Controlling the Access of Nutrients from Point and Diffused Sources with Special Reference to the Pretoria/ Witwatersrand/Vereeniging Region*

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Abstract

The present contribution of phosphorus compounds of effluent origin to rivers and impoundments in the industrialised Pretoria/Witwatersrand/Vereeniging region is estimated on the basis of the size of the contributing population. Demographic projections are then used to estimate the mass of phosphorus per year which, in the absence of control measures, could be discharged from all point sources in the Republic by the year 2000. The costs of alternative wastewater treatment technologies are then compared, and it is shown that the use of biological phosphorus removal plants in combination with physical-chemical processes is capable of producing a potable water at a cost competitive with that of developing new supplies. It is concluded that the dual objectives of eutrophication-control and augmentation of water supplies could be jointly resolved by the adoption of large-scale reclamation of wastewater. Two problems are identified as priority research areas, namely the serious lack of data on the magnitude of diffused sources of phosphorus and other nutrients; and the high cost of phosphorus removal from existing installations of nitrifying biological filters.

Introduction

In the Republic most water supplies depend on long-term storage in shallow impoundments under conditions of high solar energy input and marked seasonal stratification. Many impoundments are also subject to high nutrient loading, and combined with the abovementioned conditions this leads to eutrophication which is a serious and complex water management problem.

The precise etiology, diagnosis and treatment of eutrophication are still problematical. However, one can say with some assurance that its control will require measures over a wide front – i.e. socio-economic and land-use policies, direct treatment of affected waters, and above all, preventative approaches. These latter involve primarily the control of phosphorus, and then of nitrogen compounds and minerals in the water environment. (Toerien, et al 1975).

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Eutrophication as a Function of Urbanisation

The present position

Whether one considers point sources or dispersed sources of phosphorus, the input to most critical catchments in the interior is directly related to urbanisation. The central Witwatersrand region, for example, including the Vereeniging/Vanderbijlpark area, has a population of 2,2 million. Of the known sources of phosphorus, only those in raw wastewater can be quantified reasonably accurately (it is ca 60 t per 100 000 persons a year, as P at Johannesburg). Further, wastewater appears to dominate the nutrient, though not the mineralisation, scene in the region. Estimates of the total annual contributions of phosphorus to the water environment in the region are given in Table 1.

TABLE 1

ESTIMATED INPUTS OF PHOSPHORUS TO THE WATER ENVIRONMENT IN THE WITWATERSRAND REGION

Source		Load
*Wastewater**		
of human and industrial origin	800 t	
from synthetic detergents	530 t	
Total		1 330–1 330 t
*Urban Run-off***		50– 150 t
		1 380–1 480 t

*Based on (i) contribution of 60 t per 100 000 persons a year; (ii) detergent P contribution estimated as 40% of total wastewater contribution.

**This is only a rough estimate because there is a serious lack of information on urban topographical pollution in the Republic. However, it is known that it fluctuates widely from year to year (depending on rainfall), and likewise varies during the seasons. It also depends on the urban standards of the areas drained. Deductions made from preliminary unpublished work on watercourses emanating from the Witwatersrand escarpment suggests that at present the average soluble phosphorus contribution in urban run-off is probably about 10% of the wastewater contribution. However, in the absence of adequate data this must remain a tentative figure.

The estimated 800 t a year of human and industrially contributed phosphorus is remarkably low in relation to the quantities of phosphate used in producing food for the 2,2 million people in the region. The author estimates the mass of phosphorus in urban wastewater is less then 14% of fertiliser phosphorus used in feeding an urban population. This suggests either a high degree of utilisation of phosphorus in the food cycle, which is unlikely, or inefficient utilisation at the crop-production level. If the latter is the case, it could imply a growing agricultural contribution to topographical eutrophication from food-producing areas which could make itself felt in terms of topographical pollution in the future.

The estimated 1 330 t of phosphorus a year in the wastewater is a remarkably high figure in relation to the probable phosphorus-loading tolerance levels of impoundments in the region which, based on the work of Toerien, 1976, is probably approximately only 20–30 t a year. As the phosphorous loading limits proposed by Toerien for the Hartebeestpoort Dam appear to be based largely on the Vollenweider model, which might not be entirely appropriate for local conditions, phosphorus tolerance levels of 20–30 t a year are possibly excessively conservative. Nevertheless, the vast difference between the actual phosphorus inputs in the region and the general order of probable tolerance levels, is disturbing.

Even the estimated contribution from urban run-off substantially exceeds the tolerance level (20–30 t a year) although *at present* diffused soluble phosphorus contributions may be reduced to near the tolerance levels by self-purification in streams passing from cities to dams.

Future prospects

Projections based on the 1970 census (Bureau of Statistics, 1972) show beyond doubt that urbanisation will pose one of the greatest challenges in the history of the Republic. The implications of inevitable urbanisation patterns are dramatic:

- The total population is expected to grow from 22 to 51 million.
- The population of 23 urban centres will increase from 5,0 to 20–34 million.
- The population of the four Provincial capitals is likely to increase by a factor of 15–20. (Department of Planning and the Environment, Press release 1971).

The implications in terms of phosphorus release to the water environment are shown in Table 2. The allocation of future urban populations to specific regions is somewhat arbitrary, but the most significant total figures agree with figures produced for the Bureau of Economic Research, Stellenbosch (1975). Smaller regions have been omitted. These figures do not pretend to be accurate, but they are useful in giving an impression of the magnitude of the problem.

With reference to Table 2, the following comments can be made:

- The estimated phosphorus contribution from urban run-off is considered to be conservative. Even so, it alone will far exceed quoted phosphorus tolerance levels (20–30 t a year) in those impoundments to which urban areas drain.

TABLE 2

ESTIMATED PHOSPHORUS CONTRIBUTIONS FROM URBAN REGIONS: YEAR 2000

Region	Projected Urban Population: Year 2000 (Million)	Phosphorus contribution in t per year		
		Waste-Water	Run-off**	Total
Inland Centres				
P W V Complex	9,0*	5 400	540	5 940
Northern Natal	0,8	480	48	530
Eastern & Northern Transvaal	5,5	3 300	330	3 630
Bloemfontein/Welkom Region	1,0	600	60	660
Kimberley Region	0,4	240	24	270
Coastal Centres				
Cape Town Region	2,6	1 550	155	1 705
Durban Region	4,0	2 400	240	2 640
Port Elizabeth Region	1,2	720	72	792
East London Region	0,8	480	48	530
Richards Bay	0,5	300	30	330
Saldanha	0,4	240	24	270

*Different authorities place this forecast at between 7,0 million and 10,0 million.
**Very approximate assessment at 10% of wastewater contribution.

TABLE 3

COMPARATIVE TREATMENT COSTS

(Excluding cost of ultimate sludge disposal: 1975 cost levels: Scale 50–100 Mℓd: Assumed interest rate, 10% p.a.)

Process	Mean Effluent Standards Attainable (mg/ℓ)				Cost (c/m³)	Remarks
	C.O.D.*	N**	p***	SS		
A. Biological filtration plus rapid-gravity sand filtration	90–120	26	6,5	20	5,3	
B. Modified extended aeration without sand filtration	35–50	5	1	20	3,3	A good industrial water
C. B plus lime treatment, recarbonation high-grade sand filtration, and break-point chlorination	20	1,5	0,2	2	7,2	First-grade industrial water suitable for occasional drinking
D. C plus carbon absorption and further B.P. chlorination	10	1,5	0,2	2	10,9	Suitable for unrestricted use

*C.O.D. is dependent on origin of wastewater.
**N is expressed as total of organic and inorganic nitrogen, as N.
***P is expressed as orthophosphate, as P.

- The phosphorus contribution from urban run-off alone, disregarding topographical pollution of agricultural origin, will be more than adequate to create impoundments sufficiently productive for fish and animal-feed production. Indeed, it has yet to be demonstrated that dam management will enable the future annual phosphorus inputs, even from diffuse sources only, to be assimilated or abstracted.

- As regards control of point-source discharges of effluents, recent work at Johannesburg has established that biological-phosphorus removals of 75% are feasible and that with improved process design removals of 85% will soon be within reach. For the purpose of this paper it is assumed that by 1980 85% removals of phosphorus by biological means will generally be attainable. If the necessary technology for such reduction were applied in the Pretoria/Witwatersrand/Vereeniging (P W V) region, there would still be ca 800 t of phosphorus a year in effluent-discharges at the year 2000.

- Under these circumstances, the total of point and diffused sources of phosphorus in the region could well be in the order of 1 350 t a year, which exceeds stated tolerance-levels by a factor of 50. It is recognised that further research could possibly result in a re-assessment of the phosphorus tolerance levels of inland impoundments. However, one can be reasonably confident that any such re-assessment will not affect the order by which total phosphorus inputs will exceed the realistic phosphorus tolerance levels.

Process Control Possibilities

Wastewater is logically the first target of technological attack, since at present it probably constitutes approximately 90% of the problem in highly urbanised areas and because diffused sources are extremely difficult to control. Until recently the proper function of conventional biological filter wastewater purification works was to convert carbohydrate, protein and nitrogen complexes to simple stable compounds such as N_2, CO_2, CH_4, SO_2, XNO_3, and XPO_4. Such a process could not be expected to change the orthophosphate concentration through the plant, and in fact little reduction is effected in such plants. Their function has been to produce orthophosphates.

Eutrophication has now appeared as a new challenge, the response to which has been the recent development of the activated sludge process to achieve the reduction of NO_3 to N_2, and to remove orthophosphate from solution by attachment to, or absorbtion by, a biologically-active sludge. Further, during the last decade, physical-chemical techniques for the precipitation of phosphorus from wastewater effluents have been perfected. Thus there is a bewildering range of new technological possibilities available. The principal alternatives, in terms of standards and costs, are set out in Table 3.

Under inflationary conditions costs such as those quoted above are valid for the stated time period. Their main value is as a relative yardstick for comparison with the costs of alternative processes or water-supply sources. The figures have been derived as follows:

A: 1966 construction cost levels adjusted by the increase in construction contract prices at Johannesburg, 1966–1975.

B: 1975 contract construction costs at Johannesburg.

C: As for B in respect of extended aeration plant; costs for tertiary treatment processes based on Van Vuuren (1975) and local estimates based on conceptual designs.

TABLE 4

ESTIMATED MINIMUM PHOSPHORUS LOADINGS OF EFFLUENT ORIGIN: P W V REGION (INCLUDING PRETORIA): 1976–2000

Year	Phosphorus in t/year	Population (millions)	Treatment	Remarks
1976(a)	1 500	2,6	Mostly bio-filter plants	Direct discharge at plant
1976(b)*	1 000	2,6	Mostly bio-filter plants	Effective loading 2 km from plant discharge
1986	410	4,5	100% biological phosphorus removal plants installed**	
2000	800	9,0	100% biological phosphorus removal plants installed**	

*Reduced 1976 loading due to estimated effect of biological barrier-systems – ponds, irrigation, vleis etc., in vicinity of works, based on experience at Johannesburg.
**Assumes 85% phosphorus removal by activated sludge plants.

D: As for C; other costs based on Van Vuuren (1975). These costs appear to tally with those of Culp, quoted by Van Vuuren.

The present dynamics of changing cost-patterns is demonstrated by the fact before 1970 biological filter plants were competitive with extended aeration plants; now the cost per m^3 is almost double that of extended aeration plants. The reason is that owing to inflationary increases, and high interest rates, the cost of capital plant has increased far more rapidly than the cost of electric power. The relative increases in the unit costs of capital-intensive and energy-intensive systems in the future cannot be anticipated. However, for the foreseeable future, capital intensive bio-filter plants are at a clear economic disadvantage.

With reference to process D in Table 3, the suitability of the effluent for unrestricted reuse, raises the necessity of comparing the relevant costs with the marginal costs of new surface water supplies. This is done below:

Cost of producing safe potable water from wastewater (D in Table 3):	10,9 c/m^3
Less cost of normal wastewater treatment:	3,3 c/m^3
Nett additional cost of producing potable water:	7,6 c/m^3
Present cost of water delivered in bulk at Johannesburg:	6,56 c/m^3
Approximate marginal cost of augmenting bulk supplies to the region:	ca 8,0 c/m^3

Thus already, reclamation of wastewater would appear to be competitive with the marginal cost of new water supplies.

Process Possibilities and Public Policy

Even if the new processes for biological removal of phosphorus are applied to all new wastewater purification plant construction, the phosphorus contribution from existing biofilter plants will continue well into the eighties. On this basis, the minimum point-source phosphorus loadings from effluents in the P W V region over the next 24 years can be expected to be approximately as in Table 4.

Diffused or 'Non-point' Sources of Nutrients

Table 4 shows how existing technology can control and limit point-sources, and more advanced techniques may enable them to be limited even more. However, the contribution of eutrophying and other polluting substances from urban and agricultural run-off, unless controlled, will certainly negate the effect of vast expenditures on wastewater purification plants. Very little of practical value is known of the dimensions of diffused-origin nutrients in the Republic; overseas data are not applicable since they are complicated by the inclusion of pollutants from storm overflows from combined sewers, which are not used in South Africa. Nevertheless, the limited published data are disturbing. In the United States it is estimated that more than 50% of the total phosphorus and 75% of the total nitrogen in surface waters originate in non-point sources. In the Republic the corresponding figures are no doubt much less. Nevertheless, on the basis that diffused urban nutrient contributions might be as low as 10% of the raw wastewater contribution, the effect of increasing urbanisation will inevitably bring about a vast increase in the total of diffused-source phosphorus. In fact, the present situation is likely to be reversed as point sources are brought under control. Then, the combination of agricultural and urban diffused sources will almost certainly be far greater than the total of point sources of nutrients.

In addition to nutrients, other pollutants such as heavy metals, are involved. The 1974 Report of the US President's Council on Environmental Quality indicates, as one example, how lead from car exhausts attaches to urban dust and is flushed away during storms.

In regard to diffused agricultural sources of nutrients, there is widespread public and official concern at the loss of top soil, and consequent siltation, caused by soil erosion; but it is not

often realised what this means in terms of fertilisers, pesticides and herbicides washed with soil into dams. Toerien et al, 1975 have reported on dams having raised trophic status in agricultural areas. Dispersed sources generally are extremely difficult to handle, but this is a case where control at source by land-management procedures is feasible and deserves the same high priority as the attainment of water quality objectives.

Conclusions

1. The impoundment-enrichment problems of the Republic in the future are of vast dimensions – existing difficulties are merely a fore-runner of what is to come.

2. From Table 4 it is clear that the critical period is the next ten years. It will be a decade of rapid expansion, in which an all-out attack on every aspect of the problem is required: new biological phosphorus removal plants; research and investment into phosphorus removal from existing bio-filter effluents; enlargement and construction of nutrient barriers at all possible points on urban water-courses and rivers; eutrophication-management in dams; and intensive cropping of fish and of plants for animal feeds at enriched impoundments.

3. The point source objectives for the next decade should be:
   (a) All new construction of wastewater purification plants contributing to inland catchments should incorporate targets of phosphorus removal to 1 mg/ℓ and of total nitrogen to 5 mg/ℓ levels.
   (b) Phosphorus removal should be applied at all existing biofilter plants. However, to achieve this economically will require urgent and active research.

4. Until the 1986 target (See Table 4) of all wastewater purification plants incorporating phosphorus removal is achieved, all forms of biological nutrient barriers at wastewater purification works should be maintained and improved.

5. In the long run the problems of diffused sources of nutrients and other pollutants will probably be more serious than those from effluents at point sources. There is no sense in devoting great expenditure and technological effort on control of effluent nutrients without comparable effort on the control of dispersed sources.

6. Little factual data is available on topographical pollution, urban or agricultural, and a great deal of research is necessary both to identify the problem, and to evolve management techniques for its control.

7. The interior of the Republic faces two great imperatives in the water field, namely water quality management, which includes control of eutrophication, and augmentation of water supplies. *By 1990 it is likely that these two major objectives will have merged into a single solution through realisation of the ideal of large-scale water reclamation.* If so, the point-source problem will have been solved, but we will still be left with the major difficulty of controlling dispersed contributions to the eutrophication problem.

8. From the administrative point of view, it would appear that purely local approaches, as opposed to regional management, are unlikely to achieve control of point-source contributions of nutrients (or alternatively, large-scale reclamation), and are quite inappropriate for the solution of the great problems of diffused source contributions.

REFERENCES

DEPARTMENT OF PLANNING AND THE ENVIRONMENT, (1971): Press Release, *Die Burger*, 15 October.

TOERIEN, D.F., HYMAN, K.L. AND BRUWER, J., (1975): A preliminary trophic status classification of some South African impoundments. *Water SA* Vol 1, No 1, 23.

TOERIEN, D.F., (1975): Maximum tolerance levels of nutrients and algae in Hartebeestpoort Dam. Unpublished proceedings: *Workshop on the control of eutrophication for the optimum use of Hartebeestpoort Dam*, National Institute for Water Research, CSIR.

TOERIEN, D.F., HYMAN, K.L., AND BRUWER, J., (1975): A preliminary trophic status classification of some South African impoundments. *Water SA* Vol 1, No 1, 22.

UNIT FOR FUTURES RESEARCH, (1975): Bureau of Economic Research, A review of regional development 1975–2000, *Private internal report.*

VAN VUUREN, L.R.J., (1975): Water reclamation quality targets and economic considerations. *Water SA*, Vol 1, No 3, 140.