Sewage purification in South Africa – Quo Vadis?[+]

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Abstract

Projected future demographic changes in South Africa, particularly accelerated urbanisation, will result in rapidly increasing pollution loads on the water environment, should appropriate action not be taken. To combat this threat, a strategy comprising three approaches, namely high technology, low technology and resource utilisation, is proposed. The essential role of research and development in the practical realisation of this strategy is stressed.

The status quo

Murray (1987) and Osborn (1987) have described the history of sewage purification in South Africa, covering the period from the turn of the century to the mid-1980s. This period has witnessed extensive developments and changes in both the scope and manner in which human wastes have been treated and disposed.

What is the current situation in South Africa? Analysis of a preliminary survey of sewage works by the Department of Water Affairs (1984) indicates that in 1982 there were about five hundred sewage works in South Africa, with approximately half of this number having a purification capacity greater than 1 Mℓ/d (Table 1). In broad terms, three process types are in use, viz. oxidation ponds (predominantly for works with a capacity of less than 1 Mℓ/d), biological filtration and a variety of activated sludge processes (e.g. oxidation ditches, extended aeration and nutrient removal activated sludge processes).

Based on an assumed South African average raw sewage composition (Water Research Commission, 1982) of a COD of 650 mg/ℓ (as O), total phosphate of 13 mg/ℓ (as P) and total nitrogen of 58 mg/ℓ (as N), this represents a COD load of about 2 700 t, a total phosphate load of about 55 t (as P) and a total nitrogen load of about 250 t (as N) which these works have to treat daily. Assuming a hypothetical situation where all oxidation pond effluent is irrigated (or evaporated) and that the biofilter and activated sludge process effluents have an average quality of: COD of 65 mg/ℓ (as O), total phosphate of 6 mg/ℓ (as P) and total nitrogen of 30 mg/ℓ (as N), this would necessitate the removal of about 2 500 t of COD (as O), 30 t of phosphate (as P) and 125 t of nitrogen (as N), daily. Although this represents excellent COD removal (90%), and significant phosphate (54%) and nitrogen (48%) removal, it still means that the water environment is receiving a pollution load of about 270 t COD, 25 t phosphate (as P) and 125 t nitrogen daily (Table 2).

Discharge of purified sewage effluent to the water environment is controlled by regulations and effluent standards promulgated in terms of the Water Act of 1956 (Government Gazettes of 1956, 1962 and 1984). Broadly speaking, the *General Standard for Industrial Wastewaters and Effluents* (Government Gazette, 1962) applies (Table 3), requiring treatment to what at that time was considered technically and economically feasible. Up to the early 1970s this legislation was adequate and, in general, the water environment was in an acceptable state. However, in the late seventies and now in the eighties these standards have proved inadequate and they have had to be more restrictive as far as salts, nutrients and toxic metals are concerned (Table 3).

Considering the fact that South Africa's conventional water resources are severely limited, with demand expected to exceed

TABLE 1
CLASSIFICATION OF SEWAGE WORKS IN SOUTH AFRICA ACCORDING TO DESIGN CAPACITY (DERIVED FROM DATA OBTAINED FROM DEPARTMENT OF WATER AFFAIRS, 1984)

Province or organisation or sector	Less than 1 Mℓ/d	>1 up to 5 Mℓ/d	>5 up to 20 Mℓ/d	>20 up to 100 Mℓ/d	>100 Mℓ/d	TOTAL
Transvaal	19	25	27	17	7	95
Cape	55	41	18	7	3	124
Orange Free State	33	15	4	1	0	53
Natal	23	12	6	5	2	48
Mines	68	34	6	4	0	112
Dept. Com. Dev. [+]	57	2	0	0	0	59
AC; DC; TCPUA*	12	3	6	0	0	21
GRAND TOTAL	267	132	67	34	12	512
Percentage of total	52,2	25,8	13,1	6,6	2,3	100

* AC — Administration Councils; DC — Divisional Councils; TCPUA — Transvaal Council for Peri-urban Areas
[+] Department of Community Development

TABLE 2
ESTIMATED POLLUTANT CONCENTRATION AND LOADS FOR 1982 ON SOUTH AFRICAN SEWAGE WORKS AND WATER ENVIRONMENT[+]

Pollutant	Conc. in raw sewage	Load from raw sewage	Conc. in effluent	Load removed at works	Load on water environment
	(mg/ℓ)	(t/d)	(mg/ℓ)	(t/d)	(t/d)
COD	650	2 711	65	2 439	271
Total P	13	54	6	29	25
Total N	58	242	30	117	125

[+] Assuming a total raw sewage flow of about 4 700 Mℓ/d

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TABLE 3
GENERAL STANDARD FOR INDUSTRIAL WASTE WATERS AND EFFLUENTS AS SPECIFIED IN GOVERNMENT GAZETTES OF 5 APRIL 1962 AND 18 MAY 1984, RESPECTIVELY

Parameter	1962-Limits	1984-Limits
pH	5,5 - 9,5	5,5 - 9,5
Faecal coliforms (count/100mℓ)	Zero	Zero
COD (mg/ℓ)	<75	<75
Total dissolved solids (mg/ℓ)	increase <500	-
Conductivity (mS/m)	-	increase <75
Suspended solids (mg/ℓ)	<25	<25
Sodium (mg/ℓ as Na)	increase <50	increase <90
Free and saline ammonia (as N)	<10,0	<10,0
Sum of cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg) and lead (Pb)	-	<1,0
Dissolved orthophosphate (as P) (for selected sensitive areas)	-	<1,0

supply by about the year 2020 (Bekker and Roberts, 1981), as well as a rapidly growing population, the residual pollution load associated with purified sewage effluents will keep increasing up to a point where the water environment will no longer be able to assimilate it adequately. At that stage a collapse of the natural purifying capacity of these systems will occur with resultant serious deterioration in water quality and associated costly consequences for the users of this water. Obviously, long before this situation materialises, appropriate steps need to be taken to protect the water environment and water quality in general. A corner stone of a strategy to assure the implementation of preventative and ameliorative measures is proper and timely planning. This will entail the correct anticipation of sewage purification needs, research, development and implementation of appropriate technologies, provision of adequate funds for the design, construction and operation of suitable sewage purification works, and the availability of a properly educated and informed core of responsible sewage works personnel.

Demographic changes

Schoeman (1985) states that an important factor affecting development in South Africa today and the one expected to play a dominating role in the future, is the population growth of the country. South Africa already finds itself in a demographic crisis and, should population growth control programmes fail to attain success within the next two decades, the already apparent poverty cycle will intensify and will impoverish an ever increasing portion of the South African population.

The South African population is currently growing at an average rate of 2,3 per cent per annum (Fig. 1) and should this growth rate continue the population (including the self-governing National States) will increase from 28 million to about 47 million by the year 2000; to about 80 million by the year 2020; and to 138 million by the year 2040 (Schoeman, 1985). It is obvious that this high growth rate is going to place severe demands on South Africa's natural resources, particularly water.

It is essential that a healthy balance be maintained between population size and the country's natural resources available for sustaining such a population. An optimum population size is determined primarily by two factors. Firstly, by the rate at which supporting systems (education, health services, employment and housing) can grow; and, secondly, that the population stops growing at a level commensurate with the capabilities of that country. Based on these factors the Science Committee of the President's Council has estimated that an optimum population for South Africa would be 80 million inhabitants, with the limiting resource being water (Marais, 1984).

Should South Africa want to stabilise its population at 80 million, the current growth rate will have to be dramatically reduced. The South African Government decided to launch a National Population Development programme as a result of the recommendations of the Science Committee of the President's Council (1983). The main objective of this programme, which was launched in March 1984, is to improve the quality of life of all South Africans, by *inter alia* stabilising the size of the total population at 80 million by the end of the next century. It hopes to achieve this objective by a variety of strategies, e.g. socio-economic development, social development, family planning information, education and communication. A number of specific programme aims have been set to achieve the aforementioned objective. The aims related to sanitation for communal use are that a sufficient number of latrines must be available, viz. one pit latrine per 12 persons and one bucket system per 10 persons. Furthermore:

- for pit latrines the contents must not be accessible to flies;
- for bucket systems the contents must be buried; and
- flush latrines must be connected to approved sewerage systems.

Progress with the overall programme aims will be monitored and reported annually. Schoeman (1985) is of the opinion that the

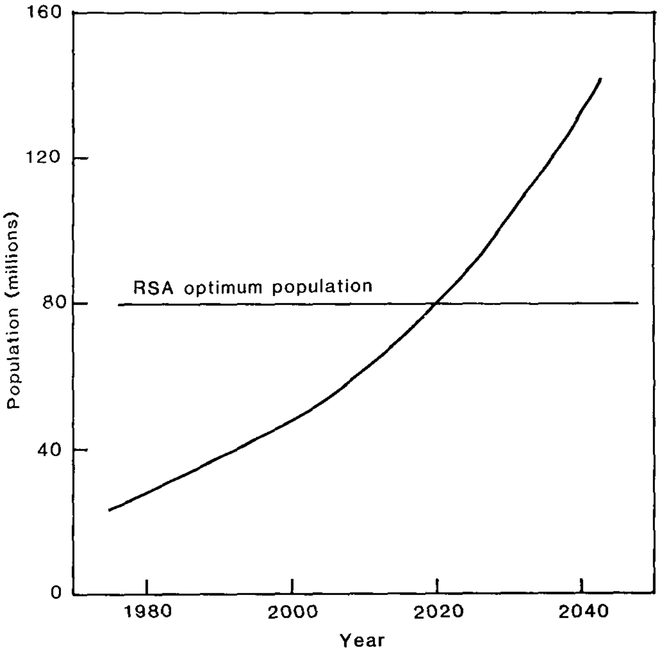

Figure 1
Projected population growth in South Africa, including self-governing states (after Schoeman, 1985).

programme should succeed in striking a balance between population growth and essential national resources in South Africa within about 25 years. However, this will require a national effort which has to transcend political differences in an honest and real desire to resolve the population growth problem.

Urbanisation and its impact on the water environment

Wilsenach (1986) points out that during 1980, only 38% of the Black population of South Africa was urbanised whereas Whites and Coloureds were already 90% urbanised at that stage. He further reports that the 1,5 to 2,0 million squatters surrounding cities and towns in South Africa are the result of an imbalance between supply and demand for housing, services and amenities, as well as a negative approach by the authorities to urbanisation. Based on this background the Committee for Constitutional Affairs of the President's Council (1985) recommended the appropriate accommodation and urbanisation of Blacks in South Africa. The Government accepted the recommendations of the President's Council regarding the pass book laws and Black property rights in mid-1986, so the rate of Black urbanisation can, therefore, be expected to increase, placing greater demands on urban development for *inter alia* sewerage and waste disposal services.

Mostert *et al.* (1985) have made population projections for the urbanisation of Blacks in South Africa taking into consideration the effect of the scrapping of influx control (Table 4). Using these urban Black population figures as well as those for urban Whites, Coloureds and Asians, projections for the increased loads of COD, total N and total P from human wastes in cities/towns as well as the resultant pollutant load on the water environment downstream of these cities/towns, if current effluent standards are maintained, are given in Table 5 and in Fig. 2.

What will the impact of these increased pollutant loads on the water environment be? High nutrient loads are already being experienced by a number of river systems in South Africa. Grobler and Silberbauer (1984) have made an assessment of the impact of phosphate on the water environment, making projections up to the year 2000, in which they considered 19 selected impoundments. One of the scenarios they investigated was the projected impact of the introduction of an effluent phosphate standard (<1 mg/ℓ dissolved orthophosphate as P) for catchments of individual impoundments. The criterion they used was that "severe nuisance conditions", defined as chlorophyll concentrations (a parameter indicating algal contents) exceeding 30 μg/ℓ, should occur for at least 20% of the year. They predicted that five of the impoundments studied would not require the phosphate standard to be introduced in their catchments, that five may require the standard and that for nine the introduction of the standard is imperative, with two of the latter requiring a phosphate standard stricter than 1 mg/ℓ.

The impact of an increasing phosphate load with time (from 1981 to the year 2000) for South Africa's most highly eutrophied (i.e. polluted with plant nutrients) impoundment, Hartbeespoort Dam, reflected in the mean chlorophyll concentration, maximum chlorophyll concentration and percentage of year with "severe nuisance conditions", is shown in Table 6. Tables 7 and 8, and Fig. 3 show the predicted impact, should effluent phosphate standards of 1,0 and 0,5 mg/ℓ respectively, be introduced. (The predictions relating chlorophyll concentrations for [Chl]>50μg/ℓ to phosphate loads may not be valid since the growth of algae at such high chlorophyll concentrations is probably limited by light rather than by phosphate).

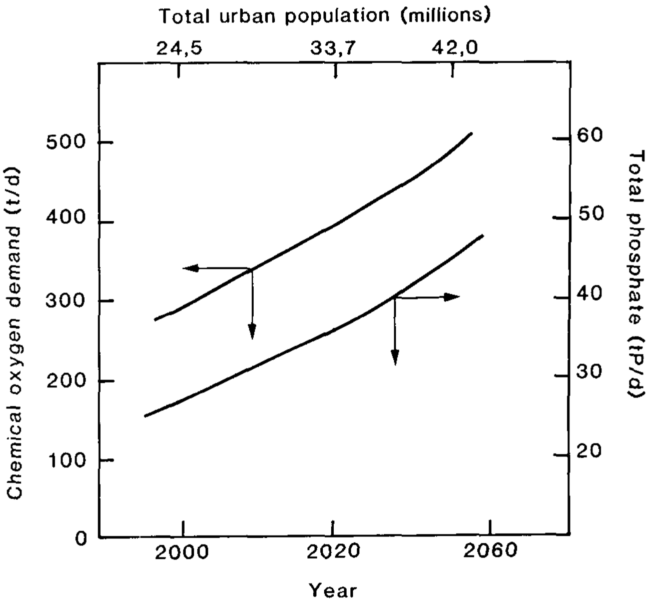

Figure 2

Projected pollutant loads on water environment for the period 2000 to 2050, based on effluent characteristics: COD — 65 mg O/ℓ; total P — 6 mg P/ℓ; total N — 30 mg N/ℓ.

TABLE 4
PREDICTION FOR URBANISATION OF THE BLACK POPULATION OF SOUTH AFRICA (AFTER MOSTERT *et al.*, 1985)

Description	1980	1990	2000	2010	2020	2030
Total black population (in millions)	20,8	27,0	34,9	44,2	53,8	63,8
Urban black population (in millions)						
Black states	1,5	1,3	2,7	3,4	4,8	6,7
Rest of country	6,6	13,7	18,8	25,0	31,1	36,5
TOTAL	8,1	15,0	21,5	28,4	35,9	43,1
Urbanisation level	39%	56%	62%	64%	67%	68%

TABLE 5
ESTIMATED POLLUTANT LOADS ON SOUTH AFRICAN (INCLUDING INDEPENDENT STATES) SEWAGE WORKS AND WATER ENVIRONMENT$^+$

Year	2000	2020	2050
Total urban population	24,5	33,7	42,0
Pollutant load on sewage works (t/d)			
COD	2 867	3 943	4 914
TKN	254	352	439
Total P	57	79	98
Pollutant load on water environment (t/d)			
COD	287	394	491
TKN	132	182	227
Total P	27	36	45

$^+$ Estimates based on urban population projections of Marais (1984) and sewage composition given in Table 2, as well as on an average per capita sewage production of 180 ℓ/d.

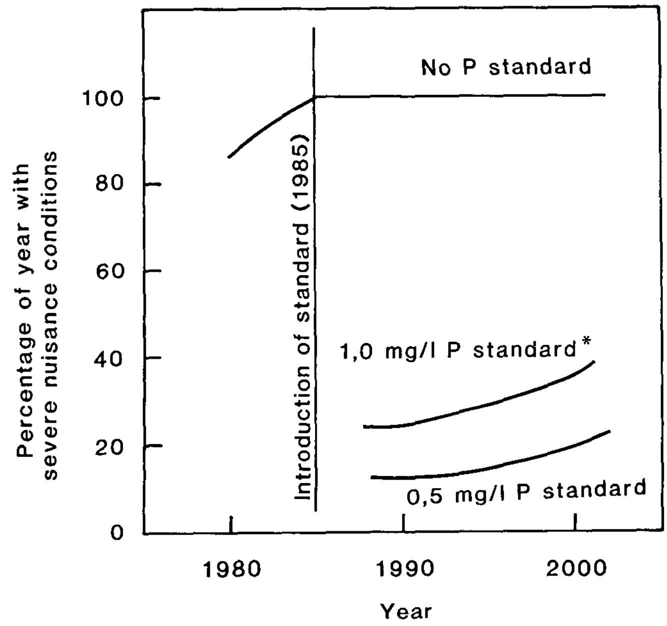

Figure 3
Impact of phosphate standard on trophic status of Hartbeespoort Dam (After Grobler and Silberbauer, 1984)
**Soluble orthophosphate expressed as mg P/ℓ*

TABLE 6
PROJECTION OF THE FUTURE TROPHIC STATUS OF HARTBEESPOORT DAM (AFTER GROBLER AND SILBERBAUER, 1984)

	1981	1985	1990	1995	2000
Total phosphorus load (t/a)	539	654	832	1 060	1 351
Mean [chlorophyll] (mg/m³)	80	92	109	129	151
Max. [chlorophyll] (mg/m³)	137	157	186	219	257
Percentage of year with severe nuisance conditions	90	100	100	100	100

TABLE 7
PROJECTION OF THE FUTURE TROPHIC STATUS OF HARTBEESPOORT DAM WITH THE INTRODUCTION OF A [SOLUBLE O-P] LIMIT = 1,0 mg/ℓ AFTER 1985 (AFTER GROBLER AND SILBERBAUER, 1984)

	1981	1985	1990	1995	2000
Total phosphorus load (t/a)	539	654	130	164	208
Mean [chlorophyll] (mg/m³)	80	92	25	30	34
Max. [chlorophyll] (mg/m³)	137	157	43	50	58
Percentage of year with severe nuisance conditions	90	100	24	29	35

TABLE 8
PROJECTION OF THE FUTURE TROPHIC STATUS OF HARTBEESPOORT DAM WITH THE INTRODUCTION OF A [SOLUBLE O-P] LIMIT = 0,5 mg/ℓ AFTER 1985 (AFTER GROBLER AND SILBERBAUER, 1984)

	1981	1985	1990	1995	2000
Total phosphorus load (t/a)	539	654	69	86	107
Mean [chlorophyll] (mg/m³)	80	92	15	18	20
Max. [chlorophyll] (mg/m³)	137	157	26	30	35
Percentage of year with severe nuisance conditions	90	100	12	15	19

From the figures reported by Grobler and Silberbauer (1984) it is clear that it has already become necessary to control the phosphate load on the water environment. It is further evident that with the expected growth in the population (Tables 4 and 5) it will be essential to further limit phosphate discharge to the water environment. Sooner or later the same will also hold for other pollutants, such as settled solids, COD, nitrogen, salts and heavy metals.

Economic situation

The Actuarial Society of South Africa (1986) published the findings of a study on the *Realities of Social Security in South Africa*. The preliminary findings of this study put South African demographic trends and the urbanisation strategy in perspective, as well as giving an indication of the economic realities which will have to be taken into account in planning a future strategy for sewage purification and water pollution control for South Africa.

The report indicates that during 1986 South African household earnings figures were as follows:

- 11 per cent of households received more than R1 400 per month;
- 56 per cent of households received less than R400 per month; and
- 40 per cent of households received less than R280 per month, the minimum subsistance level.

From these figures it is clear that the available and potential resources of South Africa will be insufficient to provide benefits to the total population on anything approaching a first world standard. Another key reality is South Africa's large third world population with a high population growth (Table 4). The Actuarial Society Report also points out the very large (and currently growing) number of under and unemployed people. The report concludes that bold rural and urban development schemes, crash practical educational programmes and a big birth control drive are required to ameliorate the problems set out above. The crucial question then becomes: can South Africa afford these? More particularly, what are the implications for sewage purification programmes?

What are the costs associated with the treatment and disposal of human wastes? They are *inter alia* a function of the type of system used (Tables 9 and 10). They can vary from a single capital outlay of about R30 per family for a ventilated improved pit (VIP) latrine, to a maximum capital outlay of about R2 800 per family plus R9,00 per family per month for sewage works running costs (1987). Comparing these figures with the above-listed monthly household earnings it is obvious that the majority of the population cannot afford water-borne sewage with the associated high degree of purification. Consequently, either a low cost sanitation option has to be adopted taking these economic realities into account, or, where water quality or other practical considerations require water-borne sewage and a high degree of purification, the associated costs will have to be subsidised.

Sewage purification strategy for the future

In the light of the aforementioned demographic trends and current economic situation in South Africa, it appears that planners of a future strategy for sewage purification are faced with a dilem-

TABLE 9
APPROXIMATE CAPITAL COSTS FOR THE TREATMENT AND DISPOSAL OF HUMAN WASTES BY VARIOUS MEANS (PYBUS, 1987)+

	System type	Cost
*	Lowest cost option: Ventilated improved pit (VIP) latrine built under self-help scheme (materials only)	R30 – R250/family*
*	Intermediate option: Latrine and septic tank built under self-help scheme (superstructure, latrine, septic tank, pipes, reticulation, ponds and outfall)	≃ R1 700/family
*	High cost option: Full water-borne sewage (toilet and superstructure, sewers and treatment works)	≅ R2 800/family

\+ These cost estimates are only given as an indication of the relative costs for different treatment and disposal systems.
* A family comprises 6 to 10 persons.

TABLE 10
TYPICAL CAPITAL AND RUNNING COSTS FOR SEWAGE PURIFICATION (BARNARD, 1987)

System	Cost
Oxidation ponds:	
– Capital costs	R15 – R25 per capita
– Total costs	1,0 – 3,0 c/m^3
Bardenpho:	
– Capital costs	R45 – R90 per capita
– Total costs	20 – 30 c/m^3

ma. On the one hand, a large section of the population cannot afford water-borne sewage and the associated sophisticated sewage purification systems. On the other hand, cheaper and less sophisticated human waste treatment and disposal systems may result in the pollution of the country's very limited water resources, with the resultant unacceptable degradation of the water environment and with rapidly increasing costs for the production of drinking water from polluted raw water. A possible solution to this dilemma is to use a holistic approach, which carefully balances the degree of pollution which can be allowed against the implications for the water environment and water quality degradation in general. In such an approach *receiving water standards*, i.e. standards based on the quality constraints of the water body *receiving* the polluted effluent, rather than effluent standards *per sê*, will play an increasingly important role (Van der Merwe, 1986).

Increasing pollutant loads (Table 5) and dwindling water resources (Bekker and Roberts, 1981) will in general result in the need for current sewage purification technologies to be improved. Not only will the traditional removal of readily biodegradable carbonaceous, phosphorous and nitrogenous material have to be improved, but also the removal of the less biodegradable fraction of these compounds will have to receive attention. Because of increased indirect (and direct) reuse of purified sewage effluents, the removal of salt (sodium, potassium, calcium and magnesium chlorides and sulphates) will have to be considered. Furthermore, because of increasing industrial activities in the areas reticulated by domestic sewers, process technology for the removal of industrial pollutants (e.g. heavy metals, pesticides and refractory organic materials) will have to be applied and refined. In developing technologies to meet these needs, due cognisance needs to be taken of process costs, energy and maintenance requirements, as well as associated requirements for operator education and practical training.

A three-pronged strategy for the development of future sewage purification technology is proposed.

- ***A high technology approach*** – probably appropriate for large towns and cities upstream of major impoundments as well as coastal cities which can reuse purified sewage effluents. High technology processes which remove pollutants from sewage to levels lower than before and which are more energy-efficient, reliable and cost-effective than the processes currently in use, are recommended. Examples of processes which could be considered are: modified activated sludge processes (e.g. Bardenpho, UCT and Phostrip), membrane processes (e.g. crossflow microfiltration and tubular reverse osmosis) and water reclamation processes (Stander and LFB). The quality of the effluents produced by these advanced processes may be so high that they can be used directly in agriculture and industry, as well as for potable purposes.

- ***A low technology approach*** – probably appropriate for rural communities and smaller towns. Low technology processes which remove the bulk of the pollutants from sewage at a cost affordable to the community under consideration, but only to such a level not to present a health risk or serious environmental problems. Examples of systems or processes which could be considered are: ventilated improved pit (VIP) latrines, pond systems (anaerobic and oxidation ponds) and reed bed systems (Kreffeld and modified root zone).

- ***Resource utilisation approach*** – probably appropriate to both urban and rural communities. In dealing with the problem of sewage sludge and brines or concentrated side-stream treatment and disposal, utilisation rather than wasteful disposal should be considered. Examples are composting of sludge or the selective enrichment of sludge with phosphate and nitrogen (by the Bardenpho and UCT processes) for use as fertiliser. Possibly the ultimate approach would be the utilisation of sewage nutrients to produce useful proteinaceous matter (algae, zooplankton or fish). To date this approach has not been successful in producing cheap protein, but with the steadily rising cost of proteins it may be viable in the long term.

Concluding remarks

The sewage purification industry faces major challenges in the short, medium and long term. Already the effluent standards promulgated in 1962 are inadequate and more stringent standards had to be introduced in 1980 and 1984, placing greater restrictions on effluent phosphate, salts and heavy metals. Future demographic changes and economic limitations in South Africa will result in a rapidly increasing pollution load on the water environment if appropriate action is not taken. In the medium and long term stricter effluent standards for total nitrogen, salts, heavy metals and other toxicants and refractory organic materials may be necessary for certain sensitive river catchments.

In developing a strategy for the development of sewage purification technology, due cognisance needs to be taken of the financial and human resources of the communities to be served. A strategy comprising a three-pronged approach is proposed, i.e.

- a high technology approach applied predominantly for large towns and cities;
- a low technology approach applied predominantly for rural areas and small towns; and
- a resource utilisation approach for sewage sludge, brines and concentrated side-streams.

To realise this strategy, research and development on new and existing unit processes and systems are essential. Considerable progress has already been made in South Africa and elsewhere in the world with the development and refinement of innovative processes and systems set out above. Furthermore, future research and development needs are being addressed, *inter alia* by the Coordinating Research and Development Committees of the Water Research Commission. Hopefully, the implementation of a strategy as outlined above will ensure clean, healthy and wholesome water for future generations of South Africans.

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