EXECUTIVE SUMMARY

In 1986, Heynike & Wiechers of the Water Research Commission (WRC) assessed the contribution made by detergent phosphorus to wastewater phosphorus discharges in South Africa and its impact on eutrophication. Their study showed that detergents comprised between 35 and 50 % of the total wastewater phosphorus load and thus presented a significant source of phosphorus to the environment, but the costs associated with eliminating or banning detergent phosphorus outweighed the benefits. The authors indicated that there was lack of suitable data for the study and several assumptions had to be made. They therefore recommended that the WRC continue to keep a watching brief on the situation, while the South African detergent industry investigates and tests cost effective substitutes for phosphate builders.

Towards the latter part of 1990, Lever Brothers (Pty.) Ltd. (Lever) approached the University of Natal, Pollution Research Group (PRG) and the University of Cape Town to discuss sponsoring an investigation into the effect of substitute detergent builders on wastewater treatment. This study was given the go ahead and commenced at UCT in 1991 as a Masters research project. Following this, a meeting was held in 1991, with representatives of the WRC, Lever, the PRG and Umgeni Water where it was agreed that the Pollution Research Group in collaboration with Umgeni Water would undertake a WRC funded study which updated the 1986 Heynike & Wiechers study. The latter investigation commenced in 1992, with the principal researcher stationed at Umgeni Water in Pietermaritzburg.

The Mgeni catchment was chosen as the study area because it was relatively well known by the researcher, was easily accessible and water quality data had been collected for the catchment as part of the Umgeni Water routine monitoring programme. It was also an important catchment in that it constituted a major developmental region in South Africa and served the water needs of major urban centres, notably, Pietermaritzburg and Durban, and several surrounding small towns and rural areas.

The topic of detergent phosphorus and its contribution to eutrophication, i.e. nutrient enrichment, is also particularly relevant to South Africa where many impoundments have become eutrophic or are threatened by eutrophication. Walmsley & Thorton investigated the trophic status of 31 major impoundments in South Africa In 1982, and reported that 9 were eutrophic and 13 bordering on eutrophication.

The major consequence of eutrophication is prolific growth of algae or certain rooted macrophytes, which may result in severe water quality problems, including, unpleasant tastes and odours, deoxygenation and fish kills. In the case of the potable user, eutrophication has resulted in considerable expense due to the requirement of sophisticated treatment measures such as the use of powdered activated carbon to treat taste and odour problems. Eutrophication may be controlled by the reduction of the nutrient discharges to the environment. Phosphorus, in particular is often singled out for reduction, as it is frequently the growth-limiting nutrient for aquatic plants.

Phosphorus sources include point discharges such as domestic and industrial wastewaters and diffuse sources such as agricultural wastes and fertilizers. In detergents, phosphorus serves as a builder that works in synergy with the surfactant to perform the cleaning function. Phosphorus arising from detergent consumption is usually in the form of orthophosphate - the bio available phosphorus form, and is therefore an attractive option for control. Various authors [e.g. Heynike & Wiechers, 1986; Sas, 1989; Edmondson, 1991] have indicated that about half the phosphorus contained in domestic wastewaters may arise from laundry detergents, which could in turn contribute significantly to the phosphorus loading to impoundments. Should this be the case in the Mgeni catchment, elimination of detergent phosphorus could contribute significantly to improving water quality in impoundments.

Over the years following the Heynike and Wiechers [1986] study, additional data and information have become available, including more detailed water quality and land use data, as well as better data and information on the costs and implications of treating water drawn from eutrophic impoundments. In addition, the number of eutrophic impoundments appears to have increased. The Nagle impoundment on the Mgeni system, previously classified as oligotrophic by Walmsley & Thornton [1982] has since 1989 displayed recurring blooms of *Cyanophycae* (or blue-green algae), resulting in severe water treatment problems [Umgeni Water, 1994]. In the light of these developments, the contribution of detergent phosphorus to eutrophication of water bodies has been re-examined in the Mgeni catchment.

The main study objectives were to assess the contribution of detergent phosphorus to eutrophication in the Mgeni system and determine the economic and water quality consequences of eliminating detergent phosphorus plus provide a methodology that could be used for studies in other catchments.

The area of study **(Figure 1.1)** - extended from the headwaters of the Mgeni river at the foothills of the Drakensberg mountains, to the Mgeni river outflow from the Inanda impoundment and comprised 4 078 km^2 of catchment area. This catchment lies in the summer rainfall region of South Africa and receives 800 to 1 200 mm of rainfall per annum. Four major impoundments, namely, the Midmar, Albert Falls, Nagle and Inanda impoundments are fed by this catchment and satisfy the water demands of the greater Pietermaritzburg and Durban areas, the surrounding rural areas as well as the recreational and environmental requirements of the Mgeni system.

Land use practices in the upper subcatchments (Midmar, Albert Falls and Nagle) are predominantly agricultural, with some informal settlements, a few small towns and a fair amount of rural subsistence settlements. The lower lying Inanda subcatchment is the largest and most developed and drains the city of Pietermaritzburg with an urban population of approximately 275 000 people (1991 Census) as well as surrounding industrial, rural and informal areas.

Various point sources of phosphates are located throughout the Mgeni catchment, the largest being the Darvill Wastewater Works, in the Inanda subcatchment, serving the greater Pietermaritzburg area. Water quality in the Inanda impoundment is expected to be the most impacted in this system owing to the nature and extent of the land use practices.

Data for the study were assimilated over the period 1990 to 1994. The assessment of detergent usage was undertaken for the October 1990 to September 1991 period, using population data from the 1991 census, while the development of phosphorus-eutrophication models and assessment of the impact of detergent phosphorus elimination on water quality utilised data collected over the four year period from February 1990 to January 1994.

Various investigations were undertaken to satisfy the identified objectives, including, calculation of the phosphorus loadings arising from urban and rural detergent usages; quantification of total and detergent phosphorus loading contributions to the four major impoundments in the Mgeni catchment; development of a predictive equation for the Inanda impoundment relating phosphorus loading to algal production and using it to determine the impact of detergent phosphorus elimination on algal production; investigation of the fate of phosphorus compounds in an impoundments, using the MINTEQA2 geochemical equilibrium speciation model; and a cost-benefit assessment of detergent reformulation.

The rural and urban per capita detergent consumptions formed the basis for all detergent phosphorus loading calculations and were estimated to be 1.63 kg per capita per annum and 3.53 kg per capita per annum, respectively. The rural population therefore used less than half as much detergent as the urban population.

The rural population in the Mgeni catchment of 610 000 people, was found to be twice the urban population of 304 000 people, but the overall detergent phosphorus loading from rural areas was still slightly lower than that from urban areas. A factor of 16 % was taken as the percentage of the rural population that washed laundry directly at a river or stream, obtained from a survey of washing practices undertaken by Lever in KwaZulu-Natal.

The Inanda sub-catchment with the largest urban and rural populations had the largest detergent phosphorus contributions to the environment. The urban area in the Inanda catchment yielded 9.2 tonnes detergent phosphorus per annum, compared with 0.3 to 2.1 tonnes per annum for the 3 upstream catchments (Midmar, Nagle and Albert Falls), while rural areas yielded 8.4 tonnes per annum, compared with a range of 0.3 to 1.4 tonnes per annum for the upstream catchments.

The proportion of detergent phosphorus relative to the total phosphorus loading was 51 % from urban areas in the upper catchments but 37 % in the Inanda catchment where industries in the Pietermaritzburg area comprised approximately 30 % of the phosphorus loading.

At the dam inflow sites, for the study period October 1990 to September 1991, 20.9 tonnes of soluble phosphorus were measured at the Mgeni inflow to the Inanda impoundment compared with only 2.8 to 3.6 tonnes at the 3 upstream impoundments inflow sites.

In the absence of detailed in stream modelling of phosphorus, three scenarios were considered for estimating the total soluble phosphorus loading from the catchment:- 1)The only sources of soluble phosphorus were wastewater effluents and detergents that entered from rural laundering undertaken directly at the water course; 2) In addition to the above loadings, non point sources (e.g. agriculture, informal settlements) contributed 20 % to the catchment soluble phosphorus loading; and 3) Non point sources contributed 50 % to the catchment soluble phosphorus loading. These showed detergents to comprise 53, 42 and 26 % of the SRP loading to the Inanda dam, respectively.

A regression model relating soluble phosphorus loading to algal production was successfully developed for the Inanda impoundment. A comparison of observed and predicted algal count indicated a very good relationship, which could be used in future by Umgeni Water for predicting algal production in the impoundment. Using the phosphorus-loading/algal-production model, it was found that eliminating detergent phosphorus would significantly reduce algal numbers in the Inanda impoundment. For the reduction scenario of 53 % (scenario 1), the algal count was estimated to reduce by 75 %.

An examination of the species distribution between dissolved and precipitated phases in the Inanda impoundment, using the MINTEQA2 equilibrium speciation model, indicated that precipitation was the dominant process and removed more than 99% of the phosphorus from solution at equilibrium. The little phosphorus remaining in solution was predominantly in the form of HPO_4^{2-} and a small percentage of calcium and magnesium complexes. The formation of soluble complexes was therefore not a significant factor in determining the bio availability of phosphorus in the impoundment

Phosphorus adsorption onto a ferric hydroxide surface was shown to successfully compete with precipitation as the major control on the distribution of phosphate species at the pH, temperature and concentrations present in the Inanda impoundment. The net effect of adsorption would be similar to precipitation, in that phosphate is effectively removed from solution and would thus not be available for further biological uptake. Phosphate desorption from an iron hydroxide surface would only make a significant contribution to the soluble phosphorus pool, when the pH exceeded 9. This is expected to occur for less than 10% of the time in the impoundment.

Low redox conditions did not favour resolubilisation of precipitated phosphorus. Modelling results indicated that reduction of ferric to ferrous ions, which has been suggested as the mechanism for phosphorus release from the adsorbed phase, would not readily occur in the impoundment and ferric hydroxide would remain the stable phase over a wide range of water conditions.

This modelling investigation was a first attempt at examining phosphorus speciation in the Inanda impoundment using the MINTEQA2 model, which considers only the thermodynamic driven equilibrium chemical composition. Using the equilibrium results predicted by MINTEQA2 together with the results of on-site monitoring provides improved understanding and insight into phosphorus inter-relationships in the impoundment. Algal production in the Inanda impoundment appears to be driven by the external nutrient loading and the modelling results serve to support this by suggesting that phosphorus entering the impoundment, if not taken up rapidly, is lost from solution and not made available at a later stage.

A review of the literature on the impact of detergent phosphorus bans on water quality suggested that both the environment and wastewater works could not benefit simultaneously from detergent phosphorus elimination. In addition, reformulating detergents may or may not accelerate deterioration of washing fabrics and washing machines. These factors led to four cost-benefit analyses, the results of which were all in favour of not eliminating detergent phosphorus.

The best option for the detergent manufacturer, which took into consideration: the increased cost to consumers as a resulting of reformulating with a zeolite builder, loss in value of washing machines and fabrics, and reduction in water treatment costs, was 35 to 1 in favour of not reformulating detergents. The least favourable option for the detergent manufacturer, which took into consideration: the increased cost to consumers as a resulting of reformulating with a zeolite builder, and savings at the Darvill WWW as a result of a reduced influent phosphorus loading, was still 2 to 1 in favour of not reformulating detergents.

The literature has suggested that phosphate-free detergents have been formulated to give performance equalling that of phosphate detergents and certain reformulations would not result in extra wear and tear on fabrics and washing machines. If this were the case in South Africa, then the cost-benefit analysis models 1 and 2 which only consider wastewater treatment and water treatment costs, would be the more likely forecasts. The results of these two cost-benefit analyses show that the cost of treating the consequences of eutrophication is less than reducing the phosphorus loading at wastewater works. This finding may however be specific to the Inanda catchment where significant river losses occur between the discharge points and the impoundment for most of the year. In addition, the phosphorus loading enters the impoundment approximately 16 river kilometers away from the point of abstraction for water treatment and the water treatment abstraction site, resulting in significant further improvement in water quality. The scope of this project, precluded estimates of the costs of environmental and recreational losses associated with eutrophication, which would need more rigorous economic modelling.

In summary, the results of the assessment of the detergent phosphorus contribution to eutrophication and the economic and water quality consequences of eliminating detergent phosphorus indicated that detergents made a significant contribution to the phosphorus loading on the environment, however, the costs of eliminating detergent phosphorus outweighed the benefits.

For the Inanda system, the cost of treating nuisance algae was cheaper than either detergent reformulation or phosphorus removal at a wastewater works. As this is likely to be a function of river distance between the discharge point and the impoundment as well as the length and assimilative capacity of the impoundment, the methodology should be applied to an impoundment where the phosphorus discharge points are closer to the impoundment and water treatment abstraction site. In such a situation fewer river losses would occur and the loading may have a greater impact on algal production and therefore treatment costs.

Alternately a study of the transport and fate of phosphorus in river systems may better help quantify movement of the constituent from point and non-point sources into bulk supply impoundments.

It is difficult to put a cost to losses to users other than domestic, which would arise from eutrophication. Methods of quantifying these losses should therefore be developed, as they may be critical components of the cost-benefit equation.

The South African detergent industry currently solely formulates with a phosphorus builder and therefore uses the maximum amount of phosphorus. The cost of binary, ternary or other systems that use less phosphorus should be investigated, as they may be cheaper to produce than phosphate-free formulations and still provide some benefit to the environment.

Apart from rural laundering at a watercourse, other non-point sources (e.g. agriculture, informal settlements) could contribute to the soluble/bio available phosphorus loading, especially during periods of high runoff when particulate phosphates may resolubilise. Monitoring programmes that improve quantification of these inputs and their contributions to the catchment phosphorus budget would provide information to decide on the more cost-effective catchment management intervention.

This project successfully met the stated objectives. The contribution of detergent phosphorus to eutrophication in the Mgeni catchment was determined by quantification of rural, industrial and domestic phosphorus loadings. In addition, the relationship between soluble phosphorus loading and algal count was determined for the Inanda impoundment. The economic and water quality consequences of eliminating detergent phosphorus was determined incorporating the results of the relationship between phosphorus loading and algal count into cost-benefit analysis procedures. The project has also provided a simple methodology that can be extrapolated to other catchments where further eutrophication control measures need to be considered.