervious	59491	28.2
total impervious	151139	71.8

Subcatchment 170b

	sqmeters	
grass	184410	50
shrubs	19328	5
formal	143030	39
industrial	8621	2
parkinglot	4389	1
school	8349	2
total1	368126	100
total2	368125	100
total pervious	203737	55.3
total impervious	164388	44.7

Subcatchment 175

	sqmeters	
	8543	0

dry pond	22714	1
cultivated	2173639	73
grass	153122	5
shrubs	516969	17
no vegetation	19550	1
formal	7999	0
industrial	72011	2
total1	2974546	100
total2	2974546	100
	Percentages	
total pervious	2894537	97.3
total impervious	80010	2.7

Subcatchment 180a

	sqmeters	
grass	45592	10
no vegetation	959	0
formal	398165	89
industrial	226	0
total1	444943	100
total2	444943	100
total pervious	46552	10.5
total impervious	398391	89.5

Subcatchment 180b

	sqmeters	
grass	174866	25
formal	476325	68
industrial	33708	5
school	15666	2
total1	700565	100
total2	700565	100
total pervious	174866	25.0
total impervious	525699	75.0

Subcatchment 185a

grass	42006	13
formal	265161	83
industrial	11804	4
total1	318970	100
total2	318971	100
total pervious	42006	13.2
total impervious	276965	86.8

Subcatchment 185b

	sqmeters	
grass	102485	25
shrubs	14508	4
formal	238184	59
informal	7849	2
industrial	17069	4
parkinglot	8418	2
school	17663	4

total2	406175	100
total pervious	116992	28.8
total impervious	289183	71.2
Subcatchment 190		
	sqmeters	
wet pond	14093	0.4
dry pond	11205	0.3
cultivated	2178087	57
grass	459474	12
shrubs	801963	21
no vegetation	75608	2
formal	108748	3
industrial	136554	4
parkinglot	2663	0
total1	3788395	100
total2	3788395	100
total pervious	3540430	93.5
total impervious	247965	6.5
Subcatchment 195a		
	sqmeters	
grass	41868	22
shrubs	12578	7
no vegetation	5811	3
formal	120073	63
industrial	9969	5
total1	190299	100
total2	190299	100
total pervious	60256	31.7
total impervious	130043	68.3
Subcatchment 195b		
	sqmeters	
grass	54491	14
shrubs	291594	73
formal	50006	13
industrial	3828	1
total1	399919	100
total2	399919	100
total pervious	346085	86.5
total impervious	53834	13.5

APPENDIX C2

BASED ON 1983 PHOTOGRAPHY

RESULTS OF LANDUSE CLASSIFICATION ANALYSIS OF SUBCATCHMENTS IN THE LOTUS RIVER CATCHMENT BASED ON 1983 PHOTOGRAPHY

Note 1 Total area values indicated by an 1 is a summation of areas for which imagery was available.
Note 2 Total area values indicated by an 2 is the total subcatchment area.
Note 3 Percentages have been calculated using total1.
Note 4 Where the cultivated land constitutes the major area of a subcatchment, this value has been calculated as a balance of total1 and total2.
Note 5 The "industrial" category includes farming buildings in the predominantly farming subcatchments includes industrial aswell
Note 6 The no vegetation category refers to open vacant land which bears no vegetation or or land uses.
Note 7 The vegetation category refers to cultivated.

Subcatchment 101

	Square meters	Percentages
vegetation	812490	63
no vegetation	406045	32
industrial	62513	5
total1	1281048	100
total2	1281048	100
total pervious	1218535	95.1
total impervious	62513	4.9

Subcatchment 105

	sqmeters	Percentages
vegetation	461871	77
no vegetation	139955	23
total1	601826	100
total2	601826	100
total pervious	601826	100
total impervious	0	0

Subcatchment 110

	sqmeters	percentages
vegetation	941220	51
no vegetation	116449	6
formal	721596	39
serviced sites	44531	2
industrial	13747	1
total1	1837543	100
total2	1837543	100
total pervious	1057669	57.6
total impervious	779873	42.4

Subcatchment 115

	sqmeters	percentages
vegetation	158423	10
no vegetation	118037	7
formal	1264768	78
relocation	43374	3
industrial	38374	2
total1	1622976	100
total2	1622976	100

total pervious	276460	17.0
total impervious	1346516	83.0

Subcatchment 120

	sqmeters	percentages
vegetation	387748	25
no vegetation	19125	1
formal	1111551	73
industrial	11341	1
total1	1529765	100
total2	1529765	100
total pervious	406873	26.6
total impervious	1122892	73.4

Subcatchment 125

	sqmeters	percentages
vegetation	3770025	96
no vegetation	88625	2
industrial	54832	1
total1	3913482	100
total2	3913482	100
total pervious	3858650	98.6
total impervious	54832	1.4

Subcatchment 126a

	sqmeters	percentages
vegetation	821708	77
no vegetation	34141	3
formal	29239	3
industrial	179505	17
total1	1064593	100
total2	1064593	100
total pervious	855849	80.4
total impervious	208744	19.6

Subcatchment 126b

	sqmeters	percentages
vegetation	748346	81
no vegetation	131509	14
industrial	39997	4
total1	919853	100
total2	919852	100
total pervious	879856	95.7
total impervious	39997	4.3

Subcatchment 127

	sqmeters	percentages
vegetation	949326	52
no vegetation	166304	9
serviced sites/rel	663567	36
industrial	54322	3
total1	1833518	100

total2	1833518	100
total pervious	1115630	60.8
total impervious	717888	39.2

Subcatchment 130a

	sqmeters	percentages
vegetation	516782	79
no vegetation	69603	11
industrial	70547	11
total1	656931	100
total2	656931	100
total pervious	586385	89.3
total impervious	70547	10.7

Subcatchment 130b

vegetation	430682	97
no vegetation	13279	3
total1	443961	100
total2	445378	100
total pervious	443961	100
total impervious	0	0

Subcatchment 131a

	sqmeters	percentages
vegetation	1103342	72
no vegetation	349118	23
industrial	76476	5
total1	1528935	100
total2	1528935	100
total pervious	1452460	95.0
total impervious	76476	5.0

Subcatchment 131b

vegetation	1123652	83
no vegetation	35346	3
industrial	91327	7
rail	103068	8
total1	1353393	100
total2	1353393	100
total pervious	1158998	85.6
total impervious	194395	14.4

Subcatchment 134a

	sqmeters	percentages
grass	418912	94
no vegetation	26371	6
total1	445283	100
total2	445170	100
total pervious	445283	100
total impervious	0	0

Subcatchment 134b

	sqmeters	percentages
vegetation	1697243	90
no vegetation	138041	7
industrial	45690	2
total1	1880974	100
total2	1880974	100
total pervious	1835284	97.6
total impervious	45690	2.4

Subcatchment 135

	sqmeters	percentages
grass	3582575	87
no vegetation	360900	8.8
industrial	169196	4
total1	4112671	100
total2	4112671	100
total pervious	3943475	95.9
total impervious	169196	4.1

Subcatchment 140

	sqmeters	percentages
vegetation	3768688	93
no vegetation	251843	6
industrial	17025	0
total1	4037556	100
total2	4037556	100
total pervious	4020530	99.6
total impervious	17025	0.4

Subcatchment 145

	sqmeters	percentages
grass	344555	81
industrial	80613	19
total1	425168	100
total2	425168	100
total pervious	344555	81.0
total impervious	80613	19.0

Subcatchment 150a

	sqmeters	percentages
vegetation	487560	82
no vegetation	42638	7
formal	14746	
industrial	48967	8
total1	593912	100
total2	593912	100
total pervious	530198	89.3
total impervious	48967	8.2

Subcatchment 167a		
	sqmeters	
vegetation	236159	92
no vegetation	7975	
formal	11647	5
total1	255781	100
total2	255781	100
total pervious	236159	92.3
total impervious	11647	4.6

Subcatchment 167b		
	sqmeters	
vegetation	138439	71
industrial	38576	20
formal	18720	
total1	195735	100
total2	195736	100
total pervious	138439	70.7
total impervious	57296	29.3

Subcatchment 167c		
	sqmeters	
vegetation	540989	92
no vegetation	17292	3
industrial	26729	5
total1	585010	100
total2	585010	100
total pervious	558281	95.4
total impervious	26729	4.6

Subcatchment 169a		
	sqmeters	
vegetation	308454	86
formal	42363	12
industrial	9150	3
total1	359967	100
total2	359966	100
total pervious	308454	85.7
total impervious	51513	14.3

Subcatchment 169b		
	sqmeters	
vegetation	77105	21
no vegetation	12855	3
formal	284027	76
total1	373987	100
total2	373987	100
total pervious	89960	24.1
total impervious	284027	75.9

Subcatchment 169c		
	sqmeters	
vegetation	11683	6

no vegetation	12855	6
formal	184027	88
total1	208565	100
total2	208565	100
total pervious	24538	11.8
total impervious	184027	88.2

Subcatchment 170a

	sqmeters	
vegetation	65617	31
formal	112386	53
industrial	32628	15
total1	210631	100
total2	210631	100
total pervious	65617	31.2
total impervious	145013	68.8

Subcatchment 170b

	sqmeters	
vegetation	194045	53
no vegetation	14510	4
formal	132193	36
industrial/school	27378	7
total1	368126	100
total2	368125	100
total pervious	208555	56.7
total impervious	159571	43.3

Subcatchment 175

	sqmeters	
vegetation	2454678	83
no vegetation	434478	15
industrial	85390	3
total1	2974546	100
total2	2974546	100
	Percentages	
total pervious	2889156	97.1
total impervious	85390	2.9

Subcatchment 180a

	sqmeters	
vegetation	112927	25
formal	332016	75
total1	444943	100
total2	444943	100
total pervious	112927	25.4
total impervious	332016	74.6

Subcatchment 180b

	sqmeters	
vegetation	2492	0.4
no vegetation	46126	7
formal	599852	86
industrial	52095	7
total1	700565	100
total2	700565	100

total pervious	48618	6.9
total impervious	651947	93.1
Subcatchment 185a		
vegetation	94849	30
no vegetation	8254	3
formal	215869	68
total1	318971	100
total2	318971	100
total pervious	94849	29.7
total impervious	215869	67.7
Subcatchment 185b		
	sqmeters	
vegetation	214586	53
formal	140174	35
industrial	51415	13
total1	406176	100
total2	406175	100
total pervious	214586	52.8
total impervious	191590	47.2
Subcatchment 190		
	sqmeters	
vegetation	3355270	88.6
no vegetation	288859	8
industrial	144266	4
total1	3788395	100
total2	3788395	100
total pervious	3644129	96.2
total impervious	144266	3.8
Subcatchment 195a		
	sqmeters	
vegetation	172541	91
no vegetation	16043	8
industrial	1715	1
total1	190299	100
total2	190299	100
total pervious	188584	99.1
total impervious	1715	0.9
Subcatchment 195b		
	sqmeters	
vegetation	373274	93
no vegetation	14344	4
industrial	12301	3
total1	399919	100
total2	399919	100
total pervious	387618	96.9
total impervious	12301	3.1

APPENDIX C3

BASED ON 1933 PHOTOGRAPHY

RESULTS OF LANDUSE CLASSIFICATION ANALYSIS OF SUBCATCHMENTS IN THE LOTUS RIVER CATCHMENT BASED ON 1933 PHOTOGRAPHY

Note 1.Total area values indicated by an 1 is a summation of areas for which imagery was available
Note 2.Total area values indicated by an 2 is the total subcatchment area.
Note 3. Percentages have been calculated using total1.
Note 4. Where the cultivated land constitutes the major area of a subcatchment,
this value has been calculated as a balance of total1 and total2.
Note 5. The "industrial" category includes farming buildings in the predominantly farming subcatchments
includes industrial aswell
Note 6 The no vegetation category refers to open vacant land which
bears no vegetation or or land uses.
Note 7. The vegetation category refers to cultivated,

Subcatchment 101

	Square meters	Percentages
vegetation	926840	72
no vegetation	304171	24
industrial	50037	4
total1	1281048	100
total2	1281048	100
total pervious	1231011	96.1
total impervious	50037	3.9

Subcatchment 105

	sqmeters	Percentages
vegetation	436562	73
no vegetation	165264	27
total1	601826	100
total2	601826	100
total pervious	601826	100
total impervious	0	0

Subcatchment 110

	sqmeters	percentages
vegetation	894363	49
no vegetation	543801	30
relocation	104881	6
formal	145229	8
serviced sites	129457	7
industrial	19813	1
total1	1837543	100
total2	1837543	100
total pervious	1543045	84.0
total impervious	294498	16.0

Subcatchment 115

	sqmeters	percentages
vegetation	784891	48
no vegetation	99717	6
formal	712021	44
industrial	26347	2
total1	1622976	100

total2	1622976	100
total pervious	884608	54.5
total impervious	738368	45.5
Subcatchment 120		
	sqmeters	percentages
vegetation	803619	53
no vegetation	135962	9
relocated	50032	3
formal	524343	34
industrial	15810	1
total1	1529765	100
total2	1529765	100
total pervious	939581	61.4
total impervious	540152	35.3
Subcatchment 127		
	sqmeters	percentages
vegetation	1772529	97
no vegetation	45029	2
industrial	15960	1
total1	1833518	100
total2	1833518	100
total pervious	1817558	99.1
total impervious	15960	0.9

APPENDIX D

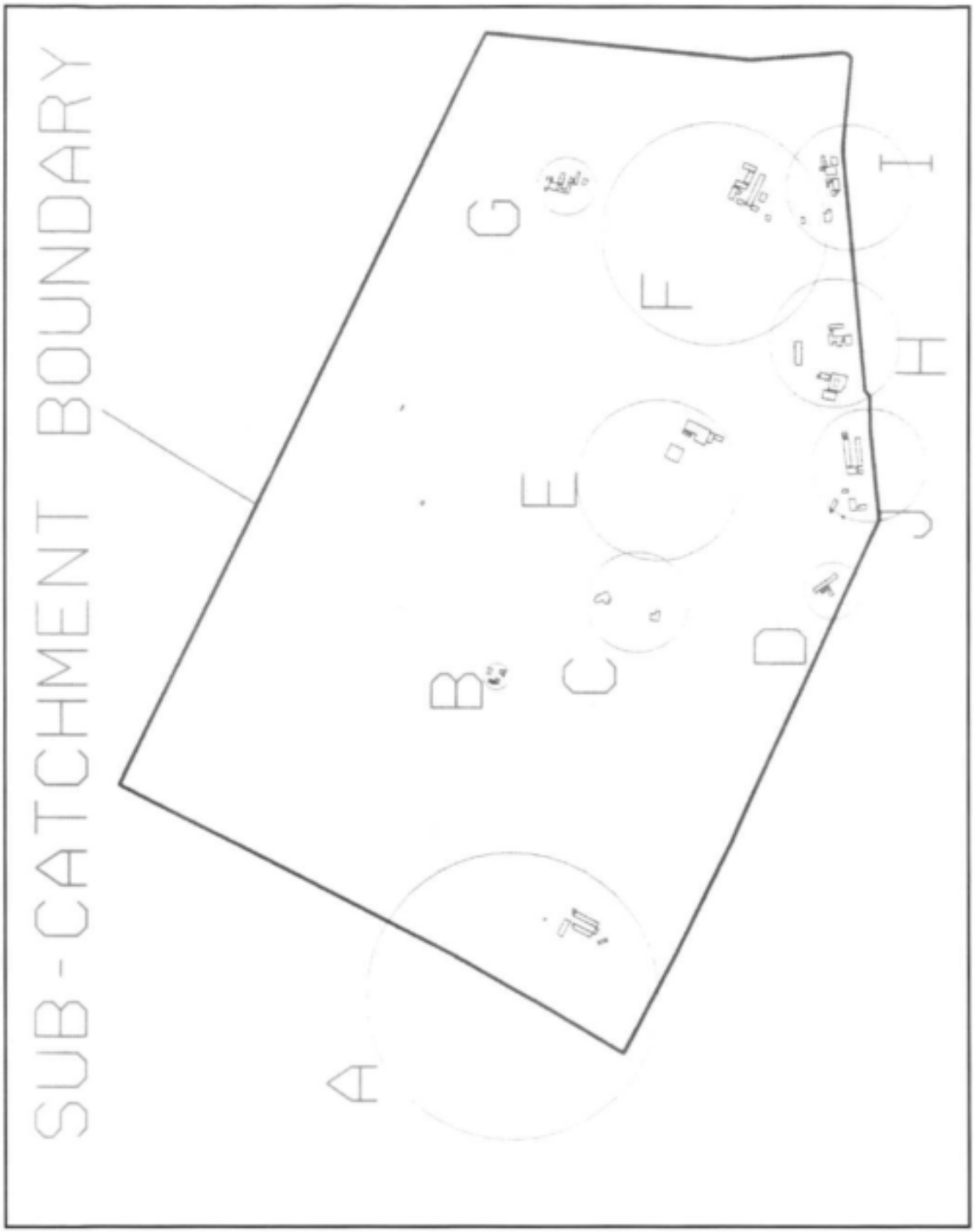


Figure 2.2:
For an estimate of the total area of building in subcatchment 110, a number of building clusters were identified for measurement. For each cluster (A-I), the area of each building was determined.

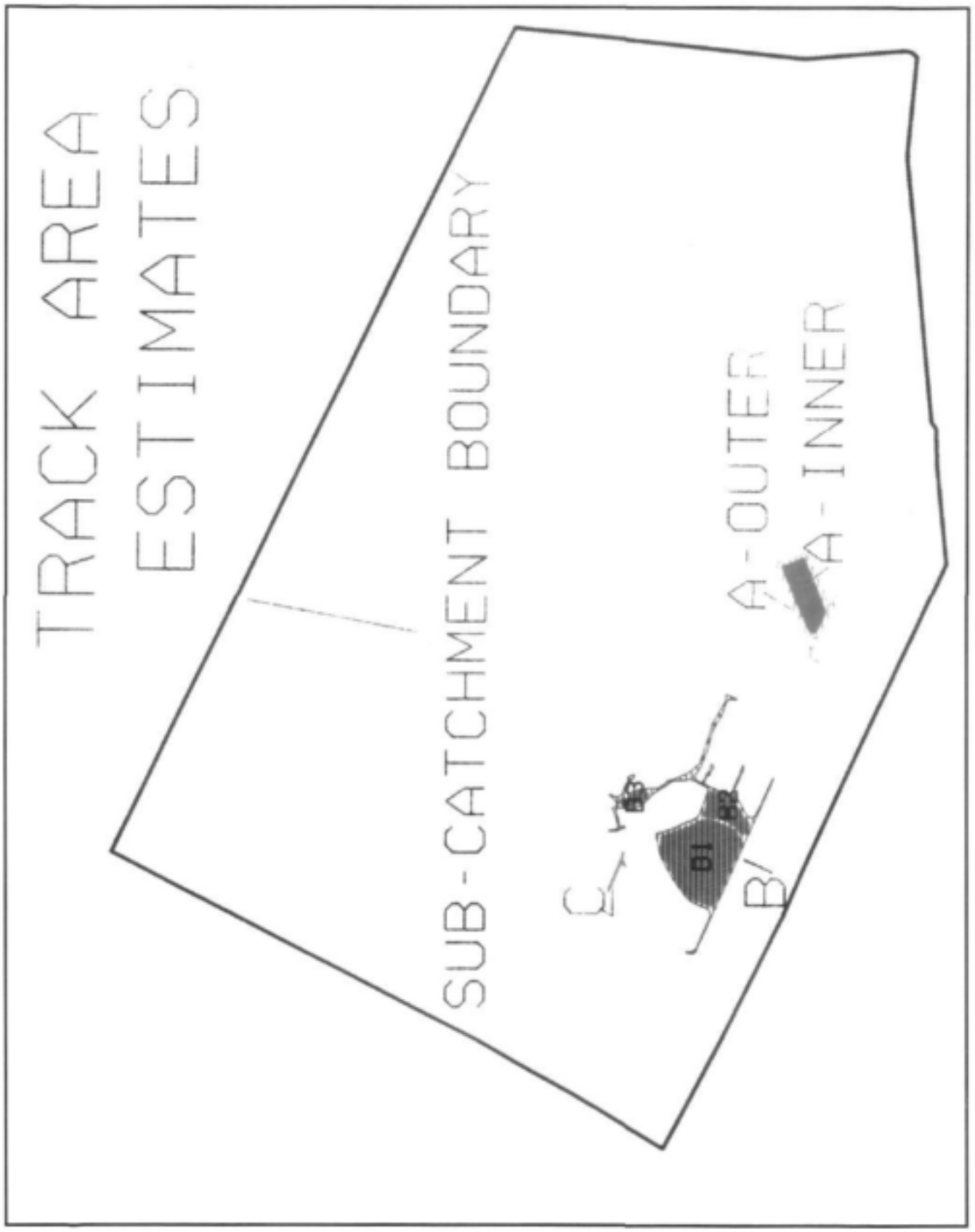


Figure 2.3:
Total area of tracks for subcatchment 110

Figure 2.4.A:
The original informal settlement housing data for sub-catchment 110. Shack polylines (ie. linestrings or lines) are shown in red.

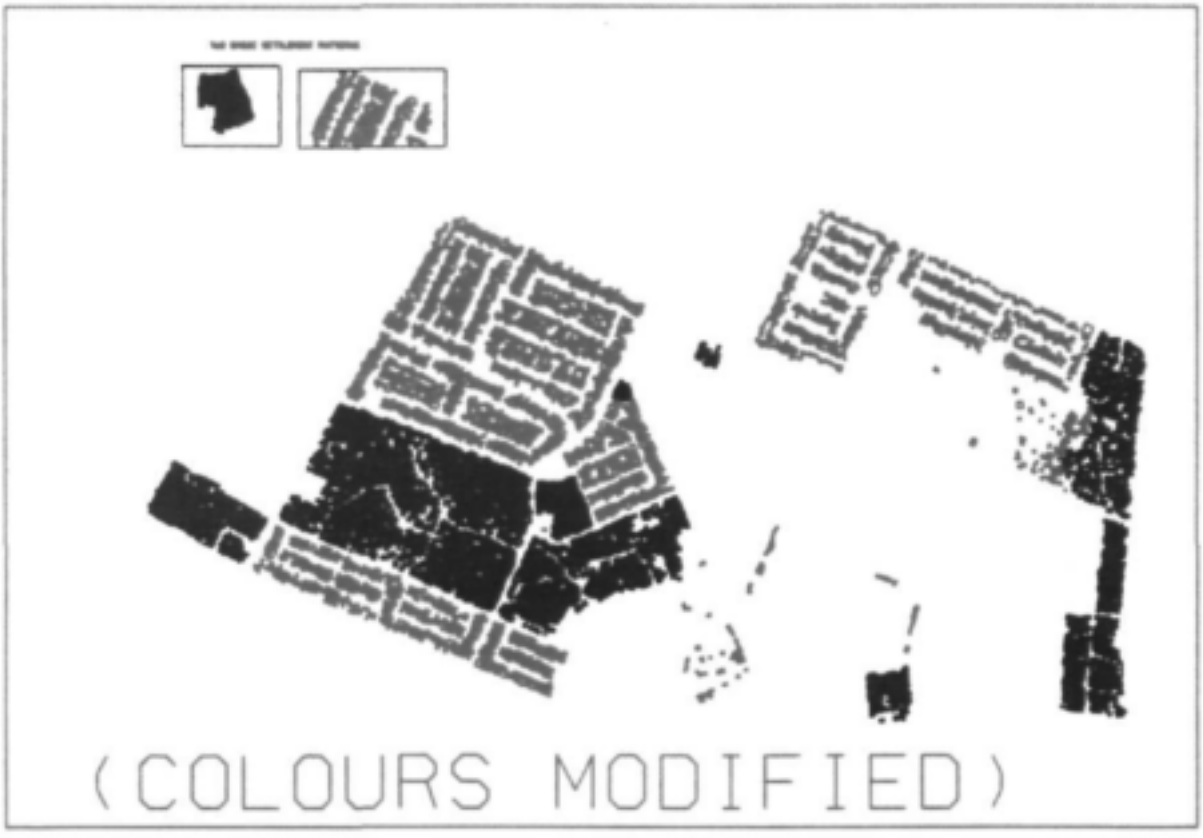


Figure 2.4.B:
A modified version of the original data set. Informal housing areas are comprised of areas which conform to the road layout (shown in magenta) and higher density housing areas which do not conform to any layout (green). For the informal housing area values measured in this study boundaries were simply placed around these two different informal housing area types. The areas measured using these boundaries thus contain open spaces between the shacks.

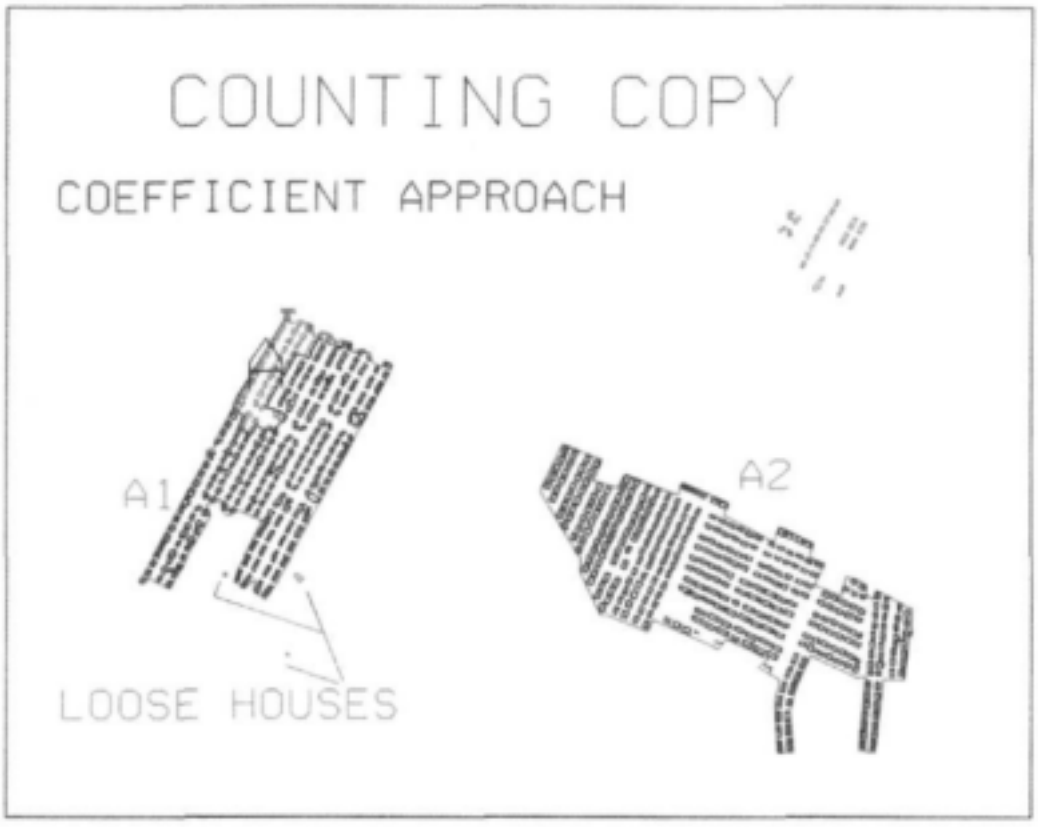


Figure 2.5.A:
The land use data for formal housing areas in this study contains open spaces. One alternative method that was experimented with to obtain formal housing area estimates excluding open space is shown here. This method involved initially measuring the total area (including the open spaces) of a housing area, and subsequently summing up the areas of individual buildings within that housing area. Using these two area estimates for the same housing area a coefficient can be calculated to correct for the open areas included in the approach which has been followed in this work.

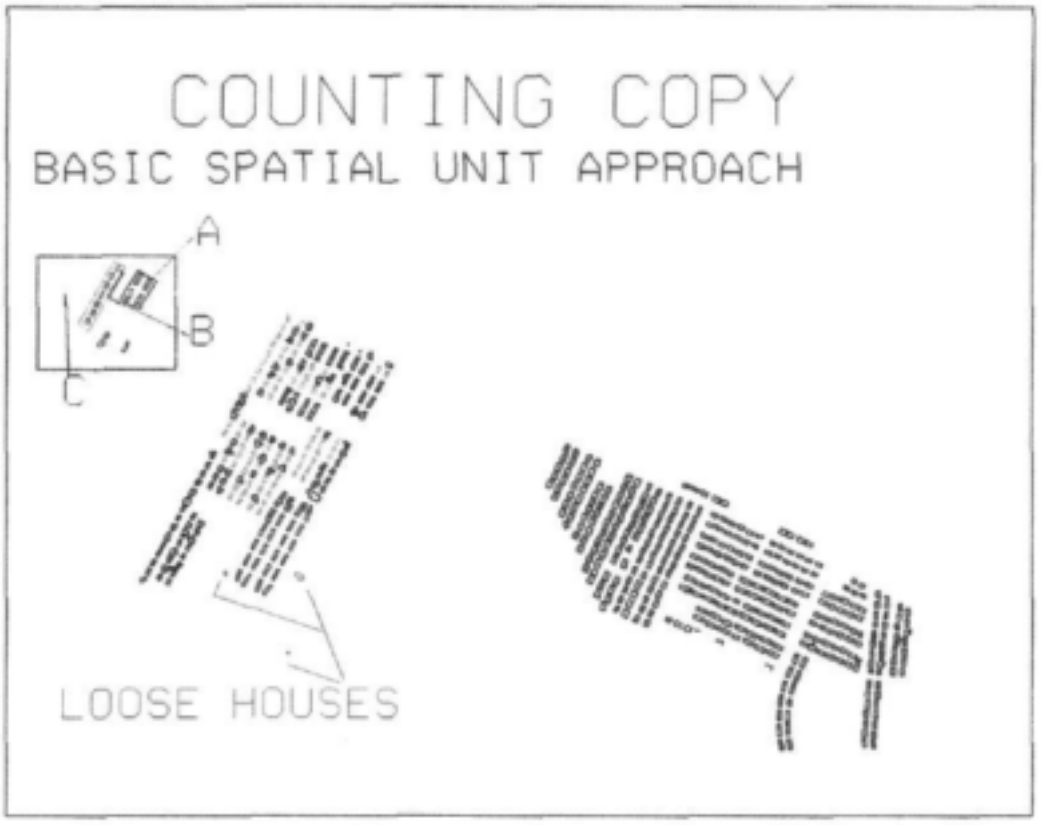


Figure 2.5.B:
A second alternative method that was experimented with involved the recognition that within the formal housing areas, three basic counting units could be applied. The first is a rectangular arrangement of four buildings (A). The second is simply a string of shorter buildings (B). The third represents four of the shorter buildings in an X - type arrangement. By accurately measuring the areas of the buildings within each unit, the counting units can be used to more rapidly obtain area estimates which take into account the open spaces within the housing areas.

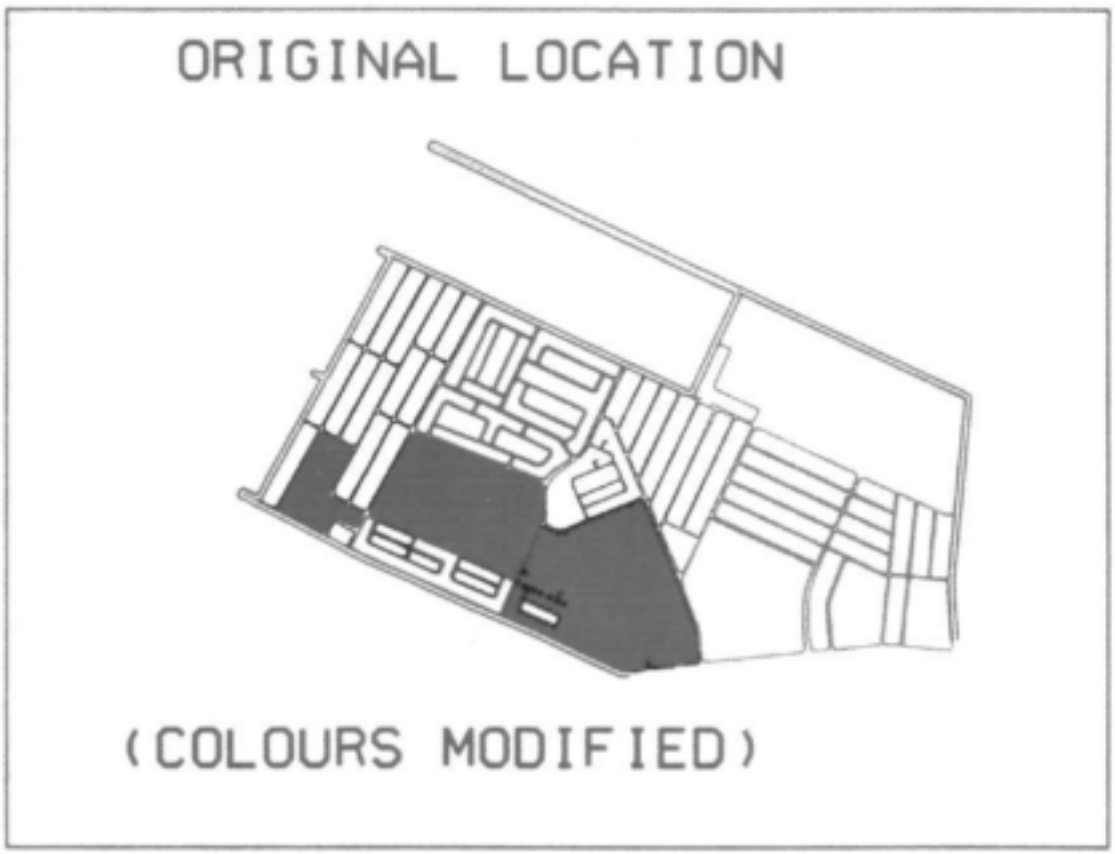


Figure 2.6.A:
The road surface area for sub-catchment 110 was calculated by subtracting the polygon areas of other land use types within the sub-catchment boundary from the total sub-catchment area. Here, in addition to the cemetery (white rectangular area in the north east of the sub-catchment) and the informal housing areas (solid magenta area), five other polygon bearing regions which were identified are shown. In order to carry out the area measurements, the linear street vectors had to be manually converted into street block polygons (a very time consuming process).

Figure 2.6.B:
This diagram shows the maximum hypothetical road area surface. It can be seen that the cemetery has been omitted from this hypothetical surface.

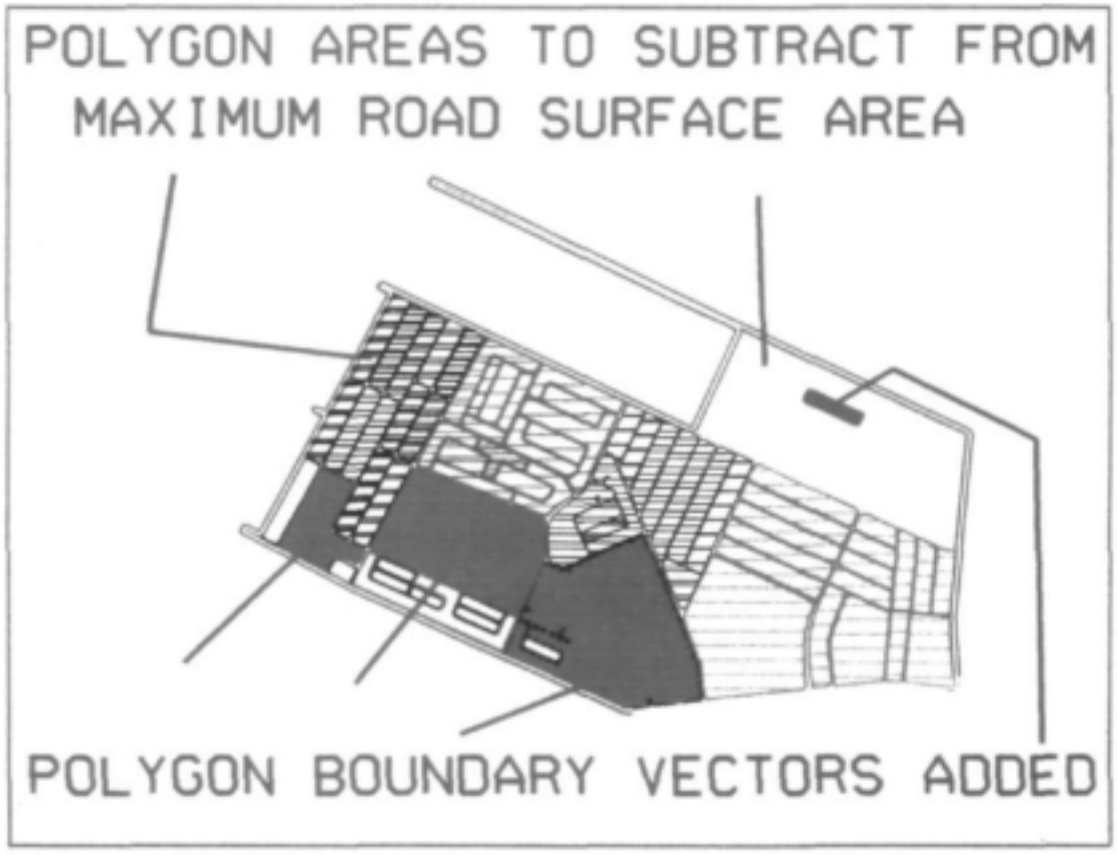
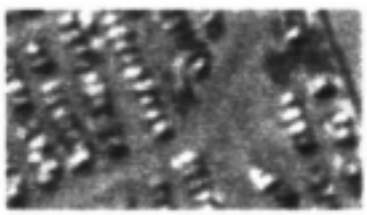
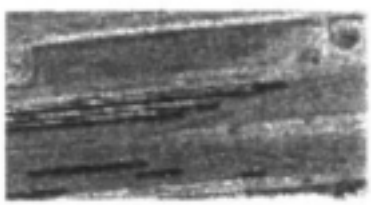
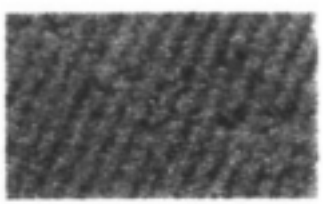


Figure 2.6.C:
This diagram illustrates the polygon areas which were systematically subtracted from the hypothetical road surface area.







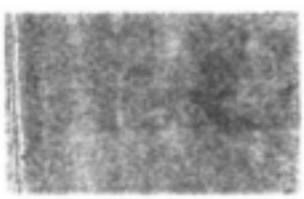


Figure 2.7:
Landuse classes used in the orthophoto-based landuse classification method (method 2) which was employed to capture all of the landuse data for this study. The inserts show the following landuse classes:
1) formal settlement area, 2) informal settlement area, 3) serviced sites, 4) industrial / commercial, 5) parking lot, 6) railways, 7) school, 8) shrubs, 9) grass, 10) vegetation (mixed), 11) cultivated and 12) unvegetated open space. A number of ephemeral water bodies are also visible on insert 12)

APPENDIX E

LIST OF CONSULTANTS' REPORTS ON THE LOTUS RIVER

CONSULTANTS' REPORTS

- Hill Kaplan Scott (HKS) (1983) "Little Lotus River - Princess Vlei/Rondevlei Drainage system"
- HKS (1983) "Lotus River Flood Study - Interim Report"
- HKS (1984) "Zeekoe Drainage System Flood Study - Volume 1"

  [This report included 1 in 50 year flood lines for the system. It investigated and made recommendations for the improvement and additions to the drainage system of the Lotus River and adjacent streams draining into Zeekoevlei. This included the construction of stormwater detention ponds and the preservation of natural ponding areas.]
- HKS (1987) "Lotus River - Philippi Stormwater system"
- HKS (1987) "Lotus River Canal - Vygekraal Road detention ponds - Soils Investigation"
- HKS (1988) "Lotus River Canal - Apportionment of Costs"

  [This report detailed (then) local authority boundaries and sub-catchments and the proposed share of capital and maintenance costs of each reach for each local authority.]
- HKS (1988) "Lotus River Canal Upgrading - Duinefontein Road to Vygekraal Road"
- HKS (1988) "Lotus River Canal - New Ottery Road culvert upgrade - Design Report and Cost estimate"
- HKS (1988) "Lotus River Canal Upgrading - Foundation Investigation"
- HKS (1994) "Lotus River Canal Upgrading - Preliminary Design Report"

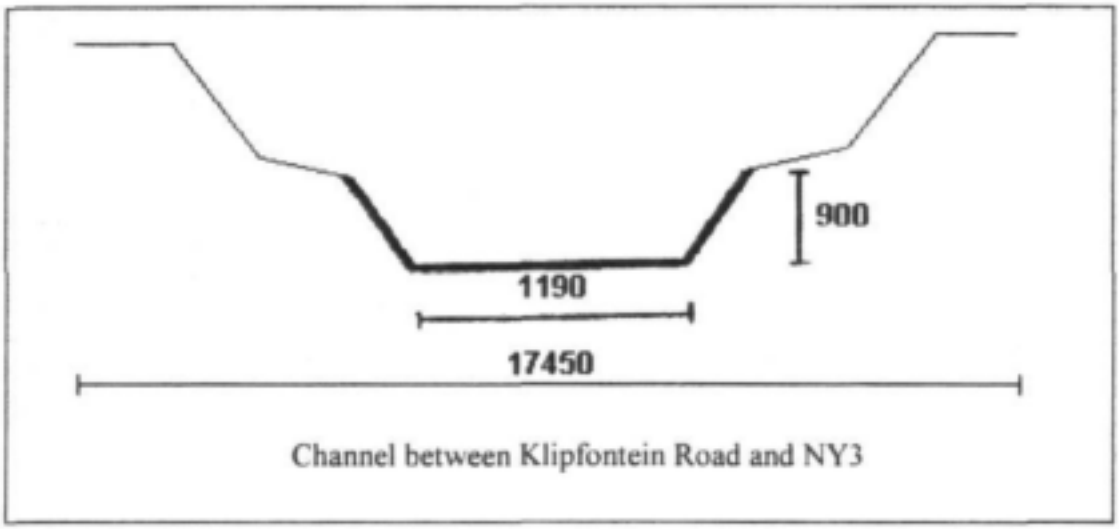
  [This report established the 1 in 50 flood levels, longitudinal canal profile, required canal cross-sections. It also detailed the location, size and control structures for detention storage and cost estimates for phased canal upgrading. This report details the hydraulics and hydrology of the Lotus River Canal catchment. It also identifies sub-catchments and their associated landuse patterns.]
- Gibb Africa (1996) "Lotus River Canal Upgrading - Phase 7 Canal Upgrading Vanguard Drive to Lansdowne Road"

APPENDIX F

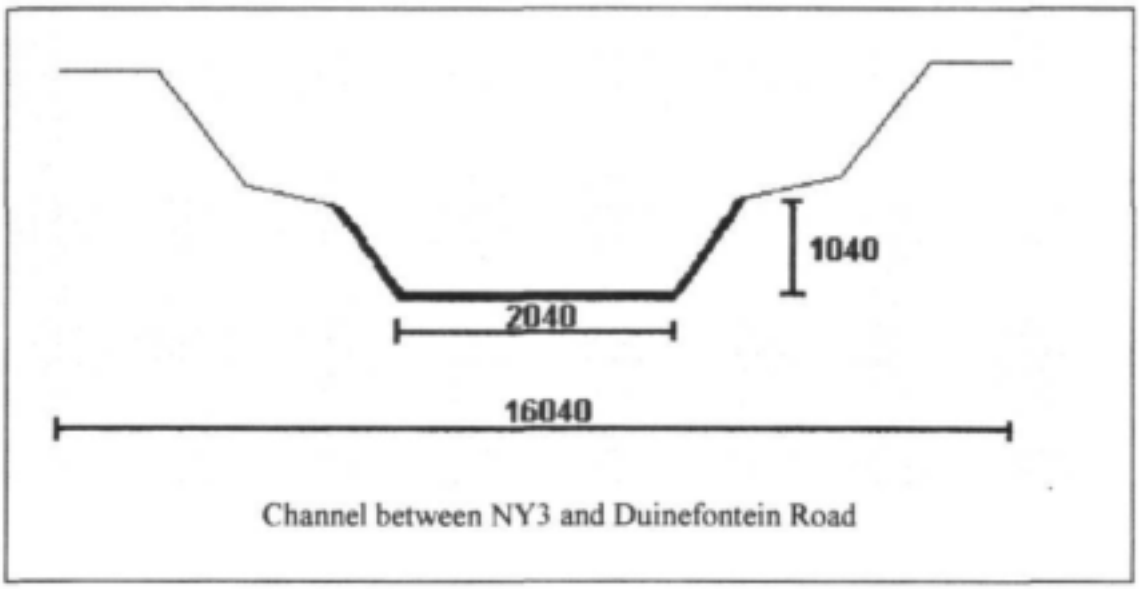
CROSS-SECTIONS FROM BELOW DUINEFONTEIN ROAD TO ZEEKOEVLEI

Great Lotus River profiles

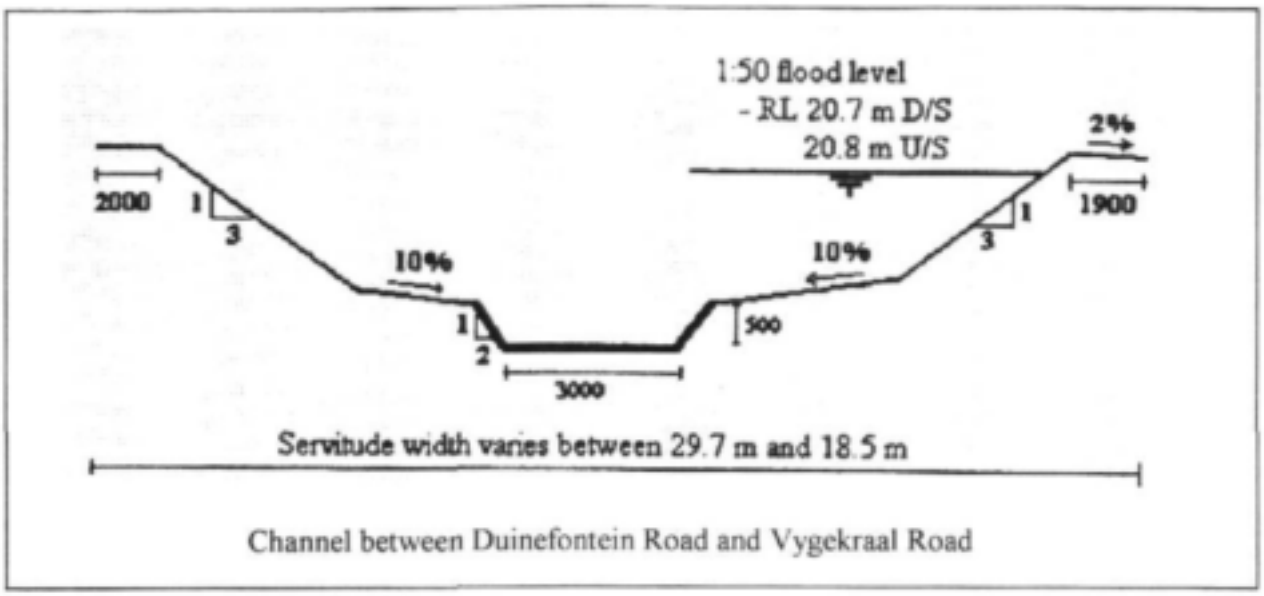
Upgrading of the Great Lotus River canal has focussed principally on the canal from below Duinefontein Road to Zeekoevlei. The profiles below are thus representations taken from design drawings completed by Gibb Africa as part of this upgrading. The section of canal in Nyanga/Gugulethu from the N2 to Duinefontein Road was historically part of Ikapa and thus ignored in the above proposed upgradings. The two profiles below, in Nyanga/Gugulethu were taken from a channel survey completed for Stewart Scott as part of stormwater upgrading in Nyanga.



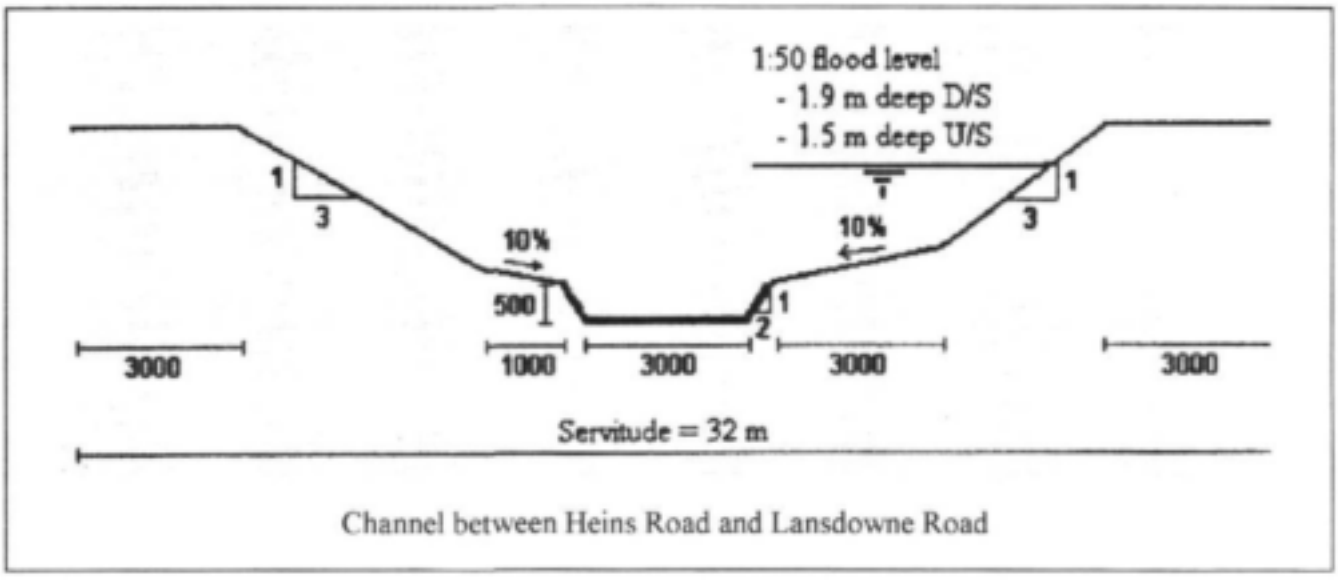
Channel between Klipfontein Road and NY3



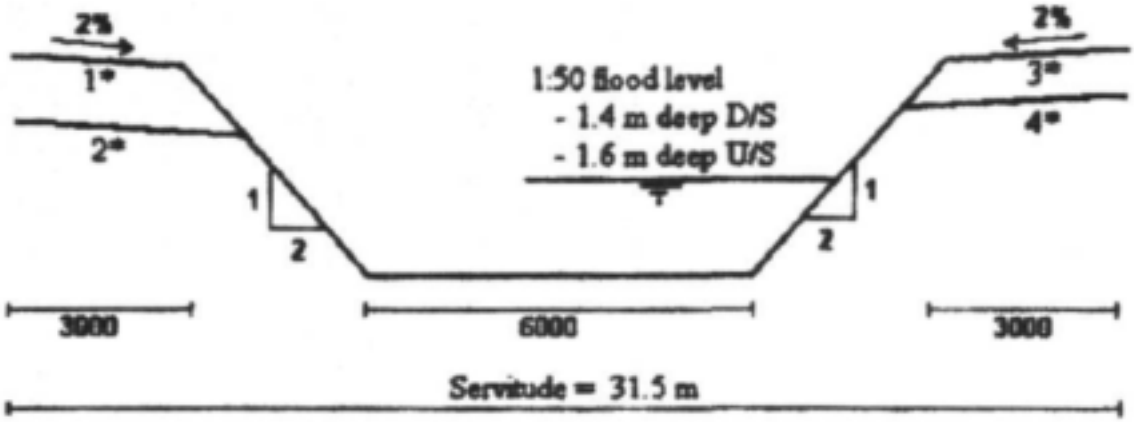
Channel between NY3 and Duinefontein Road



Channel between Duinefontein Road and Vygekraal Road

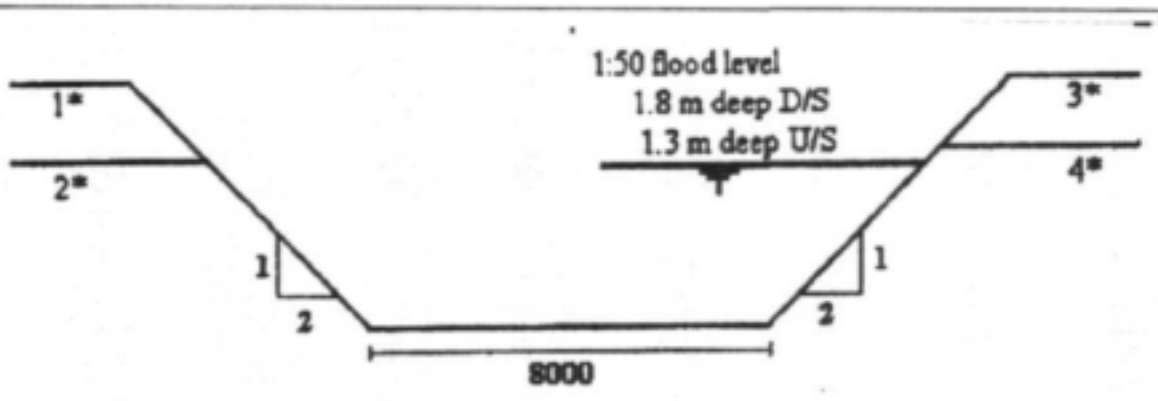


Channel between Heins Road and Lansdowne Road



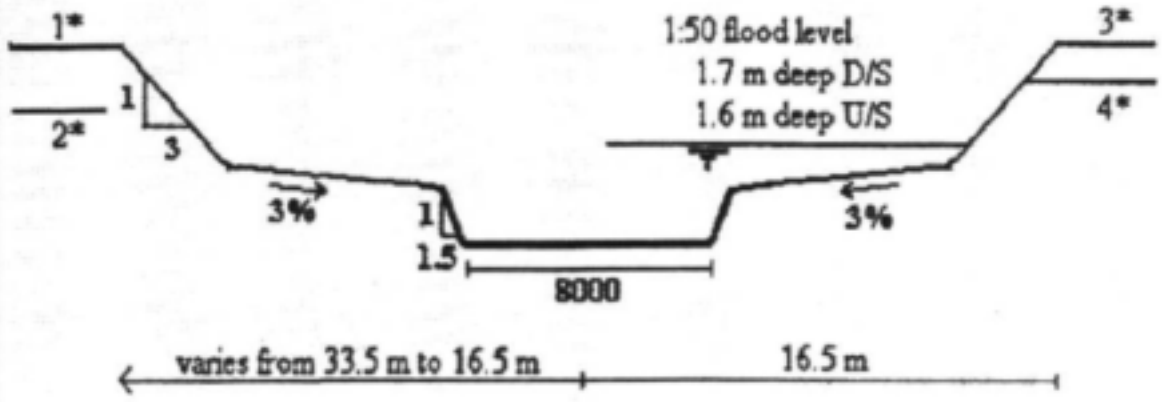
1* U/S groundlevel = 3.5 m above invert 2* D/S groundlevel = 1.9 m above invert
3* U/S groundlevel = 3.5 m above invert 4* D/S groundlevel = 2.0 m above invert

Channel between Lansdowne Road and New Strandfontein Road



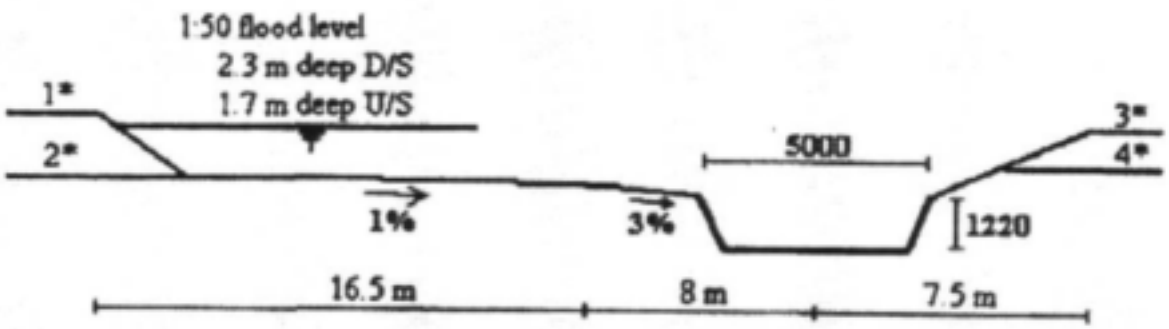
1* U/S groundlevel = 3.5 m above invert 2* D/S groundlevel = 1.9 m above invert
3* U/S groundlevel = 3.5 m above invert 4* D/S groundlevel = 2.0 m above invert

Channel between New Strandfontein Road and New Ottery Road

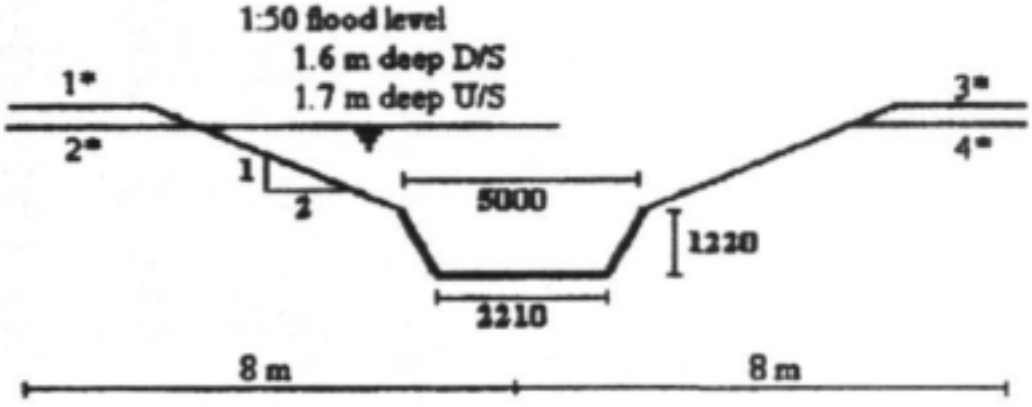


1* U/S groundlevel = 2.4 m above invert 2* D/S groundlevel = 1.3 m above invert
3* U/S groundlevel = 2.4 m above invert 4* D/S groundlevel = 1.6 m above invert

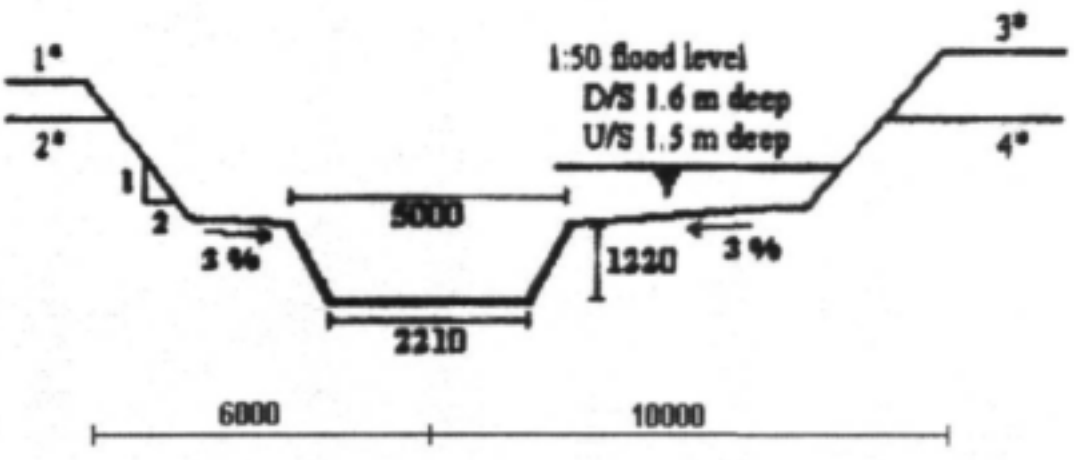
Channel between New Ottery Road and CTM Woodlands canal confluence



Channel between CTM Woodlands canal confluence and Ottery Road

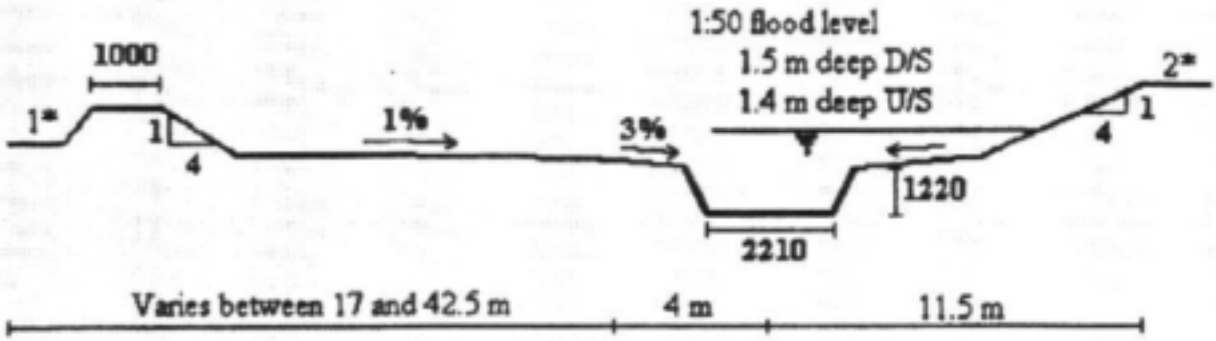


Channel between Ottery Road and Sunset Park Detention Pond

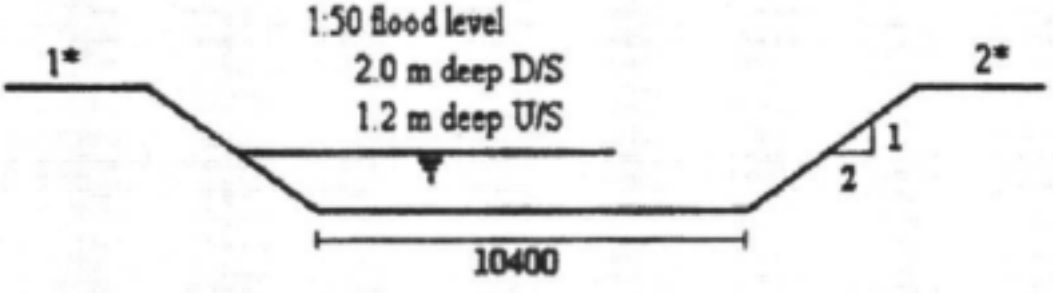


1* U/S groundlevel = 2.7 m above invert 2* D/S groundlevel = 2.5 m above invert
3* U/S groundlevel = 2.8 m above invert 4* D/S groundlevel = 2.5 m above invert

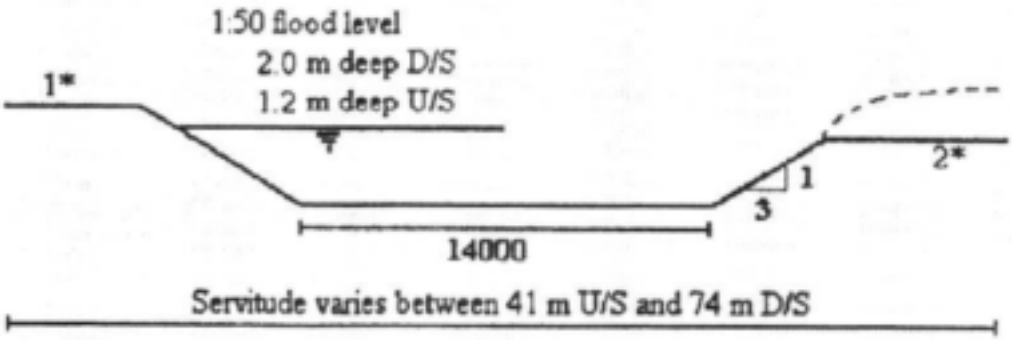
Channel between Sunset Park Detention Pond and Klip Road



Channel from Klip Road to Seventh Avenue



Channel between Seventh Avenue and Eighth Avenue



Channel between Eighth Avenue and Fisherman's Walk

APPENDIX G

ANALYTICAL RESULTS OF WATER SAMPLING:

GREAT LOTUS RIVER

LITTLE LOTUS RIVER

ANALYTICAL RESULTS FROM SAMPLING PROGRAMME - GREAT LOTUS RIVER

| | | |

Metric	1 002 (N)		2 446 Above HT1		3 002 In HT1 outlet		4 660 Below HT1		4 (a) Below Ogallala Lakeway Inn		5 066 Above Pidgeo East outlet		6 558 In Pidgeo East outlet		7 605 Below Pidgeo East outlet		8 076 Above Vigabrook Dif		9 004 In Vigabrook Dif		10 604 Below Vigabrook Dif	
	[ ] (mg/L)	Flux (mg/s)	[ ] (mg/L)	Flux (mg/s)	[ ] (mg/L)	Flux (mg/s)	[ ] (mg/L)	Flux (mg/s)	[ ] (mg/L)	Flux (mg/s)	[ ] (mg/L)	Flux (mg/s)	[ ] (mg/L)	Flux (mg/s)	[ ] (mg/L)	Flux (mg/s)	[ ] (mg/L)	Flux (mg/s)	[ ] (mg/L)	Flux (mg/s)	[ ] (mg/L)	Flux (mg/s)
TPOM (mg/l 85)	3 160	280 461	14 527	1310 851	31 321	1736 849	24 439	1528 300	17 135	826 918	14 331	2961 629	13 976	6263 629	15 751	4542 792	13 014	4501 671	11 051	482 049	12 043	5291 869
TP (mg/l P)	0 208	18 456	0 566	28 717	1 478	68 284	1 156	156 388	0 664	137 413	0 472	136 245	0 284	25 668	0 194	103 545	0 552	190 819	0 183	47 706	0 551	233 146
DIP (mg/l P)	0 270	15 304	0 233	10 082	0 763	35 603	0 667	43 477	0 362	83 514	0 377	68 593	0 207	19 447	0 158	87 760	0 481	158 333	0 148	45 836	0 488	196 524
COD (mg/l O2)	99 620	260 058	83 259	3643 504	138 936	5365 741	78 259	10343 753	62 316	13633 488	57 660	10340 679	60 309	5785 628	59 800	34855 775	58 730	39089 130	58 760	3972 660	64 864	25923 644
TSS (mg/L	-	#VALUE!	4 456	627 126	39 203	1824 359	14 859	1274 758	5 658	1797 629	16 156	1941 455	1 758	542 903	8 856	3448 015	5 374	1851 140	8 856	394 060	6 504	1756 981
TVS (mg/L	55 259	5081 836	36 178	5856 666	75 766	9429 856	61 956	9825 256	75 936	11569 367	56 864	10129 574	65 666	6664 881	60 056	37427 154	58 736	22018 536	54 650	2284 600	64 864	26836 762
EC (mS/m)	75 864		85 866		81 966		84 534		84 668		81 865		126 560		94 809		102 458		96 766		115 760	

Metric	10 (a) Lauderome Road culvert		11 066 Springfield Road		12 006 Above CCC		13 668 In CCC		14 966 Below CCC		15 089 Above Elg Road		16 809 In Pidgeo outlet		17 080 Below Elg Road		18 566 Tomah Avenue	
	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)
	14 673	5975 787	11 294	9348 284	10 533	8569 594	9 630	4518 826	9 323	6643 228	9 159	7188 857	7 687	468 791	5 408	7802 660	5 661	8689 714
	0 760	326 983	0 949	911 817	0 934	589 751	0 284	21 608	0 167	946 329	1 901	368 942	1 560	91 416	1 947	864 581	1 342	887 704
	0 643	277 829	0 823	661 384	0 902	577 127	0 249	24 189	0 167	946 329	1 560	91 416	1 560	91 416	0 879	778 334	0 968	834 078
	64 209	27633 308	68 830	87 05 934	67 209	41329 936	51 950	8934 273	70 956	50702 259	74 209	56958 153	56 756	5513 629	34 260	61156 868	70 164	62568 868
	8 806	3862 209	8 559	9426 564	4 566	3850 400	1 399	326 591	5 656	4082 173	7 550	6830 066	5 200	538 956	7 856	6565 561	6 306	5756 647
	56 956	24677 123	62 166	82703 443	48 604	29644 695	49 966	9895 280	54 956	38854 987	52 859	39861 640	44 536	3697 362	47 953	78823 178	48 650	41858 864
	130 380		87 260		74 704		27 136		23 640		84 569		79 609		83 685		80 166	

Metric	1 400 (N)		2 900 Above HT1		3 308 In HT1 outlet		4 600 Below HT1		4 (a) Below Ogallala Lakeway Inn		5 066 Above Pidgeo East outlet		6 004 In Pidgeo East outlet		7 400 Below Pidgeo East outlet		8 004 Above Vigabrook Dif		9 000 In Vigabrook Dif		10 060 Below Vigabrook Dif	
	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)
TPOM (mg/l 85)	3 467	155 361	13 761	1197 555	35 226	1949 604	23 477	2135 057	26 951	2644 648	20 370	2012 527	17 156	1232 798	17 611	3682 311	17 712	3861 107	13 222	621 604	18 143	4307 250
TP (mg/l P)	0 421	18 761	0 756	58 415	1 256	70 220	1 425	166 476	0 774	82 206	0 434	90 964	0 262	21 311	0 464	96 904	0 494	107 652	0 585	51 635	0 709	184 751
DIP (mg/l P)	0 372	16 643	0 743	51 588	1 279	61 340	0 611	59 879	0 348	52 249	0 275	30 284	0 207	16 349	0 297	61 996	0 316	69 024	0 761	35 764	0 534	136 159
COD (mg/l O2)	62 600	1941 421	50 400	3332 260	74 600	2894 209	75 256	7264 700	52 400	7439 673	56 700	7864 328	62 250	5456 845	68 650	90 072 160	58 060	13644 660	80 950	3945 450	64 754	16888 456
TSS (mg/L	1 456	75 633	2 806	154 356	21 200	848 800	13 206	959 400	7 856	1016 176	8 456	902 617	4 956	384 932	9 560	1259 595	7 856	1751 366	5 650	283 556	7 756	2021 356
TVS (mg/L	76 956	5043 766	52 556	2890 256	81 866	5273 006	63 256	6138 506	79 600	8374 751	62 700	5624 175	66 206	3757 836	65 656	9434 113	61 150	8752 280	62 566	1967 560	65 666	11756 873
EC (mS/m)	85 099		115 206		91 866		114 166		94 766		91 666		132 966		108 766		108 166		111 366		136 666	

Metric	10 (a) Lauderome Road culvert		11 066 Springfield Road		12 006 Above CCC		13 668 In CCC		14 966 Below CCC		15 089 Above Elg Road		16 809 In Pidgeo outlet		17 080 Below Elg Road		18 566 Tomah Avenue	
	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)
	15 015	5885 896	34 160	45 15 452	12 717	4665 658	5 343	259 674	11 961	4523 848	13 949	4534 478	8 870	644 952	12 060	5138 932	10 266	1135 836
	0 563	151 966	0 677	263 130	0 842	263 653	0 163	8 673	0 128	29 103	0 750	321 603	1 251	28 160	0 552	336 353	0 761	162 639
	0 467	126 647	0 572	183 266	0 751	123 683	0 139	7 682	0 103	23 534	0 627	256 416	1 100	25 139	0 648	280 531	0 642	291 057
	34 000	1396 838	72 800	36885 243	61 556	19988 236	79 400	2891 536	61 333	22134 963	67 600	27453 128	80 650	5867 629	71 360	36889 696	64 254	7602 578
	4 566	2441 536	3 556	1948 284	4 206	1320 006	1 760	69 614	10 350	7620 467	4 506	3834 358	3 650	61 207	4 806	1862 873	6 706	2141 725
	45 166	1 1681 760	59 650	47861 650	50 156	16742 256	79 136	8241 154	71 150	18194 983	56 806	23052 598	87 856	9810 854	61 560	9334 366	52 400	2 5989 687
	104 300		106 806		111 866		29 336		84 766		99 806		77 406	9810 854	84 666		81 366	

Metric	1 300 (N)		2 356 Above HT1		3 990 In HT1 outlet		4 606 Below HT1		4 (a) Below Ogallala Lakeway Inn		5 066 Above Pidgeo East outlet		6 556 In Pidgeo East outlet		7 660 Below Pidgeo East outlet		8 606 Above Vigabrook Dif		9 656 In Vigabrook Dif		10 656 Below Vigabrook Dif	
	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)
TPOM (mg/l 85)	3 664	513 527	20 725	1754 656	25 156	715 704	22 576	2013 849	18 336	2294 976	17 497	1942 167	14 564	985 436	13 454	2889 821	13 471	3862 673	11 577	443 084	14 751	5271 784
TP (mg/l P)	0 573	18 159	1 551	79 185	0 249	35 025	1 623	92 675	0 615	70 229	0 617	68 687	0 501	23 026	0 563	91 067	0 464	83 666	1 164	46 540	0 787	139 280
DIP (mg/l P)	0 488	13 348	1 303	26 737	0 344	28 556	0 687	55 156	0 457	52 329	0 643	49 346	0 228	15 958	0 347	62 643	0 351	64 935	1 162	46 460	0 443	95 879
COD (mg/l O2)	86 750	1349 572	62 750	4263 560	84 850	9835 709	67 206	6048 858	51 100	5835 258	53 950	7958 450	59 956	2785 229	64 400	9041 254	60 156	9960 758	85 606	3344 000	77 136	13873 843
TSS (mg/L	2 956	66 276	24 860	1636 866	24 750	687 756	37 856	2461 506	32 150	1387 664	43 565	1436 361	8 560	454 795	11 950	3417 756	17 906	3260 506	9 350	314 650	19 456	6234 604
TVS (mg/L	#VALUE!	#VALUE!	60 554	4626 366	77 240	2383 611	93 956	5376 506	92 900	4046 565	93 600	4763 660	76 456	2544 943	79 206	12718 812	90 256	8686 256	82 756	2763 089	91 806	9256 961
EC (mS/m)	91 699		104 756		98 866		134 966		93 206		93 966		131 766		106 866		108 766		105 366		136 566	

Metric	10 (a) Lauderome Road culvert		11 066 Springfield Road		12 006 Above CCC		13 668 In CCC		14 966 Below CCC		15 606 Above Elg Road		16 466 In Pidgeo outlet		17 806 Below Elg Road		18 566 Tomah Avenue	
	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)	[ ] (mg/L	Flux (mg/s)
	13 629	3208 435	12 514	9489 613	11 866	2980 756	4 864	181 098	10 618	3181 277	9 733	5961 466	9 621	19 864	9 473	8360 643	9 274	9414 589
	0 586	153 843	0 644	353 448	0 736	203 422	0 229	9 295	0 782	235 333	0 682	504 096	1 252	9 616	0 899	826 476	0 990	931 882
	0 552	123 403	0 526	451 446	0 597	186 903	0 283	7 961	0 609	183 037	0 750	250 899	1 252	9 616	0 726	258 512	0 760	272 849
	91 256	12772 487	73 456	47552 692	57 456	15187 613	75 150	2628 726	57 650	17526 961	63 256	24758 819	87 366	498 956	87 256	25593 854	84 856	27992 721
	12 156	2848 896	8 556	2448 806	7 156	1827 066	4 856	189 613	13 366	4457 479	8 656	2872 977	3 566	28 656	7 766	2947 826	11 156	4329 896
	81 756	18854 561	58 256	8391 366	28 656	6274 856	69 766	3716 556	66 456	5944 216	52 156	11587 629	52 856	442 864		#VALUE!	79 856	22116 598
	104 800		103 400		111 266		46 466		97 566		94 156		76 866		93 156		94 966	

| | | |

		1 660		2 090		3 960		4 350		4 (a)		5 990		6 (69		7 (80		8 060		9 990		10 (80	
		(M)		Above (ET)		In (ET) outlet		Below (ET)		Below (Ogallala (subsea loss)		Above (Valley East outlet		In (Valley East inlet		Below (Valley East outlet)		Above (Ygnacio) (D		In (Ygnacio) (D		Below (Ygnacio) (D	
		[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux
		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
TDOH (mg/l H)		1 695	56 431	28 376	945 414	20 782	328 373	23 512	1 463 352	17 207	1403 834	16 377	1 167 370	12 638	447 127	11 958	1 744 688	9 660	0 000	8 080	0 000	8 190	1 638 640
TP (mg/l P)		0 441	9 193	0 792	23 784	1 439	22 459	0 874	59 956	0 627	66 185	0 751	52 256	0 291	16 127	0 491	41 551	0 000	0 000	0 000	0 000	0 516	62 252
DIP (mg/l P)		0 382	7 181	0 299	9 964	1 254	19 815	0 859	58 824	0 486	39 709	0 439	50 940	0 253	15 843	0 359	42 851	0 000	0 000	0 000	0 000	0 587	46 689
COD (mg/l O)		71 850	559 635	58 850	3287 180	85 858	1858 134	87 460	4449 681	60 950	4884 769	62 359	4346 244	54 730	3571 388	51 550	6443 730	0 000	0 000	0 000	0 000	94 130	9332 982
TSS (mg/l)		4 160	134 947	13 856	461 134	21 858	942 097	36 580	1867 488	31 980	930 960	32 059	994 253	9 599	390 220	8 858	1381 230	0 000	0 000	0 000	0 000	58 500	1264 764
TVS (mg/l)		54 804	942 701	41 450	3047 822	61 856	973 756	48 660	2333 863	71 700	6049 912	72 200	5023 798	36 500	2370 608	41 470	7681 230	0 000	0 000	0 000	0 000	77 130	6868 780
EC (mS/m)		193 300		136 700		132 300		136 700		123 600		122 300		279 200		260 700		0 000		0 000		140 800	

		11 (a)		11 350		12 (40		13 (60		14 (80		15 (80		16 (60		17 (90		18 (60	
		Lansdowne Road culvert		Springfield Road		Above (DD)		In (DD)		Below (DD)		Above Elg Road		In Pelagic outlet		Below Elg Road		Seventh Avenue	
		[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux
		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
		12 950	1034 487	10 418	1287 651	9 (32	1048 139	3 599	25 (93	8 (40	1004 734	7 488	1019 880	#VALUE!	#VALUE!	6 499	821 472	4 811	978 934
		9 (22	62 595	9 (84	63 808	5 (32	86 374	3 084	6 472	5 766	94 425	5 772	104 220	3 (17	5 982	5 750	104 (27	4 726	104 342
		9 (28	36 986	8 (96	48 555	5 (34	63 608	3 082	6 (64	6 (38	63 836	6 (08	68 (13	5 (62	3 808	5 (49	69 623	4 648	64 (70
		74 (29	6683 895	58 (04	7827 (76	84 856	7632 506	43 (46	433 760	64 (53	7643 (04	71 900	9706 566	64 806	674 (66	57 906	8123 (67	44 604	6183 938
		27 (24	5286 489	24 (39	3112 643	34 856	3280 506	2 094	14 094	27 (39	1948 298	19 900	1776 606	8 (39	40 758	11 (59	3609 464	22 854	3283 942
		48 209	7729 (69	50 (24	4234 (67	73 706	4773 (08	15 760	989 966	49 (84	6144 878	56 476	7661 (76	36 836	184 (70	53 (59	8174 (06	56 264	8654 999
		140 (99		142 806		136 706		72 560		134 (08		130 306		122 (06		129 (90		127 760	

		1 600		2 (90		3 (00		4 (90		4 (a)		5 (84		6 (90		7 (80		8 (60		9 (90		10 (84	
		(M)		Above (ET)		In (ET) outlet		Below (ET)		Below (Ogallala (subsea loss)		Above (Valley East outlet		In (Valley East inlet		Below (Valley East outlet)		Above (Ygnacio) (D		In (Ygnacio) (D		Below (Ygnacio) (D	
		[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux
		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
TP (mg/l P)		1 243	43 877	24 874	699 (28	18 750	277 478	20 430	887 403	13 697	841 (97	11 856	652 (80	12 (60	509 380	12 442	1368 892	9 (84	0 000	9 (00	0 000	10 173	1 (40 549
DP (mg/l P)		0 940	13 772	0 442	12 (04	1 (27	22 (60	1 (80	50 (99	0 (69	41 (91	0 (16	28 (53	0 (67	34 (80	0 (47	78 (84	0 (84	0 (00	0 (80	0 (00	0 (40	45 (79
DIP (mg/l P)		0 (31	4 (69	0 (95	1 (44	0 (49	21 (61	0 (71	36 (48	0 (18	19 (32	0 (30	16 (62	0 (35	12 (22	0 (47	34 (43	0 (84	0 (00	0 (80	0 (00	0 (21	22 (85
COD (mg/l O)		94 (69	1872 (08	100 (40	2897 (06	75 (90	1243 (54	86 (76	3826 (64	69 (43	4243 (71	63 (80	7700 (60	80 (60	5216 (63	55 (08	5216 (63	0 (84	0 (00	0 (80	0 (00	68 (04	6970 (80
TSS (mg/l)		11 (04	149 (14	3 (36	144 (08	12 (40	164 (67	13 (40	489 (44	30 (80	432 (48	9 (04	130 (60	3 (90	140 (40	3 (60	317 (46	0 (60	0 (00	0 (80	0 (00	9 (04	104 (59
TVS (mg/l)		76 (08	1484 (08	63 (08	1746 (69	36 (60	1204 (08	82 (80	3466 (62	84 (40	3387 (69	68 (60	4824 (60	40 (20	994 (40	71 (20	6760 (96	0 (60	0 (00	0 (80	0 (00	78 (04	8 (40 (40
EC (mS/m)		1 (2 (90		152 (00		127 (60		120 (80		113 (20		114 (00		107 (90		102 (60		0 (00		0 (00		102 (20	

		10 (a)		11 (80		12 (80		13 (90		14 (80		15 (90		16 (80		17 (00		18 (00	
		Lansdowne Road culvert		Springfield Road		Above (DD)		In (DD)		Below (DD)		Above Elg Road		In Pelagic outlet		Below Elg Road		Seventh Avenue	
		[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux
		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
		8 (21	879 (37	7 (08	952 (40	7 (40	868 (60	3 (91	16 (43	5 (49	690 (94	0 (00	0 (0a	0 (00	0 (0a	0 (00	0 (0a	3 (58	478 (07	3 (19	492 (78
		0 (90	6 (58	0 (71	80 (94	0 (78	87 (60	0 (47	0 (83	0 (67	68 (47	0 (00	0 (0a	0 (00	0 (0a	0 (00	0 (0a	0 (82	73 (48	0 (69	66 (58
		0 (20	24 (90	0 (43	51 (31	0 (64	45 (20	0 (35	0 (43	0 (32	40 (82	0 (00	0 (0a	0 (00	0 (0a	0 (00	0 (0a	0 (20	24 (38	0 (24	22 (44
		63 (00	1247 (80	38 (40	7289 (62	39 (00	10758 (90	39 (80	449 (68	47 (40	8364 (18)	0 (00	0 (0a	0 (00	0 (0a	0 (00	0 (0a	340 (40	6826 (43	35 (60	1139 (72)
		19 (50	2076 (83	12 (80	1621 (07	21 (40	2798 (00	1 (70	8 (79	21 (60	2640 (58	0 (00	0 (0a	0 (00	0 (0a	0 (00	0 (0a	21 (80	2753 (43	22 (30	2847 (17	
		84 (20	9863 (13	67 (40	10809 (87	87 (70	13100 (90	39 (60	481 (68	70 (30	9368 (58	0 (00	0 (0a	0 (00	0 (0a	0 (00	0 (0a	83 (80	11102 (40	81 (10	10872 (81	
		139 (30		252 (00		248 (60		133 (20		133 (70		0 (00		0 (00		0 (00		130 (40		97 (60			

		1 (00		2 (60		3 (60		4 (90		4 (a)		5 (60		6 (60		7 (60		8 (60		9 (00		10 (60	
		(M)		Above (ET)		In (ET) outlet		Below (ET)		Below (Ogallala (subsea loss)		Above (Valley East outlet		In (Valley East inlet		Below (Valley East outlet)		Above (Ygnacio) (D		In (Ygnacio) (D		Below (Ygnacio) (D	
		[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux
		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
TP (mg/l P)		2 (18	0 (00	25 782	628 (03	14 (74	150 (58	19 (10	686 (42	13 (68	772 (72	12 (82	608 (78	13 (24	521 (31	11 (99	1364 (49	0 (60	0 (00	0 (60	0 (00	11 (79	0 (00
DP (mg/l P)		1 (53	0 (00	0 (43	11 (74	1 (62	12 (40	1 (03	17 (48	0 (94	13 (07	1 (05	16 (79	0 (77	14 (54	1 (01	48 (63	0 (60	0 (00	0 (60	0 (00	0 (78	0 (00
DIP (mg/l P)		0 (78	0 (00	0 (19	4 (59	0 (40	8 (30	0 (59	20 (13	0 (57	44 (87	0 (57	24 (78	0 (27	13 (24	0 (44	49 (40	0 (60	0 (00	0 (60	0 (00	0 (48	0 (00
COD (mg/l O)		75 (08	0 (00	80 (58	2160 (29	69 (58	648 (59	78 (56	2647 (.5)	94 (60	4180 (64	76 (60	3373 (60	67 (60	1883 (41	53 (60	4594 (08	0 (60	0 (00	0 (60	0 (00	53 (50	0 (00
TSS (mg/l)		35 (58	0 (00	15 (58	372 (68	17 (60	157 (69	28 (60	941 (80	16 (60	980 (23	18 (60	897 (60	7 (20	285 (37	13 (60	1372 (28	0 (60	0 (00	0 (60	0 (00	38 (50	0 (00
TVS (mg/l)		78 (29	0 (00	75 (00	1868 (04	84 (50	784 (63	60 (50	2108 (60	65 (60	3861 (94	60 (80	2946 (60	61 (30	2078 (45	59 (60	7334 (50	0 (60	0 (00	0 (60	0 (00	51 (00	0 (00
EC (mS/m)				0 (60		0 (00		0 (00		0 (00		0 (00		0 (00		0 (00		0 (00		0 (00		0 (00	

		10 (a)		11 (00		12 (60		13 (80		14 (90		15 (60		16 (60		17 (00		18 (00	
		Lansdowne Road culvert		Springfield Road		Above (DD)		In (DD)		Below (DD)		Above Elg Road		In Pelagic outlet		Below Elg Road		Seventh Avenue	
		[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux	[ ]	Flux
		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
		7 (29	672 (48	5 (63	719 (35	5 (52	151 (63	3 (87	26 (50	3 (48	568 (80	0 (00	0 (00	0 (00	0 (00	0 (00	0 (00	2 (90	75 (84	1 (71	84 (32
		0 (47	61 (07	1 (58	76 (80	0 (54	58 (67	0 (78	1 (43	0 (80	41 (22	0 (00	0 (00	0 (00	0 (00	0 (00	0 (00	0 (79	26 (23	0 (53	23 (43	
		0 (43	36 (82	0 (87	58 (89	0 (60	27 (27	0 (82	0 (49	0 (58	28 (91	0 (00	0 (00	0 (00	0 (00	0 (00	0 (00	0 (72	13 (60	0 (39	2 (67	
		74 (90	4751 (72	68 (30	6277 (78	47 (40	2584 (50	91 (20	765 (88	59 (90	2571 (73	0 (00	0 (00	0 (00	0 (00	0 (00	0 (00	83 (70	1568 (40	36 (40	1982 (77	
		15 (70	1020 (82	11 (80	701 (61	14 (60	737 (56	26 (70	210 (88	20 (50	1773 (40	0 (00	0 (00	0 (00	0 (00	0 (00	0 (00	14 (00	983 (58	13 (80	959 (08	
		135 (00	9645 (54	110 (80	4781 (61	74 (50	5329 (60	52 (70	420 (20	94 (80	2681 (81	0 (00	0 (00	0 (00	0 (00	0 (00	0 (00	66 (70	1772 (.1)	52 (60	1948 (28	
		0 (00		0 (00		0 (00		0 (00		0 (00		0 (00		0 (00		0 (00		0 (00		0 (00			

Metric	1 (c)		2 Above WTT		3 Jn WTT outlet		4 Below WTT		4 (a) Below Ogaden (sidetrap line)		5 Above Pidgin East outlet		6 Jn Pidgin East outlet		7 Below Pidgin East outlet		8 Above Ygaload DY		9 Jn Ygaload DY		10 Below Ygaload DY	
	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L
TPOH (mg/l H)	2 4315	0 000	14 554	350 400	15 4877	135 248	11 4231	456 893	8 473	383 940	8 204	335 068	6 947	234 430	7 4775	625 589	0	0 000	0	0 000	7 052	760 150
TP (mg/l P)	1 342	0 000	3 435	11 871	3 401	18 779	1 2433	43 433	1 1225	51 222	1 1695	49 062	0 97	12 465	0 4585	55 871	0	0 000	0	0 000	0 972	(36 771)
DRP (mg/l P)	1 33	0 000	0 3695	9 238	1 385	16 385	1 223	42 865	1 1195	51 039	1 115	48 851	0 326	11 232	0 364	47 943	0	0 000	0	0 000	0 82	88 387
COD (mg/l O)	78 85	0 000	134 15	2945 750	80 75	1329 451	145 85	5774 750	77	3422 300	84 25	3758 731	84 8	2824 149	91	4135 806	0	0 000	0	0 000	43 6	4689 634
TSS (mg/l)	7 65	0 000	7 95	198 750	20 5	342 177	44 67	1562 750	6	221 791	4 8	226 400	4 15	139 857	7 45	488 370	0	0 000	0	0 000	7 11	553 115
TVS (mg/l)	103 65	0 000	85 5	2190 000	70 75	870 443	153 5	3566 556	73 5	3441 364	123 25	5299 750	62 25	2097 659	76 25	2771 250	0	0 000	0	0 000	12 5	1367 500
EC (mS/m)	126 9		134 4		126 4		130 7		124 4		128 9		108 8		108 6		5		5		144	

Metric	11 (a) Lansdowne Road culvert		12 Springbok Road		13 above PWF		14 Jn PWF		14 Below PWF		15 Above Elg Road		16 Jn Pidgin outlet		17 Below Elg Road		18 Jemadi Avenue	
	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L
TPOH (mg/l H)	1 9075	457 500	4 684	508 512	3 982	586 527	2 2493	13 547	4 517	204 283	5	0 000	9	0 000	5 753	186 002	6 579	278 783
TP (mg/l P)	0 695	16 782	0 6535	19 478	0 4465	18 976	0 1343	1 084	0 484	22 962	5	0 000	9	0 000	0 4191	29 464	0 551	33 934
DRP (mg/l P)	0 525	45 138	0 517	31 756	0 284	12 871	0 041	0 427	0 278	13 189	5	0 000	9	0 000	0 183	8 866	0 124	8 749
COD (mg/l O)	77 75	6687 879	84 15	5722 200	58 85	2672 547	114 9	756 306	74 25	3617 447	5	0 000	9	0 000	47 6	3287 728	107 6	6863 317
TSS (mg/l)	7 8	498 921	6	408 000	10 5	476 025	8 5	56 000	23 1	1124 880	5	0 000	9	0 000	41 1	2808 793	36 87	2366 091
TVS (mg/l)	59 65	8571 667		#VALUE!	21	952 453	28 1	143 190	35 1	1484 188	5	0 000	9	0 000	38 53	1871 036	48 85	3134 449
EC (mS/m)	146 3		146 2		140 3		47 9		138 3		5		5		121 4		126	

Metric	1 000 (c)		2 000 Above WTT		3 000 Jn WTT outlet		4 000 Below WTT		4 (a) Below Ogaden (sidetrap line)		5 000 Above Pidgin East outlet		6 000 Jn Pidgin East outlet		7 000 Below Pidgin East outlet		8 000 Above Ygaload DY		9 000 Jn Ygaload DY		10 000 Below Ygaload DY	
	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L
TPOH (mg/l H)	2 581	0 000	43 563	1089 113	31 748	624 470	34 571	1277 821	17 395	1049 150	15 952	829 248	11 479	490 807	13 973	1391 870	0 000	0 000	0 000	0 000	14 674	(864 71)
TP (mg/l P)	0 795	0 000	0 787	19 625	1 581	31 090	1 360	42 037	0 908	61 767	0 948	49 101	0 871	51 753	0 921	82 325	0 000	0 000	0 000	0 000	0 958	(19 11)
DRP (mg/l P)	0 417	0 000	0 402	10 070	1 525	30 041	1 355	40 465	0 894	61 617	0 847	54 768	0 682	28 161	0 674	61 218	0 000	0 000	0 000	0 000	0 681	30 461
COD (mg/l O)	78 450	0 000	134 850	2871 250	119 600	2341 484	153 566	5670 224	75 060	5117 527	81 750	3189 634	64 139	1883 647	66 750	4671 278	0 000	0 000	0 000	0 000	74 550	6648 535
TSS (mg/l)	11 000	0 000	13 800	343 000	42 200	836 335	28 874	1016 488	9 400	640 961	15 800	818 842	10 636	453 577	12 700	3250 000	0 000	0 000	0 000	0 000	15 750	1740 644
TVS (mg/l)	76 600	0 000	23 200	580 000	84 350	1834 446	84 874	4030 890	104 636	6311 968	87 950	4568 812	21 000	829 444	44 850	8486 227	0 000	0 000	0 000	0 000	84 450	8436 804
EC (mS/m)	127 500		183 900		84 300		145 190		109 300		116 900		179 600		140 100		0 000		0 000		142 700	

Metric	11 (a) Lansdowne Road culvert		12 000 Springbok Road		13 000 above PWF		14 000 Jn PWF		14 000 Below PWF		15 000 Above Elg Road		16 000 Jn Pidgin outlet		17 000 Below Elg Road		18 000 Jemadi Avenue	
	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L
TPOH (mg/l H)	12 033	0 000	10 432	781 433	5 866	776 458	2 660	30 718	5 517	403 728	0 000	0 000	0 000	0 000	4 844	370 647	0 000	0 000
TP (mg/l P)	1 033	0 000	1 844	87 800	0 926	33 926	0 063	0 853	0 547	43 809	0 000	0 000	0 000	0 000	0 541	43 445	0 000	0 000
DRP (mg/l P)	0 961	0 000	1 219	81 736	0 433	18 225	0 027	0 359	0 407	31 827	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000
COD (mg/l O)	47 500	0 000	47 750	3173 300	44 350	2850 897	62 850	752 732	70 900	3457 145	0 000	0 000	0 000	0 000	44 400	3477 500	47 850	3448 775
TSS (mg/l)	4 000	0 000	1 750	551 250	2 150	349 281	1 700	13 414	10 450	778 972	0 000	0 000	0 000	0 000	10 700	5148 811	36 700	2440 563
TVS (mg/l)	76 000	0 000	34 850	5613 750	148 750	3351 162	75 000	581 000	47 000	3457 714	0 000	0 000	0 000	0 000	31 000	2207 156	42 600	7241 400
EC (mS/m)	139 500		138 200		132 400		83 900		123 700		0 000		0 000		124 500		124 700	

Metric	1 000 (c)		2 000 Above WTT		3 000 Jn WTT outlet		4 000 Below WTT		4 (a) Below Ogaden (sidetrap line)		5 000 Above Pidgin East outlet		6 000 Jn Pidgin East outlet		7 000 Below Pidgin East outlet		8 000 Above Ygaload DY		9 000 Jn Ygaload DY		10 000 Below Ygaload DY	
	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L
TPOH (mg/l H)	0 000	0 000	12 835	3162 875	24 899	1644 760	17 834	9496 277	10 947	1045 763	10 084	1054 478	9 996	1501 955	13 127	4967 748	0 000	0 000	0 000	0 000	0 000	0 000
TP (mg/l P)	0 000	0 000	0 487	128 220	1 178	77 775	0 764	235 443	0 414	241 182	0 435	230 775	0 477	72 881	0 545	206 755	0 000	0 000	0 000	0 000	0 000	0 000
DRP (mg/l P)	0 000	0 000	0 341	88 660	0 702	46 373	0 454	139 793	0 408	138 567	0 414	150 658	0 325	54 264	0 363	106 967	0 000	0 000	0 000	0 000	0 000	0 000
COD (mg/l O)	0 000	0 000	44 700	11622 600	65 500	4322 989	50 000	15410 007	46 200	17931 527	52 800	19270 004	53 200	8391 039	44 700	24731 510	0 000	0 000	0 000	0 000	0 000	0 000
TSS (mg/l)	0 000	0 000	27 700	6958 000	47 700	2991 771	40 850	12709 973	38 450	7948 200	21 450	7829 250	16 850	2810 400	22 700	12942 454	0 000	0 000	0 000	0 000	0 000	0 000
TVS (mg/l)	0 000	0 000	12 750	3315 000	30 850	2563 087	19 450	6074 133	35 850	13852 667	87 700	17949 500	21 200	8539 700	15 800	10770 842	0 000	0 000	0 000	0 000	0 000	0 000
EC (mS/m)			83 000		94 200		86 600		87 100		85 500		109 800		100 500		0 000		0 000		0 000	
pH			7 750		7 660		7 610		7 864		7 790		7 850		7 811		0 000		0 000		0 000	

Metric	11 (a) Lansdowne Road culvert		12 000 Springbok Road		13 000 above PWF		14 000 Jn PWF		14 000 Below PWF		15 000 Above Elg Road		16 000 Jn Pidgin outlet		17 000 Below Elg Road		18 000 Jemadi Avenue	
	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L	[ ] (mg/L	Flow (mg/L
TPOH (mg/l H)	11 727	6 137 915	12 187	6458 847	13 845	7758 621	7 519	580 205	12 323	7881 771	12 373	8296 182	18 290	2014 474	13 971	7442 482	11 787	7481 951
TP (mg/l P)	1 434	722 415	1 565	811 170	1 629	971 796	0 346	6 512	0 641	411 351	0 645	434 712	1 450	28 183	0 669	478 849	0 630	836 052
DRP (mg/l P)	0 463	233 609	0 457	221 035	0 429	254 786	0 213	3 113	0 441	282 172	0 455	299 870	1 167	26 564	0 453	305 716	0 471	527 724
COD (mg/l O)	54 850	28708 536	64 750	33681 000	59 400	37644 128	48 200	2304 860	54 700	22263 430	68 800	52248 564	58 400	750 840	68 750	53601 750	63 700	53496 809
TSS (mg/l)	22 500	11776 357	20 850	13050 500	25 700	20057 993	3 900	40 721	28 000	17613 447	34 500	9779 400	7 225	42 744	27 900	21584 531	34 800	33267 050
TVS (mg/l)	28 450	14899 758	25 350	15870 500	25 450	19365 961	#VALUE!	#VALUE!	23 100	14540 582	27 500	14830 390	18 400	220 800	22 150	15959 895	24 850	17235 514
EC (mS/m)	94 500		94 600		93 500		66 200		90 400		92 100		133 400		91 700		92 600	
pH	7 820		7 750		7 760		7 670		7 780		7 820		7 810		7 870		7 890	

WATU21	1 060 MD		2 380 Above HT1		3 680 In HT1 valve		4 000 Below HT1		4 ag Below Ongaire (subway loc)		5 600 Above Philipp East valve		6 000 In Philipp East valve		7 500 Below Philipp East valve		8 000 Above Vigabond TP		9 060 In Vigabond TP		10 000 Below Vigabond TP	
	[] (mg/L)	Flux (mg/L)	[] (mg/L)	Flux (mg/L)	[] (mg/L)	Flux (mg/L)	[] (mg/L)	Flux (mg/L)	[] (mg/L)	Flux (mg/L)	[] (mg/L)	Flux (mg/L)	[] (mg/L)	Flux (mg/L)	[] (mg/L)	Flux (mg/L)	[] (mg/L)	Flux (mg/L)	[] (mg/L)	Flux (mg/L)	[] (mg/L)	Flux (mg/L)
TPOP (mg/l P)	0 060	0 000	29 750	1363 982	21 400	455 964	24 830	1872 605	23 886	2143 792	23 990	2235 841	24 918	1987 414	27 124	3450 622	0 000	0 000	0 000	0 000	0 000	0 000
TP (mg/L P)	0 060	0 000	0 269	18 387	1 418	29 936	2 728	94 887	0 636	62 947	0 684	65 569	0 857	68 257	0 459	92 492	0 000	0 000	0 000	0 000	0 000	0 000
TDP (mg/L P)	0 060	0 000	0 218	11 348	0 945	19 944	0 728	45 562	0 385	29 132	0 463	41 675	0 287	19 637	0 221	44 598	0 000	0 000	0 000	0 000	0 000	0 000
TOC (mg/L C)	0 060	0 000	73 750	5054 703	14 400	1130 297	19 560	6685 566	21 300	5086 848	21 800	5270 447	42 200	7103 736	36 700	7798 357	0 000	0 000	0 000	0 000	0 000	0 000
TSS (mg/L	0 060	0 000	4 750	328 547	17 750	394 866	18 000	3837 699	10 566	1659 940	7 750	788 851	22 300	1640 125	15 650	3153 599	0 000	0 000	0 000	0 000	0 000	0 000
TVS (mg/L	0 060	0 000	44 650	3059 946	74 350	1561 757	56 150	4225 397	80 456	8187 811	122 450	12798 889	48 600	7358 318	40 700	8008 912	0 000	0 000	0 000	0 000	0 000	0 000
EC (mS/m)	0 000		207 300		90 350		185 500		151 600		164 000		250 600		207 300		0 000		0 000		0 000	
pH			8 290		7 810		8 130		8 070		8 040		7 960		8 120		0 000		0 000		0 000	

	11 ag Lansdowne Road culvert		12 000 Springhill Road		13 000 Above OOC		13 000 In OOC		14 000 Below OOC		15 600 Above Elip Road		16 000 In Philipp outlet		17 000 Below Elip Road		18 000 Swamp Avenue	
	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L
	34 960	3463 775	15 900	1958 795	34 501	3383 699	37 394	788 383	16 209	5195 594	0 000	0 000	0 000	0 000	13 750	3077 983	15 500	3836 025
	0 441	88 583	0 497	75 556	0 443	88 958	0 002	1 779	0 451	98 105	0 000	0 000	0 000	0 000	0 444	99 539	0 405	93 527
	0 546	63 759	0 521	63 456	0 561	67 859	0 004	1 258	0 581	74 162	0 000	0 000	0 000	0 000	0 517	70 047	0 367	68 697
	81 400	12155 073	45 750	8472 560	60 450	8349 550	63 900	1303 171	60 800	8799 304	0 000	0 000	0 000	0 000	44 400	9950 827	59 850	12600 568
	0 580	1501 629	4 850	991 969	4 500	897 560	1 536	29 150	10 800	2752 289	0 000	0 000	0 000	0 000	6 650	1545 125	6 297	1447 849
	58 600	10841 562	99 600	17967 630	118 750	23631 250	#VALUE!	#VALUE!	65 850	9478 733	0 000		0 000		110 500	24772 754	102 700	27529 196
	197 000		196 000		99 000		75 000		180 000		0 000		0 000		179 000		170 000	
	8 320		7 930		8 030		8 600		8 030		0 000		0 000		8 370		8 470	

WAVA08	1 000 MD		2 000 Above HT1		3 000 In HT1 valve		4 000 Below HT1		4 ag Below Ongaire (subway loc)		5 000 Above Philipp East valve		6 000 In Philipp East valve		7 000 Below Philipp East valve		8 000 Above Vigabond TP		9 000 In Vigabond TP		10 000 Below Vigabond TP	
	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L
TPOP (mg/l P)	0 128	287 264	24 670	1293 931	22 760	1024 420	20 088	2711 880	15 293	3920 088	16 369	3302 498	19 263	1126 249	15 894	4735 837	0 418	4575 623	0 892	268 527	0 424	4529 951
TP (mg/L P)	0 187	24 535	0 285	27 071	1 243	55 935	0 650	93 150	0 452	89 262	0 328	66 797	0 394	43 654	0 375	111 869	0 412	528 290	1 095	42 910	0 569	181 710
TDP (mg/L P)	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000
TOC (mg/L C)	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000
TSS (mg/L	21 850	1801 240	13 200	5054 806	48 650	1084 250	73 800	7263 600	87 260	16093 227	122 000	27256 900	99 200	11064 139	78 600	18479 046	113 850	85280 852	11 850	463 252	91 400	20298 561
TVS (mg/L	17 850	1528 498	10 750	4114 506	22 600	1117 660	8 800	1188 600	12 900	2947 313	16 750	3373 890	11 300	1233 685	8 250	1827 152	11 150	432 901	9 950	2329 338		
EC (mS/m)	92 800		139 200		109 000		115 800		82 500		102 700		178 700		139 600		139 200		182 200		155 600	
pH	7 200		7 250		7 570		7 460		7 150		7 600		7 380		7 460		7 670		7 780		7 430	

	11 ag Lansdowne Road culvert		12 000 Springhill Road		13 000 Above OOC		13 000 In OOC		14 000 Below OOC		15 600 Above Elip Road		16 000 In Philipp outlet		17 000 Below Elip Road		18 000 Swamp Avenue	
	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L
	34 960	3347 652	15 620	1828 620	33 200	4651 202	6 179	240 867	15 305	4952 315	11 690	1611 704	8 681	99 616	12 961	5195 156	11 851	5651 062
	0 444	103 341	0 428	120 469	0 684	245 862	0 124	3 230	0 330	240 959	0 669	201 777	0 457	14 353	0 664	302 528	0 724	343 858
	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000
	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000	0 000
	44 300	17342 718	28 350	7966 350	13 150	3304 879	7 150	302 773	1 500	770 058	-	#VALUE!	0 000	0 000	0 000	0 000	0 000	0 000
	9 900	2591 240	13 250	3899 250	17 500	4102 398	28 900	1240 724	74 250	32686 434	-	#VALUE!	0 000	0 000	0 000	0 000	0 000	0 000
	156 200		141 500		148 900		95 800		127 100		141 100		113 000		137 400		135 700	
	7 440		7 750		7 450		7 720		7 440		7 600		7 590		7 430		7 720	

WAHA33	1 600 MD		2 660 Above HT1		3 600 In HT1 valve		4 500 Below HT1		4 ag Below Ongaire (subway loc)		5 600 Above Philipp East valve		6 000 In Philipp East valve		7 000 Below Philipp East valve		8 600 Above Vigabond TP		9 660 In Vigabond TP		10 600 Below Vigabond TP	
	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L
TPOP (mg/l P)	0 560	48 951	29 720	966 623	25 280	746 088	28 180	1762 134	20 952	3134 076	19 242	2082 519	17 215	1491 879	18 499	4208 133	0 000	0 000	0 000	0 000	0 000	0 000
TP (mg/L P)	0 368	3 975	0 383	18 343	0 780	16 122	0 981	92 887	0 859	130 464	0 843	111 287	0 582	33 116	0 685	150 045	0 000	0 000	0 000	0 000	0 000	0 000
TDP (mg/L P)	0 150	5 558	0 217	10 609	0 680	29 037	0 824	63 139	0 671	71 827	0 438	77 795	0 268	21 445	0 393	91 304	0 000	0 000	0 000	0 000	0 000	0 000
TOC (mg/L C)	44 300	470 804	77 800	2831 300	72 700	1498 985	67 450	4307 196	58 800	8321 663	61 350	7666 306	45 750	3781 207	28 100	4791 470	0 000	0 000	0 000	0 000	0 000	0 000
TSS (mg/L	24 850	289 083	36 200	2679 800	223 560	16261 856	188 550	17837 132	68 000	16023 600	84 800	10644 060	80 850	7206 758	82 300	19122 552	0 000	0 000	0 000	0 000	0 000	0 000
TVS (mg/L	15 850	165 268	17 150	841 350	8 850	641 175	17 100	1618 918	31 450	4775 844	21 700	3043 504	16 300	892 677	13 650	3438 362	0 000	0 000	0 000	0 000	0 000	0 000
EC (mS/m)	112 000		147 500		77 400		110 700		124 000		132 300		210 000		163 100		0 000		0 000		0 000	
pH	7 680		7 680		7 730		7 590		7 450		7 730		7 450		7 650		0 000		0 000		0 000	

	11 ag Lansdowne Road culvert		12 000 Springhill Road		13 000 Above OOC		13 000 In OOC		14 000 Below OOC		15 000 Above Elip Road		16 000 In Philipp outlet		17 000 Below Elip Road		18 000 Swamp Avenue	
	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L	[] (mg/L	Flux (mg/L
	33 660	3774 308	15 307	1933 523	34 206	5169 123	5 971	131 894	14 105	5784 417	10 723	3636 587	9 113	48 799	13 468	5754 636	13 479	3084 977
	0 516	134 255	0 470	109 984	0 483	118 811	0 108	7 246	0 498	155 481	0 541	143 134	0 154	16 857	0 542	170 961	0 498	136 779
	0 377	91 748	0 344	80 618	0 382	94 053	0 241	5 313	0 274	130 211	0 439	118 998	0 188	3 589	0 406	111 574	0 370	101 438
	57 800	13931 492	47 200	10957 400	28 650	7052 980	42 700	943 085	31 700	8565 232	42 300	11309 950	23 900	327 026	34 200	9534 395	41 200	11310 626
	34 950	8411 521	25 500	5855 500	41 200	10143 944	13 500	267 301	42 800	13483 578	35 150	9462 043	19 200	516 999	32 300	9004 062	35 500	9395 808
	12 550	3024 917	13 650	3040 650	11 000	2905 394	20 600	433 604	13 350	3833 918	28 800	8238 349	14 050	222 952	31 500	878 1 675	24 200	6843 628
	109 700		140 900		158 500		55 000		154 800		133 400		40 300		144 700		143 100	
	7 760		7 680		7 770		8 150		8 030		8 090		8 400		8 090		8 120	

Well Site	1 (in)		2 (in)		3 (in)		4 (in)		5 (in)		6 (in)		7 (in)		8 (in)		9 (in)		10 (in)		
	Above ATT		Above ATT		In ATT outlet		Below ATT		Below Ogallala (Ashley Inn)		Above Platipus East outlet		In Platipus East outlet		Below Platipus East outlet		Above Vigoleval Elf		In Vigoleval Elf		Below Vigoleval Elf
	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)
TPOH (mg/l 3P)	1.284	0.004	11.814	1340.418	10.932	1142.243	10.743	2299.883	14.459	3232.807	15.767	3448.758	16.857	920.408	13.773	7802.594	11.784	3987.763	4.977	183.773	1.284	5868.781
TP (mg/l P)	0.259	0.004	3.284	36.598	3.037	42.781	3.678	98.688	3.638	129.332	3.642	128.357	3.551	56.658	3.527	149.527	3.529	137.263	1.962	30.768	0.771	240.636
BBP (mg/l P)	0.174	0.004	3.159	34.443	2.872	32.264	3.302	43.830	3.301	35.225	3.356	70.177	3.225	34.947	3.305	87.711	3.327	7.485	1.764	22.156	0.193	61.312
COD (mg/l Cr)	39.500	0.004	43.346	4547.766	39.686	2235.004	40.506	6662.895	53.256	19478.493	53.770	7147.639	53.114	1834.343	42.164	13984.739	36.200	10585.806	35.666	2863.450	16.366	36280.613
TSS (mg/l)	9.351	0.004	34.360	1501.586	34.603	1643.004	83.556	12346.400	75.906	4874.127	77.936	3458.845	75.435	3485.234	84.564	6976.953	28.900	6052.900	49.853	2025.430	48.556	31434.784
TVS (mg/l)	28.400	0.004	31.650	3264.250	31.750	548.756	67.856	2330.197	72.756	4275.779	69.809	7137.427	26.836	1768.945	31.569	6122.647	22.476	4336.100	27.986	733.583	23.850	6963.324
SC (mS/m)	44.700		121.756		131.730		134.890		120.594		120.394		5x1.106		141.466		153.904		182.955		169.560	
pH	7.650		7.994		7.983		7.940		7.990		8.022		8.233		7.984		7.980		8.007		7.974	

	11 (in)		12 (in)		13 (in)		14 (in)		15 (in)		16 (in)		17 (in)		18 (in)	
	Lauderdale Road (alley)		Springbok Road		Above ???		In ???		Below ???		Above Elg Road		In Platipus outlet		Below Elg Road		Seventh Avenue	
	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)
	11.883	4178.933	11.252	3821.824	9.422	5276.243	9.174	8?.844	9.690	9564.970	0.000	0.000	0.000	0.000	9.277	7552.155	7.813	9864.438
	0.919	581.474	0.485	140.933	0.334	182.582	0.140	2.812	0.782	181.195	0.000	0.000	0.000	0.000	0.543	285.417	0.177	206.876
	0.487	33.791	0.315	104.733	0.254	127.612	0.091	1.828	0.176	120.848	0.000	0.000	0.000	0.000	0.405	153.353	0.079	141.474
	45.000	15649.tr/g	38.666	14808.000	34.004	19401.124	49.808	863.767	61.506	23644.964	0.000	0.000	0.000	0.000	78.100	14974.421	39.666	15010.004
	11.660	4659.977	8.854	2132.274	29.200	9963.720	3.560	36.397	13.856	5013.964	0.000	0.000	0.000	0.000	11.100	5869.615	11.863	4286.978
	11.550	11675.439	27.750	7324.304	7.900	2712.614	67.850	1062.944	22.306	8347.252	0.000	0.000	0.000	0.000	34.150	19082.704	21.700	8274.748
	151.800		133.600		140.300		24.400		145.800		0.000		0.964		144.556		133.400	
	7.986		7.956		7.800		8.150		7.960		2.000		0.000		0.324		8.040	

	1 (in)		2 (in)		3 (in)		4 (in)		5 (in)		6 (in)		7 (in)		8 (in)		9 (in)		10 (in)		
Well 121	(6)		Above ATT		In ATT outlet		Below ATT		Below Ogallala (Ashley Inn)		Above Platipus East outlet		In Platipus East outlet		Below Platipus East outlet		Above Vigoleval Elf		In Vigoleval Elf		Below Vigoleval Elf
	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)
TPOH (mg/l 3P)	1.477	191.459	11.373	0.000	24.235	0.000	17.464	0.000	15.928	3326.156	13.669	5773.662	16.744	1559.854	12.723	4752.879	12.600	4366.600	12.753	1829.801	12.219	6386.472
TP (mg/l P)	0.221	15.772	0.251	0.000	0.812	0.000	0.448	0.000	0.457	93.472	0.427	91.526	0.521	145.178	0.844	214.187	0.873	230.600	0.264	103.206	1.059	134.371
BBP (mg/l P)	0.151	11.687	0.163	0.000	0.734	0.000	0.384	0.000	0.267	61.320	0.274	61.371	0.134	26.127	0.268	77.662	0.256	153.000	0.169	79.054	0.577	301.756
COD (mg/l Cr)	44.330	5161.625	51.700	0.000	58.900	0.000	47.200	0.000	43.700	19926.139	53.800	12056.394	71.100	14668.634	55.710	20777.501	59.900	23860.000	78.700	15286.704	48.300	51397.627
TSS (mg/l)	11.900	784.839	7.500	0.000	13.700	0.000	8.250	0.000	10.800	2305.514	7.900	1547.869	783.800	177?6.123	559.500	104884.594	247.500	94070.000	11.900	1734.634	101.000	99982.768
TVS (mg/l)	47.100	3369.042	34.250	0.000	58.050	0.000	21.700	0.000	40.250	9343.867	26.150	5837.111	38.450	2768.443	27.100	4397.834	0.000	0.000	0.000	0.000	20.000	19983.200
SC (mS/m)	94.700		114.800		114.900		113.500		101.200		103.700		177.300		134.106		138.900		139.900		140.800	
pH	7.770		7.980		7.730		7.940		7.900		7.940		7.980		7.944		7.980		7.980		7.979	

	11 (in)		12 (in)		13 (in)		14 (in)		15 (in)		16 (in)		17 (in)		18 (in)	
	Lauderdale Road (alley)		Springbok Road		Above ???		In ???		Below ???		Above Elg Road		In Platipus outlet		Below Elg Road		Seventh Avenue	
	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)
	11.330	4879.147	11.101	5128.942	9.000	0.000	8.900	0.000	13.675	8597.340	0.000	0.000	0.000	0.000	9.979	9484.527	10.900	6804.244	9.496	7297.884
	0.427	372.713	0.442	207.823	0.000	0.000	0.000	0.000	0.682	423.459	0.000	0.000	0.000	0.000	0.755	692.774	1.288	13.154	0.771	498.934	2.341	558.633
	0.313	303.112	0.749	250.828	0.000	0.000	0.000	0.000	0.538	343.782	0.000	0.000	0.000	0.000	0.574	597.863	0.580	388.676	2.394	431.668
	51.300	5051.948	44.756	39808.500	0.000	0.000	0.000	0.000	58.600	37340.938	59.900	44224.900	81.400	766.777	64.600	45290.220	62.400	45189.274
	0.850	5303.455	0.636	2600.290	0.000	0.000	0.000	0.000	0.956	5116.439	0.000	0.000	2.564	23.529	14.500	13368.654	14.150	7523.347
	74.900	42?9.824	?1.406	33879.206	0.000	0.000	0.000	0.000	54.459	34823.781	27.100	18423.276	21.000	191.361	13.850	9408.478	24.300	17868.613
	197.800		137.000		0.000		0.000		128.900		124.900		138.900		134.994		123.800	
	7.990		7.780		0.000		0.000		7.940		7.900		7.964		7.950		7.954	

	1 (in)		2 (in)		3 (in)		4 (in)		5 (in)		6 (in)		7 (in)		8 (in)		9 (in)		10 (in)		
Well 851	(6)		Above ATT		In ATT outlet		Below ATT		Below Ogallala (Ashley Inn)		Above Platipus East outlet		In Platipus East outlet		Below Platipus East outlet		Above Vigoleval Elf		In Vigoleval Elf		Below Vigoleval Elf
	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)
TPOH (mg/l 3P)	1.836	136.460	22.1871	954.563	20.3447	1323.036	20.955	3236.114	21.3505	8051.751	13.2791	7208.836	17.124	4295.096	17.4381	4640.113	15.579	398.456	16.574	4923.750
TP (mg/l P)	0.3915	11.271	0.3447	14.906	0.561	10.022	0.586	34.833	0.7523	119.434	0.677	86.326	0.427	92.986	0.439	171.930	0.5487	147.964	0.176	29.750	0.159	171.084
BBP (mg/l P)	0.269	9.144	0.183	7.869	0.493	13.662	0.305	23.493	0.4925	72.268	0.4795	67.521	0.13	11.694	0.305	77.396	0.3131	33.941	0.186	27.406	0.139	116.681
COD (mg/l Cr)	33.6	1149.200	34.1	2402.300	46.9	6126.804	49.1	2943.930	47	6896.375	49.5	9529.666	49.1	9366.829	72.2	17436.862	80.3	22447.795	71.3	9892.566	64.45	19283.525
TSS (mg/l)	3.45	124.936	8.4	275.266	11.3	229.906	8.8	523.948	12.45	1856.525	9.5	1349.856	840	19636.125	435	104349.908	964	94887.384	8.15	565.756	445.1	133797.604
TVS (mg/l)	0	0.000	55	2363.906	83.25	2333.876	80.75	5190.116	89.6	12867.200	33.33	1132.543	12.75	7113.866	13.45	3632.533	37	1857.040	13.85	3961.502
SC (mS/m)	113.3		142.4		123.1		147.8		138.3		138.85		188		159.1		161.4		159.7		164.3	
pH	8		7.81		7.76		7.87		8		8		7.94		7.98		7.95		7.93		7.94	

	11 (in)		12 (in)		13 (in)		14 (in)		15 (in)		16 (in)		17 (in)		18 (in)	
	Lauderdale Road (alley)		Springbok Road		Above ???		In ???		Below ???		Above Elg Road		In Platipus outlet		Below Elg Road		Seventh Avenue	
	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)	[ ] (mg/l)	Flux (mg/l)
	15.1851	4707.385	13.504	5321.884	13.242	3904.930	9.4475	5?1.428	12.445	8943.246	12.229	7812.133	8.187	683.221	11.9435	4930.861	11.344	4630.213
	0.5435	169.417	0.548	136.554	0.5925	174.812	0.148	3.673	0.579	182.778	0.6243	186.633	1.125	24.523	0.584	198.664	0.439	212.864
	0.4387	136.939	0.444	109.224	0.4843	137.046	0.123	2.563	0.455	137.766	0.4763	147.923	1.197	24.144	0.1	167.941	0.4875	175.750
	79.85	10195.586	47.1	11687.000	47	13864.918	49.4	1027.861	46.1	14729.969	52	16209.960	82.45	1834.000	58.6	19911.260	58.1	19252.147
	7.3	2279.714	8.1	2691.000	9.3	2861.896	3.4	73.899	10.8	3431.174	12	?749.347	7.25	164.250	8.45	2889.851	8.2	2814.438
	73.25	32998.438	70.9	26?1.400	40.3	12367.170	0	0.000	29.7	10060.418	31.75	10668.625	90.25	1946.746	78.35	19491.638	62.1	21351.200
	141.4		140.9		155.5		131.5		132.5		145.51		120.6		144.1		139.1	
	8.03		7.94		8.03		7.98		8.01		8.14		7.96		8.08		8.12	

	1 000		2 000		3 000		4 000		4 (a)		5 000		6 000		7 000		8 000		9 000		10 000	
MW001	(d)		Above (FF)		2a (FF) outlet		Below (FF)		Below Ongoles (railway line)		Above Pidapa East outlet		2a Pidapa East outlet		Below Pidapa East outlet		Above Vigadesal DP		2a Vigadesal DP		Below Vigadesal DP	
	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
DHOH (mg/l (H)	3 841	134 196	22 872	1042 722	24 135	784 054	24 203	1803 338	23 565	2284 784	19 326	3163 279	21 133	3852 257	19 280	2729 343	18 644	3519 552	11 591	264 843	18 283	3894 726
DI (mg/l (F)	0 393	16 552	0 279	18 625	1 288	38 425	1 622	74 430	0 783	86 972	0 750	71 343	0 823	84 284	0 594	134 829	0 729	153 452	0 825	19 464	0 754	182 644
DEF (mg/l (F)	0 284	9 593	0 243	12 225	0 624	27 705	0 631	45 788	0 529	58 690	0 497	61 464	0 631	57 637	0 543	106 275	0 536	101 760	0 765	14 748	0 584	124 318
COD (mg/l Cl)	42 630	1440 460	81 450	3052 560	34 200	1628 080	36 360	4332 560	33 108	3674 638	32 130	3468 539	30 230	4389 972	31 660	1906 2 668	32 750	3912 889	80 400	1739 163	34 250	1558 347
TSS (mg/l)	2 750	73 130	8 300	315 085	12 130	364 506	18 090	1783 080	9 890	899 647	9 850	1021 627	23 350	1950 168	19 060	3705 660	18 750	3706 400	7 350	154 756	18 150	1864 951
TVS (mg/l)	73 750	1880 760	55 300	2343 600	67 300	2019 080	73 750	3881 250	51 900	7743 478	52 850	5478 382	47 560	3973 413	44 240	8439 960	56 750	7456 400	32 400	682 191	44 230	9417 662
EC (mS/m)	113 639		141 300		111 864		143 130		137 850		140 900		155 130		159 330		155 490		147 209		152 300	
pH	7 973		8 090		7 994		7 960		8 060		7 980		7 844		8 259		7 950		8 413		7 982	

	19 (a)		11 000		12 000		3 000		14 000		15 000		16 000		17 000		18 000	
	Lapeirmer Road culvert		Springbird Road		Above CCC		2a CCC		Below CCC		Above Elg Road		2a Pidapa outlet		Below Elg Road		Tremelt Avenue	
	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
	13 808	331 304	12 446	2808 494	12 362	3953 414	3 270	36 348	11 446	2941 251	10 864	2756 385	3 034	28 180	10 434	2734 956	17 552	4588 026
	3 628	140 943	3 439	748 771	3 687	172 029	0 137	0 845	3 132	833 590	3 683	175 379	1 321	6 248	3 632	181 521	3 476	379 348
	0 581	130 499	0 536	126 732	0 555	136 962	0 118	0 817	0 549	139 476	0 523	134 288	0 518	5 456	0 532	139 794	0 492	130 146
	45 750	10275 911	45 250	16543 250	488 900	120158 800	47 350	466 387	48 400	11301 456	78 350	19448 642	89 650	496 344	73 626	14680 351	42 200	11182 934
	7 000	1572 273	7 200	1677 600	6 350	1568 450	7 500	51 936	12 500	3178 579	10 000	2567 642	8 650	36 857	10 350	2715 812	12 550	3318 383
	31 300	7030 284	44 250	10310 250	48 200	11942 450	36 800	255 525	45 850	10411 023	70 450	15207 757	77 750	209 752	66 450	12184 764	41 100	10871 937
	113 100		151 300		149 500		134 600		148 100		140 800		118 200		135 500		134 200	
	7 390		7 380		8 010		8 050		7 970		7 960		7 920		8 090		8 380	

	1 000		2 000		3 000		4 000		4 (a)		5 000		6 000		7 000		8 000		9 000		10 000	
MW004	(d)		Above (FF)		2a (FF) outlet		Below (FF)		Below Ongoles (railway line)		Above Pidapa East outlet		2a Pidapa East outlet		Below Pidapa East outlet		Above Vigadesal DP		2a Vigadesal DP		Below Vigadesal DP	
	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
DHOH (mg/l (H)	4 863	119 934	21 306	907 189	21 780	549 599	20 546	1384 233	19 512	2151 154	18 894	1984 628	18 594	1423 890	18 332	3207 428	17 931	3591 629	9 112	226 798	17 152	3293 680
DI (mg/l (F)	0 219	6 188	0 327	13 852	1 363	34 852	1 625	54 687	0 791	89 187	0 765	72 973	0 727	54 525	0 561	104 655	0 675	119 458	0 453	9 785	0 747	161 930
DEF (mg/l (F)	0 188	4 624	0 175	7 451	1 079	26 975	1 491	33 671	0 539	79 356	0 503	52 763	0 453	49 525	0 513	97 359	0 548	101 164	0 191	8 865	0 564	137 143
COD (mg/l Cl)	43 800	1071 705	74 600	3259 268	70 600	1765 080	78 850	4343 688	58 350	6917 736	52 400	5302 648	48 600	3645 000	54 150	9722 645	49 750	8864 600	#VALUE!	#VALUE!	49 150	9568 600
TSS (mg/l)	3 560	86 705	7 850	334 247	24 500	612 500	32 750	843 594	15 950	5680 917	15 350	3286 598	21 200	1590 000	23 750	4671 438	23 650	7814 600	18 450	374 752	23 800	4952 600
TVS (mg/l)	43 300	1047 236	56 450	1466 968	74 300	1872 560	77 450	1994 363	44 650	4900 287	49 850	5143 899	70 600	5965 000	71 450	9076 194	68 650	13648 900	52 150	988 250	61 400	7864 000
EC (mS/m)	134 900		141 500		134 200		150 300		150 300		159 500		167 800		164 900		147 500		139 104		143 500	
pH	7 600		7 870		7 600		7 770		7 770		7 910		7 880		7 980		8 070		8 042		8 161	

	19 (a)		11 000		12 000		3 000		14 000		15 000		16 000		17 000		18 000	
	Lapeirmer Road culvert		Springbird Road		Above CCC		2a CCC		Below CCC		Above Elg Road		2a Pidapa outlet		Below Elg Road		Tremelt Avenue	
	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
	11 393	2018 185	11 338	1655 275	10 660	1958 710	3 646	16 119	10 280	1986 453	9 949	2043 562	9 622	30 576	9 629	2114 877	9 977	2178 877
	3 542	91 927	3 780	113 807	3 852	144 364	0 136	3 205	3 629	159 960	3 791	155 863	3 734	8 428	3 733	176 023	3 687	169 221
	0 487	86 272	0 417	89 082	0 660	118 705	0 113	2 008	0 612	118 213	0 583	120 463	0 661	7 844	0 550	121 771	0 552	120 005
	44 300	7847 758	42 200	6161 200	41 100	7388 000	73 400	1279 641	46 300	8974 326	49 750	10268 750	83 950	673 600	54 000	11562 000	57 250	12480 500
	7 200	1275 482	8 700	1270 200	7 350	943 680	13 650	249 683	8 350	1625 550	7 800	1656 500	9 650	29 205	7 350	1563 750	8 000	1744 000
	39 850	9068 963	34 250	8252 500	43 600	7848 000	62 350	738 619	43 850	8849 050	24 850	3484 900	11 950	95 600	24 200	5234 600	31 950	8273 335
	140 800		0 000		0 000		0 000		0 000		0 000		0 000		0 000		144 600	
	7 990		0 000		0 000		0 000		0 000		0 000		0 000		0 000		8 020	

	1 000		2 000		3 000		4 000		4 (a)		5 000		6 000		7 000		8 000		9 000		10 000	
MW005	(d)		Above (FF)		2a (FF) outlet		Below (FF)		Below Ongoles (railway line)		Above Pidapa East outlet		2a Pidapa East outlet		Below Pidapa East outlet		Above Vigadesal DP		2a Vigadesal DP		Below Vigadesal DP	
	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
DHOH (mg/l (H)	3 539	139 903	13 894	902 208	22 277	342 563	18 832	1363 783	13 913	1941 568	13 459	1777 728	12 536	891 247	14 522	2566 579	14 907	2512 670	7 333	153 971	17 516	3689 990
DI (mg/l (F)	0 213	8 384	0 302	19 598	1 350	20 453	0 807	66 130	0 839	89 535	0 739	84 418	0 868	26 551	0 566	103 512	0 598	93 521	0 196	16 880	0 774	147 649
DEF (mg/l (F)	0 156	5 932	0 174	15 556	0 947	14 155	0 458	54 295	0 450	70 118	0 450	61 758	0 393	13 152	0 568	63 635	0 708	68 635	0 451	13 865	0 577	75 521
COD (mg/l Cl)	44 150	1587 163	73 750	3463 750	84 500	1652 629	52 650	4317 300	51 100	6550 114	52 100	5961 500	44 400	3207 765	47 250	8412 313	43 100	7131 570	36 950	1713 331	54 500	10892 000
TSS (mg/l)	7 150	269 661	3 500	221 500	#VALUE!	#VALUE!	7 850	643 700	3 500	448 638	3 500	402 500	13 150	953 256	10 000	1850 460	10 000	2332 608	9 200	190 833	11 150	2477 122
TVS (mg/l)	18 800	743 461	33 150	2374 750	#VALUE!	#VALUE!	48 750	7388 360	#VALUE!	#VALUE!	109 100	12346 500	28 750	2077 114	9 700	1771 540	26 800	4887 565	73 400	1536 647	39 200	7863 240
EC (mS/m)	134 800		156 500		113 900		144 300		136 700		137 800		155 700		150 400		138 400		141 700		157 500	
pH	7 830		7 960		7 640		7 820		7 840		7 760		7 890		7 900		8 070		8 009		7 980	

	19 (a)		11 000		12 000		3 000		14 000		15		16		17		18	
	Lapeirmer Road culvert		Springbird Road		Above CCC		2a CCC		Below CCC		Above Elg Road		2a Pidapa outlet		Below Elg Road		Tremelt Avenue	
	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow	[ ]	Flow
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
	9 278	1428 791	9 753	1561 406	9 554	1945 213	5 293	121 221	8 949	1749 128	8 961	1870 003	9 515	36 627	8 456	2128 791	9 404	2183 519
	3 593	91 249	3 633	101 280	3 674	117 863	0 147	3 353	3 647	130 278	3 625	148 636	3 005	12 117	3 675	164 771	3 673	170 169
	0 491	70 073	0 499	79 762	0 521	92 838	0 083	1 931	0 513	100 843	0 490	117 048	0 143	12 553	0 532	128 513	0 4865	120 637
	34 800	8439 134	29 800	4768 000	40 600	7630 000	99 600	1387 980	84 700	8727 200	36 2	8397 000	99 2	948 200	27 15	6804 116	47 35	12183 618
	2 200	308 012	4 500	720 000	4 250	761 250	4 050	91 616	4 200	783 864	4	940 000	4	38 400	3 45	746 040	4 5	1072 514
	41 450	6404 354	37 500	6000 000	38 500	6647 500	52 200	1191 991	23 900	4884 643	43 7	10739 500	5		27 45	954 150	35	8771 421
	143 600		0 000		0 000		0 000		0 000		0		0		0		139 1	
	7 810		0 000		0 000		0 000		0 000		0		0		0		8 12	

ANALYTICAL RESULTS FROM SAMPLING PROGRAMME - LITTLE LOTUS RIVER

97/07/22	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Carrol Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	0.000	0.000	0.000	0.000	0.000	0.000
TP (mg/l P)	0.000	0.000	0.000	0.000	0.000	0.000
SRP (mg/l P)	0.000	0.000	0.000	0.000	0.000	0.000
COD (mg/l O)	0.000	0.000	0.000	0.000	0.000	0.000
TSS (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
TVS %	0.000		0.000		0.000	
EC (mS/m)	0.000		0.000		0.000	

97/07/29	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	5.206	315.741	4.939	272.810	0.000	0.000
TP (mg/l P)	0.141	8.552	0.162	8.948	0.000	0.000
SRP (mg/l P)	0.136	8.219	0.134	7.402	0.000	0.000
COD (mg/l O)	65.950	4000.211	64.600	3568.242	0.000	0.000
TSS (mg/l)	2.500	151.638	1.500	82.854	0.000	0.000
TVS %	0.000		0.000		0.000	
EC (mS/m)	52.800		40.300		0.000	

97/08/05	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	4.694	933.670	4.120	642.724	3.818	358.634
TP (mg/l P)	0.278	55.203	0.170	26.445	0.161	15.078
SRP (mg/l P)	0.243	48.340	0.150	23.325	0.158	14.843
COD (mg/l O)	76.250	15168.277	70.100	10936.997	72.750	6834.481
TSS (mg/l)	3.500	696.249	2.300	358.846	3.150	295.926
TVS %	55.450		40.850		85.000	
EC (mS/m)	38.900		33.600		31.700	

97/08/11	19 Seventh (Little Lotus)		20 Klip Road (Little Lotus)		21 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	5.0995	971.666814	4.589	346.20059	4.1535	205.4068
TP (mg/l P)	0.19	36.2029012	0.183	13.805776	0.1955	9.66824
SRP (mg/l P)	0.16	30.48665364	0.1375	10.373193	0.1555	7.690083
COD (mg/l O)	72.25	13766.62953	72	5431.7809	74.35	3676.898
TSS (mg/l)	5.8	1105.141194	5.35	403.6115	5.8	286.8327
TVS %	68.8	13109.26107	83.95	6333.3056	62.55	3093.342
EC (mS/m)	43.5		38.3		35.8	

97/08/18	19 Seventh (Little Lotus)		20 Klip Road (Little Lotus)		21 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	5.8615	771.983	4.3975	338.889	4.2495	155.949
TP (mg/l P)	0.267	35.165	0.12	9.248	0.206	7.560
SRP (mg/l P)	0.1875	24.695	0.125	9.633	0.1485	5.450
COD (mg/l O)	67.75	8922.951	67	5163.290	69.4	2546.855
TSS (mg/l)	5.65	744.128	8.15	628.072	2.5	91.746
TVS %	66.65	8778.076	87.75	6762.368	41.65	1528.480
EC (mS/m)	45.8		39.2		36.9	

97/08/25	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	4.388	833.743	4.461	417.533	3.832	263.239
TP (mg/l P)	0.177	33.536	0.164	15.305	0.163	11.199
SRP (mg/l P)	0.161	30.496	0.123	11.467	0.156	10.718
COD (mg/l O)	71.000	13490.375	69.200	6477.582	75.200	5166.525
TSS (mg/l)	1.200	228.006	0.700	65.525	0.700	48.093
TVS %	-	-	-	-	-	0.000
EC (mS/m)	43.400		36.900		34.300	

97/09/01	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	4.701	1194.040	4.279	668.074	3.897	449.942
TP (mg/l P)	0.262	66.547	0.170	26.467	0.165	18.995
SRP (mg/l P)	0.230	58.419	0.152	23.656	0.151	17.379
COD (mg/l O)	76.850	19519.664	71.500	11164.499	70.950	8192.828
TSS (mg/l)	-	-	-	-	-	-
TVS %	-	-	-	-	-	-
EC (mS/m)	39.900		34.800		32.100	

97/09/09	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	4.623	682.209	4.201	275.623	3.993	206.793
TP (mg/l P)	0.161	23.687	0.137	8.957	0.150	7.743
SRP (mg/l P)	0.113	16.677	0.110	7.218	0.125	6.474
COD (mg/l O)	73.400	10832.697	72.300	4744.084	73.950	3830.276
TSS (mg/l)	3.150	464.891	2.650	173.884	1.850	95.822
TVS %	42.350	6250.201	55.650	3651.567	45.850	2374.823
EC (mS/m)	44.200		37.800		35.700	

97/09/15

	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	4.003	269.133	3.945	201.117	3.690	156.869
TP (mg/l P)	0.123	8.271	0.146	7.419	0.161	6.845
SRP (mg/l P)	0.094	6.287	0.115	5.838	0.132	5.591
COD (mg/l O)	72.500	4874.987	9.000	458.880	66.650	2833.811
TSS (mg/l)	5.350	359.740	3.500	178.454	2.650	112.672
TVS %	90.900	6112.224	65.700	3349.828	-	#VALUE!
EC (mS/m)	44.700		37.500		36.400	

97/09/22

	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	4.204	373.415	3.544	113.494	3.285	88.633
TP (mg/l P)	0.139	12.304	0.196	6.278	0.163	4.399
SRP (mg/l P)	0.074	6.529	0.110	3.507	0.131	3.522
COD (mg/l O)	73.000	6484.906	71.400	2286.865	61.600	1662.287
TSS (mg/l)	4.500	399.754	4.650	148.934	6.150	165.959
TVS %	83.300	7399.900	63.900	2046.648	71.050	1917.297
EC (mS/m)	46.700		37.100		35.800	

97/10/20

	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	3.070	94.206	2.770	51.452	2.885	44.303
TP (mg/l P)	0.090	2.762	0.150	2.777	0.120	1.843
SRP (mg/l P)	0.044	1.350	0.060	1.114	0.089	1.367
COD (mg/l O)	69.650	2137.272	70.200	1303.950	73.950	1135.611
TSS (mg/l)	8.300	254.693	22.650	420.719	2.850	43.766
TVS %	72.400	2221.658	37.250	691.911	39.850	611.955
EC (mS/m)	64.800		53.300		48.300	

97/11/10

	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	3.376	83.897	2.934	46.973	3.164	42.109
TP (mg/l P)	0.127	3.144	0.119	1.897	0.113	1.497
SRP (mg/l P)	0.045	1.118	0.041	0.656	0.068	0.905
COD (mg/l O)	66.950	1663.780	67.950	1087.867	71.700	954.383
TSS (mg/l)	7.800	193.838	9.650	154.495	1.300	17.304
TVS %	41.650	1035.048	44.550	713.237	######	#VALUE!
EC (mS/m)	60.400		50.800		46.700	

97/12/08	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	2.461	68.848	2.288	26.797	2.821	34.909
TP (mg/l P)	0.114	3.189	0.045	0.527	0.095	1.170
SRP (mg/l P)	0.063	1.762	0.020	0.234	0.063	0.780
COD (mg/l O)	55.250	1545.659	68.750	805.380	70.000	866.393
TSS (mg/l)	14.500	405.648	11.650	136.475	9.800	121.295
TVS %	52.900	1479.916	48.700	570.502	39.000	482.705
EC (mS/m)	57.500		47.500		44.800	

98/01/12	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	2.506	44.264	3.187	43.505	2.901	35.403
TP (mg/l P)	0.165	2.915	0.108	1.475	0.079	0.958
SRP (mg/l P)	0.059	1.034	0.056	0.765	0.063	0.769
COD (mg/l O)	66.850	1181.020	68.400	933.867	60.600	739.546
TSS (mg/l)	47.150	832.986	4.700	64.169	3.850	46.984
TVS %	44.750	790.586	60.500	826.008	12.550	153.157
EC (mS/m)	61.200		50.300		40.600	

98/02/10	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	2.514	0.000	3.498	0.000	2.794	0.000
TP (mg/l P)	0.186	0.000	0.171	0.000	0.114	0.000
SRP (mg/l P)	0.073	0.000	0.008	0.000	0.084	0.000
COD (mg/l O)	52.100	0.000	106.050	0.000	65.200	0.000
TSS (mg/l)	14.300	0.000	43.150	0.000	4.500	0.000
TVS %	50.550	0.000	50.100	0.000	56.650	0.000
EC (mS/m)	0.000		0.000		0.000	

98/03/09	19 Seventh (Little Lotus)		20 Klip Road (Little Lotus)		21 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	2.063	0.000	2.0685	0.000	1.988	0.000
TP (mg/l P)	0.0645	0.000	0.0545	0.000	0.132	0.000
SRP (mg/l P)	0.0221	0.000	0.0125	0.000	0.049	0.000
COD (mg/l O)	58.4	0.000	93.6	0.000	58.4	0.000
TSS (mg/l)	8	0.000	10	0.000	42.5	0.000
TVS %	26.5	0.000	34.75	0.000	22.1	0.000
EC (mS/m)	61.8		70.8		51.2	

98/03/30	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	1.928	0.000	2.845	0.000	2.401	0.000
TP (mg/l P)	0.086	0.000	0.092	0.000	0.137	0.000
SRP (mg/l P)	0.028	0.000	0.028	0.000	0.078	0.000
COD (mg/l O)	41.800	0.000	71.450	0.000	75.500	0.000
TSS (mg/l)	25.300	0.000	19.300	0.000	14.850	0.000
TVS %	43.200	0.000	61.650	0.000	30.000	0.000
EC (mS/m)	59.100		62.500		49.200	

98/05/11	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	0.000	0.000	0.000	0.000	0.000	0.000
TP (mg/l P)	0.000	0.000	0.000	0.000	0.000	0.000
SRP (mg/l P)	0.000	0.000	0.000	0.000	0.000	0.000
COD (mg/l O)	0.000	0.000	0.000	0.000	0.000	0.000
TSS (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
TVS (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
EC (mS/m)	0.000		0.000		0.000	
pH	0.000		0.000		0.000	

98/05/25	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	4.737	243.498	4.830	173.977	4.131	92.669
TP (mg/l P)	0.114	5.860	0.119	4.269	0.134	3.006
SRP (mg/l P)	0.055	2.801	0.046	1.639	0.064	1.436
COD (mg/l O)	60.600	3115.046	72.200	2600.925	58.100	1303.337
TSS (mg/l)	13.400	688.805	11.400	410.672	19.800	444.166
TVS (mg/l)	67.850	3487.720	79.250	2854.894	######	#VALUE!
EC (mS/m)	84.000		71.000		59.000	
pH	8.240		7.830		7.840	

98/06/08	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	5.002	571.124	5.371	354.826	0.000	0.000
TP (mg/l P)	0.117	13.360	0.089	5.847	0.000	0.000
SRP (mg/l P)	0.000	0.000	0.000	0.000	0.000	0.000
COD (mg/l O)	0.000	0.000	0.000	0.000	0.000	0.000
TSS (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
TVS (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
EC (mS/m)	68.800		55.900		0.000	
pH	8.010		8.230		0.000	

98/06/23	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	0.000	0.000	0.000	0.000	0.000	0.000
TP (mg/l P)	0.000	0.000	0.000	0.000	0.000	0.000
SRP (mg/l P)	0.000	0.000	0.000	0.000	0.000	0.000
COD (mg/l O)	0.000	0.000	0.000	0.000	0.000	0.000
TSS (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
TVS (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
EC (mS/m)	0.000		0.000		0.000	
pH	0.000		0.000		0.000	

98/07/06	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	0.000	0.000	0.000	0.000	0.000	0.000
TP (mg/l P)	0.000	0.000	0.000	0.000	0.000	0.000
SRP (mg/l P)	0.000	0.000	0.000	0.000	0.000	0.000
COD (mg/l O)	0.000	0.000	0.000	0.000	0.000	0.000
TSS (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
TVS (mg/l)	0.000	0.000	0.000	0.000	0.000	0.000
EC (mS/m)	0.000		0.000		0.000	
pH	0.000		0.000		0.000	

98/07/20	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	4.516	630.411	4.277	451.824	3.687	301.361
TP (mg/l P)	0.152	21.218	0.119	12.520	0.145	11.811
SRP (mg/l P)	0.099	13.820	0.090	9.509	0.091	7.397
COD (mg/l O)	58.900	8222.146	58.900	6222.948	59.900	4895.989
TSS (mg/l)	2.850	397.846	1.850	195.458	5.350	437.288
TVS (mg/l)	39.350	5493.063	32.400	3423.150	31.050	2537.904
EC (mS/m)	63.200		54.400		51.400	
pH	7.830		7.630		7.500	

98/08/03	19 Seventh (Little Lotus)		20 Klip Road (Little Lotus)		21 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	5.6825	471.368	5.0785	270.519	4.4745	172.392
TP (mg/l P)	0.1465	12.152	0.137	7.298	0.1455	5.606
SRP (mg/l P)	0.1015	8.419	0.105	5.593	0.112	4.315
COD (mg/l O)	65.7	5449.863	65.2	3473.044	68.7	2646.856
TSS (mg/l)	4.2	348.393	3	159.803	3.15	121.362
TVS (mg/l)	29.3	2430.456	0	0.000	56.25	2167.185
EC (mS/m)	69.8		60.6		56.6	
pH	8.13		7.95		7.83	

98/08/31	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	5.198	310.942	4.762	159.052	4.139	75.198
TP (mg/l P)	0.123	7.359	0.120	3.991	0.204	3.698
SRP (mg/l P)	0.116	6.940	0.116	3.858	0.174	3.153
COD (mg/l O)	62.000	3709.168	62.500	2087.511	62.500	1135.652
TSS (mg/l)	6.000	358.952	2.800	93.520	2.000	36.341
TVS (mg/l)	36.650	2192.597	21.700	724.784	13.350	242.575
EC (mS/m)	69.500		56.900		52.600	
pH	8.320		8.550		8.140	

98/09/14	19.000 Seventh (Little Lotus)		20.000 Klip Road (Little Lotus)		21.000 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	4.170	267.426	4.415	145.496	4.096	104.415
TP (mg/l P)	0.094	6.028	0.058	1.912	0.256	6.513
SRP (mg/l P)	0.069	4.425	0.062	2.027	0.112	2.842
COD (mg/l O)	67.950	4357.695	67.400	2221.414	65.750	1676.087
TSS (mg/l)	8.850	567.558	1.650	54.382	1.350	34.414
TVS (mg/l)	24.400	1564.794	#######	#VALUE!	######	#VALUE!
EC (mS/m)	73.100		63.100		58.000	
pH	8.440		8.160		7.940	

98/09/28	19 Seventh (Little Lotus)		20 Klip Road (Little Lotus)		21 Robin Road (Little Lotus)	
	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)	[ ] (mg/l)	Flux (mg/s)
TPON (mg/l N)	4.069	390.618	3.846	179.826	3.3495	137.103
TP (mg/l P)	0.1235	11.856	0.15	7.014	0.1105	4.523
SRP (mg/l P)	0.0675	6.480	0.0805	3.764	0.0785	3.213
COD (mg/l O)	61.7	5923.106	64.35	3008.795	47.9	1960.655
TSS (mg/l)	2.85	273.596	2.5	116.892	1.15	47.072
TVS (mg/l)	77.1	7401.483	40.2	1879.620	70.85	2900.050
EC (mS/m)	68.8		58		55.2	
pH	8.26		7.68		7.9	

APPENDIX H

DATA LOGGER RESULTS

MONTHLY SUMMARY Conductivity EC (mS/cm)

Mon 21 Jul 1997 00:00 - Thu 31 Jul 1997 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Mon 21 Jul 1997	0.67 @ 19:10	1.60 @ 14:20	0.96
Tue 22 Jul 1997	0.75 @ 00:10	1.11 @ 14:30	0.88
Wed 23 Jul 1997	0.53 @ 18:30	1.08 @ 02:30	0.90
Thu 24 Jul 1997	0.66 @ 02:50	1.06 @ 18:30	0.87
Fri 25 Jul 1997	0.49 @ 06:00	1.06 @ 20:20	0.82
Sat 26 Jul 1997	0.79 @ 19:30	1.07 @ 14:10	0.93
Sun 27 Jul 1997	0.80 @ 23:40	1.01 @ 12:40	0.85
Mon 28 Jul 1997	0.76 @ 07:00	0.93 @ 14:00	0.82
Tue 29 Jul 1997	0.76 @ 14:50	0.91 @ 14:00	0.84
Wed 30 Jul 1997	0.80 @ 22:50	1.05 @ 15:50	0.88
Thu 31 Jul 1997	0.82 @ 03:30	1.00 @ 18:00	0.90
Monthly results	0.49 @ 06:00 Fri 25 Jul	1.60 @ 14:20 Mon 21 Jul	0.87

MONTHLY SUMMARY Conductivity EC (mS/cm)

Fri 01 Aug 1997 00:00 - Sun 31 Aug 1997 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Fri 01 Aug 1997	0.28 @ 23:40	1.01 @ 13:10	0.86
Sat 02 Aug 1997	0.30 @ 00:10	0.91 @ 19:00	0.70
Sun 03 Aug 1997	0.23 @ 23:20	0.95 @ 18:20	0.80
Mon 04 Aug 1997	0.30 @ 00:10	0.73 @ 10:00	0.54
Tue 05 Aug 1997	0.73 @ 15:10	0.89 @ 15:20	0.84
Wed 06 Aug 1997	0.22 @ 16:30	0.85 @ 11:40	0.62
Thu 07 Aug 1997	0.61 @ 00:10	0.93 @ 17:00	0.78
Fri 08 Aug 1997	0.73 @ 16:10	0.98 @ 19:10	0.85
Sat 09 Aug 1997	0.74 @ 04:10	1.07 @ 15:00	0.86
Sun 10 Aug 1997	0.77 @ 08:00	1.04 @ 17:40	0.86
Mon 11 Aug 1997	0.74 @ 05:30	1.05 @ 15:40	0.88
Tue 12 Aug 1997	0.71 @ 00:30	1.07 @ 13:40	0.90
Wed 13 Aug 1997	0.78 @ 08:20	1.12 @ 15:00	0.95
Thu 14 Aug 1997	0.79 @ 02:40	1.20 @ 17:30	0.97
Fri 15 Aug 1997	0.79 @ 07:50	1.07 @ 06:50	0.92
Sat 16 Aug 1997			
Sun 17 Aug 1997			
Mon 18 Aug 1997			
Tue 19 Aug 1997	0.38 @ 19:00	1.15 @ 13:30	0.72
Wed 20 Aug 1997	0.53 @ 00:10	0.83 @ 09:30	0.70
Thu 21 Aug 1997			
Fri 22 Aug 1997			
Sat 23 Aug 1997			
Sun 24 Aug 1997			
Mon 25 Aug 1997	0.85 @ 19:30	1.08 @ 17:10	0.97
Tue 26 Aug 1997	0.89 @ 02:00	1.12 @ 17:40	0.98
Wed 27 Aug 1997	0.87 @ 00:20	1.12 @ 20:30	1.00
Thu 28 Aug 1997	0.91 @ 05:50	1.13 @ 14:00	1.01
Fri 29 Aug 1997	0.77 @ 20:20	1.08 @ 11:00	0.96
Sat 30 Aug 1997	0.64 @ 16:20	0.98 @ 12:20	0.82
Sun 31 Aug 1997	0.59 @ 06:10	0.94 @ 19:00	0.81
Monthly results	0.22 @ 16:30 Wed 06 Aug	1.20 @ 17:30 Thu 14 Aug	0.86

MONTHLY SUMMARY Conductivity EC (mS/cm)

Mon 01 Sep 1997 00:00 - Tue 30 Sep 1997 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Mon 01 Sep 1997	0.82 @ 05:30	1.17 @ 16:20	0.98
Tue 02 Sep 1997	0.90 @ 11:50	1.21 @ 17:40	1.01
Wed 03 Sep 1997	0.23 @ 13:20	1.10 @ 03:00	0.77
Thu 04 Sep 1997	0.78 @ 05:30	1.49 @ 22:10	0.99
Fri 05 Sep 1997	0.86 @ 11:20	1.21 @ 17:40	1.03
Sat 06 Sep 1997	0.90 @ 06:50	1.07 @ 13:50	1.00
Sun 07 Sep 1997	0.87 @ 07:20	1.21 @ 16:40	1.01
Mon 08 Sep 1997	0.89 @ 07:50	1.23 @ 21:50	1.04
Tue 09 Sep 1997	0.93 @ 02:30	1.17 @ 10:40	1.06
Wed 10 Sep 1997	0.99 @ 01:00	1.41 @ 18:20	1.12
Thu 11 Sep 1997	0.97 @ 09:40	1.56 @ 20:00	1.14
Fri 12 Sep 1997	1.02 @ 02:50	1.57 @ 21:50	1.15
Sat 13 Sep 1997	1.03 @ 13:30	1.39 @ 13:20	1.15
Sun 14 Sep 1997	0.94 @ 04:00	1.43 @ 21:20	1.16
Mon 15 Sep 1997	0.86 @ 22:50	1.34 @ 14:50	1.13
Tue 16 Sep 1997	0.87 @ 07:00	1.28 @ 16:40	1.06
Wed 17 Sep 1997	0.91 @ 01:20	1.09 @ 09:50	0.98
Thu 18 Sep 1997			
Fri 19 Sep 1997			
Sat 20 Sep 1997	0.87 @ 11:40	1.20 @ 16:10	1.02
Sun 21 Sep 1997	0.83 @ 12:40	1.33 @ 15:40	0.97
Mon 22 Sep 1997	0.88 @ 05:00	1.18 @ 14:50	0.97
Tue 23 Sep 1997	0.83 @ 00:10	1.28 @ 15:30	0.97
Wed 24 Sep 1997	0.84 @ 14:30	1.28 @ 14:20	0.98
Thu 25 Sep 1997	0.87 @ 04:40	1.24 @ 16:20	0.97
Fri 26 Sep 1997	0.87 @ 05:30	1.18 @ 18:50	1.00
Sat 27 Sep 1997	0.96 @ 07:30	1.31 @ 18:50	1.07
Sun 28 Sep 1997	0.95 @ 04:30	1.38 @ 16:40	1.07
Mon 29 Sep 1997	0.74 @ 07:10	1.28 @ 14:40	1.00
Tue 30 Sep 1997	0.95 @ 08:50	1.32 @ 13:30	1.08
Monthly results	0.23 @ 13:20 Wed 03 Sep	1.57 @ 21:50 Fri 12 Sep	1.03

MONTHLY SUMMARY Conductivity EC (mS/cm)

Wed 01 Oct 1997 00:00 - Fri 31 Oct 1997 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Wed 01 Oct 1997	0.97 @ 06:30	1.36 @ 16:20	1.06
Thu 02 Oct 1997	0.98 @ 06:30	1.35 @ 20:40	1.10
Fri 03 Oct 1997	0.97 @ 14:20	1.37 @ 19:10	1.10
Sat 04 Oct 1997	0.86 @ 19:30	1.33 @ 16:10	1.06
Sun 05 Oct 1997	0.67 @ 10:30	1.09 @ 00:20	0.91
Mon 06 Oct 1997	0.62 @ 19:20	1.05 @ 16:30	0.87
Tue 07 Oct 1997	0.72 @ 00:10	2.19 @ 22:40	1.01
Wed 08 Oct 1997	0.93 @ 08:20	1.74 @ 00:10	1.09
Thu 09 Oct 1997	0.92 @ 07:00	1.15 @ 11:10	0.98
Fri 10 Oct 1997			
Sat 11 Oct 1997			
Sun 12 Oct 1997			
Mon 13 Oct 1997			
Tue 14 Oct 1997	1.05 @ 19:40	1.22 @ 18:30	1.12
Wed 15 Oct 1997	1.00 @ 07:10	1.45 @ 21:10	1.13
Thu 16 Oct 1997	1.02 @ 05:00	1.35 @ 21:20	1.16
Fri 17 Oct 1997	1.06 @ 06:00	1.41 @ 18:00	1.20
Sat 18 Oct 1997	1.08 @ 07:50	1.58 @ 22:40	1.23
Sun 19 Oct 1997	1.00 @ 23:00	1.39 @ 11:40	1.20
Mon 20 Oct 1997	1.02 @ 22:10	1.30 @ 16:50	1.18
Tue 21 Oct 1997	1.05 @ 06:00	1.40 @ 13:30	1.14
Wed 22 Oct 1997	0.89 @ 14:30	1.23 @ 16:50	1.04
Thu 23 Oct 1997	0.94 @ 08:20	1.17 @ 10:40	1.05
Fri 24 Oct 1997	0.89 @ 08:10	1.28 @ 15:20	1.05
Sat 25 Oct 1997	0.88 @ 18:50	1.36 @ 13:30	1.07
Sun 26 Oct 1997	0.44 @ 11:20	1.11 @ 05:20	0.79
Mon 27 Oct 1997	0.72 @ 00:10	1.29 @ 19:40	0.97
Tue 28 Oct 1997	0.43 @ 13:30	1.43 @ 21:20	1.16
Wed 29 Oct 1997	0.81 @ 12:40	1.38 @ 16:10	1.16
Thu 30 Oct 1997	0.30 @ 12:10	1.60 @ 01:50	1.18
Fri 31 Oct 1997	1.11 @ 23:30	1.46 @ 15:30	1.28
Monthly results	0.30 @ 12:10 Thu 30 Oct	2.19 @ 22:40 Tue 07 Oct	1.09

MONTHLY SUMMARY Conductivity EC (mS/cm)

Sat 01 Nov 1997 00:00 - Sun 30 Nov 1997 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Sat 01 Nov 1997	1.04 @ 12:20	1.51 @ 23:50	1.22
Sun 02 Nov 1997	0.98 @ 11:50	1.36 @ 15:50	1.22
Mon 03 Nov 1997	1.13 @ 19:20	1.39 @ 21:00	1.25
Tue 04 Nov 1997	1.04 @ 20:20	1.39 @ 18:40	1.19
Wed 05 Nov 1997	1.04 @ 04:00	1.24 @ 14:20	1.15
Thu 06 Nov 1997	1.03 @ 19:40	1.30 @ 16:10	1.15
Fri 07 Nov 1997	1.02 @ 07:10	1.44 @ 21:20	1.18
Sat 08 Nov 1997	1.02 @ 04:20	1.38 @ 22:20	1.19
Sun 09 Nov 1997	0.60 @ 09:00	1.24 @ 21:30	0.96
Mon 10 Nov 1997	0.95 @ 08:10	1.39 @ 19:30	1.10
Tue 11 Nov 1997	0.39 @ 16:20	1.30 @ 22:30	1.04
Wed 12 Nov 1997	0.24 @ 10:40	1.48 @ 01:50	1.25
Thu 13 Nov 1997	0.37 @ 16:30	1.40 @ 10:50	1.19
Fri 14 Nov 1997	0.36 @ 12:50	1.60 @ 20:50	1.21
Sat 15 Nov 1997	0.92 @ 18:50	1.44 @ 19:10	1.25
Sun 16 Nov 1997	0.18 @ 09:40	1.26 @ 02:10	0.69
Mon 17 Nov 1997	0.67 @ 01:00	1.00 @ 15:20	0.78
Tue 18 Nov 1997	0.76 @ 00:50	1.11 @ 16:40	0.89
Wed 19 Nov 1997	0.84 @ 04:20	1.17 @ 13:10	0.97
Thu 20 Nov 1997	0.68 @ 00:00	1.29 @ 15:40	1.03
Fri 21 Nov 1997	0.51 @ 00:50	1.17 @ 14:50	0.91
Sat 22 Nov 1997	0.80 @ 07:20	1.30 @ 19:50	0.99
Sun 23 Nov 1997	0.98 @ 18:20	1.37 @ 15:30	1.11
Mon 24 Nov 1997	0.81 @ 11:50	1.27 @ 18:20	1.01
Tue 25 Nov 1997	0.32 @ 22:20	1.19 @ 13:40	0.73
Wed 26 Nov 1997	0.19 @ 04:40	1.00 @ 23:00	0.39
Thu 27 Nov 1997	0.21 @ 20:50	1.01 @ 07:40	0.48
Fri 28 Nov 1997	0.22 @ 11:40	1.16 @ 19:40	0.51
Sat 29 Nov 1997	0.39 @ 12:00	1.26 @ 17:00	0.91
Sun 30 Nov 1997	0.94 @ 00:00	1.28 @ 11:10	1.08
Monthly results	0.18 @ 09:40 Sun 16 Nov	1.60 @ 20:50 Fri 14 Nov	1.00

MONTHLY SUMMARY Conductivity EC (mS/cm)

Mon 01 Dec 1997 00:00 - Wed 31 Dec 1997 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Mon 01 Dec 1997	0.13 @ 17:50	1.14 @ 09:10	0.51
Tue 02 Dec 1997	0.15 @ 12:00	1.34 @ 14:20	0.52
Wed 03 Dec 1997	0.57 @ 00:10	1.04 @ 20:00	0.85
Thu 04 Dec 1997	0.73 @ 12:40	1.31 @ 17:10	1.09
Fri 05 Dec 1997	0.69 @ 11:40	1.27 @ 21:00	1.08
Sat 06 Dec 1997	1.14 @ 07:10	1.32 @ 14:10	1.22
Sun 07 Dec 1997	1.15 @ 06:00	1.47 @ 17:40	1.28
Mon 08 Dec 1997	0.08 @ 20:30	1.33 @ 11:10	0.77
Tue 09 Dec 1997	0.09 @ 15:50	1.19 @ 19:30	0.48
Wed 10 Dec 1997	0.14 @ 11:50	1.11 @ 20:40	0.64
Thu 11 Dec 1997	0.08 @ 11:30	1.19 @ 15:00	0.80
Fri 12 Dec 1997	0.35 @ 12:10	1.31 @ 16:40	0.96
Sat 13 Dec 1997	0.30 @ 04:10	1.28 @ 12:20	0.99
Sun 14 Dec 1997	0.33 @ 11:50	1.31 @ 11:00	1.16
Mon 15 Dec 1997	0.02 @ 18:20	1.34 @ 09:40	0.55
Tue 16 Dec 1997	0.02 @ 14:00	1.33 @ 14:40	0.32
Wed 17 Dec 1997	0.05 @ 23:40	1.03 @ 06:40	0.28
Thu 18 Dec 1997	0.04 @ 04:10	0.07 @ 14:40	0.05
Fri 19 Dec 1997	0.00 @ 17:30	0.05 @ 00:50	0.02
Sat 20 Dec 1997	0.00 @ 09:40	0.01 @ 07:40	0.00
Sun 21 Dec 1997	0.00 @ 10:00	0.01 @ 07:40	0.00
Mon 22 Dec 1997	0.00 @ 09:30	0.01 @ 01:10	0.00
Tue 23 Dec 1997	0.00 @ 09:50	1.67 @ 17:20	0.27
Wed 24 Dec 1997	0.01 @ 17:00	1.19 @ 02:30	0.42
Thu 25 Dec 1997	0.00 @ 21:10	0.04 @ 09:20	0.03
Fri 26 Dec 1997	0.00 @ 12:40	0.02 @ 08:00	0.01
Sat 27 Dec 1997	0.00 @ 00:10	1.24 @ 23:10	0.38
Sun 28 Dec 1997	0.33 @ 14:20	1.41 @ 11:20	1.11
Mon 29 Dec 1997	0.00 @ 14:50	1.15 @ 03:30	0.35
Tue 30 Dec 1997	0.00 @ 00:10	0.00 @ 00:10	0.00
Wed 31 Dec 1997	0.00 @ 00:10	0.01 @ 08:40	0.00
Monthly results	0.00 @ 17:30 Fri 19 Dec	1.67 @ 17:20 Tue 23 Dec	0.52

MONTHLY SUMMARY Conductivity EC (mS/cm)

Thu 01 Jan 1998 00:00 - Sat 31 Jan 1998 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Thu 01 Jan 1998	0.00 @ 00:10	0.00 @ 05:00	0.00
Fri 02 Jan 1998	0.00 @ 00:10	0.00 @ 07:50	0.00
Sat 03 Jan 1998	0.00 @ 01:40	1.36 @ 17:20	0.39
Sun 04 Jan 1998	0.04 @ 15:20	1.39 @ 19:30	0.95
Mon 05 Jan 1998	0.02 @ 23:10	1.28 @ 00:10	0.42
Tue 06 Jan 1998	0.00 @ 11:20	0.02 @ 01:00	0.00
Wed 07 Jan 1998	0.01 @ 00:10	1.34 @ 18:00	0.66
Thu 08 Jan 1998	0.12 @ 09:20	1.31 @ 00:50	0.66
Fri 09 Jan 1998	0.06 @ 18:10	1.24 @ 09:20	0.96
Sat 10 Jan 1998	0.92 @ 07:00	1.17 @ 18:10	1.05
Sun 11 Jan 1998	0.05 @ 11:40	1.27 @ 09:30	1.02
Mon 12 Jan 1998	0.00 @ 18:10	1.44 @ 11:00	0.62
Tue 13 Jan 1998	0.04 @ 03:40	1.25 @ 05:40	0.33
Wed 14 Jan 1998	0.07 @ 06:10	0.10 @ 18:30	0.08
Thu 15 Jan 1998	0.00 @ 16:30	0.11 @ 09:10	0.06
Fri 16 Jan 1998	0.00 @ 00:10	0.03 @ 14:40	0.01
Sat 17 Jan 1998	0.00 @ 11:00	0.03 @ 08:50	0.01
Sun 18 Jan 1998	0.00 @ 00:10	0.01 @ 08:10	0.00
Mon 19 Jan 1998	0.00 @ 00:10	0.00 @ 20:00	0.00
Tue 20 Jan 1998	0.00 @ 09:30	0.01 @ 08:20	0.00
Wed 21 Jan 1998	0.00 @ 00:10	1.46 @ 14:40	0.80
Thu 22 Jan 1998	1.01 @ 07:30	1.40 @ 13:40	1.19
Fri 23 Jan 1998	0.99 @ 16:30	1.35 @ 13:40	1.15
Sat 24 Jan 1998	1.04 @ 00:20	1.60 @ 13:40	1.28
Sun 25 Jan 1998	0.94 @ 04:20	1.28 @ 23:50	1.09
Mon 26 Jan 1998	0.68 @ 20:50	1.25 @ 18:20	1.07
Tue 27 Jan 1998	0.09 @ 19:00	1.19 @ 00:40	0.35
Wed 28 Jan 1998	0.00 @ 16:00	0.10 @ 01:00	0.05
Thu 29 Jan 1998	0.00 @ 09:40	0.00 @ 02:50	0.00
Fri 30 Jan 1998	0.00 @ 09:20	0.00 @ 04:40	0.00
Sat 31 Jan 1998	0.00 @ 00:10	0.00 @ 05:00	0.00
Monthly results	0.00 @ 00:10 Thu 01 Jan	1.60 @ 13:40 Sat 24 Jan	0.46

MONTHLY SUMMARY Conductivity EC (mS/cm)

Sun 01 Feb 1998 00:00 - Sat 28 Feb 1998 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Sun 01 Feb 1998	0.00 @ 11:50	0.02 @ 09:50	0.00
Mon 02 Feb 1998	0.00 @ 09:40	0.01 @ 09:00	0.00
Tue 03 Feb 1998	0.00 @ 01:00	0.01 @ 07:40	0.00
Wed 04 Feb 1998	0.00 @ 00:40	0.05 @ 18:00	0.02
Thu 05 Feb 1998	0.02 @ 11:40	0.09 @ 21:40	0.06
Fri 06 Feb 1998	0.07 @ 00:30	0.22 @ 10:10	0.11
Sat 07 Feb 1998	0.05 @ 19:00	1.32 @ 23:30	0.21
Sun 08 Feb 1998	0.14 @ 00:00	1.32 @ 00:20	0.81
Mon 09 Feb 1998	0.00 @ 21:40	0.13 @ 00:10	0.05
Tue 10 Feb 1998	0.00 @ 00:10	1.11 @ 12:30	0.33
Wed 11 Feb 1998	0.08 @ 13:20	1.42 @ 13:50	0.63
Thu 12 Feb 1998	0.21 @ 23:10	0.73 @ 10:30	0.50
Fri 13 Feb 1998	0.00 @ 17:10	0.30 @ 01:00	0.13
Sat 14 Feb 1998	0.00 @ 09:00	0.00 @ 06:30	0.00
Sun 15 Feb 1998	0.00 @ 08:40	0.00 @ 02:20	0.00
Mon 16 Feb 1998	0.00 @ 08:00	0.00 @ 00:10	0.00
Tue 17 Feb 1998	0.00 @ 00:10	0.00 @ 00:40	0.00
Wed 18 Feb 1998	0.00 @ 10:40	0.00 @ 03:40	0.00
Thu 19 Feb 1998	0.00 @ 00:10	0.01 @ 14:40	0.00
Fri 20 Feb 1998	0.00 @ 00:10	0.02 @ 08:20	0.01
Sat 21 Feb 1998	0.00 @ 10:50	0.02 @ 08:10	0.01
Sun 22 Feb 1998	0.00 @ 00:40	0.11 @ 10:40	0.05
Mon 23 Feb 1998	0.00 @ 11:50	0.07 @ 01:00	0.03
Tue 24 Feb 1998	0.00 @ 10:40	0.03 @ 02:40	0.01
Wed 25 Feb 1998	0.00 @ 11:50	0.13 @ 22:30	0.05
Thu 26 Feb 1998	0.01 @ 16:50	0.17 @ 08:40	0.08
Fri 27 Feb 1998	0.06 @ 00:10	0.12 @ 14:10	0.09
Sat 28 Feb 1998	0.00 @ 14:50	0.13 @ 09:20	0.08
Monthly results	0.00 @ 11:50 Sun 01 Feb	1.42 @ 13:50 Wed 11 Feb	0.12

MONTHLY SUMMARY Conductivity EC (mS/cm)

Sun 01 Mar 1998 00:00 - Tue 31 Mar 1998 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Sun 01 Mar 1998	0.02 @ 12:00	0.10 @ 08:20	0.07
Mon 02 Mar 1998	0.09 @ 00:10	0.23 @ 08:40	0.15
Tue 03 Mar 1998	0.14 @ 23:50	0.27 @ 06:00	0.19
Wed 04 Mar 1998	0.11 @ 23:30	0.19 @ 07:10	0.16
Thu 05 Mar 1998	0.10 @ 02:50	0.21 @ 20:10	0.16
Fri 06 Mar 1998	0.08 @ 16:20	0.28 @ 02:30	0.19
Sat 07 Mar 1998	0.08 @ 10:10	0.14 @ 00:10	0.11
Sun 08 Mar 1998	0.13 @ 22:30	0.22 @ 08:20	0.17
Mon 09 Mar 1998	0.11 @ 17:50	0.99 @ 19:10	0.34
Tue 10 Mar 1998	0.02 @ 12:00	0.96 @ 00:20	0.14
Wed 11 Mar 1998	0.05 @ 08:40	1.16 @ 15:50	0.46
Thu 12 Mar 1998	0.00 @ 18:20	0.13 @ 09:50	0.07
Fri 13 Mar 1998	0.00 @ 00:10	0.01 @ 10:50	0.00
Sat 14 Mar 1998	0.00 @ 00:10	0.00 @ 20:10	0.00
Sun 15 Mar 1998	0.00 @ 02:00	0.00 @ 00:10	0.00
Mon 16 Mar 1998	0.00 @ 00:20	0.02 @ 09:40	0.00
Tue 17 Mar 1998	0.00 @ 00:10	1.32 @ 14:40	0.32
Wed 18 Mar 1998	0.38 @ 16:50	0.85 @ 11:10	0.57
Thu 19 Mar 1998	0.15 @ 14:00	0.47 @ 16:00	0.27
Fri 20 Mar 1998	0.14 @ 08:20	0.21 @ 03:00	0.16
Sat 21 Mar 1998	0.04 @ 11:40	0.49 @ 15:50	0.14
Sun 22 Mar 1998	0.00 @ 18:10	0.07 @ 00:10	0.03
Mon 23 Mar 1998	0.00 @ 16:00	0.05 @ 12:40	0.01
Tue 24 Mar 1998	0.00 @ 14:40	0.07 @ 09:00	0.01
Wed 25 Mar 1998	0.00 @ 10:20	0.04 @ 00:00	0.01
Thu 26 Mar 1998	0.04 @ 00:10	0.34 @ 22:20	0.12
Fri 27 Mar 1998	0.23 @ 17:50	0.33 @ 00:10	0.27
Sat 28 Mar 1998	0.13 @ 17:00	0.28 @ 08:10	0.21
Sun 29 Mar 1998	0.12 @ 11:20	0.48 @ 20:30	0.20
Mon 30 Mar 1998	0.10 @ 23:20	0.83 @ 12:10	0.23
Tue 31 Mar 1998	0.02 @ 15:00	0.10 @ 00:10	0.06
Monthly results	0.00 @ 18:20 Thu 12 Mar	1.32 @ 14:40 Tue 17 Mar	0.16

MONTHLY SUMMARY Conductivity EC (mS/cm)

Wed 01 Apr 1998 00:00 - Thu 30 Apr 1998 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Wed 01 Apr 1998	0.00 @ 13:00	0.03 @ 00:10	0.01
Thu 02 Apr 1998	0.00 @ 00:10	0.18 @ 20:40	0.05
Fri 03 Apr 1998	0.11 @ 08:30	0.84 @ 11:20	0.24
Sat 04 Apr 1998	0.08 @ 21:30	0.13 @ 11:20	0.11
Sun 05 Apr 1998	0.08 @ 01:10	1.19 @ 05:10	0.60
Mon 06 Apr 1998	0.22 @ 00:00	0.77 @ 15:00	0.64
Tue 07 Apr 1998	0.18 @ 06:40	0.23 @ 19:00	0.20
Wed 08 Apr 1998	0.19 @ 07:30	0.22 @ 11:30	0.20
Thu 09 Apr 1998	0.18 @ 07:20	0.91 @ 14:50	0.29
Fri 10 Apr 1998	0.16 @ 14:30	0.26 @ 00:30	0.20
Sat 11 Apr 1998	0.13 @ 11:50	0.23 @ 22:20	0.18
Sun 12 Apr 1998	0.20 @ 11:30	0.29 @ 23:30	0.23
Mon 13 Apr 1998	0.22 @ 16:50	0.39 @ 23:50	0.30
Tue 14 Apr 1998	0.32 @ 17:40	0.80 @ 12:50	0.39
Wed 15 Apr 1998	0.19 @ 16:30	0.33 @ 00:10	0.25
Thu 16 Apr 1998	0.19 @ 16:30	0.23 @ 23:30	0.21
Fri 17 Apr 1998	0.18 @ 12:00	0.25 @ 23:30	0.22
Sat 18 Apr 1998	0.12 @ 17:00	1.22 @ 19:00	0.34
Sun 19 Apr 1998	0.15 @ 00:00	0.27 @ 10:30	0.21
Mon 20 Apr 1998	0.14 @ 01:40	0.17 @ 23:50	0.15
Tue 21 Apr 1998	0.17 @ 00:20	1.13 @ 09:10	0.48
Wed 22 Apr 1998	0.36 @ 15:10	0.76 @ 13:10	0.59
Thu 23 Apr 1998	0.55 @ 00:50	0.94 @ 20:40	0.77
Fri 24 Apr 1998	0.78 @ 08:20	0.98 @ 15:00	0.85
Sat 25 Apr 1998			
Sun 26 Apr 1998			
Mon 27 Apr 1998			
Tue 28 Apr 1998			
Wed 29 Apr 1998			
Thu 30 Apr 1998	1.10 @ 23:50	1.23 @ 18:50	1.17
Monthly results	0.00 @ 13:00 Wed 01 Apr	1.23 @ 18:50 Thu 30 Apr	0.32

MONTHLY SUMMARY Conductivity EC (mS/cm)

Fri 01 May 1998 00:00 - Sun 31 May 1998 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Fri 01 May 1998	0.82 @ 14:50	1.13 @ 19:20	1.03
Sat 02 May 1998	0.51 @ 16:40	1.09 @ 08:50	0.81
Sun 03 May 1998	0.67 @ 00:10	1.04 @ 00:00	0.87
Mon 04 May 1998	0.68 @ 19:50	1.08 @ 15:10	0.92
Tue 05 May 1998	0.22 @ 10:10	0.85 @ 01:20	0.45
Wed 06 May 1998	0.22 @ 04:30	0.63 @ 02:30	0.45
Thu 07 May 1998	0.19 @ 14:50	0.54 @ 02:50	0.36
Fri 08 May 1998	0.32 @ 00:00	0.68 @ 17:00	0.54
Sat 09 May 1998	0.27 @ 00:50	0.72 @ 00:00	0.52
Sun 10 May 1998	0.32 @ 08:50	0.74 @ 01:10	0.56
Mon 11 May 1998	0.45 @ 06:00	0.75 @ 19:30	0.62
Tue 12 May 1998	0.72 @ 00:20	0.96 @ 15:50	0.80
Wed 13 May 1998	0.75 @ 01:10	1.15 @ 19:50	0.87
Thu 14 May 1998	0.83 @ 10:40	1.04 @ 16:50	0.92
Fri 15 May 1998	0.85 @ 03:20	1.17 @ 16:10	0.95
Sat 16 May 1998	0.94 @ 10:40	1.19 @ 20:30	1.05
Sun 17 May 1998	0.88 @ 13:00	1.10 @ 19:40	1.00
Mon 18 May 1998	0.58 @ 19:20	1.20 @ 15:20	0.91
Tue 19 May 1998	0.73 @ 00:10	1.08 @ 17:10	0.93
Wed 20 May 1998	0.89 @ 05:30	1.10 @ 18:20	0.99
Thu 21 May 1998	0.85 @ 17:00	1.20 @ 15:50	1.01
Fri 22 May 1998	0.94 @ 06:50	1.24 @ 18:40	1.04
Sat 23 May 1998	0.94 @ 05:10	1.27 @ 16:50	1.08
Sun 24 May 1998	1.02 @ 07:00	1.22 @ 15:40	1.11
Mon 25 May 1998	1.00 @ 08:50	1.24 @ 12:10	1.10
Tue 26 May 1998	0.98 @ 02:00	1.80 @ 19:00	1.14
Wed 27 May 1998	0.42 @ 17:40	1.17 @ 15:40	0.91
Thu 28 May 1998	0.44 @ 02:50	0.89 @ 16:00	0.68
Fri 29 May 1998	0.79 @ 08:30	1.10 @ 16:40	0.89
Sat 30 May 1998	0.88 @ 00:30	1.10 @ 17:20	0.96
Sun 31 May 1998	0.94 @ 05:30	1.16 @ 16:30	1.04
Monthly results	0.19 @ 14:50 Thu 07 May	1.80 @ 19:00 Tue 26 May	0.85

MONTHLY SUMMARY Conductivity EC (mS/cm)

Mon 01 Jun 1998 00:00 - Tue 30 Jun 1998 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Mon 01 Jun 1998	0.24 @ 17:30	1.08 @ 00:10	0.73
Tue 02 Jun 1998	0.43 @ 00:20	0.78 @ 18:10	0.66
Wed 03 Jun 1998	0.70 @ 02:30	0.90 @ 14:50	0.77
Thu 04 Jun 1998	0.33 @ 02:40	0.71 @ 23:40	0.53
Fri 05 Jun 1998	0.69 @ 00:10	0.91 @ 15:40	0.79
Sat 06 Jun 1998	0.33 @ 05:20	0.81 @ 23:50	0.65
Sun 07 Jun 1998	0.77 @ 07:50	0.97 @ 16:50	0.86
Mon 08 Jun 1998	0.87 @ 01:00	1.16 @ 16:30	0.98
Tue 09 Jun 1998	0.96 @ 01:20	1.23 @ 16:00	1.06
Wed 10 Jun 1998	0.78 @ 09:30	1.11 @ 01:50	0.98
Thu 11 Jun 1998	0.96 @ 07:30	1.20 @ 17:40	1.05
Fri 12 Jun 1998	0.99 @ 07:50	1.18 @ 18:20	1.07
Sat 13 Jun 1998	1.00 @ 07:40	1.23 @ 22:20	1.09
Sun 14 Jun 1998	1.02 @ 03:10	1.23 @ 15:00	1.11
Mon 15 Jun 1998	0.93 @ 19:20	1.21 @ 14:20	1.12
Tue 16 Jun 1998	0.95 @ 23:30	1.21 @ 16:10	1.10
Wed 17 Jun 1998	0.91 @ 18:10	1.14 @ 14:10	1.04
Thu 18 Jun 1998	1.05 @ 00:10	1.24 @ 13:40	1.13
Fri 19 Jun 1998	1.00 @ 21:00	1.22 @ 15:40	1.12
Sat 20 Jun 1998	1.01 @ 08:20	1.23 @ 18:50	1.08
Sun 21 Jun 1998	1.03 @ 17:50	1.20 @ 14:50	1.11
Mon 22 Jun 1998	1.09 @ 02:10	1.23 @ 22:50	1.15
Tue 23 Jun 1998	1.10 @ 22:30	1.29 @ 15:50	1.18
Wed 24 Jun 1998	1.11 @ 00:10	1.31 @ 16:10	1.18
Thu 25 Jun 1998	1.06 @ 07:30	1.25 @ 16:30	1.14
Fri 26 Jun 1998	0.71 @ 16:20	1.18 @ 12:00	0.99
Sat 27 Jun 1998	0.81 @ 00:10	1.06 @ 20:40	0.92
Sun 28 Jun 1998	0.95 @ 03:20	1.17 @ 16:50	1.05
Mon 29 Jun 1998	1.01 @ 07:20	1.21 @ 17:30	1.10
Tue 30 Jun 1998	1.02 @ 02:40	1.28 @ 14:40	1.14
Monthly results	0.24 @ 17:30 Mon 01 Jun	1.31 @ 16:10 Wed 24 Jun	1.00

MONTHLY SUMMARY Conductivity EC (mS/cm)

Wed 01 Jul 1998 00:00 - Fri 31 Jul 1998 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Wed 01 Jul 1998	0.77 @ 18:00	1.21 @ 08:00	1.03
Thu 02 Jul 1998	0.76 @ 01:20	1.08 @ 17:50	0.92
Fri 03 Jul 1998	0.56 @ 12:20	1.08 @ 07:30	0.81
Sat 04 Jul 1998	0.76 @ 00:10	0.85 @ 04:10	0.81
Sun 05 Jul 1998			
Mon 06 Jul 1998			
Tue 07 Jul 1998			
Wed 08 Jul 1998			
Thu 09 Jul 1998			
Fri 10 Jul 1998			
Sat 11 Jul 1998			
Sun 12 Jul 1998			
Mon 13 Jul 1998			
Tue 14 Jul 1998			
Wed 15 Jul 1998			
Thu 16 Jul 1998			
Fri 17 Jul 1998			
Sat 18 Jul 1998			
Sun 19 Jul 1998			
Mon 20 Jul 1998	0.77 @ 13:30	0.89 @ 16:10	0.82
Tue 21 Jul 1998	0.67 @ 13:50	0.91 @ 16:10	0.80
Wed 22 Jul 1998	0.73 @ 07:40	0.90 @ 18:30	0.80
Thu 23 Jul 1998	0.77 @ 02:50	0.97 @ 18:00	0.87
Fri 24 Jul 1998	0.81 @ 03:20	1.02 @ 17:20	0.90
Sat 25 Jul 1998	0.82 @ 06:10	1.00 @ 18:40	0.89
Sun 26 Jul 1998	0.81 @ 10:10	1.03 @ 16:40	0.90
Mon 27 Jul 1998	0.82 @ 04:50	1.01 @ 17:40	0.92
Tue 28 Jul 1998	0.57 @ 11:50	0.95 @ 04:10	0.80
Wed 29 Jul 1998	0.80 @ 07:20	0.96 @ 17:50	0.86
Thu 30 Jul 1998	0.80 @ 05:50	0.99 @ 17:00	0.88
Fri 31 Jul 1998	0.82 @ 06:50	1.03 @ 20:10	0.92
Monthly results	0.56 @ 12:20 Fri 03 Jul	1.21 @ 08:00 Wed 01 Jul	0.87

MONTHLY SUMMARY Conductivity EC (mS/cm)

Sat 01 Aug 1998 00:00 - Mon 31 Aug 1998 00:00

Springfield Road culvert
Great Lotus River

Date	Minimum YSI Conductivity (mS/cm)	Maximum YSI Conductivity (mS/cm)	Average YSI Conductivity (mS/cm)
Sat 01 Aug 1998	0.85 @ 08:50	1.09 @ 16:40	0.93
Sun 02 Aug 1998	0.83 @ 09:30	1.05 @ 14:20	0.94
Mon 03 Aug 1998	0.41 @ 22:40	1.03 @ 16:30	0.90
Tue 04 Aug 1998	0.43 @ 01:20	1.09 @ 15:00	0.82
Wed 05 Aug 1998	0.90 @ 07:40	1.10 @ 17:00	0.98
Thu 06 Aug 1998	0.75 @ 00:00	1.21 @ 15:30	1.00
Fri 07 Aug 1998	0.71 @ 01:20	1.14 @ 15:10	0.91
Sat 08 Aug 1998	0.88 @ 05:10	1.21 @ 15:30	0.98
Sun 09 Aug 1998	0.88 @ 03:50	1.15 @ 18:20	1.00
Mon 10 Aug 1998	0.94 @ 00:00	1.22 @ 17:00	1.03
Tue 11 Aug 1998	0.93 @ 22:50	1.24 @ 17:40	1.05
Wed 12 Aug 1998	0.91 @ 22:30	1.20 @ 18:10	1.04
Thu 13 Aug 1998	0.66 @ 06:50	1.19 @ 18:00	0.94
Fri 14 Aug 1998	0.31 @ 07:00	1.03 @ 00:30	0.74
Sat 15 Aug 1998	0.76 @ 06:10	1.04 @ 19:40	0.88
Sun 16 Aug 1998	0.86 @ 00:50	1.11 @ 17:00	0.98
Mon 17 Aug 1998	0.92 @ 07:30	1.29 @ 20:20	1.05
Tue 18 Aug 1998	0.96 @ 09:00	1.31 @ 18:10	1.06
Wed 19 Aug 1998	0.92 @ 17:30	1.18 @ 21:00	1.04
Thu 20 Aug 1998	1.01 @ 16:50	1.28 @ 18:00	1.10
Fri 21 Aug 1998	0.74 @ 16:40	1.15 @ 01:00	0.92
Sat 22 Aug 1998	0.57 @ 11:10	0.88 @ 00:10	0.71
Sun 23 Aug 1998	0.64 @ 00:40	1.01 @ 15:50	0.80
Mon 24 Aug 1998	0.79 @ 09:00	1.03 @ 20:50	0.88
Tue 25 Aug 1998	0.86 @ 06:30	1.20 @ 19:10	0.96
Wed 26 Aug 1998	0.84 @ 07:00	1.00 @ 00:20	0.93
Thu 27 Aug 1998			
Fri 28 Aug 1998			
Sat 29 Aug 1998			
Sun 30 Aug 1998			
Mon 31 Aug 1998	0.91 @ 12:10	1.49 @ 19:00	1.24
Monthly results	0.31 @ 07:00 Fri 14 Aug	1.49 @ 19:00 Mon 31 Aug	0.95

MONTHLY SUMMARY Annual Flow Flow

Tue 22 Jul 1997 00:00 - Thu 31 Jul 1997 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Tue 22 Jul 1997	0.17 @ 13:50	0.23 @ 12:30	0.18	15973
Wed 23 Jul 1997	0.16 @ 08:30	0.92 @ 17:00	0.29	25135
Thu 24 Jul 1997	0.19 @ 22:20	0.55 @ 00:30	0.26	22117
Fri 25 Jul 1997	0.19 @ 00:10	0.81 @ 03:40	0.33	26789
Sat 26 Jul 1997	0.20 @ 13:50	0.25 @ 19:00	0.23	20261
Sun 27 Jul 1997	0.17 @ 09:10	0.24 @ 00:30	0.20	17426
Mon 28 Jul 1997	0.16 @ 22:20	0.21 @ 00:30	0.19	16558
Tue 29 Jul 1997	0.16 @ 00:20	0.25 @ 14:10	0.20	17403
Wed 30 Jul 1997	0.20 @ 06:10	0.23 @ 19:00	0.21	18329
Thu 31 Jul 1997	0.18 @ 22:20	0.23 @ 18:40	0.20	17526
Monthly results	0.16 @ 22:20 Mon 28 Jul	0.92 @ 17:00 Wed 23 Jul	0.23	197518

MONTHLY SUMMARY Annual Flow Flow

Fri 01 Aug 1997 00:00 - Sun 31 Aug 1997 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Fri 01 Aug 1997	0.17 @ 14:40	2.42 @ 22:40	0.39	33769
Sat 02 Aug 1997	0.25 @ 22:00	1.31 @ 00:10	0.36	31156
Sun 03 Aug 1997	0.24 @ 17:10	2.47 @ 22:00	0.51	44118
Mon 04 Aug 1997	0.40 @ 10:20	1.41 @ 00:10	0.58	21555
Tue 05 Aug 1997	0.48 @ 00:00	0.56 @ 23:50	0.51	16573
Wed 06 Aug 1997	0.46 @ 08:40	4.24 @ 16:10	1.64	141970
Thu 07 Aug 1997	0.62 @ 23:10	1.59 @ 00:10	0.88	75977
Fri 08 Aug 1997	0.55 @ 10:50	0.64 @ 01:00	0.59	51297
Sat 09 Aug 1997	0.50 @ 21:50	0.57 @ 00:20	0.54	46760
Sun 10 Aug 1997	0.49 @ 06:30	0.53 @ 11:10	0.51	43660
Mon 11 Aug 1997	0.47 @ 00:00	0.49 @ 00:10	0.48	41581
Tue 12 Aug 1997	0.45 @ 23:50	0.48 @ 06:10	0.46	39723
Wed 13 Aug 1997	0.43 @ 17:20	0.45 @ 04:00	0.44	38414
Thu 14 Aug 1997	0.43 @ 08:30	0.46 @ 20:20	0.44	38277
Fri 15 Aug 1997	0.45 @ 06:20	0.46 @ 00:30	0.45	15822
Sat 16 Aug 1997				
Sun 17 Aug 1997				
Mon 18 Aug 1997				
Tue 19 Aug 1997	0.33 @ 09:00	2.19 @ 17:00	0.91	49528
Wed 20 Aug 1997	0.51 @ 09:30	0.71 @ 00:10	0.60	20634
Thu 21 Aug 1997				
Fri 22 Aug 1997				
Sat 23 Aug 1997				
Sun 24 Aug 1997				
Mon 25 Aug 1997	0.50 @ 23:40	0.59 @ 12:50	0.55	23335
Tue 26 Aug 1997	0.46 @ 13:20	0.53 @ 00:40	0.49	42451
Wed 27 Aug 1997	0.44 @ 15:40	0.48 @ 03:40	0.46	39550
Thu 28 Aug 1997	0.40 @ 16:20	0.45 @ 05:20	0.43	36967
Fri 29 Aug 1997	0.39 @ 10:10	0.67 @ 17:30	0.47	40617
Sat 30 Aug 1997	0.45 @ 02:20	1.23 @ 14:00	0.69	59698
Sun 31 Aug 1997	0.53 @ 23:40	1.42 @ 04:30	0.65	56491
Monthly results	0.17 @ 14:40 Fri 01 Aug	4.24 @ 16:10 Wed 06 Aug	0.59	1049923

MONTHLY SUMMARY Annual Flow Flow

Mon 01 Sep 1997 00:00 - Tue 30 Sep 1997 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Mon 01 Sep 1997	0.44 @ 22:30	0.53 @ 00:10	0.48	41621
Tue 02 Sep 1997	0.39 @ 00:00	0.44 @ 00:10	0.42	36589
Wed 03 Sep 1997	0.37 @ 03:30	2.57 @ 12:10	0.67	57503
Thu 04 Sep 1997	0.31 @ 14:00	0.42 @ 16:40	0.36	31006
Fri 05 Sep 1997	0.29 @ 13:00	0.44 @ 16:40	0.34	29457
Sat 06 Sep 1997	0.36 @ 23:10	0.47 @ 14:10	0.39	33457
Sun 07 Sep 1997	0.29 @ 21:50	0.37 @ 00:10	0.33	28448
Mon 08 Sep 1997	0.25 @ 15:50	0.29 @ 00:10	0.28	23960
Tue 09 Sep 1997	0.25 @ 14:50	0.30 @ 07:20	0.28	23905
Wed 10 Sep 1997	0.15 @ 16:10	0.30 @ 19:10	0.26	22021
Thu 11 Sep 1997	0.22 @ 11:00	0.31 @ 14:20	0.28	24048
Fri 12 Sep 1997	0.18 @ 17:50	0.33 @ 12:40	0.25	21733
Sat 13 Sep 1997	0.19 @ 20:00	0.25 @ 23:20	0.22	19044
Sun 14 Sep 1997	0.18 @ 03:00	0.27 @ 02:30	0.22	18937
Mon 15 Sep 1997	0.19 @ 09:00	0.25 @ 12:20	0.22	18777
Tue 16 Sep 1997	0.17 @ 11:40	0.25 @ 22:20	0.21	18343
Wed 17 Sep 1997	0.18 @ 10:30	0.25 @ 00:20	0.22	8982.05
Thu 18 Sep 1997				
Fri 19 Sep 1997				
Sat 20 Sep 1997	0.18 @ 14:10	0.28 @ 16:30	0.23	10434
Sun 21 Sep 1997	0.17 @ 07:10	0.27 @ 15:40	0.23	19545
Mon 22 Sep 1997	0.17 @ 03:30	0.28 @ 10:10	0.23	19564
Tue 23 Sep 1997	0.18 @ 07:10	0.28 @ 15:10	0.23	20160
Wed 24 Sep 1997	0.19 @ 08:30	0.28 @ 15:10	0.24	20907
Thu 25 Sep 1997	0.23 @ 07:50	0.28 @ 08:50	0.25	21806
Fri 26 Sep 1997	0.19 @ 17:10	0.27 @ 00:10	0.24	20853
Sat 27 Sep 1997	0.22 @ 12:40	0.23 @ 08:30	0.22	19318
Sun 28 Sep 1997	0.19 @ 12:50	0.25 @ 04:40	0.22	19208
Mon 29 Sep 1997	0.18 @ 12:30	0.44 @ 01:20	0.25	21454
Tue 30 Sep 1997	0.18 @ 12:20	0.23 @ 08:00	0.21	18109
Monthly results	0.15 @ 16:10 Wed 10 Sep	2.57 @ 12:10 Wed 03 Sep	0.29	669190

MONTHLY SUMMARY Annual Flow Flow

Wed 01 Oct 1997 00:00 - Fri 31 Oct 1997 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Wed 01 Oct 1997	0.20 @ 17:10	0.23 @ 08:30	0.22	18681
Thu 02 Oct 1997	0.15 @ 16:20	0.22 @ 02:40	0.19	16552
Fri 03 Oct 1997	0.17 @ 16:50	0.22 @ 19:20	0.20	16971
Sat 04 Oct 1997	0.18 @ 11:10	0.25 @ 15:50	0.21	18543
Sun 05 Oct 1997	0.22 @ 17:20	0.60 @ 07:50	0.28	23985
Mon 06 Oct 1997	0.20 @ 12:10	0.98 @ 17:00	0.28	24061
Tue 07 Oct 1997	0.08 @ 14:00	0.25 @ 05:40	0.20	17053
Wed 08 Oct 1997	0.07 @ 15:20	0.12 @ 00:10	0.10	8911.98
Thu 09 Oct 1997	0.09 @ 01:50	0.12 @ 11:10	0.10	4059.70
Fri 10 Oct 1997				
Sat 11 Oct 1997				
Sun 12 Oct 1997				
Mon 13 Oct 1997				
Tue 14 Oct 1997	0.14 @ 17:50	0.18 @ 20:20	0.16	5468.69
Wed 15 Oct 1997	0.09 @ 16:20	0.18 @ 05:20	0.14	12302
Thu 16 Oct 1997	0.10 @ 17:00	0.18 @ 07:40	0.15	13382
Fri 17 Oct 1997	0.10 @ 14:10	0.18 @ 08:30	0.15	12880
Sat 18 Oct 1997	0.13 @ 14:50	0.17 @ 08:00	0.15	13036
Sun 19 Oct 1997	0.12 @ 13:20	0.16 @ 08:30	0.15	12636
Mon 20 Oct 1997	0.10 @ 16:10	0.16 @ 08:30	0.14	11977
Tue 21 Oct 1997	0.13 @ 11:20	0.20 @ 22:50	0.16	13843
Wed 22 Oct 1997	0.13 @ 14:00	0.20 @ 00:10	0.17	14729
Thu 23 Oct 1997	0.11 @ 12:50	0.18 @ 00:10	0.15	12768
Fri 24 Oct 1997	0.12 @ 12:30	0.18 @ 00:00	0.15	13309
Sat 25 Oct 1997	0.14 @ 14:10	0.18 @ 23:20	0.17	14527
Sun 26 Oct 1997	0.10 @ 17:40	1.56 @ 09:40	0.26	22750
Mon 27 Oct 1997	0.09 @ 15:50	0.14 @ 12:00	0.11	9202.37
Tue 28 Oct 1997	0.05 @ 15:10	0.11 @ 01:40	0.08	6607.95
Wed 29 Oct 1997	0.05 @ 15:10	0.09 @ 08:10	0.07	6121.55
Thu 30 Oct 1997	0.06 @ 12:20	0.09 @ 06:10	0.07	6337.41
Fri 31 Oct 1997	0.04 @ 16:10	0.09 @ 05:40	0.07	5776.08
Monthly results	0.04 @ 16:10 Fri 31 Oct	1.56 @ 09:40 Sun 26 Oct	0.16	356472

MONTHLY SUMMARY Annual Flow Flow

Sat 01 Nov 1997 00:00 - Sun 30 Nov 1997 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Sat 01 Nov 1997	0.06 @ 10:50	0.08 @ 23:50	0.07	5842.10
Sun 02 Nov 1997	0.05 @ 17:20	0.08 @ 03:20	0.07	6035.69
Mon 03 Nov 1997	0.04 @ 16:30	0.07 @ 04:30	0.06	5017.93
Tue 04 Nov 1997	0.04 @ 17:40	0.07 @ 04:30	0.06	4813.40
Wed 05 Nov 1997	0.04 @ 14:00	0.07 @ 07:00	0.06	4137.05
Thu 06 Nov 1997	0.04 @ 11:30	0.06 @ 23:40	0.05	4694.33
Fri 07 Nov 1997	0.04 @ 12:30	0.10 @ 21:00	0.06	5528.63
Sat 08 Nov 1997	0.05 @ 14:40	0.07 @ 00:10	0.06	5296.97
Sun 09 Nov 1997	0.06 @ 01:10	0.63 @ 07:40	0.14	12305
Mon 10 Nov 1997	0.08 @ 11:40	0.12 @ 15:40	0.10	8897.81
Tue 11 Nov 1997	0.04 @ 16:10	0.11 @ 00:10	0.08	6656.14
Wed 12 Nov 1997	0.04 @ 15:10	0.10 @ 23:40	0.07	6373.45
Thu 13 Nov 1997	0.05 @ 16:50	0.10 @ 20:20	0.08	7029.55
Fri 14 Nov 1997	0.06 @ 12:30	0.10 @ 00:30	0.08	7221.52
Sat 15 Nov 1997	0.06 @ 16:30	0.08 @ 22:30	0.07	6027.59
Sun 16 Nov 1997	0.07 @ 00:10	2.94 @ 08:10	0.64	55025
Mon 17 Nov 1997	0.08 @ 23:40	0.23 @ 17:20	0.13	11574
Tue 18 Nov 1997	0.05 @ 12:40	0.20 @ 15:10	0.12	10041
Wed 19 Nov 1997	0.16 @ 23:40	0.19 @ 01:10	0.17	15092
Thu 20 Nov 1997	0.09 @ 16:40	0.59 @ 23:20	0.16	13995
Fri 21 Nov 1997	0.12 @ 19:10	0.45 @ 00:10	0.15	12710
Sat 22 Nov 1997	0.11 @ 23:10	0.23 @ 01:40	0.16	13644
Sun 23 Nov 1997	0.11 @ 12:10	0.15 @ 14:30	0.12	10460
Mon 24 Nov 1997	0.09 @ 17:00	0.24 @ 09:00	0.14	11832
Tue 25 Nov 1997	0.10 @ 13:40	0.14 @ 14:20	0.12	10039
Wed 26 Nov 1997	0.10 @ 16:30	0.13 @ 23:10	0.12	10116
Thu 27 Nov 1997	0.08 @ 15:50	0.14 @ 05:40	0.12	9980.37
Fri 28 Nov 1997	0.10 @ 15:50	0.15 @ 20:20	0.12	10242
Sat 29 Nov 1997	0.11 @ 15:50	0.15 @ 04:00	0.13	11509
Sun 30 Nov 1997	0.12 @ 16:40	0.16 @ 08:00	0.14	11852
Monthly results	0.04 @ 11:30 Thu 06 Nov	2.94 @ 08:10 Sun 16 Nov	0.12	313989

MONTHLY SUMMARY Annual Flow Flow

Mon 01 Dec 1997 00:00 - Wed 31 Dec 1997 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Mon 01 Dec 1997	0.09 @ 13:00	0.15 @ 07:00	0.12	10368
Tue 02 Dec 1997	0.11 @ 11:10	0.84 @ 21:00	0.23	19672
Wed 03 Dec 1997	0.16 @ 17:30	0.40 @ 10:50	0.22	19015
Thu 04 Dec 1997	0.12 @ 16:50	0.18 @ 04:00	0.15	12996
Fri 05 Dec 1997	0.11 @ 16:50	0.15 @ 07:00	0.14	11896
Sat 06 Dec 1997	0.14 @ 17:40	0.16 @ 05:40	0.15	12881
Sun 07 Dec 1997	0.13 @ 13:00	0.16 @ 07:40	0.14	12392
Mon 08 Dec 1997	0.08 @ 17:20	0.16 @ 07:30	0.13	11054
Tue 09 Dec 1997	0.09 @ 17:20	0.12 @ 07:30	0.11	9243.68
Wed 10 Dec 1997	0.07 @ 14:50	0.12 @ 05:10	0.10	8460.81
Thu 11 Dec 1997	0.07 @ 17:10	0.10 @ 04:50	0.09	7387.57
Fri 12 Dec 1997	0.06 @ 13:00	0.10 @ 07:10	0.08	6962.32
Sat 13 Dec 1997	0.09 @ 00:10	0.11 @ 23:50	0.10	8244.14
Sun 14 Dec 1997	0.09 @ 16:30	0.11 @ 05:40	0.10	8502.53
Mon 15 Dec 1997	0.09 @ 14:40	0.12 @ 10:10	0.10	8634.96
Tue 16 Dec 1997	0.10 @ 09:10	0.57 @ 15:10	0.16	14045
Wed 17 Dec 1997	0.11 @ 17:20	0.15 @ 05:40	0.12	10768
Thu 18 Dec 1997	0.11 @ 19:40	0.13 @ 07:00	0.12	10406
Fri 19 Dec 1997	0.09 @ 15:00	0.13 @ 08:30	0.11	9335.61
Sat 20 Dec 1997	0.07 @ 16:20	0.15 @ 08:20	0.11	9584.28
Sun 21 Dec 1997	0.08 @ 15:50	0.12 @ 21:20	0.10	8740.26
Mon 22 Dec 1997	0.07 @ 15:40	0.11 @ 05:20	0.09	7583.18
Tue 23 Dec 1997	0.07 @ 16:30	0.11 @ 23:50	0.09	7929.05
Wed 24 Dec 1997	0.08 @ 16:50	0.13 @ 09:20	0.11	9235.17
Thu 25 Dec 1997	0.06 @ 16:50	0.11 @ 10:00	0.09	7416.73
Fri 26 Dec 1997	0.07 @ 17:10	0.10 @ 08:50	0.09	7526.48
Sat 27 Dec 1997	0.09 @ 17:40	0.12 @ 22:50	0.11	9411.34
Sun 28 Dec 1997	0.10 @ 14:20	0.14 @ 08:00	0.12	10319
Mon 29 Dec 1997	0.08 @ 16:40	0.14 @ 06:10	0.11	9547.42
Tue 30 Dec 1997	0.10 @ 16:20	0.12 @ 09:30	0.11	9653.13
Wed 31 Dec 1997	0.09 @ 17:00	0.13 @ 07:50	0.12	9958.09
Monthly results	0.06 @ 16:50 Thu 25 Dec	0.84 @ 21:00 Tue 02 Dec	0.12	319167

MONTHLY SUMMARY Annual Flow Flow

Thu 01 Jan 1998 00:00 - Sat 31 Jan 1998 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Thu 01 Jan 1998	0.07 @ 15:40	0.13 @ 09:20	0.10	8938.31
Fri 02 Jan 1998	0.08 @ 15:10	0.12 @ 07:30	0.10	9027.00
Sat 03 Jan 1998	0.08 @ 15:10	0.13 @ 09:50	0.11	9088.16
Sun 04 Jan 1998	0.08 @ 14:30	0.12 @ 08:50	0.10	8907.12
Mon 05 Jan 1998	0.08 @ 16:20	0.11 @ 05:20	0.09	8176.10
Tue 06 Jan 1998	0.08 @ 18:20	0.11 @ 08:20	0.10	8504.15
Wed 07 Jan 1998	0.10 @ 00:10	0.13 @ 10:40	0.11	9717.12
Thu 08 Jan 1998	0.10 @ 19:10	0.14 @ 11:00	0.12	10405
Fri 09 Jan 1998	0.09 @ 18:00	0.19 @ 07:20	0.13	11209
Sat 10 Jan 1998	0.10 @ 17:20	0.16 @ 01:20	0.12	10022
Sun 11 Jan 1998	0.08 @ 17:20	0.11 @ 06:00	0.10	8600.13
Mon 12 Jan 1998	0.07 @ 14:30	0.13 @ 11:50	0.10	8370.09
Tue 13 Jan 1998	0.10 @ 14:10	0.34 @ 06:10	0.15	12734
Wed 14 Jan 1998	0.08 @ 17:10	0.13 @ 10:40	0.10	8741.88
Thu 15 Jan 1998	0.07 @ 16:30	0.10 @ 07:00	0.09	7614.37
Fri 16 Jan 1998	0.08 @ 18:40	0.10 @ 11:00	0.09	7609.51
Sat 17 Jan 1998	0.09 @ 00:10	0.10 @ 23:50	0.09	8139.25
Sun 18 Jan 1998	0.09 @ 17:30	0.11 @ 10:00	0.10	9033.48
Mon 19 Jan 1998	0.07 @ 19:30	0.11 @ 09:40	0.09	8139.25
Tue 20 Jan 1998	0.08 @ 16:30	0.11 @ 14:00	0.09	7695.77
Wed 21 Jan 1998	0.08 @ 07:40	0.10 @ 20:00	0.09	8016.53
Thu 22 Jan 1998	0.10 @ 00:10	0.11 @ 22:50	0.10	8737.43
Fri 23 Jan 1998	0.10 @ 16:50	0.11 @ 00:10	0.11	9113.67
Sat 24 Jan 1998	0.10 @ 11:50	0.10 @ 00:10	0.10	8511.44
Sun 25 Jan 1998	0.10 @ 00:10	0.11 @ 15:50	0.11	9185.36
Mon 26 Jan 1998	0.10 @ 09:00	0.11 @ 00:00	0.10	8981.64
Tue 27 Jan 1998	0.07 @ 18:30	0.11 @ 02:50	0.09	8160.71
Wed 28 Jan 1998	0.05 @ 17:00	0.08 @ 08:10	0.07	6114.26
Thu 29 Jan 1998	0.06 @ 16:40	0.08 @ 10:00	0.07	6105.75
Fri 30 Jan 1998	0.05 @ 15:00	0.08 @ 02:30	0.07	6189.18
Sat 31 Jan 1998	0.05 @ 15:30	0.09 @ 09:20	0.08	6586.89
Monthly results	0.05 @ 17:00 Wed 28 Jan	0.34 @ 06:10 Tue 13 Jan	0.10	266374

MONTHLY SUMMARY Annual Flow Flow

Sun 01 Feb 1998 00:00 - Sat 28 Feb 1998 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Sun 01 Feb 1998	0.06 @ 15:40	0.09 @ 08:20	0.08	6887.80
Mon 02 Feb 1998	0.05 @ 17:40	0.11 @ 08:50	0.09	7703.47
Tue 03 Feb 1998	0.09 @ 15:50	0.11 @ 09:30	0.10	8250.22
Wed 04 Feb 1998	0.09 @ 16:50	0.11 @ 05:50	0.10	8396.42
Thu 05 Feb 1998	0.07 @ 15:50	0.10 @ 08:20	0.09	7968.74
Fri 06 Feb 1998	0.06 @ 15:50	0.10 @ 09:40	0.08	7201.68
Sat 07 Feb 1998	0.07 @ 16:40	0.11 @ 23:20	0.08	7270.12
Sun 08 Feb 1998	0.06 @ 17:40	0.11 @ 00:40	0.09	7613.15
Mon 09 Feb 1998	0.05 @ 00:00	0.08 @ 09:50	0.07	6000.45
Tue 10 Feb 1998	0.04 @ 17:00	0.09 @ 10:00	0.05	4725.11
Wed 11 Feb 1998	0.05 @ 00:10	0.09 @ 14:50	0.06	5595.05
Thu 12 Feb 1998	0.08 @ 00:10	0.11 @ 14:50	0.09	7933.10
Fri 13 Feb 1998	0.09 @ 19:50	0.12 @ 13:00	0.11	9211.28
Sat 14 Feb 1998	0.06 @ 18:20	0.12 @ 02:20	0.09	7538.23
Sun 15 Feb 1998	0.06 @ 06:50	0.09 @ 15:50	0.07	6245.47
Mon 16 Feb 1998	0.06 @ 19:20	0.09 @ 06:10	0.08	6642.37
Tue 17 Feb 1998	0.07 @ 15:40	0.09 @ 02:40	0.08	6695.43
Wed 18 Feb 1998	0.05 @ 18:50	0.08 @ 11:10	0.07	5857.89
Thu 19 Feb 1998	0.05 @ 00:10	0.09 @ 11:40	0.07	6471.87
Fri 20 Feb 1998	0.08 @ 00:10	0.10 @ 12:20	0.09	7669.85
Sat 21 Feb 1998	0.06 @ 09:10	0.09 @ 23:20	0.08	6771.57
Sun 22 Feb 1998	0.08 @ 23:50	0.10 @ 19:20	0.09	7756.12
Mon 23 Feb 1998	0.08 @ 22:00	0.09 @ 16:10	0.08	7153.48
Tue 24 Feb 1998	0.08 @ 00:10	0.09 @ 12:40	0.08	7006.87
Wed 25 Feb 1998	0.08 @ 00:10	0.10 @ 17:30	0.09	7406.20
Thu 26 Feb 1998	0.05 @ 14:30	0.10 @ 04:10	0.07	6332.95
Fri 27 Feb 1998	0.06 @ 13:20	0.09 @ 20:20	0.07	6471.46
Sat 28 Feb 1998	0.05 @ 15:50	0.09 @ 00:10	0.07	6241.02
Monthly results	0.04 @ 17:00 Tue 10 Feb	0.12 @ 13:00 Fri 13 Feb	0.08	197017

MONTHLY SUMMARY Annual Flow Flow

Sun 01 Mar 1998 00:00 - Tue 31 Mar 1998 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Sun 01 Mar 1998	0.05 @ 18:00	0.08 @ 10:40	0.06	5599.91
Mon 02 Mar 1998	0.05 @ 03:20	0.10 @ 09:30	0.07	6037.71
Tue 03 Mar 1998	0.07 @ 08:30	0.09 @ 19:00	0.07	6427.72
Wed 04 Mar 1998	0.06 @ 17:50	0.09 @ 00:10	0.08	6900.76
Thu 05 Mar 1998	0.07 @ 15:00	0.08 @ 06:40	0.08	6552.87
Fri 06 Mar 1998	0.06 @ 17:40	0.08 @ 00:10	0.07	5827.92
Sat 07 Mar 1998	0.06 @ 17:30	0.08 @ 00:00	0.07	5900.42
Sun 08 Mar 1998	0.06 @ 14:10	0.08 @ 02:10	0.07	6422.86
Mon 09 Mar 1998	0.07 @ 13:50	0.13 @ 21:00	0.08	6913.32
Tue 10 Mar 1998	0.05 @ 09:40	0.10 @ 00:10	0.07	6001.67
Wed 11 Mar 1998	0.07 @ 00:10	0.16 @ 11:50	0.10	8480.25
Thu 12 Mar 1998	0.05 @ 12:00	0.08 @ 00:10	0.06	5380.80
Fri 13 Mar 1998	0.04 @ 13:10	0.06 @ 02:30	0.06	4804.09
Sat 14 Mar 1998	0.05 @ 02:00	0.08 @ 14:00	0.07	5825.90
Sun 15 Mar 1998	0.03 @ 23:30	0.07 @ 03:50	0.06	5207.87
Mon 16 Mar 1998	0.03 @ 00:10	0.05 @ 06:00	0.04	3624.73
Tue 17 Mar 1998	0.03 @ 00:10	0.67 @ 15:40	0.13	11124
Wed 18 Mar 1998	0.08 @ 23:50	0.11 @ 00:20	0.09	7648.79
Thu 19 Mar 1998	0.06 @ 14:10	0.08 @ 00:10	0.07	5978.18
Fri 20 Mar 1998	0.05 @ 16:10	0.07 @ 15:10	0.06	5221.23
Sat 21 Mar 1998	0.05 @ 11:50	0.09 @ 15:20	0.06	5593.83
Sun 22 Mar 1998	0.04 @ 17:10	0.06 @ 00:10	0.05	4526.66
Mon 23 Mar 1998	0.04 @ 14:20	0.06 @ 19:40	0.05	4473.20
Tue 24 Mar 1998	0.05 @ 16:40	0.06 @ 00:10	0.06	4815.02
Wed 25 Mar 1998	0.06 @ 01:10	0.08 @ 14:40	0.07	5848.98
Thu 26 Mar 1998	0.06 @ 16:30	0.07 @ 00:10	0.07	6245.47
Fri 27 Mar 1998	0.07 @ 06:10	0.07 @ 23:30	0.07	6140.18
Sat 28 Mar 1998	0.05 @ 18:30	0.07 @ 00:10	0.06	5175.47
Sun 29 Mar 1998	0.05 @ 03:30	0.07 @ 20:30	0.06	5063.69
Mon 30 Mar 1998	0.06 @ 12:10	0.09 @ 13:00	0.08	6664.65
Tue 31 Mar 1998	0.06 @ 19:10	0.08 @ 00:10	0.07	5964.00
Monthly results	0.03 @ 23:30 Sun 15 Mar	0.67 @ 15:40 Tue 17 Mar	0.07	186392

MONTHLY SUMMARY Annual Flow Flow

Wed 01 Apr 1998 00:00 - Thu 30 Apr 1998 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Wed 01 Apr 1998	0.05 @ 13:00	0.08 @ 16:20	0.07	6016.65
Thu 02 Apr 1998	0.06 @ 11:40	0.12 @ 18:30	0.08	7339.37
Fri 03 Apr 1998	0.09 @ 06:30	0.09 @ 00:10	0.09	7523.24
Sat 04 Apr 1998	0.07 @ 18:30	0.09 @ 00:10	0.08	6750.51
Sun 05 Apr 1998	0.08 @ 00:10	0.88 @ 11:00	0.23	19661
Mon 06 Apr 1998	0.09 @ 21:30	0.11 @ 00:40	0.10	8702.60
Tue 07 Apr 1998	0.08 @ 12:20	0.10 @ 18:20	0.09	7723.72
Wed 08 Apr 1998	0.08 @ 18:40	0.10 @ 11:10	0.09	7688.08
Thu 09 Apr 1998	0.08 @ 12:50	0.12 @ 14:20	0.09	7355.98
Fri 10 Apr 1998	0.07 @ 14:10	0.08 @ 08:00	0.08	6798.70
Sat 11 Apr 1998	0.07 @ 22:10	0.08 @ 08:50	0.08	6488.88
Sun 12 Apr 1998	0.07 @ 00:10	0.08 @ 10:50	0.08	6501.03
Mon 13 Apr 1998	0.07 @ 11:30	0.08 @ 09:10	0.08	6546.39
Tue 14 Apr 1998	0.04 @ 12:30	0.08 @ 12:40	0.07	6333.36
Wed 15 Apr 1998	0.05 @ 00:00	0.08 @ 15:20	0.06	5318.84
Thu 16 Apr 1998	0.05 @ 00:10	0.07 @ 19:30	0.06	5296.97
Fri 17 Apr 1998	0.06 @ 15:20	0.07 @ 11:50	0.07	5886.24
Sat 18 Apr 1998	0.01 @ 16:20	0.15 @ 17:30	0.07	5714.52
Sun 19 Apr 1998	0.06 @ 11:10	0.07 @ 08:40	0.07	5627.85
Mon 20 Apr 1998	0.06 @ 00:50	0.08 @ 23:10	0.07	6113.45
Tue 21 Apr 1998	0.07 @ 03:20	0.61 @ 17:20	0.21	18231
Wed 22 Apr 1998	0.11 @ 09:50	0.89 @ 13:40	0.24	20471
Thu 23 Apr 1998	0.07 @ 21:40	0.13 @ 00:10	0.09	7364.89
Fri 24 Apr 1998	0.06 @ 05:00	0.09 @ 15:20	0.07	3901.75
Sat 25 Apr 1998				
Sun 26 Apr 1998				
Mon 27 Apr 1998				
Tue 28 Apr 1998				
Wed 29 Apr 1998				
Thu 30 Apr 1998	0.16 @ 17:00	0.25 @ 17:10	0.25	6336.60
Monthly results	0.01 @ 16:20 Sat 18 Apr	0.89 @ 13:40 Wed 22 Apr	0.10	201692

MONTHLY SUMMARY Annual Flow Flow

Fri 01 May 1998 00:00 - Sun 31 May 1998 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Fri 01 May 1998	0.09 @ 21:30	0.25 @ 00:10	0.18	15359
Sat 02 May 1998	0.09 @ 08:00	0.09 @ 00:10	0.09	7871.95
Sun 03 May 1998	0.00 @ 10:30	0.09 @ 00:10	0.09	7724.12
Mon 04 May 1998	0.09 @ 05:10	0.09 @ 00:10	0.09	7871.14
Tue 05 May 1998	0.09 @ 00:10	2.48 @ 10:10	0.89	76933
Wed 06 May 1998	0.74 @ 18:30	2.67 @ 03:00	1.23	106000
Thu 07 May 1998	0.83 @ 01:30	4.04 @ 14:40	1.82	157362
Fri 08 May 1998	0.46 @ 12:30	2.26 @ 23:50	0.92	78116
Sat 09 May 1998	0.43 @ 00:00	2.13 @ 00:10	0.81	70201
Sun 10 May 1998	0.42 @ 00:50	1.32 @ 07:40	0.73	63481
Mon 11 May 1998	0.39 @ 23:40	0.92 @ 02:00	0.59	50025
Tue 12 May 1998	0.37 @ 08:00	0.40 @ 20:50	0.38	32696
Wed 13 May 1998	0.35 @ 00:00	0.38 @ 16:20	0.36	31404
Thu 14 May 1998	0.33 @ 23:10	0.35 @ 00:10	0.34	28963
Fri 15 May 1998	0.31 @ 15:10	0.33 @ 01:50	0.32	27352
Sat 16 May 1998	0.27 @ 23:00	0.31 @ 00:10	0.29	24730
Sun 17 May 1998	0.24 @ 16:00	0.31 @ 08:40	0.26	22692
Mon 18 May 1998	0.23 @ 13:00	0.87 @ 17:50	0.32	27936
Tue 19 May 1998	0.24 @ 16:00	0.28 @ 00:10	0.25	21562
Wed 20 May 1998	0.22 @ 16:30	0.25 @ 00:20	0.23	19682
Thu 21 May 1998	0.21 @ 10:10	0.28 @ 15:10	0.24	20351
Fri 22 May 1998	0.22 @ 22:30	0.25 @ 00:10	0.23	19811
Sat 23 May 1998	0.21 @ 23:20	0.23 @ 16:30	0.22	15106
Sun 24 May 1998	0.21 @ 13:50	0.22 @ 05:10	0.21	18203
Mon 25 May 1998	0.17 @ 14:40	0.21 @ 00:20	0.20	17105
Tue 26 May 1998	0.17 @ 00:00	0.23 @ 14:30	0.19	16503
Wed 27 May 1998	0.17 @ 02:30	1.60 @ 17:20	0.38	32642
Thu 28 May 1998	0.23 @ 22:20	0.99 @ 02:00	0.38	32495
Fri 29 May 1998	0.18 @ 11:10	0.24 @ 01:50	0.21	18025
Sat 30 May 1998	0.18 @ 20:20	0.21 @ 01:10	0.20	16855
Sun 31 May 1998	0.15 @ 22:30	0.18 @ 01:10	0.17	14635
Monthly results	0.00 @ 10:30 Sun 03 May	4.04 @ 14:40 Thu 07 May	0.41	1099692

MONTHLY SUMMARY Annual Flow Flow

Mon 01 Jun 1998 00:00 - Tue 30 Jun 1998 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Mon 01 Jun 1998	0.16 @ 05:40	2.56 @ 14:30	0.67	57815
Tue 02 Jun 1998	0.25 @ 00:00	0.43 @ 00:10	0.29	25047
Wed 03 Jun 1998	0.23 @ 13:00	0.63 @ 00:00	0.26	22314
Thu 04 Jun 1998	0.30 @ 00:00	1.60 @ 02:00	0.61	52646
Fri 05 Jun 1998	0.26 @ 10:30	0.31 @ 15:30	0.28	24174
Sat 06 Jun 1998	0.28 @ 00:10	1.67 @ 04:30	0.58	49717
Sun 07 Jun 1998	0.28 @ 15:40	0.40 @ 03:20	0.31	26891
Mon 08 Jun 1998	0.27 @ 12:10	0.33 @ 20:30	0.30	25579
Tue 09 Jun 1998	0.26 @ 23:30	0.30 @ 14:00	0.28	21697
Wed 10 Jun 1998	0.25 @ 00:10	0.50 @ 06:20	0.31	27215
Thu 11 Jun 1998	0.26 @ 01:30	0.28 @ 15:30	0.27	23200
Fri 12 Jun 1998	0.25 @ 12:00	0.27 @ 18:30	0.26	22142
Sat 13 Jun 1998	0.24 @ 11:50	0.26 @ 15:10	0.25	21271
Sun 14 Jun 1998	0.23 @ 20:30	0.25 @ 18:20	0.24	21073
Mon 15 Jun 1998	0.23 @ 13:30	0.30 @ 16:20	0.24	21117
Tue 16 Jun 1998	0.22 @ 03:30	0.35 @ 15:30	0.26	22286
Wed 17 Jun 1998	0.24 @ 00:00	0.35 @ 15:00	0.27	23012
Thu 18 Jun 1998	0.22 @ 10:40	0.27 @ 12:40	0.24	20621
Fri 19 Jun 1998	0.22 @ 01:20	0.29 @ 17:40	0.24	20321
Sat 20 Jun 1998	0.22 @ 00:30	0.26 @ 07:10	0.24	20540
Sun 21 Jun 1998	0.22 @ 16:00	0.24 @ 12:20	0.23	20113
Mon 22 Jun 1998	0.22 @ 00:00	0.24 @ 15:50	0.23	19668
Tue 23 Jun 1998	0.21 @ 09:10	0.25 @ 16:20	0.23	19513
Wed 24 Jun 1998	0.21 @ 05:00	0.22 @ 07:30	0.22	18916
Thu 25 Jun 1998	0.21 @ 13:00	0.28 @ 18:10	0.22	19379
Fri 26 Jun 1998	0.22 @ 07:20	0.70 @ 15:10	0.30	26043
Sat 27 Jun 1998	0.23 @ 16:00	0.34 @ 04:50	0.25	22014
Sun 28 Jun 1998	0.21 @ 23:20	0.23 @ 00:20	0.22	19127
Mon 29 Jun 1998	0.21 @ 12:20	0.24 @ 21:30	0.22	18624
Tue 30 Jun 1998	0.20 @ 14:30	0.21 @ 00:20	0.20	17637
Monthly results	0.16 @ 05:40 Mon 01 Jun	2.56 @ 14:30 Mon 01 Jun	0.29	749714

MONTHLY SUMMARY Annual Flow Flow

Wed 01 Jul 1998 00:00 - Fri 31 Jul 1998 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Wed 01 Jul 1998	0.21 @ 03:20	0.63 @ 14:50	0.32	28038
Thu 02 Jul 1998	0.23 @ 23:40	0.41 @ 00:10	0.28	23969
Fri 03 Jul 1998	0.22 @ 02:50	0.59 @ 09:30	0.38	32989
Sat 04 Jul 1998	0.28 @ 03:40	0.30 @ 00:10	0.29	5390.12
Sun 05 Jul 1998				
Mon 06 Jul 1998				
Tue 07 Jul 1998				
Wed 08 Jul 1998				
Thu 09 Jul 1998				
Fri 10 Jul 1998				
Sat 11 Jul 1998				
Sun 12 Jul 1998				
Mon 13 Jul 1998				
Tue 14 Jul 1998				
Wed 15 Jul 1998				
Thu 16 Jul 1998				
Fri 17 Jul 1998				
Sat 18 Jul 1998				
Sun 19 Jul 1998				
Mon 20 Jul 1998	0.43 @ 00:00	0.50 @ 12:30	0.45	19056
Tue 21 Jul 1998	0.38 @ 12:40	0.44 @ 02:30	0.42	36247
Wed 22 Jul 1998	0.33 @ 23:50	0.40 @ 02:20	0.37	32071
Thu 23 Jul 1998	0.31 @ 10:50	0.33 @ 00:10	0.32	27848
Fri 24 Jul 1998	0.29 @ 04:40	0.32 @ 00:40	0.30	26350
Sat 25 Jul 1998	0.29 @ 23:50	0.32 @ 07:50	0.31	26503
Sun 26 Jul 1998	0.28 @ 09:40	0.30 @ 01:20	0.29	24698
Mon 27 Jul 1998	0.25 @ 21:40	0.29 @ 07:10	0.27	23612
Tue 28 Jul 1998	0.25 @ 02:20	0.72 @ 09:10	0.37	31832
Wed 29 Jul 1998	0.28 @ 21:20	0.32 @ 10:00	0.30	25735
Thu 30 Jul 1998	0.26 @ 23:20	0.28 @ 00:10	0.27	23451
Fri 31 Jul 1998	0.25 @ 11:40	0.28 @ 20:40	0.26	22344
Monthly results	0.21 @ 03:20 Wed 01 Jul	0.72 @ 09:10 Tue 28 Jul	0.32	410134

MONTHLY SUMMARY Annual Flow Flow

Sat 01 Aug 1998 00:00 - Mon 31 Aug 1998 00:00

Springfield Road culvert
Great Lotus River - 22/07/97 to 31/08/98

Date	Minimum Flow Rate (m3s)	Maximum Flow Rate (m3s)	Average Flow Rate (m3s)	Total Flow (m3)
Sat 01 Aug 1998	0.25 @ 15:30	0.28 @ 01:40	0.26	22619
Sun 02 Aug 1998	0.24 @ 13:20	0.28 @ 03:30	0.26	22381
Mon 03 Aug 1998	0.23 @ 16:00	1.27 @ 22:00	0.36	31505
Tue 04 Aug 1998	0.37 @ 22:00	0.91 @ 00:10	0.51	43868
Wed 05 Aug 1998	0.29 @ 23:40	0.37 @ 00:20	0.32	28034
Thu 06 Aug 1998	0.28 @ 12:50	0.53 @ 22:40	0.32	27890
Fri 07 Aug 1998	0.31 @ 07:20	0.48 @ 00:20	0.34	29136
Sat 08 Aug 1998	0.29 @ 21:00	0.37 @ 17:20	0.31	27209
Sun 09 Aug 1998	0.26 @ 23:20	0.33 @ 16:40	0.30	25495
Mon 10 Aug 1998	0.18 @ 13:50	0.47 @ 16:50	0.33	28099
Tue 11 Aug 1998	0.36 @ 23:20	0.44 @ 15:50	0.39	33433
Wed 12 Aug 1998	0.29 @ 21:40	0.42 @ 10:40	0.36	30805
Thu 13 Aug 1998	0.25 @ 23:20	0.55 @ 04:00	0.32	28028
Fri 14 Aug 1998	0.25 @ 01:10	1.68 @ 06:00	0.53	45932
Sat 15 Aug 1998	0.28 @ 17:00	0.43 @ 03:20	0.34	29577
Sun 16 Aug 1998	0.25 @ 17:40	0.33 @ 03:20	0.28	24568
Mon 17 Aug 1998	0.23 @ 00:00	0.31 @ 02:40	0.26	22690
Tue 18 Aug 1998	0.22 @ 15:40	0.25 @ 18:10	0.23	20166
Wed 19 Aug 1998	0.21 @ 15:20	0.24 @ 00:40	0.23	19928
Thu 20 Aug 1998	0.22 @ 15:30	0.25 @ 21:30	0.23	20218
Fri 21 Aug 1998	0.22 @ 00:20	0.44 @ 07:00	0.31	27042
Sat 22 Aug 1998	0.31 @ 00:40	0.58 @ 09:00	0.45	39283
Sun 23 Aug 1998	0.34 @ 14:40	0.47 @ 00:10	0.38	32567
Mon 24 Aug 1998	0.30 @ 23:50	0.37 @ 02:00	0.34	29360
Tue 25 Aug 1998	0.25 @ 14:20	0.31 @ 05:50	0.29	25175
Wed 26 Aug 1998	0.26 @ 10:40	0.28 @ 08:10	0.27	10329
Thu 27 Aug 1998				
Fri 28 Aug 1998				
Sat 29 Aug 1998				
Sun 30 Aug 1998				
Mon 31 Aug 1998	0.21 @ 16:10	0.25 @ 21:40	0.22	9647.46
Monthly results	0.18 @ 13:50 Mon 10 Aug	1.68 @ 06:00 Fri 14 Aug	0.33	734984

APPENDIX I

1. *MACRO-INVERTEBRATE FAMILIES*
2. *PLANT LIST*
3. *AMPHIBIAN SPECIES*

1: List of all the macro-invertebrate families recorded on the Lotus River

	Order	Family	Recorded in channel	Recorded in vegetation
Insects				
	Coleoptera	Dytiscidae	X	x
		Hydrophilidae	x	x
	Diptera	Chironomidae	x	x
		Culicidae	x	x
		Ephydridae	x	x
		Psychodidae	x	0
		Simuliidae	x	0
		Syrphidae	x	x
	Ephemerellidae	Baetidae	x	x
		Leptophlebiidae	x	0
	Hemiptera	Belostomatidae	x	x
		Corixidae	x	x
		Gerridae	0	x
		Naucoridae	x	0
		Nepidae	x	0
		Notonectidae	x	0
		Pleidae	x	x
	Odonata	Aeshnidae	x	x
		Coenagriidae	x	x
		Corduliidae	x	x
		Gomphidae	0	x
		Libellulidae	x	x
Other invertebrates				
	Annelida	Hirudinea	x	x
	Gastropoda	Lymnaeidae	x	0
		Physidae	x	x
		Planorbidae	x	x
		Hydrobiidae	x	0
	Hydracarina	Hydrachnellae	x	x
	Turbellaria	Planaria	x	0
	Oligochaeta	Tubificidae	x	x
	?	Lumbriculidae	x	x
Total			29	22

2: *Plant list compiled from two day-trips to the Lotus River catchment*

Aquatic plants

Azolla filiculoides
Ceratophyllum demersum
Eichhornia crassipes
Filamentous algae
Lemna sp
Polygonum undulatum
Potamogeton pectinatus
Rorripa nasturtium-aquaticum
water celery (sci name?)

Grasses, reeds, sedges and restio's

*Agrostis montevidensis**
*Avena fatua**
Chondropetalum tectorum
Scirpus sp
Scirpus nodosus
Ehrharta calycina
Fericulum vulgar
Inferata cylindrica
Juncus sp
Juncus craussi
*Lagarus ovatus**
Paspalum dilatatum
Pennisetum clandestinum (Kikuyu)*
Phragmites australis
Typha capensis

Shrubs

*Acacia saligna**
Chrysanthemoides incana
Cliffortia sp
Helichrysum sp
Myrica quercifolia
Otholobium fruticans
Phylica sp
Polygala sp
Rhus laegivata
Spartinia sp (spanish broom)

Herbacious plants

*Acanthus sp**
*Anagonis sp**
Anthospermum ciliare
*Cana sp**
Carpobrotus edulis
*Chrysanthemum ponosum**
Chrysocoma coma-aurea
Cotula coronopifolia
Cotula vulgaris
Cynanchum africanum
Datura sp
*Euphorbia pepelis**
Gazania pectinata
Geranium incanum
*Icium sp**
Lightfootia sp
Linum sp
Lythrum hyssopifolia
*Malva sp**
Metalasia muricata
Metalasia sp
Moraea sp
*Moriscus sp**
Muraltia sp
*Nasturtium aquaticum**
Orphium frutescens
Passerina vulgaris
Pelargonium betulinum
Pelargonium capitatum
*Picris iciodes**
Psoralia sp
Raphanus raphanistrum
*Resida sp**
*Rumex sp 1**
*Rumex sp 2**
*Rumex sp 3**
*Rupistrum sp**
*Santius sp **
Sarcocornia littorea
Senecio elegans
Senecio halimifolius
*Senecio pterophorus **
Senecio sp
Solanum nigrum
Tetragonia fruticosa
Zantedeschia aethiopica

3: List of amphibian species occurring originally on the Cape Flats. Conservation status and expected present day occurrence (based on habitat availability) in the Lotus River catchment (data from {De Villiers, 1997}, and {Griffeth and Erasmus, 1997})

Species	Common name	Conservation status	Occurrence
Bufo pardalis	leopard toad	locally threatened	*recorded
Bufo angusticeps	sand toad	locally threatened	expected
Breviceps rosei	sand rain frog	locally threatened	expected
Cacosternum boettgeri	common caco	common	*recorded
Hyperolius horstockii	arum lily frog	locally threatened	expected
Microbatrechella capensis	micro frog	locally endangered	not expected
Rana fuscigula	Cape river frog	common	expected
Semnodactylus wealii	rattling frog	locally threatened	expected
Strongylopus grayii	spotted grass frog	common	*recorded
Tomopterna delalandii	Cape sand frog	common	expected
Xenopus laevis	common platana	common	expected
Xenopus gilli	Cape platana	endangered	not expected

APPENDIX J

WORKSHOPS' GROUP REPORTS

GROUP REPORTS FROM THE WORKSHOPS

Saturday 27/06/98 and Sunday 28/06/98

The following report is a compilation of the discussions that occurred in community workshops that were facilitated by Abbott Grobicki. The workshop began with a short presentation on the meaning and the implications of implementing integrated catchment management in urban areas. This presentation also highlighted the key role players that would have to be involved in the process of integrated catchment management, including negotiating on aspects like the nature of catchment management structures, their role and responsibility and their operation.

The workshop was attended by a number of representatives from civics and development forums operating within the catchment area. Workshop participants were divided into three groups. These groups were mixed according to the different areas of the catchment. The groups were given an hour to discuss in details the following questions and to report on the outcomes of these discussions.

LOTUS RIVER PROJECT
Community Participation Workshop – Catchment Management Model

Discussion Questions

What are the key areas and issues that must be addressed in the development and management of the Lotus River Catchment Area and the Canal that are important for your area? Discuss under the following guiding categories:-

- Crime and Security
- Community and Environmental Health
- Physical Development Needs and Flood Control
- Municipal Service Delivery
- Public Amenities

What are the key areas that must be addressed to sustain the involvement of communities and their organisations in the management of the catchment area?

- Organisational Capacity
- Information Management
- Organisation and Individual Training/Skills Transfer
- Nature of Environmental Education Projects
- Provision of Technical Support
- Financial Support/Remuneration of Participants
- Nature of Development Projects
- Job Creation Opportunities

These questions were also translated into Xhosa so that people using Xhosa only as a medium of communication could participate fully in the discussions. The questions were as follows:

Intatho Nxaxheba Yemibutho Nabameli Boluntu - Uqulunqo longaqo-nkqubo wokwakhiwa kwesiseko solawulo lomfula nengingqi yeLotus River

Imibuzo yokukhokela ingxoxo

Yeyiphi imiba ephambili okanye ebalulekileyo ekufuneka iqwalaselwe kuphuhliso nakwisiseko solawulo lwalomfula nengingqi eziwungqongileyo? Xoxa phantsi kwezingongoma zilandelayo ezisisikhokhelo:-

- Ubundlobongela nokhuseleko loluntu jikelele
- Impilo yoluntu kwakunye neyezendalo
- Uphuhliso olufunekayo kunye nolawulo lwezikhukhula
- Inkonzo zikaMasipala
- Indawo zolonwabo zabadala nabantwana

Yeyiphi imiba ekufuneka iqwalaselwe ukuze imibutho yoluntu kwakunye noluntu ngokubanzi ibenokuqhubekeka ngokuthabatha inxaxheba ixesha elide kulawulo lwalomfula nengigqi yawo? Xoxa phantsi kwezingongoma zilandelayo ezisisikhokhelo:-

- Isimo namandla yemibutho yasekuhlaleni
- Imfundiso ngolwazi nencubeko enokuncedisana nentatho-nxaxheba yoluntu
- Ulawulo lolwazi olunokusetyenziswa ekuthatyathweni kwezigqibo
- Ikusasaza ulwazi ngokubaluleka kwempilo nokuphuculwa kwezendalo
- Intlawulo kubathathi nxaxheba
- Uncedo lwezochwepheshe
- Uphuhliso olunokungenisa izimali okanye luphucule ukuhlala
- Imisebenzi yoluntu

Each group was given a set of flip-chart sheets and pens to write down the group's response to the various questions. Each group chose a person amongst them to report to plenary. At the end of the hour, the groups then report to plenary. The following are group reports:

Group 3

1. Environmental Education Programmes must aim to educate people about the

   Practical advantages of a clean environment and the importance of biological diversity
   Environmental clean-up campaigns must be long-term and be linked educational projects
   Facilitate environmental awareness through long-term environmental education projects
   Environmental education projects must be linked to implementation projects
   Facilitate local action by building capacity of local environmental groups and civics
   Support direct involvement of local people on environmental projects

2. Need to support these efforts with appropriate levels of service delivery and housing

   Provide housing and infrastructure to address the proliferation of informal settlements
   Provide public rubbish bins to discourage littering
   Provide public toilets and baths to improve sanitation and health awareness
   Improve service provision through partnerships with local organisations
   Build capacity of local authority to enable them to engage in local partnership

3. Upgrade Stormwater system in residential areas

   Improve stormwater system to reduce the risk of flooding
   Stormwater system must also be seen as a resource
   - to provide recreational amenities
   - source of future potable water
   - to recharge ground water and other water-bodies

4. Upgrade old and collapsed civil infrastructure to support healthy environments

   Implement integrated development to improve deteriorating civil infrastructure in historically disadvantaged areas to reduce the risk of sewerage spillage into the stormwater system
   Co-ordination in service delivery must be encouraged

5. Stormwater management or flood control infrastructure must be

   Aesthetically pleasing, environmentally friendly and be viewed as a beneficial public amenities
   Effective security control measures for public amenities must be explored with the community
   The municipality must explore long-term integrated security programmes for all public amenities in local areas

6. Refer to 5, there must be a temporal fencing off of the canal were there is a security problem

7. Environmental education projects must be long-term and promote healthy living environment

   Environmental education projects should target schools and organised environmental groups
   Environmental education must be integrated into the school curriculum
   Local physical development must be linked to environmental education and training
   Local groups must be involved in implementation of local environmental projects

Section Two

8. Establish focus groups and task teams at local level to focus on environmental projects

   Form implementation partnership task teams with cleansing department of municipalities
   Explore environmental competitions for community based-groups and schools
   Explore partnership opportunities that promote local planning and implementation

9. Municipalities must support the development of strong local groups

   Providing focused capacity building and training to local CBOs
   Explore linking training with current environmental projects
   Establish capacity building fund to develop local implementation institutions (CBOs and NGOs)

10. Explore Partnership programmes that will focus on the improvement of the environment

    Involve development forums, CBOs, NGOs and Municipalities in implementation partnerships
    Explore municipal-school partnership on environmental projects

11. Use open spaces along the canal

    To provide recreational park, flower gardens, sports fields, amphitheatre etc for public use

12. Physical development projects should be implemented through labour intensive methods

13. The CMC and Local Authorities should provide technical support to communities

    Catchment Management fund to be used to also provide technical support to local communities

14. The CMC and local authorities should explore setting-up a Catchment Management Fund

    To facilitate and support the establishment of community participation structures and mechanisms
    To provide technical support to the community and the Catchment Management Body
    Support project development and feasibility studies

Group 4

1. Solution is to cover the canal and use underground stormwater system

2. Use the grounds for the provision of locally maintained sports grounds

3. Provide improved stormwater system to prevent flooding

4. Co-ordinated service delivery must be undertaken in partnership with local communities

5. Good pedestrian crossing facilities over the canal necessary

6. Facilitate locally monitored security systems and promote sense of ownership

7. Provide recreational amenities and parks for adults and children

Section 2

8. Implement environmental education programmes, targeting both children and adults

9. Local planning, operation and maintenance through partnership must be encouraged

Group 2

1. Facilitate local workshops to address local environmental issues to promote local involvement

2. Environmental education should be integrated into schools curriculum

3. Environmental projects should be managed and operated locally

4. Provide capacity building and training to local organisations

5. Environmental Advocacy programmes must be encouraged

6. Service delivery must be co-ordinated

7. Provide mentorship programmes to facilitate skill transfer in terms of administration and technical skills. These must be linked to projects that are happening on the ground to facilitate sustained involvement of local organisation

8. Local structures must be provided with support through for example, ability to approach private sector environmental consultancies for technical advice and training

9. Local Government must provide financial support to facilitate local involvement, capacity building and training

Group 1

1. Council must provide services or even upgrade places like Phola Park and Waterfront

2. Provision of housing and appropriate infrastructure is the better route, but is a long-term process. Therefore should also be supported by short-term solutions like public sanitation facilities

3. Fencing of canal is an option in minimising pollution of water

4. The above must be based on the provision by the municipality of improved and co-ordinated service delivery (cleansing, water and sanitation, upgrading of deteriorating sewerage and stormwater infrastructure, and administration)

5. Parks and other recreational amenities be provided by council and be managed or operated, and maintained on a partnership basis between communities and the municipality

6. Fencing, integrated security provision projects must be considered

7. The canal must be fenced in the short term for security reasons, while projects are being considered

8. Footbridge or pedestrian crossing over the canal must be upgraded

Sunday Workshop (28 June 1998)

Group 3

1. Combination of short and long-term health and environmental awareness projects to deal with the consequence of pollution, polluted rivers and polluted environments. These must be undertaken in partnership between the community, environmental NGOs and the municipality. There should be improved communication lines and information flow between municipal government and the community

2. Housing delivery and upgrading of infrastructure must be on the top of municipal agenda to address informal settlements along the canal, and to limit pollution. Short-term projects to collect litter at local level through the involvement of the schools and the community must be co-ordinated by the Development Forum with support from the municipality. However need to seriously consider the cost of providing housing and improving services on Rates and the need to pay for services

3. Turn open spaces into temporal soccer fields and other sports facilities and also consider landscaping along the canal to discourage illegal dumping and littering

4. The municipality must support closer working relationship between itself, NGOs and local communities

5. Explore possibility of inner city mini-lakes/public water bodies and wetlands to improve water quality. Consider up market housing development for housing along the canal with tariffs linked to privilege for canal improvement. There must be controlled access points to the canal, to facilitate pollution control, litter control and water quality improvement. Canal and water must be used as recreational facility.

6. Access points to facilitate security provision

7. RDP and Council should work out litter, pollution, and security control measures linked to job creation.

8. Local Organisational Capacity must be supported by municipality to manage the portion of the canal within area of activity

9. Provide Lighting for security, and to provide jogging, cycling, dog walking, hiking and other sports facilities to turn the canal into a beneficial amenity

10. On-going workshops need to be organised to focus on local environmental issues involving local community organisations, NGOs and local schools.

11. RDP together with council and other interested parties to determine local environmental education and physical development projects

12. Eco-tourism, local relevance, environmental health projects must lead to employment, increased opportunities, upliftment and improved services and quality of life, improved areas, less crime, skills training, Catchment improvement will benefit all communities due to length of canal

Group 2

1. Educational programmes to improve awareness of the benefits of environmental health and appreciation for the environment

   Pollution prevention programmes

2. Upgrade aging and overloaded civil infrastructure. Proper planning, operation and maintenance

   Development of wetlands - barred

3. Recreational and aesthetic value of canal and water ways to be enhanced, Partnership Arrangement to prevent crime and to educate

4. Turn waterways from being a liability to being assets for education, recreation, food, primary needs

Section 2

5. Support the formation of environmental portfolio in each CBO

6. Development of an integrated environmental awareness programme

Group 4

. . no data

Tape Recorded Group Reports

Workshop I

Date 27 June 1998

Group 1

Community and Environmental health
Phola Park

Must either be fully upgraded or be provided with temporary water and sanitation services if it is to be relocated because people will continue to use it as a sewerage and cleansing system in the absence of these services.

Physical development

There must be some buffer area between households and the river so that these households do not use the river as a garbage removal system.
Some people must be relocated, particularly those who are on the banks of the river, to make way for this buffer area
Concrete walls must be considered to prevent people from abusing the river and water pollution
There must be integrated and improved services like street cleansing, garbage collection and disposal, services for garden waste and building rubble removal
Deteriorating civil infrastructure must be upgraded and upgrading must take into account population numbers and other socio-economic issues. This will prevent sewerage system failure and consequently the spillage of sewerage into the river and other water bodies
There must be public parks for both adults and children provided near the river with cleansing and garbage collection service. In these parks there must be security provided to prevent criminals abusing them parks. Security measures like appropriate fencing, controlled entry and exit points and security personnel during certain times of the day
Jobs can be created through the provision of these parks

Public Amenities - In areas where recreational and income generating services cannot be provided, these must be fenced off
Public amenities - Foot bridge over the river must be upgraded appropriately particularly in relation of both adults and children

Capacity Building - Workshops like these must be brought closer to the people and be broadened to include reps of street committees so that people can begin to appreciate the relationship between the river and immediate environment

Environmental Education – Public meeting and activities to inform and promote environmental issues and environmental advocacy groups must be encouraged

Job Creation – Environment related training must be linked to job creation environmental projects, focusing on people that are involved in organised groups, civics and development forums

Technical Support – Independent Environmental NGO or Consultancies must be provided with resources to provide technical support and training to CBOs so that they can participate meaningfully in the catchment management process

Financial Support – The mobilisation and deployment of financial and other resources to make participatory catchment management possible must be the role of the CMC and its substructures

Group II Peter Mokoena

Community and Environmental Health

In particular areas the Canal must run underground and in these particular areas there must be sport fields, (cricket, bicycle, soccer, skateboarding, etc), so that the community can use this land to their benefit

Flood Control

Civil infrastructure must be upgraded in line with development and increasing population

Municipal Services

Street cleansing and garbage collection services must be improved. Implementation of this improvement must be negotiated with the community to take into account their needs and interests.

Crime and Security

Fencing and the development of parks, with appropriate lighting must be considered

Organisational Capacity

Development forums, Civics and other organised groups must be encouraged to participate in catchment management through the provision of technical information, advice and training

Learners at Primary and High School level must be targeted for environmental development and management projects so that environmental awareness can reach all households and streets

Appropriate and decent footbridge needs to be provided for crossing the river in areas where the canal is exposed

Job Creation Opportunities

Parks and other projects related to the canal must be done on a labour intensive basis
Parks near the canal must be considered because this will provide recreational facilities and will provide long-term jobs in relation to their maintenance

Landscaping that is provided for these parks, like trees and other vegetation, must be such that it does not expose people to more crime. Parks must be provided with security measures, like fencing, controlled exit and entry points and public use times

Group III

Environmental Health

Long-term Environmental health education programmes must be provided to communities and schools

Infrastructure

Public toilets must be provided not only in parks but also for example close to public baths and swimming pools

Phola Park and other informal settlements must be provided with infrastructure and housing, or if this is not possible to be relocated

Flood Control

Upgrade stormwater system and provide garbage facilities for builder's rubble and garden waste

Municipal Services

Services must be improved and co-ordinated so that when stormwater, sewerage system and streets are being cleaned, the dirt is simultaneously collected and disposed of

Streets must be cleaned and swept frequently

Public Amenities

Parks for children and adults must be provided near the canal so that these parks are linked to the canal to make the canal valuable to the people

Crime and Security

Temporal and long-term security measures must be provided to the parks and other projects that are linked to the canal. These must be negotiated with the community so that these are appropriate and address the needs of the community

Environmental Education

Schools must be targeted to integrate environmental education and awareness into the curriculum.
Where there are school based environmental groups these must be encourage through the provision of support and training

The municipality must support the formation of environmental health groups in every school. It is the youth that can make an immediate and significant impact on the status of our environment

Environmental Task Teams that are linked to CBOs and development forums must be supported because these will eventually form part of the catchment management body
There should be a catchment management body that will coordinate all work that is related to the canal and environment in general. This body must include communities, municipalities and other role-players and these parties must negotiate the make up, role and responsibilities of this body

Public recreational amenities

The canal must be linked to parks and other recreational amenities so that the community can begin to view the canal as a contributing to the improvement of quality of life. It would also be easy to mobilise the people to take control of the canal and contribute to its maintenance and cleaning

Job Creation

Projects that are implemented along the canal must be based on job creation. These parks will also provide jobs in relation to their construction and maintenance

Technical Support

The municipality must work together with CBO, RDP forums and independent agencies to build capacity and skills of the community through their organisations in terms of environmental management and awareness

Financial Support

All spheres of government must contribute to the financial needs of the participatory catchment management process

The private sector must be encourage to contribute financially and in terms of technical skills

GENERAL DISCUSSION

The catchment management body must be inclusive particularly in terms of CBOs, and Development forum. Temporary Toilets can pose a problem in terms of maintenance. Public toilets are necessary to provide sanitation to the public not only parks but other public areas like shopping centres, public swimming and washing facilities, public open spaces, and these must maintained by the municipality

If possible Phola Park must be upgraded to provide housing and infrastructure and the over-spill must be relocated. All other settlements must be upgraded for hosing if possible
Phola Park must be upgraded to be linked with the hostel upgrading project that is underway there. This development must be improved to include a public recreational amenity that is linked to the canal with public toilets provided
On other side of the canal opposite Phola Park, a public recreational area with landscaping that will include sport and playing facilities, picnic and braai spot for adults and children must be seriously considered. This will greatly improve the residential component across the canal
Temporary toilets that are provided to informal settlements and used on a shared basis cause a lot of social problems:

- neighbours fighting over who should maintain them, or
- one household putting a padlock and locking the toilet such that other households are not able to use it
- maintenance problem regarding the municipality

There is a problem managing and co-ordinating the relocation of people to other areas because it is usually done on a piecemeal basis and this cause disruption and the remaining community is not able to control the re-invasion of cleared plots
The improvement or the redevelopment of the canal will not succeed if it is not linked to what is happening to adjoining areas like Phola Park/Water Front
There seem to be consensus of about the development of a park on the other side of Phola Park. The upgrading of Phola Park to be linked to the hostel upgrading and who should benefit is a matter that needs to be discussed by the community

Workshop II

Date 28 June 1998

Group I

Community and Environmental Health
Homes and Upgrading

These are related because unless you have a decent home, something that is yours to be proud of, you will never be able to appreciate the importance of the your immediate environment and be proud of anything.

If we encourage social development through participatory physical development, through the provision and of decent homes and improving the existing stock, then you begin to encourage people to own their immediate environment. They begin to realise that they have a stake in making sure that their decent homes cannot co-exist with a poor and unclean environment. Therefore an improved environment begins with people taking ownership of their lives, through the provision of decent homes and participation in their development.

Environmental Education

We should target the young in schools to broaden the understanding of the relationship between what we do at home and the quality of the environment

Upgrading areas will come with better housing and ownership of decent homes will bring appreciation of the environment and long-term environmental education programmes will provide sustainability

Municipal Services

There is no co-ordination between the various arms of the municipality. It is pointless to adopt grand plans in terms of environmental programmes if these bear no relation to the realities on the ground. Consequently there will be a waste of resources and garbage and dirt will end up in the canal. There is a need for community-municipal partnership for the provision of services

Organisation Capacity

The capacity of local organisation to engage effectively in these partnerships for the co-ordination and implementation of environmental improvement and management programmes is important. Without strong organisations it would be a huge task to achieve co-ordinated, integrated and participatory service delivery

Group II

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General Discussion

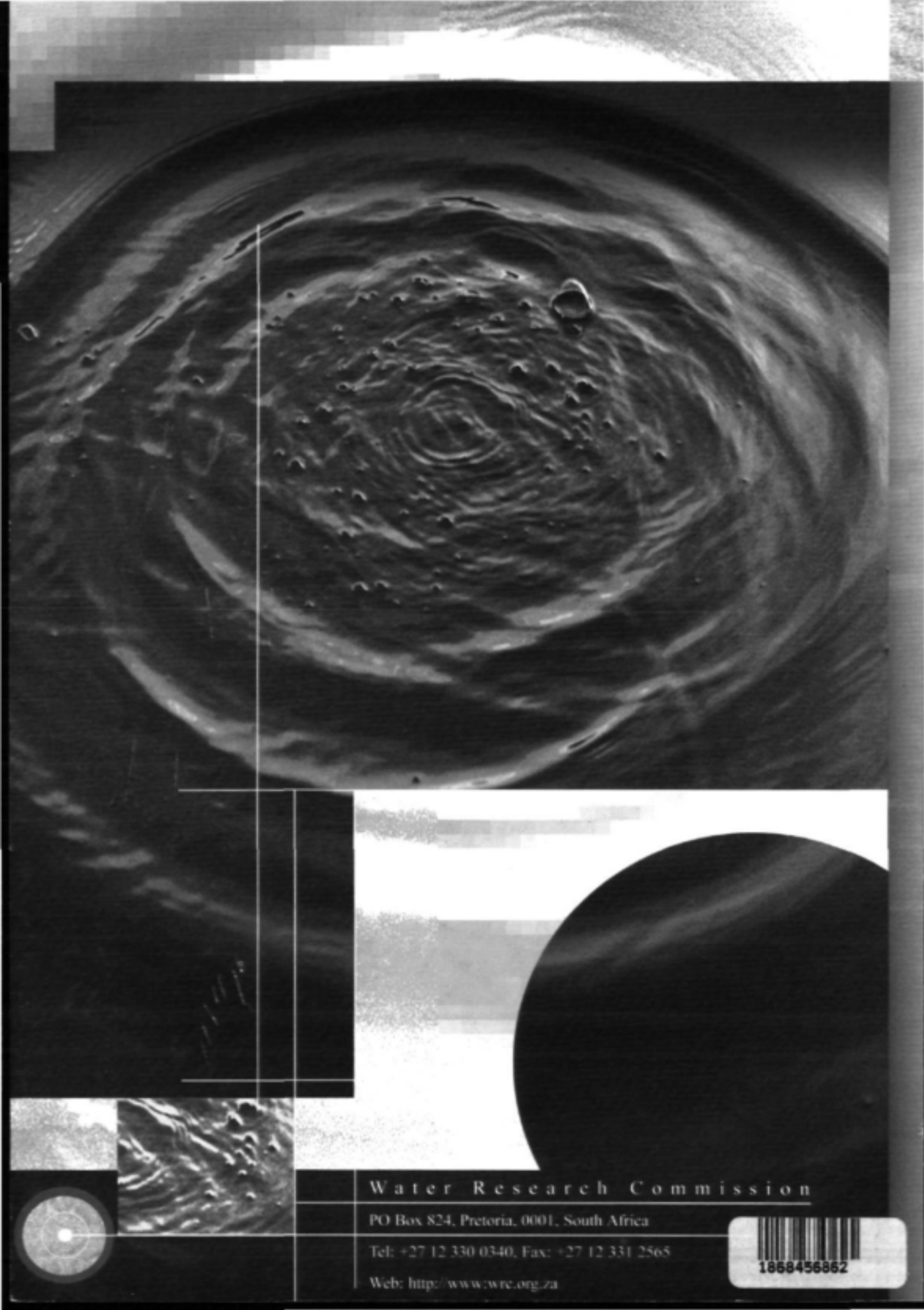
Social and Economic development need to be encourage through municipal and community partnerships. These partnerships should look at service delivery, environmental management, physical and economic development. The promotion of community involvement through the building of capacity local organisations, training and skills transfer would facilitate integrated development.

Recycling Depot for bottles, paper, tin, etc close to communities will facilitate both environmental improvement and job creation

Critical that Environmental Management and Improvement is not politicised
Critical that we do not relate environmental status with the political party that is governing be cause the environmental status today may have been caused by actions many years ago

Mega-City (Unicity) concept may pose problems in relation to implementation of participation and catchment management. Distance between people and policy makers

Area management concept is very critical for service delivery and the partnership with local contractors will facilitate co-ordinated and improved service delivery because it would be easy to reach the responsible structure/authority/contractor and there would be a quicker response. Service delivery and environmental management should be done at a local level with the involvement of the local communities because people begin to own their environment and become more responsible because they are good response from the local area management centre. Devolution of service delivery and the involvement of communities in planning and implementation is critical



Water Research Commission

PO Box 824, Pretoria, 0001, South Africa

Tel: +27 12 330 0340, Fax: +27 12 331 2565

Web: http://www.wrc.org.za

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