EVALUATION OF SEWAGE TREATMENT PACKAGE PLANTS FOR RURAL, PERI-URBAN AND COMMUNITY USE

P Gaydon • N McNab • G Mulder •
I Pillay • M Sahibdeen • P Thompson

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Report to the
WATER RESEARCH COMMISSION

by

Paul Gaydon, Neil McNab, Garth Mulder, Indran Pillay, Minnesh Sahibdeen, & Peter Thompson

Wastewater Treatment and Trade Effluent Section,
Engineering and Scientific Services,
Umgeni Water

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Executive Summary

The challenges of effective environmental protection from the impacts of domestic sewage disposal in recently developed and rural areas are a matter of international concern.

The technologies required to successfully treat sewage have been well established, although successful treatment becomes less common with systems treating smaller daily volumes. Smaller plants are more prone to failure due to the lack of capacity to attenuate variations in load or flow. Package plants may be defined as any on-site sewage treatment system, although some authors have sought to further refine the definition to include only privately owned plants that discharge less than $2000m^3.day^1$. Small on-site systems are often promoted as the best means of dealing with increasing water pollution problems, and are on occasion legally required alternatives to septic tanks where the impact of such tanks has been questioned.

Typically the more technically complicated plants are recommended for use in areas where soil conditions are unsuitable for subsurface sewage drainage fields and regional sewerage systems do not exist. Package plants are thus generally employed in areas not served by larger centralised sewage treatment works.

Package plants themselves vary widely in the level of technology used. The simplest low technology units are anaerobic treatment systems such as septic tank and soil drains that require no separate energy supply and are virtually maintenance free. Requirements for greater degrees of sophistication progressively bring in engineered pond and wetland treatment systems, trickling filters, rotating biological contactors and mechanically aerated treatment systems.

The international experience with sewage package plants has indicated that there is no simple formula to use in order to select which sewage treatment technology to choose. Investigations reviewed concluded that it is difficult to find significant correlations of effluent quality with specific design features of package treatment plants.

The current South African understanding that package plants should be treated with circumspection has clearly been mirrored elsewhere. However, provided building specifications rule out the use of inappropriately designed units, good quality effluent is a reasonable expectation provided adequate provision is made for the necessary expenditure on maintenance, skilled operation and meaningful quality monitoring.

To this end and in view of the technical nature of treating sewage for safe release to the environment, the project team recommended that the Water Research Commission or the national regulator consider future funding for the establishment of an assessment and accreditation facility for small scale onsite sewage treatment works.

The facility should provide for the testing of performance of package plant technologies against set standards in order to ensure their effectiveness. The testing centre should also be

able to provide a consulting service to property owners, developers and local authorities on the suitability of technologies for specific applications.

It was proposed that the basis for this accreditation could largely be the American NSF/ANSI 40-2005 standard, as the authors believed this system to be comprehensive and useful in structuring an accreditation procedure for South Africa. Typical advantages of such an accreditation are that it would provide a national basis for testing; users, regulators and those with environmental interests would thus be provided with an excellent understanding of achievable performance over a range of practical loading conditions.

Within the context of the overall need for improved environmental protection, the Water Research Commission approved a proposal to investigate the performance of small-scale sewage package plants under South African conditions.

The criteria selected for the evaluation of the package plants performance were the standards contained in the revised General Authorisation published in March 2004. This standard offers two sets of criteria: one for discharge into a water resource, and the other for irrigation.

It was noted that that biological processes require time to develop sufficient biomass to effectively treat sewage, thus the evaluation of a plant's performance may only be accurately carried out after the development of steady state conditions. That is, compliance figures are only meaningful after making allowance for a start-up period for the systems involved. For this study it was decided that only performance after an initial 3 week period would be considered as representative of normal performance.

In terms of the General Authorisation, users must ensure the establishment of programmes to monitor the quantity and quality of the discharge prior to the commencement of the discharge. The monitoring requirements for domestic sewage discharges are reproduced in Table 1.1. in Chapter 1.

The prime motivation for publication of standards is protection of the aquatic and other environments. Ideally the water returned to the environment should be of an equal or better quality than that existing already in the environment. In addition, treated sewage should also always be discharged to the same catchment that it originated from to ensure that the river flows are as natural as possible. In reality there is always some degradation of the environment and the purpose of regulations is thus to limit degradation to acceptable limits. Achievable regulations must be tied to technology, thus they should be set so that they can be achieved in a "reasonable" percentage of the time by available technologies. The project team proposed that a compliance percentage of 80% or better should constitute acceptable performance for package plants due to the scale of their environmental impact, their sensitivity to diurnal fluctuations and the common lack of expertise in operation.

The study determined that there is an estimated 600 small scale sewage treatment systems (package plants) installed in South Africa and these tend to fail most often in their ability to effectively nitrify ammonia, and in disinfecting against bacteria. Removal of chemical oxygen demand and suspended solids tended to be successfully done by the small scale technologies. In comparing average performance of the 3 technologies tested (a submerged bio-contactor, a rotating bio-contactor and an activated sludge system) small scale plants achieved an average of 31% compliance with General Authorisation requirement for ammonia, and 85% compliance with the *E.coli* standard. Chemical oxygen demand was complied with in 94% of results under steady state conditions, and the suspended solids data was 97% compliant with requirements.

It was found that the failures of these smaller plants was not due to the processes being unable to attenuate the various pollutants, but that faults lay in the design and operation of the treatment systems. It was concluded that the design capacity problem could be addressed by the dissemination of effective design parameters. To this end, Appendix 4, a Guideline for users and designers of package plants, was compiled to assist in ensuring process requirements are met in the design phase of package plant implementation.

The difficulties arising from poor operation and maintenance of privately owned sewage treatment systems remain an intractable problem. The reality of units producing effluents with pollution potential in the hands of inexperienced or uninformed operators is a tremendous difficulty facing the authorities, which may largely be addressed by the implementation of the previously mentioned national accreditation facility.

The project team strongly recommended treated effluents be irrigated wherever possible. Where irrigation is impractical, discharge to river may be the most commonly applicable alternative disposal strategy. In this regard, it was concluded that the South Africa's General Limit Values (under Section 39 of the National Water Act, Act 36 of 1998) should be able to be regularly met by properly designed package plants. Special Limit Values applying in areas of particular environmental sensitivity would be expected to require purpose designed treatment equipment. The authors concluded that the requirements set out in the General Limit Values are realistic and sustainable.

The study concluded that the growth in the use of on-site sanitation, in particular package plants, is likely to be an increasing trend in South Africa and internationally. The driving factors included economic factors, site development in areas with physical constraints limiting the choice of on-site sewage treatment processes and a greater degree of environmental impact monitoring and legislative control.

Both within South Africa and abroad, failures are most commonly ascribed to poor design and construction, insufficient or no maintenance and mechanical breakdowns.

It was found that package plant manufacturers face a number of challenges including small plant dimensions, high variability of influent sewage, and a lack of maintenance and operational skills which were further exacerbated by limitations in the funding of research and development of package plant technologies. Package plant development appears to have chiefly been in the hands of private individuals without the benefit of substantial research.

It was observed that the legislative framework for package plants in South Africa is a neglected area. While there are the General Authorisations for discharge to water bodies and irrigation, the compliance levels were not stated. There is also debate about whether the permissible irrigation of crops and pastures should include domestic lawns. The authors argued that inclusion of lawn irrigation as an allowable form of effluent disposal would fall within the spirit of grey water reuse, would assist in demand management, as well as attenuating the diurnals experienced by the receiving streams. A life cycle assessment for the irrigation of effluent should prove to have a favourable outcome as it should help reduce the use of electricity, with a concomitant lowering in the generation of greenhouse gases.

There are essentially three technologies available in package plants in South Africa:

- Activated sludge (conventional extended aeration or sequencing batch reactor)
- Submerged bio-contactors (fixed or random packing)
- Rotating bio-contactors

The rotating bio-contactors appear to have the major share of the market, by virtue of volume, at present. Examples of all three technologies were assessed in this study. The submerged bio-contactor followed by artificial wetland was shown to be capable of achieving 80% compliance with the General Authorisation for direct discharge for factors other than ammonia. Without an effluent polishing step COD and SS compliance are likely to become problematic in addition to the previously noted difficulty in complying with the ammonia standard.

The rotating bio-contactor experienced problems mainly in terms of compliance for nitrification (10% compliance) and disinfection (71% compliance) when compared to the General Authorisation for direct discharge. The compliance for COD and suspended solids removal was 100% and 91% respectively once problems with an underperforming clarifier were resolved.

The sequencing batch reactor, a somewhat larger plant than its peers in this study, achieved compliances in excess of 80% throughout the evaluation for both standards.

In investigating the reasons for the failure of the attached medium systems (the rotating bio-contactor and the submerged bio-contactor) to successfully nitrify their influent ammonia, authoritative texts were referenced and it was concluded that these systems were overloaded with respect to the biomass area required for successful nitrification.

Much of the adverse publicity surrounding sewage package plants relates to pressures being placed on municipalities to limit development in the formally "rural" peri-urban areas. Furthermore, property developers typically minimise the space and budgetary allocations for sewage treatment in their projects, which has contributed to the current situation. As to whether this is a sewage treatment or a planning issue is a matter of opinion but both locally and internationally enormous complications of administering and policing a multitude of package plants are real problems faced by those responsible for human health and environmental protection.

The study found that the addressing of issues of the legislative framework and technological development may assist in managing the problems relating to dispersed sewage treatment in South Africa.

It was concluded that there should be a single set of regulations for package plant effluent throughout South Africa. The General Authorisations for direct discharge and irrigation should be adopted for these plants. Poor performance may be addressed by the establishment of a national accreditation based on the NSF 40 system. If necessary, bylaws could be amended to ensure that accreditation be obtained before permission to install a plant would be granted by local authorities. This should help ensure package plant suppliers and property developers do not install sub-standard systems simply as a means of minimising costs. It was also recommended that a full maintenance contract system should be implemented to ensure that preventative maintenance is performed to prevent breakdowns.

With respect to technological development, is was clear that under certain conditions, the manufacturers of the submerged bio-contactor and rotating bio-contactor technologies need to re-visit the design specifications they are using, and to adopt more conservative parameters.

Manufacturers using septic tanks as the initial step in their process train were strongly encouraged to investigate the use of anaerobic baffled reactors in place of conventional septic tanks. This technology should greatly reduce loading on subsequent aerated treatment steps, although it will have no effect on the nitrification of influent ammonia. It was noted that anaerobic baffled reactor technology needs to be further investigated under a strong diurnal fluctuation to fully develop its potential in the field.

It was noted that disinfection was often a weak point. To this end the manufacturers need to review the design of their chlorination equipment. If they utilise commonly available chlorine pills, the size should be stipulated together with whether the pills should be stabilized or not, and if there is a preferred brand. The authors recommended that all package plants should include an effluent polishing step, such as a constructed wetland or gravel filter. Disinfection should take place after this.

It is recommended that the manufacturers of packages plants organise themselves to have a representative body for the industry. This group should be tasked with representing the manufacturer's interests in negotiations with the state and other regulatory bodies. In addition, the organisation would be ideally situated to facilitate the dissemination of advances in technology, and other new developments and well as fostering general cooperation amongst suppliers.

It is hoped that with the attention this field of sewage treatment is receiving, the package plant supply industry, regulators and users will recognise the potential for environmental impact that sewage treatment disposal has. These role players need to be well informed as to the practical limitations of, and the potential for, effective treatment and where responsibilities lie to improve the current situation.

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Mr. L. Laas	Ethekwini Metro
Mr. K. Fawcett	City of Cape Town
Mr. L. Gravelet-Blondin	Dept. Water Affairs & Forestry
Prof. C. Buckley	University of KwaZulu-Natal
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List of Abbreviations

In the interests of ease of reading, the authors have attempted to minimise the use of abbreviations. However due to space constraints in tables and other such factors, it was periodically necessary. To avoid possible misinterpretations, the following shortened forms were used in this document:

Abbreviation	Meaning
Alk	Total alkalinity
BOD	Biological Oxygen Demand
Cl_t	Total Chlorine Concentration
COD	Chemical Oxygen Demand
NSF	National Sanitation Foundation
PE	Person Equivalent
PLC	Programmable Logic Circuit
RBC	Rotating bio-contactor
SBC	Submerged bio-contactor
SBR	Sequencing Batch Reactor
SRP	Soluble reactive phosphorous
TKN	Total Kjeldahl nitrogen
TP	Total phosphorous
TSS/SS	Total suspended solids/ suspended solids
USEPA	United States Environmental Protection Agency

1. Introduction

1.1 Background

Minimising the impact of human development on the environment has become increasingly difficult with population increases, greater proportions of populations living in more dispersed settlements and as the ability to detect man's influences on the environment improves.

The technologies required to successfully treat sewage have been relatively well established and are often successfully applied, most frequently in the larger scale centralised sewage treatment facilities which are ubiquitous in the cities of both the developed and the developing world.

However, despite the general success of treating sewage at a large scale, successful treatment has become less reliable as the volume treated per day decreases. Smaller scale treatment plants have typically failed to successfully treat their influent as a result of their smaller buffering capacities. Smaller plants are much more prone to treatment problems due to changes in the quality of their influents, and their smaller size results in them being subject to a far greater range in hydraulic loads during a normal diurnal fluctuation in flow than do their larger counterparts.

The internationally observed increase in development from urban to peri-urban areas exacerbates the problem. This has been attributed to several factors including:

- Unfavourable economics of developing centralised wastewater treatment facilities in peri-urban areas.
- Development of sites with physical constraints to the choice of on-site sewage treatment processes.
- The tendency of developers to minimise areas allocated for sewage treatment.
- Increased environmental monitoring and greater sensitivity to pollution.
- Legislative agents have tended to apply discharge standards generally rather than on individually bases. No consideration for localised environments to attenuate the pollution loads is usually considered.

These difficulties in dealing with sewage treatment in areas remote from centralised treatment systems have been the subject of much debate internationally. The issue has over the previous few years has become particularly acute in KwaZulu Natal, where Ethekwini Water and Waste have noted problems relating to sewage effluent disposal in the more dispersed areas of their metropolitan area. This has been mainly due to high density housing developments in the Hillcrest/Waterfall areas which are situated outside of the "waterborne fringe", i.e. not serviced by municipal sewage treatment works. Previously a sparse settled area, with homesteads served by septic tanks in large gardens, the more recent developments sprung up rapidly with little provision for sewage treatment, with developers even minimising the space available for package plants. Developers were also reluctant to budget sufficiently for this service. This resulted in environmental concerns and extremely stringent monitoring by the Ethekwini Metro. This in turn resulted in a moratorium on further developments until the sewage treatment package plants were shown to comply with strict standards set by the Metro.

Given the importance of this topic within the overall recognition of the need for improved environmental protection, the Water Research Commission supported this study to investigate the performance of small-scale sewage package plants under South African conditions.

1.2 Global Overview

In order to effectively gain an understanding of the topic, the following tasks were identified as necessary components of this investigation:

- To gain an understanding of sewage package plant technologies.
- To identify local suppliers of these technologies in South Africa.
- To test the performance of the selected technologies under controlled conditions.
- To develop a decision support system to assist South African users of the systems tested.
- To identify areas where further research into the field may be warranted.

The objective was to undertake the investigation in a scientifically defensible manner and to increase the capacity of members of the scientific community to undertake further investigations of this nature.

1.3 Project aims and objectives

The following major project aims were identified:

- To identify and classify the locally available package treatment plants according to the treatment technology employed, and with due consideration for the maintenance these systems would require to operate.
- To identify *in situ* performance, operational and maintenance characteristics of package plant technologies in general.
- To assess the treatment performance of selected package plants with respect to regulatory requirements and claimed performance. Shortfalls in performance were to be identified, as would any reliability or operational problems detected in the course of the investigation.
- To identify and record any *in situ* operational and maintenance problems experienced with the representative technologies selected for testing, and to recommend improvements where possible.
- To produce guidelines and recommendations to assist decision makers in the selection of appropriate plants for different applications.
- To review the regulatory framework under which these plants are used in South Africa, and to highlight any problems that the investigation uncovered.

1.4 Criteria for evaluation

1.4.1 Selection of commercially available package plants

A market investigation was conducted to identify plants available for assessment at the Darvill Waste Water Works in Pietermaritzburg, KwaZulu Natal. Based on the information gained from the reviews of systems employed internationally, plants were sought in each of the three different technologies identified, namely:

- Submerged bio-contactor
- Rotating bio-contactor
- Activated sludge

In order to qualify for assessment the plants had to be constructed in South Africa, they had to have a reasonable number of units in use, and to have service available. A 2kℓ.day^{-1} plant capacity was chosen as an ideal size due it being typical of a 1 to 2 dwelling unit. This size also easily allowed the units to be supplied by a common sewage feed supply from a tank, helping assure uniformity of influent quality between the technologies under test.

1.4.2 Criteria for evaluation of plants

The criteria selected for the evaluation of the plants were the set of standards contained in the revised General Authorisation published in March 2004 (Government notice 399 in Gazette 26187). Further evaluations were made taking cognisance of operational and maintenance problems as described in Section 5.4, Fault evaluations.

With regard to compliance with standards for effluents, there are two sets of criteria contained in the General Authorisation, one for discharge into a water resource, and one for irrigation. Requirements to meet these two standards vary greatly, and a variety of requirements were found depending on factors such as the daily volume produced.

In order to fully evaluate the plants in the light of either set of compliance standards, it was decided to compare average effluent values for the 3 respective plants with the General Authorisation's standards for discharge to water and for irrigation of up to 2000 litres per day. Thus average values for effluent determinands of interest would be compared with the various standards; the percentage compliance for each determinand computed against the standards, and percentage removals would also be calculated, as this was commonly a useful performance indicator encountered in the literature.

Since it has been clearly understood that biological processes require time to develop sufficient biomass to effectively treat sewage, it was further decided to evaluate the performance of the plants in the light of operation under "steady state" conditions. That is, to compute the compliance figures only after making allowance for a start-up period for the plants involved. It was decided that data from start-up would be recorded, but for performance evaluation, only results obtained in the period following 3 weeks after initial start up would be considered as representative of usual performance.

1.4.3 Monitoring requirements

In terms of the General Authorisation, users must ensure the establishment of programmes to monitor the quantity and quality of the discharge prior to the commencement of the discharge.

The monitoring requirements for domestic sewage discharges were reproduced in Table 1.1. Data in Table 1.1 indicated that discharges below $10m^3$ per day require no monitoring, unless otherwise specified under individual by-laws, regulations or other bodies of legislation.

Table 1.1. Monitoring requirements for domestic sewage discharges

Daily Discharge Volume	Monitoring Requirements
< 10 cubic metres	None Specified
10 to 100 cubic metres	pH Electrical Conductivity ($mS.m^{-1}$) Faecal Coliforms ($100\ m\ell^{-1}$l)
100 to 1000 cubic metres	pH Electrical Conductivity ($mS.m^{-1}$) Faecal Coliforms ($100m\ell^{-1}$) Chemical Oxygen Demand ($mg.\ell^{-1}$) Ammonia as Nitrogen ($mg.\ell^{-1}$) Suspended Solids ($mg.\ell^{-1}$)
1 000 to 2 000 cubic metres	pH Electrical Conductivity ($mS.m^{-1}$) Faecal Coliforms ($100m\ell^{-1}$) Chemical Oxygen Demand ($mg.\ell^{-1}$) Ammonia as Nitrogen ($mg.\ell^{-1}$) Nitrate/Nitrite as Nitrogen ($mg.\ell^{-1}$) Free Chlorine ($mg.\ell^{-1}$) Suspended Solids ($mg.\ell^{-1}$) Ortho-Phosphate as Phosphorous ($mg.\ell^{-1}$)

1.5 Regulatory Framework for Sewage Treatment Package Plants

When drawing up regulations, the prime motivation is the protection of the aquatic or other environments i.e. the quality of the receiving water body should be impacted as little as possible in order to retain high biodiversity and an aesthetically pleasing environment. The quality of water for the downstream user is also a matter of prime concern.

Ideally the water being returned to the environment should be of an equal or better quality than the existing water in the aquatic environment. The treated sewage should also always be discharged to the same catchment that it originated from to ensure that the river flows are as natural as possible.

In reality, however, there is always some degradation of the environment. The purpose of regulations is thus to limit degradation to acceptable limits. Regulations in order to be achievable have to be tied to technology and affordability. In other words the regulations must be set such that they can be achieved a "reasonable" percentage of the time using the available, affordable technologies.

The available technology must also be affordable to the user, and be able to be maintained by the user. Ideally it would be desirable to have perhaps an activated sludge plant followed by a

Reverse Osmosis system with ozone or ultraviolet radiation for disinfection. In reality this would be extremely expensive and would require dedicated operation and maintenance.

The technology for package plants must also be reliable, with ease of operation and maintenance. One of the problems with any water technology is that of scale. The smaller the unit is, the more difficult it becomes to operate. This is due to limitations in the size of pumps, fittings, and pipes. Furthermore the relative size of debris increases as the size of the unit decreases, making blockages more likely and the requirement for maintenance more frequent.

Another factor of importance is that of diurnals. It is common knowledge that the smaller the number of connections to a sewage works the greater the diurnal. This is usually expressed as a ratio of the peak flow to the average flow and is well documented. The diurnals experienced by package plants are usually fairly severe as a result of this, and thus provision may need to be made for flow equalization. With the diurnals also comes fluctuations in load to the plant, and the design must be such that these can be treated adequately.

The diurnal has an effect on the COD reduction, nitrification, denitrification, settling and disinfection. If flows exceed the rate at which these occur then only partial treatment will be achieved.

1.5.1 International Standards

The applicability of effluent standards from other countries to the South African situation is questionable for the following reasons:

- Different degrees of emphasis placed on the environment
- River sizes are different
- Climatic differences
- Degrees of enforcement vary

Thus care has to be taken in the interpretation of standards arising from any particular country.

1.5.2 Standards from Africa

The authors were unsuccessful in obtaining standards for package plants from any African countries. This was not entirely unexpected as many of the countries have little in the way of wastewater treatment, and as such would be unlikely to have rules for smaller plants. Even Botswana, one of the more prosperous countries in Africa does not have wastewater effluent standards of their own, rather relying on the WHO guidelines. Even these are poorly monitored and regulated.

1.5.3 Standards from the developed nations

An extensive search for standards for package plants was not particularly fruitful. It did however yield the EPA National Sanitation Forum certification system for package plants. This certification procedure was found in the standard named NSF/ANSI 40-2005, an extremely comprehensive document. In view of the comprehensive nature of the NSF standard it was decided to concentrate on this as a basis for local standards.

The NSF standard contains minimum requirements for residential sewage treatment systems having rated treatment capacities between 1514 $\ell.day^{-1}$ and 5678 $\ell.day^{-1}$ (converted from gallons).

The standard (available for purchase over the internet from the American National Standards Institute) includes:

- Definitions
- Materials
- Design and construction
- Product literature
- Other documentation
- Performance testing and evaluation

It is the last section that is important in this study. In terms of this the plant is tested under a specific feeding regime which includes:

- Wash-day stress
- Working-parent stress
- Power / equipment failure stress
- Vacation stress

The effluent samples are taken as flow proportional, 24 hour composites. Samples must then be analysed for pH, TSS, BOD_5, $CBOD_5$, colour, odour, oily film, and foam. At least 96 data days are required. From the results of analysis the 7-day and 30-day averages are calculated.

In order for the plant to be classified as a Class I residential sewage treatment system the following criteria have to be met (Assuming $CBOD_5 = 0.65 \times COD$. $CBOD_5$ is the Carbonaceous Biological Oxygen Demand i.e. the oxygen demand without nitrification. It was not stated whether a nitrification inhibitor was used):

- The 30-day average $CBOD_5$ concentration must not exceed 25mg.ℓ^{-1} (a COD of approximately 38.5mg.ℓ^{-1})
- The 7-day average $CBOD_5$ concentration must not exceed 40mg.ℓ^{-1} (a COD of approximately 61.5mg.ℓ^{-1})
- The 30-day average TSS concentration must not exceed 30mg.ℓ^{-1}
- The 7-day average TSS concentration must not exceed 45mg.ℓ^{-1}
- pH between 6 and 9
- Colour – no criteria
- Odour – not offensive for three diluted composite samples
- Oily film and foam – None visually detected in diluted composite samples

In addition to this, for the plant to be classified as a Class I residential sewage treatment system the following criteria have to be met:

- Not more than 10% of the effluent $CBOD_5$ values shall exceed 60mg.ℓ$^{-1}$
- Not more than 10% of the effluent TSS values shall exceed 100mg.ℓ$^{-1}$

1.5.4 Discussion of Current Regulations

There are currently two sections in the General Authorisation which govern the quality of the effluent produced by package plants. They are the Discharge Standard and the Irrigation Standard. The former applies to the discharge of effluent directly to a watercourse, while the latter applies to the irrigation of water on crops and pastures.

1.5.4.1 Discharge Standard

The discharge standard which is currently applicable to the discharge of package plant effluents directly into water bodies is shown in Table 1.2.

1.5.4.2 Irrigation Standard

In terms of the General Authorisation a user can irrigate up to 500 cubic metres of domestic or biodegradable industrial wastewater on any given day, provided the-

a) Electrical conductivity does not exceed 200 milliSiemens per metre (mS.m^{-1});
b) pH is not less than 6 or more than 9 pH units;
c) Chemical Oxygen Demand (COD) does not exceed 400 mg.ℓ$^{-1}$ after removal of algae;
d) faecal coliforms do not exceed 100 000 100 mℓ-1; and
e) Sodium Adsorption Ratio (SAR) does not exceed 5 for biodegradable industrial wastewater.

1.5.5 Assessment of regulations

1.5.5.1 General Standard

The project team believed that the General Limit of the Discharge Standard should be met by properly designed package plants on a regular basis, but that the Special Limit will require a purpose designed plant. The authors were happy to observe that the faecal coliform standard is set at 1000 counts.100mℓ$^{-1}$, as a standard of 0 counts.100mℓ$^{-1}$ is extremely difficult to achieve on an ongoing basis without excess disinfection. The question of the fate of chlorinated organics in the environment is currently an important aspect of ongoing research internationally.

Table 1.2. General Authorisation Standards

Substance/Parameter	General Limit	Special Limit
Faecal Coliforms (per 100 mℓ)	1 000	0
Chemical Oxygen Demand (mg.ℓ$^{-1}$)	75*	30*
pH	5,5-9,5	5,5-7,5
Ammonia (ionised and un-ionised) as Nitrogen(mg.ℓ$^{-1}$)	6	2
Nitrate/Nitrite as Nitrogen (mg.ℓ$^{-1}$)	15	1,5
Chlorine as Free Chlorine (mg.ℓ$^{-1}$)	0,25	0
Suspended Solids (mg.ℓ$^{-1}$)	25	10
Electrical Conductivity (mS.m^{-1})	Intake +70 mS.m^{-1} Max 150 mS.m^{-1}	Receiving + 50mS.m^{-1} Max 100 mS.m^{-1}

Substance/Parameter	General Limit	Special Limit
Ortho-Phosphate as phosphorous ($mg.\ell^{-1}$)	10	1 (median) and 2,5 (maximum)
Fluoride ($mg.\ell^{-1}$)	1	1
Soap, oil or grease ($mg.\ell^{-1}$)	2,5	0
Dissolved Arsenic ($mg.\ell^{-1}$)	0,02	0,01
Dissolved Cadmium ($mg.\ell^{-1}$)	0,005	0,001
Dissolved Chromium (VI) ($mg.\ell^{-1}$)	0,05	0,02
Dissolved Copper ($mg.\ell^{-1}$)	0,01	0,002
Dissolved Cyanide ($mg.\ell^{-1}$)	0,02	0,01
Dissolved Iron ($mg.\ell^{-1}$)	0,3	0,3
Dissolved Lead ($mg.\ell^{-1}$)	0,01	0,006
Dissolved Manganese ($mg.\ell^{-1}$)	0,1	0,1
Mercury and its compounds ($mg.\ell^{-1}$)	0,005	0,001
Dissolved Selenium ($mg.\ell^{-1}$)	0,02	0,02
Dissolved Zinc ($mg.\ell^{-1}$)	0,1	0,04
Boron ($mg.\ell^{-1}$)	1	0,5

* After removal of algae

The authors believe that the requirements as set out in Table 1.2 are realistic and sustainable. It is important, however, that all package plants should be able to comply in full with the Discharge Standard and that to this end each manufacturer should be required to obtain a compliance certificate from an accredited assessment centre. This will be discussed later in the chapter.

It was thus recommended that the Discharge Standard be retained as it is (with the ammonia amendment to $6mg.\ell^{-1}$).

1.5.5.2 Irrigation Standard

The project team strongly recommends that wherever possible the treated effluent from package plants should be irrigated. The reasons being as follows:

- Water is a scarce commodity in South Africa, and reuse will reduce demand for potable water for gardening purposes.
- Any reduction in demand will strongly assist in municipal demand management schemes and should result in reduced capital infrastructure requirements.
- The effluent being discharged from the package plants seldom returns close to the original abstraction points, and thus has the potential to significantly change the stream flows if directly discharged into local watercourses. This would be particularly significant in the case of housing developments.
- The nutrients contained in the effluent are also a valuable resource. It seems pointless to waste this, instead supplementing with commercial fertilizers which often contain heavy metals, and whose production results in environmental degradation.

Although this quality is suitable for agricultural use, and is currently limited to thereto (there is currently a move to include irrigation of domestic gardens in this Standard), it is doubtful that that the high COD is suitable for irrigation in urban and peri-urban areas where the unstabilised organics may cause odour and exacerbate fly nuisances. The high faecal coliform concentration is also a concern as this may result in the infection of lacerations when children, or adults, play on the grass. Obviously some disinfection will take place due to UV radiation, but it has been the author's experience that there is still a health threat.

Another question which needs to be addressed is that of the responsibility for the monitoring of the package plants. Should the responsible party be the Department of Water Affairs and Forestry or the Local Municipality? In terms of the current legislation it can be either. At present the Department of Water Affairs and Forestry appears to lack the resources to conduct the monitoring required, and thus the responsibility for monitoring has devolved upon the Local Authorities. One of the problems with this is that while the Department of Water Affairs and Forestry are prepared to negotiate relaxations of the standards where necessary, the Local Municipalities may not, probably due to a lack of technical skills or process knowledge necessary for such negotiations.

Some confusion may also exist as to the General and Special Standards. The Special Standards are more stringent than the General Standards and are intended for implementation in listed areas which contain strategic water resources. The purpose of this is to protect ensure that eutrophication of the water resource does not occur and to protect environmentally sensitive areas.

1.5.5.3 Monitoring requirements

It is recommended that the monitoring requirements set out in the General Authorisation be retained as they are deemed to be reasonable.

However, accurate measurement for small flows is difficult, and the equipment required is costly and thus for the purposes of record keeping it is suggested that the sewage volume be taken as 70% of the water consumed in the system discharging to the package plant.

1.5.5.4 Compliance

One of the main problems with the General Authorisation is the issue of compliance. No figures are provided for the percentage compliance required. It could be questioned whether a plant running at 95% compliance is a failing plant. In reality it is not. The project team thus believe that a compliance of 80% be deemed to be satisfactory. Compliance figures such as 80% are easily stipulated, but also need to be defined. Compliance can be defined in a number of ways, two of which are indicated below:

- As the number of analyses which are compliant with the standard, divided by the total number of analyses (this seems to be the norm with reporting results to the Department of Water Affairs and Forestry, and is the method used the authors).
- For each individual determinand, i.e. if any one determinand is out of range for a sample then the sample is said to be sub-standard.

The first method tends to give realistic results, while the latter tends to be overly stringent. The question of compliance is however complicated and needs to be further investigated. This should be the subject of a follow-up project.

1.5.5.5 Accreditation of package plants

In the purchase of any goods the principle of *caveat emptor* ("let the buyer beware") applies. The expression thus warns that the buyer must ensure that they are adequately aware of the risks involved in the purchase.

Unfortunately the highly technical nature of sewage treatment package plants is such that few people are able to make an adequately informed decision when buying one, or to assess the risks involved. Furthermore the impact of an incorrect choice does not only impact on the purchaser, but also the natural environment and possibly their neighbours.

In view of the serious health, environmental and nuisance risks associated with sewage treatment it is strongly recommended that all parties concerned be protected by municipal authorities requiring that all new package plants installed in their area be accredited by a suitable facility.

1.5.6 Regulatory recommendations

1.5.6.1 General authorisations

As previously stated, the project team support the use of the General Authorisations as the yardstick against which performance of sewage treatment processes is to be measured in South Africa. In addition, it is recommended that where ever possible water re-use, such as by means of irrigation, should be encouraged wherever possible. There appears to be some debate amongst the regulators as to the risk associated with sewage effluent irrigation on domestic lawns, and the team propose that this should be permitted provided the following limits are applied:

- Maximum COD of $150 mg.\ell^{-1}$ to prevent nuisances
- Maximum *E.coli* count of $1000 counts.100m\ell^{-1}$ where the lawn is for general use, e.g. sport
- No disinfection required for lawns of restricted use

As lawns have a high nitrogen uptake rate it is recommended that there should be no nitrogen concentration restriction. It should be noted however that it may be difficult to achieve disinfection (as in the case of general use) where ammonia concentrations are high due to the formation of chloramines and the resulting slower disinfection rate in chlorine based systems. This may be able to be compensated for by using a greater contact times.

It is the opinion of the Project Team that the irrigation of high ammonia effluent will not cause a nuisance as the smell is rapidly diluted by the atmosphere. This is borne out by experience at the Darvill wastewater works, where the chief smells tend to be hydrogen sulphide and volatile fatty acids (in the case of irrigation of stored waste activated sludge mixed with anaerobically digested sludge). No complaints have been received regarding the high ammonia concentrations.

1.5.6.2 Accreditation recommendations

In view of the technical nature of treating sewage for safe release to the environment, the project team recommend that the Water Research Commission or the national regulator consider future funding for the establishment of an assessment and accreditation facility for small scale onsite sewage treatment works.

The facility should provide for the testing of performance of package plant technologies against set standards in order to ensure their effectiveness. The testing centre should also be able to provide a consulting service to property owners, developers and local authorities on the suitability of technologies for specific applications.

With the information to hand at the time of writing, the basis for this accreditation could largely be based upon the American NSF/ANSI 40-2005 standard. The authors believe a certification regime based along upon this system would be comprehensive and thus encourage its use as a basis for accreditation in South Africa. The advantage of such an accreditation is that it would provide a national basis for testing, and should give users, regulators and a good understanding of achievable performance over a range of practical loading conditions.

1.6 Scene setting

1.6.1 In situ plant trials

As detailed in the project aims and objectives (Section 1.3), on-site trials were used to monitor the performance of the selected technologies at the Darvill Wastewater Works, the central wastewater processing facility for Pietermaritzburg in KwaZulu Natal.

In order to assist in the understanding of the performance of the treatment technologies over the period of testing, and also to better enable comparisons in performance to be made with areas with different climatic conditions, the figures for maximum and minimum temperature as well as for rainfall recorded over the period January to December 2005 were presented in Table 1.3, and for ease of interpretation also in Figure 1.1.

Certain unanticipated delays were experienced in implementing the on-site plant trial component of the investigation. This was due to difficulties in obtaining firstly a rotating bio contactor and subsequently an activated sludge system. It was initially an objective to start all plants together, but finally it was decided to start up the submerged bio-contactor and rotating bio-contactor systems towards the end of February 2005, and then to commission the SBR as soon as possible thereafter.

Actual start up of the submerged bio-contactor and the rotating bio-contactor systems was on 22 February 2005 and the sequencing batch reactor was commissioned on 24 April 2005.

Table 1.3. Climatic data for Darvill January to December 2005.

	Temperature °C			Rainfall (mm)		
	Mean Maximum	Mean Minimum	Daily Range	Total	Daily Range	Monthly Mean
January	28.7	19.2	37.0 to 15.0	201.4	0-32.5	126.8
February	30.2	19.2	37.6 to 15.5	70.9	0-37.6	119.3
March	27.8	16.8	34.5 to 10.0	97.5	0.6-25.5	111.2
April	27.2	14.1	35.5 to 7.2	8.0	0.3-3	50.5
May	27.3	7.2	33.0 to 1.2	2.4	0-1.2	25.8
Jun	25.4	5.5	31.5 to -0.2	9.5	3-6.5	13.7
July	25.3	4.7	35.0 to 0.0	0.0	0-0	14.2
August	26.4	9.6	14.8 to 3.5	26.8	0-12.5	25.0
September	27.7	12.3	38.5 to 3.4	24.5	0-7	46.9
October	28.0	14.7	40.5 to 6.5	59.8	0.2-13.5	81.5
November	27.8	16.6	39.2 to 10.5	63.3	0.1-14	104.5
December	27.3	16.6	38.5 to 11.0	71.5	0.3-13	123.2

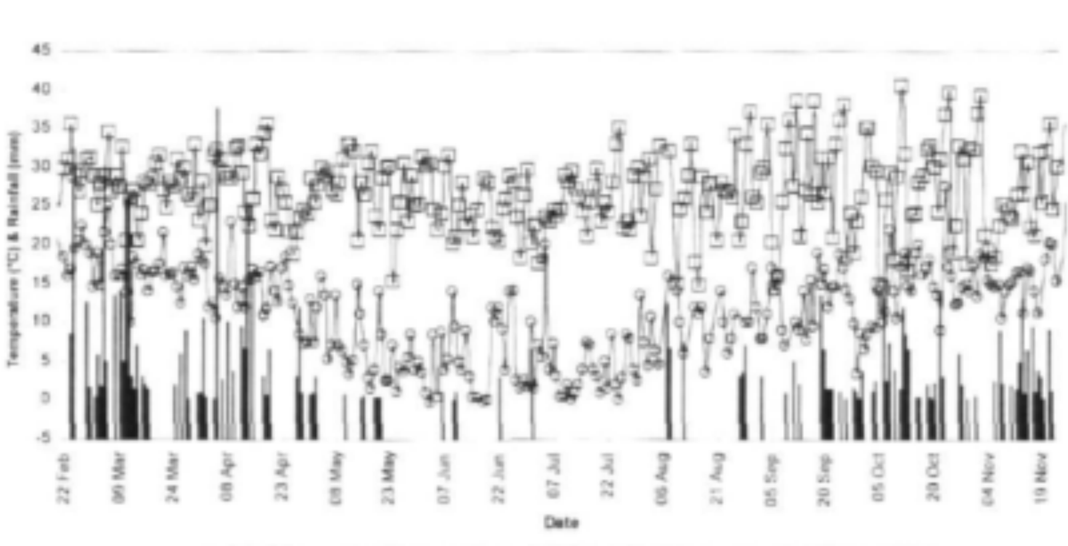

Figure 1.1. Climate data for Darvill over the duration of the trial.

2. Literature review

2.1 Introduction

It is an international trend that populations are increasing and that legislation is tending to become increasingly stringent in controlling the release of pollutants to the environment. As a result, the issue of dealing with sewage treatment in a manner which balances social, environmental and legal compliance concerns with the need to minimise costs of establishment, operation and maintenance is a matter of great concern to those responsible for managing civil society.

The means of dealing with sewage generated in people's homes has become a general expectation, and with increasing urbanisation, the responsibility to deal with the practicalities of this issue has moved from the individual home owner to the development and municipal authorities.

Internationally, the vast majority of townspeople have their sewage piped to central wastewater treatment works, and advances in the understanding of treatment process have resulted in the technical capability of treating this sewage to render it safe to return to the environment. Where populations are not sufficiently dense to warrant central processing facilities, on-site treatment is the only option. Rapid urban growth into dispersed communities; developments in terrain not conducive to successful sewerage reticulation and the need to protect rural environments have resulted in the increasing use of package treatment plants for sewage purification. The performance of these on-site systems is becoming a matter of increasing concern for authorities responsible for public health and environmental protection, as perceptions exist that effluent quality is often poor.

2.2 International appraisal of package plants

2.2.1 Description and application of package plants

Package plants may be defined as any on-site sewage treatment system. Authors have sought to further refine the definition to include only privately owned plants that discharge less than $2000m^3.day^{-1}$ (Laas & Botha, 2004). Small on-site systems have been promoted in Thailand over recent years as the best means of dealing with increasing water pollution problems (Panswad & Komolmethee, 1997), and since 1985 in Norway prefabricated package plants have been legal alternatives to septic tanks. Typically, more technically complicated plants are recommended for use in areas where soil conditions are unsuitable for subsurface sewage drainage fields and regional sewerage systems do not exist (Paulsrud & Haraldsen, 1993). Package plants are thus employed in areas not served by larger centralised sewage treatment works, and the plants themselves vary widely in the level of technology used. The simplest low technology units are anaerobic treatment systems such as septic tank and soil drains that require no separate energy supply and are virtually maintenance free (Voigtländer & Kulle, 1994). A requirement for greater sophistication brings in engineered pond and wetland treatment systems, increasing in engineering complexity to trickling filters, rotating biological contactors and the more sophisticated mechanically aerated treatment systems.

Regardless of the mechanical complexity involved, the underlying treatment processes are reliant on broadly similar biological pathways, and maximising the effectiveness of these biological systems is the objective of effective treatment plant design.

2.2.2 Occurrence and demand for package plant systems

It is a common experience internationally amongst municipal service utilities that the numerical majority of sewage treatment plants treat sewage arising in smaller communities. In the United Kingdom (UK), Thames Water reported that it operated about 400 sewage treatment plants in 1990, and about half of these served communities of less than 2000 people (Dakers & Cockburn, 1990). Other investigators reported that approximately 7000 sewage treatment plants in the UK process effluents from population groups of under 10 000 people (Chambers, Whitaker and Elvidge, 1993). In Norway, 30% of the population are not served by formal reticulated sewerage (Paulsrud & Haraldsen, 1993) while in the old Czechoslovakian Republic, it was estimated that 80% of treatment works serve settlements of less than 5000 people. Over a thousand rotating biological contactor plants were installed in Czechoslovakia between 1980 and 1990 (Wanner, Sýkora, Kos, Miklenda and Grau, 1990). Hanna, Kellam and Boardman (1995) estimated that over 700 000 Virginians depend on on-site sanitation systems at the time their article was written, so the increasing demand for effective on-site treatment of sewage is an international trend driven both by population growth and increasing sensitivity to negative environmental impacts.

Package treatment plants are often viewed as a cheaper operating option in the long term than conservancy tanks (Laas & Botha, 2004). It has been observed that since the 1980s, sewage package plants have made significant advances in addressing the sewage treatment needs of small communities. Their selection by developers is influenced by reduced capital costs, the perception of innovative technology and ease of operation (Hulsman & Swartz, 1993). Prefabricated systems are have been found to be less costly and quicker to construct than individually designed systems, and are thus often selected despite their occasional lack of flexibility in meeting site specific needs (Bucksteeg, 1990). It has been noted that in new building projects, developers tend to utilise the maximum possible area for housing to best realise profits. This often does not allow sufficient space for common septic tank systems (especially in multiple housing units), so where regional sewerage reticulation is absent the only alternative is to make use of package plants employing more sophisticated technologies (Laas & Botha, 2004).

As previously observed, the reduced capital costs and space efficiencies are factors favouring the employment of sewage package plants. This positive aspect is further advanced when the units make use of commercially available components, so allowing for both construction and maintenance to be extremely quick and cost effective (Hulsman & Swartz 1993). Package pants lend themselves to standardisation of motors, pumps, timers etc. across a range of plant sizes, which can greatly assist in reducing maintenance complexity and cost (Stoodley, 1989). Supplementary advantages include ease of transport for units that can be housed in containers, the potential for reduced noise and odours and year round heat conservation for colder climates (Hulsman & Swartz 1993).

Chambers et al., 1993 observed that technically advanced package plant design should have the following objectives:

- Plant prefabrication to reduce construction costs
- Minimal civil work
- Low area requirements
- Geometric similarity between plants of different size to promote ease of maintenance
- Automatic operation consistent with small works operator manning levels
- Low capital cost (UK 1993 suggested target cost less than £250 per head (R3250 at 13:1conversion rate).

In addition to providing a treatment facility in rural or non-sewered urban areas, package plants are also employed as temporary treatment works where modules of larger works are off-line for maintenance or refits and treatment of influent must continue (Dakers & Cockburn, 1990; Chambers et al., 1993).

2.2.3 Performance of package plants

The negative environmental impact of poorly treated sewage is a cause for great concern as population pressure mounts. Adequate treatment of sewage by package plants is the core issue motivating this investigation and the importance of this concern is such that it will be addressed under a separate section in this literature review. However, some introductory observations on performance in the context of international appraisal of package plant usage follow in this section. These observations necessarily make reference to different treatment technologies, which are covered in greater detail in the relevant section of the review.

For many years, bad experiences in Norway with package plants arising from poor design and construction and insufficient or non-existence of maintenance resulted in authorities permitting only septic tank/drainage field systems where reticulation networks were absent. During the early 1980s, a new generation of plants suitable for single homes were developed and tested by the authorities. Only systems meeting stringent criteria were allowed to be implemented in the field (Paulsrud & Haraldsen, 1993).

Hanna et al. (1995) reported that numerous field studies conducted over a 30 year period in the state of Virginia (USA) have indicated that aerobic package treatment plant systems often perform poorly. These reports attributed failures to maintenance, mechanical failures, and poor designs resulting in unacceptable effluents produced by mechanically sound systems. A detailed study of their own conducted by these researchers over 12 months confirmed earlier reports in finding effluent quality to be 'generally poor', as effluent samples failed discharge standards for biological oxygen demand over 5 days (BOD5), total suspended solids (TSS) and faecal coliforms in 60-80% of samples analysed.

Similarly, investigations into package plant performance in the Thames Water area of control in the UK also led researchers to conclude that effluent quality was a cause for concern at a number of plants in the study area. Such was Thames Water's concern over effluent quality from these plants that a programme was initiated whereby it was planned to achieve compliance with discharge standards for small works in 10 out of 12 monthly effluent samples (Dakers and Cockburn, 1990).

Other work investigating the performance of pack plants utilising rotating biological contactor treatment systems also found unacceptable non-compliance of effluent quality with discharge standards. However, particularly in the case of rotating bio-contactor systems in the North West of England, effluent quality failures appear to be related more to site-specific factors such as ancillary equipment performance and inadequate maintenance than to influent quality (Greaves, Thorp and Critchley, 1990). Although Greaves et al. (1990) reported that activated sludge package plants generally produce good quality effluent in the North West of England, they observed that activated sludge package plants have a reputation for lower reliability than rotating bio-contactor plants. Typical activated sludge plant problems included mechanical breakdowns, macerator blockage or breakage, airlift pump blockage, sludge carry-over and broken drive belts on compressors.

2.2.4 Process challenges of package plant treatment systems

It is widely acknowledged in the literature that the smaller dimensions of package plants impose limitations on the treatment processes they are capable of carrying out. The most obvious result of small volume treatment vessels is that they have less capacity to balance flow than do the larger units found at centralized processing units. This, together with the fact that flows from a limited number of sources are inherently more variable than flows from a wider network means that the effects of irregular flow on treatment processes need to be well understood (Bucksteeg, 1990; Chambers et al., 1993; Hulsman & Swartz, 1993; Panswad & Komolmethee, 1997). Better-attenuated flows tend to result in more reliable performance. Flow balancing becomes most critical as hydraulic retention times are minimised (Hanna et al., 1995). The influence of highly variable diurnal flows is largely on solids settling capabilities. A common shortfall in designs is to have generous primary settling capacity, but inadequate secondary settling volumes (Dakers & Cockburn, 1990). Small activated sludge plants are usually designed on the basis of a 24-hour hydraulic retention time in order to balance flows. This design parameter is not always successful in maintaining good effluent quality and is energy inefficient as unnecessarily large volumes of mixed liquor are aerated (Chambers et al., 1993). Well maintained, and operated plants have been used which produce poor quality effluents due to excessive hydraulic retention times (Hanna et al., 1995), so the challenge for designers is to accommodate the expected diurnal fluctuations and yet preserve the needs of process dynamics. In addition to diurnal flow fluctuation, infiltration by rainwater in older sewerage systems can also be the direct cause of operational problems in small works. This may result in doubling of the flow to the works during rain events (Dakers & Cockburn 1990).

Another issue widely reported in the context of package plant reliability is the influence of maintenance and operational skill at most package plants. Mechanically aerated systems are some of the most complicated package plant systems, and failures of mechanical components are widely reported (Hanna et al., 1995). Part of the problem is that small machinery units are physically less robust than larger ones, and small plants are generally run by less skilled operators than larger ones (Bucksteeg, 1990). Bucksteeg (1990) concluded that equalisation of flow in package plants gives more safety in operation than the provision of complicated treatment systems, and simple, robust and easily maintained machinery should be preferred to economising tank volumes and minimising energy consumption. However, given adequate design parameters, reliability of even the most mechanically complicated package is not an issue under proper operation and maintenance conditions (Croce et al., 1996, Hanna et al., 1995, Hulsman & Swartz, 1993).

Another point to be aware of when implementing package plant treatment is that all plants need time to overcome problems associated with start-up. Greaves et al., (1990) reported that effluent quality from a number of rotating biological contactors was consistently good, but only once the start-up phase had been completed. Under European conditions, processes such as nitrification can take as long as six weeks to fully establish themselves (Chambers et al., 1993).

2.2.5 Institutional aspects of package plant usage

The common theme of poor performance by sewage package plants in the literature has resulted in development authorities searching for ways in which to best regulate this service, which is essential, both for public and general environmental protection. Many authorities appear to have decided only to allow the use of accredited package plant designs (Hanna et al., 1995; Laas & Botha, 1994; Paulsrud & Haraldsen, 1993), which may have the effect as it did in Norway of 'weeding out' unreliable processes due to design faults (Paulsrud & Haraldsen, 1993). However, this process does not necessarily deal with the operation and maintenance issues that are so often the factors limiting performance, nor does it necessarily help with adequate quality control if monitoring capabilities are inadequate. The Norwegian experience was to build rigid maintenance requirements into the plant licensing procedure (Paulsrud & Haraldsen, 1993), and expensive monitoring programmes are required to meaningfully scrutinise package plant performance. Assessing and raising the standards of legal compliance for a large number of package treatment plants requires the use of formal project management techniques to best assure the chances of success (Dakers & Cockburn 1990). Often very low sampling frequencies are used by regulators in order to save costs, but monitoring codes requiring (for example) an annual effluent sample are inadequate. A single sample cannot be considered representative of package plant effluents, as the quality of these wastes have been clearly shown to vary widely in intensive field sampling investigations. Diurnal fluctuations in effluent quality are significantly smaller than fluctuations between different sampling days (Hanna et al., 1995), so careful consideration needs to be given to avoid collecting misleading information on plant effluent quality.

The experience of water utilities is often that poor package plant performance passes unnoticed for considerable periods of time, and investigations into problems when they are reported lead to the discovery of large-scale problems. The question of addressing issues which may well have been inherited as a result of historically inadequate controls or plant specifications poses an enormous problem. Dakers & Cockburn (1990) observed that schemes to determine and uplift package plant performance where multiple plants are involved require the following specialised project management tasks:

- Identification of works failing to meet standards, or likely to fail to meet standards.
- Identification of the reasons for poor performance and proposition of solutions to the identified problems. Design briefs where new capital works are required must be prepared at this stage.
- Specialist design and construction teams must be available to undertake these functions.
- Operational problems must be addressed by a specialist team, particularly where new capital works are not necessary.
- All project teams must sign off projects for an intervention to be properly completed.

2.2.6 Conclusions drawn through international experience

The number of years experience in international usage of sewage package plant treatment systems has shown that there is no simple formula which developers can use in order to select which sewage treatment technology to choose (Bucksteeg, 1990). Investigations reviewed to date conclude that it can be difficult to find significant correlations of effluent quality with specific design features of package treatment plants (Greaves et al., (1990), (in observations specifically related to design modifications in rotating biological contactors).

It would appear that the current South African understanding that package plants should be treated with circumspection has been clearly mirrored elsewhere. However, provided building specifications rule out the use of inappropriately designed units, good quality effluent is a reasonable expectation provided adequate provision is made for the necessary expenditure on maintenance, skilled operation and meaningful quality monitoring.

2.3 Technologies employed in sewage package plants

Package sewage treatment plant systems could be divided into those that make use of anaerobic processes to treat sewage, and those that make use of aerobic treatment systems, although many systems rely on both mechanisms. Both basic technologies have numerous technical refinements aimed to maximize their effectiveness, but in general the traditional on-site treatment systems have relied on the lower technology/higher reliability of anaerobic or mixed systems such as septic tanks, stabilization ponds and biological filtration (Hulsman & Swartz, 1993). Systems employing more complex technology include emergent hydrophyte treatment systems, artificially aerated ponds, trickling filters, rotating biological contactors and activated sludge systems.

Favoured technologies in South Africa include fixed media systems (rotating bio-contactors, biological filters and submerged biological contactors), activated sludge systems and combinations of the treatment technologies (Hulsman & Swartz, 1993, Laas & Botha, 2004). European systems in rural and less developed areas are largely made up of pond systems and rotating bio-contactors (Bucksteeg, 1990; Wanner et al., 1990), while in addition to these technologies, Norwegian investigators also reported general use of chemical treatment plants and other chemical precipitation systems (Paulsrud & Haraldsen (1993). In the North West Water area of the United Kingdom, the vast majority of package plants are rotating bio-contactors, followed in frequency of use by activated sludge systems and occasional biological filtration plants (Greaves et al., 1990)

Some aspects of each of these technologies commonly reported in the literature relating to on-site sewage treatment will be considered further in this section.

2.3.1 Purely anaerobic systems

Systems making use only of anaerobic processes are probably the simplest and least demanding to operate and maintain of any on-site system, and have an established history for single dwellings or even remote collective units provided the soil conditions for tank effluent drainage are suitable. They are only suited to environments where the overall nutrient and hydraulic load from the plant is within that environment's assimilative capacity. The anaerobic plant's nutrient removal capacity is not normally very great; typical performance figures are 6-10% removal of N and 3-9% removal of P (Panswad & Komolmethee, 1997). German anaerobic treatment system costs varied between 2000DM per population equivalent (P.E.) and 1400 DM. $P.E.^{-1}$ in 1993 (Voigtländer & Kulle,1994).

Septic tanks are prefabricated tanks which serve as unheated, unmixed anaerobic digesters which partially treat influent sewage for disposal in subsurface soil absorption systems (Tchobanoglous & Burton, 1979). The European application of anaerobic systems is usually in the form of multi- compartment septic or digestions tanks that may serve up to 1500 people (Bucksteeg, 1990).

2.3.2 Pond systems

Pond systems are common in rural areas, particularly where combined sewages are treated. Their advantages include ease of construction and operation and low operator requirements. However, they require large areas of land and they may produce offensive odours. Naturally and artificially aerated pond systems are found in rural Germany (Bucksteeg, 1990), and are commonly considered where populations in excess of 100 people need to be served (Mara, Pearson & Silva, 1996).

Naturally aerated pond systems in Germany are the preferred pond option where populations less than 1000 are served, where storm water is co-disposed with wastewater and where space permits as 10-15m^2 $P.E.^{-1}$ will be required under European conditions. Under these conditions, pond systems are typically able to treat sewage strengths of up to 20$mg.\ell^{-1}$ BOD5. Artificially aerated ponds are used where areas are partially limiting, but population numbers are low ($\leq$ 1000P.E.), or where food industry effluent requires treatment (Bucksteeg, 1990).

Pond systems show many advantages to more technically orientated solutions because of their simplicity and tremendous equalisation capability. Effluents from properly designed pond systems can reasonably be expected to meet compliance specifications, and they are often the most appropriate treatment technique in rural areas (Bucksteeg, 1990). Both Bucksteeg (1990) and Mara et al. (1996) observed that waste stabilisation ponds are often unnecessarily considered 'old fashioned'. They contended that the technology should be the treatment of choice where space and climate permit. Mara et al, (1996) cites cases in warm climates where larger volumes of effluents can be effectively treated by ponds; a case in point is the treatment of 350 000 $m^3.day^{-1}$ of effluent in a 310ha pond system at Melbourne, Australia.

Pond systems can be particularly effective when used in combination with other treatment technologies. Voigtländer & Kulle (1994) observed that pond systems fed by effluent from anaerobic digestions units show enormous purification efficiencies, presumably as a result of the production of organic acids in anaerobic breakdown.

2.3.3 Emergent hydrophyte systems

Emergent hydrophyte treatment systems (reed-beds) have become an interesting technology to maximise low technology treatment options in recent years. Details of the actual process were not carefully evaluated in this review, as it has been observed that research has not yet achieved a good understanding of these systems particularly with regard to obligatory dimensions, construction standards, costs of treatment and long term experiences. Thus they should be considered as a treatment option under development (Bucksteeg, 1990), a sentiment with which Mara et al., (1996) concur. Consequently mention is made of the systems at this point, with no further discussion considered necessary at present.

2.3.4 Trickling filter systems

Trickling filter systems make use of aerobic attached-growth processes to treat influent sewage. These processes are usually effective in treating organic loads, and have effective nitrification capabilities (Tchobanoglous & Burton, 1979). Trickling filter systems have been in use in England since 1893 (Tchobanoglous & Burton, 1979), are well suited to treat sewage from up to 3000 P.E. These plants are amongst the simplest of 'technical' treatment systems, although to perform well they often need effective primary settling tanks and adequate humus treatment. These plants are prone to unpleasant odour production (Bucksteeg, 1990). Modern configurations of trickling filters claim to improve performance over the conventional systems by:

- Having lower capital costs
- Lower land area requirements
- Having no noise, odour or insect nuisance
- Lower maintenance requirements
- Very low obtrusiveness

2.3.5 Rotating Biological Contactors

Most investigations into package plant usage mention that rotating bio-contactors are extremely common, and seem to have long been popular choices internationally (Bucksteeg, 1990; Greaves et al., 1990; Hulsman & Swartz, 1993; Laas & Botha, 2004; Paulsrud & Haraldsen 1993; Wanner et al., 1990). The systems employed obviously display some variety of configurations, but the common factors are

- Primary sedimentation
- A biological treatment zone employing rotating discs supporting attached biofilms
- A secondary settlement zone

Continuous and complete mixing of an aerobic treatment module is facilitated by large diameter discs mounted on a horizontal drive shaft (Hulsman & Swartz, 1993). These plants are very low energy consumers, but reliability requires robust construction of the machinery which rotates the contact block (Bucksteeg, 1990). In Eastern Europe, much of the development of these systems was undertaken in the 1960s and 70s, with the first authoritative Czechoslovakian review of the technology being published in 1981 (Wanner et al., 1990).

The biological loading rate is the main criteria considered when specifying the dimensions of a rotating bio-contactor plant. British Standard Code of Practice 6927 (1983) recommends a maximum loading of 7.5g $BOD.m^{-2}.day^{-1}$ for rotating bio-contactors treating raw sewage, and 5g $BOD.m^{-2}.day^{-1}$ for plants treating settled sewage. Field investigations in the North West of England encountered actual loading rates between 2.4g and 13.8g $BOD.m^{-2}.day^{-1}$.

These units are considered particularly reliable when their mechanical components are sufficiently robust (Bucksteeg, 1990), and another advantage is that their de-sludging frequencies are regularly within a 6-12 week time period as opposed to other technologies that require de-sludging on a variable basis (Greaves et al., 1990).

Under European conditions, rotating bio-contactors tend to be cheaper to run than equivalent capacity activated sludge systems. Trickling filter systems are similar in cost to rotating bio-contactor systems serving up to 1000 people; however, rotating bio-contactors are much more efficient in terms of area requirements than equivalent percolating filter systems. Rotating bio-contactor units, particularly if integrated, are inconspicuous and completely enclosed and are thus highly acceptable in term of visual impact and odour production and in addition are resistant to vandalism. They are understood to operate effectively and reliably with low capital and running costs (Greaves et al., 1990).

2.3.6 Activated sludge systems

Activated sludge treatment systems are often some of the most complicated of the technical package treatment plant options, and the process suitability for use in package plants has received mixed reports in the literature. Bucksteeg (1990) reported that the German experience of activated sludge systems was that the process is easily applicable to package sized systems. Such plants are usually cheaper to construct than other technical options, but in Germany are more expensive to run than systems such as rotating bio-contactors. Consensus amongst German engineers was that the activated sludge plants are typically less reliable than alternate technologies, unless they are of larger dimensions (Bucksteeg, 1990).

Hulsman and Swartz (1993) found that the activated sludge process is favoured in South African package plant systems. The plants are viewed here as being the most reliable system to produce good quality effluent (Bachelor et al. 1991, cited by Hulsman & Swartz, 1993). Hulsman & Swartz (1993) further reported that the running costs of activated sludge package plants in South Africa compared favourably with rotating biological contact discs; energy requirements were found to be $45kW.day^{-1}$ to treat 25 kg $COD.day^{-1}$.
Of the literature reviewed to date, activated sludge package plants received the greatest attention to detail relating to the importance of design criteria to optimise the treatment process. Of fundamental importance is to design the plant to allow for a suitable hydraulic retention time (Greaves et al., 1990; Hanna et al. 1995).

Chambers et al. (1993) reported that in North West Water's UK experience, activated sludge plants were capable of producing very good quality effluents. These authors observed that activated sludge plants should be designed with plug-flow aeration tank configurations to maximise the settling characteristic of the sludge. Where nitrification is required, anoxic zones to enhance de-nitrification also assist with sludge settling (Chambers et al., 1993).

The activated sludge process lends itself to very compact designs; scaling down the anoxic and aerobic tank requirements to meet the needs of package plant designs can be solved by an annular design, which results in a very compact plant. Aeration tank retention should be based on a 12 hour nominal sewage retention time, and annular designs in the UK typically require $0.08m^2$ $P.E.^{-1}$ (Chambers et al., 1993). Being the more complicated type of plants, activated sludge package plants should be designed with ease of maintenance in mind, for example fine bubble diffusers could be mounted on grids to facilitate removal without needing to drain the reactor vessel (Chambers et al., 1993).

Further sections of this review will report in greater detail the problems and possible solutions of activated sludge treatment systems. An overview obtained from the literature available to date indicates that while activated sludge package plant performance is often not ideal, the problems appear to firmly attributable to operation and maintenance issues; the process itself is capable of producing very good quality effluent if correctly controlled.

2.3.7 Applications of package plant technologies

One of the greatest advantages of package plant systems is their modular nature. Increases in load due to new developments are easily handled by installing additional modules (Stoodley, 1989). Bucksteeg (1990) observed that combinations of different technologies could be successfully employed for treating intractable site-specific problems. This author quoted an example where ponds in combination with trickling filters were used to treat effluent in a system where storm water was co-disposed with sewage effluent in an area serving a population of somewhat less then 3000 people. Under the correct operating conditions, appropriately designed package plants appear capable of producing good quality effluent, but their reputation is often for less than ideal performance. The following section will examine some of the most commonly reported problems with package plant performance.

2.4 Performance issues with sewage package plants

2.4.1 Process independent performance issues

In order to correctly assess package plant performance, it is critically important that monitoring programmes are correctly planned to enable properly representative sampling to take place. For practical reasons, authorities often rely on samples collected as infrequently as annually. Detailed sampling at plants both within and between diurnal cycles indicates that effluent quality is highly variable, and infrequent sampling cannot be representative of performance (Hanna et al., 1995; Stoodley 1989).

Many researchers have intensively investigated package plant performance, and some general observations can be made regarding failures that have occurred. Public complaints regarding package plants are usually as a result of offensive odours (Stoodley, 1989), although in extreme cases the environmental impacts of poor effluent quality are also noted by lay people

(Laas & Botha, 2004). Compliance monitoring, even if not properly representative, does reveal areas in which package plants tend to fail. Failure to meet discharge standards obviously varies between countries as the severity of pollutant ceilings may differ. However, the literature clearly indicates that failure to remove organic pollution is common, as problems with BOD or COD failures are widely reported (Greaves et al., 1990; Hanna et al., 1995; Laas & Botha, 2004; Paulsrud & Haraldsen, 1993 ; Voigtländer & Kulle,1994 and numerous other authors).

Failure to meet ammonia standards for discharge are similarly widely reported, for example Chambers et al., (1993); Dakers & Cockburn (1990); Laas & Botha (2004) etc. Nitrification failures are particularly problematic in cold climates (Dakers & Cockburn (1990).

Another effluent quality problem frequently occurring is the suspended solids concentration. Apart from this resulting from hydraulic overloads, nitrification processes in oversized secondary settlement systems will lead to the same problem (Stoodley, 1989).

Plants designed to disinfect their effluents often experience performance problems with this final stage; dry medium hypochlorite dispensers clog easily in the humid environments and de-chlorination chemicals similarly fail. Operator failures to replenish chemicals obviously result in the failure of disinfectants. Many of these problems are detailed in Chambers et al., (1993) and Hanna et al., (1995).

2.4.1.1 Design issues

The reasons for failures in processes in the various types of package plants reviewed are many. Flimsy designs and construction materials lead to leaks and failures (Stoodley, 1989) and improperly specified components can negatively impact on flow dynamics. Stoodley's 1989 investigation found over-specified de-sludging pumps induced additional flow surges that interfered with the ability of process to properly treat sewage. The same study also found frequent electrical control equipment failures due to condensation build-ups in electrical control boxes, that in enclosed plants, are constantly exposed to extremely humid conditions. Stoodley also noted that the compact design of certain plants can make troubleshooting and resolution very difficult; access to the secondary settlement tanks in some trickling filter designs is impossible as these vessels are completely enclosed.

Many of the operational problems encountered by sewage package plants are attributed to the effects of extreme fluctuations in diurnal flow patterns (Stoodley, 1989). Systems with long retention times such as septic tanks and pond systems are obviously less sensitive to this, but the smaller more technically orientated units often fail due to the effects of intermittent high flows on their processes (Hanna et al., 1995). Under-sizing reaction volumes results in dilution of the active biomass, the transferral of septic tank solids to aerobic or other downstream treatment processes, solids overloading of secondary settling and so forth (Stoodley, 1989; Paulsrud & Haralsen, 1993). At the opposite extreme, excessive hydraulic retention time, particularly in activated sludge modules can also lead to failure of the process to adequately treat the sewage (Hanna, et al.,1994).

The use of appropriate design parameters for any package plant system is thus of cardinal importance.

Apart from hydraulic characteristics, factors often neglected in package plant specification include:

- the installation of suitable fat traps (particularly at schools, shopping centres etc.) (Laas & Botha, 2004).
- access to proper analytical facilities to monitor performance (Laas & Botha, 2004).
- adequate influent screening, particularly in the light of the propensity of plastic packaging materials used at present (Dakers & Cockburn, 1990).

2.4.1.2 Operational issues

Most reviews of package plant performance attribute many failures to a lack of maintenance or skilled operation. Hulsman & Swartz (1993) observed that the reliability of package plants is not an issue under proper operation and maintenance conditions, and their study was focused on the performance of activated sludge plants, possibly the most demanding of all package plants with which to consistently achieve good effluent quality. The practical problems are that package plants are small, geographically dispersed and being privately owned are often under the care of people not aware of the maintenance requirements or operational needs.

Paulsrud & Haraldsen (1993) detail the rigorous processes employed in Norway to manage package plants, including systems which detail mandatory maintenance and spares availability in the plant permission approval process. Even under these carefully controlled conditions, failures are encountered with operator maintenance, usually related to failure to de-sludge systems as required, failure to replenish treatment chemicals and failure to observe plant performance characteristics indicative of imminent failure. Dakers & Cockburn's 1990 article related the experience of dealing with the more than 200 package plants in Thames Water's area of control. Their findings were that formal project management skills were needed for authorities to properly manage the control of large numbers of discrete plants. Their system formalised an identification matrix for package plants attributing failures to the following factors:

- Inadequate capacity (hydraulic or organic)
- Inadequate capacity (hydraulic NOT organic)
- Inadequate capacity (organic NOT hydraulic)
- Volumetric displacement of activated sludge
- Serious dilapidation of asset
- Unsatisfactory operation/maintenance procedures
- Temporary mechanical/electrical breakdown
- Tertiary treatment problems
- Problems with sewerage
- Regular trade effluent
- Un-consented discharge (e.g. spillages)

- Third party (e.g. vandalism)
- Exceptional weather
- Commissioning of new works
- Refurbishment in progress
- Inappropriate sampling process/point
- Suspected or known error in analytical procedure
- Inappropriate consent
- Not known
- Other

2.4.2 Process performance issues

Attention has been given to some of the problems encountered with package plants regardless of the particular process employed, but there are certain problems that are more likely to be encountered in specific processes. Brief descriptions of such problems follow on a system by system basis.

2.4.2.1 Anaerobic systems

Septic tanks must be watertight and structurally sound in order to operate correctly. The common problems encountered in their use relate to overloading and failure of the sub-surface drainage field to deal with the hydraulic loads imposed. In addition, solids build-up and scum accumulation can necessitate the removal of tank contents at frequent intervals. Specific applications such as restaurants, laundromats etc should have adequate grease traps installed to prevent excess loading of fats (Tchobanoglous & Burton, 1979). Use of septic tank technology in densely settled areas, or in soils that cannot attenuate the loads imposed upon them results in harmful environmental impacts. These are the chief selection criteria for alternate package plant systems. Organic pollutant removal by anaerobic systems is often quite limited at around 35% of the influent load. Structural modifications to the tanks can result in great improvements, with removal rates in excess of 60% (Voigtländer & Kulle, 1994). Intractable effluents are often broken down effectively by anaerobic systems, although high hydraulic loads can reduce organic and suspended material removal. Variable hydraulic loads are adequately treated provided a stable retention time is maintained (Panswad & Kolomethee, 1997).

2.4.2.2 Ponds

Pond systems that are organically overloaded produce unpleasant odours and poor quality effluents. Mechanical aeration systems or the addition of additional treatment volumes may solve such problems. Due to the nature of treatment undertaken in pond systems, the algal content in the effluent may be marked. Thus where monitoring systems do not differentiate between the BOD arising from algae and that arising from non-oxidised pollutants, poor legislative compliance will result. Ponds that are too shallow (<1m) allow for the emergence of vegetation that can lead to problems with mosquito and other problem insects (Mara et al., 1996).

2.4.2.3 Emergent hydrophyte treatment systems

Literature reviewed to date has not provided much detail on the operational characteristics of these systems, although it is likely that material on constructed wetlands would provide much useful information, although somewhat outside the scope of this review. It is obvious that overloading will result in poor effluent quality, odour development and as observed by Mara et al. (1996) problem insects may need to be considered. Requirements for adequate areas and suitable slopes would be anticipated as major limiting factor to this technology. Mara et al., (1996) and Bucksteeg (1990) refer to these systems as 'experimental'.

2.4.2.4 Trickling filters

Bucksteeg (1990) reported that trickling filters are periodically responsible for the production of offensive odours, and are subject to failure if primary and secondary sludge handling facilities are inadequate. Additional problems commonly encountered are blockages (and subsequent process by-passing) of the biomass support materials if influent screening is inadequate (Dakers & Cockburn, 1990).

2.4.2.5 Rotating biological contactors

Rotating bio-contactor units are frequently used internationally, and are considered to possess good mechanical reliability characteristics. This is the case where the mechanical components driving the rotating contactor units are sufficiently robust (Bucksteeg, 1990), although they are also sometimes subject to leakage between compartments which adversely affects performance (Greaves et al., 1990). Greaves also observed failures in these plants when over specified humus return pumps resulted in surcharges from the main tank at the head of the units so affected. Rising sludge and scum build-ups were other problems noted by Greaves et al. (1990).

The thickness of the biofilm layer retained on the rotating contactor varies widely depending on the characteristics of the influent sewage (Wanner et al, 1990). Diffusion of oxygen into this layer and the trough below the contactor limits treatment capacity. The mixing effect of the rotating bio-disc is often not energetic enough to prevent humus accumulation (particularly in start-up phases), which may be the cause of performance failures. High rotation speeds to achieve better aeration of the trough biota are limited by shear forces in the shaft and impacts caused by the packed disc aeration elements incident upon the liquid retained below the contactor. Aerator mechanisms located around the periphery of the contactor disk greatly assist in oxygen transfer to the trough biota (Wanner et al., 1990).

2.4.2.6 Activated sludge units

Activated sludge systems are relatively easily converted to a package plant scale, but these units have a reputation for unreliable performance at many sites. Design criteria suited to large scale activated sludge systems do not always apply in the smaller scale units (Chambers et al, 1993), but successfully designed units are capable of reliable performance (Laas & Botha, 2004). It would appear that the process technology itself is not usually at fault; simply the mechanical complexity and skill required for effective operation appear to be the main limiting factors in activated sludge plant performance at small-scale plants (Wanner et al., 1990). Greaves et al., 1990 observed that prefabricated extended aeration systems generally performed well in North West Water's area of control, but the units were much more demanding in terms of energy, operational requirements and maintenance than other technologies. In contrast, Laas & Botha (2004) contended that activated sludge plants in

South Africa were comparable in energy expenses to other technologies, which is perhaps indicative of relatively low energy costs in South Africa.

Numerous American and other field studies conducted over a 30-year period have indicated that aerobic package treatment plant systems often perform poorly. These reports attribute failures to maintenance and mechanical failures, and poor designs resulting in unacceptable effluents produced by mechanically sound systems (Hanna et al., 1995)

The aerobic modules within activated sludge plants are particularly sensitive to variation in flow conditions; with optimal performance easily lost if loads are too low or too high. These particular modules within the plants may be particularly sensitive to shock loads of certain types such as high volume laundry effluents (Hanna et al., 1995). A common design problem encountered by Hanna et al. (1995) in their investigation of a number of activated sludge units in Virginia (USA) was that the aerobic modules were over-sized, and retention times in excess of 24 hours resulted in declining ability of the aerobic biota to break down the sewage effectively.

In the Virginian rural plants evaluated, Hanna et al. (1995) found the average retention time in the aerobic module to be 3.8 days, which was wasteful of energy used to aerate this large volume, and resulted in dilute mixed liquor. The inability of field aerobic treatment plants to maintain a sufficient biological population reduces the effective sludge age. Without effective flocculation and return sludge systems, the sludge age in the aerobic module reduces to the hydraulic retention time. This explains the inability of these units to properly oxidise organics or nitrify ammonia properly. Hydraulic retention times as low as 12 hours in the aerobic reaction modules of activated sludge plants effectively treat most domestic sewage streams (Hanna et al., 1995).

Hulsman & Swartz (1993) observed that activated sludge package plants required operator input on a regular basis 2-3 times per week, mainly to ensure mixed liquor suspended solids concentrations are properly controlled. However, such plants operated reliably and with acceptable effluent quality compliance.

2.5 Proposed solutions to problems encountered

2.5.1 General observations

In common with any sewage treatment system, it is of cardinal importance that package plants are designed to treat the volume and organic load characteristics of the area they serve. Without appropriate design, no system can be expected to perform correctly. However, as any review of the literature on package plants indicates, effluent quality is an issue of concern, and references to poor performance abound. While the issues such as variations in diurnal flow are particularly challenging to deal with in small treatment units, a recurring theme throughout the different treatment technologies is that unskilled plant operation and lack of maintenance are most often responsible for poor plant performance. A realisation by plant owners of the training and costs involved is possibly the only completely sustainable means of dealing with this aspect of the problem.

As with all engineering solutions, improvements are constantly being sought. Improvements in methods that are applicable to all technologies include modelling, flow-variation attenuation and improved screening.

Watson, Rupke, Takács & Patry (1994) reported that unit processes in sewage treatment are sufficiently described to enable successful mathematical modelling. Some of the pitfalls of models Watson et al. detailed included the assumption that biological processing ceases in the secondary settling modules; it was noted that the processes occurring in settling are sometimes important, particularly de-nitrification processes. Accurate models of unit dynamics at the point of failure are another weakness in certain models, it is particularly important to model the hydraulic conditions at which the secondary settling systems will begin to fail (Watson et al., 1994), as this is often the point of effluent quality failure in sewage treatment.

Another generic improvement that can be made with most treatment technologies is to engineer effective flow equalisation measures (Hanna et al., 1995). It is often not sufficient to simply install suitably large tanks upstream of processing units; the outflow from these tanks must be controlled to match the design parameters of the downstream processes.

Effective screening is essential to reduce the load of non-biodegradable constituents to purification processes, and is an important step in reducing de-sludging requirements and wear and tear on downstream processes. Modern automated screens permit very effective handling of the screenings loads typically encountered at present (Dakers & Cockburn 1990).

A brief description of the main points of improvement that can be obtained with selected treatment methodologies now follows.

Hanna et al., (1995) pointed out that performance of the mechanically aerated treatment systems investigated in Virginia could have been greatly improved if they were fitted with alarms to warn owners of imminent failure, and that plants should be covered by extensive warrantees. Response to alarms requires an appropriate level of competence by operators, as Hanna's study related some inappropriate operator responses to alarms that resulted in process bypassing and consequent depletion of effluent quality.

Effluent qualities from both anaerobic and aerobic treatment systems are often greatly improved if passed through a sand filter (Hanna et al., 1995). The extremely effectively reduction in suspended solids concentrations has the result of radically reducing factors such as BOD5. Hanna et al., (1995) reported decreases in BOD5 of the order of 93% in anaerobic effluents and of 67% in activated sludge plant effluents. The authors also observed that bed area requirements for aerobic plant effluent treatment was half that needed to effectively filter anaerobic plant effluent due to the lower organic strength of aerobically processed effluent.

2.5.2 Anaerobic systems

Voigtländer & Kulle (1994) observed that the purification capacity of simple multi-compartment septic and anaerobic digestion tanks can be improved by:

- increasing the available biomass at constant retention time.
- improving hydraulic efficiency by maximising the flow path.
- extending the biomass carrier material surface area.

2.5.3 Rotating biological contactors

The factor often limiting treatment capacities in rotating bio-contactor plants is the aeration of the active biomass. Oxygen transfer to the attached biota on the rotating disc is usually excellent, but the biota suspended in the solution in the trough beneath the disc is often under severely oxygen limited conditions. Dissolved oxygen concentrations in the aerobic modules are greatly improved where the disc design maximises the surface area to disc diameter ratio and the depth of liquid in the trough is minimised. Peripheral aeration elements on rotating discs have been shown to increase aeration of the trough media by 110% (Wanner et al., 1990). Similarly, packed cage aerator discs also improve aeration; trials show a 20% improvement of discs packed with suitable media when compared with non-packed discs (Wanner et al., 1990). Maximising the agitation of the liquid in the trough below rotating discs not only improves oxygen transfer to the biota suspended in the trough, but also prevents humus accumulation which interferes with processing efficiencies. Improved aeration and agitation need not require more powerful disc drive motors (Wanner et al., 1990).

Scum accumulation has been reported as a problem in some rotating bio-contactor units. Greaves et al. (1990) found that these problems were minimised if de-sludging frequencies are optimised, and plant maintenance is adequate.

2.5.4 Activated sludge plants

Failures of adequately designed activated sludge plants appear to be easily attributable to either poor operational understanding of the plant processes or to improper maintenance. Education of plant owners as to the necessary operator inputs necessary to run these processes properly, as well as to the maintenance costs required to run these plants successfully would appear to be the logical answer to this problem. There have been successes in running these plants by considering some of the following recommendations.

Hanna et al. (1995) observed that quarterly inspections of aerobic plants by skilled technicians should be the longest un-supervised period considered. The researchers did note that this inspection frequency could be reduced given adequate training of the normal plant operators, and with changes in design to facilitate automated procedures.

Aerator basins with retention times longer than 24 hours are likely to prove problematic, and should not be considered for implementation (Hanna et al., 1995).

Effective sludge return systems are key to maintaining a healthy population of biota in activated sludge systems. Sludge return pumping systems in some South African plants were designed to co-pump primary sludge to the activated sludge module at times of low flow, so making provision for an additional substrate source and also taking care of the need to deal with accumulated primary sludge (Hulsman & Swartz, 1993).

Greaves et al. (1990) reported that in North West Water's experience, successful activated sludge plants utilised air lift pumps run on timers to effectively bring about the sludge return flow required to maintain the necessary biota in the aerobic modules of these units.

Intermittent aeration of activated sludge modules in package plants reduces running costs and introduces a periodic anoxic environment that facilitates denitrification. Laboratory studies indicate that informal anoxic zones may be as much as 20% more effective in denitrification than is usually encountered in compartmentalised systems. Aerator cycling times between 7:3 and 7:5 minutes on:off achieve good COD and TKN removal. The longer the off time in the cycle, the better the de-nitrification, but the non-aerated time must be balanced by the need for sufficient air to permit adequate COD removal (Hulsman & Swartz, 1993).

Flow equalisation has a marked positive impact on the performance of activated sludge package plants in particular (Hanna, 1995), and may be the most effective way of improving activated sludge plant processes (Bucksteeg, 1990).

Chambers et al (1993) reported some design criteria that are common amongst the most successful activated sludge package plants in Anglian Water Services' area. The criteria included:

- Maximum upflow velocity in secondary settling of $1.0 m.hr^{-1}$.
- Use of air lift pumps for return sludge recycling
- Waste sludge is decanted from the anoxic modules
- Optimal sludge age of 12 days maintained
- Secondary settling designed to deliver a sludge density of $30000 mg.\ell^{-1}$.

2.6 Regulatory considerations

Norwegian regulations permit the use only of approved package plants for any application. To obtain accreditation, actual field tests must be carried out on a minimum of 3 plants if serving single homes, or 4 plants if 2 homes are to served by a particular plant. Each category evaluated must have one plant running at its maximum loading capacity (Paulsrud & Haraldsen, 1993).

The Norwegian accreditation system allows these tests to occur at any time of year, but the test must last for at least 6 months, and should preferably include a period of zero loading to investigate performance relating to holiday periods. The test requires effluent samples to be taken every 20 minutes by auto-samplers, or during discharge for batch operated plants. Composite samples are analysed for BOD7, COD, total phosphorous and suspended solids. In addition monthly grab samples of the effluent are tested for faecal coliforms and faecal streptococci. Onsite measurements of pH, temperature, dissolved oxygen, mixed liquor suspended solids and sludge accumulation are made on a weekly or twice weekly basis. Hydraulic flow through the plant is logged by a flow meter, and the homeowner has a test protocol for monitoring any abnormal occurrences. Approved plants must meet

- official materials, strength and physical design requirements.
- availability of a handbook for plant assembly, operation and maintenance.
- The plant must be housed in a building (to permit proper operation and maintenance during winter).
- Average values for 95% of performance tests must meet official standards.

The Norwegian authorities attribute past system failures in package plants largely to difficulties related to operation and maintenance. Consequently, their approval system requires a valid service contract to be in place before a permit to install wastewater-processing facilities for less than 35 people will be issued. Plant manufacturers or suppliers are required to provide the maintenance service, the plants themselves must be guaranteed for at least 2 years and suppliers must undertake to provide spares for at least 20 years. Fees to be paid by the customer are also specified up front (Paulsrud & Haraldsen, 1993).

Norwegian package plant inspection criteria are that service inspections must take place at least twice per year, and plants requiring 4 or more service inspections per year will not be granted approval. Approval is granted for 5 years only, and can be withdrawn following poor performance. Costs of obtaining approval are borne by the manufacturer. These stringent regulations have resulted in:

- Unreliable products being weeded out, saving homeowners and authorities from the problems such systems cause.
- The high cost of gaining approval ensures manufacturers carefully consider their designs before entering the market.
- Major performance and product improvements.
- Service contracts which ensure system reliability and to maintain stable operation of the treatment plants in the longer term.

Failures do occur despite this system; mainly due to hydraulic overloading, discharge of toxic chemicals and improper maintenance (often failure to remove sludge when necessary) (Paulsrud & Haraldsen, 1993). The authors also noted that most municipalities showed little interest in monitoring plant performance despite being responsible for discharges in their area.

North Carolina legislation requires all package plant systems be monitored by a licensed operator, while Tennessee law requires licensed operators to be used only at plants which discharge directly into surface water bodies (Hanna et al., 1995). The authors also noted that Virginia codes requiring an annual effluent sample are inadequate, as a single sample cannot be considered representative of an effluent whose quality varies as widely.

2.7 Some overall observations

The international literature clearly indicates that the South African experience of treating package plant performance with some degree of suspicion is not uncommon and not without justification. However, the literature is equally clear that the range of sewage treatment technologies employed in package plants are not usually at fault so long as the plant design is suitable for the site specific characteristics where these plants are used.

It would appear that the greatest weakness in package plants is that they are privately owned and operated. Consequently, insufficiently trained operators often control them, and an understanding of appropriate maintenance and maintenance budgeting is also often lacking.

Legislation may help alleviate this problem if suitable enforcement is undertaken, but even this is no guarantee for success. It would appear that a clear understanding between designers, operators and civil authorities of the various system capabilities and limitations is required to meet the needs of environmental protection, which is usually at the hands of non-technical operators. Perhaps the cost of environmental protection has been under-estimated in the past, and the cost of adequate monitoring of these systems needs to be built into the rates structures for areas which necessarily employ package plant systems.

The selection of package plant technologies needs to site specific, and caution should be exercised in applying foreign estimates of costs of treatment to the same systems in South Africa. South Africa's energy costs do not always have the same influence on the costs of running processes, so this aspect in particular should be applied with caution when using international data for local decision support.

It would appear that adequately designed and operated package plants may reasonably be expected to comply with local discharge standards, however they are not automatically a cheap treatment option. The real costs of monitoring widely dispersed and privately controlled treatment systems needs to be considered by authorities when planning or upgrading property developments.

3. Supplier Surveys

3.1 Results of Questionnaires

The researchers sent out two questionnaires to nineteen package plant suppliers via e-mail. The first questionnaire was more qualitative, while the second was quantitative.

Despite reminders the response was not good, with eight responses to the first questionnaire, and five responses to the second questionnaire. Some businesses completed the first questionnaire, and not the second, and visa versa. This has had the result of skewing the results from the second questionnaire and will be indicated later.

Copies of the questionnaires can be found in Appendix 1.

<u>Number of years in business</u>

It was determined that 87.8% of the businesses had operated for more than five years with 12.5% having operated for between one and five years (12.5%).

Design and production of package plants

All suppliers designed and manufactured their own plants.

Availability of Customer Addresses

All suppliers were willing to provide the addresses of their customers.

Design Criteria

All the suppliers design their plants according to the expected flow and strength of the sewage, while 25% also take into account specifications from their customers.

Permission from authorities

87% of the respondents said that permission was obtained from an authority prior to installation. Permission is usually granted by a local town engineer, building inspector, wastewater inspector, district municipalities, Public Works Department, Department of Housing or an official from the Department of Water Affairs and Forestry. A consultant for the customer often obtains the permission. In the Western Cape permission is granted by Department of Water Affairs and Forestry in sensitive areas and includes an environmental impact assessment.

Major problems affecting package plant performance

According to responses received, suppliers considered that poor performance could be attributed to:

- Maintenance schedule neglected
- Replenishment with chlorine neglected
- Problems with biocides
- Lack of alkalinity
- Use of inferior materials
- Plants can be undersized/overloaded
- Insufficient aeration
- No authoritative regulation or directive
- Problems with downscaling
- Seasonal loads at holiday resorts
- Big range in influent concentrations
- Lack of maintenance contract

Problems with regulators

Supplier comments regarding difficulties with the regulators were termed as follows:

- Ethekwini due to historical problems.
- Need a national regulator – DWAF. Other state departments have different criteria which causes complication.
- A lack of understanding of the package plant industry.
- Dissemination of confidential and un-audited information to third parties.
- Unfair treatment by authorities whose own plants perform no better.
- Conflict of interests within municipalities. Water services provider also regulator of package plants.

Geographical Distribution of Package Plants

The geographical distribution of the plants according to province is shown in Figure 3.1. Data utilised includes that provided by a rotating bio-contactor manufacturer which accounts for approximately 50% of the plants by number.

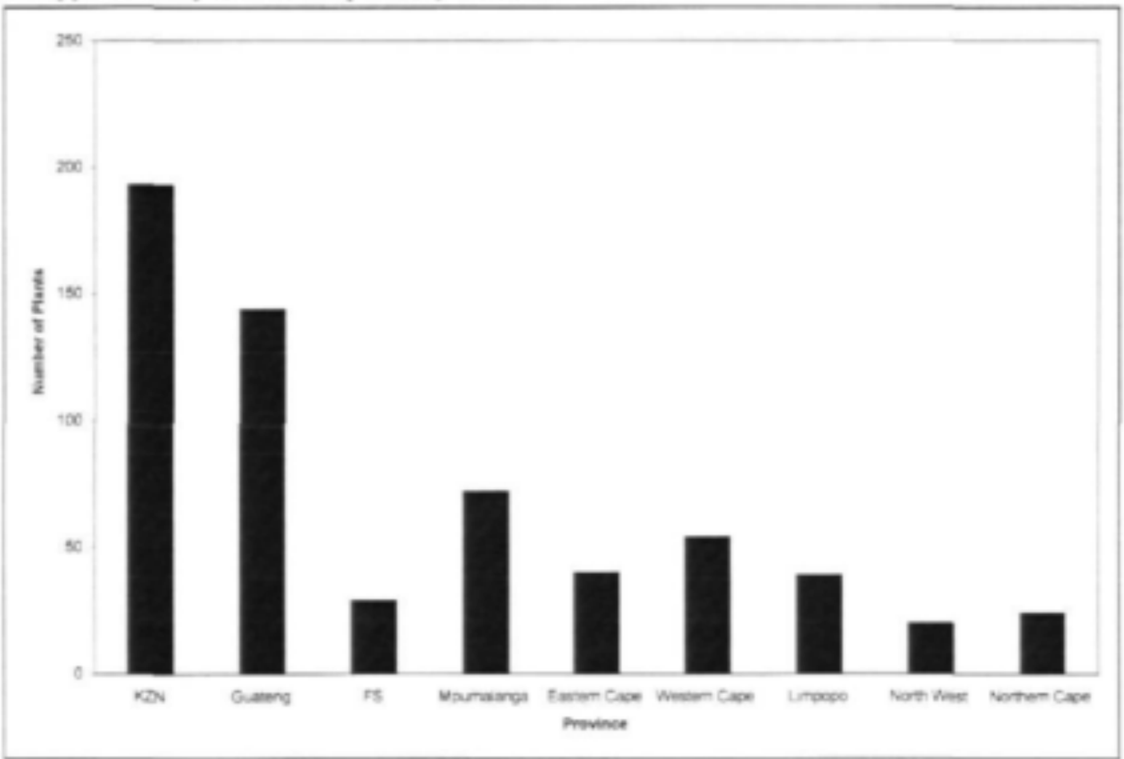

Figure 3.1. Geographical distribution of package plants.

It is clear that the majority of plants are situated in KwaZulu – Natal and Gauteng. The other provinces have markedly fewer package plants.

Capacity distribution

The distribution of pilot plants in terms of treatment capacity is shown in Figure 3.2. Unfortunately the large rotating bio-contactor manufacturer mentioned above as accounting for approximately 50% of the plants by number was not able to provide us with plant treatment capacities. Since most rotating bio-contactor plants probably fall in the range of 10

– 250 $m^3 day^{-1}$ the results the figure is not a good representation, being skewed towards the small plants.

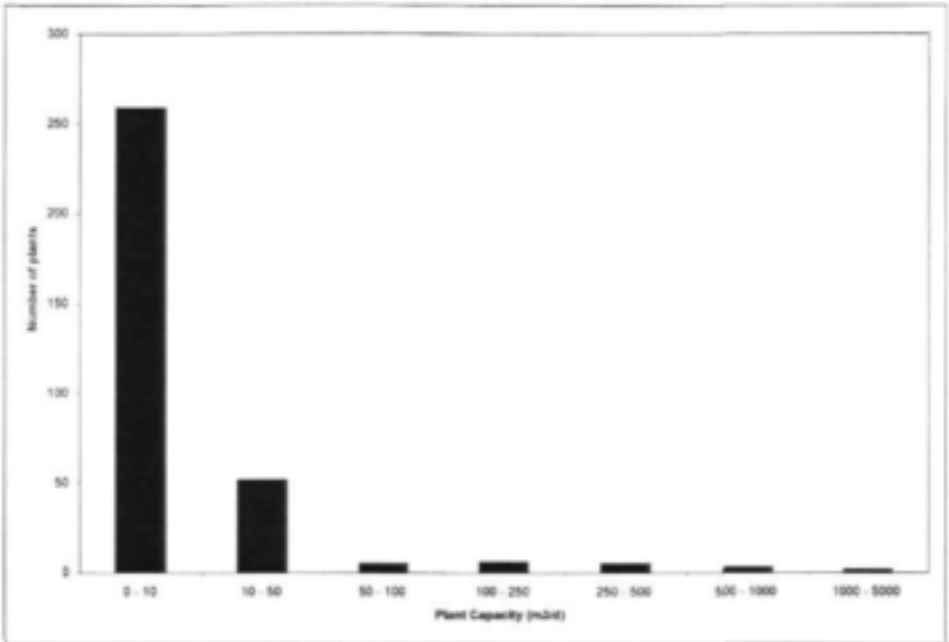

Figure 3.2. Reported capacity distribution of package plants

If the plants installed by the large rotating bio-contactor manufacturer are included in the statistics and assumed to be distributed evenly in the 10 – 250$m^3.day^{-1}$ range then the above figure can be modified to produce Figure 3.3.

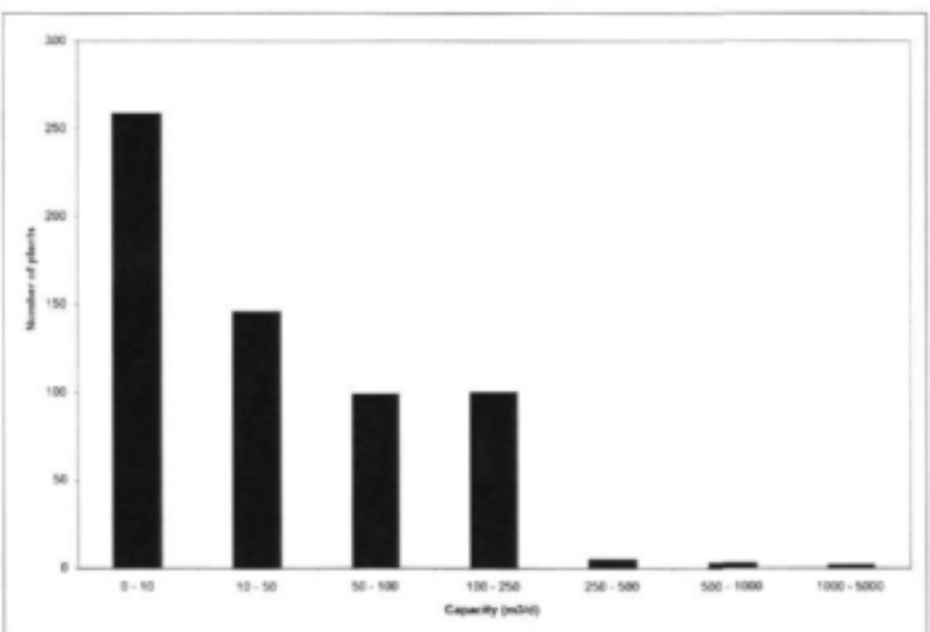

Figure 3.3. Extrapolated capacity distribution of package plants

The results of this questionnaire showed that a total of 615 package plants have been installed in South Africa at present.

4. Methodology

4.1 Selection of Technologies

Three plants were chosen for testing at the Darvill wastewater works in Pietermaritzburg, as follows:

- Submerged bio-contactor – a 2kℓ.day^{-1} unit was chosen which was widely distributed in South Africa.. The unit was supplied with a comprehensive operation and maintenance guide, users being encouraged to utilise the final effluent for lawn irrigation.
- Rotating bio-contactor – a unit rated for 2kℓ.day^{-1}. The supplier distributes nationally based on designs developed in the United Kingdom. Design features included polyethylene bio-contactors rather than fibreglass, stronger central rotating shafts, and stronger gearboxes than are normal on similar units in South Africa.
- Activated sludge – the supplier was seen as a market leader in South Africa and supplies a tried and tested technology. They supplied sequencing batch reactor unit of a 60m^3.day^{-1} capacity, much larger than originally anticipated. Attempts to secure smaller units from other suppliers were met with reluctance and disinterest.

4.2 Process descriptions

4.2.1 Submerged bio-contactor

A schematic diagram of the process is provided in Figure 4.1.

Screened and de-gritted raw sewage passes through a set of two single chamber septic tanks (total of 1 day retention time at design flow) where settling of solids and anaerobic digestion takes place. The flow subsequently passed through an equalisation tank and was pumped to an aeration tank filled with randomly orientated plastic packing. Thereafter treated effluent was fed to a constructed wetland, following which disinfection was facilitated by means of contact with chlorine tablets and discharged from the plant. A pump for irrigation is included in the plant. Construction is of custom made polypropylene tanks, with aeration by means of a relatively fine bubble diffuser pressurized by an air pump.

Process characteristics were monitored by sampling at several points. The raw influent was sampled before it reached the septic tanks, with subsequent sampling points between the equalisation tank and the aerobic module (designated L1); at the outflow from the aerobic module (designated L2) and at the outflow from the chlorine contact tank at the end of the constructed wetland; designated sample point L3.

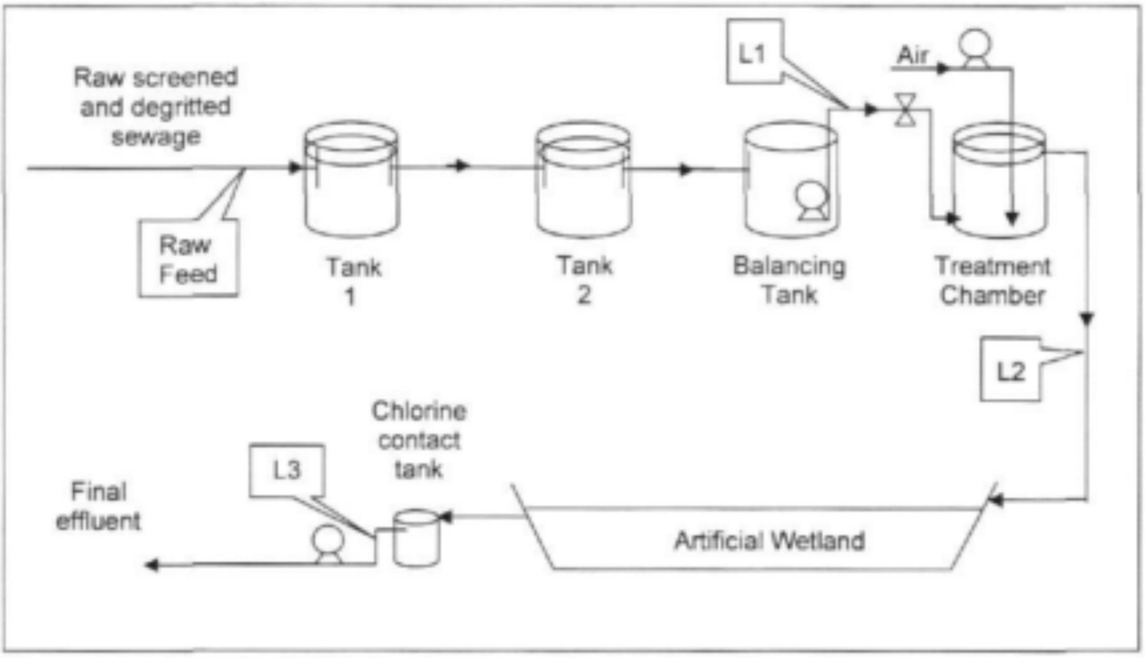

Figure 4.1. Schematic of SBC showing process flow and sampling points.

4.2.2 Rotating bio-contactor

A schematic diagram of the process flow is provided in Figure 4.2.

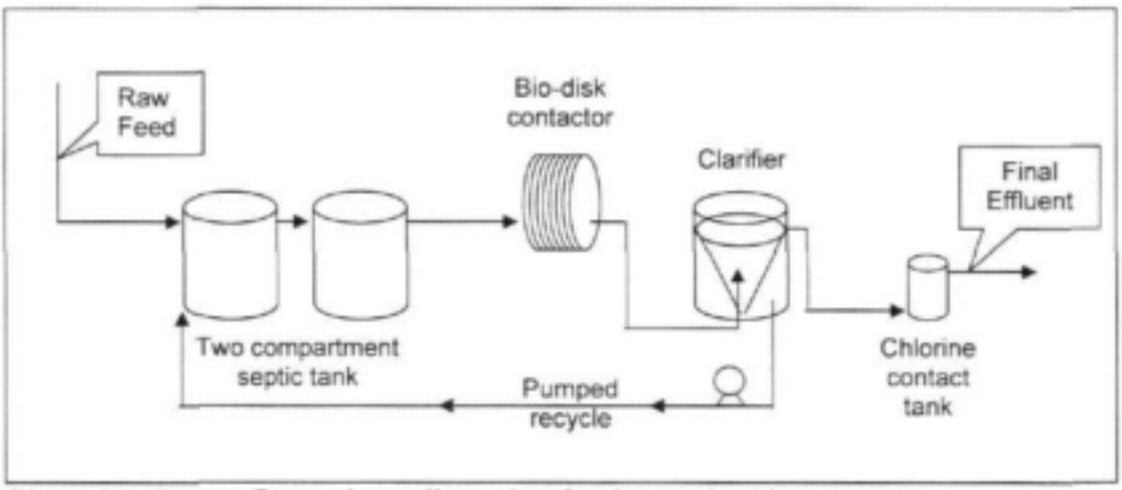

Figure 4.2. Process flow and sampling points for the rotating bio-contactor.

The sewage passed through two tanks where settling of solids and some anaerobic digestion took place. Retention time in these tanks was approximately 4 days at the design flow rate. Following the anaerobic step, the sewage then passed through the aerated phase where it was treated by the rotating bio-contactors. From the bio-contactor, the effluent passed to the clarifier for solids removal and the final effluent was disinfected using a chlorinator loaded with a cassette of chlorine tablets. A submersible pump located in the clarifier periodically returned effluent to the septic tank as a means of de-sludging the clarifier and also serving to reduce the nitrate production of the unit.

Construction was of standard polypropylene tanks for the septic tanks, a custom made reactor and a polypropylene clarifier. The unit is usually built in the ground using civil structures.

Process monitoring was undertaken by means of analysis of the influent sewage and the outgoing chlorinated effluent.

4.2.3 Activated Sludge

The sequencing batch reactor obtained was a unit in which extended aeration takes place prior to settling in the same tank. Once the aeration cycle is completed, the aerator switched off and the tank contents were allowed to settle before decanting the effluent to two $15m^3$ plastic tanks in series. Disinfection was by means of the addition of a measured dose of sodium hypochlorite solution injected into the flow between the reactor tank and the first plastic tank. The two plastic tanks thus served dual purposes to permit adequate contact time for the chlorinated effluent and also to balance the outflow rate. The plant also made provision for sand filtration of the effluent using a pressurised upflow filter, but as this was not a normal feature in sewage treatment, the effluent was not filtered in the course of this trial. The entire system is managed by a Programmable Logic Controller (PLC), which allowed variations to be made to the aeration cycle, settling time, chlorine dose etc.

Process characteristics were monitored by analysis of the influent sewage, monitoring the mixed liquor in the batch reactor tank and by sampling the final effluent.

The sequencing batch reactor was seeded with 12kℓ of thickened waste activated sludge (approximately 3%) from the Darvill WWW in order to reduce the start-up period.

4.3 Feeding regime

All feed sewage was taken from the main inlet channel at Darvill Wastewater Works following 16mm screening and de-gritting.

4.3.1 Submerged Bio Contactor and Rotating Bio Contactor systems

These two units were fed from a 10 000-litre common supply tank, with a total of 2kℓ per day being fed to each unit split into two feeding periods. Half the total feed was pumped to the plants between 04:30 and 10:30 in the morning, and the other half during the period 16:00 to 22:00. Each unit was fed by a separate Pedrollo Top Vortex submersible pump, and these units were controlled by an unequal cycling timer. The timer was set so that sewage would be pumped to the package plants in approximately 20 litre quantities during the 2 periods of feeding per day. This was in an attempt to mimic normal diurnal fluctuations in sewage flow such as are experienced in the sewage discharge from a domestic home.

The sewage entering the common supply tank was screened through a stainless steel bucket with 5mm perforations to protect the dosing pumps. A third submersible pump (Pedrollo Top Vortex initially, later replaced by Zenit Draga 75/2M) was placed on the floor of the feed tank and run continuously to ensure homogeneity of the stored sewage.
Samples of the feed sewage were taken from the supply tank to characterise the influent sewage.

4.3.2 Activated sludge system

Due to the volumes required for the sequencing batch reactor, the common feed system planned to supply the package plants was under-sized.

Consequently, the sequencing batch reactor was fed using a separate submersible pump placed in the main inlet channel to Darvill. At the point of intake, the Darvill influent had passed through 16mm raked screens and a vortex degritting system.

The feed regime selected was to daily supply 30kℓ intermittently between 04:00 and 10:00 and a further 30 kℓ intermittently between 16:00 and 22:00. Feed quality data was obtained from the routine sampling of the sewage influent to the main works.

4.4 Problems encountered

A number of problems were encountered in the initial stages with the feed pumps for the submerged bio-contactor and the sequencing batch reactor. These included power failures, tripping of the earth leakage (due to an intermittently failing seal in the raw sewage mixing pump) and periodic over-feeding of the smaller units due to failures of the unequal cycling timers.

In an attempt to classify the types and reasons for faults and failures, a system was developed to logically categorise failures into the categories of sewage supply breakdowns, initialisation failures, operational breakdowns and maintenance breakdowns.

Faults were found to have occurred in two broad categories; those arising as a result of sewage effluents that failed to meet the discharge standard to water and failures as a result of unscheduled conditions other than poor effluent quality.

This second category would include overflows of untreated sewage, failures of transfer pumps within the treatment systems, failure of disinfection apparatus etc.

4.4.1 Sewage supply failures

Sewage supply breakdowns occurred as a result of failures due to problems in the feed systems, and were not considered to be related to the plants under test. Thus failures of this nature should not count against the units involved.

4.4.2 Initialisation failures

These were defined as constituting a failure of the package plant system to produce an effluent within the required quality specification due to normal operational conditions not being achieved.
Typically problems of this nature would be encountered during the days after initial start-up, and should cease after adequate development of biomass in the treatment system.

While failures in the start-up phases are to be expected, these were logged for reference purposes, but results obtained within the first 3 weeks of operation were not considered to be representative of the normal performance standards potentially achieved by the units under test.

4.4.3 Operational breakdowns

Operational breakdowns were defined as being those failures to deliver the required quality of effluent due either to design weaknesses or improper specification or unforeseen failure in any component in the treatment chain. These were separated from maintenance breakdowns, which were considered to be faults preventable by reasonable intervention of the operator.

4.4.4 Maintenance breakdowns

Maintenance breakdowns were defined as failures to operate or to produce the required quality of effluent as a result of the failure of the operator to carry out reasonable maintenance.

For the time scale of this trial, this was limited to replenishment of disinfection chemicals, but in the longer term would also include factors such as de-sludging of septic tanks, routine maintenance to mechanical equipment etc. Since proper maintenance is a reasonable expectation by any equipment supplier, faults of this nature were not included in the numerical fault allocation process since it was accepted that they should not prejudice a technology.

4.4.5 Fault allocation

The allocation of any faults to the specified categories required an assessment to be made as to the reasons underlying any fault that was logged. Faults were logged whenever planned conditions did not occur, that is if plants were over/underfed, surcharges were noted or any analytical results failed to meet requirements.

Once the fault data was collated, it became apparent that the faults could be classified into sub-categories within each class. Whether the net result was an effluent that failed to comply with the discharge standards, or the fault was found to be due to other breakdowns, they were found to be as a result of one or more of the following factors:

- design faults
- electrical faults
- maintenance faults (not included in statistical analysis)
- other faults

Thus with respect to out of range results, the root cause could be assigned to either poor design, a failure in the electrical supply (not due to a design problem), a maintenance fault (in the case of out of range results frequently due to maintenance required from the operator); or if of unknown origin, the fault would be ascribed to "other" factors.

Faults in performance due to breakdowns or other such factors were slightly different in character than those traced back from failures resulting in sub-standard effluent. Once again, design faults would obviously result in some sort of interruption of the normal operational process, which affected sewage or electricity supply, or some difficulty in maintenance, maintenance in this case being required due more to design than to operation.

Further refinement of the system may well be warranted, but within the time constraints of the investigation, the fault evaluations as described were reported under the relevant section of the Results and Discussion chapter.

4.5 Sampling regime

In order to ensure the investigation was carried out under the most controlled conditions possible, and that the required monitoring was undertaken, the following sampling regime was adopted:

Composite samples of the sewage influent feed for attached medium processes were taken. Equal volume samples were taken each day Monday to Friday, preserved with mercuric chloride and stored in a refrigerator. Once a week, the week's samples were pooled and submitted for analysis of ammonia, nitrate, total Kjeldahl nitrogen, total phosphorous and soluble phosphorous, soap oil and grease, alkalinity, chemical oxygen demand, pH and suspended solids.

The sewage flow from the septic tanks on the submerged bio-contactor was grab sampled twice weekly and analysed for ammonia, nitrate, total Kjeldahl nitrogen, total phosphorous and soluble phosphorous, alkalinity, chemical oxygen demand, pH and suspended solids. The purpose of this monitoring was to monitor the performance of the septic tanks, and to gain an understanding of the feed to the aerobic phase of this treatment process.

The effluent samples were also grab sampled twice weekly and analysed for ammonia, nitrate, total Kjeldahl nitrogen, total phosphorous and soluble phosphorous, alkalinity, chemical oxygen demand, pH and suspended solids. A weekly analysis for *E.coli* was also undertaken on the effluents.

In addition, regular twice-weekly sampling of the mixed liquor for suspended solids analysis was undertaken on the suspended medium unit.

Furthermore regular checks on the sewage feed pump calibrations were undertaken by daily dip reading of the sewage tank supplying the attached medium systems, and regular checks of the pump volumes dispatched by the dosing pumps.

The suspended medium system was somewhat harder to monitor the feed volume accurately, but measurements of the upper and lower levels of sewage in the reactor vessel were periodically undertaken and found to be within acceptable limits.

4.6 Loading rates

In order to gain insight into the performance of the package plants used in this evaluation it is important to compare their loading parameters with those in authoritative texts. This will confirm whether they are correctly designed or not.

4.6.1 Sequencing Batch Reactor

The sequencing batch reactor is a modification or adaptation of extended aeration activated sludge. The conventional design criteria for extended aeration activated sludge is 12 hours hydraulic retention time in the aerobic reactor, with a MLSS of 3500 -5000mg.ℓ^{-1}.

In this evaluation the plant processed 60m^3 of sewage in two batches per day, which gives an hydraulic retention time of 12 hours. This is equal to the design criteria given above. The MLSS concentration was maintained in the range given above.

4.6.2 Rotating Bio-Contactor

The design parameters for rotating bio-contactors are somewhat more complicated than activated sludge, and are clearly set out in the section on design criteria. They are sourced from WISA (1988). This gives a number of tables and guidelines for rotating bio-contactor design, and these will be used to calculate the sizing of the disks below.

In order to ensure nitrification it is necessary to reduce the COD to 25mg.ℓ^{-1} – if it is greater than this nitrification will not occur.

Influent COD = 300mg.ℓ^{-1}
Effluent COD = 25mg.ℓ^{-1}

From Figure 5.1 in the above manual the hydraulic loading rate for COD removal is:

Hydraulic loading = 80 ℓ.m^{-2}.day^{-1}

Thus the area needed for a flow of 2000 litres is:

Wetted area = 2000 l / 80ℓ.m^{-2}.day^{-1}
= 25m^2

Due to the high diurnal this should be multiplied by a factor of 1.3 giving

Wetted area = 32.5m^2

This disk area should be arranged in two stages for more efficient treatment.

An extra stage of disks is used for nitrification. These are designed assuming the following:

Influent ammonia = 31mg.ℓ^{-1}
Effluent ammonia = 3mg.ℓ^{-1}

From figure 5.2 in the above manual the hydraulic loading rate for nitrification is:

Hydraulic loading = 50 ℓ.m^{-2}.day^{-1}

Thus the area needed for a flow of 2000 litres is:

$$\text{Wetted area} = 2000\ l / 50\ \ell.m^{-2}.day^{-1}$$
$$= 40\ m^2$$

Due to the high diurnal this should be multiplied by a factor of 1.3 giving

$$\text{Wetted area} = 52\ m^2$$

The combined wetted disk area is thus 32.5 + 52 m^2 which is 84.5 m^2.

The rotating bio-contactor used in this evaluation has a total surface area of 90 m^2 (according to the supplier), divided into two stages, each with a surface area of 45 m^2. This area is much the same as that calculated above, but nitrification remained poor. The authors measured the disks and directly calculated the wetted area of the flat disks, while modelling loosely the undulating disks as having alternating half circles (much like a sine wave). The combined wetted area according to these calculations was 65m^2, which would explain the lack of nitrification.

4.6.3 Submerged Bio-Contactor

Design criteria for submerged bio-contactor technology were not easily obtained, with most of the authoritative texts skirting the issue. The authors managed to find an EPA Technical fact sheet for trickling filter nitrification (USEPA 2000b) which had design parameters which are applicable to submerged bio-contactor technologies. The applicability is possible since a submerged bio-contactor and a trickling biofilter are essentially the same thing, with the exception that the former is submerged while the latter is not. The difference in means of aeration is irrelevant provided that the dissolved oxygen in the water is >2mg.ℓ^{-1}. Fortunately the fact sheet has design loadings for trickling biofilters using plastic media.

Unfortunately the design loadings for nitrification are based on volume and not media area, and thus an assumption has been made that the specific area of both plastic media is the same. *This assumption may not be correct.*

The organic loading rates are given in Table 4.1.

Table 4.1. Organic loading rates to ensure nitrification

Loading rate based on BOD	192 – 288 gBODm^{-3}.day^{-1}
Loading rate based on COD	295 – 443 gCODm^{-3}.day^{-1}

* based on BOD = 0.65 x COD

The loading rate for the submerged bio-contactor used for the evaluation was calculated as follows:

Volume of sewage fed per day	=	2000 litres
Average COD of sewage	=	295 $mg.\ell^{-1}$
COD load per day	=	590 $g.day^{-1}$
Volume of aerobic reactor	=	1 m^3
COD loading	=	590 $gCOD.m^{-3}.day^{-1}$

Thus the COD loading calculated above is in excess of the design parameters given in the fact sheet, and this may explain problems encountered with nitrification.

5. Results and discussion

5.1 Influent Sewage Quality

Table 5.1 displays the means for analytical data for the influent sewage sampled from the common feed tank which supplied the submerged bio-contactor and the rotating bio-contactor. The table also provides the results arising from composite sampling of the raw Darvill influent. This sewage was the feed both to the common tank for the two smaller units and the direct feed to the sequencing batch reactor. Table 5.1 also provides some typical values for these determinands referenced from Ekama et al. (1984) for comparison purposes.

The complete set of analytical data for all analyses is attached as Appendix 2.

Table 5.1. Influent Sewage Quality for the duration of the investigation.

		Feed tank		Darvill influent		Typical
Determinand	**Unit**	**Mean**	**n**	**Mean**	**N**	**Sewage**
Alkalinity	$mg.\ell^{-1}$ $CaCO_3$	284	31	241	104	
COD	$mgO_2.\ell^{-1}$	537	31	602	93	500-800
NH_3	$mgN.\ell^{-1}$	31	25	26	81	
NO_3	$mgN.\ell^{-1}$	0.29	18	0.54	76	
pH		7.1*	31	7.1*	105	
SOG	$mg.\ell^{-1}$	63	23			
SRP	$\mu g.\ell^{-1}$	7596	20	6426	82	
SS	$mg.\ell^{-1}$	238	31	254	39	270-450
TKN	$mgN.\ell^{-1}$	51	20	46	17	35-80
TP	$\mu g.\ell^{-1}$	11285	19	12153	21	8000-18000

*Mode value

The concentrations of ammonia and the chemical oxygen demand are two critically important factors in the design of wastewater treatment systems. Thus the data for these determinands as measured in the feed to the attached medium processes are presented in Figures 5.1 and 5.2 to illustrate their respective fluctuations throughout the period of testing.

As indicated in the section on the investigation methodology, the feed tank was filled only during peak hydraulic and sewage strength flows to the works, which explains the slight discrepancies in analytical data between the feed tank data and the Darvill influent data which was obtained by composite (time based) sampling of the inflow channel to the works.

For the data displayed in Figure 5.1, of a total of 31 results, 9 were below the normal lower expected value of $500mg.\ell^{-1}$ for COD, and 2 results were greater than the expected value of $800mg.\ell^{-1}$ reported as normal by Ekama et al. (1984).

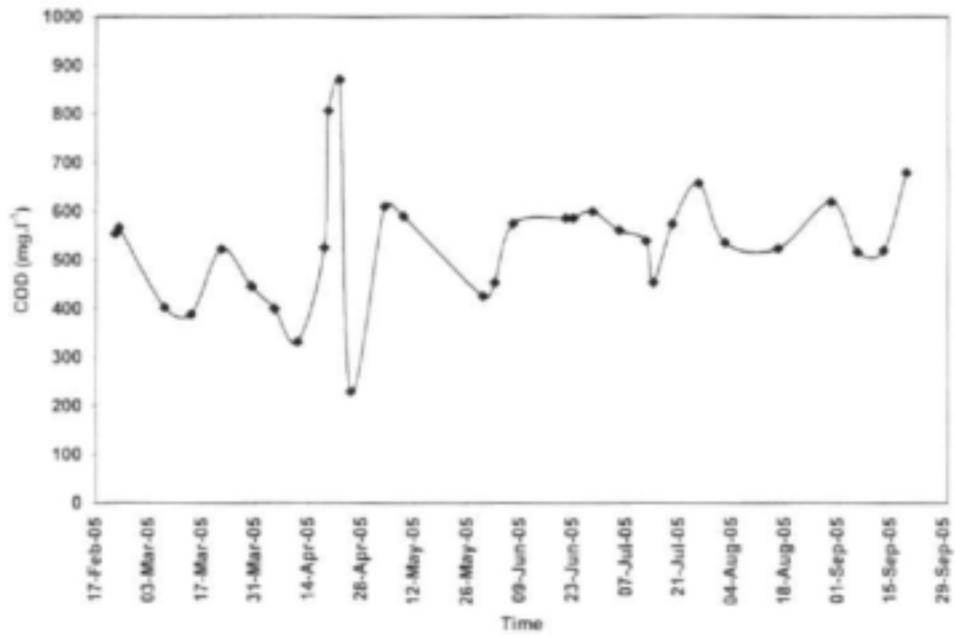

Figure 5.1. COD concentrations in the feed sewage.

The sewage was considered representative of normal sewage as the mean COD value over the period of testing was 537 mg.ℓ^{-1} with the median value for the data being 540 mg.ℓ^{-1}. This indicates the sewage COD concentration was slightly lower than might be expected, but none the less fell within normal parameters.

It was concluded that the sewage influent to Darvill complied well with the normal ranges of quality expected in untreated domestic effluent. While it must be noted that up to 10% of the feed to Darvill is of industrial origin, the variation in sewage strength concentrations fell within the ranges expected for domestic sewage.

Figure 5.2 illustrates the fluctuation of ammonia concentrations in the sewage fed to the two small attached medium plants for the duration of the trial. It was concluded that the range of ammonia concentrations fell within expected ranges for domestic sewage, although reports were received of much higher ammonia concentrations in septic tank effluents in cases such as tanks serving office blocks.

Considering the critical sewage parameters of ammonia and COD, it was concluded that the Darvill influent could be considered normal, and consequently that performance of the package plants should not be adversely affected by the industrial component of the influent.

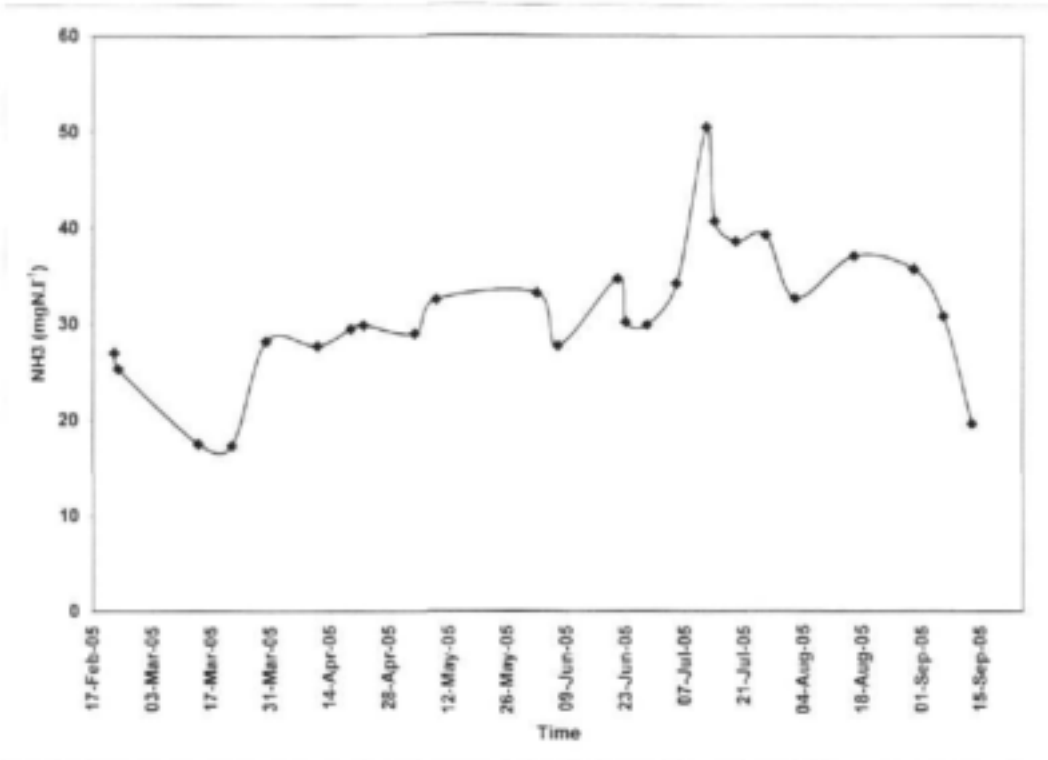

Figure 5.2. Ammonia Concentration in the feed sewage

5.2 Effluent quality

The mean values for analytical results of samples taken at various stages in the treatment processes of the different plants are recorded in Table 5.2 for the purposes of illustrating changes in quality through the processes and for comparison of the effluent data.

For the submerged bio-contactor, sample points L1, L2 and L3 are listed. The layout of these sample points is detailed in Section 4.2.1, but in summary point L1 is septic tank sewage feeding the aerobic phase of the process; L2 is the point following aerobic treatment and L3 is the point following an artificial wetland.

These results are discussed in the various sub sections that follow. Table 5.2 details the statistics obtained for samples drawn throughout the period of monitoring. The complete set of analytical data from which these mean values were calculated is attached as Appendix 2.

Table 5.2. Mean quality values for all effluent data.

		SBC						RBC		SBR	
Determinand	**Units**	L1	n	L2	n	L3	n	Effluent	n	Effluent	n
Alkalinity	mgCaCO$_3$ ℓ^{-1}	320	41	303	50	279	38	254	51	167	33
COD	mg ℓ^{-1}	289	41	117	50	55	38	89	51	44	38
Cl_{total}	mg ℓ^{-1}					1	35	0.46	52	0.35	24
E.coli	100mℓ^{-1}			200	3	320	11	275826	13	1410	19
NH_3	mgN ℓ^{-1}	45	36	33	46	28	37	23	45	9	37
NO_3	mgN/l	1	33	1	43	3	36	3	47	6	36
pH		7.2*	41	7.32*	50	7.35*	38	7.26*	51	7.52*	38
SRP	µg ℓ^{-1}	8390	36	7773	45	4899	36	7481	46	5142	35
SS	mg ℓ^{-1}	117	41	40	50	12	38	40	51	9	38
TKN	mgN ℓ^{-1}	51	36	46	37	38	34	46	41	11	35
TP	µg ℓ^{-1}	10856	35	10345	35	7359	34	10345	39	6767	35
MLSS**	mg ℓ^{-1}									2794	33

*Mode

**Mixed liquor Suspended Solids

Table 5.3 was drawn up and excludes results of analyses obtained before the onset of steady state of operation, that is excluding the first three weeks of analyses. Data obtained in this start up period was deemed not be representative of the general effluent quality as the biological treatment processes may not have stabilised in the start up phase of operation.

Table 5.3. Mean quality values for effluents at steady state.

		SBC						RBC		SBR	
Determinand	**Units**	L1	n	L2	n	L3	n	Effluent	n	Effluent	n
Alkalinity	mgCaCO$_3$ ℓ^{-1}	322	33	308	44	278	30	245	22	154	27
COD	mg ℓ^{-1}	308	33	119	44	53	30	52	22	37	27
Cl_{total}	mg ℓ^{-1}					1	28	0.64	24	0.35	24
E.coli	100mℓ^{-1}			500	1	257	9	3818	7	166	15
NH_3	mgN ℓ^{-1}	49	28	35	41	28	29	22	21	4	26
NO_3	mgN ℓ^{-1}	1	25	2	40	3	28	4	21	8	25
pH		7.16*	33	7.32*	44	7.53*	30	7.26*	22	7.25*	27
SRP	µg ℓ^{-1}	8644	29	8095	40	5290	29	8842	21	5353	24
SS	mg ℓ^{-1}	128	33	44	44	14	30	15	22	8	27
TKN	mgN ℓ^{-1}	52	30	46	36	38	27	32	19	5	24
TP	µg ℓ^{-1}	11135	29	10345	35	7829	27	10044	19	7075	24
MLSS**	mg ℓ^{-1}									2790	24

*Mode

**Mixed liquor Suspended Solids

5.2.1 Submerged bio-contactor system

Tables 5.2 and 5.3 provide data of mean values for the effluent from the submerged bio-contactor and compare the effluent quality with those from the other plants.

Further detail on the statistical analysis of data from the effluent arising from the submerged bio-contactor plant is provided in Table 5.4, with a complete data set attached in Appendix 2.

Table 5.4. Steady State Effluent quality for submerged bio-contactor L2.

Determinand	Unit	Mean	n	Range	Std. Dev	% Removal	C1	C2
Alkalinity	$mgCaCO_3.\ell^{-1}$	308	44	225 - 394	43.8	-7.0		
COD	$mg.\ell^{-1}$	119	44	30 - 207	38.2	78.2	9	100
E.coli	$100m\ell^{-1}$	78175	4	500 - 241900	112412	2 Log	25	75
NH_3	$mgN.\ell^{-1}$	35	41	16 - 51.4	8.6	-12.6	0	
NO_3		2	40	0.25 - 15.4	3.8	-422.2	100	100
pH	$mg.\ell^{-1}$	7.32*	44	6.53 - 7.72		-3.1		
SRP	$\mu g.\ell^{-1}$	8095	40	4300 - 10300	1299	-6.6		
SS	$mg.\ell^{-1}$	44	44	1 - 80	21.3	83.1	18	
TKN	$mgN.\ell^{-1}$	46	36	27.7 - 59.3	7.8	10.4		
TP	$\mu g.\ell^{-1}$	10345	35	6460 - 16760	1750	8		

*Mode

C1 = % compliance with GA for discharge to river

C2 = % compliance with GA for irrigation

The submerged bio-contactor system failed to comply to any reasonable extent with standards for discharge to water which would include *E.coli* and ammonia analyses. The plant consistently failed to successfully nitrify, which is a matter for concern in areas where an ammonia standard may be applied to plants discharging less than $10m^3$ per day.

The satisfaction of normal parameters conducive for nitrification (sufficient substrate, dissolved oxygen and alkalinity) led the researchers to believe that nitrification was theoretically possible in the submerged bio-contactor unit throughout the trial period. The main Darvill plant showed acceptable nitrification during this period, so the question of toxic inhibition does not appear to explain the lack of ammonia removal in the submerged bio-contactor.

As discussed under Section 4.6.3, the normally accepted design parameters for biomass loading under submerged bio-contactor conditions were exceeded in the investigation. Thus either greater margins of safety in the calculation of provision of suitable biomass area for treatment are necessary or alterations needed to be made to the process to favour conditions for the nitrifier development and retention. This is an area possibly warranting further research to improve nitrification in small scale sewage treatment processes.

Table 5.4 details effluent quality for the submerged bio-contactor before passing through the artificial wetland, and is recorded as most units encountered did not have wetlands attached to them. In order to indicate the possible improvements in effluent quality brought about by the process of passing the effluent through a wetland, Table 5.5 was compiled for comparison purposes.

Table 5.5. Steady state effluent quality for submerged bio-contactor after wetland.

Determinand	Unit	Mean	n	Range	Std. Dev	% Removal	C1	C2
Alkalinity	$mgCaCO_3.\ell^{-1}$	278	30	54 - 394	71.0	2.0		
COD	$mg.\ell^{-1}$	53	30	26 - 87	17.7	90.1	83.3	100.0
Cl_{total}	$mg.\ell^{-1}$	1	28	0.01 - 5	1.0			
E.coli	$100m\ell^{-1}$	65125	16	5 - 241900	98057	2 Log	50.0	68.8
NH_3	$mgN.\ell^{-1}$	28	29	2.82 - 45.2	10.5	9.9	3.4	
NO_3	$mgN.\ell^{-1}$	3	28	0.25 - 16	3.5	-1012.8		
PH	$mg.\ell^{-1}$	7.53*	30	4.94 - 7.53		-1.4	97.4	97.4
SRP	$\mu g.\ell^{-1}$	5290	29	320 - 9550	2145	30.4		
SS	$mg.\ell^{-1}$	14	30	0 - 25	5.7	94.3	100.0	
TKN	$mgN.\ell^{-1}$	38	27	11.7 - 67.6	12.4	25.2		
TP	$\mu g.\ell^{-1}$	7829	27	250 - 14050	2911	30.6		

*Mode

C1 = % compliance with GA for discharge to river

C2 = % compliance with GA for irrigation

The successful removal of COD indicated that these processes and mechanisms were fully active, but that nitrifiers were unable to successfully establish themselves. Discussions with various specialists as to possible reasons for this were somewhat inconclusive, although high rates of flow through the contact system were generally recognised to constitute conditions unfavourable for the successful establishment of the autotrophic nitrifier organisms.

Further reviews of literature specific to the topic of nitrification in trickling filters indicated that high COD values were indicative of conditions unfavourable for nitrifier development (Yang & Zhang, 1995; USEPA, 2000), thus indicating that modifications may be possible to the process to promote nitrification.

The presence of the constructed wetland markedly improved effluent quality on the submerged bio-contactor system, and is a recommended design feature in standard wastewater engineering texts (Tchobanoglous & Burton, 1979). Removal of suspended solids and the allied COD concentrations are markedly improved by the filtering action of the wetland. As this polishing step is a feature which will require maintenance, Figure 5.3 was compiled to indicate the changes in certain key performance parameters for the effluent from the wetland. Growth of plant material will require periodic cutting back, the frequency of which would depend on the plant species involved and the climatic conditions experienced. As Figure 5.3 indicates, there is a gradual build up of solids in the wetland effluent resulting in decreased filtering capacity which at some point would become unacceptable. This could be catered for by having parallel wetlands (or other polishing devices) so that when one unit required maintenance, the flow could be channelled through the alternate path.

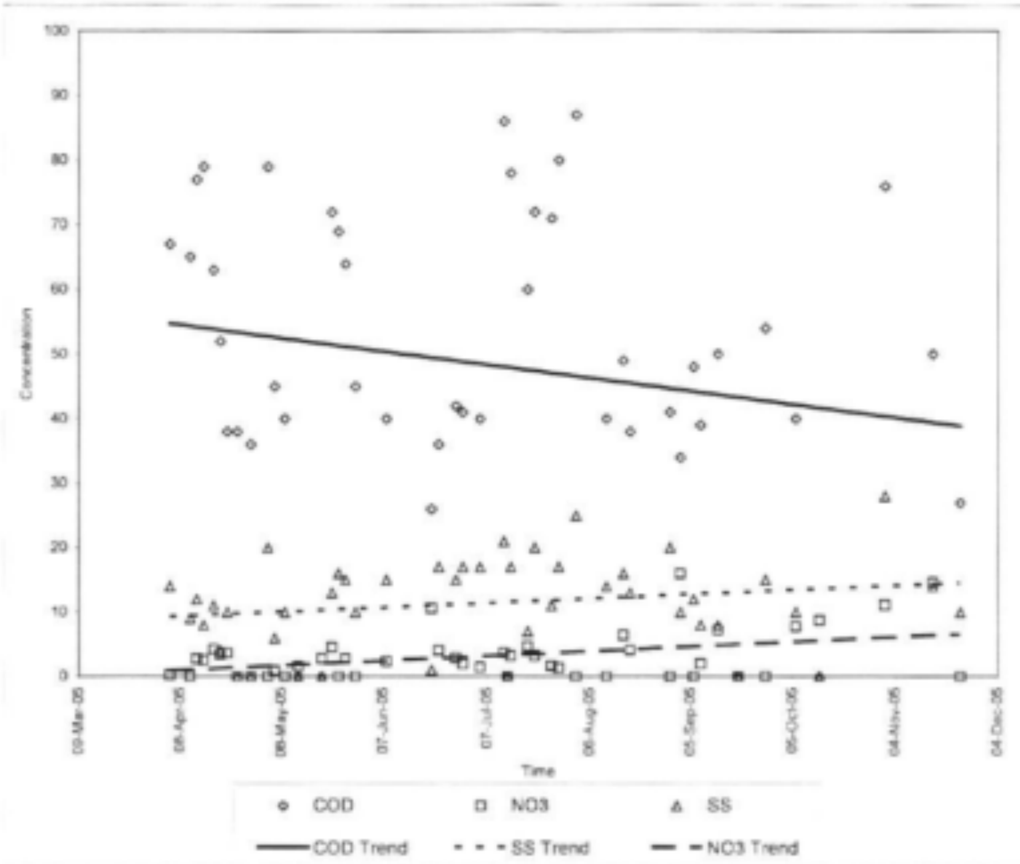

Figure 5.3. Key determinand trends for wetland effluent (L3)

The chlorination system employed in the submerged bio-contactor system has the capacity to effectively disinfect the effluent, but is heavily reliant on operator maintenance on a weekly basis. This fact is clearly pointed out in the operator's manual delivered with the unit, and failure to replenish the chlorine tablet supply in good time leads to a rapid decline in the disinfection success.

For the purposes of easy illustration, the critical performance indicators of ammonia and the chemical oxygen demand for effluent from the submerged bio-contactor are presented in Figure 5.4 for the samples drawn before and after the constructed wetland.

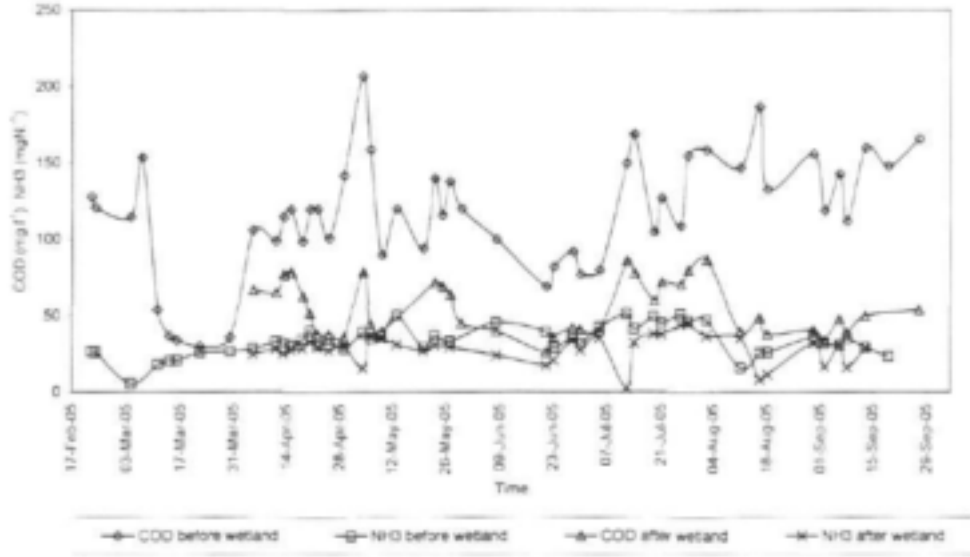

Figure 5.4. Submerged bio-contactor COD and ammonia concentrations

The reduction in COD in comparing the influent to the wetland (L2) and the effluent from it (L3) clearly indicates the benefit of added filtration. With adequate solids removal, whether by means of a filter, a wetland or a clarifier, compliance with requirements for suspended solids removal is much improved.

It must be noted that a filtration step adds to the maintenance requirements of the plant as the accumulated solids will need to be removed from time to time. Except perhaps in the case of very large wetlands, constructed wetlands will also periodically require solids to be removed, and in any case will normally require maintenance to cut back excess plant growth, remove weeds etc. Some design outlines specify two parallel wetlands used alternately so that while one is receiving attention, the other can be used.

5.2.2 Rotating Bio-contactor system

Tables 5.2 and 5.3 provide data of mean values for the effluent from the rotating bio-contactor and the tables compare the effluent quality with results from the other plants. More detail on the statistical analysis of data from the effluent arising from the rotating bio-contactor plant is provided in Table 5.6, with a complete data set attached in Appendix 2.

In common with the other fixed medium system tested in this trial, the rotating bio-contactor failed to nitrify incoming ammonia to anywhere close to the 6mgN.ℓ^{-1} standard which some municipalities require. Some degree of nitrification did appear to occur, but it was inconsistent and generally insufficient to meet such standards.

Table 5.6. Steady State Effluent quality for RBC at steady state

Determinand	Unit	Mean	n	Range	Std. Dev	% Removal	C1	C2
Alkalinity	$mgCaCO_3.\ell^{-1}$	254	43	129 - 452	55	10		
COD	$mg.\ell^{-1}$	71	43	34 - 166	34	87	72	100
Cl_{total}	$mg.\ell^{-1}$	0.51	46	0 - 4	1	0		
E.coli	$100m\ell^{-1}$	419388	24	0.8 - 2419000	784511	1 Log	33	71
NH_3	$mgN.\ell^{-1}$	23	42	1.91 - 37.9	8	25	5	
NO_3	$mgN.\ell^{-1}$	2	42	0.25 - 17.4	4	-54		
pH	$mg.\ell^{-1}$	7.26*	43	6.65 - 7.62		-2	100	100
SRP	$\mu g.\ell^{-1}$	7708	42	1780 - 10970	1920	-1		
SS	$mg.\ell^{-1}$	19	43	3 - 49	11	92	74	
TKN	$mgN.\ell^{-1}$	32	38	13.4 - 48.7	10	38		
TP	$\mu g.\ell^{-1}$	9465	37	4160 - 12990	1768	16		

*Mode

C1 = % compliance with GA for discharge to river

C2 = % compliance with GA for irrigation

In common with the other attached medium system tested, conditions should have been favourable for the development of nitrifiers, since adequate substrate, adequate dissolved oxygen and adequate alkalinity was found to be present in the reactor during the trial. As detailed in section 4.6.2, it would appear that the effectively active zone of the rotating bio-contactor was somewhat overloaded with respect to influent COD, consequently selecting against the favourable establishment of nitrifier micro organisms.

The results for the rotating bio-contactor were initially adversely impacted by the installation of a malfunctioning clarifier at the beginning of the project. Poor solids settling led to high values for SS, COD and bacteriological contamination, while chlorination was consequently ineffective. Installation of an improved clarifier on June 14 brought about an enormous improvement in the effluent quality, a fact which is not apparent from examination of average effluent values.

The chlorination system in the tested rotating bio-contactor was a standard Klorman clean water unit, and has performed reasonably well. The unit was highly effective when the chlorine supply (a magazine of ten solid hypochlorite 'pills') is new, but tends to become problematic toward the end of the useful life of the system. Disinfection failures have been noticed even when the chlorine magazine is more than half full with tablets. It would appear that a weekly clean out of this chlorination unit would help achieve greater success in disinfection.

As expected no notable removal of phosphate appears to occur with the rotating bio-contactor system in its configuration as tested.

Once again for ease of illustration of performance, the COD and ammonia results for effluent produced by the rotating bio-contactor are graphically presented in Figure 5.5.

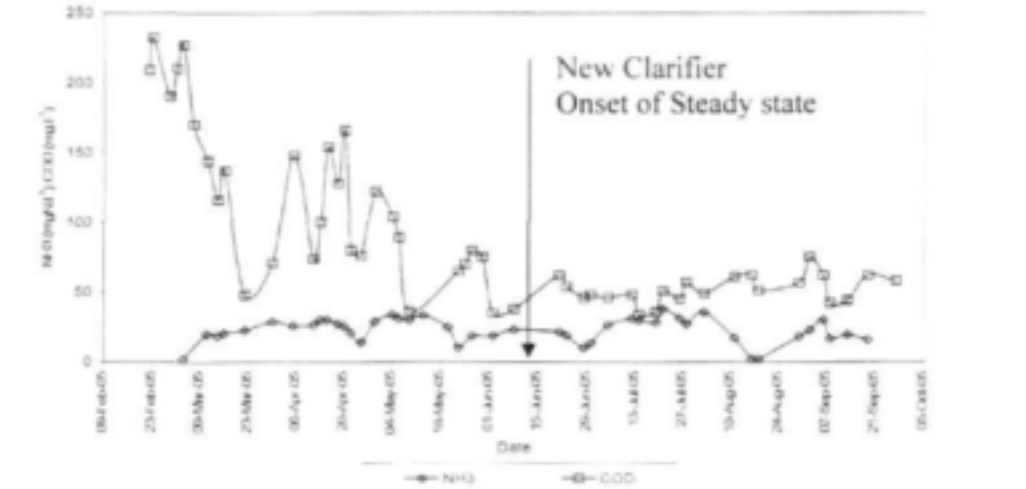

Figure 5.5 COD and ammonia data for effluent from the rotating bio-contactor

A complete presentation of the data obtained during the trial is attached in Appendix 2.

5.2.3 Sequencing batch reactor

Tables 5.2 and 5.3 provide data of mean values for the effluent from the sequencing batch reactor and the tables compare the effluent quality with results from the other plants. Further statistics computed on data from the sequencing batch reactor effluent is provided in Table 5.7, with a complete data set attached in Appendix 2.

Table 5.7. Effluent quality for Sequencing Batch Reactor at steady state.

Determinand	Unit	Mean	n	Range	Std. Dev	% Removal	C1	C2
Alkalinity	$mgCaCO_3.\ell^{-1}$	154	24	65 - 785	680	0		
COD	$mg.\ell^{-1}$	36.9	27	22 - 67	11.5	93	100	100
Cl_{total}	$mg.\ell^{-1}$	0.4	24	0 - 0.7	0.2	0		
E.coli	*$100m\ell^{-1}$*	*1668*	*16*	*5 - 24190*	*5835*	*3Log*	*87.5*	*100*
NH_3	$mgN.\ell^{-1}$	4.1	26	1.86 - 13.3	2.7	87	81	
NO_3	$mgN.\ell^{-1}$	7.7	25	0.25 - 19.5	5.5	-2546		
pH	$mg.\ell^{-1}$	7.25*	27	6.76 - 7.62		-2	100	100
SRP	$\mu g.\ell^{-1}$	5800	22	1150 - 10920	2329	24		
SS	$mg.\ell^{-1}$	7.8	27	0 - 24	6.9	97	100	
TKN	$mgN.\ell^{-1}$	5.2	24	1.5 - 16.4	3.4	90		
TP	$\mu g.\ell^{-1}$	7075	24	1070 - 17170	3727	37		

*mode

C1 = % compliance with GA for discharge to river

C2 = % compliance with GA for irrigation

The sequencing batch reactor tested almost completely complied with the stringent discharge standards more appropriate to much larger scale treatment systems.

Initially, the plant was started up with feed of raw sewage only and operated manually. Effluent quality improved visually within a matter of days, but nitrification took some weeks to become effective.

Following a breakdown resulting from a failure in the aerator gearbox, the plant was re-started with about 12m^3 of activated sludge pumped to the batch reactor from the Darvill activated sludge basin. The effluent sample collected from the first decant after the restart appeared excellent, and nitrification to bring the ammonia below 6mgN.ℓ$^{-1}$ occurred almost immediately. It is obviously preferable to seed the reactor with thickened activated sludge whenever possible to minimise the start-up or initialisation period.

The automatic operation of the plant was almost faultless; the only difficulty experienced when the air supply to the pneumatically controlled valves was interrupted as a result of a compressed air line failure. The matter was easily and quickly resolved.

The critical performance indicators of ammonia and COD are presented graphically for the sequencing batch reactor in Figure 5.6.

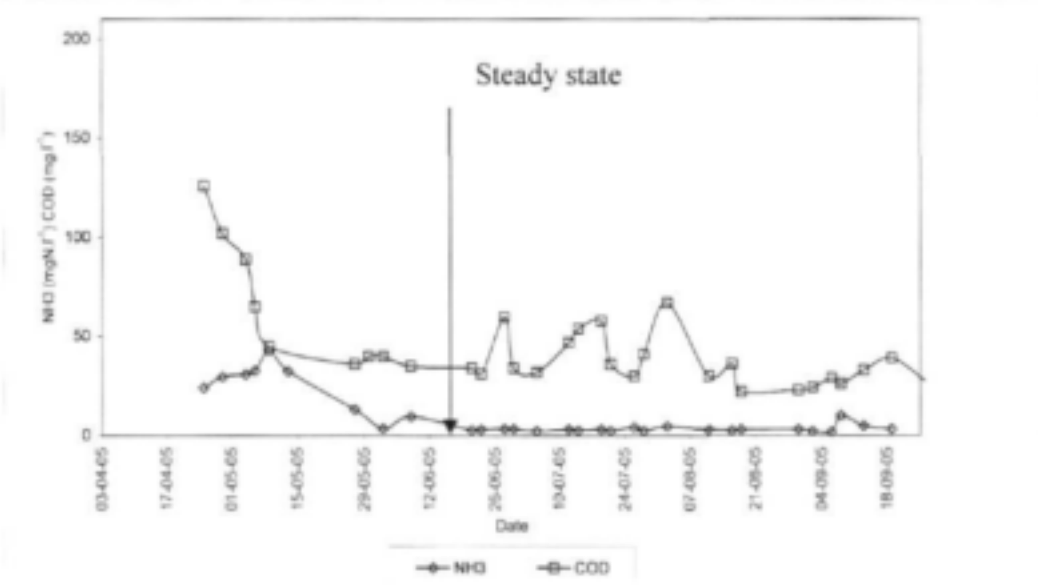

Figure 5.6. Effluent COD and ammonia data from the sequencing batch reactor

5.2.4 Summary of performance indicators

In order to allow for an assessment of the performance of the different technologies in comparison with one another, the critical performance indicators were collated and compared with the influent values. For ease of interpretation of this data, they were graphically depicted in Figures 5.6 to 5.9.

5.2.4.1 Ammonia data

As expected the influent ammonia concentrations fluctuated, with measurements between 17.28 and 50.5mgN.ℓ$^{-1}$ being recorded. Average incoming ammonia was 31mgN.ℓ$^{-1}$.

The submerged bio-contactor effluent from point L2 often indicated ammonia concentrations higher than the incoming sewage, possibly indicative of mineralization of ammonia from other nitrogen containing compounds under the anaerobic conditions of the septic tanks feeding the aerobic phase of the process. Data from point L2 indicated the system was unable to effectively remove ammonia to any notable degree, and often failed to reduce the heightened ammonia concentrations to concentrations found in the influent. The ammonia concentrations at point L3 were somewhat improved over point L2, and fairly consistently indicated a reduction in ammonia relative to the influent sewage, however with an average ammonia concentration of 28mgN. l^{-1}, the system was obviously not nitrifying effectively.

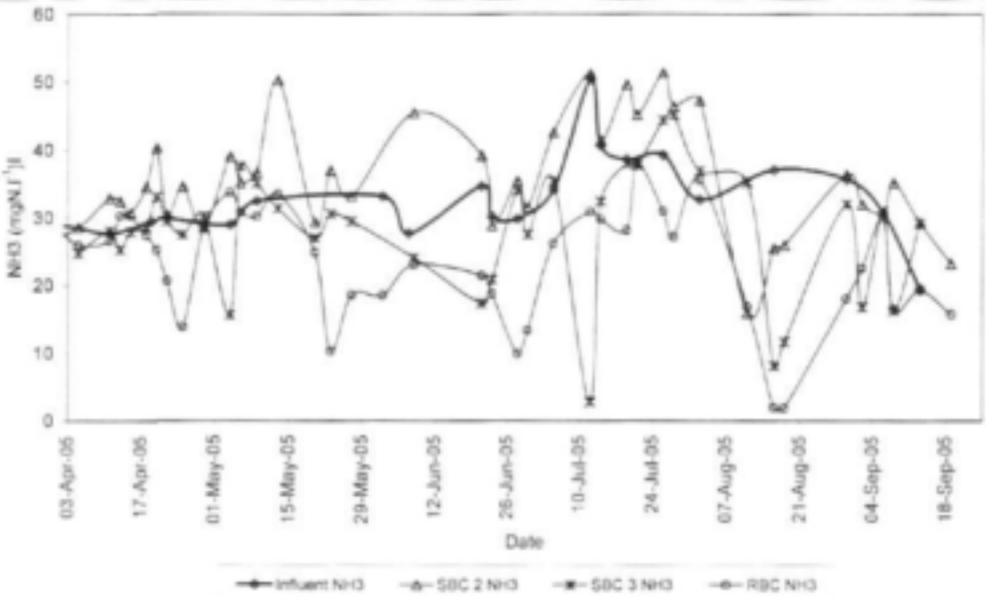

Figure 5.7 Influent and effluent ammonia concentrations

The rotating bio-contactor produced an effluent ammonia concentration consistently lower than the incoming sewage, indicating that nitrification was occurring to some degree, especially if mineralization of nitrogen was also occurring in the septic tank system feeding this system.

While septic tank ammonia on this plant was not measured directly on the rotating bio-contactor system, data from point L1 (effluent from a septic tank effluent from a system approximately half the size) indicated that mineralization did occur with a mean ammonia concentration of 45mgN.ℓ^{-1}.

The sequencing batch reactor received its feed from a source different from that supplying the fixed medium systems, and in an attempt to minimise the clutter of results portrayed in Figure 5.7 the influent/effluent data for the sequencing batch reactor was portrayed separately in Figure 5.8. As Figure 5.8 indicates, after an initial period in which nitrification was problematic, the sequencing batch reactor acquired the biomass necessary and thereafter reliably nitrified the incoming ammonia to a very low level, averaging 3.7mgN.ℓ^{-1} between June and the end of September 2005.

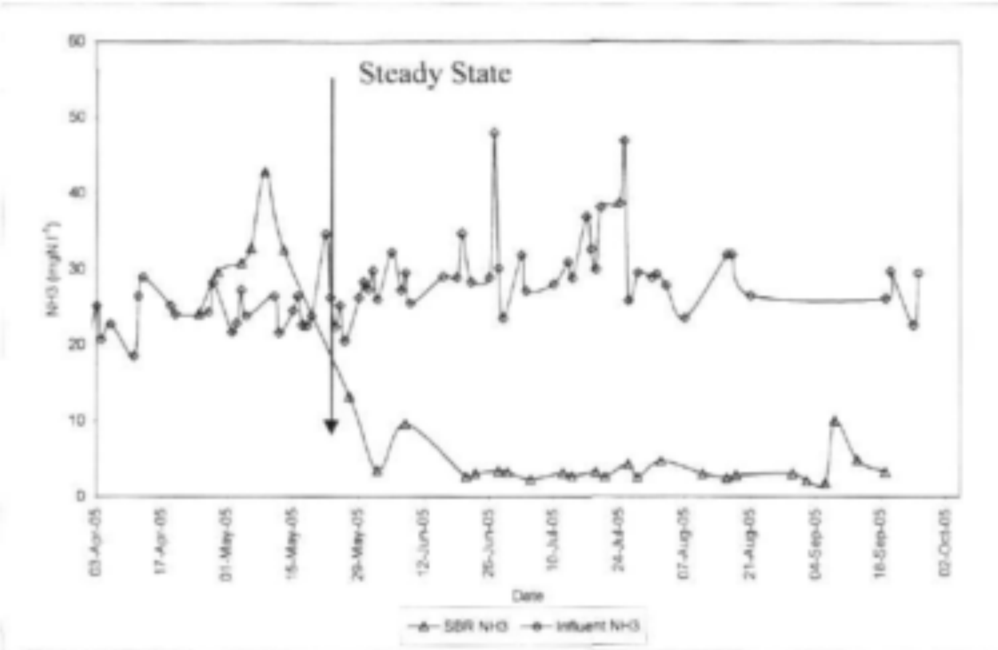

Figure 5.8 Ammonia removal in the sequencing batch reactor system.

5.2.4.2 Chemical oxygen demand removal

In order to compare the different technologies in their capacity to remove COD, the data for the attached medium plants was plotted in Figure 5.9.

While some initial fluctuation in incoming COD was noted in the sewage feed to the attached medium systems, for the majority of the trial it ranged between 400 and $600 mg.\ell^{-1}$, well within the range described as typical by Ekama et al. (1984).

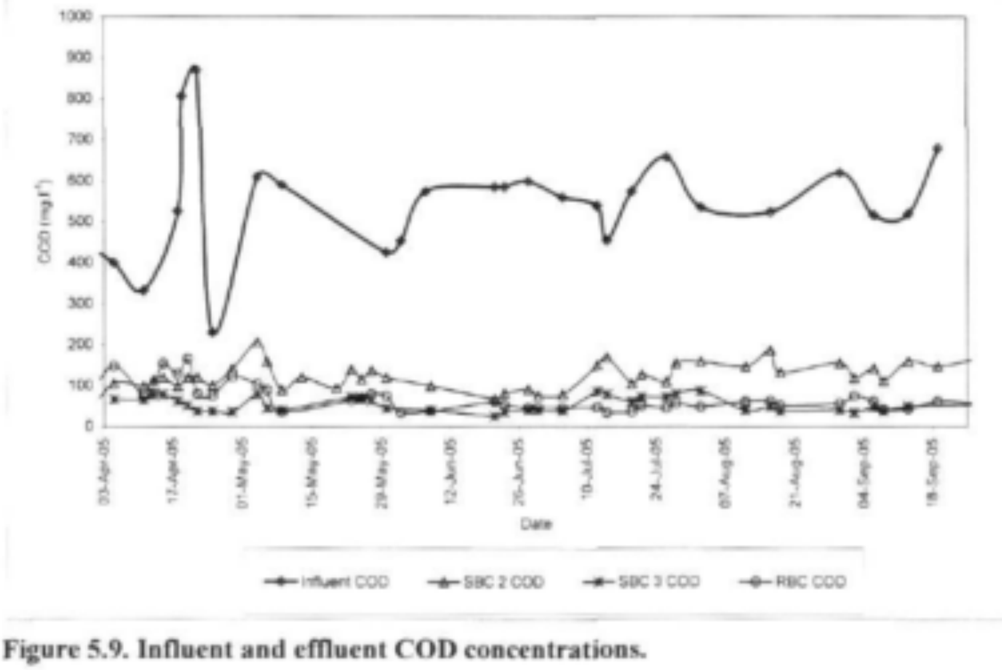

Figure 5.9. Influent and effluent COD concentrations.

With the submerged bio-contactor, point L2 (before the wetland) showed fluctuations of COD mostly outside of the range required for discharge to river. The value of the filtering mechanism provided by the constructed wetland was once again demonstrated when comparing the effluent COD readings between points L2 and L3 (before and after the wetland respectively). The wetland reduced the average COD from 119.3 to 53 due mainly, it is suggested, to the retention of solids.

For the rotating bio-contactor, initial high COD results became more acceptable following changes made to the clarifier on June 14, 2005.

COD removal in the sequencing batch reactor is separately illustrated in Figure 5.10. The fluctuations of influent COD clearly did not adversely affect the performance of the sequencing batch reactor, and it complied completely with the discharge standard to water for the period of testing following an initial period of biomass accumulation.

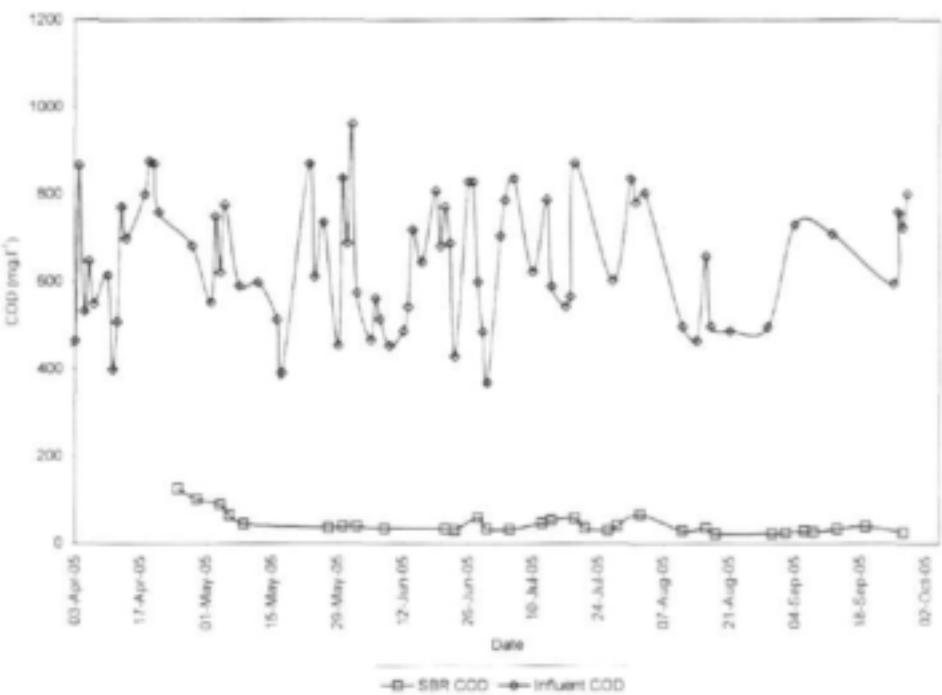

Figure 5.10 Influent and effluent COD for the sequencing batch reactor.

5.3 Compliance comparisons

In order to place the performance of the tested units into context, the compliance data was compared with compliance data from other package treatment plants and other plants in the central and coastal areas of KwaZulu Natal for which data could be obtained. Compliance percentages for total chlorine, chemical oxygen demand, *E.coli*, ammonia and suspended solids were collated and compared. The results are presented in Table 5.8

Table 5.8. Percentage compliance of small scale works and package treatment plants

	Trial plants		56 small works		Durban package plants*	
Determinand	Results	% Compliance	Results	% Compliance	Results	% Compliance
COD	186	94	53	78	194	76
E.coli	49	85	53	32	165	49
NH_3	175	31	46	82	197	28
SS	186	97	53	72	196	77

*Data utilised in Laas et al., 2002

The 56 small scale water works were small scale works scattered around the central inland and coastal areas of KwaZulu Natal, and were monitored by the Department of Water Affairs and Forestry as point pollution sources. The works were of varying sizes, and are typified by works treating the effluent for rural housing estates, prisons, hospitals etc. The data includes results from some industrial operations that operate their own treatment works.

The Durban package plant data was data obtained from Ethekwini Metro from its monitoring of 46 sewage package plants around the Durban Metro area.

The count figure indicates the number of results on which the mean values for percentage compliance were calculated and the mean is the mean percentage compliance for each determinand.

The results indicate that the plants tested in this study performed somewhat better than most in terms of effluent COD, *E.coli* and suspended solids, but were worse than many plants in terms of their compliance with the ammonia standard.

This is indicative that the feeding regime employed was a rigorous one, and effectively tested the plants under the most arduous conditions. Lower diurnal fluctuations would in all likelihood dramatically improve the performance of these plants. However, the testing regime employed was considered to be reasonable, as it was conceded that many plants of this nature would be subject to diurnal fluctuations typical of a working family where little or no flow to the sewage system is experienced during much of the day. In terms of the American NFS standard 40 for on-site treatment works, this "working parent" diurnal is one that plants should be expected to have the capability to handle.

5.4 Fault Evaluation

As detailed in Section 4.4, an attempt to classify faults was made under the categories of supply breakdowns, initialisation failures, operational breakdowns and maintenance breakdowns. Faults were logged whenever planned conditions did not occur, or the analytical results indicated that treatment had failed to meet the requirements for discharge. Faults were categorised as follows:

- Supply breakdowns
- Initialisation failures
- Operational Breakdowns
- Maintenance breakdowns

Supply breakdowns were generally not attributable to the design of the processing plants, but reflected difficulties experienced in the sewage supply system to deliver the correct quantities of sewage at the required times or rates. The supply system described fully in the section on methodology (Sections 4.3.1 and 4.3.2) operated relatively well throughout the test period, with breakdowns experienced due to a failure of the mixing pump, failure on the electronic timers when pump off cycle times were not correct (classified as electrical problems) and electricity supply problems due to power outages.

Initialisation failures were poor quality effluents and other abnormal conditions which could be attributed to failure of the plants as a result of insufficient biomass or other such factors resulting in poor performance. In the case of the rotating bio-contactor, many out of range results were found due to the poor performance of the clarifier, and this was rectified on 14 June 2005. Data failing to conform with the desired performance parameters due to the clarifier was therefore logged as an "initialisation fault" and would not count against the performance of the technology. Apart from this problem with the rotating bio-contactor, It was assumed that sufficient biomass would have acquired 3 weeks after start-up and that steady state conditions would therefore be reached.

Operational breakdowns were failures to process sewage effectively as a result of design faults, electrical breakdowns, maintenance issues or other unassigned reasons; this factor was thought beforehand to account for most of the problems associated with small package plants to effectively treat their influent sewage.

Maintenance breakdowns were defined as failures to effectively process influent sewage because of the failure of the operator to carry out reasonable or required maintenance, usually of a routine nature. Thus, out of range *E.coli* results combined with low total chlorine concentrations in the effluent which could not be attributed to equipment failures in the disinfection systems were assigned to this class. It was assumed to be the responsibility of the operator to ensure that, for example, sufficient disinfectant chemical is supplied to enable the units to disinfect their effluents effectively. Consequently maintenance breakdowns were not included in the total number of breakdowns as these should not count against the technologies tested.

An overall summary of the faults encountered is provided in Table 5.9; the underlying data used to formulate this table is attached as Appendix 3.

Table 5.9 Summarised fault evaluation for sewage package plants

Unit	Supply Breakdown	Initialisation Failure	Operational Breakdown
Submerged bio-contactor	6	19	173
Rotating bio-contactor	0	63	13
Sequencing batch reactor	0	10	5

A more detailed discussion of the faults found follows for each of the technologies tested.

For the purpose of these discussions, it was noted that faults were found to fall into various groups within two classes. Two classes identified were

- faults due to out of range results (assuming discharge to water being the criteria for evaluation)
- other unexpected conditions which were recorded in a fault log.

Within each class of fault, the reason for the unacceptable condition was assigned to one of 4 groups;

- design faults
- electrical faults
- maintenance faults (not included in numerical analysis)
- other faults

An analysis of these faults is discussed under each of the individual technologies.

5.4.1 Submerged bio-contactor

The detailed classification of faults logged for the submerged bio-contactor is provided in Table 5.10.

Table 5.10. Submerged bio-contactor fault classifications

	Out of range results				Fault Log				
	Design	Electrical	Other	Sum	Design	Electrical	Other	Sum	Total
Supply Breakdown	0	0	0	0	2	3	1	6	6
Initialisation Failures	0	0	19	19	0	0	0	0	19
Operational Breakdown	144	0	9	153	20	0	0	20	173
Total	144	0	28	172	22	3	1	26	198

The high number of operational breakdown faults reported for the submerged bio-contactor unit relate largely to the failure of the unit to produce an effluent which would meet the general limit values of the General Authorisation for discharge to water (see Table 1.2). Of the out of range data recorded and ascribed to design faults, insufficient nitrification accounted for 46%; 28% were related to out of range COD values in either L2 or L3, and 40% related to excessive suspended solids in the effluent at L2.

It was considered likely that with sufficient solids removal, the COD data would also have been much improved, as little out of range data for COD or SS was noted for effluent having passed through the constructed wetland; that effluent only failed to meet the $10mgN.\ell^{-1}$ standard for ammonia.

Another component of operational breakdown faults attributed to design in the submerged bio-contactor was the need to carefully regulate the flow from the equalisation tank to the aerobic zone. The unit as installed at Darvill achieved this control by means of running the feed pump against a partially closed valve, with subsequent problems arising due to blockages occurring at the narrow aperture. This necessitated fairly frequent adjustments to the positioning of the valve, a factor unlikely to be of concern to the average homeowner where provision for overflows from the equalisation tank could be made. No provision for such overflow was made at Darvill in a deliberate attempt to ascertain performance problems under the most stringent conditions, and recalibrations of this nature accounted for 17 failures.

5.4.2 Rotating bio-contactor faults

The fault allocation apportionment for the rotating bio-contactor is detailed in Table 5.11.

The unit was relatively trouble free from an operational maintenance viewpoint with breakdowns due to maintenance being limited to attention required to the chlorinator.

Table 5.11. Rotating bio-contactor fault classifications

	Out of range results				Fault Log				
	Design	Electrical	Other	Sum	Design	Electrical	Other	Sum	Total
Supply Breakdown	0	0	0	0	0	0	0	0	0
Initialisation Failures	63	0	0	63	0	0	0	0	63
Operational Breakdown	10	0	0	10	2	1	0	3	13
Total	73	0	0	73	2	1	0	3	76

The unit supplied to Darvill unfortunately suffered from poor clarifier performance, which, until this issue was attended to in June, resulted in poor COD, SS and *E.coli* compliance. These were logged as initialisation failures, as improvements made to the clarifier on June 14 resulted in much improved results, and it was these improved results which were used to calculate the compliance rates with standards in Table 5.6.

As mentioned previously, this attached medium system also failed to successfully nitrify the influent ammonia to any degree of success, and it would appear that this may have been partially as a result of overloading of the available biomass. With a greater area of biomass available, nitrification may have been better achieved, although research into establishing to what level the influent COD must be lowered before nitrification occurs readily may still be warranted.

Of the operational failures attributed to design, 56% arose as a result of high ammonia concentrations, 14% were due to high COD, 14% to out of range *E.coli* results and 16% to excess suspended solids in the effluent.

5.4.3 Sequencing batch reactor faults

The fault apportionments for the sequencing batch reactor are detailed in Table 5.12.

Table 5.12. Sequencing batch reactor fault classifications

	Out of range results				Fault Log				
	Design	Electrical	Other	Sum	Design	Electrical	Other	Sum	Total
Supply Breakdown	0	0	0	0	0	0	0	0	0
Initialisation Failures	10	0	0	10	0	0	0	0	10
Operational Breakdown	0	0	0	0	0	4	1	5	5
Total	10	0	0	10	0	4	1	5	15

Apart from failures occurring in the start-up phase for this equipment, very few failures were experienced. Some out of range results for total chlorines and for *E. coli* were obtained due to failure to replenish the hypochlorite supply, but as "maintenance faults" these were not included in the numerical analysis of the plants.

Other faults encountered included a faulty pressure switch failed to activate the compressor on two occasions before the fault was traced and fixed, and an air line breakage also accounted a failure in one instance.

The plant's design and larger size thus enabled it to far more successfully treat its influent than did its smaller counterparts. The only problem with the technology is its translation to smaller units. The sequencing batch reactor tested at Darvill was designed for and successfully treated an inflow of 60kℓ.day^{-1} sewage for the duration of the investigation. This is a factor of 30 times greater than the attached medium plants, and this must be borne in mind when comparing the performance of the units. Unfortunately the cost of treatment per unit of sewage tends to increase as smaller and smaller designs are required.

5.5 Other topics requiring discussion

Other matters which require discussion and have not been covered above are:

1. The ability of package plants to treat decreased flows resulting from lower water usage i.e. from demand side management or water restrictions.

In times of drought or with increased demand side management the volume of sewage entering a package plant may well halve. The amount of waste in the stream is unlikely to change, i.e. the load to the plant is unlikely to decrease. As a result of this the "strength" of the sewage will double. The question asked is whether this will affect the process? The answer, in the authors' opinion, is that if anything the treatment will be improved, mainly due to the longer hydraulic retention time. This will result in greater COD removal in the septic tank, an unchanged aeration capacity requirement, and a halving in the upflow rate in the clarifier. The latter is particularly desirable as this is the most critical part of the design in many of the technologies. The disinfection contact time will also be doubled which will be advantageous, resulting in improved kills. The only concern would be the "thickening" of the sewage due to its increased strength (normal raw sewage has a percentage solids of approximately 0.07% - this would double to 0.14%). The authors believe that this is not a problem, as raw sewage is already low in solids and a doubling of the solids is unlikely to cause problems with the hydraulics of the plant or pumping of the sewage.

2. The ability of package plants to deal with sewage emanating from hospitals that contains *antibiotics and antiseptics which may act as biocides.*

The treatability of hospital sewage/effluent is unknown, and could form part of a future study. While the effluent from pharmaceutical factories is known to be a problem due to the presence of antibiotics and antiseptics, the authors have observed that sewage treatment plants at rural hospitals appear to have conventional designs. From this it would appear that most of the antibiotics are metabolised as they pass through the patients, and that disinfectants do not reach concentrations at which they are toxic. Sporadic incidents of toxicity may however occur if large amounts of pharmaceuticals were to be discarded during a hospital pharmacy spring-clean. A definitive answer cannot however be given. As a precaution against possible toxic events, one can either increase the size of the plant by up to 100%, or ensure that the technology used has a completely mixed rather than plug-flow configuration. The latter will ensure maximum dilution of the toxic species as it enters the aerobic reactor.

3. The significance of a large number of package plants in a small area.

When a large number of package plants are situated in close proximity, especially in the case of townhouse developments, where flows are large for the area of the development, the likelihood of degradation of the riverine environment is obviously much greater. Greater care will thus have to be taken to ensure that plants are satisfactorily operated. This is further complicated by the increase in workload to monitor a large number of plants. A practical solution may be to get body corporates and developers to pool their resources to build a communal package plant which will be able to treat the combined flows. This will simplify operational and monitoring requirements.

4. The specifications contained in supplier contracts.

A minimum standard needs to be set for the plant specifications contained in the supplier contract. These should include:

- The power or amperage requirement for the plant.
- The quality of the raw sewage it is designed to treat, including flow, chemical oxygen demand, and total kjeldah nitrogen.
- A statement defining any precautionary requirements and restrictions regarding the use of disinfectants and biocides, disposal of cooking oil and fats, and the use of non-ammoniated cleaning materials.
- The specification should also state the expected effluent quality that can be achieved for normal domestic sewage.

- A detailed owners manual including a process description, troubleshooting section and maintenance schedule.

5. The question of whether the Water Services Authority in an area should be supplying and operating the package plants in the area instead of the property owners.

There seems to be some debate as to the responsibility of the Water Services Authority with regard to supplying and operating the package plants instead of the homeowners. While this does not fall within the scope of the current project it will be discussed briefly. The debate is not unique to this country; it was also evident that similar debates are in progress in other countries, as discovered while conducting the literature survey. For the property owner it would be a major advantage as the responsibility would be taken away from them. The possible disadvantages would be the cost implications as local municipalities are not known for their cost efficiencies or service levels, and abuse of the plants by the householders. The authors thus believe that the matter should be further researched, bearing in mind the overbearing pressures being experienced by the local authorities during this period of transformation in service delivery.

6. The use of telemetry for monitoring.

There are a number of technologies, which when combined with telemetry, could be used for both alarm and remote monitoring of package plants. These include suspended solids devices, high level float switches and video monitoring. The author has experience of purpose built in-house systems used to detect rising sludge blankets and solids carryover. The same device could even be calibrated to detect cloudy effluents which indicate high ammonia. The float switch is useful to detect overflows due to pump failures. Cameras can be set up to set digital images of the effluent discharge, enabling a remote operator to get a visual assessment of the effluent. Discussions with instrument technologists indicate that all three devices can be connect to cell phone cards, enabling both alarm and scheduled information to be SMS'ed to a remote party. The authors have been assured that this is relatively inexpensive technology. More sophisticated visual systems are available which could be used to monitor an entire plant. These have been developed in South Africa for the forestry industry, as well as for monitoring ocean outfall plumes. The use of this technology for medium to large scale package plants would certainly seem feasible and would probably assist the operators in preventing serious process breakdowns.

7. The importance of user education.

User education is paramount. Many of the package plant failures in the field relate to simple problems such as a lack of electrical supply. It is important that the owner understands the process, what failures can occur, and how to assess the effluent visually i.e. is the effluent high in suspended solids, is it cloudy? This also assists the supplier in diagnosing the problem telephonically before sending out the service crew. The simplest way of achieving user education is a properly detailed operations and maintenance manual, giving a process flow diagram and a description of what processes occur in each of the units or reactors. The manual should include a detailed troubleshooting section which may take the form of a "tree" diagram (also called a decision support matrix) or a table which is easily interpreted by a layman. The manual should also include an account of the maintenance required on a daily, weekly and monthly basis. In addition to a hard copy manual, it would be a good idea to have the manual available in ".pdf" format on a CD, and in a similar form on the manufacturer's website.

6. Conclusions and Recommendations

6.1 Conclusions

6.1.1 Preliminary remarks

The increasing use of on-site sanitation, and in particular package plants, is not just a South African phenomenon, but has been observed internationally. The underlying factors include:

- Unfavourable economics of developing centralised wastewater treatment facilities in peri-urban areas.
- Development of sites with physical constraints to the choice of on-site sewage treatment processes.
- Developers' tendency to minimise the space allocated for sewage treatment
- Increased environmental monitoring detects pollution with much greater sensitivity.
- Legislative agents tend to apply standards for discharge generally rather than individually considering the ability for localised environments to attenuate the pollution loads introduced into them.

Similarly, neither are the problems with on-site package plants peculiar to South Africa. Internationally, these are most commonly ascribed to poor design and construction, insufficient or no maintenance, mechanical breakdowns, pump blockages and clarifier carryover.

Package plant manufacturers face a number of difficult challenges. These include small plant dimensions (and concomitant problems in downscaling), high variability in flow and strength of influent sewage, little flow equalization capacity, and a lack of maintenance and operational skills. The latter challenges are not only a problem for package plants locally, but also for the majority of full-scale plants at this stage.

Selection of package plants is also not simple as it appears from the literature that all technologies have a tendency to be problematic unless properly maintained and operated.

6.1.2 Legislative framework

The legislative framework for package plants in South Africa is a neglected area. While there are the General Authorisations for Discharge to water bodies and irrigation which the authors believe are attainable, the compliance levels are not stated, and there is debate about whether irrigation of crops and pastures should include domestic lawns. The inclusion of the latter form of effluent disposal would appear to fall within the spirit of water reuse, and would assist in demand management, as well as attenuating the diurnals experienced by the receiving streams. This is important in preserving more natural streamflow characteristics as well as effectively utilising nutrients in the effluent and accessing the natural assimilative capacity of soils. A life cycle assessment for the irrigation of effluent should also prove to have a favourable outcome, as it should help reduce the use of electricity, with a simultaneous lowering in the generation of greenhouse gases.

A further complication arising in the irrigation of effluent has been the introduction of local bylaws by municipalities in an attempt to regulate the effluent quality in their areas. The authors believe that in some cases these have been too stringent, possibly as the result of the standards being set by staff with little process experience, resulting in unreasonable compliances being required. Many of these are unlikely to be attained by full-scale plants manned by trained staff on a 24 hour basis.

The enforcement of rather stringent regulations by the Ethekwini Municipality in the absence of a stronger role by the Department of Water Affairs and Forestry, while difficult for the manufacturers and property developers, has provided leadership in highlighting the problems of performance, and their efforts must be acknowledged.

6.1.3 Accreditation of package plants

An examination of international standards for package plant effluents was not particularly fruitful. It appears that in many cases these are fragmented and that enforcement is not carried out. An interesting standard which did come to light was the NSF/ANSI Standard 40-2005 document, which outlines the accreditation of package plants by the United States EPA. In terms of this, package plants are measured for compliance against a relatively simple set of standards, and if successful, gain accreditation for the entire country. This is a relatively simple method of regulation for both the suppliers and regulators, to be discussed further later in the recommendations section.

6.1.4 Available technologies

There are essentially three technologies available in package plants in South Africa. These are:

- Activated sludge (conventional extended aeration or sequencing batch reactor)
- Submerged bio-contactors (fixed or random packing)
- Rotating bio-contactors

The latter appears to have the major share of the market, by virtue of volume, at present.

Examples of all three technologies were assessed in this study. The units used were provided either free of charge, or at a reasonable rental. In the case of the rotating bio-contactor a demonstration unit was used.

The units were chosen according to a list of criteria detailed in Section 1.4.1 of this report.

The suppliers are thanked for their assistance both in the supply of the units, and in assisting the authors in understanding the challenges faced by the industry.

6.1.5 Criteria for assessment

The performance of the units was measured against the General Authorisations mentioned above. The reason for this was three-fold:

- They obviously have a sound scientific basis in order to have been promulgated.

- They are, in the opinion of the authors, achievable with the available technology if correctly specified (a compliance level of 80% is considered reasonable).
- There was a reluctance by the authors to further complicate matters by introducing another set of standards which would need to be debated and scientifically defendable.

6.1.6 Supplier survey

Response to the survey sent to the suppliers was at best reasonable which is in line with most questionnaire responses in South Africa, especially those sent out and not completed together with the respondent.

Perhaps the most useful information gained from the replies was the spatial and capacity distribution of the plants. The replies also pointed out the need for a single regulator.

6.1.7 Methodology

The methodology used in the study is fully detailed in chapter 4. The feeding regime used was of a marked diurnal in an attempt to fully represent the major problem facing package plants, that of high flow and strength variability. The quality of sewage fed to all three units was compared to typical sewage quality found in South Africa and correlation with typical domestic sewage characteristics was found to be satisfactory. Although ten percent of the inflow to the Darvill Works is industrial effluent, this had little effect on the quality. No toxic events (nitrification or methanogen failure) were experienced on the main plant during the evaluation.

A thorough evaluation of the effluent quality and operational and maintenance problems was conducted. The findings were very much in line with the literature, and the experience of the Ethekwini Metro and the authors.

6.1.8 Discussion of results

The submerged bio-contactor followed by artificial wetland achieved better than 80% compliance with the General Authorisation for direct discharge for key determinants other than ammonia (only 3.4% compliance). In terms of the irrigation standard it exceeded 80% compliance.

The standard wastewater engineering text from Metcalf and Eddy Inc. (Tchobanoglous & Burton, 1979) strongly recommend that this technology be followed by an effluent polishing step. Without the artificial wetland, failure to comply with the direct discharge standards would have grown to 9% for COD, and 0% for ammonia. In all likelihood, disinfection would have been dramatically compromised as well.

The rotating bio-contactor experienced problems mainly in terms of compliance for nitrification (5% compliance) and disinfection (33%) when compared to the General Authorisation for direct discharge. The compliance for COD and suspended solids removal was 72% and 74% respectively after the problems relating to poor performance with the effluent clarifier were effectively dealt with.

The sequencing batch reactor, somewhat larger plant than its peers in this study achieved compliances in excess of 80% throughout the evaluation for both standards.

6.1.9 Loading parameters

Calculations were performed to compare the loadings for each of the technologies assessed with those specified in authoritative texts. The results indicated that both the submerged bio-contactor and the rotating bio-contactor were overloaded when compared to design parameters obtained from the texts, and this would explain the lack of nitrification. The resulting high ammonias resulted in the formation of chloramines upon chlorination which negatively affected the disinfection rates, and thus efficiency.

The design of the sequencing batch reactor was found to fall within normal design parameters for activated sludge.

A concise discussion of design criteria is given in Appendix 4. This includes design criteria for all three technologies, and highlights design considerations needed in coping with the problems faced by package plants.

6.1.10 Operation and maintenance faults

These are discussed in detail in chapter 5, and are largely related to design problems. Careful maintenance would eliminate some of the faults.

Appendix 5 gives a suggested operating and maintenance schedule for each of the three technologies.

6.1.11 Other considerations

It is clear from the preceding discussion that there are failings in the implementation of two of the three technologies tested. These failings were not confined to the particular brands chosen, as there are reported to be failings with many similar plants, especially with respect to nitrification and effective disinfection.

Development of these products has typically been at the entrepreneurs own personal expense, thus limiting the available resources. To have employed professionals to develop the technologies would have been desirable, but extremely costly.

The more sophisticated the plant, the more expensive it would tend to be, and as with all goods the market, resistance to higher prices would decrease demand for pricier units.

The lack of an adequate legal framework has exacerbated this. There has been no single authority responsible for driving the process of regulating the package plant industry. Furthermore, it is not only sewage treatment package plants that give performance problems – many potable water plants also experience problems and suffer from a lack of maintenance.

Added to this is the recent growth in numbers of small package plants where cost pressures and down-scaling problems are the most acute.

The problems with poor performance are not only limited to package plants in South Africa. Many large plants are producing sub-standard effluents as a result of extremely poor maintenance and poorly trained personnel. The vast quantity of failed effluent from these plants must surely render that of the package plants insignificant, both in terms of quality and quantity.

Much of the adverse publicity relates to political and environmental pressure being placed on municipalities to limit development in the formally "rural" peri-urban areas. This is very pertinent on the Outer West area of the Ethekwini Metro area. Perhaps what has aggravated matters is that the area in question once comprised fairly low population density special residential suburbs, which are now being turned into high population density cluster housing estates. This has resulted in vastly increased sewage disposal in the area previously serviced by septic tanks, where the extremely poor quality effluent produced was dissipated out of sight without any environmental concerns despite potential interflow with rivers and surface emergence.

Furthermore, property developers typically minimise the space and budgetary allocations for sewage treatment in their projects. Some developments have large estates on which the effluent can be irrigated (which is ideal), but others do not have this luxury.

In this regard, there are also a number of questions which need to be asked, some of which are echoed in the literature:

- Is this a town planning problem rather than a wastewater treatment problem, with wastewater treatment merely being a convenient scapegoat?
- Should the water service provider not be responsible for the wastewater treatment, even if a new decentralised strategy has to be adopted? This would certainly be most cost effective due to economies of scale, and the simpler functioning and greater reliability of larger plants.
- Should the water service provider not meet the cost of the package plants, and maintenance contracts?
- Should water be supplied to an area if there is no formalised plan for wastewater treatment?

These questions are not only pertinent to the Ethekwini area, but to the rest of South Africa, and internationally. The literature very clearly confirms this debate, and the complications of administering and policing a multitude of package plants.

Reverting to the technical discussion, recommendations are made below to address the institutional and technical problems being experienced with package plants in South Africa.

6.2 Recommendations

From the interaction the authors had during the project, both with the suppliers of package plants and the relevant authorities, it became evident that the use of package plants is growing. The reasons for this have been discussed previously. At this point the estimated replacement cost of the package plants installed in South Africa is R162.9m with an estimated total volume treated of $40.7 Ml.d^{-1}$. For this reason it is important that clear guidelines are set up in which the industry can grow and operate with as few bureaucratic obstacles as possible, while maintaining appropriate effluent quality levels.

To this end the following recommendations are made:

6.2.1 Legislative framework

- There should be a single set of regulations for package plant effluent throughout South Africa. This will simplify matters for both the manufacturers and municipalities.
- That the General Authorisations for direct discharge and irrigation be adopted for these plants, both in rural and peri-urban areas.
- The definition of "irrigation" should be amended to include parks and gardens.
- That an accreditation centre be established to conduct accreditation based on the NSF 40 system. This accreditation needs to be obtained before a plant can be installed without problems with local authorities. It will also ensure that the playing grounds are levelled for the package plant suppliers and that property developers do not install sub-standard systems simply based on cost.
- A full maintenance contract needs to be implemented. This needs to be stipulated by the assessment centre after testing, and based upon the technology used. The purpose of this would be to ensure that preventative maintenance is performed to prevent breakdowns.
- Responsibility for the package plant should lie with the owner.
- The package plant installations should not only be registered with the Local Municipality, but also with the Department of Water Affairs and Forestry in order to create a national database of installations.
- The package plant owner or his designated service provider should notify the Local Municipality should a major malfunction occur on the plant.

6.2.2 Technological development

- It is quite clear that the manufacturers of the submerged bio-contactor and rotating bio-contactor technologies need to re-visit the design specifications they are using, and adopt more conservative parameters.
- The more conservative design parameters should be based on the design parameters recommended in this report.
- Manufacturers using septic tanks as the initial step in their process train are strongly encouraged to investigate the use of Anaerobic Baffled Reactors in place of conventional septic tanks. The authors believe that this technology will greatly reduce the COD of the sewage reaching the aerated step. It will however have no effect on the ammonia concentrations.

- Anaerobic baffled reactor technology needs to be further developed under a strong diurnal to investigate and develop its full potential for use in the field. This would be an ideal project for the WRC to fund.
- The research project mentioned above should also investigate the adaptation of circular tanks for use as anaerobic baffled reactors. The authors believe that this is an essential technology which could be used to replace conventional septic tanks in a cost effective manner. This could result in a franchising opportunity for the WRC.
- Disinfection needs to be improved, and to this end the manufacturers need to review the design of their chlorination equipment. If they utilise commonly available chlorine pills, the size should be stipulated together with whether the pills should be stabilized or not, and if there is a preferred brand (certain brands may dissolve faster and give a higher chlorine dose
- The authors believe that all package plants should include a constructed wetland or gravel filter (media size 5 – 10mm) to act as an effluent polisher, and a barrier to accidental solids carryover. Disinfection should take place after this

6.2.3 Institutional arrangements

- It is strongly recommended that all manufacturers of packages plants be members of an industry body to represent them in negotiations with the state and other regulatory bodies, and to act as a forum to advance technology development and general cooperation.

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Appendix 1 Supplier Questionnaires

In terms of the study brief, the following manufacturers and suppliers of package treatment plants were identified and contacted for information pertinent to the industry in South Africa.

Company Name	Location	Telephone
Amitek Solutions	49 - 7th St, Linden, Johannesburg	011-7824608
Aquator MBR Technology	Suider Paarl	021-8631796
Beacon Watertech	Pretoria	012-804 1128
Bio Remediation Consultants	440 Charles St Brooklyn, Pretoria	012-4607651
Biobox W&WW treatment systems	309 Zasm St Waltloo, Pretoria	012-8037601
Biwater (PTY) LTD	P.O. Box 2216,Honeydew,Randburg,2040	011-5497600
David Harris Engineering Systems	44 Cathcart St Bergsig, George	044-8742401
Effluent Management	Worcester	023-3476415
Flowline Technology	Durbanville	021-9483392
Lilliput Sewage Treatment Systems	Lot 119, Drummond, Hillcrest	031-7834276
Ozone Services Industries	Randburg	011-4764862
Prentec	Gauteng	011-9765254
SAME	Alberton	011-9024900
Sannitree	Cape Town	021-7011266
Scarab Technologies CC	Factory 2, 19 Martin Dve Queensburgh	031-4641703
Siyageza Systems CC	14 Plantation Rd, Eastleigh, Edenvale	011-4526800
Tecroveer	Gauteng	011-7521191
Total Water Solutions	Lushof FM, Tzaneen	015-3076359
Wettech SA	Cape Town	021-8681016

Two questionnaires were circulated in the course of this investigation

Questionnaire 1 Follows.

Dear Sir/Madam,

The treatment of sewage in areas not served by formal sanitation systems remains one of the greatest environmental challenges in both the developed and the developing world. An obvious solution to this problem in the provision of small on-site systems which treat the sewage to render it safe for release into the environment. Typically these are septic tanks, but not every site is suitable for septic tanks, and small on-site treatment plants often known as package plants are often utelised.

However, experience in South Africa and internationally has indicated that these small package plants have a poor track record. In order to investigate whether this is merely a perception or whether something can be done to improve the situation, the Water Research Commission has embarked upon a project to investigate the performance of package plants used for treating sewage in South Africa.

As the researcher undertaking this investigation, we understand that you may have experience or information of relevance, as we ask you to share that knowledge with us. The following questionnaire outlines what we think are the important issues, and we would greatly value any information you could provide us with.

With thanks,

Paul Gaydon
Umgeni Water, Research Project Leader.

Sewage Package Plant Questionnaire

Company or Organisation details:

Name: ______________________________

Address: ______________________________

____

____

______________________ Post Code: __________

Telephone: Code:____________ Day Number: ______________

Contact Person: ______________________________

2) Are you a supplier or a user of sewage package plant technology? ☐ **USER**

Please tick the appropriate box. ☐ **SUPPL**

If you are a package plant USER please turn to page 3

If you are a package plant SUPPLIER, please turn to page 5

SECTION FOR COMPLETION BY PACKAGE PLANT USERS

Please tick the box which best answers the question.

How do you select your package plant?

- ☐ Own selection
- ☐ Advice of municipality
- ☐ Based on contractor's advice
- ☐ Other

Was your local authority involved in your decision to install a package plant?

- ☐ Yes
- ☐ No
- ☐ Don't know

Do you have any ideas to improve on the performance of your package plant?

- ☐ Yes
- ☐ No

If **YES**, please specify what should be done:

____

____

____

____

____

____

Are you satisfied you are able to operate your plant fully?

☐ Yes
☐ No
☐ Don't know

Are you satisfied with you plant's performance?

☐ Yes
☐ No
☐ Don't know

Have you experienced any serious problems with your plant?

☐ Yes
☐ No
☐ Don't know

If **YES**, what were the problems?

____

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SECTION FOR COMPLETION BY PACKAGE PLANT SUPPLIERS

Please tick the box that best answers the question.

How many years has your organisation been in the business of supplying package plants?	☐	Less than 1 year
	☐	1-5 years
	☐	More than 5 years

Do you design and produce your own package plants?	☐	Yes
	☐	No

If NO, please state types of plants you supply, and contact details of the manufacturer.

____

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Would you be prepared to give us addresses where your plants have been installed?	☐	Yes
	☐	No

How do you select which package plant to supply?

- [ ] On expected flow volume and/or strength
- [ ] Specified by client (or others)
- [ ] Based on site size constraints
- [ ] Other criteria

If based on OTHER criteria, please give some examples:

____

____

____

____

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____

____

____

In your experience, is permission from municipalities/others usually required?

- [ ] Yes
- [ ] No

If YES, what official usually gives permission? (building inspector, planner etc).

____

____

____

____

In your view what are the major problems with sewage package plant performance (operational skill, maintenance etc)

As a supplier, have you encountered problems with regulators accepting your units?

Questionnaire 2

This was a brief additional page e-mailed to obtain further information:

Dear Sir/Madam,

Thank you very much for answering our questionnaire. We are extremely grateful for your valuable time. We would be most grateful if you could urgently complete the following table regarding the number and size and province for the plants you have installed. We wish to assure you that the results will not be shown individually firm by firm, but rather amalgamated for the industry in total.

Plant capacity (m3/day)	No. of plants installed	Province (please give number per province if more than one province)
0 – 10		
10 – 50		
50 - 100		
100 – 250		
250 – 500		
500 – 1000		
1000 - 2000		

Thank you once again for your cooperation.

Appendix 2 Analytical data

2.1 Data for suspended medium influent

Date	pH	EC	Alk	NO3	NH3	TP	SRP	SS	COD	TKN
22/02/2005	7.6	77	248	0.5	19.8	17700	4620	291	371	
23/02/2005	7.9	97	218	0.5	13.3	16700	7330			
24/02/2005	7.1	53	175	0.5	17.2	18200	3370	215	406	
27/02/2005	7.1	48	188	0.5	17.4		3230	128	327	
28/02/2005	7.2	62	229	0.5	20.3	10700	4250			
01/03/2005	7.1	58	213			14400			537	
02/03/2005	6.8	47	214			13500			419	
03/03/2005	7.4	49	205	0.5	23.9		680	200	447	
06/03/2005	7.3	48	181					162	338	
07/03/2005	7.1	44	178						416	
08/03/2005	6.7	38	104	3.2	6.3		1080		347	
09/03/2005	6.5	49	148	0.5	11.2		1830		194	
10/03/2005	6.7	47	153	0.5	10.5		1980	132	283	
13/03/2005	6.6	44	155	0.5	13.7		4070		401	
14/03/2005	7	60	210	0.5	17		3450		724	
15/03/2005	6.8	52	203	0.5	19.4					
16/03/2005	6.5	48	197	0.5	15.5		4220		562	
17/03/2005	7.5	51	196					144	461	
21/03/2005	7	60	299						407	
22/03/2005	6.9	57	216						56	
23/03/2005	7.4	57	279						592	
30/03/2005				0.5	17.6		4940			
31/03/2005	6.6	57	207					206	452	
03/04/2005	7.1	55	260	0.5	25.2		4350		465	
04/04/2005	6.5	48	205	0.5	20.8		5590	400	867	
05/04/2005	7.6	59	200						533	
06/04/2005	7	60	223	0.5	22.8		8220		648	
07/04/2005	7.4	52	233	0.5			5330	203	550	
10/04/2005	7.4	45	224					248	616	
11/04/2005	7.4	50	210	0.5	18.6		5250		400	
12/04/2005	6.3	70	122	0.5	26.5		5960	194	509	
13/04/2005	6.6	60	204	0.5	29		16100		772	
14/04/2005	7	65	234					295	700	
18/04/2005	7.3	58	231					346	801	
19/04/2005	6.9	54	241	0.5	25.2		5040	405	877	
20/04/2005	7	65	197	0.5	24.1		4650		871	
21/04/2005	7	52	199					300	760	
27/04/2005	7.1	53	240	0.5	24.4		7100			
28/04/2005	6.9	49	235	0.5	28.3		4870	270	683	
01/05/2005				0.5						
02/05/2005	6.8	51	234	0.5	21.8		5220		553	44
03/05/2005	6.8	69	245	0.5	23		7600		750	
04/05/2005	6.5	58	204	0.5	27.3		10300		622	
05/05/2005	9.4	68	291	0.5	23.9		8090	319	777	
08/05/2005	7.3	47	267						591	

Date	pH	EC	Alk	NO3	NH3	TP	SRP	SS	COD	TKN
11/05/2005					26.5		7600			
12/05/2005	7.3	49	260	0.5	21.7		5820		599	
15/05/2005				0.5	24.6		5350			
16/05/2005	8.1	58	340	0.5	26.5		9110		514	
17/05/2005	7.8	58	234	0.5	22.7		6710	240	392	
18/05/2005				0.5	22.6		14700			
19/05/2005				0.5	23.9		7360			
22/05/2005	7.1	56	262	0.5	34.7		7180	483		
23/05/2005	7.2	50	234	0.5	26.3		9940		871	
24/05/2005	8.9	59	311	0.5	22.5		1990	235	612	
25/05/2005	7.1	72	223	0.5	25.3		5910			
26/05/2005	7.2	60	199	0.5	20.6		5450	354	737	
29/05/2005	7.4	94	208	0.6	26.3		6620	176	454	
30/05/2005	7.3	91	239	0.5	28.4		4700		838	34
31/05/2005	6.8	69	236	0.5	27.4		5600	216	689	42
01/06/2005	7.1	82	254	0.5	29.9		4970		962	
02/06/2005	7.2	74	239	0.5	26.1		9510	278	575	
05/06/2005	7.3	92	251	0.5	32.3		3360	182	468	
06/06/2005	8.5	92	246						563	
07/06/2005	7	69	288	0.5	27.3		5660		515	
08/06/2005	7.3	85	313	0.5	29.6		12900			
09/06/2005	7.5	78	255	0.5	25.6		7150	176	454	
12/06/2005	7.7	66	320					216	488	
13/06/2005	7.2	51	193						543	
14/06/2005	6.5	73	255						720	
16/06/2005	7.3	72	242	0.5	29.1		3810		646	
19/06/2005	6.4	101	190	0.5	29		6160		809	
20/06/2005	7.3	77	249	0.6	34.8		6320		682	
21/06/2005	8	85	250					281	772	
22/06/2005	7.2	64		0.5	28.4		4650		689	
23/06/2005	7	68	248					180	429	
26/06/2005	8.3	72	326	0.5	29		8050		830	
27/06/2005	8.3	72	326	0.5	48		9920		830	
28/06/2005	8.2	64	182	0.5	30.2		5590		600	
29/06/2005	6.7	75	236	0.5	23.6		9250		486	
30/06/2005	7.1	72	253	0.5			9500	125	368	
03/07/2005	7.1	60	230	0.5	31.9		10660	295	705	
04/07/2005	7.1	74	304	0.5	27.2		21050		787	
06/07/2005	7.1	78	235						837	
07/07/2005	7.2	73	239			12400		230		33
08/07/2005										
09/07/2005										
10/07/2005	7.2	55	227		28.1		3360	287	623	37
13/07/2005	7.4	58	296	0.5	31		9870		788	
14/07/2005	6.5	55	198	0.5	28.9	12900	7870	262	589	
17/07/2005	6.9		285	0.5	37		5950		543	
18/07/2005	6.7	66	308	0.5	32.7	13800	6600		566	43
19/07/2005	6.3	63	281	0.5	30	15500	7590		872	

Date	pH	EC	Alk	NO3	NH3	TP	SRP	SS	COD	TKN
20/07/2005				0.5	38.2		7180			32
22/07/2005										
23/07/2005										
24/07/2005				0.5	38.7	12200	5690			58
25/07/2005				0.5	46.9		6690			
26/07/2005				0.5	25.9		9990			
27/07/2005	7.8	70	328			8440			603	54
28/07/2005				0.5	29.6	5960	4170			51
29/07/2005										
30/07/2005										
31/07/2005	6.9		283	0.5	28.9	15000	6050	325	836	
01/08/2005										
01/08/2005	6.7	72	243	0.5	29.4	8580	9960		782	
02/08/2005								332		
03/08/2005	6.6	69	221	0.5	27.9	10400	7840		805	62
05/08/2005										
06/08/2005										
07/08/2005				0.5	23.6	2520	3310			55
08/08/2005	8.2		336							
09/08/2005										
11/08/2005	7.1	66	230						498	
12/08/2005										
13/08/2005										
14/08/2005	7	54	230						465	
15/08/2005										
16/08/2005	7.3	69	273		32		4305		659	42
17/08/2005	7	80	287		32		6100		498	
18/08/2005										
19/08/2005										
20/08/2005										
21/08/2005	6.7	56	252		26.6		3390		487	
22/08/2005										
23/08/2005										
24/08/2005	6.6	85	261			13600				56
25/08/2005						15000				51
26/08/2005										
27/08/2005										
28/08/2005						8320		265		36
29/08/2005	7.1	95	281			9400			496	59
30/08/2005										
01/09/2005										
02/09/2005										
03/09/2005										
04/09/2005	6.9		248						731	
05/09/2005	6.7	91	341							
06/09/2005	7.2	78	294							
07/09/2005										
08/09/2005										
09/09/2005										

Date	pH	EC	Alk	NO3	NH3	TP	SRP	SS	COD	TKN
10/09/2005										
12/09/2005	7.2		297						709	
13/09/2005										
14/09/2005										
15/09/2005										
16/09/2005										
17/09/2005										
18/09/2005										
19/09/2005					26.2		7400			
20/09/2005					29.8		6900			
21/09/2005										
22/09/2005										
23/09/2005										
24/09/2005										
25/09/2005	6.5	84	238	0.5	22.7		2960		596	
26/09/2005	6.8	75	261		29.6		2450		760	
27/09/2005	6.9	75	322					320	725	
28/09/2005	6.8	79	253						802	

2.2 Descriptive statistical for suspended medium feed.

	pH	EC	Alk	NO3	NH3	TP	SRP	SS	COD	TKN
Count	105	100	104	76	81	21	82	39	93	17
Mean	7.1*	65	241	0.54	25.9	12153	6426	254	602	46
Maximum	9.4	101	341	3.2	48	18200	21050	483	962	62
Minimum	6.3	38	104	0.5	6.3	2520	680	125	56	32
Std. Dev.		14	47	0.31	6.9	3955	3244	81	175	10

*Mode

2.3 Data for attached medium influent

Date	Alkalinity	COD	NH3	NO3	pH	Soap	SRP	SS	TKN	TP
22/02/2005	250	554	27		7.1			220		
23/02/2005	279	567	25.3		7.53			263		
24/02/2005						39.2				
06/03/2005						42.2				
07/03/2005	201	403			7.31			175		
14/03/2005	229	389	17.5		6.98			208		
22/03/2005	217	523	17.28		6.91	13		248		
30/03/2005	226	446	28.2		7.2	50.4		190		
05/04/2005	220	400			7.3	125		218		
11/04/2005	240	332	27.7		7.59	160		128		
18/04/2005	293	526			7.33	44.8		248		
19/04/2005	211	807	29.5	0.25	6.68		5980	336	50.8	11490
22/04/2005	234	871	29.9	0.5	7.23		7450	483	52.3	10970
25/04/2005	291	230			7.3	48.4		89		
29/04/2005						92				
04/05/2005	260	610	29	0.25	7.32		7530	360	58	
09/05/2005	270	590	32.5	0.25	7.47		8009	190	58.2	11810
30/05/2005	285	426			6.4			186		
02/06/2005	212	454	33.2	0.25	7.1	73.2	8110	176	57.4	10300
07/06/2005	367	575	27.7	0.25	7.1	59.4	7690	278	52.5	9980
21/06/2005	370	586	34.7	0.25	7.35	71.4	187	187	38.7	10130
23/06/2005	370	586	30.2	0.25	7.35		7360	264	52.4	10130
28/06/2005	182	600	29.9	0.25	8.17	58.4	7200	320	50.6	10220
05/07/2005	361	561	34.2	0.25	6.88	63.4	7930	256	54.6	9750
12/07/2005	313	540	50.5	0.25	6.77	57.2	9360	256	50.7	11040
14/07/2005	373	454	40.7	0.25	6.87		9320	187	59	10650
19/07/2005	359	574	38.6	0.25	7.11	19.2	9030	237	54.1	11420
26/07/2005	331	658	39.3	0.25	6.4	71.4	9340	237	64.4	16700
02/08/2005	357	536	32.7	0.25	7.17	52.2	8020	178	68.1	14610
16/08/2005	258	524	37.1	0.76	6.84	42.6	7490	286	48.2	11960
30/08/2005	361	620	35.7	0.25	6.92	39.8	9400	241	49	9400
06/09/2005	311	517	30.8		6.79	60.6	8730	210	50.5	8960
13/09/2005	257	520	19.6		6.9	90.4	5690	222	24.9	14180
19/09/2005	304	680		0.25	6.57	70.6	8100	310	25.7	10710

2.4 Descriptive statistical for attached medium feed

	Alkalinity	COD	NH3	NO3	pH	Soap	SRP	SS	TKN	TP
Count	31	31	25	18	31	23	20	31	20	19
Mean	284	537	31	0.29	7.1*	63	7596	238	51	11285
Minimum	182	230	17.28	0.25	6.4	13	187	89	24.9	8960
Maximum	373	871	50.5	0.76	8.17	160	9400	483	68.1	16700
Std. Dev.	59.8	126.3	7.3	0.1		31.9	2027.4	73.8	10.7	1947.0

*Mode

For computational purposes, results below detection limits were calculated as if they were equal to half the detection limit.

2.5 Data for Submerged bio-contactor point L1

Date	Alkalinity	COD	NH3	NO3	pH	SRP	SS	TKN	TP
05/04/2005	276	178	27.2	0.25	7.33	7300	50	44	
11/04/2005	338	247	31.5	0.25	7.02		106		7250
13/04/2005	295	258	26	0.75	7.03	5850	86		
15/04/2005	263	201	28.9	0.25	7.3	6690	74	49	8680
18/04/2005	337	177	30.8	0.25	7.2	7610	62	55.8	10020
20/04/2005	346	195	30.2	0.53	7.24	8490	100	49.2	10630
22/04/2005	302	295	31.3	0.5	7.1	7580	80	43.8	10430
25/04/2005	344	114	33.9	0.25	7.15	7840	38	46	10030
29/04/2005	284	240	26.3	0.25	7.38	9150	96	47.1	11750
04/05/2005	320	307	40.3	0.25	7.2	8870	108	56.6	11360
06/05/2005	300	220	35.5	0.25	7.24	9140	45	59.8	11460
09/05/2005	369	300	37.2	0.25	7.16	8540	120	50.8	11290
13/05/2005	280	270	37.9	0.25	7.28	8230	90	58.5	13440
20/05/2005	301	281	38.5	0.25	7.06	8720	108	43.6	12720
23/05/2005	301	320	36.4	0.25	7.06	8950	108	60.8	11150
25/05/2005	291	265			7.31		122		
27/05/2005	354	292	46.4	0.25	7.32	9240	113	58.6	11140
30/05/2005	325	391			7.16		190		
08/06/2005	310	300	38.9	0.25	7.01	8920	100	65.9	10930
21/06/2005	289	294	34.7	0.25	7.2	6960	126	49.8	11350
23/06/2005	296	313	27.6	0.25	6.87	6870	134	40.8	9010
28/06/2005	310	441	30.9	0.25	6.94	7710	175	32.9	9750
30/06/2005	381	369	35.5	0.25	6.88	8520	202	46.7	8780
05/07/2005	393	437	38.3	1.43	7.16	9000	97	50.7	9640
12/07/2005	326	291	53.5	0.25	6.82	8760	126	59.8	9500
14/07/2005	348	203	43.3	0.25	6.9	9240	86	60.5	9940
19/07/2005	326	271	46	0.25	6.71	9330	98	57	10540
21/07/2005	386	362	42.7	0.25	6.81	9300	149	44.9	10890
26/07/2005	311	173	40.2	0.25	6.88	9660	86	56	16400
28/07/2005	245	224	36.7	0.25	7.34	9890	65	57	15680
02/08/2005	316	283	21.3	0.25	7.14	3490	90	56.7	10000
11/08/2005	264	231	30.6	4	6.72	8230	103	57.1	10130
16/08/2005	346	299	37	0.25	6.99	7430	138	47.7	10350
18/08/2005	317	221	39.4	0.25	7.04	8480	94	43	11050
30/08/2005	327	295			7.05		110	56.8	
02/09/2005	368	219	356.8ol	15.3	7.13	9140	104	59.5	11080
06/09/2005	321	331	38.8		6.81	8250	170	54.4	10690
08/09/2005	281	498	38	17.6ol	7.06	7850	254	54.1	8810
13/09/2005	359	400	47.2	15.9ol	6.87	15020	175	37.1	13860
19/09/2005	330	390			7.13	7800	236	27.3	10220
27/09/2005	361	448			7.63		200		

Note: ol = outlier. Result not included in statistical analysis.

2.6 Descriptive statistical for submerged bio-contactor point L1

	Alkalinity	COD	NH3	NO3	pH	SRP	SS	TKN	TP
Count	41	41	36	33	41	36	41	36	35
Mean	320	289	45	1	7.2*	8390	117	51	10856
Minimum	245	114	21.3	0.25	6.71	3490	38	27.3	7250
Maximum	393	498	356.8	15.3	7.63	15020	254	65.9	16400
Standard Deviation	35.1	84.3	53.9	2.7		1662.5	49.0	8.5	1830.9
Performance									
Count**	33	33	28	25	33	29	33	30	29
Performance Mean	322	308	49	1	7.16*	8644	128	52	11135
Performance Min	245	173	21	0	7	3490	45	27	8780
Performance Max	393	498	357	15	8	15020	254	66	16400
Performance SD	36	78	61	3		1719	48	9	1816
% Removal	-13.6	42.6	-57.7	-259	-0.8	-13.8	46.4	-1.4	1.3

For computational purposes, results below detection limits were calculated as if they were equal to half the detection limit.

*Mode

**Performance stats: Stats for values during steady state conditions (start date + 3 weeks)

2.7 Data for Submerged bio-contactor point L2

Date	Alkalinity	COD	*E.coli*	NH3	NO3	pH	SRP	SS	TKN	TP
22/02/2005	221	128		26.78	ms	7.4	6500	20		
23/02/2005	205	121		26.3	na	7.56	6460	15		
04/03/2005	223	115		5.64	0.25	7.18	5100	11		
06/03/2005			50							
07/03/2005	241	154	50			7.32		36		
11/03/2005	236	54		18	0.25	7.31	3910	0	43.8	
14/03/2005	480	37	4880	20.3	0.25	7.33	4020	0		
16/03/2005	359	34		21	0.25	7.29	4300	1		
22/03/2005	243	30	61300	25.9	0.25	7.42		5		
30/03/2005	231	36	241900	26.8	0.25	7.46		10		
05/04/2005	276	106	9000	28.6	0.25	7.32	7440	28	42.6	
11/04/2005	281	99	500	32.9	0.25	7.63	5140	38		
13/04/2005	325	115		32.5	0.25	7.12	7050	28		
15/04/2005	225	120		30.8	0.25	7.32	6910	40	43.4	8810
18/04/2005	251	99		34.6	0.25	7.34	7440	24	49.4	9560
20/04/2005	335	120		40.3	0.25	7.32	8470	29	59.3	10590
22/04/2005	324	120		30.4	0.25	7.22	7510	30	40	10020
25/04/2005	304	101		34.6	0.25	7.23	7860	24	44.5	10450
29/04/2005	367	142		28.5	0.25	7.48	9040	35	42.8	11960
04/05/2005	327	207		39.1	0.25	7.33	6260	66	55.5	10480
06/05/2005	352	159		35.2	0.25	7.42	9140	35	59.2	11310
09/05/2005	295	90		36.7	0.25	7.39	8610	35	46.3	11330
13/05/2005	275	120		50.3	0.25	7.33	8530	35	49.6	12260
20/05/2005	310	94		29.3	0.25	7.66	8005	30	27.7	11080
23/05/2005	310	140		37	0.25	7.66	7880	68	53.5	10500
25/05/2005	277	116				7.69		62		
27/05/2005	323	138		33.2	0.25	7.72	8240	77	52.4	10920
30/05/2005	310	120				7.38		70		
08/06/2005	362	100		45.5	0.25	7.36	8750	66	52.5	9810
21/06/2005	297	69		39.2	0.25	7.66	8730	36	42	11770
23/06/2005	257	82		28.9	0.25	7.28	6770	25	32.4	7580
28/06/2005	320	92		35.5	0.25	7.24	7310	58	35.5	9670
30/06/2005	380	77		31.6	0.25	7.28	8620	37	41.7	9110
05/07/2005	304	80		42.6	0.25	7.47	9560	59	43.9	9560
12/07/2005	376	150		51.3	0.25	7.34	8100	78	51.3	8100
14/07/2005	384	169		41.4	0.25	7.23	9150	79	49.9	9150
19/07/2005	340	105		49.7	0.25	7.18	8960	19	49.7	10590
21/07/2005	394	127		45.2	0.25	7	9780	40	45.2	10260
26/07/2005	302	109		51.4	0.25	7.16	10230	18	52.4	16760
28/07/2005	337	155		46.4	0.25	7.47	10300	45	46.8	12990
02/08/2005	341	159		47.3	0.25	7.46	6720	68	51.9	8400
11/08/2005	246	147		16	4.16	6.53	8190	80	47.6	9890
16/08/2005	349	187		25.5	0.25	7.3	7580	62	42.7	10190
18/08/2005	293	133		26	4.04	7	8040	56	42.2	10000
30/08/2005	292	156		36.4	0.25	7.34	6000	68	55.5	6460
02/09/2005	320	119		32	0.94	7.2	9570	42	54.4	11590
06/09/2005	292	143		30.8		6.75	8890	40	30.3	10660
08/09/2005	253	112		35.2	15.4	6.81	7790	78	40.5	8650
13/09/2005	279	160		29.3	15.4	6.91	9930	30	36.5	10360
19/09/2005	229	148		23.3	12.6	7.02	8440	38	36.8	11260
27/09/2005	318	166				7.05	8550	35		

2.8 Descriptive Statistics for submerged bio-contactor point L2

	Alkalinity	COD	*E.coli*	NH3	NO3	pH	SRP	SS	TKN	TP
Count	50	50	7	46	43	50	45	50	37	35
Mean	303	117	45383	33	1	7.32*	7773	40	46	10345
Minimum	205	30	50	5.64	0.25	6.53	3910	0	27.7	6460
Maximum	480	207	241900	51.4	15.4	7.72	10300	80	59.3	16760
Standard Deviation	54.6	39.1	89407	9.8	3.7		1577	22.7	7.7	1749.5
Performance Count**	44	44	4	41	40	44	40	44	36	35
Perf. Mean	308.3	119.3	78175.0	35.1	1.5	7.32*	8095	43.8	45.8	10345.1
Perf. Min	225.0	30.0	500.0	16	0.3	6.5	4300	1.0	27.7	6460.0
Perf. Max	394.0	207.0	2.4E+05	51.4	15.4	7.7	10300	80.0	59.3	16760.0
Perf. SD	43.8	38.2	112412	8.6	3.8		1299	21.3	7.8	1749.5
% Removal	-7.0	78.2	2Log	-13	-422	-3.1	-6.6	83.1	10.4	8.3
Ceiling 1		75	1000	6		5.5-9.5		25		
Ceiling 2		400	1.0E+06			6.0-9.0				
% Comp. C1		9	25	0		100		18		
% Comp. C2		100	75			100				

For computational purposes, results below detection limits were calculated as if they were equal to half the detection limit.

*Mode

**Performance stats: Stats for values during steady state conditions (start date + 3 weeks)

2.9 Data for Submerged bio-contactor point L3

Date	**Alkalinity**	**COD**	*Clt*	*E.coli*	**NH3**	**NO3**	*pH*	**SRP**	**SS**	**TKN**	*TP*
05/04/2005	285	67	0.1	9000	24.8	0.25	7.35		14	33.7	6800
11/04/2005	281	65	0.01		28.1	0.25	7.63	3360	9	42.6	4140
13/04/2005	248	77			25.3	2.75	7.15	2250	12		
15/04/2005	235	79	0.5	500	27.9	2.53	7.31	2060	8	36.5	4020
18/04/2005	269	63	0.05	700	28.7	4.23	7.35	3120	11	34.4	4660
20/04/2005	339	52	1		33.1	3.46	7.31	3290	4	30.5	4920
22/04/2005	323	38	0.1		29.5	3.67	7.3	2900	10	34.8	6120
25/04/2005	289	38	0.1	9300	27.5	0.25	7.35	5990	0	38	8180
29/04/2005	307	36	0.1	155300	30.2	0.25	7.53	5990	0	38.2	9660
04/05/2005	330	79	0.1		15.7	0.25	7.28	3600	20	42.4	8940
06/05/2005	284	45	0.1	241900	37.6	0.93	7.46	4600	6	60.1	6400
09/05/2005	394	40	0.1	241900	35.1	0.25	7.43	5570	10	46.6	8250
13/05/2005			1		31.4	1.54		3540		40.8	7250
20/05/2005			0.8		27	2.8		5740	**	11.7	8330
23/05/2005	299	72	0.5		30.6	4.54	7.47	4270	13	31.7	5890
25/05/2005	253	69	0.3				7.47		16		
27/05/2005	272	64	0.5		29.5	2.77	7.41	4990	15	30.45	7160
30/05/2005	329	45	1				7.13		10		
08/06/2005	292	40	0.05	241900	24.1	2.4	7.36	6350	15	29.7	7620
21/06/2005	113	26	1		17.4	10.6	6.65	390	1	28.3	1620
23/06/2005	218	36	0.8	1000	20.9	4.03	6.85	2730	17	23.4	4490
28/06/2005	256	42	2	50	34.1	2.9	7.26	5360	15	34.3	5850
30/06/2005	366	41	0.5		27.5	1.97	7.33	6320	17	33.8	8260
05/07/2005	258	40	0.1	24190	35.4	1.43	7.53	3920	17	36.6	7570
12/07/2005	54	86	5	50	2.82	3.7	4.94	320	21	20	250
13/07/2005			1.4								
14/07/2005	289	78	0.3		32.4	3.21	7.04	4950	17	35.8	6530
19/07/2005	373	60	0.2	29900	38	4.67	7	6460	7	40.5	7100
21/07/2005	345	72	0.3		37.8	3.22	7.1	7760	20	59.9	8600
26/07/2005	347	71	0.8	50	44.4	1.69	7.32	8700	11	46.2	14050
28/07/2005	333	80	0.1		45.2	1.35	7.35	9550	17	46.4	12580
02/08/2005	323	87	2	50	36.9	0.25	7.27	4070	25	67.6	11940
11/08/2005	222	40	*0.4*		*35.2*	*0.25*	7	7650	14	48	*10030*
16/08/2005	272	49	0.01	104600	8.18	6.46	7.22	5310	16	34.1	7630
18/08/2005	208	38	0.3		11.7	4.08	6.91	6080	13		
30/08/2005	295	41	1	50	32	0.25	7.11	8460	20	39.9	10530
02/09/2005	284	34			16.8	16	7.1	6150	10		
06/09/2005	290	48		5	30.9		7.31	4160	12	44.1	8300
08/09/2005	256	39		1010	16.3	2.03	7.31	3780	8	23.3	6930
13/09/2005	240	50		50	29.2	7.23	7.2	6640	8	36.5	9620
19/09/2005											
27/09/2005	238	54					7.08		15		

2.10 Descriptive statistics for submerged bio-contactor point L3

	Alk	**COD**	**Clt**	***E.coli***	**NH3**	**NO3**	**pH**	**SRP**	**SS**	**TKN**	**TP**
Count	38	38	35	20	37	36	38	36	38	34	34
Mean	279	55	1	53075	28	3	7.35*	4899	12	38	7359
Minimum	54	26	0.01	5	2.82	0.25	4.94	320	0	11.7	250
Maximum	394	87	5	241900	45.2	16	7.63	9550	25	67.6	14050
Standard Deviation	64.7	17.3	0.9	90588	9.3	3.2		2149.1	5.8	11.2	2826
Performance Count**	30	30	28	16	29	28	30	29	30	27	27
Perf. Mean	278	53	0.74	65125	28	3	7.53*	5290	14	38	7829
Perf. Min	54	26	0.01	5	3	0	4.9	320	0	12	250
Perf. Max	394	87	5.00	2.0E+05	45	16	7.5	9550	25	68	14050
Perf. SD	71	18	1.00	98057	10	3		2145	6	12	2911
% Removal	2.0	90.1		2Log	9.9	-1013	-1.4	30.4	94	25	31
Ceiling 1		75		1000	6		5.5-9.5		25		
Ceiling 2		400		1.0E+06			6.0-9.0				
% Comp C1		83		50	3		97		100		
% Comp. C2		100		69			97				

For computational purposes, results below detection limits were calculated as if they were equal to half the detection limit.

*Mode

**Performance stats: Stats for values during steady state conditions (start date + 3 weeks)

2.11 Data for Sequencing Batch Reactor Effluent

Date	Alkalinity	Clt	COD	*E.coli*	NH3	NO3	pH	SRP	SS	TKN	TP	MLSS
25/04/2005	216		126		24.2	0.25	7.22	6370	29	30.8	7560	945
29/04/2005	237		102	2400	29.7	0.25	7.52	6800	22	35	9650	1260
04/05/2005	202		89		30.9	0.25	7.72	5760	16	36.2	6640	1300
06/05/2005	219		65	50	32.9	0.25	7.89	6650	20	49.9	7920	
09/05/2005	469		45		42.9	0.65	7.95	8002	19	37.9	8870	
13/05/2005					32.6	4.93		8400		34.8	9790	
27/05/2005	202		36		13.3	1.81	7.62	280 ol	14	16.4	1070	
30/05/2005	99	0.7	40				7.13		10			
02/06/2005	83	0.3	40	5	3.52	8.87	7.35	4760	10	3.79	5200	
03/06/2005		0.3										
06/06/2005		0.4										
07/06/2005		0.5										
08/06/2005	785	0.5	35	500	9.66	0.25	7.43	4220	0	7.19	4310	1840
21/06/2005	584	0	34		2.74	13.8	7.28		6	10.7	10270	1480
23/06/2005	95	0	31		3.17	10.6	7.25	6680	5	3.17	6990	1776
24/06/2005		0.5		10								
28/06/2005	141	0.3	60	130	3.49	10.2	7.44	3590	24	8.02	4210	2445
30/06/2005	107	0.3	34		3.35	11.7	7.52	593	6	3.35	4630	2320
05/07/2005	154	0.5	32	150	2.37	11.3	7.37	4330	22	1.5	10730	2055
12/07/2005	106	0.4	47	50	3.22	12.4	6.76	4130	18	3.33	4130	2840
13/07/2005		0.4		N								
14/07/2005	80	0.4	54		2.83	10.5	7.38	7990	11	1.5	8040	3006
19/07/2005	82	0.5	58	5	3.3	12.2	7.16	7680	12	3.3	7680	3358
21/07/2005	120	0.4	36		2.64	8.75	7.25	10540	4	1.5	10090	3432
26/07/2005	105	0.1	30	304	4.33	11	7.17	8090	0	5.86	10870	2848
28/07/2005	132	0.1	41		2.62	9.02	7.41	5790	12	2.91	9130	2568
02/08/2005	76	0.6	67	1100	4.72	16	7.46	7660	18	5.16	10440	2462
11/08/2005	98	0.2	30		3.11	0.25	7.1	4630	6	3.31	5550	2048
16/08/2005	100	0.5	36	120	2.53	8.53	7.29	4040	10	7.46	5610	3098
18/08/2005	108	0.3	22		2.85	0.61	7.29	7030	0			3448
30/08/2005	152	0.3	23	40	3.1	0.25	7.51	4800	8	4.72	5320	2538
02/09/2005	124		24		2.18	0.25	7.24	5060	4			2842
06/09/2005	122		29	5	1.86		7.42		2	3.83	3870	3190
08/09/2005	100		26	24190	10.1	5.64	7.42	5690	0	1.5	17170	2495
13/09/2005	97		33	50	4.93	3.62	7.6	5080	0	5.43	5450	3770
19/09/2005	65		39	5	3.29	19.5	7.08	10920	4	5.43	12580	4060
27/09/2005	114		26				6.98		4			3775
06/10/2005	128		33	20	2.86	3	7	1150	0	7.29	1960	3260
13/10/2005					3.49	3.26		3730		7.89	4500	
01/11/2005	94		47		3.31	3.18	7.58	2840	6	13	5000	3528
03/11/2005	110		35	50	6.49	1.09	7.4	2080	4	8.06	3520	3220
04/11/2005	103		40	5	3.87	2.82	7.28	1200	8	10.2	2460	3600
07/11/2005	120		44		3.63	4.15	7.3	1370	6	10.7	2420	3362
14/11/2005	119		32	24190	0.79	4.59	7.4	2030	8	4	3220	3940
23/11/2005	308		38				7.3		6			4100

Note: ol = outlier. Data not included in statistical analyses.

2.12 Descriptive statistics for sequencing batch reactor effluent

	Alk	**Clt**	**COD**	***E.coli***	**NH3**	**NO3**	**pH**	**SRP**	**SS**	**TKN**	**TP**
Count	38	24	38	21	37	36	38	33	38	35	35
Mean	167	0.35	44	2542	9	6	7.52*	5427	9	11	6767
Minimum	65	0	22	5	1	0	7	1150	0	2	1070
Maximum	785	1	126	24190	43	20	8	10920	29	50	17170
Standard Deviation	146.4	0.2	21.8	7218.1	11.0	5.4		2503	7.7	12.8	3469.5
Performance Count**	27	24	27	16	26	25	27	22	27	24	24
Perf. mean	154.0	0.4	36.9	1668	4.1	7.7	7.25*	5800	7.8	5.2	7075.0
Perf. Min	65.0	0.0	22.0	5.0	1.9	0.3	6.8	1150	0.0	1.5	1070.0
Perf. Max	785.0	0.7	67.0	24190	13.3	19.5	7.6	10920	24.0	16.4	17170.0
Perf. SD	158.0	0.2	11.5	5835	2.7	5.5		23629	6.9	3.4	3726.9
% Removal	45.7		93.1	3Log	87.0	-2546	-2.1	23.7	96.7	89.8	37.3
Ceiling 1			75	1000	6		5.5-9.5		25		
Ceiling 2			400	1.0E+06			6.0-9.0				
% Comp. C1			100	88	81		100		100		
% Comp C2			100	100			100				

For computational purposes, results below detection limits were calculated as if they were equal to half the detection limit.

*Mode

**Performance stats: Stats for values during steady state conditions (start date + 3 weeks)

2.13 Data for Rotating Bio-Contactor effluent

Date	Alkalinity	Clt	COD	*E.coli*	NH3	NO3	pH	SRP	SS	TKN	TP
22/02/2005	254		209			23.27	7.28	6110	16		
23/02/2005	253		232			21.06	7.47	5780	20		
28/02/2005	241		190				7.18		15		
02/03/2005	246	0	210				7.23		25		
04/03/2005	266	0	227		1.92	1.41	7.11	150ol	29	38.5	
06/03/2005				2419000							
07/03/2005	195	0	170				7.43		20	15.5	5830
11/03/2005	266	0	144		19.7	0.25	7.21	4470	40	38.5	5950
14/03/2005	334	0	116	2419000	18.4	0.25	7.26	4010	18		
16/03/2005	359	0	137		20.4	0.25	7.29	4130	4		
22/03/2005	244	0	48	1986000	22.7	0.25	7.23	5600	10	35	
30/03/2005	285	0	71	2419000	28.8	0.25	7.26	6900	14		
05/04/2005	294	0	148	880000	26	0.25	7.31	6440	26	34.1	9440
11/04/2005	240	0.03	74	910000	26.6	0.25	7.59	6410	21	32.4	7950
13/04/2005	226		100		30.3	0.25	7.48	6720	37	37.7	7830
15/04/2005	240		154		30.3	0.25	7.52	6720	43	37.7	7830
18/04/2005	238	0.05	128	3000	27.4	0.25	7.56	7210	35	31.9	8820
20/04/2005	270	0.05	166		25.3	0.25	7.47	7800	30	26.1	9510
22/04/2005	239	0.05	80		20.7	0.25	7.42	7910	16	21.7	9350
25/04/2005	214	0.05	76	1046000	13.9	0.25	7.36	8050	12	17.8	9580
29/04/2005	287	0.05	122	2419000	28.7	0.25	7.48	8660	22	37.8	11200
04/05/2005	291	0.05	104		33.8	0.25	7.45	7800	16	46.5	10850
06/05/2005	220	0.05	89	91000	30.9	0.25	7.5	1780	25	46.8	4160
09/05/2005	452	0.05	36		30.2	0.25	7.53	3370	10	44.2	5050
13/05/2005		0.05			33.5	0.25		6540		42.5	9360
20/05/2005					24.9	0.25		7009		15.1	10550
23/05/2005	290	0	65		10.3	0.25	7.4	7320	26	18.6	11290
25/05/2005	242	0	70				7.52		30		
27/05/2005	202	0	80		18.6	0.25	7.62	7250	49	19.6	8670
30/05/2005	211	1	75				6.81		28		
02/06/2005	266	1	35	5	18.6	0.25	7.24	6560	6	29.4	7520
03/06/2005		1									
06/06/2005		0.1									
07/06/2005		4									
08/06/2005	218	1	38	5	23.1	4.41	7.2	7890	6	24.1	10390
21/06/2005	207	3	62		21.5	1.94	7.21	6560	28	30.8	8290
23/06/2005	182	0.8	54		18.8	1.3	7.26	6550	8	22.4	7270
24/06/2005		0.4		18							
28/06/2005	180	1.2	46	100	9.97	1.88	7.3	7270	12	13.4	8470
30/06/2005	250	1	48		13.4	0.95	7.52	8220	28	13.6	8680
05/07/2005	235	0	46	24190	26.2	0.25	7.53	8980	15	26.2	8980
12/07/2005	284	0.05	48	72700	30.9	1.66	6.65	9360	24	30.9	9360
13/07/2005		2		N							
14/07/2005	277	0.4	34		29.8	0.25	7.33	8820	7	33.1	8890
19/07/2005	290	0.1	36	28500	28.2	0.25	7.25	9550	3	46.3	9550
21/07/2005	300	0.3	51		37.9	0.25	7.3	10030	12	48.7	10050
26/07/2005	255	0.1	45	130000	31	0.25	7.1	10070	8	31.8	12990
28/07/2005	252	0.1	57		27.2	1.47	7.27	10970	10	32.6	10990

Note ol = outlier. Result not included in statistical analysis.

Date	Alkalinity	Clt	COD	*E.coli*	NH3	NO3	pH	SRP	SS	TKN	TP
02/08/2005	326	1.6	49	8700	35.6	0.54	7.54	9260	8	38.5	11100
11/08/2005	176	0.7	61		16.9	4.11	6.72	9950	22	39.8	11110
16/08/2005	221	0.1	62	5000	2.02	3.94	7.2	10360	22	21.7	11250
18/08/2005	129	0.7	51		1.91	4.07	6.66	9280	18		
30/08/2005	304	0.7	57	17800	18.1	4	7.48	9520	20	42.4	10570
02/09/2005	209		75	0.8	22.6	0.97	7.13	10190	24		
06/09/2005	303	0.5	62	50	30.1	0.97	7.46	9020	16	43.2	11240
08/09/2005	256	0.1	42	24190	16.5	16.7	7.46	5120	10	32.9	11590
13/09/2005	295	0.3	44	50	19.3	17	7.62	8230	8	35.4	10270
19/09/2005	185	0.3	62	5	15.8	17.4	7.26	8370	14	20.1	10190
27/09/2005	274	0.2	58				7.07		14		

2.13 Descriptive statistics for Rotating Bio-Contactor effluent

	Alk	Clt	COD	*E.coli*	NH3	NO3	pH	SRP	SS	TKN	TP
Count	51	52	51	13	45	47	51	46	51	41	39
Mean	254	0.46	89	275826	23	3	7.26*	7481	19	32	9281
Minimum	129	0	34	5	1.91	0.25	6.65	1780	3	13.4	4160
Maximum	452	4	232	2419000	37.9	23.27	7.62	10970	49	48.7	12990
Standard Deviation	52.5	0.8	55.1	705060	8.7	5.8	0.2	1995.9	10.4	10.1	1897.4
Performance Count**	22	24	22	7	21	21	22	21	22	19	19
Performance mean	245	0.64	52	3818	22	4	7.26*	8842	15	32	10044
Performance Min	129	0.00	34	5	2	0	6.7	5120	3	13	7270
Performance Max	326	3.00	75	17800	38	17	7.6	10970	28	49	12990
Performance SD	53	0.71	10	6959	10	6		1453	7	10	1409
% Removal	13.6		90.3	1Log	30.6	-103.0	-2.3	-16.4	93.7	37.7	11.0
Ceiling 1			75	1000	6		5.5-9.5		25		
Ceiling 2			400	100000			6.0-9.0				
% Compliance (1)			100	71	10		100		91		
% Compliance (2)			100	100			100				

For computational purposes, results below detection limits were calculated as if they were equal to half the detection limit.

*Mode

**Performance stats: Stats for values during steady state conditions (start date + 3 weeks); after new clarifier

Appendix 3 Fault evaluation data

Date	Unit	Source	Fault	Attribute	Description
21-Feb-05	SBC	Fault log	SC	N	SBC plant pipe work alterations
22-Feb-05	SBC L2	Out of range result	IB	N	
22-Feb-05	SBC L2	Out of range result	IB	N	
22-Feb-05	SBC L2	Out of range result	IB	N	
22-Feb-05	RBC	Out of range result	IB	N	
23-Feb-05	Feed	Fault log	SC	N	Pumps calibrated at low level. New unequal set.
23-Feb-05	SBC L2	Out of range result	IB	N	
23-Feb-05	SBC L2	Out of range result	IB	N	
23-Feb-05	SBC L2	Out of range result	IB	N	
23-Feb-05	RBC	Out of range result	IB	N	
24-Feb-05	Feed	Fault log	SC	N	Feed pumps calibrated at mid level
25-Feb-05	Feed	Fault log	SC	N	New feed: 25l/cycle; feeding 20 hrs per day
28-Feb-05	SBC	Fault log	SC	N	SBC re-commissioned on slab. Feed wasted.
28-Feb-05	RBC	Out of range result	IB	N	
01-Mar-05	SBC	Fault log	OB	D	New timer settings. SBC overflowing. Service call made. Unit re-calibrated.
02-Mar-05	SBC	Fault log	OB	D	SBC overflowing all feed to waste. Service call made.
02-Mar-05	RBC	Out of range result	IB	N	
03-Mar-05	SBC	Fault log	OB	D	SBC recalibrated by honest. All flow to plant at 11:00.
04-Mar-05	SBC L2	Out of range result	MB	M	
04-Mar-05	SBC L2	Out of range result	IB	N	
04-Mar-05	SBC L2	Out of range result	IB	N	
04-Mar-05	RBC	Out of range result	IB	N	
04-Mar-05	RBC	Out of range result	IB	N	
04-Mar-05	RBC	Out of range result	IB	N	
04-Mar-05	SBC L2	Out of range result	MB	M	
06-Mar-05	RBC	Out of range result	OB	D	
07-Mar-05	SBC L2	Out of range result	MB	M	
07-Mar-05	SBC L2	Out of range result	IB	N	
07-Mar-05	SBC L2	Out of range result	IB	N	
07-Mar-05	SBC L2	Out of range result	IB	N	
07-Mar-05	RBC	Out of range result	IB	N	

Fault Code Legend	
IB	Initialisation breakdown
MB	Maintenance breakdown
OB	Operational Breakdown
OC	Operational Comment
OM	Operational Maintenance
SB	Supply Breakdown
SC	Supply Comment
D	Attributed to design
E	Attributed to electrical fault
M	Attributed to maintenance fault
N	Not attributed

Date	Unit	Source	Fault	Attribute	Description
11-Mar-05	SBC L2	Out of range result	MB	M	
11-Mar-05	SBC L2	Out of range result	IB	N	
11-Mar-05	SBC L2	Out of range result	IB	N	
11-Mar-05	RBC	Out of range result	IB	N	
11-Mar-05	RBC	Out of range result	IB	N	
11-Mar-05	RBC	Out of range result	IB	N	
14-Mar-05	SBC L2	Out of range result	MB	M	
14-Mar-05	SBC L2	Out of range result	IB	N	
14-Mar-05	SBC L2	Out of range result	MB	M	
14-Mar-05	SBC L2	Out of range result	IB	N	
14-Mar-05	RBC	Out of range result	IB	N	
14-Mar-05	RBC	Out of range result	OB	D	
14-Mar-05	RBC	Out of range result	IB	N	
15-Mar-05	SBC	Fault log	OB	D	SBC overflowing. Re-calibrated. Feeder pipe work re-routed
16-Mar-05	SBC	Fault log	SC	N	Large volume sewage wasted during pipe refit. SBC unequal cycle timer changed; old one not turning off.
16-Mar-05	SBC L2	Out of range result	MB	M	
16-Mar-05	SBC L2	Out of range result	OB	D	
16-Mar-05	SBC L2	Out of range result	OB	D	
16-Mar-05	RBC	Out of range result	IB	N	
16-Mar-05	RBC	Out of range result	IB	N	
17-Mar-05	SBC	Fault log	SB	D	New diurnal: 04:30-10:30 and 16:00-22:00. . SBC recalibrated. No dip reading due to pipe re-routing.
18-Mar-05	SBC	Fault log	SC	N	New diurnal: pumps re calibrated. SBC output set to 40sec/litre
22-Mar-05	SBC	Fault log	SC	N	SBC outflow 48sec/l. Not changed (no overflow at 09:30). RBC outflow 34sec/l.
22-Mar-05	SBC L2	Out of range result	MB	M	
22-Mar-05	SBC L2	Out of range result	OB	D	
22-Mar-05	SBC L2	Out of range result	MB	M	
22-Mar-05	SBC L2	Out of range result	OB	D	
22-Mar-05	RBC	Out of range result	OB	D	
22-Mar-05	RBC	Out of range result	IB	N	

Date	Unit	Source	Fault	Attribute	Description
23-Mar-05	SBC	Fault log	SC	N	Unequal cycle timer off time reduced to 90%. New Cl pill added to SBC unit (6 days use)
24-Mar-05	SBC	Fault log	SB	D	SBC overflowed at 10:30. Off cycle increased to 100%. SBC wetland installation.
29-Mar-05	Feed	Fault log	SB	N	Power cut 23:30 on 28/3 to 11:30 29/3. Plants not running. No sampling. Approx 1000l fed to each plant.
30-Mar-05	Feed	Fault log	sc	N	Vol. Unreliable due to power cut. Both s cloudy & smell of vfas. SBC wetland planted out & Cl point moved to end of wetland.
30-Mar-05	SBC L2	Out of range result	MB	M	
30-Mar-05	SBC L2	Out of range result	OB	D	
30-Mar-05	SBC L2	Out of range result	OB	D	
30-Mar-05	SBC L2	Out of range result	OB	D	
30-Mar-05	SBC L2	Out of range result	MB	M	
30-Mar-05	RBC	Out of range result	OB	D	
30-Mar-05	RBC	Out of range result	OB	D	
30-Mar-05	SBC L2	Out of range result	MB	M	
31-Mar-05	SBC	Fault log	SC	N	SBC from wetland v. turbid (muddy colour). Cl pill finished but not replenished.
01-Apr-05	SBC	Fault log	OM	N	SBC Cl pill replenished.
05-Apr-05	SBC L2	Out of range result	OB	D	
05-Apr-05	SBC L2	Out of range result	OB	D	
05-Apr-05	SBC L2	Out of range result	OB	D	
05-Apr-05	SBC L2	Out of range result	MB	M	
05-Apr-05	SBC L3	Out of range result	IB	N	
05-Apr-05	RBC	Out of range result	OB	D	POOR CLARIFIER DESIGN
05-Apr-05	RBC	Out of range result	OB	D	
05-Apr-05	RBC	Out of range result	OB	D	
05-Apr-05	RBC	Out of range result	OB	D	
11-Apr-05	SBC L2	Out of range result	OB	D	
11-Apr-05	SBC L2	Out of range result	OB	D	
11-Apr-05	SBC L2	Out of range result	OB	D	
11-Apr-05	SBC L3	Out of range result	IB	N	

Date	Unit	Source	Fault	Attribute	Description
11-Apr-05	RBC	Out of range result	OB	D	
11-Apr-05	RBC	Out of range result	OB	D	
13-Apr-05	SBC L2	Out of range result	OB	D	
13-Apr-05	SBC L2	Out of range result	OB	D	
13-Apr-05	SBC L2	Out of range result	OB	D	
13-Apr-05	SBC L3	Out of range result	OB	N	
13-Apr-05	SBC L3	Out of range result	IB	N	
13-Apr-05	RBC	Out of range result	OB	D	POOR CLARIFIER DESIGN
13-Apr-05	RBC	Out of range result	OB	D	
13-Apr-05	RBC	Out of range result	OB	D	
15-Apr-05	SBC L2	Out of range result	OB	D	
15-Apr-05	SBC L2	Out of range result	OB	D	
15-Apr-05	SBC L2	Out of range result	OB	D	
15-Apr-05	SBC L3	Out of range result	OB	N	
15-Apr-05	SBC L3	Out of range result	MB	M	
15-Apr-05	SBC L3	Out of range result	IB	N	
15-Apr-05	RBC	Out of range result	OB	D	POOR CLARIFIER DESIGN
15-Apr-05	RBC	Out of range result	OB	D	
15-Apr-05	RBC	Out of range result	OB	D	
18-Apr-05	SBC L2	Out of range result	OB	D	
18-Apr-05	SBC L2	Out of range result	OB	D	
18-Apr-05	SBC L2	Out of range result	OB	D	
18-Apr-05	SBC L3	Out of range result	IB	N	
18-Apr-05	RBC	Out of range result	OB	D	POOR CLARIFIER DESIGN
18-Apr-05	RBC	Out of range result	OB	D	
18-Apr-05	RBC	Out of range result	OB	D	
18-Apr-05	RBC	Out of range result	OB	D	
20-Apr-05	SBC L2	Out of range result	OB	D	
20-Apr-05	SBC L2	Out of range result	OB	D	
20-Apr-05	SBC L2	Out of range result	OB	D	
20-Apr-05	SBC L3	Out of range result	IB	N	
Date	Unit	Source	Fault	Attribute	Description
20-Apr-05	RBC	Out of range result	OB	D	POOR CLARIFIER DESIGN

20-Apr-05	RBC	Out of range result	OB	D	
20-Apr-05	RBC	Out of range result	OB	D	
22-Apr-05	SBC L2	Out of range result	OB	D	
22-Apr-05	SBC L2	Out of range result	OB	D	
22-Apr-05	SBC L2	Out of range result	OB	D	
22-Apr-05	SBC L3	Out of range result	IB	N	
22-Apr-05	RBC	Out of range result	OB	D	POOR CLARIFIER DESIGN
22-Apr-05	RBC	Out of range result	OB	D	
25-Apr-05	SBC L2	Out of range result	OB	D	
25-Apr-05	SBC L2	Out of range result	OB	D	
25-Apr-05	SBC L2	Out of range result	OB	D	
25-Apr-05	SBC L3	Out of range result	OB	D	
25-Apr-05	SBR	Out of range result	IB	N	
25-Apr-05	SBR	Out of range result	IB	N	
25-Apr-05	SBR	Out of range result	IB	N	
25-Apr-05	RBC	Out of range result	OB	D	POOR CLARIFIER DESIGN
25-Apr-05	RBC	Out of range result	OB	D	
25-Apr-05	RBC	Out of range result	OB	D	
26-Apr-05	SBC L3	Out of range result	MB	M	
29-Apr-05	SBC L2	Out of range result	OB	D	
29-Apr-05	SBC L2	Out of range result	OB	D	
29-Apr-05	SBC L2	Out of range result	OB	D	
29-Apr-05	SBC L3	Out of range result	MB	M	
29-Apr-05	SBC L3	Out of range result	OB	D	
29-Apr-05	SBR	Out of range result	IB	N	
29-Apr-05	SBR	Out of range result	MB	M	
29-Apr-05	SBR	Out of range result	IB	N	
29-Apr-05	RBC	Out of range result	OB	D	POOR CLARIFIER DESIGN
29-Apr-05	RBC	Out of range result	OB	D	
29-Apr-05	RBC	Out of range result	OB	D	

Date	Unit	Source	Fault	Attribute	Description
04-May-05	SBC L2	Out of range result	OB	D	
04-May-05	SBC L2	Out of range result	OB	D	
04-May-05	SBC L2	Out of range result	OB	D	
04-May-05	SBC L3	Out of range result	OB	N	
04-May-05	SBC L3	Out of range result	OB	D	
04-May-05	SBR	Out of range result	IB	N	
04-May-05	SBR	Out of range result	IB	N	
04-May-05	RBC	Out of range result	OB	D	POOR CLARIFIER DESIGN
04-May-05	RBC	Out of range result	OB	D	
06-May-05	SBC L2	Out of range result	OB	D	
06-May-05	SBC L2	Out of range result	OB	D	
06-May-05	SBC L2	Out of range result	OB	D	
06-May-05	SBC L3	Out of range result	MB	M	
06-May-05	SBC L3	Out of range result	OB	D	
06-May-05	SBR	Out of range result	IB	N	
06-May-05	RBC	Out of range result	OB	D	POOR CLARIFIER DESIGN
06-May-05	RBC	Out of range result	OB	D	
06-May-05	RBC	Out of range result	OB	D	
09-May-05	SBC L2	Out of range result	OB	D	
09-May-05	SBC L2	Out of range result	OB	D	
09-May-05	SBC L2	Out of range result	OB	D	
09-May-05	SBC L3	Out of range result	OB	D	
09-May-05	SBR	Out of range result	IB	N	
09-May-05	RBC	Out of range result	OB	D	
13-May-05	SBC L2	Out of range result	OB	D	
13-May-05	SBC L2	Out of range result	OB	D	
13-May-05	SBC L2	Out of range result	OB	D	
13-May-05	SBC L3	Out of range result	OB	D	
13-May-05	SBR	Out of range result	IB	N	
13-May-05	RBC	Out of range result	OB	D	

Date	Unit	Source	Fault	Attribute	Description
20-May-05	SBC L2	Out of range result	OB	D	
20-May-05	SBC L2	Out of range result	OB	D	
20-May-05	SBC L2	Out of range result	OB	D	
20-May-05	SBC L3	Out of range result	OB	D	
20-May-05	RBC	Out of range result	OB	D	
23-May-05	SBC L2	Out of range result	OB	D	
23-May-05	SBC L2	Out of range result	OB	D	
23-May-05	SBC L2	Out of range result	OB	D	
23-May-05	SBC L3	Out of range result	OB	N	
23-May-05	SBC L3	Out of range result	OB	D	
23-May-05	RBC	Out of range result	OB	D	
23-May-05	RBC	Out of range result	OB	D	
25-May-05	SBC L2	Out of range result	OB	D	
25-May-05	SBC L2	Out of range result	OB	D	
25-May-05	RBC	Out of range result	OB	D	
27-May-05	SBC L2	Out of range result	OB	D	
27-May-05	SBC L2	Out of range result	OB	D	
27-May-05	SBC L2	Out of range result	OB	D	
27-May-05	SBC L3	Out of range result	OB	D	
27-May-05	RBC	Out of range result	OB	D	POOR CLARIFIER DESIGN
27-May-05	RBC	Out of range result	OB	D	
27-May-05	RBC	Out of range result	OB	D	
30-May-05	SBR	Fault log	OM	N	SBR chlorine dosing pump adjusted to 40%
30-May-05	SBC L2	Out of range result	OB	D	
30-May-05	SBC L2	Out of range result	OB	D	
30-May-05	RBC	Out of range result	OB	D	
01-Jun-05	RBC	Fault log	OB	D	RBC clarifier & contact tank cleaned out. Recycle reset to 45sec:2min on: off
01-Jun-05	SBC	Fault log	SB	N	SBC feed pump jammed on. Sludge flow to bed bad. System turned off & flushed. Drying bed dried for 24 hrs.
02-Jun-05	SBR	Fault log	OC	N	SBR chlorine dosing pump adjusted to 50%

Date	Unit	Source	Fault	Attribute	Description
02-Jun-05	SBC	Fault log	OM	N	SBC wetland cleared of sludge & system turned back on.
02-Jun-05	SBR	Fault log	OM	N	SBR desludge timer reset to desludge for 2 minutes per decant cycle
02-Jun-05	RBC	Out of range result	OB	D	
03-Jun-05	RBC	Fault log	OB	D	Tony Wellard on site. Looks as if sludge carry-over due to inadequate slope on clarifier floor. Will ask a local contractor to improve slope & raise chlorinator to above contact tank height.
06-Jun-05	All	Fault log	OM	N	New Cl pills for SBC & RBC. RBC effluent excellent in appearance.
08-Jun-05	All	Fault log	OM	N	Normal samples taken
08-Jun-05	SBC L2	Out of range result	OB	D	
08-Jun-05	SBC L2	Out of range result	OB	D	
08-Jun-05	SBC L2	Out of range result	OB	D	
08-Jun-05	SBC L3	Out of range result	MB	M	
08-Jun-05	SBC L3	Out of range result	OB	D	
08-Jun-05	RBC	Out of range result	OB	D	
09-Jun-05	Feed	Fault log	sc	E	Power to plants tripped out. Feed pump to SBC stuck open on re-start. Sludge build up in reactor. Flushed out. No scheduled samples taken
10-Jun-05	Feed	Fault log	sc	E	Intermittent power supply problems encountered. Did not re-occur in pm.
13-Jun-05	Feed	Fault log	SC	N	Power supply ok. SBC showing some signs of biofilm development
14-Jun-05	RBC	Fault log	OB	E	New clarifier for RBC system installed by SBC. SBC wetland being bypassed to dry out sludge. SBR feed put onto unequal cycle timer.
15-Jun-05	Feed	Fault log	OC	N	Power supply ok.
17-Jun-05	Feed	Fault log	sc	E	Paul reported system tripped out. Fault traced to recirculation pump.
20-Jun-05	SBR	Fault log	OB	E	SBR overflowed. Air supply interrupted (connector failure) so valves did not open.
21-Jun-05	Feed	Fault log	SC	N	All ok. SBR timer re-set; had been under delivering. Normal short sample sc taken.
21-Jun-05	SBC L2	Out of range result	OB	D	
21-Jun-05	SBC L2	Out of range result	OB	D	
21-Jun-05	SBC L2	Out of range result	OB	D	
21-Jun-05	SBC L3	Out of range result	OB	D	
21-Jun-05	SBR	Out of range result	MB	M	
21-Jun-05	RBC	Out of range result	OB	D	

Date	Unit	Source	Fault	Attribute	Description
21-Jun-05	RBC	Out of range result	OB	D	
22-Jun-05	SBC	Fault log	OB	D	All looked OK. SBC running a bit fast. Slowed down by altering feed weir height. NH3 (Process lab): L3 6.0 RBC 8.0. SBR underfed slightly pump off time reduced to 40%.
23-Jun-05	SBC	Fault log	OB	D	All ok. SBC feed a bit slow. Recalibrated. Normal short set taken. SBR Compressor back online. SBR timer off time reset to 35%
23-Jun-05	SBC L2	Out of range result	OB	D	
23-Jun-05	SBC L2	Out of range result	OB	D	
23-Jun-05	SBC L2	Out of range result	OB	D	
23-Jun-05	SBC L3	Out of range result	OB	D	
23-Jun-05	SBR	Out of range result	MB	M	
23-Jun-05	RBC	Out of range result	OB	D	
24-Jun-05	SBC	Fault log	OB	D	All ok. SBC recalibrated.
27-Jun-05	All	Fault log	OM	N	Screens & pumps all cleaned. New pills for L3 and new Klorman magazine for RBC chlorinator. Compressor v-belt slipping; re-tightened. SBR feed pump taken off un-equal cycle timer. Put onto plug-in timer. 1on/1off; 1 on/1 off; 1:08 on: off (total pump timer 3:08 in 6 hours)
28-Jun-05	SBC L2	Out of range result	OB	D	
28-Jun-05	SBC L2	Out of range result	OB	D	
28-Jun-05	SBC L2	Out of range result	OB	D	
28-Jun-05	SBC L3	Out of range result	OB	D	
30-Jun-05	SBC L2	Out of range result	OB	D	
30-Jun-05	SBC L2	Out of range result	OB	D	
30-Jun-05	SBC L2	Out of range result	OB	D	
30-Jun-05	SBC L3	Out of range result	OB	D	
30-Jun-05	RBC	Out of range result	OB	D	
30-Jun-05	RBC	Out of range result	OB	D	
04-Jul-05	All	Fault log	OM	N	Normal clean-up given. No problems noted
05-Jul-05	SBC	Fault log	OB	D	Normal samples taken. SBC recal & sludge accumulation cleared from aerobic reactor.
05-Jul-05	SBC L2	Out of range result	OB	D	

Date	Unit	Source	Fault	Attribute	Description
05-Jul-05	SBC L2	Out of range result	OB	D	
05-Jul-05	SBC L2	Out of range result	OB	D	
05-Jul-05	SBC L3	Out of range result	MB	M	
05-Jul-05	SBC L3	Out of range result	OB	D	
05-Jul-05	RBC	Out of range result	OB	M	
05-Jul-05	RBC	Out of range result	OB	D	
07-Jul-05	SBC	Fault log	OB	D	No samples taken: Alan's meeting in morning. Sludge accumulation in SBC cleaned up & wetland bypassed.
08-Jul-05	SBR	Fault log	OM	N	New NaOCl for SBR added.
11-Jul-05	SBC	Fault log	OB	D	SBC overflowing. L1 Recalibrated. New chlorine pill for L3. L3 & RBC sump flushed out
12-Jul-05	SBR	Fault log	OB	E	SBR overflowed. Compressor tripped out. Trip reset & all ok. Jojo Dip: 1500. Inlet screen cleaned.
12-Jul-05	RBC	Fault log	OB	D	Normal samples taken. RBC effluent not looking too good. Cl in RBC low; Klorman adjusted to give higher dose
12-Jul-05	SBC L2	Out of range result	OB	D	
12-Jul-05	SBC L2	Out of range result	OB	D	
12-Jul-05	SBC L2	Out of range result	OB	D	
12-Jul-05	SBC L3	Out of range result	OB	N	
12-Jul-05	RBC	Out of range result	MB	M	
12-Jul-05	RBC	Out of range result	OB	D	
13-Jul-05	SBC	Fault log	OB	D	RBC effluent. Looking much better. L3 recalibrated: pumping too slowly to L1. All else ok.
14-Jul-05	SBC	Fault log	OC	N	Lots filamentous organisms in SBC aerobic tank. Soapy influent.
14-Jul-05	SBC L2	Out of range result	OB	D	
14-Jul-05	SBC L2	Out of range result	OB	D	
14-Jul-05	SBC L2	Out of range result	OB	D	
14-Jul-05	SBC L3	Out of range result	OB	N	
14-Jul-05	SBC L3	Out of range result	OB	D	
14-Jul-05	RBC	Out of range result	OB	D	
15-Jul-05	SBR	Fault log	OM	N	SBR desludge timer reset to desludge for 2 minutes per decant cycle

Date	Unit	Source	Fault	Attribute	Description
18-Jul-05	SBC	Fault log	OB	D	SBC overflowed. Re-cal. & desludge.
19-Jul-05	SBC	Fault log	OB	D	Recalibrated SBC
19-Jul-05	SBC L2	Out of range result	OB	D	
19-Jul-05	SBC L2	Out of range result	OB	D	
19-Jul-05	SBC L2	Out of range result	OB	D	
19-Jul-05	SBC L3	Out of range result	MB	M	
19-Jul-05	SBC L3	Out of range result	OB	D	
19-Jul-05	RBC	Out of range result	MB	M	
19-Jul-05	RBC	Out of range result	OB	D	
20-Jul-05	SBC	Fault log	OB	D	Recalibrated SBCRunning too fast.
21-Jul-05	SBC L2	Out of range result	OB	D	
21-Jul-05	SBC L2	Out of range result	OB	D	
21-Jul-05	SBC L2	Out of range result	OB	D	
21-Jul-05	SBC L3	Out of range result	OB	D	
21-Jul-05	RBC	Out of range result	OB	D	
22-Jul-05	SBC	Fault log	OB	D	SBC overflowed. Recal.
23-Jul-05	SBR	Fault log	OB	E	SBR Compressor tripped out. Some spillage. Lime dosed to SBC & RBC
26-Jul-05	SBC	Fault log	OB	D	SBC bit fast. Recal.
26-Jul-05	SBC L2	Out of range result	OB	D	
26-Jul-05	SBC L2	Out of range result	OB	D	
26-Jul-05	SBC L2	Out of range result	OB	D	
26-Jul-05	SBC L3	Out of range result	OB	D	
26-Jul-05	SBR	Out of range result	MB	M	
26-Jul-05	RBC	Out of range result	MB	M	
26-Jul-05	RBC	Out of range result	OB	D	
27-Jul-05	SBC	Fault log	OB	D	SBC overflowed. Recal.
28-Jul-05	Feed	Fault log	OC	N	All ok. SBR underfed due to channel closure
28-Jul-05	SBC L2	Out of range result	OB	D	
28-Jul-05	SBC L2	Out of range result	OB	D	
28-Jul-05	SBC L2	Out of range result	OB	D	

Date	Unit	Source	Fault	Attribute	Description
28-Jul-05	SBC L3	Out of range result	OB	N	
28-Jul-05	SBC L3	Out of range result	OB	D	
28-Jul-05	SBR	Out of range result	MB	M	
28-Jul-05	RBC	Out of range result	OB	D	
30-Jul-05	Feed	Fault log	OC	N	All ok. SBR feed interrupted by work on screen 3.
02-Aug-05	SBC L2	Out of range result	OB	D	
02-Aug-05	SBC L2	Out of range result	OB	D	
02-Aug-05	SBC L2	Out of range result	OB	D	
02-Aug-05	SBC L3	Out of range result	OB	N	
02-Aug-05	SBC L3	Out of range result	OB	D	
02-Aug-05	SBR	Out of range result	OB	N	
02-Aug-05	RBC	Out of range result	MB	M	
02-Aug-05	RBC	Out of range result	OB	D	
11-Aug-05	SBR	Fault log	OM	N	SBR desludge timer reset to desludge for 1 minute per decant cycle (falling MLSS). Suspect SBR dump valve sticking.
11-Aug-05	SBC L2	Out of range result	OB	D	
11-Aug-05	SBC L2	Out of range result	OB	D	
11-Aug-05	SBC L2	Out of range result	OB	D	
11-Aug-05	SBC L3	Out of range result	OB	D	
11-Aug-05	RBC	Out of range result	OB	D	
16-Aug-05	SBC L2	Out of range result	OB	D	
16-Aug-05	SBC L2	Out of range result	OB	D	
16-Aug-05	SBC L2	Out of range result	OB	D	
16-Aug-05	SBC L3	Out of range result	MB	M	
16-Aug-05	RBC	Out of range result	MB	M	
18-Aug-05	SBC L2	Out of range result	OB	D	
18-Aug-05	SBC L2	Out of range result	OB	D	
18-Aug-05	SBC L2	Out of range result	OB	D	
18-Aug-05	SBC L3	Out of range result	OB	D	
30-Aug-05	SBC L2	Out of range result	OB	D	

Date	Unit	Source	Fault	Attribute	Description
30-Aug-05	SBC L2	Out of range result	OB	D	
30-Aug-05	SBC L2	Out of range result	OB	D	
30-Aug-05	SBC L3	Out of range result	OB	D	
30-Aug-05	RBC	Out of range result	MB	M	
30-Aug-05	RBC	Out of range result	OB	D	
02-Sep-05	SBC L2	Out of range result	OB	D	
02-Sep-05	SBC L2	Out of range result	OB	D	
02-Sep-05	SBC L2	Out of range result	OB	D	
02-Sep-05	SBC L3	Out of range result	OB	D	
02-Sep-05	RBC	Out of range result	OB	D	
06-Sep-05	SBC L2	Out of range result	OB	D	
06-Sep-05	SBC L2	Out of range result	OB	D	
06-Sep-05	SBC L2	Out of range result	OB	D	
06-Sep-05	SBC L3	Out of range result	OB	D	
06-Sep-05	RBC	Out of range result	OB	D	
08-Sep-05	SBC L2	Out of range result	OB	D	
08-Sep-05	SBC L2	Out of range result	OB	D	
08-Sep-05	SBC L2	Out of range result	OB	D	
08-Sep-05	SBC L3	Out of range result	MB	M	
08-Sep-05	SBC L3	Out of range result	OB	D	
08-Sep-05	SBR	Out of range result	MB	M	
08-Sep-05	SBR	Out of range result	OB	N	
08-Sep-05	RBC	Out of range result	MB	M	
08-Sep-05	RBC	Out of range result	OB	D	
13-Sep-05	SBC L2	Out of range result	OB	D	
13-Sep-05	SBC L2	Out of range result	OB	D	
13-Sep-05	SBC L2	Out of range result	OB	D	
13-Sep-05	SBC L3	Out of range result	OB	D	
13-Sep-05	RBC	Out of range result	OB	D	
19-Sep-05	SBC L2	Out of range result	OB	D	

Date	Unit	Source	Fault	Attribute	Description
19-Sep-05	SBC L2	Out of range result	OB	D	
19-Sep-05	SBC L2	Out of range result	OB	D	
19-Sep-05	SBC L3	Out of range result	OB	D	Feed off to mimic holiday. Wetland absorbed full flow without producing
19-Sep-05	RBC	Out of range result	OB	D	
27-Sep-05	SBC L2	Out of range result	OB	D	
27-Sep-05	SBC L2	Out of range result	OB	D	
27-Sep-05	SBC L2	Out of range result	OB	D	
27-Sep-05	RBC	Out of range result	OB	D	

Appendix 4 Guidelines for Designers

A4.1 Introduction.

There are many different factors which result in failure by package plants to meet their discharge standards. Flimsy designs and construction materials lead to leaks and failures (Stoodley, 1989) and improperly specified components can negatively impact on flow dynamics. Poor specification generally results in the inability of otherwise suitable processes to properly treat sewage. The compact design of package plants can make troubleshooting and resolution very difficult and many of the operational problems encountered with sewage package plants are attributed to the effects of extreme fluctuations in diurnal flow patterns.

The use of appropriate design parameters for any package plant system is thus of cardinal importance. Apart from hydraulic characteristics, factors often neglected in package plant specification include:

- the installation of suitable fat traps (particularly at schools, shopping centres etc.) (Laas & Botha, 2004).
- access to proper analytical facilities to monitor performance (Laas & Botha, 2004).
- adequate influent screening, particularly in the light of the propensity of plastic packaging materials used at present (Dakers & Cockburn, 1990).

Package plant manufacturers face a number of challenges. These include small plant dimensions (and concomitant problems in downscaling), high variability in flow and strength of influent sewage, little flow equalization capacity, and a lack of maintenance and operational skills. For these reasons it is imperative that due attention is given to the design of these systems. Reducing the areas or volumes of active biomass to the lowest possible value may appear attractive as a cost cutting measure, but reliability of the final product will often be compromised as a result. No responsible supplier willingly provides sub-standard equipment, but the pressures exerted to minimise prices may provide motivation to reduce margins of safety.

In an effort to collate useful design an operation information into a coherent and accessible format, this appendix was compiled based on many established principles for effective sewage treatment design. Where deemed appropriate commonly used units in design have been converted to units more easily monitored by most wastewater analytical facilities, and inferences drawn from larger scale systems reliant on similar treatment principles that are commonly employed in package plant systems.

A4.2 Available technologies and technology selection

The following technologies are readily available for sewage treatment package plants in South Africa:

- Activated sludge – conventional and sequencing batch reactor
- Rotating bio contactor
- Submerged bio contactor

There may be other technologies available, which the Project Team has not encountered, but these are likely to be variations of the above technologies. It is surprising that no conventional biofilters have been encountered, the reason probably being the need for regular maintenance of the distributor arms, and sunken clarifiers to prevent flooding. For this reason it appears that submerged bio contactors are used which are essentially the same as a biofilter, with the exception that they are flooded and require mechanical aeration.

The Project Team believes that membrane bio-reactors have tremendous potential for use in package plants due to the following:

- Small footprint due to the use of high mixed liquor concentrations
- No need for clarifiers
- No need for disinfection
- Low maintenance requirements

The costs of membrane bio reactor technology are high at present, but the technology is imminently suited for package plant production, having a small footprint, high quality effluent and no need for disinfection.

A4.3. Capacities

Package plant units appear to be generally tailor made to meet the criteria specified by the client on an individual basis. The smallest readily available units are of the '1 household' size, which would not generally be specified for a daily sewage flow up to $1m^3day^{-1}$.

For larger installations, the specification appears to often be scaled up in increments of $1m^3day^{-1}$.

Activated sludge treatment systems tend to be better suited for larger applications, typically in excess of the $2m^3day^{-1}$ limit considered in the planning stages of this investigation. For the smaller sized units, it would appear that activated sludge units would become extremely expensive, although with larger capacity units economies of scale would result in their becoming more economically competitive.

A4.4. Design parameters

A4.4.1 Sewage quality

It is extremely important to ensure that the quality of the sewage inflow is properly evaluated. In many cases where package plants are used for non-domestic wastewater the quality can differ markedly from that of typical domestic sewage.

In the case of office block /supermarket complexes the sewage quality tends to be stronger than normally expected due to lack of low COD flows such as bathing and laundry. Ammonia concentrations may also be high due to the use of "unflushed" urinals in the gent's toilets. Supermarkets and restaurants also tend to have high oils and greases due to the indiscriminate dumping of cooking oil and scrapings down the drains.

Commercial premises may also suffer from toxicity problems from time to time due to the liberal use of disinfectants in drains to combat odour problems.

Typical South African sewage quality is given in Table A4.1 below, adapted from Ekama, 1984.

Table A4.1. Analytical criteria for typical South African sewages

Determinand	Unit	Typical Sewage
COD	$mgO_2.\ell^{-1}$	500-800
SS	$mg.\ell^{-1}$	270-450
TKN	$mg.\ell^{-1}$	35-80
TP	$\mu g.\ell^{-1}$	8-18

If an unusual sewage is suspected then it is important to obtain a sample of sewage from a similar source and evaluate the quality in terms of a minimum of COD, total Kjeldahl nitrogen and total phosphate. The size of the reactor vessels will then need to be adjusted accordingly.

A4.4.2 Sewage flow rates

Any sewage treatment plant operates optimally under a steady flow and load. The smaller the system feeding a plant, the more marked flow spikes and diurnals will be. This is well documented. Where the nature of the flow is uncertain, and suspected to be unusual it is imperative to evaluate the flow regime, either of the facility in question, or a similar one.

Measuring actual sewage flows is a difficult and not particularly pleasant job, and a simpler method is to measure the potable water supply to the facility by means of the water meter supplying the facility. The meter should be read hourly for 24 hours on a typical usage day and the flow per hour calculated. The results can then be evaluated to determine whether the flow variations require flow balancing.

A4.4.3 Flow equalisation tank

Where the flows are highly variable and the unit in question has not been tested on a similar application it is important to install a flow equalization tank. This usually takes the form of a 12 hour retention tank from which the sewage is fed to the plant at a constant rate.

The flow equalization tank is usually fitted after the septic tank. The reason for this is that the septic tank retains most of the debris in the sewage, ensuring that it does not reach the pump that feeds the aerobic treatment section.

A4.4.4 Screening

Screenings are a problem in all sewage treatment plants with major implications in terms of pipe and pump blockages. As the flows diminish and pipe sizes are reduced the problems become more exaggerated. It is thus important to remove as much debris as possible. The international trend is towards the use of fine screens even in large plants as the savings in maintenance costs are significant.

Septic tanks appear to provide an excellent form of screening and degritting, but where these are not fitted it is essential to provide some form of screening to prevent blockages and pump breakages. This is even more crucial where the system is serving a communal building where unusually large amounts of debris are often deposited into the toilet (e.g. rags and plastic packets).

Traditional bar screens such as those found on small conventional sewage works are not particularly suitable in many applications as they require daily cleaning, and may cause odours. In this project the researchers made use of a bucket at the inlet to the storage tank which was manufactured from stainless steel with 5mm perforations. The perforated stainless steel is available as a stock item from steel merchants. The bucket worked extremely well, and tends to be self cleaning for faecal matter as the turbulence of the incoming sewage breaks up any organic solids. Obviously the size of the bucket depends on the flow. The regularity of cleaning the bucket with need to be assessed according to the application, but will obviously be more frequent in communal applications.

One big advantage of the bucket screen is the small perforation size, and the prevention of the screenings being "raked over the top" of the screen by maintenance staff – a fairly common problem.

A4.5 Design Criteria

A4.5.1. Septic tanks

The design parameters for septic tanks preceding package plants are simple and can, for the purposes of this report, be condensed to a minimum of one day's hydraulic retention time.

There are a number of important design details for the tanks, and there are numerous texts which detail these.

It is also advisable to consider building a simple anaerobic baffled reactor which gives enhanced COD reduction for the same space requirement. Obviously this is highly desirable as the lower the COD reaching the aerobic stage the less the load and the better the performance.

A4.5.2. Activated sludge

Activated sludge is an excellent technology for sewage treatment, providing a good quality effluent if properly designed. The chief problems incurred with activated sludge is maintaining the correct sludge age, and preventing carryover from the secondary clarifiers.

Carryover of solids from the clarifier is a big problem in activated sludge and needs to be controlled in two ways. The mixed liquor concentrations must be maintained in the correct range by careful control of sludge wasting, and flow peaks must be eliminated as far as possible. The reason for this is that the solids-liquid separation in the clarifier is a difficult one due to the small difference in density between the two due to the activated sludge floc bacteria comprising mainly water. Thus settling is slow and upflow rates have to be limited.

Activated sludge plants can be preceded by a septic tank, the advantage being that screenings are well removed, and the anaerobic process will remove up to 50% of the COD with minimal solids yield, thus lowering the COD entering the activated sludge plant and reducing the sludge wasting. The septic tank can also be used to attenuate flows.

Simple design parameters for activated sludge are given in Table A4.2.

Table A4.2. Activated sludge design parameters.

Sludge Age (days)	Sludge loading rate (kgCOD applied per day per kg MLSS)*	Recommended sludge density (kg MLSSm^{-3})
30	0.118	5.0
25	0.134	4.4
20	0.154	3.9
15	0.186	3.5
10	0.24	3.3
5	0.389	3.2

*These loadings originate from WISA (1988), but have been converted to COD from BOD assuming BOD = 0.65 x COD

The reactor volume (V_r) can then be calculated as:

$$V_r = \frac{M_L}{X} \quad (m^3)$$

Where: M_t = Total mass of sludge required (kg)
X = Recommended sludge density (kgm^{-3})

The sludge age is usually 15 days or greater in order to ensure it is properly stabilize, and will not cause a fly or odour problem.

The volume of sludge to be wasted on a daily basis is the volume of the reactor divided by the sludge age when wasting from the reactor. When wasting from the return sludge line the volume is calculated as follows:

$$\text{Volume wasted} = \frac{\text{volume of reactor x MLSS}}{\text{sludge age x RSS}}$$

Where: RSS = Concentration of sludge in return sludge

The return sludge flow rate from the clarifier should be the same as the peak inflow rate. Flow equalization will thus decrease the pumping capacity needed.

The oxygen requirement for COD removal and nitrification must be calculated separately. The oxygen requirement for COD removal depends upon the sludge age, and is shown in Table A4.3.

The oxygen requirement for nitrification is simpler to calculate, being 4.5mg O_2 per 1mg ammonia as N nitrified. It is also important to note that nitrification consumes alkalinity as it generates nitric acid. For every 1 mg as N ammonia that is nitrified 7 mg of alkalinity as $CaCO_3$ is consumed. If denitrification takes place half of this is recovered.

Table A4.3. Oxygen requirements to achieve nitrification in activated sludge.

Sludge Age (days)	Sludge loading rate (kgCOD applied per day per kg MLSS)	Dissolved oxygen required for COD oxidation (kg O_2.kg COD^{-1} removed)*
30	0.118	1.092
25	0.134	1.066
20	0.154	1.021
15	0.186	0.949
10	0.24	0.845
5	0.389	0.689

*These oxygen requirements originate from WISA (1988), but have been converted to COD from BOD assuming BOD = 0.65 x COD

It is important to realize that the pH will drop with nitrification, especially in soft waters, and this will inhibit further nitrification. When this occurs slaked lime must be added to compensate. The simplest way of achieving this is to flush a calculated amount of slaked lime down the toilet once or twice a week in the case of small plants. For larger plants slaked lime can be added once or twice a week directly into the reactor. The authors have had good success with this in larger package plants. The addition of slaked lime also produces a more robust floc.

Slaked lime is calcium hydroxide and should be handled with care. Agricultural lime, which is calcium carbonate, cannot be used as it does not readily dissolve.

Aeration equipment is usually specified in terms of kg $O_2\,kWh^{-1}$, which allows one to calculate the power of the aeration equipment. There are however adjustments which need to be made for motor efficiency, alpha factor (related to impurities in sewage such as salts and detergents) and beta factor (related to altitude, temperature and residual dissolved oxygen). Care must also be taken with submerged aeration to consider the path length of the bubbles through the sewage (i.e. the depth of the sewage).

Clarifier design must be carried out with much care, and a conservative attitude should be adopted as carryover of solids is fatal for the quality of the final effluent, giving high suspended solids and COD. Problems will also be experienced in disinfection as the result of increased chlorine demand from the organics and the shielding of bacteria within flocs.

Few package plant clarifiers will have motorized sludge scrapers. In view of this the walls must not be less than 60 degrees to the horizontal for the sludge to fall to the bottom of the clarifier. The walls should also be as smooth as possible, with concrete structures being painted with epoxy type paint. The inlet to the clarifier must be carefully designed to prevent short circuiting of the sludge to the weir. Turbulence should be kept to a minimum. Care should be taken in designing the weir to ensure that it can be properly levelled to prevent short circuiting. Where an annular ring pipe is used always has the holes on the outside of the pipe in order to capture debris on the inside of the ring and thus prevent blocking.

A good rule of thumb for clarifier design is not to exceed 1 $m.h^{-1}$ upflow rate at peak dry weather flow. Solids flux loadings should not exceed 8 $kg.m^{-2}.h$. Should these two parameters be exceeded it is likely that clarification will fail.

Submersible pumps or airlift pumps can be used for the recycling of the return activated sludge.

Whenever possible the plant should be seeded with thickened activated sludge to reduce the initial start-up period during which a poor quality effluent is generated.

A4.5.3 Rotating bio-contactors

These are plants in which the aerobic treatment takes place on disks arranged on a central shaft which rotates in a bath of sewage. The shaft remains above the surface of the sewage, and thus only about 40% of the disk surface is in the sewage at any one time. The disks vary in diameter between 1 and 3.5m and rotate at 1 to 5 rpm.

A biofilm is formed on the disk as it rotates and this contains the organisms required to treat the sewage. As the disk rotates through the sewage it picks up a film of sewage and aerates it as it passes through the air. When the biofilm growths too thick the inner layer dies off due to a lack of nutrients and it "sloughs" off. The biofilm has an aerobic layer on the outside, but this becomes anoxic as one goes deeper into the layer due to a lack of dissolved oxygen.

The disks are usually made of fibreglass or polyethylene. Some contemporary designs comprise a large cylindrical cage filled with packing as found in bio-towers.

With proper design rotating bio-contactor's can remove COD, ammonia and denitrify. Many are not adequately designed and are known for producing odours. They usually have some kind of fibreglass or plastic cover which is prone to damage from veld fires, so it is wise to surround the plant with a few meters of stone chips to prevent it going up in smoke.

The wetted area as a function of influent and effluent COD is shown in Figure A4.11.

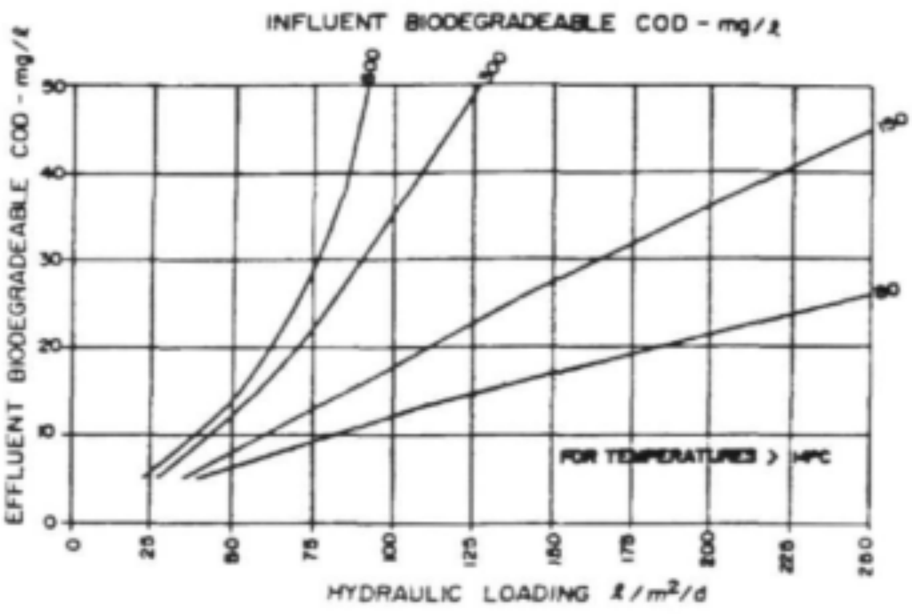

Figure A4.1. COD removal curves

Rotating bio-contactors have been shown to perform significantly better when staged in series If more than 2 stages are used then the wetted surface area can be reduced, as shown in Table A4.4:

Table A4.4. Correction factor for staging

No. of stages	Correction Factor
3	0.95
4	0.90
>4	0.86

When using staging the load on the initial stages can become very high, causing odours. Due to this an organic loading of 100g biodegradable COD.m^{-2}.day^{-1} should not be exceeded.

Nitrification will only take place once the COD of the sewage has been reduced to 25mg.ℓ$^{-1}$. If sufficient alkalinity is present to ensure that the pH does not go lower than 7 then Figure A4.2 can be used for design to remove ammonia.

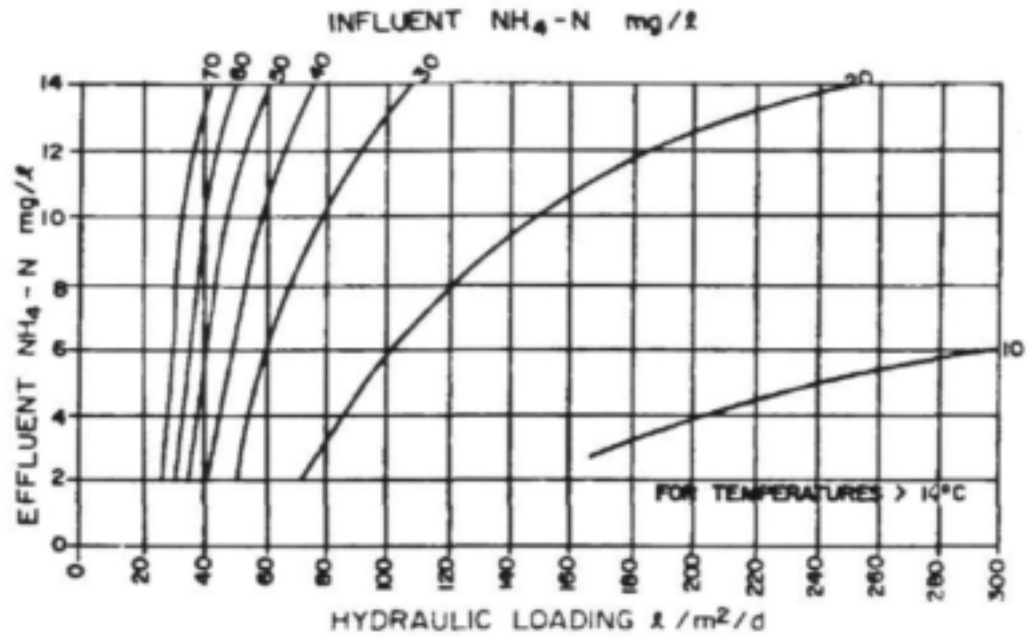

Figure A4.2 Nitrification parameters in rotating bio-contactors.

The above design criteria are for a steady state system i.e. constant flows. In view of the diurnal flow of sewage the following correction factors should be adopted (Table A4.5).

Table A4.5. Correction factor for diurnal

Population	Correction factor
400	1.3
400 – 1500	1.3 – 1.1
1500 – 5000	1.1 – 1.0

The above design parameters work well in the temperature range of 14 – 30 °C. If colder temperatures are experienced then the correction factors provided in Table A4.6 should be adopted.

Table A4.6. Correction factors for low temperature

Temperature (°C)	Correction factor
14	1.00
12	1.05
10	1.15
8	1.30
6	1.40

Rotational speed of the disks is usually between 1 and 5 rpm. Little improvement in treatment has been observed at higher speeds, but the power consumption is somewhat higher.

The settling tank after the bio-contactor is designed using criteria for a humus tank. Where a Dortmund type tank (no mechanical scraper) is used then the design parameters in Table A4.7 should be adopted.

Table A4.7. Dortmund tank design parameters.

Upward velocity at average dry weather flow	<= 1 m.h^{-1}	Use whichever gives the larger surface area
Average velocity at peak dry weather flow	<= 1.5m.h^{-1}	

Table A4.7 data was formulated assuming that any recycle will take place from the bio-contactor trough back to the septic tank, or from the bottom of the clarifier to the septic tank. If the recycle is from after the settling tank then the recycle must be added to the normal flow. Recycling from the settling tank to the septic tank means that drying beds and conventional desludging of the settling tank is not needed as the solids are removed to the septic tank where they are treated anaerobically. Such a recycle is necessary for denitrification.

For a flat-bottomed scraped settling tank the parameters are provided in Table A4.8.

Table A4.8. Flat bottomed scraped settling tank parameters.

Retention period of peak dry weather flow + recirculated flow	<= 1.5 m.h^{-1}	
Upward velocity at average dry weather flow + recirculated flow	<= 1 m.h^{-1}	Use whichever gives the larger surface area
Average velocity at peak dry weather flow + recirculated flow	<= 1.5 m.h^{-1}	

Table A4.8 recommendations are made assuming that any recycle will take place from the bio-contactor trough back to the septic tank, or from the bottom of the clarifier to the septic tank. If the recycle is from after the settling tank then the recycle must be added to the normal flow. Recycling from the settling tank to the septic tank means that drying beds and conventional desludging of the settling tank is not needed as the solids are removed to the septic tank where they are treated anaerobically. Such a recycle is necessary for denitrification.

The recycle needed for denitrification should be in a ratio of 3:1 to the average dry weather flow. Denitrification halves the alkalinity requirement for nitrification which is desirable. Where necessary slaked lime should be added to boost the alkalinity.

A4.5.4 Submerged bio-contactors

Submerged bio-contactors are normally preceded by a septic tank which provides a screening and degritting role, as well as lowering the COD markedly while producing little biomass due to the nature of anaerobic digestion. The final chamber of the septic tank can also be used as an anoxic reactor for nitrification.

Few design criteria are available in the references commonly used by the authors. These include the "Manual on the design of Small Sewage Works" and Metcalf and Eddy (Tchobanoglous & Burton, 1979). This paucity of "recognized" design criteria may be part of the reason for the performance problems currently being experience by this technology.

In view of this it appears that their design should be based on trickling filters as they are essentially the same in operation, with the submerged bio-contactor merely being "flooded" and having forced aeration. Certain trickling filters under high COD load are in fact force aerated, usually from the bottom.

There are advantages of using submerged bio-contactors over trickling filters, especially for small scale plants. These are:

- Distribution of the influent is not a problem as it is in trickling filters
- The media always remains submerged thus eliminating the problem of "drying out" under no flow or low flow conditions
- Forced aeration makes it simple to ensure that sufficient oxygen is supplied

In activated sludge it is well known that for nitrification to occur the dissolved oxygen concentration must be maintained above $2mg.\ell^{-1}$. In submerged bio-contactors this alone does not produce nitrification. The efficiency of nitrification depends on the organic loading. When a biofilm forms and there are both heterotrophs (COD removers) and nitrifiers (ammonia removers), nitrifiers tend to attach themselves onto the heterotroph biofilm. Because the heterotrophs grow much faster at higher COD loading rates the nitrifiers become overgrown and nitrification ceases (EPA Technology Fact Sheet 9, USEPA, 2000a).
This is fairly well documented in the literature, and was confirmed with Ekama (1984). It is also confirmed in the results produced by the package plants of a number of manufacturers using this technology. All examples seen thus far exhibit poor nitrification.

The EPA in their Technical Fact Sheet for trickling filter nitrification (USEPA, 2000b) give a range of organic loadings for plastic media biofilters which will provide 75 to 85% nitrification. These are summarized in Table A4.9.

Table A4.9. Organic loading rates to ensure nitrification

Loading Rate basis	Loading rate requirement
Loading rate based on BOD	192 – 288 $gBOD.m^{-3}.day^{-1}$
Loading rate based on COD	295 – 443 $gCOD.m^{-3}.day^{-1}$

* based on BOD = 0.65 x COD

As nitrification is temperature dependant, the more conservative loading rates should be used to ensure nitrification.

The pH is also extremely important, and should be maintained above 7. pHs of under 6.5 result in nitrification failure. Since nitrification causes the pH to drop it must be carefully monitored. Slaked lime is used to maintain a suitable pH and can be added once or twice a week, either by flushing it down the toilet, or into the septic tank, depending on the size of the plant and thus the amount of lime.

It is advised that the safety factors used in trickling filters for trickling filters be used for submerged bio-contactors.

Where the effluent is to be discharged to a water body a recycle from the outlet of the aeration tank back to the final compartment of the septic tank must be instituted to achieve denitrification. This has the added advantage of recovering half the alkalinity lost in nitrification, and hence halving the addition of slaked lime. The recycle ratio should be 1:1 with the peak dry weather flow.

The solids discharged by these plants are generally low, and may well comply with the General Authorisation. It is prudent though to pass the final effluent through a stone filter or reedbed. The stones in the filter or artificial wetland should be 5-1-mm in diameter. The filter or wetland will require cleaning periodically.

A4.6 Disinfection

Disinfection can be achieved using a number of technologies, including chlorination, ozone and UV radiation. Ozonators tend to be expensive and require dry air to give good yields and reliability, while UV radiation apparatus is also expensive and requires regular maintenance due to the growth of biofilm on the quartz tube which reduces the UV radiated.

Chlorine is the most popular chemical used for disinfection. Chlorination is available in granular or pill form (as used in swimming pools), liquid form as a hypochlorite solution, and gaseous form.

The granular or pill form is simple and safe to use, and is generally placed in a floating canister or device through which the flow passes. The more water passing the granules the more chlorine is released providing a pseudo-proportional dose.

Hypochlorite solution can be added to the final effluent using a dosing pump, but achieving a flow related dose is not easy unless there is some kind of controller. Hypochlorite solution is safe to use, but can be difficult to procure.

Gaseous chlorine is dangerous to use and requires the operator to have special training. Special breathing apparatus is also required. A leak can prove to be a major risk to the surrounding population. Proportional dosing once again requires a controller.

A chlorine dose of $3mg.\ell^{-1}$ is normally sufficient to ensure disinfection of the effluent. A contact time of 30 minutes should be ensured.

It is very important to understand the role of ammonia in the failure of disinfection. When ammonia is present during chlorination it reacts with the chlorine to form chloramines according to the reaction:

$$NH_3 + Cl_2 \rightarrow NH_2Cl + HCl$$

where NH_2Cl is known as a chloramine. Further reactions take place to produce dichloramine and trichloramine.

The chloramines are much weaker disinfectants than straight chlorine and require a much longer contact time. Thus if the ammonia levels are high a large amount of chlorine has to be added to satisfy the chlorine demand from the ammonia before any free chlorine that will disinfect can be achieved.

A4.7 Sludge handling

Sludge management is an important aspect of pilot plant management and should not be neglected. All plants will need de-sludging from time to time. It should be remembered that sludges can cause odour and fly problems if the sludge is not sufficiently stabilised.

In the case of an activated sludge plant the volume to be de-sludged is determined by the sludge age and is in fact the reciprocal of the sludge age multiplied by the total reactor volume if wasting from the full reactor, or the reciprocal of the sludge age multiplied by the volume of the sludge after decanting in the case of the sequencing batch reactor. The latter approach is preferable as the sludge volume to be treated is halved. Sludge can then either be treated directly or further digested to reduced sludge solids further and improve their stability. Sludge management can be by means of drying beds, dewatered in a "Bateman" type bag, or other suitable methods such as composting. The labour required for drying beds can be reduced by lining the drying be with a high shade (80%) shade-cloth before use and then shaking the dry sludge into the centre of the shade-cloth much as one shake a blanket. Drying beds can also be covered with carport like structures when rainfall is high in the area.

Where septic tanks are used to precede a package plant a vacuum tanker is normally contracted to remove the contents of the tank and transport it to a nearby sewage works. The frequency of servicing ranges from once a year to once every three years.

The sludge from the bottom of the submerged bio-contactors can be emptied back into the septic tank for further treatment.

All package plants should be sold with details of the sludge management plan in their instruction manuals.

Appendix 5 User Guidelines for Technology Selection, Operation and Maintenance

A5.1 Technology selection

Factors affecting technology selection are:

- Receiving environment
- Complexity of flow and load variations
- Affordability
- Size availability
- Reliability
- Ease of operation and maintenance

These factors are best examined individually.

Receiving environment

Plants installed in any of the listed areas indicated in the General Authorisation should ideally be specially designed to ensure compliance with the Special Standard. The manufacturer should be asked for references on his plants ability to operate under this standard, and to specify what additional processes have been included to cater for the Special Standard. There are specialists who design plants specifically to meet the Special Standard, and it is probably worth asking them to conduct a design review on proposed plants to ensure adequate design.

In areas where the plant should not be obtrusive such as game parks the rotating biofilter has an advantage in that it is built into the ground, while the other two technologies are generally situated above ground. Care should be taken in the disposal of effluent to ensure that there is not an unintended change in the natural environment as a result of the extra water.

All three technologies were found to be quiet in their operation.

Complexity of flow and load variations

The sequencing batch reactor has an advantage of not requiring flow equalization to cope with diurnals as this is inherent in their design. Other technologies will require adequate design for higher than average diurnals in terms of both flow and load. It would be wise to include a 12hour capacity equalization tank in the design, feeding the aerobic plant via a pump of suitable capacity to achieve a more even flow. Load variations may be partly mitigated by a septic tank preceding the aerobic plant.

Affordability

Affordability is a major issue especially for the individual homeowner where money is limited. The use of concrete and steel obviously adds markedly to costs, and thus the submerged bio-contactor technology is probably the most affordable. It is also the only technology available for single house installations.

For larger installations cost is probably not as much of an issue. The main issue here will be reliability and ease of operation and maintenance. Property developers must also ensure that the influent volumes are based on similar developments elsewhere in order to ensure that figures for the correct socio-economic group are used.

Size availability

The different technologies come in different sizes and thus one has to choose a technology available for the size required. The size ranges are given below for the three manufacturers of the technologies used in this assessment.

Sequencing batch reactor	5 – 2000m3/d*
Rotating bi-contactor	1 – 650m3/d
Submerged bio-contactor	<=2-500 m3/d

*2000m3/d plants can be added in parallel as needed in case of rapid development.

Reliability

Reliability is of utmost concern when buying a package plant. How does one know if a plant is reliable? The answer to this question is not simple! The authors recommend the following:

- Ask for a list of installations with contact numbers and contact a sample of the clients and ask them for their opinions.
- Discuss the matter with other property owners in the area who are in a similar situation.
- Check the number of moving parts, and their quality and robustness.
- With rotating bio-contactors ensure that as strong a shaft as possible is fitted to prevent breakage. Also check that the bearings supporting the rotating shaft are able to swivel in their housing to give more flexibility. Finally ensure that a suitably sized gearbox is used to prevent early failure.
- Ascertain the availability of parts if the manufacturer were to close down. If parts are readily available from alternate outlets this ensures that their cost will remain reasonable, and reduces dependence on the supplier, possibly resulting in quicker repairs.

Ease of Operation and Maintenance

A package plant should be easy to operate and maintain. In order to ensure this:

- Ask for a copy of the operation and maintenance manual. Is it easily understood and comprehensive?
- Review the operation and maintenance requirements of the plant. Can they be achieved with the resources available? Is there a training course which can be attended?
- Are all the serviceable parts easily accessible and replaceable?

- Are parts readily available from sources other than the supplier?
- Is a maintenance contract available?
- What is the period of the guarantee, and what are its terms?

A5.2 Operations and Maintenance

The operation and maintenance required for a sewage treatment package plant depends largely upon the technology used and thus the three technologies will be discussed individually. It is important to point out that most operational issues can be picked up simply by observing the final effluent. By visually checking the plant and carefully listening most mechanical faults can be picked up before failure, and full failure can be prevented by rapid attention, saving on cost and minimizing downtime.

SBR - Activated Sludge

The SBR is operated by a PLC and thus there are no operational requirements on a regular basis apart from checking the hypochlorite used for disinfection. If a large tank is used for hypochlorite in place of a 25 litre drum then this will have to be checking on a far less regular basis. There is also little maintenance required on an ongoing basis. Most of these units are likely to be installed at a large complex and a staff member should be trained to do maintenance work and fill in a maintenance schedule. The following maintenance should be conducted according to the schedule:

Daily

- Inspect plant final effluent to ensure it is clear (i.e. no power failure, motor failure, or blockage).
- Listen for any unusual noises (aerator motor or gearbox problems, compressor problem).
- Check hypochlorite level
- Look for any surcharging (blockages)

Weekly

- Ensure that area surrounding package plant is mown to prevent veld fire damage.

Annually

- Get supplier to replace gearbox oil and check aerator for wear.
- Supplier to ensure PLC and electrical board are clean and in a good state
- Supplier to check compressed air system and air operated valves

RBC

There is little maintenance to perform on the RBC. Most RBCs will be fitted at fair sized institutions and a staff member should be trained to perform the little maintenance properly. A suggested maintenance schedule is provided below.

Daily

- Check that final effluent is clear
- Listen for gearbox or motor problems
- Check disinfectant
- Inspect for surcharging

Quarterly

- Grease bearings
- Check gearbox oil levels

Annually

- Supplier to check bearings and gearbox for wear
- Supplier to ensure electrical board is clean and in a good state

After power failure

- Clean discs with high pressure cleaner to remove unbalanced biomass which grows on immersed portion of disk (this unbalanced biomass results in mechanical stress and failure)

SBC

There is little maintenance to perform on the SBC. SBC's are fitted at both domestic residences and larger institutions. When installed at a domestic residence the homeowner will have to conduct the maintenance while at larger institutions staff member should be trained to perform the little maintenance properly. A suggested maintenance schedule is provided below.

Daily (for a domestic home this will probably become weekly)

- Check that final effluent is clear (identifies breakdown in pumps)
- Check that airpump(s) are running
- Check disinfectant
- Inspect for surcharging

Annually

- Supplier to check airpumps and submersible pumps for wear
- Supplier to ensure electrical board is clean and in a good state

De-sludging

The RBC wastes sludge every day to maintain a specified sludge age. This sludge is run to drying beds which must be cleared on a regular basis. The RBC and SBC require desludging when the septic tanks become full.

Alarms

Units should ideally be fitted with alarms to indicate malfunction. Alarms should be easily obtainable for a power failure problem and this will also serve as an alarm for the submersible pump if installed on the same circuit, assuming that the circuit breaker will trip if the pump burns out.

A high level alarm in the septic tank can also be fitted to indicate supply pump failure. Where the system flows purely by gravity a stone filter at the end can be fitted to indicate solids carryover or dirty filter.

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Fax Number: 012 331 2565
E-mail: publications@wrc.org.za

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Water Research Commission
Private Bag X03, Gezina, 0031, South Africa
Tel: +27 12 330 0340, Fax: +27 12 331 2565
Web: http://www.wrc.org.za

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