Investigation of the positive and negative consequences associated with the introduction of zero-phosphate detergents into South Africa

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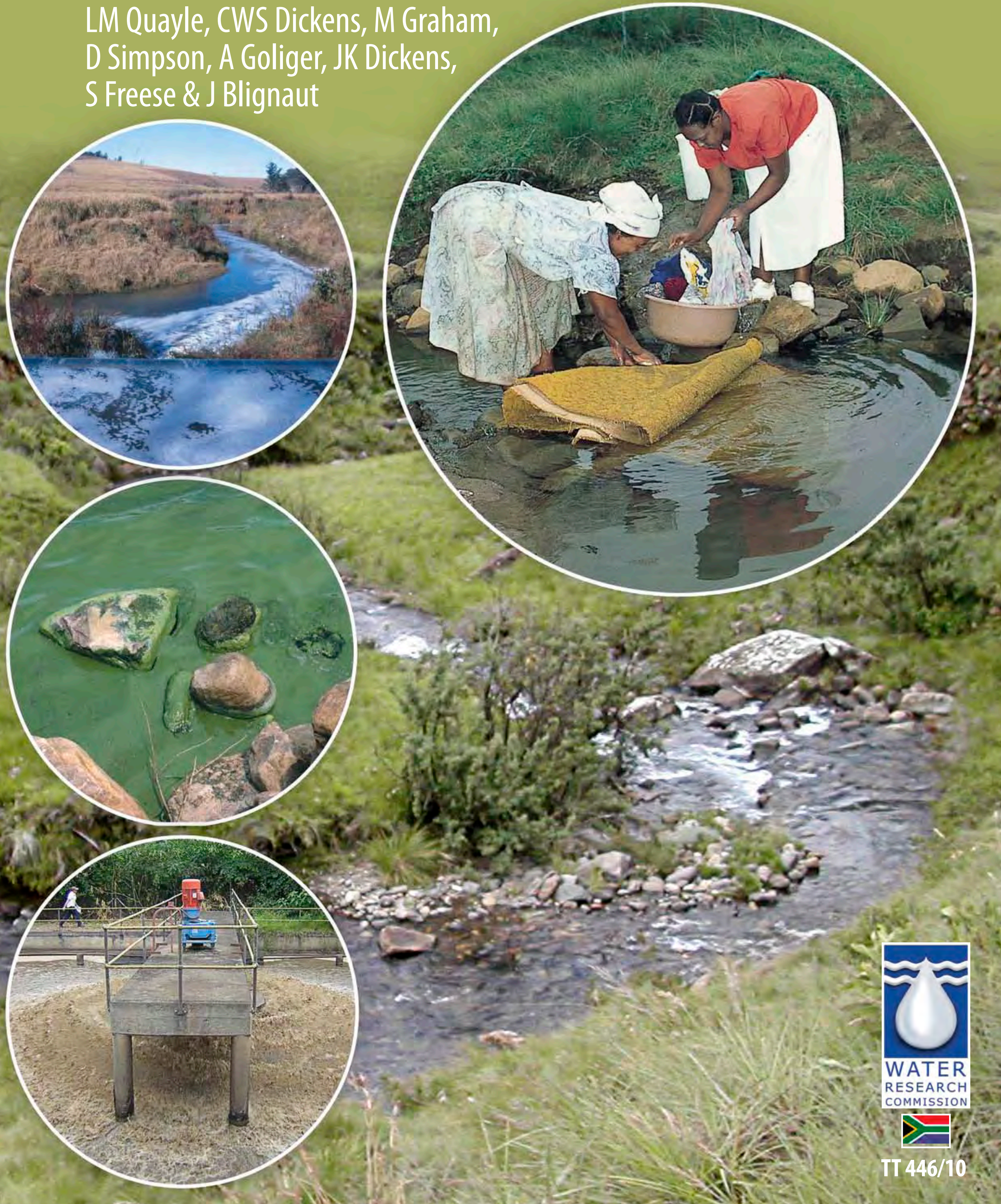

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EXECUTIVE SUMMARY

1.0 Introduction

1.1 Project background

In response to the growing awareness of the role played by phosphate contained in powdered laundry detergents in the eutrophication of water resources, and the apparent failure of the legislated 1 mg/ℓ effluent phosphate concentration standard to control this problem, the WRC identified the need to investigate the positive and negative consequences associated with the introduction of zero-phosphate (zero-PO_4) powdered laundry detergents into the South African market. The WRC solicited proposals to conduct such an investigation and subsequently contracted the Institute of Natural Resources (INR).

Phosphate is used in detergents as a builder in the form of pentasodium tri-polyphosphate (STPP) which acts to soften hard water by complexing calcium, ferric and magnesium ions and to assist in the cleaning process by buffering the pH of the washing solution, preventing rust and corrosion and keeping dirt particles in suspension. STPP is easily hydolysed in the presence of water to bio-available orthophosphate (PO_4), an important nutrient which, when released into the aquatic environment contributes to eutrophication in surface water bodies (rivers and reservoirs).

It is important to note that the element phosphorus (P) is contained in other components of detergents, such as the fluorescers and optical brightners. There is no known substitute for phosphorus in these components and they thus cannot be removed from formulations. This project considers only the phosphorus contained in the phosphate STPP builder component.

1.2 Project Aims

The aims of this project were:

1. to review the current local and international best practice with regards to the use and restriction of phosphates in detergents (ch. 2),
2. to estimate the impact detergent phosphates are having on the phosphate loading and efficacy of Waste Water Treatment Works (WWTWs) (ch. 3), and their ability to meet the 1 mg/ℓ phosphate standard for effluent (ch. 4),
3. to estimate the impact detergent phosphates are having on the phosphate loading and the frequency and severity of algal blooms in key dams around the country (ch. 5 &6),
4. to estimate the cost savings that may occur at Water Treatment Works (WTWs) and at WWTWs if detergent phosphate were to be eliminated (ch. 4 & 7),
5. to conduct a cost benefit analysis of the introduction of zero-phosphate detergents across all sectors including the costs that may accrue to consumers in the form of damage to fabrics and washing machines (ch. 8),
6. to investigate the impacts of the introduction of zero-phosphate detergents on the Waste Discharge Charge System (WDCS) (ch. 8).

1.3 Project approach

The approach followed in order to satisfy the aims of this project was to investigate the consequences of the introduction of zero-phosphate detergents;

1) internationally and locally through a comprehensive literature review, and

2) locally through the desktop analysis and modeling of existing data drawn from a number of arenas, namely:

- Detergent market statistics
- Waste Water Treatment Works (WWTWs)
- Phosphate loading to key dams
- Algal growth and eutrophication in key dams
- Water Treatment Works (WTWs)
- Costs and benefits for society at large.

The majority of data for analysis of WWTWs was sourced from Darvill WWTW in Pietermaritzburg, while detergent manufacturers (particularly Unilever) provided much of the consumption and detergent market related data. Predictions of in-dam water quality and of the frequency and intensity of algal blooms (given a predicted reduction in phosphate loading) were made using internationally recognized calculation models and were based on water quality data collected from various sources as well as on landuse based phosphate export coefficient models developed for each study catchment. Data and information for the cost benefit analysis was sourced mainly through interviews and literature review, and were assessed qualitatively to arrive at a conclusion.

2.0 Literature Review

A thorough review of international as well as local literature was carried out. This review indicated that, internationally, the use of phosphates in detergents is commonly being restricted through legislation in countries where eutrophication of water resources is a problem. In some countries, voluntary restrictions have been put in place. Some countries have also instituted limits or outright bans on a regional or municipal scale.

A study in Whittlesea, Australia, (Haliwell, 2001) showed that between 14% and 38% of phosphorus arriving at the WWTW originated from detergents, and a study carried out by Pillay (1994) showed a detergent phosphate contribution of 38% to the total phosphorus loading (TP) of the WWTW in the Umgeni catchment. This figure was revised by Brian Moss (undated review of Pillay's study) who suggested that it would be 25%.

In the same study, the contribution of detergent phosphates to the loading of dams of the Umgeni system was determined by Pillay to be 30.7%, while Moss revised this figure to 25%.

Pillay's study also determined the costs and benefits associated with the elimination of detergent phosphates. Her findings were that the costs far outweighed the benefits, but these costs were largely based on the possible damage to fabrics and washing machines. Subsequently, the correct formulation of detergents has been shown not to impact on fabrics and washing machines, which thus nullifies these costs. Furthermore, her study did not consider the environmental costs of eutrophication and the benefit of its reduction.

The effect of zero-phosphate detergents on WWTWs efficiencies was examined and case studies in the USA revealed that significant cost savings were made at WWTWs through the reduction in the volume of sludge being produced (Sonzogni et al., 1986) as a result of less phosphate having to be removed. This was countered by studies in Europe which showed that sludge production would increase due to the fact that a greater mass of builder is required when formulating with alternative builders (Acke, 2001).

3.0 Detergent phosphate loading at WWTWs

Using Darvill WWTW (uMngeni River catchment in KwaZulu-Natal) as a case study, the contribution of detergent phosphates to the loading of WWTWs was estimated. Darvill WWTW showed a loading contribution of 22% (TP) or 40.3% (SRP), with a significant non-detergent contribution from industrial sources. It was determined that if waste water was limited to purely domestic sewerage, the detergent contribution would be approximately 33% (TP).

Table 1: Contribution of detergent phosphate to the total phosphorus loading at Darvill WWTW

No of households	57500	
Avg people per household	3.6	
Detergent consumption	17.3	kg/hshld.annum^{-1}
% P composition of detergents (from builder only)	5.3	%
Household Pdet consumption	0.917	kg/hshld.annum^{-1}
Darvill Pdet total	52.72	T/annum
Darvill TP total	239.4	T/annum
Darvill SRP Total	130.6	T/annum
% TP composition	**22.0%**	
% SRP composition	**40.3%**	

Table 2: Contribution of detergent phosphate to the phosphate loading of domestic sewerage

No of households	57500	
Avg people per household	3.6	
Detergent consumption	17.3	kg/hshld.annum^{-1}
% P composition of detergents (from builder only)	5.3	%
Person Pdet consumption	0.255	kg/capita.annum^{-1}
Household Pdet consumption	0.917	kg/hshld.annum^{-1}
Metabolic P production	0.4745	kg/capita.annum^{-1}
Metabolic P production	1.7082	kg/hshld.annum^{-1}
Household Pmet	98.2215	T/annum
Migrant / Resident ratio	0.25	
Migrant Population	51750	
Migrant Pmet	12.278	T/annum
Darvill Pdet total	52.72	T/annum
Darvill Pmet total (inc 0.75 of Migrant Pmet)	107.43	T/annum
Proportion of domestic P is Pdet	**32.9%**	

4.0 Impact of Zero-Phosphate detergents on WWTWs efficacy and costs.

The impact of zero-phosphate detergents on the efficacy and costs incurred by a WWTW was assessed based on the case study of Darvill WWTW in Pietermaritzburg. This works is typical of those around the country where approximately 80% of the waste water in South Africa is treated by approximately 20% of the WWTWs. These are facilities with a capacity of greater than 10 Mℓ/day.

It was also found that, at Darvill WWTW, sludge production that comes about as a result of phosphate removal through the use of aluminium sulphate (alum) is equivalent to approximately 10% of the volume of sludge produced in the activated sludge process. There would thus be a 10% reduction in sludge following the reduction in use of alum.

Should the detergent component of the total phosphorus loading to Darvill WWTW be removed, and the facility continues to target the 1 mg/ℓ effluent concentration standard, a treatment cost saving equivalent to the cost of using alum could be realised. This is approximately R2million per year. However, this would mean that there would be no benefit passed on to the environment, which raises the question of whether the 1 mg/ ℓ standard continues to be appropriate and suggests that this targeted concentration should be reduced.

5.0 Contribution of detergent phosphate to the phosphorus loading of key dams

The extent of each dam's catchment and the landuses contained therein were mapped. Using phosphorus export coefficients for the landuse categories identified, the proportion of phosphorus loading at the inflow to key dams, that is attributable to detergent phosphate, was estimated. This was centred on an urban residential coefficient of 5 kg/Ha/annum, which was calculated based on effluent concentrations at Darvill WWTW in Pietermaritzburg.

- **NB –** It is acknowledged that Darvill WWTW represents a reasonably efficient facility with regards to phosphate removal, using both biological nutrient removal as well as alum dosing to achieve the 1 mg/ℓ standard.
- Less efficient facilities (often the smaller WWTWs) which do not remove phosphate as effectively may thus result in higher export coefficients. **Results from this study should thus be seen as a conservative estimate.**

The calculations established the proportional contributions of detergent phosphates (or potential reductions in the event of the introduction of zero-phosphate detergents) to the total phosphorus loading of key dams. These results are reported below in table 3.

Table3: Proportional contributions of detergent phosphate to the total phosphorus loading of key dams.

Catchment	Total P	kg Pdet	Proportion (%)
Albert Falls	9302.83	1627.4	17.49
Allemanskraal	35081.8	1212.4	3.46
Bloemhof	1156796.4	175825.8	15.20
Bronkhorstspruit	14677.94	771.7	5.26
Erfenis	47952.6	2141.1	4.47
Grootdraai	101481.2	7620.6	7.51
Hartbeespoort	321421.69	90020.8	28.01
Hazelmere	3498.7	772.1	22.07
Henley	1961.3	176.8	9.01
Inanda	62011.30	17362.2	28.00
Klipfontein	8353.4	1560.5	18.68
Klipvoor	208420.4	55957.6	26.85
Koppies	22770.78	736.7	3.24
Laing	42859.3	12125.4	28.29
Lindleyspoort	5995.1	591.9	9.87
Midmar	16405.48	541.2	3.30
Misverstand	115431.1	7780.1	6.74
Nagle	8032.3	625.8	7.79
Roodekopjes	92508.73	7856.7	8.49
Roodeplaat	64378.5	18883.4	29.33
Shongweni	21944.1	4608.7	21.00
Vaal	393329.65	33645.9	8.55
Welbedacht	194567.7	26596.8	13.67
Witbank	63647.72	5427.1	8.53

Colour Key
>25%
20-25%
10-20%
5-10%
0-5%

6.0 Contribution of detergent phosphate to the water quality of key dams

Key dams' phosphate concentrations were assessed by means of two models (OECD model (Organisation for Economic Cooperation and Development) and the Walker Reservoir Model), to estimate the in-dam phosphate concentration reductions that might come about as a result of the elimination of detergent phosphate loading in catchments. This was based on the calculated inflow loadings, reported earlier in this document. Chlorophyll 'a' concentrations were similarly assessed using the OECD model and the Vollenweider model. The results are reported below in tables 4 and 5, and presented graphically in figure 1.

Table 4: Predicted reductions in dam phosphate concentrations based on reduced inflow loading

Dam	Mean of Model Predicted % Reductions	Median Dam Results µg/ℓ		Mean Dam Results µg/ℓ	
		Current	Predicted	Current	Predicted
Albert Falls	11%	22.7	20.2	31.2	27.8
Allemanskraal	3%	99	95.9	135	130.7
Bloemhof	14%	86	74	99	85.2
Bronkhorstspruit	5%	77	73.3	89	84.7
Erfenis	4%	165	158.3	182	174.6
Grootdraai	7%	59	55	66	61.5
Hartbeespoort	26%	106	78.6	181	134.3

Hazelmere	21%	28.2	22.4	34.7	27.6
Henley	12%	33	28.9	41.9	36.8
Inanda	35%	16.2	10.6	21.1	13.8
Klipfontein	17%	94	77.9	114	94.5
Klipvoor	25%	702	528.4	869	654.1
Koppies	3%	100	97.1	126	122.3
Laing	26%	132	97.6	140	103.5
Lindleyspoort	9%	49	44.6	65	59.1
Midmar	5%	19.5	18.4	23.8	22.5
Misverstand	6%	97	91	126	118.3
Nagle	4%	20.5	19.6	30.4	29
Roodekopjes	8%	39	36	57	52.6
Roodeplaat	27%	208	151.7	242	176.5
Shongweni	26%	42	31.2	59.2	43.9
Vaal	8%	83	76.5	107	98.6
Welbedacht	13%	99	86.6	160	140
Witbank	8%	31	28.6	44	40.6

Table 5: Predicted reductions in dam chlorophyll 'a' concentrations based on reduced inflow loading

Dam	**Model** Predicted **% Reductions**	**Median Dam Results µg/ℓ**		**Mean Dam Results µg/ℓ**	
		Current	**Predicted**	**Current**	**Predicted**
Albert Falls	9.3%	6.8	6.2	9.1	8.3
Allemanskraal	2.7%	4.0	3.9	10.8	10.5
Bloemhof	11.9%	16.3	14.4	33.5	29.5
Bronkhorstspruit	4.1%	20.6	19.8	43.6	41.8
Erfenis	3.4%	2.0	1.9	4.5	4.3
Grootdraai	5.8%	5.0	4.7	10.0	9.4
Hartbeespoort	22.2%	28.0	21.8	72.6	56.4
Hazelmere	17.6%	1.6	1.3	2.2	1.8
Henley	10.4%	3.0	2.7	4.3	3.9
Inanda	30.1%	3.6	2.5	5.2	3.6
Klipfontein	14.6%	7.0	6.0	24.4	20.8
Klipvoor	21.3%	46.7	36.8	112.6	88.6
Koppies	2.5%	9.0	8.8	17.6	17.2
Laing	22.5%	2.1	1.6	2.7	2.1
Lindleyspoort	7.7%	4.0	3.7	6.3	5.8
Midmar	4.6%	3.0	2.9	3.5	3.3
Misverstand	5.2%	5.0	4.7	10.0	9.5
Nagle	3.8%	4.3	4.1	13.5	13.0
Roodekopjes	6.6%	7.0	6.5	10.0	9.3
Roodeplaat	23.3%	31.3	24.0	46.7	35.8
Shongweni	22.3%	34.0	26.4	53.7	41.7
Vaal	6.6%	3.0	2.8	7.2	6.7
Welbedacht	10.6%	6.6	5.9	10.4	9.3
Witbank	6.6%	4.0	3.7	6.7	6.3

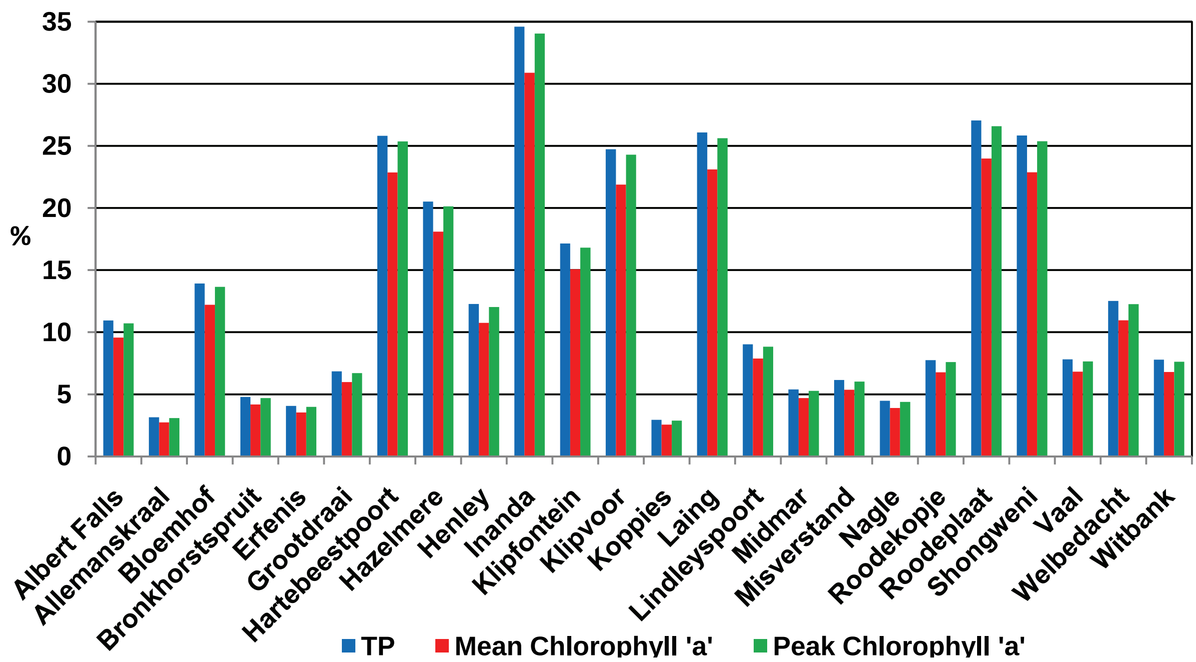

Figure 1: Graphical representation of reductions in Total Phosphate and Chlorophyll 'a' concentrations should zero-phosphate detergents be introduced.

Overall, a summed predicted decrease (across all catchments) in the inflow phosphate concentrations of 16% was predicted to result in an approximately 11-12% reduction in summed TP concentration (across all dams), and a summed 12% reduction in chlorophyll 'a' concentrations (across all dams). These results are presented below in Table 6.

Table 6: Summary of predicted reductions in dam total phosphorus and chlorophyll 'a' concentrations across all dams

	With Detergent P, tons	Without Detergent P, tons	Percentage Reduction
TP in Inflow	2 993	2 518	16%
TP in Dam, Model Predicted from Inflow Concentrations	805	708	12%
TP in Dam, Observed Less Model Predicted Reductions	621	554	11%
Chlorophyll 'a' in Dam, Observed Less Model Predicted Reductions	99	87	12%

7.0 Impact of zero-phosphate detergents on WTWs

The impact of detergent phosphate removal, and the consequent predicted reduction in algal concentrations in dams, on the costs of water purification was assessed based on a model developed for another WRC project at the Zuikerbosch and Balkfontein water treatment facilities.

Dams which showed the greatest potential for improvement in chlorophyll 'a' concentrations and which spent the most time in a hypereutrophic state or in a eutrophic state were selected as candidates for the greatest impacts. The following dams were selected:

- Hartbeespoort
- Roodeplaat
- Klipvoor

The results showed a modest reduction in costs estimated to be R616,134.00 per year for these three dams, or R9 per Mℓ. This was calculated from the results reported in Table 7.

Table 7: Summary of water treatment costs (and savings) for selected dams on the basis of the application of zero-phosphate detergents

Dam	**Hartbeespoort**	**Roodeplaat**	**Klipvoor**	**Total**
Volume treated (Mℓ/day)	90	90	5	
Predicted decline in Chl 'a' concentration (%)	22.2	23.3	21.3	
Base treatment cost (no P reduction)	R108	R90	R134	
Reduced treatment cost (zero-phosphate detergents used in respective catchment)	R97	R83	R118	
Estimated annual cost saving	R350,516	R236,641	R28,978	R616,134

8.0 Cost benefit analysis

A qualitative cost benefit analysis was undertaken to assess the impact of zero-phosphate detergents on the environment, WWTW, WTW, the manufacturers and on consumers. Issues were scored using a weighting score for importance (1- unimportant to 5- very important) and an impact score for magnitude of the issues' impacts (-2 as a strong negative to +2 as a strong positive). These scores were multiplied together to arrive at a measure of an issue's cost or benefit (range of -10 to +10).

Several issues scored negatively, such as the inability to recycle zeolite and hence the increased volume of sludge waste that may be produced, the cost of upgrading manufacturing plants and the possibility of residue being left on clothes.

These negative costs were however outweighed by positive benefits such as the decrease in overall environmental phosphate loading and algal growth, the avoidance of the rising cost of phosphate and its resultant increase in cost of detergents, the improvement in the aesthetic and recreational quality of aquatic resources and possible cost savings at WWTWs and WTWs. This resulted in an overall assessment that the introduction of zero-phosphate detergents is in fact beneficial. This finding is significant in that it reverses the findings of previous cost benefit studies which have shown that the introduction of zero phosphate detergents would in fact have a net cost to society. The shift to that of a net benefit is largely due to the change in understanding that zero-phosphate detergents may in fact not damage washing machines and fabrics (as previously assumed), and due to the rising cost of phosphate.

9.0 Conclusions

1. Regulation of detergent phosphate is a widely practiced method of addressing eutrophication problems, with many countries in Europe and many states in the USA either banning phosphate in detergents or introducing concentration limits. Many countries and states have undertaken this voluntarily without a legislative requirement.

2. Based on international experience in the use of alternative detergent builders (Hartig et al., 1990 and H. Boolah – pers com), those costs previously associated with zero-phosphate detergents such as damage to fabrics and washing machines (Pillay, 1994) are now realistically expected to be nil.

3. The impact of detergent phosphorus on WWTWs' phosphate loading varies significantly between facilities, depending on the contribution made by industrial sources in the facility's catchment, but may be up to 50% (SRP) and 32% (TP) in WWTWs treating predominantly residential sewerage. Darvill WWTW in Pietermaritzburg receives a detergent phosphate contribution of 22% (TP) and 40% (SRP) and was used as the case study in this investigation.

4. In the event of the detergent component of total phosphorus loading being eliminated, a reduction in costs associated with the removal of phosphates is possible should WWTWs continue to strictly target the 1 mg/ℓ standard. At Darvill WWTW this could possibly amount to a R2 million per year reduction.

   Obviously however, the benefit of the phosphate loading reduction will then not be seen by the wider environment which suggests that the 1 mg/ ℓ standard should be reduced in order to pass the benefit onto the environment where more substantial benefits will be obtained.

5. The efficiency of each facility will determine the impact the introduction of zero-phosphate detergents will have on down-stream water resources i.e.

   - *The phosphate concentration in effluent from facilities not operating to the 1 mg/ℓ standard is likely to be* ***reduced by up to 50% (SRP)****. It is acknowledged that very few facilities do in fact meet the 1 mg/ℓ standard consistently (Hohls, 1998; Gaydon et al., 2007; Snyman et al., 2006).*

   - *Those facilities operating to the 1 mg/ℓ standard may benefit from cost savings due to reduced need to remove phosphorus in order to meet the standard.* ***Their effluent concentration will however remain the same if they continue to target 1 mg/ℓ as an effluent phosphate concentration and no benefit will be passed on to the environment.***

   - *All facilities effluent concentrations will benefit in the event of overflow*

6. The impact of detergent phosphate on key dams varies significantly according to the level of residential settlement in its catchment, and the efficiency of WWTWs in its catchment.

7. Reductions of in-dam TP concentrations due to the elimination of detergent phosphate are estimated to range between **3% and 35%**. Dams most affected are:

    - **Inanda 35%**
    - **Roodeplaat 27%**
    - **Laing 26%**
    - **Hartbeespoort 26%**
    - **Shongweni 26%**
    - **Klipvoor 25%**

    The summed reduction for all the 24 priority dams investigated was 11-12%

8. Reductions of chlorophyll 'a' concentrations due to elimination of detergent phosphate are estimated to range between **2.5% and 30%**. Dams most affected are:

    - **Inanda 30%**
    - **Roodeplaat 23%**
    - **Laing 23%**
    - **Hartbeespoort 22%**
    - **Shongweni 22%**
    - **Klipvoor 21%**

    The summed reduction for all the 24 priority dams investigated was 12%

9. Water treatment cost savings associated with reductions in algal blooms appear to be relatively small – R616,134.00 per year over 3 facilities – R9 / Mℓ

10. The significant increase in the cost of phosphorus increases the benefit of zero-phosphate detergents to consumer and producer and will increasingly do so into the future.

11. The introduction of zero-phosphate detergents will impact on the Waste Discharge Charge System by reducing potentially collectable revenue. Revenue collection is however not the goal of this system, and given that the reduction will not result in knock-on effects for other industries / polluters, this impact is deemed to be negligible.

12. Based on a qualitative cost benefit analysis, **a switch to zero-phosphate detergents appears to offer potential benefits for the environment, the water purification industry and the manufacturer. The negative impacts to WWTWs, the WDCS and to the consumer are determined to be negligible.**

10.0 Recommendations

1. Based on the arguments developed through this report and summarized here, it is the conclusion of this report that the **elimination of phosphate from detergents is both beneficial and desirable**, and it is thus recommended that the replacement of phosphate containing detergents with zero-phosphate alternatives should be carried out as soon as is feasible.

2. It is also the recommendation of this study that negotiations be entered into between the DWA and detergent manufacturers to **establish a mutually agreeable process for this transition to be achieved**.

3. Although it is recommended that this process be approached in a co-operative manner that **allows manufacturers to take a leading role** (and thus achieve a maximum benefit from the process through marketing and public relations exercises), it is important that **the change to zero-phosphate detergents be consolidated through legislation**. This would mean that, should a change in world markets result in phosphate rich detergents once again providing a competitive advantage, that the possibility of manufacturers returning to them is negated.

4. It is also recommended that the relevance and implementation of **the 1 mg/ℓ phosphate effluent standard be reviewed**. This is specifically important given the predicted reductions in influent phosphate loading at WWTWs that will result from the elimination of detergent phosphates, and the importance of transferring that benefit to downstream aquatic environments.

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- Mr G Grobler (DWA)
- Dr WR Harding (D.H. Environmental Consulting)
- Dr CE van Ginkel (DWA)
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- Mr S van der Heyden (Pegasys)

List of acronyms and abbreviations

DO	Dissolved Oxygen
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
INR	Institute of Natural Resources
LSM	Living Standards Measure (Socio-econonomic categorization)
P	Phosphorus
PO_4	Ortho-Phosphate
Pdet	Phosphorus originating from detergent
Pmet	Phosphorus originating from human metabolism
SRP	Soluble Reactive Phosphorus
STPP	Sodium Tri-PolyPhosphate
TP	Total Phosphorus
WDCS	Waste discharge charge system
WRC	Water Research Commission
WTW(s)	Water treatment works
WWTW(s)	Waste water treatment works
Zero-PO_4	Zero phosphate

Investigation of the positive and negative consequences associated with the introduction of zero-phosphate detergents into South Africa

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1. INTRODUCTION

1.1 Project background

Eutrophication poses a major threat to South Africa's scarce water resources. Phosphate is known to be one of the limiting factors in algal growth (Walmsley, 2000) and it is thus an important contributor to the eutrophication of water bodies (Pillay, 1994).

Following a report by Heynike et al. (1986) which concluded that removing phosphate at WWTWs was more feasible than removing it at source, and in response to growing awareness of the threat posed by phosphate pollution, a 1 mg/ℓ effluent concentration standard for soluble reactive phosphorus (SRP) was legislated in South Africa. This was intended to limit the loading of sensitive surface water bodies by point source effluent such as that released by Waste Water Treatment Works (WWTWs). At the time, this measure was considered sufficient to combat the eutrophication threat, and the subject receded from the research limelight.

It has more recently become apparent that the 1 mg/ℓ standard has not managed to curtail phosphate pollution, or have an impact on eutrophication. Some specialists are of the opinion that the 1 mg/ℓ standard is far too lenient and that the standard concentration should have been set far lower than this value (W. Harding – Pers comm.). Whatever the case, heavy phosphate pollution continues largely because WWTWs are unable to consistently achieve reductions in effluent concentration even to this lenient 1 mg/ℓ standard (Hohls (1998); Gaydon et al. (2007*);* Snyman (2006b)) and also because of the vast volume of waste water being treated and being released into the catchments of key dams.

It has been suggested that up to **35-50% of this phosphate** is suggested to be derived from **powdered laundry detergents** (Pillay, 1994) and thus limiting the use of this ingredient in the manufacture of detergent products presents an attractive way to help reduce eutrophication and its associated costs.

The Water Research Commission (WRC) thus identified the need to investigate the positive and negative consequences associated with the introduction of zero-phosphate (Zero-P) powdered washing detergents into the South African market place. The WRC solicited proposals to conduct such an investigation and subsequently contracted the Institute of Natural Resources (INR).

Powdered laundry detergents were specifically focused on due to the vast market share that they command. According to Unilever's consumer survey, it is estimated that upwards of 97% of all households use powdered laundry detergents. Automatic dishwasher detergents do contain phosphate, but their contribution to phosphate loading is negligible in comparison to powdered laundry detergents due to the relatively few people using dishwashers and the small doses involved (R. Plumbley – Pers comm.). Liquid soaps and laundry bars do not contain phosphate. These products have thus not been considered.

It is important to note that the element phosphorus (P) is contained in other components of detergents such as the fluorescers and optical brightners. There is no effective substitute for phosphorus in these components and they thus cannot be removed from formulations. This project considers only the phosphorus contained in the phosphate STPP builder component.

1.2 Project aims

The aims of this project were:

1. to review the current local and international best practice with regards to the use and restriction of phosphates in detergents (ch. 2),
2. to estimate the impact detergent phosphates are having on the phosphate loading and efficacy of Waste Water Treatment Works (WWTWs) (ch. 3), and their ability to meet the 1 mg/ℓ phosphate standard for effluent (ch. 4).
3. to estimate the impact detergent phosphates are having on the phosphate loading and frequency and severity of algal blooms in key dams around the country (ch. 5&6)
4. to estimate the cost savings that may occur at Water Treatment Works (WTWs) and at WWTWs if detergent phosphate were to be eliminated (ch. 4 & 7)
5. to conduct a cost benefit analysis of the introduction of zero-phosphate detergents across all sectors including the costs that may accrue to consumers in the form of damage to fabrics and washing machines (ch. 8)
6. to investigate the impacts of the introduction of zero-phosphate detergents on the Waste Discharge Charge System (WDCS) (ch. 8).

1.3 Project approach

The approach of the project was to investigate the possible consequences of introducing zero-phosphate detergents, 1) internationally and locally, through a comprehensive literature review, and 2) locally, through the desktop analysis and modeling of existing data from a number of arenas, namely:

- **Waste Water Treatment Works (WWTWs)** – concentration and loading data from various WWTWs, but particularly Darvill WWTW in Pietermaritzburg was studied to assess the proportion of phosphate arriving at a WWTWs that is attributable to detergents;
- **Phosphate loading of key dams** – dam catchment loading data, derived from landuse based phosphate export coefficients, was used to estimate the proportion of phosphate loading at key dams that is attributable to detergents;
- **Algal growth and eutrophication in key dams** – possible reductions in phosphate loading calculated earlier in the project were used to provide input data for well known predictive models to estimate the reduction in dam phosphate concentrations and chlorophyll 'a' concentrations that may come about as a result of the removal of detergent phosphate;
- **Water Treatment Works (WTWs)** – potential reductions in chlorophyll 'a' concentrations calculated earlier in the project were used as the basis for estimating reductions in the costs of water purification using cost modeling techniques developed in other studies;

- **Costs and benefits for society at large** – the potential costs and benefits of introducing zero-phosphate detergents were assessed through literature review, interviews, and cost modeling, resulting in a qualitative assessment of the societal value of introducing zero-phosphate detergents.

1.4 Report Structure

Chapter 1:

Introduction – This chapter includes the project background, aims and approach.

Chapter 2:

Literature review. This chapter reviews local and international literature assessing phosphate management best practice through case studies and other relevant literature.

Chapter 3:

The impact detergent phosphorus has on WWTWs. This chapter attempts to assess the impact of detergent phosphates on the phosphate loading of municipal WWTWs. This is done through case studies, using detergent consumption statistics and household data from serviced urban areas.

Chapter 4:

The cost implications of detergent phosphates and zero-phosphate detergents, for WWTWs. This chapter reviews Darvill WWTW processes and attempts to establish the impact of detergent phosphate on the facility, and if there are any savings that may arise through its elimination.

Chapter 5:

The impact of detergent phosphate on the phosphate loading of key dams. This chapter estimates the proportion of phosphate loading at key dams that is attributable to detergent phosphates. This is done using landuse phosphate export coefficients and a landuse map of each dam's catchment.

Chapter 6:

The impact of detergent phosphates on the frequency and severity of algal blooms in key dams. This chapter uses several well known predictive models to estimate the effect that a reduction in phosphate loading will have on the in-dam phosphate concentration and the chlorophyll 'a' concentration (a measure of algal growth) in the dam.

Chapter 7:

The impact of zero-phosphate detergents on the water purification process. This chapter estimates the changes in the costs of water purification given the possible reduction in algal concentrations due to the introduction of zero-phosphate detergents.

Chapter 8:

A cost benefit analysis of the introduction of zero-phosphate detergents. This chapter assesses the economic impact of the introduction of zero-phosphate detergents, looking at impacts to manufacturers, consumers, the environment and the wider economy.

Chapter 9:

Conclusions and recommendations.

2. LITERATURE REVIEW

2.1 Introduction

Phosphate is known to be one of the limiting factors in algal growth (Walmsley, 2000) and it is thus an important contributor to the eutrophication of water bodies (Pillay, 1994). However up to 35-50% (Pillay, 1994) of this phosphate is suggested to be derived from detergents and thus limiting the use of this ingredient in detergents presents an attractive way to help reduce eutrophication and its associated costs.

In order to understand the implications of limiting detergent phosphate it is necessary to first understand something about detergents. A detergent is a cleaning compound with dual hydrophilic and hydrophobic properties thus enabling it to remove organic and inorganic soils. In order for a detergent to be of high quality it consists of four parts; the surfactant, builder, bleach and various additives. In this case the builder is of interest as it contains the phosphate component as the polyphosphate builder, pentasodium triphosphate (STPP). The STPP is easily hydrolyzed and thus made available for biological systems as orthophosphate, enhancing eutrophication (Pillay, 1994)

The criteria that a builder, such as STPP, must fulfill to be effective are according to Pillay (1994) and Heynike et al. (1986):

- It must soften hard water by forming complexes with calcium, ferric and magnesium ions.
- Prevent spotting, graying or scale deposition by sequestering Ca and Mg ions.
- Preventing rust and corrosion by chelating iron and aluminum
- Keep soil particles in suspension in micellar form
- Buffer the pH of the washing solution for optimum washing and to prevent soil re-deposition.

The STPP and phosphate content of laundry detergents is on average 26% and 6.5%, by weight (Pillay, 1994). After use it enters the environment in two main ways. The first is through wastewater treatment works in urban areas (thus termed urban detergent P) entering the environment as point sources of waste water effluent. The second way is through use in rural areas where it enters the environment untreated as a non-point source (thus known as rural detergent P). Thus eliminating phosphate from detergents may be an effective way of controlling both point and non point phosphate pollution (Pillay, 1994).

An example of the success of banning detergent phosphate comes from the James River, Virginia. Before the ban the increase in phosphate loading between two sites, above and below Richmond, was 85% (0.11 mg/ℓ) and after the ban was only a 13% increase (0.02 mg/ℓ). The dissolved orthophosphate proportion which previously increased by 88% (0.08 mg/ℓ) as the river passed through the city was now reduced to 25% (0.02 mg/ℓ) (Hoffman, 1994).

The alternative to banning or limiting detergent phosphate is the same as the situation currently found in South Africa i.e. to actively remove the phosphate from the waste water. Phosphate can be removed from wastewater treatment works (WWTWs) biologically by the activated sludge process that utilizes microorganisms to strip the phosphorus, in artificially created reed beds or chemically by addition of iron or aluminum salts that form insoluble phosphate precipitates that can be removed by sedimentation. The resulting sludge may be incinerated, land filled or used as agricultural fertilizer. More recent processes include the Smit Nymegan process which utilizes a carrier magnetic material or the Crystalactor, which is a compact fluidized bed reactor. Both these processes will remove the phosphate from the waste and then provide high grade phosphate for use in phosphate and phosphoric acid products such as animal feeds, fertilizers and pharmaceuticals (Pillay, 1994 12).

However phosphate removal is expensive and does not solve the problem of rural detergent phosphate loading, a major issue in South Africa, added to which is the widespread failure of WWTWs to successfully remove the phosphate so even point source pollution is not successfully controlled. Combined with the fact that current phosphate deposits will only last another 100 years (Tangsubkul, 2005) suggests that it may be more reasonable to either ban or recycle detergent phosphorus, although banning it may prove to be the most cost effective.

The problem of detergent phosphate was recognized in the late 1960s in North America, Western Europe and Japan and to some extent these countries have all imposed regulations restricting the use of detergent phosphate (Pillay, 1994). This generally only applied to laundry detergents but recent concern over dishwashing detergents has led Washington State in 2006 to ban dishwashing detergent phosphate (Ebeling, 2007). This move has led the rest of the developed world to also consider such a ban, with this project being a South African initiative to consider the issue.

As with any imposed restriction such as this, the repercussions are potentially large, so in this review we investigate the implications for the operation of the wastewater treatment works , the loading to the rivers and dams and the resulting cost-savings in terms of water treatment, and the potential extra cost to consumers. Also discussed will be the local and international status and best practices with regard to detergent P.

2.2 The current local and international status and best practices with regard to the use of phosphate in detergents

In the 1970s pioneering legislation in the USA was implemented limiting the STPP content of detergents from 15-60% down to 8.7% (Litke, 1999) as well as banning it in states bordering the Great Lakes due to concern over eutrophication (Pillay, 1994) . Other eutrophication prone areas across the USA soon followed suite resulting in 28% of the USA having a detergent ban and 30% of the detergent market consisting of P-free detergents in the 1980s (Litke, 1999)). The banning continued until 53% of the USA was under ban in 1998 (Litke, 1999), as shown below.

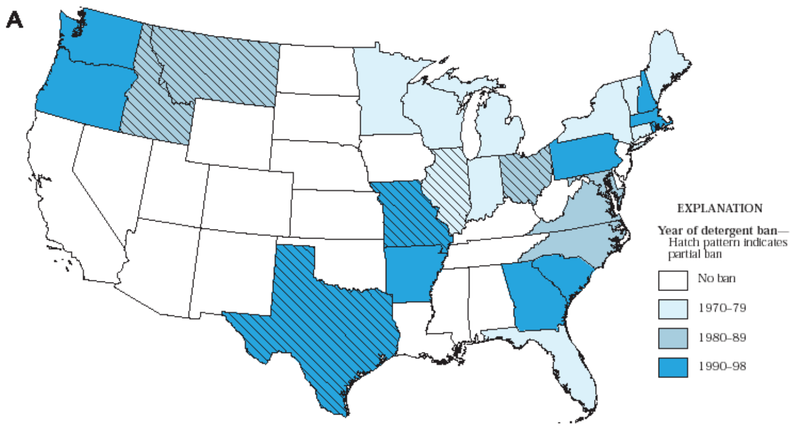

Figure 1: States with phosphate detergent bans (Litke, 1999). Striping indicates a partial ban.

In 1975 Italy and Switzerland implemented a 1% limit on the phosphate content of detergents and voluntary implementation in the Netherlands led to a 95% reduction in phosphate detergent use. Japan also implemented a legal limit of 4.3% and by 1992 100% of detergents were P-free (Pillay, 1994). In the UK the Soap and Detergent Industry Association stated that "there were no environmental benefits of limiting phosphate in detergent but rather that removing the phosphate load by phosphate stripping at WWTWs was more effective" and so no phase-outs were planned or enforced but never-the-less one fifth of UK detergents soon became P-free (Pillay, 1994). Table 1 is a summary of detergent phosphate limitations throughout the world.

Yet, despite the move to ban phosphate detergents, Acke (2001) suggested that the claims to limit eutrophication had been overstated and that the ban seemed to be futile in parts of the USA, Western Europe and Japan. Evidence for this from Europe showed that only 11% of the total phosphorus load of surface waters was from detergent phosphate. Instead, agriculture (49%) and human waste in sewage (23%) were the largest loaders of phosphate. He thus suggested that changing to P-free detergents will not solve the eutrophication problem entirely but is nevertheless a step in the right direction.

Along with the banning of detergent phosphorus, most of these countries have a standard maximum concentration of SRP for waste water effluent. This is usually in the range of 0.5-1.5 mg/ℓ in the USA (Litke, 1999). Having less phosphate in the influent due to the absence of phosphate detergents makes it easier and cheaper for WWTWs to reach this standard. This is significant as shown by Hartig et al. (1990) that 41% of the municipal flow into Lake Erie results from WWTWs unable to achieve their phosphate standard of 1 mg/ℓ.

The recent reductions in phosphate detergent use in the West can be seen from the reduction in STPP production in China, which produces 60% of the worlds STPP. In 2006 55% (1,8 million tons) of the 3,3 million tons of detergents that were exported from China were P-free. This shows a 50%

decrease in P-detergents from China since 2000 and is mirrored by the 31.6% increase to 500 000 tons/annum in zeolite A production as an alternative to STPP (Xigao, 2007).

More recent concern is over the use of dishwashing detergents containing phosphate and thus dishwasher detergent manufacturers (Procter & Gamble or Reckitt Benckiser) are moving to develop P-free dishwasher detergents by 1 July 2010 as was required by Washington State in 2006, which introduced a 0.5% by weight limit on phosphate content of dishwasher detergents (Ebeling, 2007).

Table 1: Summary of countries with detergent phosphate restrictions or bans (Pillay, 1994)

Country	**Year**	**Status**	**% Phosphate**
Switzerland	1986	Legislative	Banned[1,2,3]
Germany	1984	Legislative	5.5[1], 5.0[3]
Austria	1987	Legislative	5.5[1], 5.0[3]
The Netherlands	1983	Voluntary	5.5[1], 5.0[3]
Sweden	1970	Voluntary	7.5[1,3]
France		Voluntary	5.0[3]
Finland	1970	Legislative	7.0[1,3]
Italy	1986	Legislative	2.5[1], 1.0[2,3]
Norway	1986	Legislative	3.0[1], banned [3]
Japan (Shiga and Tokyo)		Legislative	banned [3,5]
Japan	1978	Legislative	4.3[1], 2.5[3]
Venezuela		Legislative	banned[3]
Canada	1973	Legislative	2.3[1], 2.2[3]
USA States		Legislative	
Connecticut	1972	Legislative	8.7[3,4]
Florida	1972	Legislative	8.7[1,3,4]
Maine	1972	Legislative	8.7[1,3,4]
Indiana	1973	Legislative	banned[1,3]
Maryland	1985	Legislative	banned[1,3]
Michigan	1977	Legislative	banned[1,3]
Minnesota	1979	Legislative	banned[1,3]
New York	1973	Legislative	banned[1,3]
Vermont	1978	Legislative	banned[1,3]
Wisconsin	1984	Legislative	banned[1,3]
Virginia		Legislative	banned[1,3]
North Carolina		Legislative	banned[3]
South Carolina	1991	Legislative	0.5[4]
Oregon	1991	Legislative	0.5[4]
USA Selected Counties			
Dade County		Legislative	8.7[3]
Idaho		Legislative	banned[4]
Montana		Legislative	banned[4]
Ohio		Legislative	banned[4]

Texas	1992	Legislative	banned[4]
Country	**Year**	**Status**	**% Phosphate**
USA Municipalities			
Washington DC	1986	Legislative	banned[1,3]
Chicago		Legislative	banned[3]
Akron		Legislative	banned[3]
Portland		Legislative	banned[4]
Ore		Legislative	banned[4]
Spokane		Legislative	banned[4]
Washington		Legislative	banned[4]
USA Communities			
Illinois		Legislative	banned[4]
New Hampshire		Legislative	banned[4]
Idaho		Legislative	banned[4]

1 Andree et al., 1987, 2 - Department of the Environment, 1991, 3 - United Nations, 1992, 4 - Ainsworth, 1992, 5 - Houston, 1987

Research into STPP substitutes that display the requirements of an effective builder has been prolific and the eight builders or co-builders that can be used are listed below along with their attributes (Pillay, 1994).

Zeolite A-Is one of many insoluble sodium aluminosilicates that are applicable for detergent use however in order to equal the effectiveness of phosphate detergents they are used in combination with the co-builders NTA, polycarboxylates, carbonates and citrates. The most favoured substitute is possibly the three builder system of zeolite A, sodium carbonate and polycarboxylate.

Nitrilotriacetic acid (NTA)- is excellent at sequestration but lacks other qualities required of a builder. It is prepared from hydrogen cyanide and is thus expensive. However this would be an economically feasible substitute if the hydrogen cyanide could be obtained as an industrial byproduct such as produced by the formation of polyacrylonitrile.

Sodium silicate- mainly used as an alkaline buffer and for controlling corrosion but has no effect on softening water and redeposition, which is a quality required for a builder to be effective.

Sodium citrate- is considered mainly due to its excellent hydrolytic stability, safety and biodegradability. Furthermore it is derived from renewable resources such as starch hydrolysates, sugar and cane and beet molasses. However, at high temperatures (>60 C) its calcium binding capacity decreases drastically but, < 60 C it performed far better than STPP when used in combination with zeolite A. The only real downside of sodium citrate is that of cost.

Sodium carbonate- used in phosphate and P-free detergents due to its cheapness and good alkaline buffering it also softens water by depositing hard ions. The main negative is that the life-span of fabrics and machine parts is reduced due to the salt deposits but this can be reduced by incorporating some STPP into the detergent, which thus partially defeats the purpose of eliminating phosphate. Sodium carbonate is commercially produced by the reaction of sodium chloride with carbon dioxide.

Carboxylic acids- a co-builder not able to replace STPP entirely because of its insufficient complexing capability but is desired for its ability to disperse dirt particles and precipitates and thus prevent graying and encrustation of fabrics and machine parts. Their economic advantage is marked by outstanding homogenization and stabilization capabilities. They are manufactured either by homopolymerisation of acrylic acid or modified by the copolymerization of acrylic acid and maleic anhydride.

Soaps- are good and readily available water softeners whose performance is generally good and production renewable using easily obtained oils and fats, however their weakness lies in their inability to cope with heavily soiled items and thus they have limited use.

Ethylenediamine tetrataacetic acid (EDTA)- used to increase bleaching efficiency by controlling levels of free ions in solution due to its powerful chelating abilities. Even though only a small amount is required it is far more costly than STPP and thus is unlikely to replace it.

The above summary of STPP substitutes shows that none of the substitutes alone are as effective as STPP, however some combinations are quite effective. Nevertheless much controversy surrounds this issue, where effectiveness and cost are important factors. Evaluations into the effectiveness of zero-phosphate detergents were carried out by the Consumers Union, in the USA (Hartig et al., 1990) and Shuster Laboratories (Hanrahan, 2004). These are coupled by evaluations into the cost of zero-phosphate detergents by Choice (2005), Xigao (2007) and Hanrahan (2004). It was found that zero-phosphate detergents can indeed be made as effective as PO_4 detergents with little cost to the consumer.

Compared to the developed world South Africa has done very little to control phosphate loading of water sources. To date, the main emphasis has been on phosphate removal at the WWTWs and not on limitation of detergent phosphate. A standard of 1 mgP/ℓ was implemented on the 1st August 1980 for effluents discharged into seven sensitive catchments but this has often not been achieved (Walmsley, 2000). Lack of enforcement and monitoring and a low priority status by the government resulted in nutrient enrichment remaining a major problem in South Africa (Walmsley, 2000).

An example of this failure to effectively implement the phosphate standard comes from the Roodeplaat dam subcatchment, part of the seven identified catchments in need of P-limitation (Hohls, 1998). The main P-contributors to the dam were the Baviaanspoort and Zeekoegat WWTWs, which were meant to implement the standard by 1988. However, from 1992-1995 the effluent SRP concentration exceeded the standard 50% and 77% of the time at Baviaanspoort and Zeekoegat, respectively. Moreover, there were times when the concentration exceeded 5 and 10 mg SRP/ℓ (8.5% and 3% of the time) at Zeekoegat. The large SRP concentrations from Zeekoegat resulted from the failure of equipment such as chemical dosing equipment, biological reactors and pumps.

In a controversial report released in 2007, by Gaydon et al it was noted that most of the 600 small WWTWs in South Africa were not meeting even their most basic targets, with as little as 10% compliance, and that there does not seem to be a short-term solution. This lack of implementation of policy provides compelling reason to ban detergent phosphate as it removes the responsibility from the WWTWs to prevent the eutrophication of the downstream water resources.

The decision to ban phosphate or stay with current practice could have a profound effect on South African water resources. The growing population means that phosphate loading can only be expected to increase and the eutrophication of surface waters will worsen. Hols (1998) suggested that if the 155 µg/ℓ of SRP in the Roodeplaat dam likely to occur in 1999 were projected into the future, the phosphate concentration would increase to 320 µg/ℓ in 2010 if current legislation is followed, but probably would be worse than that given currently inability to meet discharge targets. However, Hols suggested that if influent SRP were cut by half due to banning detergents than the 2010 concentration could be limited to 175 µg/ℓ. Thus banning detergent phosphate may effectively mitigate future phosphate load increases.

An issue often regarded as a lesser problem to eutrophication is that of salt loading. For every 1 mg/ℓ of phosphate removed the salt concentration increases by 10 mg/ℓ. Therefore 24-32 mg/ℓ of salt may be attributed to detergent phosphate removal at WWTWs and the effluent may pose a serious threat to the river ecosystem (Heynike et al., 1986).

2.3 The contribution that detergent phosphate is making to the phosphate loading of waste water treatment works.

2.3.1 Case Study 1 (local): Detergent phosphate's contribution to the phosphate loading of WWTWs in the Umgeni Catchment (Pillay, 1994); and Moss, (undated review of Pillay's study).

The phosphate loading of WWTWs was found by calculating the per capita detergent phosphate consumption and applying this to the urban population of the subcatchments. Thus it was assumed that all the detergent phosphate used in urban areas would reach the WWTWs and none from rural areas, as they are not linked by infrastructure.

It was calculated that the per capita detergent phosphate consumption for the Umgeni catchment area was 0.229 kg/(capita.annum) found by multiplying the detergent consumption of 3.53 kg.(capita.annum) and the average phosphate content of 6.5% by weight.

The loadings of WWTWs in subcatchments shown in Table 2 below are for the waste water influent collected from all the WWTWs in the (sub) catchment. For example, the total phosphorus load of 0.9/**1.5** (the two figures representing the calculations by Pillay and Moss respectively) for the Nagle subcatchment is the sum of the phosphate discharge from the Howick Mid Hospital, Howick WWTW, Sarmcol 1 & 2, Mountain Home, Midmar, Cedara, Ladsworth, Hilton College and Golden Pond WWTWs effluents.

Moss (undated review of Pillay's report) suggests an error in Pillay's calculations as she only considered urine and not human excreta in general as contributors to phosphate loading, which inflated the detergent phosphate contribution considerably. Moss's revised values are given in **bold** (using 0.55 kgP/capita/year from excreta instead of the 0.219 kgP/capita/year from urine only).

Table 2: The % of detergent phosphate in phosphate loading of WWTWs per subcatchment of the Umgeni catchment (formulated from data by Pillay (1994) and Moss *[figures in bold]* ***(undated review of Pillay's study)).***

		Phosphate Load in the influent (tons/annum)							
		Urban Detergents	urine	**human excreta incl. urine**	Industry	Total		% detergent P	
Subcatchment	urban population					Pillay	**Moss**	Pillay	**Moss**
Midmar	16370	3.8	3.6	**9**	0	7.3	**12.8**	51	**30**
Albert Falls	10624	2.4	2.3	**5.8**	0	4.8	**8.2**	51	**29**
Nagle	2007	0.5	0.4	**1**	0	0.9	**1.5**	51	**33**
Inanda	274848	63.1	60.2	**151**	47.9	171.1	**262**	37	**24**
Total	303849	69.7	66.5	**166.8**	47.9	184.1	**284.4**	38	**25**

Note: the totals of Pillay and Moss incorporate urine and human excreta respectively.

From Table 2 it is calculated that the per capita contribution of SRP as 0.9g/capita/day for the Umgeni catchment, which is similar to the 1 g/capita/day calculated by Weddepohl (1992) for South Africa in general. This 'standard' holds for much of South Africa but it is skewed in places where industrial discharges either dilute or concentrate the phosphate load. Most importantly, though, in this relevant and local case study, it was found that detergent phosphate contributes 25% (69.7 tons/annum out of 284.4 tons/annum (according to Moss)) of the phosphate loading of WWTWs. According to Pillay (1994) the range was 37-51% which is very near the 34-50% predicted for major cities by Heynike and Wiechers (1986) in Table 3.

Table 3: The 1981/82 contribution of detergent phosphate to domestic sewage works in various geographical localities around South Africa (Heynike and Wiechers, 1986).

Town/City	SRP load (kg/day)			% contribution by detergent P
	human excreta	detergent	Total	
Cape Town	696	549	1245	44
Johannesburg	2600	1560	4160	38
Bloemfontein	260	134	394	34
Benoni	47	47	94	50
Total	3603	2290	5893	40

2.3.2 Case Study 2 (international): The Whittlesea Local Treatment Plant (LTP), Melbourne, Australia (Halliwell, 2001).

The Whittlesea LTP receives waste water from an entirely domestic source of 425-525 homes with an average of 2.8 persons in each.

Most washing activity takes place from 0600 to 2300 with three peaks, shown in Figure 2, occurring during the mid-morning, midday and late afternoon washing periods. Figure 2 also shows the ariance in phosphorus loading on days of low (△) and high (□) washing activity. The average amounts of detergent phosphate entering the LTP were 260g P/day and 355g P/day on days of low and high washing activity. However, calculations were only done on the contribution of detergent phosphate to the total phosphorus load on a day of low washing activity day as the results for the day of high washing were inadequate.

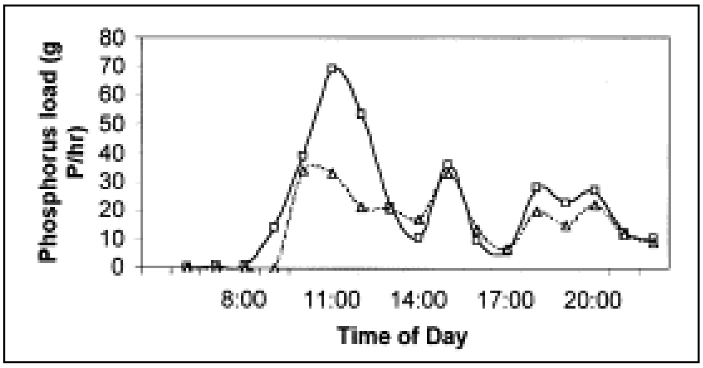

Figure 2: Estimated loads for the (□) high and ( ) low phosphate loads for the load days based on the median flow data.
Error bars are ±1 σn−1(n=3) (Halliwell, 2001).

The load of detergent phosphate entering the LTP was between 202-339 gP/day (25-75% percentiles). However it was discovered that biocatalysis and temperature increased the rate of hydrolysis of triphosphate (the original form of detergent P) and thus these figures were an underestimate. In order to rectify this, the half lives shown in Figure 3 were used to calculate the original mass of triphosphate in the sewage at 20°C. This was found to be 2070-3390gP/day and 11-30% of this, or 370-621g/day, was contributed by detergent phosphate.

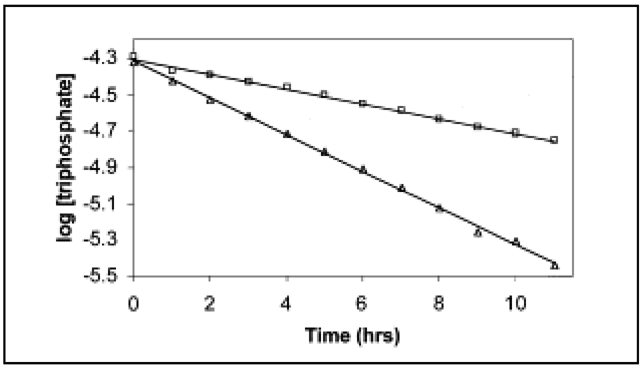

Figure 3: The hydrolysis rate of triphosphate in Whittlesea sewage at (□) 15°C and ( ) 20°C.
Error bars are ±1 σn−1(n=3). An increase of 5 degrees doubles the rate of hydrolysis as the half-lives for triphosphate at 15 and 20°C respectively are 7.42±0.15 and 2.97±0.04 h (Halliwell, 2001).

An error was discovered in these figures due to the data obtained by Halliwell (2001) as the sewage tested had been filtered of particles >0.2µm. It was later found by Halliwell that 20% of the triphosphate was removed in the residue and therefore the contribution of detergent phosphate to the total phosphorus load was 14-38% (25-75 percentiles). This gives 593-983g/day contributed by detergent phosphate out of a total SRP load of 2588-4238g/day.

The amount of phosphorus entering the LTP can also be found using the population (425 houses x 2.8 people) and detergent phosphate consumption per capita (0.85 gP/person/day) which gives an answer of 1012g/day of detergent phosphate loading on the LTP. This is significantly higher than the value calculated above based on concentrations, but this is a combination of low and high washing activity days (whereas the number above is for low washing activity) and also includes the 20% detergent phosphate removed by the filtering process. The loading figures are thus not that dissimilar.

Considering both case studies it is interesting to note that the SRP contribution from detergent phosphate is much the same, with 25% detergent phosphate contribution in the Umgeni catchment and 14-38% at the Whittlesea LTP. Whittlesea had a slightly higher detergent phosphate contribution possibly as it was purely domestic and had no industrial SRP sources, as did the Umgeni catchment.

2.4 The contribution that detergent phosphate to the phosphate loading of dams.

Phosphate is distributed in impoundments mainly by turnover, stratification, soluble complex formation, precipitation and dissolution, absorption and desorption, redox processes and biological uptake and mineralization (Pillay, 1994)

2.3.1 Case Study 3: The contribution that detergent is having on the impoundments of the Umgeni catchment (Pillay, 1994; Moss, undated).

This case study can be seen as a continuum of 'Case Study 1' as they both deal with the Umgeni catchment. To calculate the phosphate loading of the four main impoundments it is necessary to know the urban and rural detergent phosphate contributions.

For the urban detergent loading calculation, the percentage of detergent phosphate in the influent, from Table 2 has been applied to the Total SRP loading of effluent, measured by Pillay to obtain the Total Urban detergent phosphate loading in waste water effluent. It was assumed that the proportion of detergent phosphate in the total SRP load will be constant, even as the SRP concentration is reduced by the WWTWs. The results are shown in Table 4, with those in **bold** indicating they have been modified by Moss (undated review of Pillay's study).

Table 4: The Total urban detergent phosphate loading of impoundments, through effluent (formulated from data by Pillay (1994) and Moss (undated).

Subcatchment	Total SRP loading due to waste water effluent (tons/annum) – Pillay.	**% detergent P (Moss)**	**Total urban detergent P loading in effluent (tons/annum) – Moss.**
Midmar	1.09	**30**	**0.33**
Albert Falls	4.18	**29**	**1.21**
Nagle	0.55	**33**	**0.18**
Inanda	24.9	**24**	**6**
Total	30.72	**25**	**7.72**

Next, to calculate the rural detergent phosphate contribution it was shown by *Lever Bros*. that 16% of rural washing took place at the river/dam thus the rural detergent loading results are given below (Pillay, 1994). The rural detergent phosphate consumption is 0.106 kg/(capita.annum) calculated from 1.63 kg detergent per capita per annum and average phosphate content of 6.5%. Once again these results are potentially flawed as it is likely that some of the detergent phosphate from laundering at sites away from the water source would find their way to the river, thus increasing the rural detergent load. Also not much is known about the 'life cycle' of rural detergent phosphate as it makes its way to the impoundment as much of this may be assimilated into the ecosystem *en route*.

Table 5: The Total rural detergent loading of impoundments (Pillay, 1994).

subcatchment	rural population	Total detergent P consumption (tons/annum)	Total (16% of consumption) detergent P loading (tons/annum)
Midmar	16 678	1.8	0.28
Albert Falls	16 514	1.7	0.28
Nagle	82 493	8.7	1.4
Inanda	494 786	52.4	8.4
Total	610 471	64.5	10.3

When the urban and rural loadings are combined, in Table 6, we can see that they contribute 43% (12.15 tons/annum) and 57% (10.3 tons/annum) of the total detergent phosphate loading of impoundments, respectively. Once again the **bold** figures are those modified by Moss.

Table 6: The Total detergent phosphate loading arising from rural and urban laundering (formulated from data by Pillay (1994) and Moss (unknown)).

Subcatchment	detergent P loading (tons/annum)		
	Rural	**Urban**	**Total**
Midmar	0.28	**0.33**	**0.61**
Albert Falls	0.28	**1.21**	**1.49**
Nagle	1.4	**0.18**	**1.58**
Inanda	8.38	**6**	**14.38**
Total	10.34	**7.72**	**18.06**

With the above knowledge of detergent phosphate loading it is possible to develop three scenarios (see tables below) that indicate the contribution that detergent phosphate has on the total phosphorus loading of the largest impoundments on the Umgeni catchment.

The 0%, 20% and 50% diffuse source contribution scenarios, for scenarios 1-3, are obtained from Pillay (1994) but as stated by Moss these are purely notional and he suggested a 33% diffuse source contribution in scenario 4. Those results in **bold** have been modified by Moss (undated) and the rest are sourced from Pillay (1994).

<u>Scenario 1</u>: The only sources of soluble phosphate were wastewater effluents and detergents that entered from rural laundering carried out directly at the watercourse (see

Table 7).

<u>Scenario 2</u>: In addition to the loading from wastewater effluents and rural laundering, non point sources (e.g. agricultural lands, informal settlements) contributed 20% to the catchment soluble phosphate loading. (See Table 8. Figures in bold are from Moss (undated)).

Table 7: Scenario 1 – only phosphate source is WWTWs and rural laundering in streams / rivers / dams

Subcatchment		SRP loading (tons/annum)				% detergent P
	Point source/ urban	Rural	Other non-point	Total catchment	Total detergent P	
Midmar	1.09	0.28	0	1.37	0.84	61
Albert Falls	4.18	0.28	0	4.46	2.42	54
Nagle	0.55	1.4	0	1.95	1.68	86
Inanda	24.9	8.38	0	33.28	17.56	53
Total	30.72	10.34	0	41.06	22.5	55

Table 8: Scenario 2 – Sources of phosphate include WWTWs, rural laundering and 20% diffuse source contribution

Subcatchment	Soluble P loading (tons/annum)						% Detergent P	
	Point source	Rural Detergent	Other non-point (20%)	Total Catchment	Total Detergent P			
					Pillay	**Moss**	Pillay	**Moss**
Midmar	1.09	0.28	0.34	1.71	0.84	**0.61**	49	**35**
Albert Falls	4.18	0.28	1.11	5.57	2.42	**1.49**	43	**27**
Nagle	0.55	1.4	0.49	2.44	1.68	**1.58**	69	**65**
Inanda	24.9	8.38	8.32	41.6	17.56	**14.38**	42	**35**
Total	30.72	10.34	10.26	51.32	22.5	**18.06**	44	**35**

Scenario 3: In addition to the loading from wastewater effluents and rural laundering, non point sources (e.g. agricultural lands, informal settlements) contributed 50% to the catchment soluble phosphate loading. (See Table 9. Figures in bold are from Moss (undated)).

Table 9: Scenario 3 - Sources of phosphate include WWTWs, rural laundering and 50% diffuse source contribution

Subcatchment	Soluble phosphate loading in tons						% detergents	
	Point	Rural detergent	Other non point (50%)	Total catchment	Total detergents			
					Pillay	**Moss**	Pillay	**Moss**
Midmar	1.09	0.28	1.37	2.75	0.84	**0.61**	31	**22**
Albert Falls	4.18	0.28	4.46	8.92	2.42	**1.49**	27	**17**
Nagle	0.55	1.4	1.95	3.9	1.68	**1.58**	43	**41**
Inanda	24.9	8.38	33.28	66.57	17.56	**14.38**	26	**22**
Total	30.72	10.34	41.06	82.14	22.5	**18.06**	27	**22**

Scenario 4: In addition to the loading from wastewater effluents and rural laundering, non point sources (e.g. agricultural lands, informal settlements) contributed 33% to the catchment SRP loading. (See Table 10. Figures in bold are from Moss (undated).

Table 10: Scenario 4 - Sources of phosphate include WWTWs, rural laundering and 33% diffuse source contribution

Subcatchment	Soluble phosphate loading in tonnes					**% detergents**
	Point	Rural detergent	**Other non point (33%)**	**Total catchment**	**Total detergents**	
Midmar	1.09	0.28	**0.69**	**2.06**	**0.61**	**30**
Albert Falls	4.18	0.28	**2.23**	**6.69**	**1.49**	**22**
Nagle	0.55	1.4	**0.98**	**2.93**	**1.58**	**54**
Inanda	24.9	8.38	**16.64**	**49.92**	**14.38**	**29**
Total	30.72	10.34	**20.54**	**61.6**	**18.06**	**29**

Thus the contributions of detergent phosphorus, calculated by Pillay and Moss respectively, to the soluble phosphate loads of the 4 impoundments are given in Table 11 below. It must be noted that the results of 'scenario 1' are excluded as they are deemed improbable by Moss.

Table 11: The contributions of detergent phosphate to the SRP loading of the largest Umgeni impoundments expressed as mass and percentage. Figures in bold are from Moss (undated).

Impoundment	Total P loading (tons/annum)	Contribution of detergent P to the P loading of the impoundment			
		(tons/annum)		%	
		Pillay	**Moss**	Pillay	**Moss**
Midmar	1.7-2.75	0.84	**0.61**	31-49	**22-35**
Albert Falls	5.57-8.92	2.42	**1.49**	27-43	**17-27**
Nagle	2.44-3.9	1.68	**1.58**	43-69	**41-65**
Inanda	41.6-66.57	17.56	**14.38**	26-42	**22-35**
Overall	51.32-82.14	22.5	**18.06**	27-44	**22-35**

Therefore it can be conclude that detergent phosphate contributes 22-35% of the phosphate loading of the Umgeni impoundments, as calculated by Moss or 27-44% calculated by Pillay. These are the values for the proposed 20-50% contribution to phosphate loading by diffuse sources but as expressed by Moss, a 33% diffuse source contribution is the most likely. This gives a percentage contribution by detergent phosphate of 29% (between the values of 22-35% and 27-44% quoted by both Pillay and Moss).

One further issue remains unaccounted for in the above calculations; it is that in theory a reduction in detergent phosphate will not influence the SRP concentration of the effluent if the standard of 1 mg/ℓ is met as required by the Water Act 54 of 1956. However, from the Roodeplaat dam example given above and from Gaydon et al. (2007) it is known that compliance is not always achieved. Even in the USA the standard is not always met, in Lake Erie 580tons/annum of phosphate is received by the lake as a result of non-compliance (Hartig et al., 1990).

If the standard were consistently achieved, which is unlikely as overflows and breakdowns are inevitable, then the detergent phosphate loading from effluent drops to zero (according to Moss (undated)). This means that the Total SRP loading values when 20, 33 and 50% are contributed by diffuse phosphate sources will decrease from 51-40, 62-50 and 82-71 tons/annum, respectively. This is a reduction of 17% on average and is far less than the 42-75% reduction stipulated by Pillay. Even though Moss's results are significantly different to Pillay's they are both based on several notional values, especially with regards to the contribution of diffuse phosphate sources to phosphate loading and therefore more work is required to better understand the contribution of detergent phosphate to the phosphate loading of impoundments.

The phosphate loading of impoundments may vary greatly to the TP loading of the catchment as large amounts of phosphate are removed in the river by biological uptake by macrophytes and microorganisms (Davies et al., 1998). Also bioavailable phosphate may be occluded (locked into Fe/Al oxides where it loses its availability) or nonoccluded, by attaching to soil particles but remaining bioavailable (Gilpin, 2007). These natural processes in rivers and their catchments can reduce the amount of phosphate in the water thus changing the phosphate loading of an impoundment from what is expected. This factor also needs to be considered in these calculations.

2.5 Estimating the saving to water treatment costs to regional facilities due to the projected decrease in frequency and severity of algal blooms.

The quality of the water entering a major water treatment plant heavily impacts the cost of treatment, as was found for water treatment works in the Umgeni Water operational area (Graham et al*.,* 1998). It has been seen above that detergent phosphate is a major contributor causing the eutrophication of surface waters. This can create unpleasant odors and tastes, increase turbidity, total organic carbon and the amount of suspended solids, which are costly and complicated to treat if the water is required for potable use (Pillay, 1994). It is possible therefore, as is examined in the following case study, that by limiting the use of detergent phosphate and thus reducing eutrophication, the cost of treating water can be reduced.

2.5.1 Case Study 4: The possible savings to water treatment costs at Durban Heights Water Works if detergent phosphate were banned (Graham et al., 1998).

At Durban Heights WW, the large numbers of *Anabaena* and *Microcystis* in the water received from Lake Nagle hugely increase the water treatment cost. The average spent on water treatment per annum by Umgeni Water (in 1998) was R8 000 000.

Maximum cell counts for Durban Heights of 16 869 cells/Mℓ and 6 117 cells/Mℓ of *Anabaena* and *Microcystis* respectively, in the raw water were recorded in March 1994.This increases relative water treatment costs from a mean of R28/Mℓ, where 45% of the cost was for coagulants and 38% for chlorine, to R65/Mℓ during particularly severe algal blooms. This increase was mainly due to the use of Powdered Activated Carbon (PAC).

When these treatment costs are compared to those of non-eutrophic water, such as at the DV Harris WW, which sources its water from Lake Midmar, it is immediately obvious how algal blooms can increase the cost of water treatment. The mean water treatment cost at the DV Harris WW is

R25/Mℓ but ranges from R22-49/Mℓ. Most of this (50%) cost is for disinfectants. This level of disinfection is inflated as other (coagulant) costs are low relative to eutrophic systems.

A Multiple Linear Regression model to predict water treatment cost (Graham *et al.,* 1998)

A multiple linear regression model that expresses water treatment cost as a function of the following variables is given below. The bold variables are those influenced by detergent phosphate (as established by the above authors).

Turbidity (NTU)	Potassium (mg/ℓ)
Total Aluminum (µg/ℓ)	Dissolved Oxygen (mg/ℓ O_2)
Iron (mg/ℓ)	**Soluble Reactive Phosphorus (µg/ℓ)**
Suspended solids (mg/ℓ)	Manganese (mg/ℓ)
Nitrate (mgN/ℓ)	Coliforms (colony counts/100 ml)
Total Organic Carbon (mg/ℓ)	*E. coli* (colony counts/100 ml)
Suspended Solids (mg/ℓ)	Sulphate (mg/ℓ)
pH	Temperature (ºC)
Secchi (m)	Conductivity (mS/m)
Silicon (mg/ℓ)	*Trachelomonas* cells/ml
Chloride (mg/ℓ)	*Chlorella* cells/ml
Sodium (mg/ℓ)	*Cryptomonas* cells/ml
Hardness (mg/ℓ $CaCO_3$)	**Crucigena cells/ml**
Calcium (mg/ℓ)	***Anabaena* cells/ml**
Magnesium (mg/ℓ)	

Equation

Cost = $\alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \ldots\ldots\ldots\ldots \alpha_n X_n$

Where; Cost = Water Treatment cost in 1996 Rands per mega litre (R/Mℓ) terms.

X_i = Variables selected as affecting water treatment costs.

α_i = Estimated regression coefficients.

Application of the multiple regression model to the cost of water treatment at the Durban Heights WW

The model is applied to the Durban Heights WW with R^2=64%, thus capturing a significant amount of information.

Cost = 67.9 + 0.383Temp + 0.005Colif – 8.681pH + 0.084Turb +1.613Fe + 0.084SS – 0.748Secchi + 0.617 Cond + 0.256Hard + 0.823K + 0.577Si + 3.177NO_3 + 0.618TOC – 0.940DO + 0.021*Microcystis* + 0.001*Anabaena*

From the equation we can see that the regression coefficients for *Microcystis* and *Anabaena* are highly significant and positive therefore an increase in their abundance (partly due to detergent P) will lead to increased water treatment costs.

The model can be used to predict the outcome of changes in the treatment cost based of changes in water quality. Thus we can predict that the abundance of *Anabaena* needed to maintain the mean treatment cost of R25/Ml is 600 cells/ml. Anything above this would cause a cost increase. For example if the *Anabaena* count was 6000 cells/ml this would be a R4.22/Ml cost increase, amounting to R801 800 a year if 190 000 Ml of water is treated. For 16 000 cells/ml (as in 1994) the cost increase would be R11.71/Ml amounting to R2 224 900 more spent on water treatment. So it is obvious that improving raw water quality by limiting detergent phosphate could save considerable amounts of money through water treatment especially if water consumption is to rise in the future.

Pillay (1994) states that banning detergent phosphate will decrease algal blooms by 42-75%, which amounts to a saving of R104 000-R190 000, which is less than predicted by Graham *et al.* (1998). It must be noted, though, that Pillay only considered PAC, used to treat foul odors and tastes, in the cost decrease, but as shown by the model above there are many other factors at play.

The reduction of algal blooms suggested by Moss is even less, at 18-34% and the savings would be even less.

As both Moss and Pillay's calculations are based on stipulations, as discussed in 'part 4', these values are not entirely accurate. The only trend truly apparent is that the algal blooms will decrease and therefore so will water treatment costs albeit be they small.

Furthermore, it was found that the rupturing of algal cells in the aqueduct connecting the dam with the WW also increases the cost of water treatment. At the Durban Heights WW, which receives water from Nagle, 67% of algal cells rupture during transfer. This increases the water treatment cost from 4-21% using varying coagulants if there were 10 000 cells/ml and 35-85% if there were 100 000 cells/ml (Dickens et al., 1996). Since the amount of cells can be decreased by banning detergent phosphate the amount spent on water treatment due to ruptured cells can be decreased

2.6 The impact that use of zero-phosphate detergents would have on wastewater treatment works

In South Africa WWTWs such as Darvill in the Umgeni catchment are required to comply with the 1 mg/ℓ standard of SRP in their effluent by removing the excess phosphate from the wastewater. This is usually done by dosing with a coagulant to remove phosphate and may be supplemented by an additional biological process. By reducing the phosphate load by 50% (if detergent phosphate is banned) it may be possible to reduce the need for coagulant and thus cut treatments costs by half (R 4 200 000 per annum was the predicted savings to WWTWs removing phosphate in 1981 if a detergent phosphate limit was enforced (Heynike et al., 1986)). Darvill WWTW, alone, would save R260 000 per annum (Fred Lee, 2002).

Besides the saving on phosphate removal costs, banning detergent phosphate would help prevent the costly interference with the coagulation process that results from very high phosphate concentrations (Weddepohl, 1992). A lower P:COD ratio in waste water resulting from a limit in detergent phosphate will also be beneficial for biological phosphate removal systems and the reduced variability in phosphate loading of WWTWs will facilitate simpler and more efficient process control (Heynike et al., 1986).

The main implication for WWTWs if zero-phosphate detergents are mandated is that it is thought the sludge production would drastically increase. This is because 0.7g STPP is equivalent to 0.9g zeolite combined with 0.2g polycarboxylates (the preferred substitutes). Furthermore, they cannot be recycled. Currently, sludge disposal is the biggest single expense for European water companies and larger amounts of sludge would complicate the 1999 EU Landfill Directive, which aims to implement a 65% reduction of biodegradable waste going into landfills over the next 15-19 years. Increasing sludge production would thus be both expensive and inconvenient. If France were to change to totally P-free detergents they would produce 135 000 tonnes/year more sludge than for P- detergents. In Switzerland 15 000 tonnes more dry waste was produced due to P-free detergents (Acke, 2001)., There is however another perspective, as is illustrated by what was experienced in the Great Lakes region (Case study 5).

2.6.1 Case Study 5: The implications of the use of low phosphate detergents on the waste water works of The Great Lakes region (Sonzogni et al., 1986)

The Great lake states of New York, Indiana, Michigan, Minnesota, Wisconsin and Ontario (Canada) all have a ban on detergent phosphate limiting it to 0.5% by weight of detergents. The other Great Lake states of Ohio, Illinois and Pennsylvania have regional bans. Also, effluent from WWTWs discharging more than 3 785 m^3/d is limited to 1 mg/ℓ phosphate concentration. The implication of this for WWTWs is that, due to the limiting of detergent phosphate, the phosphate load of influent waste water is, on average, decreased by 1.5 mg/ℓ.

The main result of this reduction for WWTWs has been the reduction of chemical, sludge handling and disposal costs. This is contrary to what was reported by Acke (2001). Phosphate removal increases sludge production by 20-200% as the amount of alum or ferric chloride needed to remove 1 mg phosphate is 7.48 and 9.96 mg respectively. This figure is also an underestimate as due to other ions also precipitating out, the more likely amount is 35% higher. Therefore 10.1 and 13.4 mg of sludge is produced to remove 1 mg of phosphate using alum and ferric chloride respectively and the resulting ratio of sludge produced to phosphate is 12:1. The result is that 5 kg/ capita.yr^{-1}less sludge is produced, thus saving $0.15-0.75/capita.yr^{-1} (based on an average sludge handling and disposal cost of $50-150/metric dry ton).

Firstly, at the Escanaba WWTW in Michigan, the amount of iron chloride and polymer used to remove phosphate was considerably reduced and this led to less sludge production and therefore reduced the sludge handling/disposal costs, saving them $10 292 in 10 months (Hartig et al., 1990).

Sonzogni (1986) reports that since the detergent phosphate ban, an average cost saving of $0.5/capita.yr^{-1} has been made at 9 surveyed Michigan WWTWs with savings ranging from $0.22-$0.94/ capita.yr^{-1} ($113-$42 373). This is double the $0.26 that had been predicted by Foth and Van Dyke (1981).

One investigation at Milwaukee South Shore Treatment Plant reported that $0.23-$0.67 was the recorded savings resulting from reduced sludge production due to the detergent phosphate ban. Foth and Van Dyke (1981) concluded that $0.24/capita.yr would be saved.

The Midland WWTW saved 26% of their usual chemical cost of $2.06/ capita.yr^{-1}, reducing it to $1.53/ capita.yr^{-1} (SAIC, 1988). In association with the saving of chemical costs, the WWTW would also save by reducing capital expenditures, such as labour and operational costs, such as power. This was predicted at $0.12/ capita.yr^{-1} (Folsom et al., 1980) and was clearly evident at the Chicago Metropolitan Sanitary, which saved $55 million in capital expenditures and operational costs (Alexander., 1978).

Therefore it can be concluded that $0.2-$1.7/ capita.yr^{-1} can be saved in waste water treatment by reducing the phosphate load of influent by 1.5 mg/ℓ. In New York this translated to $50 million saved by the state. It should be noted, moreover, that the cost of phosphate removal and sludge disposal will likely become more expensive in the future due to population growth, increases in chemical prices and less land available for sludge disposal. It is likely therefore, that relative to today, the savings made in the future will increase even more.

2.7 The first order estimate of the extra cost to users of detergents that would be associated with zero-phosphate detergents.

From the consumers points of view phosphate detergents seem better because they are more effective (the only compound yet discovered to posses all the necessary qualities of an effective detergent), much cheaper and are used in smaller amounts to phosphate free detergents. This was confirmed in tests done by CEEP (Acke, 2001).

Nevertheless, despite this, much controversy surrounds this issue, where effectiveness and cost are important factors. An evaluation of detergent performance in 1987 by the Consumers Union, in the USA, found that 6 of the top 10 detergents were P-free, showing that P-free detergents can perform in the market just as well as phosphate detergents (Hartig et al., 1990). This is supported by Shuster

Laboratories (Hanrahan, 2004) who showed that over 5 cycles P-free dishwashing detergent was just as effective as phosphate detergent. A separate investigation into the cost of detergent found that out of the 9 front loader detergents that cost under 35c (US) per wash 2 of them were zero-phosphate detergents (Choice, 2005). Although they did also show that low/no-phosphate detergents did not wash as effectively.

For a P-free detergent to be as effective as a phosphate detergent it may cost more. This is shown by Xigao (2007) that for a Zeolite A built P-free detergent to have the same effectiveness as a phosphate detergent, in China, it would cost the consumer 15% more to buy. Although when one deducts retail price increases and distribution costs, as would happen if P-free detergents became wholesaleable, then the cost would decrease by a further 5% (Hanrahan, 2004). Therefore P-free would only cost 10% more than phosphate detergents. So we can see that zero-phosphate detergents can be made to be as effective as phosphate detergents with minimal price increases.

In addition to this the competition over diminishing global resources of phosphate with the animal feed and fertilizer industries is becoming a real issue. In the USA (the largest producer of phosphate prior to 2005) most the Florida phosphate rock reserves have been depleted and two phosphate rock mines and four fertilizer factories closed permanently. This meant that phosphate production fell to a 40 year low of 35 million tons in 2005 (Jansinski, 2007). This is the first evidence that global phosphate resources are running out and that the low phosphate prices we know now will not exist in 50 years (EcoSanRes, 2005). In 60-130 years phosphate resources will run out altogether (Steen, 1998). Therefore even though most zero-phosphate detergents are presently more expensive than phosphate detergents, the tables will turn in the near future as increasing demand for phosphate causes prices to go up.

2.8 Cost benefit analysis of the various parties affected by the zero-phosphate detergents.

According to Pillay (1994), for the Inanda catchment, it is twice as expensive to reformulate phosphate detergents than to reduce phosphate at the wastewater works and three times more expensive to reformulate than to treat eutrophication at the water treatment works. This may be due to river losses between discharge and impoundment and the length of the impoundment, which naturally improve water quality (Pillay, 1994). *It is also important to appreciate that this cost-benefit exercise did not sufficiently incorporate all of the other environmental "externalities" such as the cost to the biodiversity, the amenity value of the water-ways, etc.*

2.8.1 Case Study 6: A Cost-benefit analysis of the parties affected by a detergent phosphate ban in the Umgeni Catchment (Pillay, 1994)

Cost of reformulating detergents

For *Lever Bros* (Durban detergent manufacturer) to reformulate detergents with Zeolite A would cost R310 per ton, therefore 31c per kg. This creates a cost increase to Inanda consumers of R551 100.

Cost Savings at a Wastewater Works

Darvill WWTW, where biological treatment and alum dosage are used, was considered. The biological treatment cost would not change but if the phosphate load was decreased by 50% so would the amount of alum required and thus the cost of alum would be cut from R518 000 to R259 000.

Cost Savings at Water Treatment Works

Predictions for water treatment at Inanda were made using data from the Durban Heights Water Works at Nagle where water is treated for taste and odor by adding carbon. The predicted annual amount of C needed is 65 000 kg amounting to a cost of R230 000. Eliminating detergent phosphate is shown by Pillay to reduce algal bloom by 42 to 75% and thus a saving of R104 000 (for 42%) to R190 000 (for 75%) is made per year.

Cost of reduced life of washing machines and fabrics

The predicted loss in value of washing machines and fabrics due to the reformulation of detergents in South Africa in 1991 was R3.8 million and R62.5 million respectively. This extrapolates to R0.12 million and R6 million for the Umgeni catchment. However it must be stressed that this loss was not evident in countries where reformulation had taken place and washing machines and fabrics will only be damaged if the detergent is incorrectly reformulated. (Pillay, 1994)

Cost benefit analysis

From these figures Pillay came up with 4 cost-benefit scenarios all of which are in favour of not eliminating detergent phosphate. However, there are many hidden costs such as the impact on the aquatic environment, recreational activities, agriculture and health problems, such as carcinogenic toxins from *Microcystis* that have not been included.

The loss in revenue to the phosphorus industry, which would have to seek alternative outlets, was not included into the cost-benefit analyses.

Table 12: Cost benefit comparison of detergent phosphate elimination costs in the Inanda catchment and benefits to Darvill WWTW (Pillay, 1994)

Issue	Cost	Benefit
Increase to consumers as a result of eliminating detergent P (reformulation)	551 100	
Predicted saving with half influent P Loading and improved biological P removal at Darvill WWTW		260 000
Total	551 100	260 000
Cost-benefit ratio	2:1	

Table 13: Cost benefit comparison of detergent phosphate elimination costs in the Inanda catchment and benefits to water treatment facilities (Pillay, 1994)

Issue	Cost	Benefit
Increase to consumers as a result of eliminating detergent P	551 100	
Reduced water treatment costs		190 000
Total	551 100	190 000
Cost-benefit ratio	3:1	

Table 14: Cost benefit comparison of detergent phosphate elimination costs in the Inanda catchment, reduction in value of fabrics and washing machines and benefits to Darvill WWTW (Pillay, 1994).

Issue	Cost	Benefit
Increase to consumers as a result of eliminating detergent P	551 100	
Loss in value of washing machines	120 000	
Loss in value of fabrics	6 000 000	
Predicted saving with half influent P Loading and improved biological P removal at Datrvill WWTW		260 000
Total	6 671 100	260 000
Cost-benefit ratio	26:1	

Table 15: Cost benefit comparison of detergent phosphate elimination costs, reduction in value of fabrics and washing machines and benefits to water treatment facilities (Pillay, 1994).

Issue	Cost	Benefit
Increase to consumers as a result of eliminating detergent P	551 100	
Loss in value of washing machines	120 000	
Loss in value of fabrics	6 000 000	
Reduced water treatment costs		190 000
Total	6 671 100	190 000
Cost-benefit ratio	35:1	

This cost-benefit analysis does not include many hidden costs. Some, such as health benefits are mentioned, but others are not. For example there may even be a link between detergent phosphate and red tides (Kontas, 2004), although this is poorly understood, but which on the west coast of South Africa can cost the economy millions annually. In addition, this study may underestimate the savings that could be gained through recreational industries if detergent phosphate is banned. In Lake Erie, Ohio, the Sports Fishing industry is worth $800 million and is reliant on good quality non-eutrophic water. Therefore banning phosphate is indirectly protecting sports fishing, a multi-million dollar industry (Hartig et al., 1990). There is little research into the link between good quality water and other recreational activities, such as boating or bathing, but it is likely that improving water quality can only help protect these industries as well.

It appears then that Pillay's 35:1 ratio can be contested. For example her R3.8 and R62.5 million loss in value of washing machines and fabrics may be challenged, as Hartig et al. (1990) pointed out that modern zero-phosphate detergents are just as effective as phosphate detergents. Moss (undated) notes that the main reason that a detergent phosphate ban would be more costly than beneficial is due to the damage caused to washing machines and fabric. Internationally though, it has been seen that this can be eliminated, as effective zero-phosphate detergents have been formulated (H. Bhoola, Pers comm.). Additionally, her saving to water treatment costs are far less than those predicted by Graham et al. (1998) and the cost of handling and disposing of the large amounts of sludge generated by P-removal are not factored in, which would decrease with a detergent phosphate ban, as was seen in 'case study 5'

The cost benefit ratio is therefore a far narrower one than Pillay's study suggests. In terms of reducing eutrophication, the main intent of the ban, the benefit is noted as being significant, reducing algal blooms by up to 75%. If the other underestimates (those of water treatment and savings to WWTWs) are factored in, it is possible that this ratio would reflect the benefits outweighing the costs.

2.9 Conclusion

For the most part, the available literature suggests that banning detergent phosphate seems to be the cheapest and easiest way to attenuate the eutrophication of surface waters in South Africa. There are many 'success stories', such as that of the James River and the decrease by 16% in the phosphate concentration in Chesapeake Bay (Hoffman, 1994), following the detergent bans of the 1970s. Therefore, it seems that the voluntary or legislative regulation of detergent phosphate in the developed world has been effective in improving surface water quality.

However it must be noted that some restraint should be exercised as a detergent phosphate ban may not prevent eutrophication as was discovered by Acke (2001). He showed that detergent phosphate (in Europe) provides only 11% of the total phosphorus load of surface waters and therefore banning it will only reduce, not solve the problem.

Many countries, such as the UK, deem it more feasible to remove phosphate from waste water effluent than to ban its use in detergents. However, this is not always true as experience from the Great Lakes showed that removing phosphate at a treatment facility significantly increased sludge production, which increases handling and disposal costs for the facility. In New York State alone $50 million were saved due to the use of zero-phosphate detergents, which produced less sludge and decreased the amount of chemicals needed to remove the phosphate to the required standard concentration. Capital expenditure was reduced by up to $55 million at the Chicago metropolitan Sanitary, as the amount of treatment required by the sewage was reduced (Sonzogni et al*.,* 1986)

By banning detergent phosphate and reducing SRP concentrations in the influent it has become easier for WWTWs to comply with the implemented phosphate standard (Hartig et al., 1990). Reports such as those by Hohls (1998) and Snyman et al. (2006b) show that waste water treatment facilities in South Africa are struggling to attain the 1 mg/ℓ standard. Phosphate loading from non-point sources and malfunctions, such as overflowing septic tanks or broken sewage treatment equipment can also be reduced through the introduction of zero-phosphate detergents. .

The manufacturers have shown that there are many effective substitutes for STPP in detergents that can act as builders, albeit be they a combination of compounds. It is common to read about the cost of substituting STPP with another builder, however, tests reported above found that modern zero-phosphate detergents can be as cost effective as their phosphate counterparts. Added to this, in the light of the finding that phosphate deposits will only last another 100 years at present consumption rates, (Tangsubkul, 2005) it seems that a decision may be forced onto society if it is not taken in the short term.

Recently there has also been interest and action taken (in Washington State (Ebeling, 2007)) to implement P-free dishwashing detergents used in automatic dishwashers as previous legislation dealt only with laundry detergents. Therefore if South Africa were to launch a detergent phosphate ban it should be considered whether to extend this to dishwashing detergents as well.

In terms of the phosphorus loading of waste water treatment plants by detergent phosphate two case studies were investigated. The first was done by Pillay (1994), who found that 37-51% of the SRP or 69.7out of 184.1 tons per annum was contributed by detergent phosphate to the phosphorus loading of the WWTW in the Umgeni catchment. This confirmed in general terms the prediction made by Heynike and Wiechers (1986) of 35-50%.

In another example from Whittlesea, Australia, 14-38% (593-983g/day out of 2588-4238g/day) of the total phosphorus was contributed by detergent phosphate on a day of low washing activity. The per capita contribution in this case worked out to be 0.85g/capita/day, similar to that calculated by Weddepohl (1992) for South Africans in general of 1g/person/day.

The ‘case study 1’ by Pillay (1994) was extrapolated to ‘case study 3’ to investigate the contribution of detergent phosphate in the phosphate loading of the four largest impoundments (Midmar, Albert Falls, Nagle and Inanda) in the Umgeni catchment. The results show that the contribution of detergent phosphate to the total SRP loads of the various impoundments were 31-61% (Midmar), 27-54% (Albert Falls), 43-86% (Nagle) and 26-53% (Inanda). The results vary due to three different scenarios contributing to the phosphate loading of the impoundments. For the highest value the only sources of soluble phosphate were wastewater effluents and detergents that entered from rural laundering carried out directly at the watercourse, but the % values decrease as the contribution of non-point sources increases from 0-50%.

The potable water treatment industry would benefit greatly from a detergent phosphate ban, which would reduce the frequency and severity of algal blooms and thus decrease treatment costs. In ‘case study 4’ by Graham et al. (1998) the water treatment cost at Durban Heights WW rose from a mean of R28 to R65 to treat 1 Ml of water during a severe algal bloom. This is mainly due to the need for Powdered Activated Carbon to treat the foul odors, tastes and toxins. The cost of water treatment can be predicted by a multiple regression model developed by Graham in ‘case study 4’ and is unique for every water body. The extra cost of water treatment is obviously variable but ‘extra costs’ of up to R2 224 900 were recorded at the Durban Heights WW, due to a particularly severe algal bloom in Lake Nagle, in 1994. As Pillay (1994) points out, banning detergent phosphate will reduce algal blooms by 42-75% thus the savings to treatment costs will be huge.

Finally the cost-benefit ratios ranging from 2:1 to 35:1 calculated by Pillay suggested that it would not be effective to ban detergent phosphate. This study did not however consider the many ‘hidden’ costs associated with eutrophication. These include the costs to recreational activities, such as fishing which generates $800 million in Lake Erie alone and is reliant on good quality water. Also her calculations of savings by the water treatment industry and waste water works are possibly underestimated. This was shown by the regression model calculated by Graham et al. (1998), which predicted a saving in water treatment costs of up to R2 224 900 compared to Pillay's estimate of R190 000, for Durban heights. The examples of the savings generated by the Great Lakes WWTW (case study 5) due to zero-phosphate detergent also suggest that her estimate of R260 000 for Darvill WWTW, which only factors in the decrease in chemical requirement, is an underestimate.

Most significantly though, the greatest costs associated with zero-phosphate detergents in this study, those associated with damage to washing machines and fabrics, have, through international experience, been shown to be negligible provided that the detergents are correctly formulated (Hartig et al., 1990; H. Bhoola, Pers comm). This conclusion, in itself, makes the prospect of zero-phosphate detergents altogether more acceptable than is shown in Pillay,s cost benefit analysis, and in the light of rising phosphate prices, a more current cost benefit calculation may indicate that removing detergent phosphate may be cost effective after all.

Chapter 2: Findings summary

1. It is clear from international examples that the phosphates contained in powdered laundry detergents are in fact sufficient cause for concern that banning or limitation thereof through legislation has become a common worldwide practice.

2. Research has shown that the contributions of detergent phosphorus to the overall total phosphorus loading of waste water can be as high as 50% but is more commonly closer to 30%.

3. International experience has shown zero-phosphate detergents to be as effective as phosphorus containing detergents, and certain negative costs previously thought to be associated with zero-phosphate detergents have, through international experience, been shown to be almost nil. These are primarily costs associated with damage to washing machines and fabrics.

4. The increasing global price of phosphate and the impact detergent phosphate has had on water bodies around the world suggests that, from an international view point, its elimination has been seen as desirable, if not imperative.

3. THE CONTRIBUTION OF DETERGENTS TO THE TOTAL PHOSPHORUS LOADING AT WWTWs

3.1 Introduction

Phosphate arrives at Waste Water Treatment Works (WWTWs) having originated from a number of sources. Human excreta, industrial use of compounds such as phosphoric acid and domestic laundry detergents are three of the most common sources. The objective of this section of the study is to examine the impact that phosphate rich laundry detergents have on the phosphate loading of WWTWs.

Phosphorus levels in water are commonly measured using two parameters – Soluble Reactive Phosphorus (SRP) which is biologically available ortho-phosphate (PO_4), and Total Phosphorus (TP) which, as the name implies, is a measure of all phosphorus in the sample. The phosphate component of detergents contributes to both of these and is included in detergents in the form of Sodium Tripolyphosphate – $Na_5P_3O_{10}$ (STPP) as a builder and a water softener. This substance is not toxic and in the presence of water, quickly hydrolyses to SRP, making it indistinguishable from other sources of phosphate. Because of this reasonably quick transformation, in the case of a large sewer network, it is not possible to trace the origin of phosphates by chemical analysis after they arrive at the WWTW. Although hydrolysis does occur reasonably rapidly, to ensure that all detergent phosphorus (Pdet) is taken into account, Total Phosphorus is preferable as a measurement parameter since some STPP derived phosphate may have been assimilated into TP through biological processes by the time it arrives at a WWTW. However, where possible in this report, both measurements (SRP and TP) have been included.

This chapter attempts to calculate the proportion of phosphorus arriving at WWTWs which originates from detergents using detergent consumption data (supplied by Unilever) linked to spatial census data and municipal sewer connection statistics. This allows an estimate to be made as to the number of consumers living in a particular area and the amount of detergent being consumed in a sewered area.

3.2 Method

The ease with which STPP hydrolyses to SRP makes it difficult to measure the detergent phosphate contribution by analytical means. This means that this estimate must be calculated instead using various assumptions. These are listed in section 3.2.1 below. The approach adopted in this report is to identify the number of households contributing waste water to WWTWs and to then estimate the amount of detergent phosphate each household contributes. Knowing the total amount of phosphorus and phosphate arriving at a WWTW, it is possible to estimate the percentage of the total amount that is attributable to detergents.

3.2.1 Calculating detergent phosphate loading in the Darvill Catchment

According to the uMsunduzi municipality, Darvill WWTW services approximately 47 000 single connections and approximately 700 multiple connections (S. Gaydon – pers com). These multiple connections include combined living complexes such as blocks of flats and simplexes. For the purposes of this report, it is assumed that the average number of households serviced by a multiple connection is 15. This gives a total of 57 500 households connected to the municipal sewer network.

The average household size for the uMsunduzi area was calculated by selecting the census sub-place areas which fall within the sewer network area. Population total and number of households were then used to calculate an average number of people per household. This is calculated as **3.66** people per household. This value is roughly consistent with the national average household size which according to the 2001 census is **3.8** people per household.

Assumptions

a. It is assumed that should a household be connected to a sewer network, all grey water emanating from this household would be disposed of into the sewer. This would include machine washing, as well as hand washing done in a bath or in a basin.
b. It is assumed that on average, fifteen households are connected to the network through a multiple connection (e.g. block of flats).
c. Given that the average market penetration of detergent products is 99.6% (Unilever) it is assumed that every sewer connected household utilizes phosphate containing detergent.

Detergent consumption

A household's detergent consumption was calculated using consumption estimates provided by Unilever. These estimates have been arrived at through comprehensive consumer surveys, and are laid out in Table 16 below. This study has calculated the average household size in the Darvill works' catchment as lying between 3 and 4 members. The average household consumption figure of 17.3 kg/annum was thus used as an estimate for household consumption volumes in the Darvill catchment.

Table 16: detergent consumption estimates by household size (Plumbley, R – Pers Comm)

Household size	Average detergent consumption (kg/annum)	% Market penetration
1 Member	12.8	98.3
2 Members	15.4	99.1
3 or 4 Members	17.3	99.8
5 or more Members	19.3	99.9

An attempt was made to link the consumption of detergents to household's socio-economic status using Living Standards Measure (LSM) categories (see Table 17 below), however, this information could then not be linked spatially to catchments and thus census data (which can be mapped by sub-place units) and household size data were thus preferred.

Table 17: Powdered detergent consumption by LSM socio-economic groups (Plumbley, R – Pers Comm)

LSM Group	Consumption (Kg/annum)
New LSM Group 01-03 (poor)	14.6
New LSM Group 04	17.4
New LSM Group 05	18.7
New LSM Group 06	18.9
New LSM Group 07	18.5
New LSM Group 08	19.5
New LSM Group 9	18.8
New LSM Group 10 (wealthy)	18.3

Phosphorus content of detergents

According to formulations provided by Unilever, the average phosphorus content of detergents in South Africa is approximately **5.3%** (R Plumbley – pers com). This figure only takes into account the phosphorus contained in the phosphate STPP builder component of a detergent formulation. phosphorus is contained in other components of the detergent (estimated to be less than 1% – H Bhoola pers com), however these are not replaceable and are thus ignored by this report.

3.2.2 Total Phosphorus concentration of inflow at Darvill WWTW

Figure 4 below shows the fluctuating total phosphorus concentration values of influent at Darvill WWTW over the period 2000-2008.

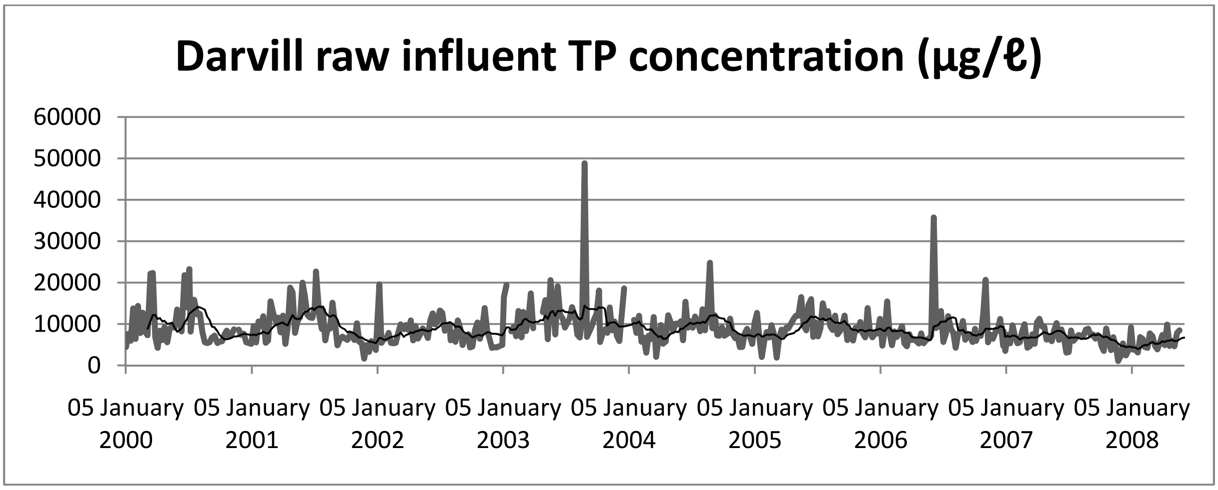

Figure 4 - The daily TP concentration of raw sewage arriving at Darvill WWTW: 2000-2008

The thin black line shows a 10 day average trend, which reveals an annual cyclical trend with concentrations increasing to a peak during the drier winter months, and decreasing during the wetter summer months. This decrease in concentration during the wetter season can most likely be attributed to the influx of storm-water into the sewer network during storms which would dilute phosphorus concentrations (S Terry. Pers Comm). It is suggested that the spikes which occur in the raw data are caused by sporadic industrial use of phosphoric acid (S Terry. Pers Comm). The average daily TP concentration over the 8 year period is measured as **9026.5 µg/ℓ**. The SRP average is measured as **4926.5 µg/ℓ** (see Table 18 below).

Table 18: Average TP and SRP concentrations over the period 2000-2007

Year Average	Average Conc. TP (µg/ℓ)	Average Conc. SRP (µg/ℓ)
Average 2000	9581.0	5967.8
Average 2001	9611.0	5625.0
Average 2002	8242.0	3562.2
Average 2003	11810.4	6393.4
Average 2004	8841.8	5041.2
Average 2005	9171.0	5472.7
Average 2006	8450.0	4307.8
Average 2007	6504.9	3042.1
Average of 8 Years	**9026.5**	**4926.5**

3.2.3 Total phosphorus loading at Darvill WWTW

Figure 5 below reflects the daily total load of phosphorus arriving at Darvill WWTW. This shows variations in load with a slightly less distinct seasonality pattern than is shown by the concentration graph (Figure 4), but one that nonetheless shows annual peaks often occurring during the middle months of the year. The trend line reflects a 10 day average, which is less affected by the short term spikes caused by sporadic industrial use of large quantities of phosphorus containing chemicals.

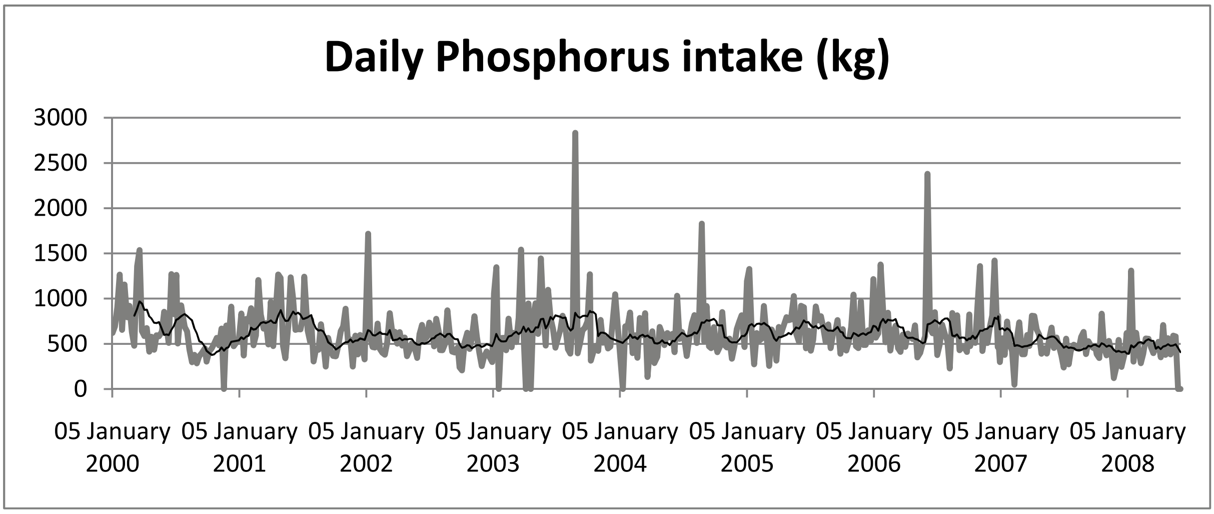

Figure 5: Average daily load of Total Phosphorus arriving at Darvill WWTW: 2000-2008

The average daily Total Phosphorus load is **652.8 kg**, while the calculated average daily SRP load is **340.4 kg** (See Table 19).

Table 19: Average daily TP and SRP quantities arriving at Darvill WWTW over the period 2000-2007

Year Average	Average Daily TP Volumes (kg/day)	Average Daily SRP Volumes (kg/day)
Average 2000	673.4	423.6
Average 2001	653.5	376.1
Average 2002	545.1	228.9
Average 2003	742.2	406.3
Average 2004	605.5	346.4
Average 2005	651.3	378.2
Average 2006	675.9	343.9
Average 2007	675.9	219.7
Average of 8 Years	652.8	340.4

3.2.4 Waste water inflow at Darvill

The volume of waste water entering Darvill WWTW over the period 2001-mid 2008 is shown in Figure 6 below. The data have been averaged and this figure used to estimate the total annual phosphorus loading. Again a line representing a 10 day average shows a trend, though in this graph the difference between the actual values and the 10 day average is much less obvious, probably reflecting more drawn out periods of high and low flow as opposed to sudden spikes as is seen in the phosphorus concentration graph above (Figure 4).

Table 20: Average daily waste water inflow volumes for the period 2000-2007

Year	Flow (Mℓ)
Average 2000	74.7
Average 2001	73.5
Average 2002	67.0
Average 2003	63.4
Average 2004	70.7
Average 2005	73.7
Average 2006	81.4
Average 2007	77.0
8 Year Average	72.7

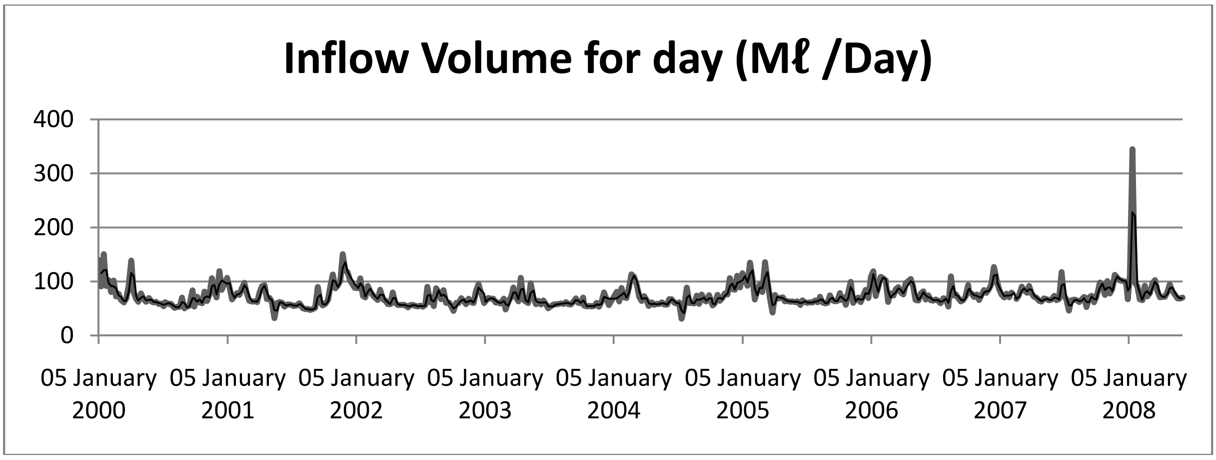

Figure 6 - Daily total volume of waste water arriving at Darvill WWTW: 2000-2008

The calculated average daily inflow volume over this period is 72.7 Mℓ per day (see Table 20 above). This figure is used together with the average phosphorus concentration figure to calculate the average annual load of phosphorus arriving at the WWTW.

3.3 Darvill Results

Assuming 57 500 domestic sewer connections to the Darvill network, and using an average household size figure of 3.6, together with the consumption statistics (tabled above), it is possible to estimate the average detergent phosphorus consumption in this area. If a 3-4 member household consumes on average 17.3 kg of detergent per annum, with a phosphorus content of 5.3% (that originating from the buider component), this gives a total detergent phosphorus contribution in the Darvill basin of **52.72 Tons/annum**.

If the average daily TP concentration of the Darvill intake is 9026.5 µg/ℓ (2000-2008), and the average daily volume of intake is 72.7 Mℓ (2000-2008), then the average daily load of total phosphorus arriving at Darvill WWTW is calculated as **652.8 kg/day**. This represents **239.4 Tons per annum**. It is thus estimated that detergent derived phosphorus represents approximately **22%** of the Total Phosphorus arriving at Darvill annually. Since STPP hydrolyses over time in the presence of water to SRP, the same calculation can be performed using SRP (340 kg/day & 130.6 T/annum intake) and this shows that approximately **40.3%** of SRP arriving at Darvill originates from detergents (see Table 21).

Table 21: Calculation of the percentage contribution made by detergents to the overall total phosphorus loading of Darvill WWTW

Estimation of Pdet contribution to phosphate loading: Darvill KZN		
No of households	57500	
Avg people per household	3.6	
Detergent consumption	17.3	kg/hshld.annum^{-1}
% P composition of detergents (from builder only)	5.3	%
Household Pdet consumption	0.917	kg/hshld.annum^{-1}
Darvill network Pdet consumption total	52.72	T/annum
Darvill TP total	239.4	T/annum
Darvill SRP Total	130.6	T/annum
% TP composition	**22.0%**	
% SRP composition	**40.3%**	

3.4 Comparison with other WWTW

In an attempt to compare the Darvill case study results with other WWTWs, phosphate data was sourced from Johannesburg Water for the following facilities:

I. Bushkoppies
II. Goudkoppies
III. Oliphantsvlei
IV. Driefontein
V. Ennerdale and
VI. Northern Works

Unfortunately, only SRP data is available for the Johannesburg WWTWs above, and the only data from before 2007 is available for Northern works (due to the suspension of SRP sampling in early 2007). Using the same calculations as those outlined above for Darvill, the SRP values for the Johannesburg works can be compared with that calculated for Darvill (see Table 22 below). These calculations can be found in appendix 4.

Table 22: Comparison of Pdet contributions to SRP totals at various WWTW

WWTW	Pdet (SRP) % contribution	River Affected	Study dams downstream
Darvill	40.30	uMsunduzi River	Inanda
Bushkoppies	17.75	Klip River	Bloemhof
Goudkoppies	15.40	Klip River	Bloemhof
Driefontein	15.10	Crocodile River	Hartbeespoort / Roodekopjes
Ennerdale	58.82	Rietvlei	Bloemhof
Oliphantsvlei	28.12	Klip River	Bloemhof
Northern	28.53	Jukskei River	Hartebeestpoort / Roodekopjes

The overall impression of the results shown above is the high variability between facilities. This can largely be attributed to the variable contribution of industrial sources of phosphorus. Ennerdale and Darvill works collect predominantly domestic waste, and thus show a high proportion of detergent phosphate.

Several of the facilities show detergent composition to be between 10% and 20%. These facilities likely collect a higher proportion of industrial waste. A good example is Bushkoppies WWTW, which collects effluent from the industries to the South of Johannesburg, notably from a yeast factory which produces a low volume of waste but with a very high organic load (A. Pitman, pers com) and thus shows a relatively low detergent contribution.

3.5 Accounting for different WWTW's catchments

As is discussed above, the major variable factor in estimating the phosphorus loading contribution due to detergents at any WWTW is the contribution made by industry. Based on this level of variability, it is extremely difficult to characterize the proportional contribution of detergent phosphorus to all WWTWs. It is, in the context of this report, more meaningful to estimate the proportion of phosphorus emanating from domestic sources that is attributable to detergents, as this figure will apply more universally to waste water across the country.

There are assumed to be three major contributors to WWTW phosphorus loading, namely the products of human metabolism i.e. excreta (Pmet), Detergents (Pdet) and Industry (Pind). The first two make up the domestic contribution. Heynike and Wiechers (1986) determined that the phosphorus contribution made by human excreta is approximately **1.3g/capita/day**, which equates to **0.4745 kg/capita/annum**.

Table 23- Calculation of domestic phosphorus contributions to Darvill WWTW.

Estimation of Pdet contribution to domestic phosphorus: Darvill KZN		
No of households	57500	
Avg people per household	3.6	
Detergent consumption	17.3	$kg/hshld.annum^{-1}$
% P composition of detergents (from builder)	5.3	%
Person Pdet consumption	0.255	$kg/capita.annum^{-1}$
Household Pdet consumption	0.917	$kg/hshld.annum^{-1}$
Metabolic P production	0.4745	$kg/capita.annum^{-1}$
Metabolic P production	1.7082	$kg/hshld.annum^{-1}$
Household Pmet	98.2215	T/annum
Migrant / Resident ratio	0.25	
Migrant Population	51750	
Migrant Pmet	12.278	T/annum
Darvill Pdet total	52.72	T/annum
Darvill Pmet total (inc 0.75 of Migrant Pmet)	107.43	T/annum
% Domestic P composition	**32.9%**	

Using the figures shown in Table 23 above, calculations show that detergent phosphorus contributes approximately **33%** of the total phosphorus originating from domestic sources. This includes a Pmet contribution attributed to migrants who live outside Darvill's catchment, but work inside it. It is assumed this population is one quarter the size of the resident population. Also, since the majority of their daylight hours (but not all) are spent at work, a fraction of three quarters has also been applied to their Darvill phosphorus contribution.

Given that the estimates for detergent consumption have been applied uniformly across the country, this Pdet proportion (33%) is considered applicable to all domestic waste water disposed of through municipal sewer networks in South Africa.

3.6 Industry's contribution to Darvill WWTW

Having estimated the contribution of detergent and human excreta to the total phosphorus load, the overall percentage contributions of the three assumed sources can be calculated. The contribution made by industry is thus estimated as being 33.1% of the total phosphorus load arriving at Darvill (See Table 24 below). This will value will undoubtedly differ in other catchments as can be seen in the variability of Pdet contributions to WWTWs in the Johannesburg area in Table 22 above.

Table 24: Percentage contributions of the assumed three sources of waste water phosphorus at Darvill WWTW

	Mass (T/A)	Percentage contribution
Industry	79.25 (Ptot – Pmet – Pdet)	33.1%
Metabolism	107.43	44.9%
Detergent	52.72	22.0%
Total	239.4	100.0%

3.7 Discussion

Using the assumed figure of 57 500 municipal sewer connections as an estimate of the number of households connected to the Darvill sewer network, and the average household size in the area of 3.66 people, results in an estimated detergent phosphate contribution figure of 52.72 tons per annum. This represents **22%** of Total Phosphorus (TP) arriving at Darvill and **40.3%** of SRP.

Currently, in Europe, in areas where STPP is used as a builder, detergents contribute up to 50% of the SRP in municipal waste water (Helsinki commission) while according to Chiaudani et al. (1978), before the ban of phosphate rich detergents in Italy, detergents contributed up to 55% of the Total Phosphorus content of urban sewage. In the light of these estimates, 22% TP and 40.3% SRP reflect relatively conservative estimates.

In a study of a small WWTW in Australia (Whittlesea) which services domestic waste only from 450 connections, Halliwell et al. (2000) found that the detergent contribution to TP loading of the facility was between 23% and 39%. The method used was similar to the method used in this project whereby consumption figures were used to estimate detergent phosphate volumes. Since the Whittlesea facility is a domestic waste water only facility, one can compare these results with the **32.9%** obtained by this report for **domestic** contributions to WWTWs (see Table 23). The two results compare well.

Higher levels of industrial waste water contributions can be seen to reduce the proportional contribution of detergent derived phosphorus. This is illustrated in particular by Bushkoppies and Goudkoppies facilities, the catchments of which include the industrial southern areas of Johannesburg (see Table 25). In comparison to the Gauteng WWTW's, Darvill exhibits a detergent phosphate contribution that reflects a catchment delivering a low to moderate industrial component. The results in Table 25 however illustrate that detergent phosphate can **constitute up to 59% of the SRP loading at waste water treatment works** in residentially dominated catchments.

Table 25: Summary comparison of Pdet proportions from reviewed WWTWs

WWTW	TP proportion (%)	SRP Proportion (%)
Darvill – KZN, RSA	22	40.3
Whittlesea – AUS	23-39	-
Bushkoppies – Gau, RSA	-	17.75
Goudkoppies – Gau, RSA	-	15.40
Driefontein – Gau, RSA	-	15.10
Ennerdale – Gau, RSA	-	58.82
Olifantsvlei – Gau, RSA	-	28.12
Northern – Gau, RSA	-	28.53

Chapter 3: Findings summary

1. **The proportion of detergent phosphorus in overall phosphorus loading at WWTWs varies according to the contribution of industrial sources of phosphorus in the catchment area.**

2. **If industrial sources of phosphorus are excluded, the proportion of domestic phosphorus derived from detergents is estimated to be 33% (TP).**

3. **22% of the TP loading and 40% of the SRP loading at Darvill WWTW originates from detergents.**

4. **Detergent phosphate loading at Gauteng WWTWs range from 15% to 59% (SRP), depending on the source and nature of the inflow waste water (some source from heavily industrialized areas, others from predominantly residential areas).**

4. DETERGENT IMPACTS ON WASTE WATER TREATMENT EFFICACY

4.1 Introduction

In the 1980s the Water Research Commission of South Africa (WRC) funded research by Heynike and Wiechers (1986) to assess the impact of detergent phosphate on eutrophication in South Africa. This investigation indicated that detergents were responsible for between 35 and 50% of the total phosphorus loading on domestic wastewaters and contributed a significant amount of phosphorus to the environment. However, in the absence of more accurate data, it was concluded that the cost implications of banning detergent phosphate in South Africa, outweighed the benefits that would be derived from such a banning.

In the early 1990s the WRC funded another study to update the findings of Heynike and Wiechers and provide more accurate data (Pillay, 1994). The uMngeni catchment was chosen for the study, the reasons being that a substantial amount of water quality data was available for this catchment since it formed part of the Umgeni Water routine monitoring programme and that apart from representing a major developmental region in the country, this catchment provides water to the two largest cities in KwaZulu-Natal, Durban and Pietermaritzburg.

It has been shown (Heynike and Wiechers, 1986; Edmondson, 1991) that approximately half of the phosphorus present in raw wastewaters may arise from detergents and could therefore impact significantly on phosphorus levels present in impoundments downstream of wastewater effluent discharges. Removal of phosphorus during wastewater treatment is therefore crucial, and although removals of as high as 95% are possible at wastewater works that are designed for phosphorus removal and which are being operated optimally, removal may be as low as 5% at some facilities. WWTWs discharging to sensitive catchments, such as the Darvill WWTW in Pietermaritzburg, which discharges into the uMsunduzi River, an important contributor to the Umgeni Catchment, have special discharge limits imposed on the effluent discharge by the Department of Water Affairs (DWA) which restricts the phosphate in the discharge to 1 mg/ℓ. This limit is generally only achievable through the use of coagulant chemicals such as aluminium sulphate, or ferric chloride, which in turn necessitate the use of yet more chemicals such as lime to counteract the effect on the treatment process of the coagulants. This obviously impacts significantly on treatment costs at the WWTW.

The objective of this chapter is to assess the savings in wastewater treatment costs that could be anticipated should the use of phosphate in detergents be limited or banned. The Darvill WWTW has been chosen for this cost assessment for a number of reasons, namely:

- A significant amount of water quality data is available for both the Darvill WWTW and the Umgeni Catchment, to which the Darvill WWTW discharges.
- Previous studies have been conducted on the Umgeni Catchment into phosphorus loadings and sources.

- The Umgeni Catchment represents an important developmental region of the country.
- The Darvill WWTW is a fairly large plant using both biological nutrient removal and chemical addition for phosphorus removal.

4.2 The Darvill wastewater treatment works

The Darvill WWTW is situated in Pietermaritzburg and treats predominantly domestic wastewater, but also receives industrial effluent from surrounding industries. The plant has a design capacity of 80 Mℓ/d and generally operates at around 75 to 90% of its design capacity. The plant is a typical biological nutrient removal plant, and consists of an inlet works comprised of screening degritting and flow measurement. The screened degritted sewage is then settled in primary settling tanks, where the sewage is separated into settled sewage, which flows into the activated sludge plant, and into primary sludge. The primary sludge contains about 30% of the organic load and after pre-thickening, is anaerobically digested.

The settled sewage is pumped into the activated sludge plant, where both biological and chemical nutrient removal takes place. The effluent from the activated sludge plant is settled in secondary settling tanks, in order to remove the activated sludge. The supernatant from the secondary settling tanks is chlorinated and then passes through a series of maturation ponds before being discharged to the uMsunduzi River. The uMsunduzi River joins the Umgeni River at a point between the Nagle and Inanda Dams, impoundments on the Umgeni River, both of which are raw water sources for the greater Durban area.

4.2.1 Nutrient removal at Darvill WWTW

Data was obtained for the Darvill WWTW for the past 5 years (i.e. 2003 to 2008). The data included daily raw sewage inflows to the plant as well as the weekly SRP and ammonia concentrations of the raw influent, the settled sewage and the final effluent, the weekly nitrate concentrations of the raw sewage and final effluent and the daily SRP, nitrate and ammonia concentrations of the final effluent. The average values for this period, as well as the maximum and minimum values and where relevant, percentile values are listed in Table 26.

The average daily inflow over the past 5 years was 76 Mℓ/day, the minimum inflow during the same period was 30.9 Mℓ/d, while the maximum was 344 Mℓ/d. Certain areas in Pietermaritzburg were built with the stormwater drains connected to the sewers and as a result, the incoming flows to the works can be extremely high during storm events. An attenuation dam was built at the works to cope with this problem and during periods of excessively high inflows, raw sewage is diverted to the attenuation dam.

Table 26 - SRP, nitrate, ammonia and inflow data for Darvill WWTW for the period 2003 to 2008

	SRP (mg/ℓ P)				**NO_3 (mg/ℓ N)**	**NH_3 (mg/ℓ N)**	**Raw Sewage inflow Mℓ/d**		
	Avg	**Min**	**Max**	**Percentile**	**Avg**	**Avg**	**Avg**	**Min**	**Max**
Raw	4.57	0.150	20.25	8.70 (95)	0.55	23.11	76	30.9	344
Sett	4.11	0.250	18.10	8.45 (95)	-	22.29	-	-	-
Final	0.661	0.100	14.65	0.972 (85)	1.68	6.52	-	-	-

The data indicate that the plant was generally providing effective nutrient removal during the data collection period. The average ammonia concentration in the raw sewage during this time was 23.11 mg/ℓ N. As expected, very little nitrification occurred in the primary settling tanks, but the average ammonia concentration of the final effluent for the same period was 6.52 mg/ℓ N, indicating good nitrification had occurred in the activated sludge process. Furthermore, the average nitrate concentration of the final effluent during this period was 1.68 mg/ℓ N, so it is clear from a mass balance of the nitrogen present in the final effluent, that denitrification was also being achieved in the activated sludge plant.

The average SRP concentration of the raw sewage during the data collection period was 4.57 mg/ℓ phosphorus, although the SRP of the raw sewage was fairly variable. However the 95 percentile value for the data was 8.67 mg/ℓ phosphorus, indicating that most of the data was less than 9 mg/ℓ phosphorus.

Plant experience over the past 10 to 15 years, has shown that the SRP entering the plant in the raw sewage inflow is generally between 4 and 8 mg/ℓ phosphate. Biological nutrient removal, according to the literature (Metcalf and Eddy, 1991), is effective in removing between 10 and 90% phosphorus, depending on factors such as plant design and the operational regime used on the plant. The Darvill WWTW generally achieves around 35 to 70% SRP removal, which means that with an SRP inflow of 4 to 8 mg/ℓ SRP, even with a 70% reduction through the plant, around 1.2 to 2.4 mg/ℓ phosphate still remains. For this reason, when the raw sewage SRP concentration is above 4 mg/ℓ phosphorus, it is generally necessary to add aluminium sulphate to the activated sludge plant to reduce the SRP to below the 1 mg/ℓ phosphate specified by the Special Discharge limit imposed on the Darvill WWTW.

When the SRP concentration of the raw sewage inflow is less than 4 mg/ℓ phosphorus, it is usually not necessary to dose aluminium sulphate as it is generally possible to comply with the 1 mg/ℓ phosphate limit using only biological nutrient removal.

SRP data were used since the DWAF General and Special limits for wastewater effluent discharge are based on ortho-phosphate and SRP provides a measure of ortho-phosphate. Detergent phosphate is added to detergents in the form of condensed polyphosphates which degrade to ortho-phosphate when exposed to water. Ortho-phosphate is the bio-available form of phosphate (Metcalf and Eddy, 1991) and therefore the species of interest in terms of eutrophication.

The average total phosphorus entering the plant has been found to be 9.03 mg/ℓ for data collected over the past 8 years and the contribution due to detergent phosphorus has been found to be only 22% of the this load to the Darvill WWTW, which is lower than the 35 to 50% quoted by other researchers. This means that the average concentration of detergent phosphate entering the Darvill WWTW is 1.99 mg/ℓ phosphate and as explained above, this will all degrade to ortho-phosphate once dissolved in water. In other words, approximately 44% of the average SRP concentration of the raw sewage at Darvill WWTW is estimated to be derived from detergent phosphate.

4.3 Assessment of expected cost savings

4.3.1 Effect of Plant Size

Presently, around half of all wastewater works in South Africa have a capacity of less than 5 Mℓ/d (see Table 27), while over 80% of all wastewater works in the country have capacities of less than 10 Mℓ/d. Smaller plants, generally those treating less than 10 Mℓ/d are not very effective for phosphate removal. Therefore, reducing the phosphate in detergent can be expected to impact significantly on the phosphate present in the discharge of these smaller works.

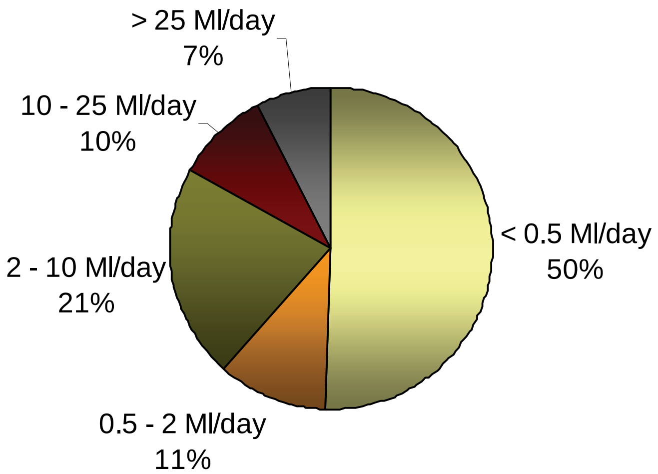

Figure 7 - Distribution of wastewater works in South Africa based on Mℓ/d sewage treated.

Table 27 - Estimated total volume of wastewater treated in South Africa (5 800 to 7 859 Mℓ/d based on two methods of estimation from DWAF data 2006)

Plant size category (Mℓ/d)	Estimated number of plants (#)[1]	Median wastewater flow treated (Mℓ/d)[2]	Total volume of wastewater treated (Mℓ/d)
< 0.5	488	0.25	122
0.5-2	108	1.25	134
2-10	208	6	1248
10-25	93	17.5	1625
25-100	71	62.5	4460
Estimated total volume of wastewater treated in South Africa			**7589**

[1] Estimated number of plants obtained from the DWAF data base corrected for the plant category sizes used in the report V Pillay, 2008.
[2] The actual plant sizes in each plant size category were available.

WWTWs with capacities greater than 10 Mℓ/d account for less than 20% of all the wastewater treatment works in South Africa, but in terms of volume have been estimated to treat more than 80% of all reticulated wastewater in the country (Pillay, 2008). It is at these plants where more effective phosphate removal can be expected. Based on the fact that the larger plants will be better regulated by DWAF than the smaller plants and that effective phosphate removal is more likely to occur at these larger plants, it has been assumed (an assumption that needs to be addressed) that a decrease in detergent phosphate would not have any significant effect on the phosphate concentration of effluents from these plants, as they will continue to operate to the phosphate discharge limits currently relevant to the plant. The only impact due to a reduction in phosphate in the raw sewage will be in treatment cost savings.

For the Darvill case, the predominant impact of reducing phosphate in the raw sewage influent, will be on the treatment cost savings, since as mentioned previously, the plant will continue to operate at the 1 mg/ℓ phosphate limit Special Discharge Limit. In other words, there will be no impact on the receiving water course and impoundments in terms of phosphate loadings, although there is a strong case to be made to reduce the 1 mg/ℓ standard and thus to pass this benefit onto the receiving environment where greater benefits may be found.

4.3.2 Biological Nutrient Removal

The question was raised as to whether biological nutrient removal would still be required if the phosphate concentration in the raw sewage were to be reduced. Detergent phosphate has been found to account for between 35 and 50% of the total phosphorus loading on domestic wastewater, so certainly in the case of a wastewater works such as Darvill WWTW, which has an average SRP concentration of 4.57 mg/ℓ phosphate in the influent, a 35 to 50% reduction would still result in an average SRP concentration of between 2.3 and 3.0 mg/ℓ phosphorus, so biological nutrient removal would still be required if the effluent were to comply with the 1 mg/ℓ phosphate standard. Furthermore, other nutrients, such as ammonia and nitrate will in most cases exceed both the General and the Special limits, unless adequate biological nutrient removal is achieved. For example, the average ammonia concentration in the Darvill WWTW raw effluent is 23.11 mg/ℓ N, which is typical for a raw domestic sewage. The ammonia limit for final sewage effluent is 3 and 2 mg/ℓ N for the General and Special limits respectively, so biological nutrient removal would still be necessary, even if phosphate was completely eliminated. Since biological nutrient removal would still be required, a reduction in the detergent phosphate concentrations is also not expected to have any effect on the energy costs incurred at the plant. Reduction in the SRP of the activated sludge will not reduce the need for aeration, nor will it reduce the amount of oxygen required for nutrient removal, denitrification being the predominant reaction.

A reduction in detergent phosphate is also not expected to impact significantly on the operation of package treatment works, or small works in terms of treatment costs or operational regimes. Presently, small plants, including package treatment plants, in almost all cases have to comply with the General Standard for Phosphate, which is 10 mg/ℓ phosphate and this is generally achievable, especially since the ortho-phosphate concentration of most raw domestic wastewaters is less than 10 mg/ℓ phosphate (Metcalf and Eddy, 1991).

The possibility that detergent phosphate differs from naturally occurring phosphate in any way, such as biodegradability or can be analytically distinguished from naturally occurring phosphate has been considered, but there is no evidence for this. Detergent phosphate has been found to be indistinguishable from naturally occurring forms of phosphate.

4.3.3 Lime Usage

The impact that a reduction in detergent phosphate would have on lime usage at the Darvill WWTW works was also considered. However, it has been found from plant experience that the lime usage is not affected noticeably when aluminium sulphate is being dosed. The pH and alkalinity of the settled sewage at the Darvill WWTW are fairly low (Gaydon et al., 2007), averaging 7.1 and 241 mg/ℓ $CaCO_3$ for pH and alkalinity respectively. In order to ensure optimum biological nutrient removal, it is important to keep the pH above 7. 2 and preferably between 7.2 and 8.6 (Metcalf and Eddy, 1991) and it is therefore necessary to add lime to the activated sludge plant at Darvill WWTW, even when aluminium sulphate is not being added. Furthermore aluminium sulphate reacts with the alkalinity present in water according to the following equation:

$$Al_2(SO_4)_3.14H_2O + 3CaCO_3 \rightarrow 3CaSO_4 + 2Al(OH)_3 + 6CO_2 + 14H_2O \quad [1]$$

Based on the respective molecular weights of aluminium sulphate and calcium carbonate, one obtains the following:

1 mg/ℓ aluminium sulphate = 3 x 100 / 594 = 0,505 mg/ℓ $CaCO_3$

This means that an aluminium sulphate dose of 45 mg/ℓ (highest dose generally used at the Darvill WWTW), would react with 22.7 mg/ℓ $CaCO_3$, which is less than 10% of the average alkalinity concentration of 241 mg/ℓ $CaCO_3$. The impact of this aluminium sulphate dose on the overall alkalinity of the settled sewage in the activated sludge plant is too small to make a significant difference to the lime required to ensure effective biological nutrient removal.

4.3.4 Sludge Disposal

The initial wastewater sludge disposal guidelines (Department of Health, 1991) were based on agricultural recommendations and were found to be impractically stringent and were almost impossible to apply, being up to 150 times more stringent than the USEPA regulations. More recently, as the result of a Water Research Commission project, new properly scientifically founded guidelines have been produced. The first volumes of these guidelines were published recently (Snyman and Herselman, 2006) and replace the previous document and addendum (WRC, 1991; WRC, 1997).

The new Guidelines (Snyman and Herselman, 2006), in line with the resolution of the World Summit on Sustainable Development held in South Africa in 2003, support the principle of appropriate and/or sustainable use of resources. These guidelines also provide far wider ranging options in terms of disposal options for wastewater sludges. Whereas the 1997 Guidelines (WRC, 1997) considered the option of using the sludge only as a soil conditioner and provided no clear guidelines on other disposal options, the new Guidelines conclusively differentiate between the different management options available for wastewater sludge in a series of guideline volumes.

These new guidelines deal with both sustainable and unsustainable management options, the choice of management option being decided by applying the user-friendly classification system provided. Sustainable management options refer to those that are not environmentally harmful in that they do not involve the use of a non-renewable resource, nor do they result in an accumulation of compounds that exceed the assimilative capacity of the receiving environment. Various sustainable management options are available, with agricultural use of sludge being the preferred option. However, there are situations where none of the sustainable management options are feasible, for example when agricultural land is impractically distant or the sludge contains heavy metals or other contaminants at unacceptably high concentrations. For cases such as these, the Guidelines provide alternative management options, such as disposal to landfill and incineration, providing information on the technical and legislative aspects associated with each option.

Sludge classification is based on the microbiological content of the sludge (classified as A, B or C), the stability of the sludge (classified as 1, 2 or 3) and the organic and inorganic pollutants contained in the sludge (classified as a, b or c). Therefore, the best quality sludge would be a Class A1a sludge. When considering a sludge for agricultural use, the metal content is particularly important, especially that of Cu, Zn, Pd and Cd, although obviously a full classification of the sludge as described above is required before any conclusive decision regarding the management option to be used, can be made. The important factor here is that neither aluminium nor phosphorus (or phosphates) are listed as pollutants affecting the classification of wastewater sludge and therefore changes in the phosphate or aluminium content of the sludge that might occur due to reductions in detergent phosphate would not have any effect on sludge disposal at the works.

The impact that aluminium sulphate dosing has on the volume of sludge produced was also investigated. In practice it has been found that dosing aluminium sulphate at the Darvill WWTW for phosphate removal does not impact significantly on the volume of sludge produced in the activated sludge plant. Calculation of the amount of sludge that would be produced at an aluminium sulphate dose of 45 mg/ℓ, which is at the upper end of dosages used on the plant, confirms that even at this dose, the additional sludge produced would constitute only around 10% of the total sludge production of the activated sludge plant.

Activated sludge with a solids content of around 5 000 mg/ℓ is wasted from the secondary settling tanks at an average daily volume of around 2.9 Mℓ/d (around 3.4 Mℓ/d is wasted Monday to Saturday, with no wasting taking place on Sunday, which is an average of approximately 2.9 Mℓ/d). This equates to a dry solid mass of 14.5 tons per day. An aluminium sulphate dose of 45 mg/ℓ (as $Al_2(SO_4)_3.14H_2O$) would be expected to produce 11.8 mg/ℓ aluminium hydroxide precipitate according to the following:

$$Al_2(SO_4)_3.14H_2O \rightarrow 2Al(OH)_3 + 3H_2SO_4 + 8H_2O \qquad [2]$$

Or 18,5 mg/ℓ as $AlPO_4$, according to the following:

$$Al^{3+} + H_nPO_4^{3-n} \rightarrow AlPO_4 + nH^+ \qquad [3]$$

18.5 mg/ℓ $AlPO_4$ relates to a dry solid mass of 1.48 ton/d for an inflow of 80 Mℓ/d (the design capacity of the works) or around 10.2% of the total waste activated sludge produced when there is no aluminium sulphate addition. This is of course a simplification of the reactions occurring, but provides some indication of the amount of additional sludge that can be expected due to the addition of aluminium sulphate.

4.3.5 Cost Breakdown for the Darvill WWTW

The average SRP concentration of the raw sewage inflow to Darvill WWTW for the past 5 years is 4.57 mg/ℓ phosphate. Biological nutrient removal (BNR) removes a significant amount of this phosphate, but aluminium sulphate is added to the activated sludge generally whenever the SRP is of the raw sewage exceeds 4 mg/ℓ phosphate in order to reduce the SRP of the final effluent to below the DWAF Special limit of 1 mg/ℓ phosphate. The aluminium sulphate dose at Darvill is between 35 and 45 mg/ℓ as $Al_2(SO_4)_3.14H_2O$ (solution contains between 46 and 48% active ingredient, but dosages and costs are always determined for active ingredient only, although the fact that the solution contains only around 50% active ingredient needs to be considered when calculating transport costs).

Normally, the lowest aluminium dose of 35 mg/ℓ is used when the SRP of the raw sewage is around 4 mg/ℓ phosphate and this relates to an Al dose of 3.18 mg/ℓ. The basic reaction involved in the precipitation of phosphate with aluminium is as follows:

$$Al^{3+} + H_nPO_4^{3-n} \rightarrow AlPO_4 + nH^+ \qquad [4]$$

In other words, 1 mole of aluminium will react with 1 mole of phosphate. However, this is a very simplified depiction of what is in fact a highly complex reaction, involving a number of competing reactions, whose equilibrium constants are influenced by factors such as pH, alkalinity and the presence of elements and compounds found in the sewage (Metcalf and Eddy, 1991). It is therefore not possible to estimate the aluminium sulphate dose required based on the reaction of aluminium with phosphate using reaction [4]. Instead, the aluminium sulphate dose required is usually determined experimentally in the laboratory or alternatively, through full scale operation. In the case of the Darvill WWTW, the ratio of aluminium to phosphate required for phosphate removal has been found to be in the region of 3:1 aluminium to phosphate on a molar basis (i.e. 81 mg Al: 31 mg phosphate or 2,61:1).

Therefore an Al dose of 3.18 mg/ℓ (aluminium sulphate of 35 mg/ℓ), relates to a phosphate concentration of 1.2 mg/ℓ phosphate. This means that since 35 mg/ℓ aluminium sulphate is used for an SRP concentration of 4 mg/ℓ phosphorus, and that this removes approximately 1.2 mg/ℓ phosphorus, in order for the final effluent to comply with the Special limit of 1 mg/ℓ phosphorus, biological nutrient removal must be responsible for removing at least 1.8 mg/ℓ phosphorus, which is 45% of the total SRP.

Based on the above, at the average SRP concentration of 4.57 mg/ℓ phosphate entering the Darvill WWTW, biological nutrient removal is expected to remove 2.06 mg/ℓ phosphate. This leaves 2.51 mg/ℓ phosphate and in order to comply with the Special limit of 1 mg/ℓ phosphorus, at least 1.51 mg/ℓ phosphate still needs to be removed chemically using aluminium sulphate. Based on the Al:P ration of 2.61:1, 43 mg/ℓ aluminium sulphate would be required to achieve this.

However, if the detergent phosphate contribution to the SRP is 1.99 mg/ℓ phosphate at the average SRP concentration of 4.57 mg/ℓ phosphorus, then biological nutrient removal would be adequate for complying with the Special limit and no aluminium sulphate addition would be required. In other words, reducing the total phosphorus load into the plant by 22% is expected to completely preclude the need for aluminium sulphate addition. This is in fact what has been found. When the phosphates coming in to the plant remain low (between 2 and 4 mg/ℓ, alum is not required as biological nutrient removal is adequate on its own.

A dose of 43 mg/ℓ alum is equivalent to 43 kg/Mℓ so at an average inflow rate of 76 Mℓ/d, this relates to 3 268 kg/d. As mentioned before, although supplied as a 46-48% solution, costs and doses are always based on active ingredient, namely $Al_2(SO_4)_3.14H_2O$. The cost of aluminium sulphate, including transport is presently R1 700/ton of active ingredient and therefore the potential saving in aluminium sulphate at the Darvill WWTW is R2 027 794/annum as is shown below in Table 28.

Table 28: Darvill's potential cost savings should zero-phosphate detergents reduce the need for alum dosing.

Average Darvill inflow SRP concentration	4.57 mg/ℓ
Standard allowable effluent concentration	1.0 mg/ℓ
Biological removal	2.06 mg/ℓ
Remaining P currently removed chemically to meet standard	1.51 mg/ℓ
Alum dose required	43 kg/Mℓ
Average Darvill inflow	76 Mℓ/day
Quantity of Alum required	3268 kg/Day
Price of Alum	R1700/ton
Possible cost saving	R2 027 794.00 / annum

The calculated savings of R2 million per annum are savings that may accrue to Darvill WWTW in the event of detergent phosphate being eliminated. This will only be the case however if Darvill continues to target the 1 mg/ℓ effluent concentration standard once the influent loading has been reduced. In order for the benefit of the reduced loading to be passed on to the aquatic environment downstream, the WWTW processes will need to remain unchanged despite the reduction in influent loading which will then reduce the effluent loading by an equivalent amount.

Chapter 4: Findings summary

1. Approximately 80% of the waste water in South Africa is treated by approximately 20% of the WWTWs. These are facilities with a capacity of greater than 10 ML/day

2. Alum dosing to remove phosphates was found to generate a volume of sludge equivalent to approximately 10% of the sludge produced by the activated sludge process.

3. Possible cost savings that may be realized should detergent phosphate be removed and Darvill continue to target 1 mg/ℓ as an effluent concentration standard are estimated to be approximately R2 million per year.

4. Potential benefits to the environment from eliminating detergent phosphate will only be realised should the treatment process remain unchanged, and the effluent concentration be reduced by the equivalent of the detergent phosphate contribution.

5. THE CONTRIBUTION OF DETERGENTS TO THE TOTAL PHOSPHORUS LOADING OF KEY DAMS

5.1 Introduction

Phosphorus enters the dams and waterways of our water supply network through different routes, some of which are diffuse sources (P entering watercourses at no particular point, rather all along the edge of the water course, largely carried by rain runoff) and others of which are point sources (compounded high concentration phosphate sources entering a water course at one point).

Point sources of detergent phosphate contribute more significantly to the detergent phosphate loading of waterways and dams than diffuse sources. These are restricted to the outfalls of WWTWs and places along rivers where laundry is washed regularly.

Diffuse sources of detergent phosphate might arise from situations where grey water from washing is disposed of on the ground (from bucket hand washing), following which it makes its way overland (washed by surface flow usually following heavy rain events) and finally arrives in a water course. Due to the complex number of processes that soluble phosphate can be involved in during this overland journey, and the ease with which it is assimilated into these processes, diffuse sources of detergent phosphate are difficult to account for in the overall balancing of phosphate in rivers, especially considering the many other sources of phosphate which also contribute to the volume of phosphate entering water courses diffusely.

For this reason, all detergent phosphate disposed of away from streams and rivers is assumed to be assimilated into biological processes or adsorbed into soil particles before it is able to enter a water course. This includes that portion disposed of in septic tank systems, as it is assumed that most of these are located some distance from a water course. Only laundry washing carried out directly in a river or stream and the release of WWTW's effluent are assumed to introduce detergent phosphate into water courses.

5.2 Dams included in this study

The dams included in this study are based on the 30 key dams used in Harding's study (2008). This list is reduced to the dams that he found to be appropriate for modelling (17), and added to by a selection of important dams from KwaZulu-Natal which has appropriate data sets available (7). This means that ultimately 24 dams of regional and national importance have been assessed. This list is found below in Table 29.

The catchments for these dams have been mapped based on quaternary catchments, and these maps have been used as the basis for all calculations of phosphate loading. The national distribution of these catchments can be seen in Figure 8 below.

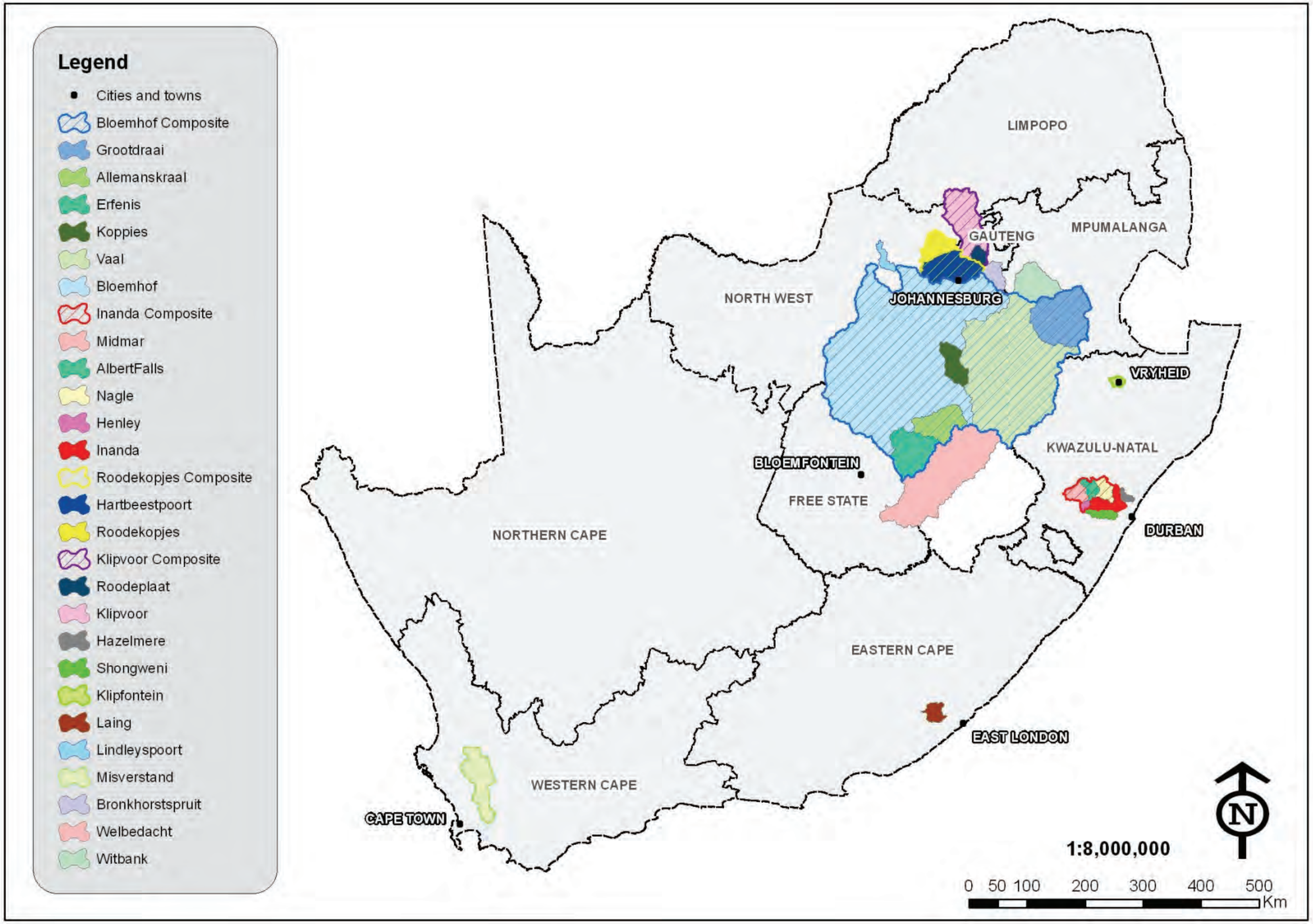

Figure 8: National distribution of the catchments supplying the dams studied in this report

Table 29: List of dams (reservoirs) included in this study

	Reservoir	Catchment Area (Ha)	River
1	**Albert Falls**	72814.96	uMngeni River
2	**Allemanskraal**	363716.26	Sand River
3	**Bloemhof**	5784121.88	Vaal River
4	**Bronkhorstspruit**	126126.21	Bronkhorstspruit River
5	**Erfenis**	473990.58	Groot Vet River
6	**Grootdraai**	798335.46	Vaal River
7	**Hartbeespoort**	411508.91	Crocodile (West) River
8	**Hazelmere**	3752.60	uMdloti River
9	**Henley**	21968.23	uMsunduzi River
10	**Inanda**	127777.90	uMngeni River
11	**Klipfontein**	34015.00	White Mfolozi River
12	**Klipvoor**	545614.22	Pienaars River
13	**Koppies**	216419.22	Renoster River
14	**Laing**	92555.79	Buffalo River
15	**Lindleyspoort**	70905.77	Elands River
16	**Midmar**	92529.03	uMngeni River
17	**Misverstand**	409937.84	Berg River
18	**Nagle**	92850.46	uMngeni River
19	**Roodekopjes**	201994.36	Crocodile (West) River
20	**Roodeplaat**	68356.22	Pienaars River
21	**Shongweni**	78503.23	uMlazi River
22	**Vaal**	3064914.94	Vaal River
23	**Welbedacht**	1530768.74	Caledon River
24	**Witbank**	358247.47	Olifants River

5.3 Catchment consumption of detergent phosphate.

Utilising GIS software, the total consumption of detergent phosphate can be mapped and calculated per catchment. This is done using census data combined with detergent consumption estimates supplied by Unilever (see Table 16). Household detergent consumption estimates are based on household size as was discussed in chapter 3 of this report. Any particular catchment's total detergent consumption is then calculated based on the following equation:

(No of 1 member households * 12.8) + (No of 2 member households *15.4) + (No of 3-4 member households * 17.3) + (No of >5 member households * 19.3) = Total consumption (kg/annum)

The total consumption per catchment figures are of limited value to this study as a significant portion of this phosphate will in all likelihood not reach water courses due to it being disposed of on the ground and being absorbed by biological processes or adsorbed to soil particles. It is however worthwhile considering that, with the exception of that portion extracted by WWTWs, the total consumption figure is a reflection of the total volume of detergent phosphate introduced into the catchment environment every year. The intensity of consumption (kg/ha) figure is more useful, as this figure provides an indication of which of the catchments experience the highest consumption (and thus disposal) of detergent phosphate per unit area (see Table 30).

The maps produced by this exercise (See appendix 3) are also useful indicators of where the majority of detergent is consumed within a catchment. It can be seen in the example of the Inanda composite catchment below (Figure 9) that the majority of detergent is consumed in the Pietermaritzburg / Edendale area. This is the most densely populated area of the catchment. Unsurprisingly therefore, the largest source of detergent phosphorus in this catchment is Darvill WWTW, which services this area.

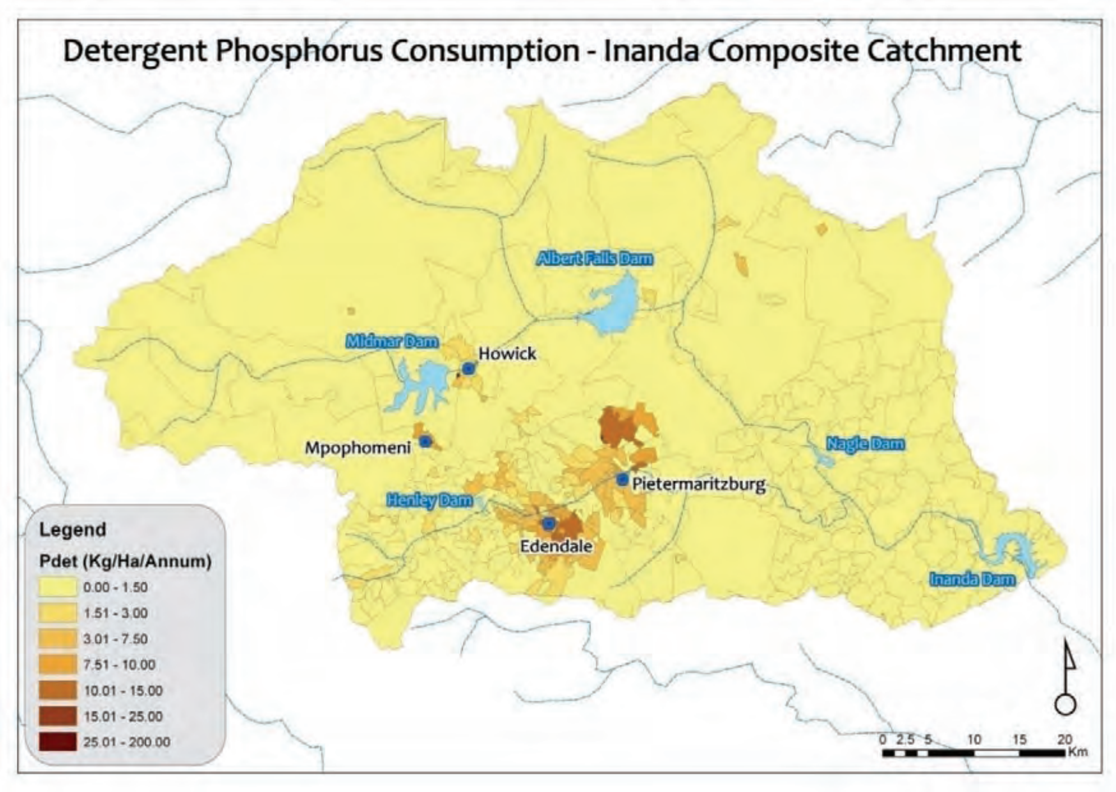

Figure 9 - Detergent phosphate consumption in the Inanda Catchment

5.4 Detergent phosphate contribution to total phosphorus loading of dams

5.4.1 Method

Establishing the contribution of detergent phosphate to the total phosphorus loading of various dams is made difficult by the complicated biological and chemical processes that phosphorus is involved in, in the natural environment. In an attempt to largely eliminate the complexity introduced by these processes and phosphorus mass balancing, it was decided to utilise the total potential export of phosphorus from a catchment land area and calculate the proportion of this potential export that is attributable to detergents. The assumption was thus made that detergent phosphorus would undergo the same processes in the aquatic environment that other naturally occurring phosphorus would undergo, thus the proportion of the phosphorus originating from different sources would remain the same throughout the course of the river. This proportion can then be applied to the total phosphorus loading measured entering the dams in question.

Table 30: The total volume of detergent phosphate consumed in the catchments of the 24 key dams.

			Dam catchment	Total phosphate consumption (t/a)	Phosphate consumption intensity (kg/Ha)
Inanda	Nagle	Albert falls	Midmar	9.58	0.104
Inanda	Nagle	Albert falls	Albert Falls	7.25	0.100
Inanda	Nagle		Nagle	12.45	0.134
Inanda			Henley	16.04	0.731
Inanda			Inanda	130.33	1.022
	Bloemhof	Vaal	Grootdraai	42.6	0.053
	Bloemhof	Vaal	Vaal	197.64	0.065
	Bloemhof		Allemanskraal	10.09	0.028
	Bloemhof		Erfenis	11.57	0.024
	Bloemhof		Koppies	9.59	0.044
	Bloemhof		Bloemhof	1718.74	0.297
		Klip voor	Roodeplaat	122.84	1.800
		Klip voor	Klipvoor	292.04	0.536
		Roode kopjes	Hartbeespoort	618.71	1.505
		Roode kopjes	Roodekopjes	49.12	0.244
			Bronkhorstspruit	15.56	0.123
			Hazelmere	8.76	0.233
			Klipfontein	7.95	0.234
			Laing	43.12	0.466
			Lindleyspoort	2.56	0.036
			Misverstand	55.78	0.136
			Shongweni	30.58	0.390
			Welbedacht	37.02	0.024
			Witbank	22.76	0.064
			Total (T/annum)	3472.68	

Landuse:

GIS software was used to clip out landuse coverage for each dam from the 2001 CSIR landuse coverage. An example of this is seen below in Figure 10, illustrating the landuse coverage for the Inanda composite catchment. The surface area of each of the various landuse categories occurring in each catchment was then calculated. For a complete list of the categories see appendix 1.

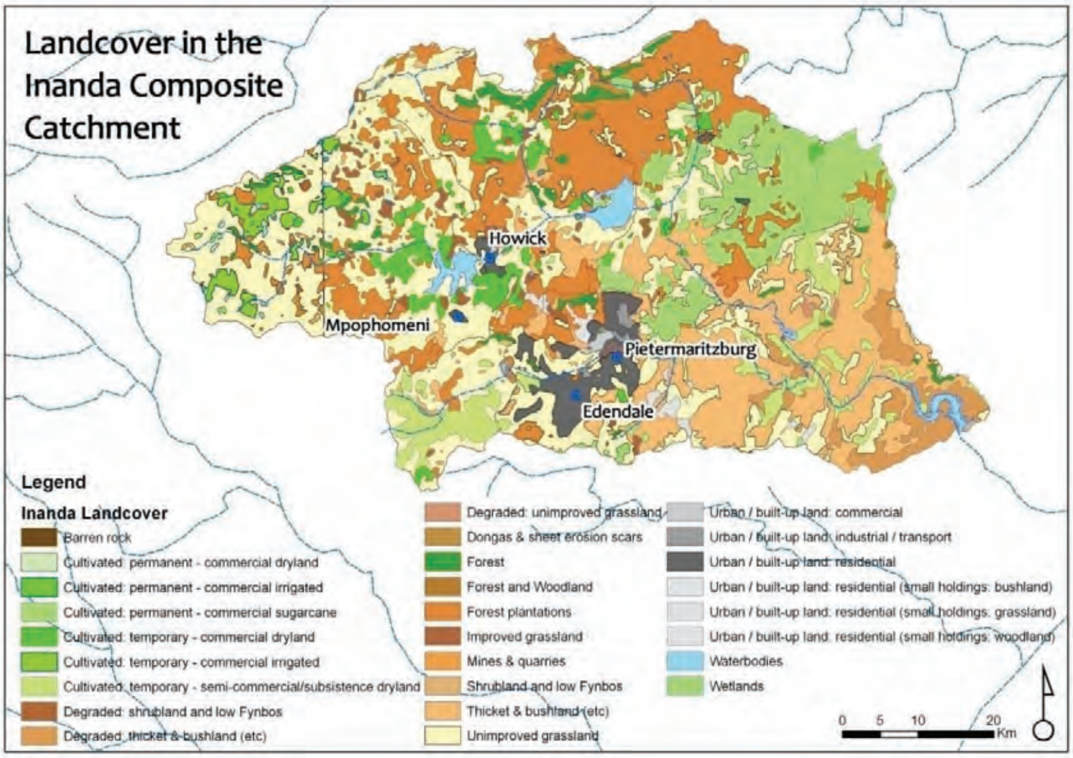

Figure 10 - Landcover in the Inanda Catchment (CSIR)

***Export coefficients*:**

Export coefficients for each of the landuse categories have been derived from a list of determined sets of coefficients. These were sourced from various literature publications and studies, though many of them were summarised by Enongene and Rossouw in their report "*Collation and Development of Nutrient Export Coefficients for South Africa*", which was completed for DWAF (2007). For each landuse category, the published coefficients were evaluated, and the most applicable one (based on the appropriateness of the study from which it originated) selected. This has resulted in a composite set of landuse coefficients which can be seen in appendix 1.

As is shown in Table 31 below, an **urban residential** phosphorus coefficient of 5.0 kg/ ha.annum^{-1} has been calculated for the Pietermaritzburg area based on effluent data for the Darvill sewage works (this includes a 0.6 kg/ha.annum^{-1} run-off coefficient). This WWTW operates a biological nutrient removal facility and additionally practices alum addition to ensure effluent maintains effluent phosphate levels below the 1 mg/ℓ SRP concentration standard. This coefficient has been used as an approximation of

WWTW effluent around the country, however, it is accepted that many of the WWTWs operating in the catchments of the dams included in this study do not operate as efficiently as this particular facility. The urban residential export coefficient, and the results derived from using this value should be viewed in the light of this fact. As an example, using the same calculation methods, Howick WWTW, which operates much less efficiently, shows an export co-efficient of 8.5 P kg/ha.annum^{-1}.

Table 31: Calculation of the TP export coefficient for urban residential areas in Pietermaritzburg

TP concentration at Darvill	1556.33	µg/ℓ
	1.56	mg/ℓ
	0.001556	g/ ℓ
Flow volume	72.70	M ℓ /day
	72700000.00	ℓ /day
P Loading	113145.43	g/day
	113.15	kg/day
	41298.08	kg/annum
Darvill catchment area	9435.48	Ha
Darvill export coefficient	4.38	kg/ha.annum^{-1}
Runoff coefficient	0.60	kg/ha.annum^{-1}
PMB residential	**5.0**	**kg/ha.annum^{-1}**

Based on these coefficients, a total phosphorus export potential has been calculated for each catchment. These results can be seen in appendix 2.

It should be noted that very few experimentally calculated phosphate export coefficients exist. This is considered a limitation in the context of this study. The coefficients that have been used are based on estimates for particular catchments and the accuracy of these may vary considerably between catchments of differing morphology and character.

5.4.2 Calculations

The detergent phosphorus loading of the key dams is determined by dividing the sources of detergent phosphorus into urban and rural categories. It is assumed that detergent phosphorus will originate only from residential areas.

<u>Urban Areas:</u>

The CSIR landuse coverage defines several urban landuse classes, amongst which are residential, commercial and Industrial classifications. The assumption is made that in urban areas, detergent phosphate will only be generated in residential areas and that it will be disposed of through municipal sewer systems. In a previous chapter of this report, detergent phosphate has been calculated as constituting approximately 22% of the total phosphorus arriving at Darvill WWTW in KZN (Table 21). The overall loading however includes a significant contribution made by local industrial sources which reduces the proportional contribution of detergents. The industrial contribution will vary considerably when considering other WWTWs.

The proportion of <u>domestic</u> phosphorus (that phosphorus emanating from residential areas) attributable to detergent phosphate was also calculated and established as being approximately 33%

(see Table 23). This value is thought to be a reasonably consistent estimate that will apply at any WWTW.

In trying to estimate the proportion of urban total phosphorus attributable to detergents, a total export per landuse is estimated using the export coefficients derived from several sources as discussed previously. The phosphorus export coefficient for urban residential is estimated to be 5.0 kg/Ha/year (see Table 31). Detergent phosphate is thus estimated to contribute 33% of this value.

Rural Areas:

In rural areas, the areas of concern for this project are the areas where rural residential settlement density results in a significant number of people washing their laundry directly in rivers. This residential landuse is harder to define spatially since the CSIR landuse coverage does not define a rural residential landuse category. A case study site was identified at Vulindlela in the upper uMsunduzi valley near Pietermaritzburg, where the area is characterised by a mosaic of relatively dense housing and subsistence agriculture plots. A comparison between the CSIR landuse coverage and aerial photography has shown that areas of this nature are designated as “Cultivated temporary – semi commercial / subsistence”. For the purposes of this project, this category of landuse was recognised as rural residential.

Investigations into the proportion of phosphorus in rivers emanating from rural residential areas proved difficult, and a significant assumption was made to facilitate calculations. It is assumed that if people source their domestic water directly from a river (i.e. they have no access to piped water), they will wash their clothes at the water source. 2001 Census data gives an indication of the number of people who source their water from rivers. This data has been used to get an indication of the number of people washing their clothes directly in rivers. In the case of Vulindlela, this has been calculated as 726 households

According to the DWAF water service national information system website, **(http://www.dwaf.gov.za/dirws/wsnis/default.asp?nStn=wsnisindex)**, the number of households with no access to piped water (or access below RDP standards) has been reduced in KwaZulu-Natal from 859431 to 448904 since 2001. This fact means there is a probability that the number of households sourcing water from rivers in any particular KZN catchment has decreased by 52% due to increased service provision of water. This decrease has been applied as a reduction to the number of households sourcing water from a river in the Vulindlela area. The number of households washing laundry directly in rivers in the Vulindlela area is thus estimated to be 380.

Data from the inflow to Henley Dam shows the Total Phosphorus concentration averages approximately 46.4 µg/ℓ and the flow averages 0.88 m^3/sec. These figures result in a total phosphorus loading of approximately 1.29 Tons/annum. Given that there are an estimated 380 unserviced households in this area, this is thought to result in 0.29 Tons of detergent phosphorus being used directly in the river per annum (based on 14.6 kg/household/annum – the Unilever consumption statistic for the ‘black rural’ population group). Detergent phosphorus is thus thought to account for **22.7%** of the total phosphorus export from rural residential landuse areas.

It is acknowledged that the calculation of the volume of detergent phosphorus originating from in-stream washing has important limitations in that rural residential population density, access to water provision services and the proximity of people's residences to rivers will all impact on the volume of detergent being used in rivers. Additionally, river ecosystems readily consume bio-available phosphates, and thus the quantity being introduced into a river will likely be reduced considerably before concentration measurement can take place downstream. The calculation method used in this report may be further compromised by the fact that in some areas, water from stand pipes is charged for, and people with access to this water may still prefer to wash their clothes in a river where there is no charge. Determining a single fixed value for this type of scenario in different catchments is thus fraught with problems, and could be the subject of a separate study which would help to refine the outputs of this project.

5.5 Results – Detergent Phosphate Loading of Key Dams

The different landuse categories present in a catchment are the most important drivers behind the export of phosphorus into the catchment's waterways. The release of detergent phosphate into the environment is almost entirely associated with urban and rural residential landuse.

Varying from predominantly unimproved grassland and dryland agriculture to predominantly urban landuse, the catchments studied in this report reflect a range of different levels of residential density. Predictably, those catchments with the greatest proportion of residential landuse also show the greatest intensity of detergent phosphorus use (see Table 30 above).

Based on the export coefficients drawn from several reports (see appendix 1), and from calculations made in the Darvill WWTW catchment, total phosphorus export potential values have been calculated for each catchment (see appendix 2). Using the calculated values of 32.9% (urban residential) and 22.7% (rural residential), the volume of detergent phosphorus originating from residential areas has been calculated, and converted to a percentage of the Total Phosphorus exported from all landuses in the respective catchments. This figure represents the total proportion of catchment phosphorus loading which is attributable to detergents.

The urban residential export coefficient is especially important for this study. Its calculation was discussed in depth in section 4.4.1. It is important to note that because the results of the calculations carried out in this chapter reflect a percentage contribution of detergent phosphate to a dam's total phosphorus intake, and because Urban residential contributes by far the most significantly to this value, the total contribution will tend towards 32.9%. This is because detergent phosphate has been calculated as making up 32.9% of domestic sewage, and assuming there is no other contributing source (i.e. a hypothetical dam where total phosphorus intake is limited to sewage) 32.9% will be the contribution made by detergent phosphate. For this reason, the results of highly urbanised catchments such as Roodeplaat and Hartbeespoort approach this value.

This figure also represents the potential reduction in phosphate loading which may be realized if zero-phosphate detergents were to be introduced. The potential reductions in total phosphorus loading are reported in Table 32 below.

The results correlate well with the calculation of detergent phosphate consumption intensity (Table 30) showing those catchments with the greatest detergent consumption intensity are also the catchments with the greatest potential for phosphorus load reduction through the elimination of detergent phosphate.

Table 32: Percentage of the total phosphorus loading of key dams that is attributable to detergents.

Catchment	Total P	kg Pdet	Pdet proportion (%)
Albert Falls	9302.83	1627.4	17.49
Allemanskraal	35081.8	1212.4	3.46
Bloemhof	1156796.4	175825.8	15.20
Bronkhorstspruit	14677.94	771.7	5.26
Erfenis	47952.6	2141.1	4.47
Grootdraai	101481.2	7620.6	7.51
Hartbeespoort	321421.69	90020.8	28.01
Hazelmere	3498.7	772.1	22.07
Henley	1961.3	176.8	9.01
Inanda	62011.30	17362.2	28.00
Klipfontein	8353.4	1560.5	18.68
Klipvoor	208420.4	55957.6	26.85
Koppies	22770.78	736.7	3.24
Laing	42859.3	12125.4	28.29
Lindleyspoort	5995.1	591.9	9.87
Midmar	16405.48	541.2	3.30
Misverstand	115431.1	7780.1	6.74
Nagle	8032.3	625.8	7.79
Roodekopjes	92508.73	7856.7	8.49
Roodeplaat	64378.5	18883.4	29.33
Shongweni	21944.1	4608.7	21.00
Vaal	393329.65	33645.9	8.55
Welbedacht	194567.7	26596.8	13.67
Witbank	63647.72	5427.1	8.53

Colour Key
>25%
20-25%
10-20%
5-10%
0-5%

NB It is acknowledged that Darvill WWTW represents a reasonably efficient facility with regards to phosphate removal, using both biological nutrient removal as well as alum dosing to achieve the 1mg/ℓ standard. Less efficient facilities (especially the many smaller facilities) which do not remove phosphate as effectively may thus result in higher phosphorus export coefficients. **Results from this study should thus be seen as a reasonably conservative estimate.**

Chapter 5: Findings summary

1. The proportion of overall phosphorus loading of dams attributable to detergent phosphate varies according to the extent of residential landuse in the catchment. **Dams with small catchments but high urban landuse show the highest proportions of detergent based phosphorus loading.**

2. **The urban residential landuse phosphorus export coefficient was found to be 5 kg/ha.annum^{-1}**. This is based on a residential area serviced by a relatively efficient WWTW, and should thus be seen as a conservative estimate. Smaller WWTWs are generally less efficient in phosphate removal and will consequently exhibit higher export values.

3. Based on landuse coefficients, contributions to the total phosphorus loading of key dams attributable to detergent phosphate varies from **3.2% to 29.3%**. The 5 dams most affected are:

    a. Roodeplaat – 29.3%

    b. Laing – 28.3%

    c. Hartbeespoort – 28%

    d. Inanda – 28%

    e. Klipvoor – 26.9%

6. IMPACTS OF ZERO-PHOSPHATE DETERGENTS ON THE INCIDENCE OF ALGAL BLOOMS

6.1 Data analysis for dams and inflows

6.1.1 Data Sources

Water quality data and basic morphological data for 16 of the 17 dams monitored as part of the Resource Quality Services (RQS) department of DWAF were obtained from Dr W R Harding of D H Environmental Consulting (author WRC Report No 1687/1/08). Water quality data for the remaining dam, Hartbeespoort Dam, were obtained from Dr C van Ginkel of RQS since these data were not included in the former source. Data for the 7 KwaZulu-Natal dams were obtained from Umgeni Water in Pietermaritzburg. The basic morphological data for the 24 dams are given in Table 33.

Table 33: Basic morphological data for the 24 dams included in this study.

	Dam Catchment. Area	Dam Volume	Dam Surface Area	Inflow Volume	Retention Time	Mean Depth
	ha	^MCM	ha	MCM/a	Yrs	M
Albert Falls	72814.96	289.1	2354.2	244.8	1.18	12.3
Allemanskraal	363716.26	179	2648	22	8.14	6.8
Bloemhof	5784121.88	1240	23329	635	1.95	5.3
Bronkhorstspruit	126126.21	58	861	12	4.83	6.7
Erfenis	473990.58	212	3292	23	9.22	6.4
Grootdraai	798335.46	356	3882	221	1.61	9.2
Hartbeespoort	411508.91	195	2065	154	1.27	9.4
Hazelmere	3752.60	17.8	181.3	62.1	0.29	9.8
Henley	21968.23	1.5	32.1	22.2	0.07	4.7
Inanda	127777.90	241.7	1463.4	328.9	0.74	16.5
Klipfontein	34015.00	18.0	296	19	0.95	6.1
Klipvoor	545614.22	42.0	753	54	0.78	5.6
Koppies	216419.22	42.0	1385	12	3.50	3.0
Laing	92555.79	20.0	204	42	0.48	9.8
Lindleyspoort	70905.77	14.0	180	3	4.67	7.8
Midmar	92529.03	235.4	1792.5	215.2	1.09	13.1
Misverstand	409937.84	8.0	255	502	0.02	3.1
Nagle	92850.46	23.2	156.1	282.8	0.08	14.9
Roodekopjes	201994.36	102.0	1559	60	1.70	6.5
Roodeplaat	68356.22	43.0	395	34	1.26	10.9
Shongweni	78503.23	3.8	56.9	99	0.04	6.7
Vaal	3064914.94	2610.0	32276	1242	2.10	8.1
Welbedacht	1530768.74	12.0	1018	702	0.02	1.2
Witbank	358247.47	104.0	1211	133	0.78	8.6

^MCM = Million cubic metres

6.1.2 Data Periods and Sampling Frequencies

The data collection periods and average frequencies for sample collection for the two basic chemical parameters analysed in this report, namely Total Phosphorus (TP) and Chlorophyll 'a', are listed in Table 34. The overall period ranges from 1990 to 2008, 18 years, with periods for individual dams ranging from 3 years, but only for 2 dams, to 12 to 16 years for the majority. These significant periods will give a measure of confidence to the analyses and conclusions drawn and model predictions made.

Table 34: Sample periods and average frequencies of TP and chlorophyll 'a' sampling for the studied dams

Dam	Data Period		Frequency		
			Dam TP	Dam Chlorophyll 'a'	Inflow TP
Albert Falls*	Jan-95	Nov-08	2 W	2 W	M
Allemanskraal	Feb-90	Jun-03	M	M	-
Bloemhof	Jan-90	Nov-05	2 W	M	-
Bronkhorstspruit	Jan-90	Jun-06	M	M	-
Erfenis	Jan-90	Oct-05	2 W	M	-
Grootdraai	Jan-90	Nov-05	W	M	-
Hartbeespoort	Jan-90	Jul-08	W	M	-
Hazelmere*	Jan-95	Nov-08	2 W	2 W	M
Henley*	Jan-95	Nov-08	2 W	2 W	2 M
Inanda*	Jan-95	Nov-08	W	W	M
Klipfontein	Sep-92	Feb-96	W	2 W	-
Klipvoor	Jan-90	Mar-06	2 W	M	-
Koppies	Jan-90	Mar-04	M	2 M	-
Laing	Mar-92	Nov-03	2 W	6 M	-
Lindleyspoort	Jan-90	Jan-06	2 W	M	-
Midmar*	Jan-95	Nov-08	2 W	2 W	M
Misverstand	Jan-90	Jan-06	2 W	M	-
Nagle*	Jan-95	Nov-08	W	W	M
Roodekopjes	Jan-90	Feb-06	M	2 M	-
Roodeplaat	Jan-90	Jan-06	W	W	-
Shongweni*	Jan-95	Nov-08	2 W	M	M
Vaal	Jan-90	Feb-06	W	M	-
Welbedacht	Mar-03	Nov-05	M	M	-
Witbank	Jan-90	Jan-06	M	M	-

M = Monthly, W = Weekly, *KZN dams

As may be seen from Table 34, the frequency of sample collection for the DWAF monitored dams varied between weekly and monthly intervals with analyses for Chlorophyll 'a' values generally being at monthly intervals, but analyses for TP more frequently and weekly for some dams such as Hartbeespoort and Roodeplaat. Monitoring of the KZN dams, marked with asterisks, by Umgeni Water was either weekly or two-weekly.

It may be noted that no dam inflow data were available for the DWAF monitored dams, but for the KZN Umgeni Water monitored dams inflows were generally sampled at monthly intervals for quality analyses.

6.1.3 Data Preparation

It was noted that for the DWAF monitored dams, samples for TP and Chlorophyll 'a' analyses were variously taken at different depths below the surface ranging up to 20 m. As a consequence of this, the results for some dams needed to be individually sorted and selected in order to obtain the best possible representative data to maximise the accuracy in meeting the objectives of the project. For individual dams, between 5 and 630 results were deleted for subsequent analyses, with the total being more than 800. The logic behind this data selection was as follows:

- It was assumed that the "photic depth" or sunlight penetration for algal activity to take place in a dam would be approximately 5 m and therefore only TP results for samples taken from either the surface or up to 5 m depth were selected for the analyses carried out. It was observed that samples taken at deeper depths had significantly higher TP concentrations than samples in the above depth range, no doubt due to steady settlement of suspended solids containing adsorbed phosphate. As an example of increasing concentration with depth, data for Hartbeespoort Dam showed that TP concentrations for samples at 10 m depth were 75% higher than those for surface samples, and at 20 m depth more than 300% higher. Although upwelling in the dams may well take place at times, thus making the higher TP concentrations more available for algal growth, it was considered that such sample results would positively bias mean dam concentrations for both descriptive and modelling purposes. A similar selection procedure was carried out for the selection of Chlorophyll 'a' sample results. However, the majority of samples were integrated ones taken over a 0-5 m depth interval.

For the KZN dams, the sampling practice is to take samples for chemical analyses from just below the surface and therefore dam TP concentrations represent surface samples. The sampling practice for algal and hence chlorophyll 'a' analyses is to take both surface and integrated 0-5 m depth samples. However, only integrated sample results were selected for analyses in this report as considered more representative.

The underlying objective of the data selection was to obtain data sets for the DWAF sampled dams that were considered representative for the analysis of current conditions and for use in modelling to predict possible changes as a result of the possible removal of phosphate from detergents.

In order to determine TP loads to the 17 DWAF monitored dams where there was no sampling and analyses carried out on inflows, the Institute for Natural Resources (INR) embarked on a Land Use – TP Export Coefficient exercise to calculate annual TP inflow loads to the dams. The areas of particular land-uses were determined and corresponding TP export coefficients (coefficients determined from the literature) applied to calculate the total loads, which is described elsewhere in the report (see chapter 4).

However, for the 7 KZN dams monitored by Umgeni Water, inflow quality and quantity were available and therefore inflow loads could be calculated. These data were considered to be more accurate that the Land-Use Export Coefficient results. The monthly inflow loads were calculated from the product of mean monthly inflow TP concentrations, where weekly or 2-weekly sampling was in practice, and monthly inflow volumes. Annual loads were then determined by the summation of monthly loads.

Since the 7 KZN dams were also included in the Land Use – TP Export Coefficient exercise by the INR to calculate annual TP inflow loads, a comparison was made of these with loads calculated from quality and flow data described above. Comparative data are shown in Table 35.

Table 35: Comparison of INR land-use calculation of total phosphorus loadings to the KZN dams with loads calculated from inflow concentration and flow data

Dam	INR Land-Use Data, kg/a	Flow and Concentration Data, kg/a	Percentage Difference of Land-Use to Flow and Concentration Data Calculation
Albert Falls	9303	13605	-46%
Hazelmere	3499	3458	1%
Henley	1961	1318	33%
Inanda	62011	46482	25%
Midmar	16405	9147	44%
Nagle	8032	12729	-58%
Shongweni	21944	16444	25%

Comments on differences between the two loads determined are as follows:

Albert Falls – The large underestimation from the land-use calculation may be due to an underestimate of the assumed Urban Residential Export Coefficient of 5 kg TP/ha/a which includes Wastewater Works (WWTW) effluent from Howick WWTWs. This value was based on calculations made at the Darvill WWTW. The quality and concentration of TP, and other constituents in effluents from WWTW will vary considerably throughout the country due to many factors such as the efficiency with which the WWTW is run and whether or not Biological Nutrient Removal (BNR) and/or alum is dosed to precipitate phosphate from the effluent in order to meet discharge standards. Consequently, the selection of an appropriate coefficient applicable to all dam catchments with urban areas is both subjective and difficult.

Hazelmere – There is very good agreement between Land-Use and inflow calculated loads, probably due to the fact that the Urban Residential area in the catchment is less than 1%.

Henley – The higher land-use load calculated could be due to some river losses not being taken into account. It is well know that phosphate is taken up by biota, flora and sediments in rivers and clearly the greater the distance between the point source and the dam, the greater the loss will be.

Inanda – There is quite a large overestimate of 25% by the Land-Use method, but a combination of not including river losses, discussed above, and the Urban Residential Export Coefficient possibly being a little low, may be the reason. From data given in the publication by Simpson and Pillay (2000), it was determined that approximately 25 500 kg of TP would be removed by the uMngeni River in transit from Pietermaritzburg to Inanda Dam over the 85 km distance, which would then have resulted in an underestimate of 21% from the inflow calculated load.

Midmar – The large overestimate of the Land-Use load could be due to river losses, as stated above, not being taken into account.

Nagle – The large underestimate is most probably due to the presence of feedlots within the catchment not being taken into account. There was no category for this land-use. A WRC research report on runoff water quality from a disused feedlot found that the export coefficient for TP was greater than 2 kg/ha.annum^{-1} and therefore highly polluting from a phosphate point of view (Simpson, 1998).

Shongweni – The overestimate could possibly be due to river losses not being taken into account.

These comparisons, where agreement of Land-Use calculated TP dam inflow loads using assumed export coefficients with the more accurate loads determined from inflow quality and volume data is poor, clearly indicates the potential inaccuracy of the method. However, when inflow quality and quantity data is not available, such calculations using Land-Use export coefficients must suffice as an estimate. It is important, however, that the selection of export coefficients for the different land use types is made with due care taking into account all available literature.

6.1.4 Current Dam Water Qualities

The TP and Chlorophyll 'a' data for the dams was subjected to statistical and trend analyses and a number of tables and graphs have been produced to describe the current conditions pertaining to each dam. This will be discussed below.

6.1.4.1 Statistical Analyses

Statistical analysis of dam TP inflow concentration, only measured for the KZN dams, dam TP concentration and Chlorophyll 'a' value data sets are given in Table 36. It may be noted that the number of sample results on which the analyses for means and medians are based are substantial, mostly being well in excess of 100 and ranging up to 2000 for Hartbeespoort Dam. As said for the sampling periods, these high sample numbers add credibility to the results of the analyses. Median results are all lower than mean ones due to the fact that in determining medians, the influence of high outlier results is nullified. As examples, the mean TP concentration for Hartbeespoort Dam is 41% higher than the median value, while for Roodeplaat Dam the mean Chlorophyll 'a' value is 33% higher than the median value. Similar large differences may be observed for the other dams. It is debatable whether either median of mean values are of more value, or which should used for modelling purposes for the maximum accuracy of predictions and therefore both have been included in the subsequent modelling analyses.

Table 36: Inflow and dam total phosphorus and dam chlorophyll 'a' statistics for studied dams

Dam	Inflow TP, µg/ℓ			Dam TP, µg/ℓ			Dam Chlorophyll 'a'		
	Mean	Median	n	Mean	Median	n	Mean	Median	N
Albert Falls	68.1	54.2	166	31.2	22.7	427	9.1	6.8	438
Allemanskraal	-	-	-	135	99	265	10.8	4.0	162
Bloemhof	-	-	-	99	86	391	33.5	16.3	246
Bronkhorstspruit	-	-	-	89	77	282	43.6	20.6	188
Erfenis	-	-	-	183	165	339	4.5	2.0	232
Grootdraai	-	-	-	66	59	659	10.0	5.0	275
Hartbeespoort	-	-	-	181	106	2077	72.6	28.0	1980
Hazelmere	43.4	35.3	166	34.7	28.2	427	2.2	1.6	407
Henley	56.2	40.7	71	41.9	33.0	288	4.3	3.0	309
Inanda	111.2	93.6	166	21.1	16.2	494	5.2	3.6	558
Klipfontein	-	-	-	114	94	335	24.4	7.0	61
Klipvoor	-	-	-	869	702	329	112.6	46.7	272
Koppies	-	-	-	126	100	165	17.6	9.0	111
Laing	-	-	-	140	132	314	2.7	2.1	27
Lindleyspoort	-	-	-	65	49	461	6.3	4.0	271
Midmar	42.5	34.6	166	23.8	19.5	452	3.5	3.0	521
Misverstand	-	-	-	126	97	555	10.0	5.0	157
Nagle	43.3	33.7	166	476	30.4	20.5	13.5	4.3	515
Roodekopjes	-	-	-	57	39	203	10.0	7.0	111
Roodeplaat	-	-	-	242	208	1017	46.7	31.3	934
Shongweni	112.3	85.2	146	59.2	42.0	80.0	53.7	34.0	234
Vaal	-	-	-	107	83	624	7.2	3.0	216
Welbedacht	-	-	-	160	99	39	10.4	6.6	39
Witbank	-	-	-	44	31	325	6.7	4.0	265

6.1.4.2 Data Trend Analyses

Data trend analyses involved the plotting of all of the available data, TP inflow and dam concentrations as well as Chlorophyll 'a' values, as time related scatter plots, the addition of linear trend lines followed by the application of the trend line equations to the beginning and end period dates of the data sets in order to calculate both the overall percentage changes for the periods and the average annual percentage changes.

6.1.4.2.1 Dam TP Inflow Concentration Trends

The trend analysis for TP inflow concentrations to the dams could only be carried out for the 7 KZN dams as inflow quality data were not available for the DWAF monitored dams. The results are shown for the KZN dams in Table 37.

Table 37: Trend analysis of total phosphorus inflow concentrations for KZN dams

Dam	Period of Data		TP Concentrations, µg/ℓ		Increase	Increase/a
			Start of Period	End of Period		
Albert Falls	Jan-95	Nov-08	25	114	355%	26%
Hazelmere	Jan-95	Nov-08	129	135	5%	0%
Henley	Jan-95	Nov-08	127	132	4%	0%
Inanda	Jan-95	Nov-08	91	141	54%	4%
Midmar	Jan-95	Nov-08	32	53	67%	5%
Nagle	Jan-95	Nov-08	30	57	91%	7%
Shongweni	Jan-95	Nov-08	55	164	196%	14%

Table 37 shows very clearly that there have been large overall percentage increases in TP inflow concentrations over the periods for all of the dams, with the exception of Hazelmere and Henley dams. Albert Falls Dam shows an overall increase of 355% in the TP inflow concentration from 1995 to 2008, while the average annual increase is 26%/a. This extremely rapid increase may be due to the Howick WWTW receiving ever increasing inflow loads, becoming overloaded and perhaps not operating optimally, as well as the growing presence of informal settlements in the dam catchment area. A similar comment may be applicable to the increasing inflow concentration rate to Shongweni Dam of 14%/a. Should the high positive trend persist with the inflow to Albert Falls Dam, there may well be a significant deterioration in water quality with time resulting in associated water treatment problems *via* Nagle Dam for water supply to Durban, as well as possible recreational problems through poor aesthetics of “green water” and *Microcystis* algal toxin releases posing health problems to users. A change in algal genera dominance to *Microcystis*, has already been noted from another investigation.

6.1.4.2.2 Dam Total Phosphorus Concentration Trends

The trend analysis results for dam TP concentrations are shown for all dams in Table 38 below, with as given above, data periods and trend equation results calculated for the beginning and end period concentrations. Data trend analyses involved the plotting of the available data, the addition of linear trend lines and application of the trend line equations to the beginning and end period dates in order to calculate the overall changes and then annual average changes as percentages.

Six of the 24 dams, or 25%, showed slightly decreasing trends, while 13 dams, or 54%, showed either annual stable or increasing trends of 10% or less. However, the other 5 dams, 21%, namely Allemanskraal, Bronkhorstspruit, Nagle, Roodekopjes and Welbedacht displayed overall increases for the periods under review of from 176% to 531%, with mean annual increases from 19% to 66%/a for Bronkhorstspruit Dam to Welbedacht Dam respectively. These alarming upward trends in dam TP concentrations will, if left unchecked, likely exacerbate both water treatment and recreational problems, where applicable for these uses, through the promotion of algal growth.

Table 38: Trend analysis of dam total phosphorus concentrations

Dam	Period of Data		TP Concentrations, µg/ℓ		Absolute Change	Change/ annum
			Start of Period	End of Period		
Albert Falls	Jan-95	Oct-08	32	30	-5%	0%
Allemanskraal	Feb-90	Jun-03	70	260	271%	20%
Bloemhof	Jan-90	Nov-05	89	108	21%	1%
Bronkhorstspruit	Jan-90	Jun-06	27	113	316%	19%
Erfenis	Jan-90	Oct-05	157	249	59%	4%
Grootdraai	Jan-90	Nov-05	61	76	24%	1%
Hartbeespoort	Jan-90	Jul-08	93	269	190%	10%
Hazelmere	Jan-95	Oct-08	34	36	4%	0%
Henley	May-95	Feb-08	37	48	29%	2%
Inanda	Jan-95	Oct-08	17	26	48%	4%
Klipfontein	Sep-92	Feb-96	103	108	5%	1%
Klipvoor	Jan-90	Mar-06	1099	608	-45%	-3%
Koppies	Jan-90	Mar-04	146	103	-29%	-2%
Laing	Mar-92	Nov-03	113	173	53%	5%
Lindleyspoort	Jan-90	Jan-06	89	37	-59%	-4%
Midmar	Jan-95	Oct-08	20	32	62%	4%
Misverstand	Jan-90	Jan-06	95	179	88%	6%
Nagle	Jan-95	Oct-08	14	53	286%	21%
Roodekopjes	Jan-90	Feb-06	22	139	531%	33%
Roodeplaat	Jan-90	Jan-06	270	227	-16%	-1%
Shongweni	Jan-95	Dec-02	80	34	-57%	-7%
Vaal	Jan-90	Feb-06	115	99	-14%	-1%
Welbedacht	Mar-03	Nov-05	95	262	176%	66%
Witbank	Jan-90	Jan-06	40	49	24%	1%

6.1.4.2.3 Dam Chlorophyll ‘a’ Concentration Trends

The trends in dam Chlorophyll ‘a’ values are shown for all dams in Table 39, with as above, data periods and equation calculated beginning and end period concentrations, overall changes and mean annual percentage changes.

The greatest overall increases in chlorophyll ‘a’ concentrations over the given periods for the dams were shown for Albert Falls, 393%, Bronkhorstspruit, 3 371%, Hartbeespoort, 1 006%, Inanda, 151%, Nagle, 3 586%, Roodeplaat, 237% and Vaal at 225%, while the annual rates were 27%, 251%, 92%, 10%, 301%, 15% and 14% respectively. Bearing in mind, both the increasing inflow TP concentration trends, only measured for the KZN dams, and the increasing dam TP concentration trends for many, the problems associated with excessive algal growth in these dams are likely to increase unless action is taken to limit nutrient inputs, which is most likely to be phosphate rather than nitrogen as the limiting nutrient.

Table 39: Trend analysis of dam chlorophyll ‘a’ concentrations

Dam	Period of Data		Chlorophyll ‘a’ Concs., µg/ℓ		Chang e	Change/ a
			Start of Period	End of Period		
Albert Falls	Mar-94	Dec-08	3.3	16.1	393%	27%
Allemanskraal	Feb-90	Jan-97	21.9	3.9	-82%	-12%
Bloemhof	Jan-90	Nov-05	253.4	272.0	7%	0%
Bronkhorstspruit	Jan-93	Jun-06	2.3	79.5	3371%	251%
Erfenis	Jan-90	Jan-02	8.8	1.2	-86%	-7%
Grootdraai	Jan-90	Jun-05	9.7	10.4	7%	0%
Hartbeespoort	Jan-90	Dec-00	7.4	81.5	1006%	92%
Hazelmere	Mar-94	Dec-08	1.4	3.2	121%	8%
Henley	Mar-94	Dec-08	3.4	5.9	74%	5%
Inanda	Mar-94	Dec-08	3.1	7.8	151%	10%
Klipfontein	Dec-94	Nov-05	28.4	16.1	-43%	-4%
Klipvoor	Apr-90	May-06	79.8	141.3	77%	5%
Koppies	Apr-90	Mar-04	19.0	15.8	-17%	-1%
Laing	May-90	Sep-03	1.8	2.9	63%	5%
Lindleyspoort	May-90	Feb-06	9.4	3.4	-64%	-4%
Midmar	Mar-94	Dec-08	2.4	5.0	104%	7%
Misverstand	May-90	Dec-05	8.0	11.3	42%	3%
Nagle	Jan-97	Dec-08	1.2	43.1	3586%	301%
Roodekopjes	Mar-90	Feb-06	7.3	15.2	109%	7%
Roodeplaat	Jan-90	May-06	18.0	60.5	237%	15%
Shongweni	Jun-94	Dec-08	10.0	80.6	702%	48%
Vaal	Mar-90	Mar-06	3.4	11.0	225%	14%
Welbedacht	Mar-03	Nov-05	12.8	7.4	-42%	-16%
Witbank	Apr-90	Mar-04	5.9	7.4	26%	2%

6.1.4.3 Current classification of trophic states of the dams by chlorophyll ‘a’ concentrations and dam TP concentrations by the 55 µg/ℓ criterion

Frequency analyses were conducted on all available Chlorophyll ‘a’ and TP data for the dams in order to determine the percentages of Chlorophyll ‘a’ results found within established ranges for classification of trophic status and for dam TP concentrations to determine the number of results either below of above the 55 µg/ℓ “threshold limit”. The reference for the Chlorophyll ‘a’ trophic classification is van Ginkel et al. (2001) and for the dam TP concentration threshold limit, Harding (2008) where the statement “Threshold in-lake median TP concentration above which SA impoundment exhibit a marked increase in algal biomass” is made. The results of these analyses are shown in Table 40, as well as graphically in Figure 11 and Figure 12 for ease of viewing.

Table 40 shows that for the trophic classification, 20 of the 25 dams or 80%, exhibited Oligotrophic status for more than 50% of results, while Eutrophic to Hypertrophic states for more than 50% of results are shown for 4 dams or 16%. Notably, the most eutrophied dams shown are Bronkhorstspruit, Hartbeespoort, Klipvoor, Roodeplaat and Shongweni, where Hypertrophic status was exhibited for 38%, 47%, 62% and 51% of results respectively.

However, for the TP classification, 14 of the 25 dams, or 56%, had TP concentrations higher than the 55 µg/ℓ threshold for more than 50% of the results, while conversely the other 11 dams or 44%, had concentrations below this value for more than 50% of results. Some anomalous results for

Chlorophyll 'a' and TP correlations, that is low Chlorophyll 'a' trophic status but with high TP concentrations, were shown for some dams such as Allemanskraal where the dam TP concentration was higher than 55 µg/ℓ for 88% of the results, but was classified as Oligotrophic by 82% of the results. Similar anomalies may be noted for Erfenis, Laing and Misverstand dams. There is no ready explanation for these anomalies, though it is possible that high turbidity in these dams may have resulted in restricted algal growth , i.e. high potential for algal growth, on the basis of high nutrient status, but high turbidities preventing this from translating into algae.

Table 40: Frequency of current dam trophic states adjudged by chlorophyll 'a' concentrations according to DWA recognised ranges and dam total phosphorus concentrations above and below the DWA recognised threshold concentration for possible excessive algal growth and water quality problems of 55 µg/ℓ.

Dam	Chlorophyll 'a'					TP, µg/ℓ		
	0-10 µg/ℓ	11-20 µg/ℓ	21-30 µg/ℓ	>30 µg/ℓ	n	<= 55	> 55	n
	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic				
Albert Falls	70%	22%	4%	4%	438	87%	13%	425
Allemanskraal	82%	9%	2%	7%	162	12%	88%	265
Bloemhof	39%	21%	13%	27%	246	20%	80%	391
Bronkhorstspruit	37%	12%	13%	38%	187	25%	75%	232
Erfenis	92%	4%	1%	3%	232	1%	99%	339
Grootdraai	80%	9%	3%	8%	275	42%	58%	659
Hartbeespoort	26%	15%	12%	47%	1969	12%	88%	2077
Hazelmere	99%	1%	0%	0%	407	84%	16%	426
Henley	92%	6%	2%	0%	309	74%	26%	286
***Inanda, 0.3 km**	86%	11%	2%	1%	558	95%	5%	490
***Inanda, 7.5 km**	79%	16%	3%	1%	-	-	-	-
***Inanda, 14 km**	52%	25%	11%	12%	-	-	-	-
Klipfontein	59%	10%	11%	20%	61	17%	83%	335
Klipvoor	14%	13%	10%	62%	270	1%	99%	329
Koppies	61%	20%	5%	14%	111	15%	85%	165
Laing	100%	0%	0%	0%	27	5%	95%	314
Lindleyspoort	87%	10%	2%	1%	271	60%	40%	461
Midmar	97%	3%	0%	0%	521	92%	8%	447
Misverstand	76%	13%	3%	8%	157	6%	94%	555
Nagle	78%	9%	3%	10%	515	89%	11%	472
Nungwane	96%	4%	0%	0%	460	93%	7%	406
Roodekopjes	65%	25%	3%	7%	111	73%	27%	203
Roodeplaat	19%	17%	13%	51%	932	3%	97%	1017
Shongweni	23%	13%	11%	53%	234	65%	35%	80
Vaal	88%	7%	0%	5%	216	25%	75%	624
Welbedacht	67%	21%	5%	8%	39	28%	72%	39
Witbank	86%	8%	2%	4%	265	85%	15%	325

*Sample Site distances from the dam wall. Sample periods for the 7.5 km and 14 km sites are only from 1995-2000, whereas for the 0.3 km site the sample period was up to 2008. No TP data were available for the 7.5 km and 14 km sites.

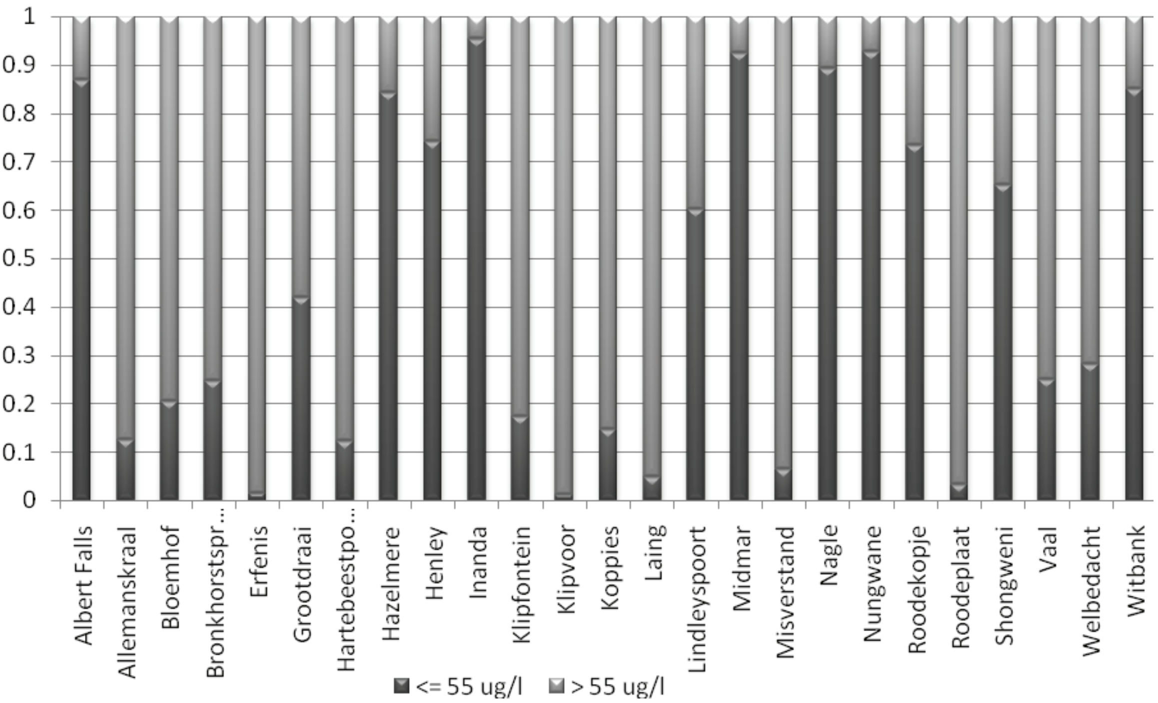

Figure 11: Dam total phosphorus concentrations classified by the DWA threshold limit for potential eutrophication problems

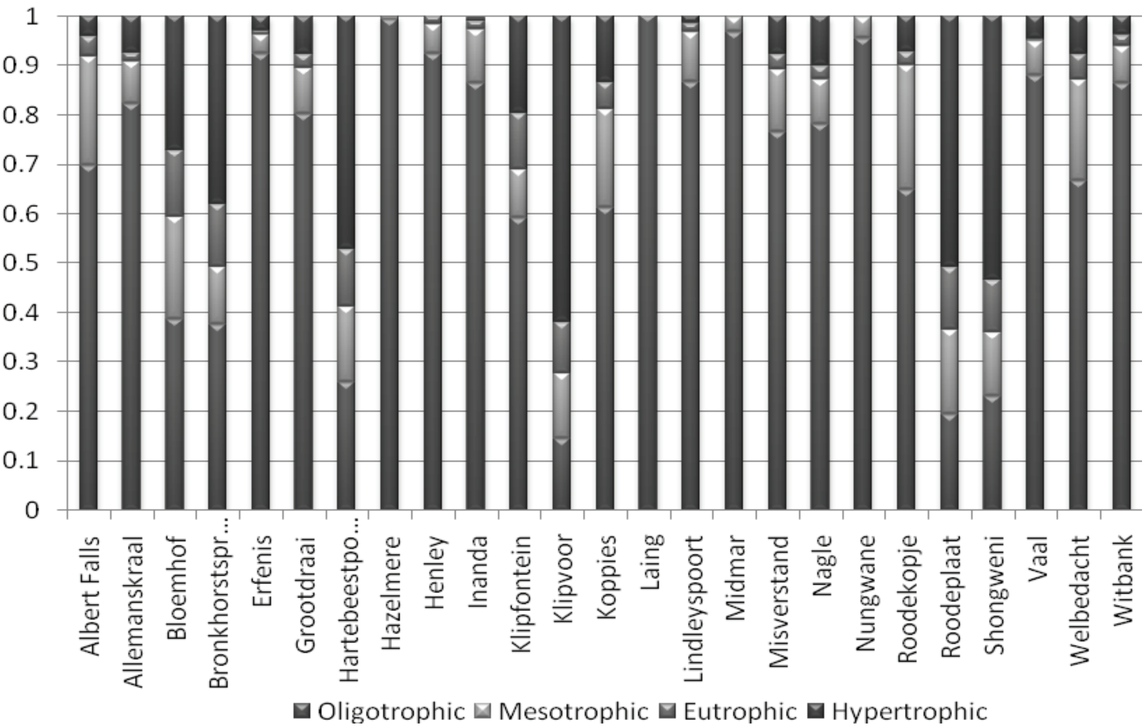

Figure 12: Current trophic classification of dams from chlorophyll 'a' data, DWA criteria

6.2 Total dam phosphorus loads with and without detergent phosphate

As stated above, the TP inflow loads to the DWAF monitored dams were determined by the Land-Use Export Coefficient exercise while for the Umgeni Water monitored dams in KZN, marked with asterisks in Table 41, the TP loads were calculated from measured inflow quality and volume data. Table 41 shows the current TP loads to the dams, which represents loads with Detergent Phosphate and then without Detergent Phosphate after subtraction of these loads as calculated from the Land-Use Export Coefficient data. The mean TP inflow concentrations were calculated from the inflow loads and inflow volumes for both the current situation and without Detergent Phosphate loads.

The percentages of Detergent Phosphate of the total loads ranged from 3.2% for Koppies Dam to a maximum of 37.4% for Inanda Dam, the variation in the data being a reflection of the different percentages of urban areas in the respective dam catchments from which sewage effluents would emanate. Other dams with high percentage Detergent Phosphate loads are Hartbeespoort with 28% and Roodeplaat Dam with 29.3%. Naturally, the same percentage reductions are shown for the reductions in TP inflow concentrations since the calculations are load based.

Table 41: Total phosphorus loads to the dams and inflow concentrations with and without detergent phosphate, percentages of detergent phosphate of the total loads and inflow concentration reductions as a result

Dam	Dam TP Loads			% Det. P of Total Load	Dam Inflow TP		Inflow Conc. Reduction Without Det. P
	With Det. P	Without Det. P	Det. P Load		With Det. P	Without Det. P	
	kg/a	kg/a	kg/a		µg/ℓ	µg/ℓ	
Albert Falls*	13605	11978	1627	12.0%	55.6	48.9	12.0%
Allemanskraal	35082	33869	1212	3.5%	1594.6	1539.5	3.5%
Bloemhof	1156796	980971	175826	15.2%	1821.7	1544.8	15.2%
Bronkhorstspruit	14678	13906	772	5.3%	1223.2	1158.9	5.3%
Erfenis	47953	45812	2141	4.5%	2084.9	1991.8	4.5%
Grootdraai	101481	93861	7621	7.5%	459.2	424.7	7.5%
Hartbeespoort	321422	231401	90021	28.0%	2087.2	1502.6	28.0%
Hazelmere*	3458	2686	772	22.3%	55.7	43.3	22.3%
Henley*	1318	1141	177	13.4%	59.3	51.3	13.4%
Inanda*	46482	29120	17362	37.4%	141.3	88.6	37.4%
Klipfontein	8353	6793	1561	18.7%	439.7	357.5	18.7%
Klipvoor	208420	152463	55958	26.8%	3859.6	2823.4	26.8%
Koppies	22771	22034	737	3.2%	1897.6	1836.2	3.2%
Laing	42859	30734	12125	28.3%	1020.5	731.8	28.3%
Lindleyspoort	5995	5403	592	9.9%	1998.4	1801.0	9.9%
Midmar*	9147	8606	541	5.9%	42.5	40.0	5.9%
Misverstand	115431	107651	7780	6.7%	229.9	214.4	6.7%
Nagle*	12729	12103	626	4.9%	45.0	42.8	4.9%
Roodekopjes	92509	84652	7857	8.5%	1541.8	1410.9	8.5%
Roodeplaat	64379	45495	18883	29.3%	1893.5	1338.1	29.3%
Shongweni*	16444	11835	4609	28.0%	166.1	119.5	28.0%
Vaal	393330	359684	33646	8.6%	316.7	289.6	8.6%
Welbedacht	194568	167971	26597	13.7%	277.2	239.3	13.7%
Witbank	63648	58221	5427	8.5%	478.6	437.7	8.5%

6.3 Modelling of dam water quality responses without detergent phosphate

The purpose of the modelling exercise is to predict the water quality changes that are likely to occur in the dams should phosphate be removed from detergents, the focus being on dam TP concentrations and Chlorophyll 'a' values. The foregoing data analysis has shown that many of the dams are not in desirable states for water uses such as abstraction for treatment and recreation. Two different types of models were employed for this purpose, one for prediction of dam TP concentrations and the other for prediction of Chlorophyll 'a' values.

6.3.1 Modelling Dam TP Concentrations

The models used to predict dam TP concentrations from inputs of TP inflow concentrations and other required dam morphological data were the OECD (Organisation for Economic Cooperation and Development) and the Walker Reservoir Model (WRM) models. They were obtained from the report Harding (2008). This report found that the above models, compared to a number of other models, were the better ones in coming closest in their predictions to observed dam TP concentrations. The purpose in running both models for the dams was to determine the predicted percentage decreases in dam TP concentrations from current to decreased loads without Detergent Phosphate and then to use this data with observed median and mean dam data to predict future dam concentrations.

The results of running the models are given in Table 42 showing predicted current and future dam TP concentrations without Detergent Phosphate loads as well as the percentage decreases for each dam. The OECD model predicted reductions of dam TP concentrations of from 2.7% for Koppies Dam to 31.0% for Inanda Dam, while the WRM model similarly predicted reductions for the same dams of from 3.2% to 37.4%. The OECD model generally predicted dam TP concentrations with and without Detergent Phosphate about 28-30% higher than the WRM model, but this divergence is considered to be a reasonable agreement. On average, the predicted reductions for all dams were 12.2% for the OECD model and 14.6% for the WRM model.

The method used to derive the predicted dam TP concentrations without Detergent Phosphate loads was to average the percentage reductions in TP concentrations predicted by both models for each dam and then apply to median and mean data. It was decided to use the average predicted reductions for the two models since neither one was consistently closer with their predictions to observed data than the other. The results showed that for both calculations using observed median and mean data, the OECD model predictions were closest for 9 of the dams, as against 15 dams for the WRM model. Using a criterion of the predicted dam concentrations being within 30% of the observed median data, the count was positive for 7 dams for the OECD model and 8 for the WRM model. For comparison with observed mean data, the positive count for this criterion was 10 results for the OECD model and 12 for the WRM model. Hence, the decision was made to use the average of the predicted percentage reductions for the two models in order to predict dam TP concentrations without Detergent Phosphate loads. The underlying assumption made in applying the model predicted percentage reductions to the observed data is that the decreases in dam TP concentrations would in reality be proportional to the modelling predictions.

Table 42: Models predicted dam total phosphorus concentrations for inflow loads with and without detergent phosphate

Dam	OECD Model			WRM Model		
	Predicted Dam TP Concs. μg/ℓ		% Reduction	Predicted Dam TP Concs. μg/ℓ		% Reduction
	With Det. P	Less Det. P		With Det. P	Less Det. P	
Albert Falls	22.9	20.6	9.9%	20.1	17.7	12.0%
Allemanskraal	216.9	210.7	2.8%	134	129.4	3.5%
Bloemhof	356.9	311.8	12.6%	171.1	145.1	15.2%
Bronkhorstspruit	203.2	194.4	4.3%	119	112.8	5.3%
Erfenis	260.1	250.5	3.7%	157	150	4.5%
Grootdraai	120.6	113.1	6.2%	69	63.8	7.5%
Hartbeespoort	440.4	336.4	23.6%	157.9	113.7	28.0%
Hazelmere	29.5	24	18.7%	28.1	21.8	22.3%
Henley	36.4	32.4	11.1%	42	36.4	13.4%
Inanda	54.1	36.9	31.9%	36.5	22.9	37.4%
Klipfontein	130.5	110.1	15.6%	82.5	67.1	18.7%
Klipvoor	805.6	623.4	22.6%	278.1	203.4	26.8%
Koppies	318.3	309.9	2.7%	215	208.1	3.2%
Laing	295.6	225	23.9%	134.2	96.3	28.3%
Lindleyspoort	307	281.9	8.2%	144.8	130.5	9.9%
Midmar	18.7	17.7	4.9%	17	16	5.9%
Misverstand	121.5	114.7	5.6%	162.7	151.8	6.7%
Nagle	28.6	27.4	4.0%	31.8	30.3	4.9%
Roodekopjes	321.6	299	7.0%	146.7	134.2	8.5%
Roodeplaat	406.7	306	24.8%	143.9	101.7	29.3%
Shongweni	88.5	67.6	23.6%	102.3	73.6	28.0%
Vaal	83.5	77.6	7.1%	56.9	52.1	8.6%
Welbedacht	141.1	125.1	11.4%	189.6	163.7	13.7%
Witbank	145.3	135.1	7.0%	81.3	74.4	8.5%

Table 43 shows the predicted decreases of dam TP concentrations with the removal of phosphate from detergents for two scenarios, one using the median of observed data and the other using the mean of observed data, as both observed results are representative of the existing conditions in the dams. It is debatable whether it is more accurate, or more representative, to use either median or mean data for modelling purposes, since both have their merits. While a median result is usually lower than a mean one for the same data set due to the ordering of results, and thus the presence of high outliers being negated, the mean result which includes outliers, but being calculated arithmetically in line with model calculations, may well be the better one to use for the purpose of predicting future dam TP concentrations.

Table 43: Mean of models predicted percent reductions in dam total phosphorus concentrations without detergent phosphate loads and application to current dam median and mean concentrations to predict new concentrations

Dam	Mean of Model Predicted % Reductions	Median Dam Results μg/ℓ		Mean Dam Results μg/ℓ	
		Current	Predicted	Current	Predicted
Albert Falls	11%	22.7	20.2	31.2	27.8
Allemanskraal	3%	99	95.9	135	130.7
Bloemhof	14%	86	74	99	85.2
Bronkhorstspruit	5%	77	73.3	89	84.7
Erfenis	4%	165	158.3	182	174.6
Grootdraai	7%	59	55	66	61.5
Hartbeespoort	26%	106	78.6	181	134.3
Hazelmere	21%	28.2	22.4	34.7	27.6
Henley	12%	33	28.9	41.9	36.8
Inanda	35%	16.2	10.6	21.1	13.8
Klipfontein	17%	94	77.9	114	94.5
Klipvoor	25%	702	528.4	869	654.1
Koppies	3%	100	97.1	126	122.3
Laing	26%	132	97.6	140	103.5
Lindleyspoort	9%	49	44.6	65	59.1
Midmar	5%	19.5	18.4	23.8	22.5
Misverstand	6%	97	91	126	118.3
Nagle	4%	20.5	19.6	30.4	29
Roodekopjes	8%	39	36	57	52.6
Roodeplaat	27%	208	151.7	242	176.5
Shongweni	26%	42	31.2	59.2	43.9
Vaal	8%	83	76.5	107	98.6
Welbedacht	13%	99	86.6	160	140
Witbank	8%	31	28.6	44	40.6

The mean of model predicted percentage reductions show a wide range from just 3% for Allemanskraal Dam to 26-27% for Hartbeespoort, Laing, Roodeplaat and Shongweni dams and a maximum of 35% for Inanda Dam. The magnitude of these percentage reductions is a reflection of the amounts of urban areas within the dam catchments and therefore the presence of sewage effluents. As stated above, with dam median results being lower than mean ones, the predicted dam TP concentrations using medians are therefore also lower, such as for Hartbeespoort Dam where the predicted lower concentration using the median is 78.6 μg/ℓ compared to 134.3 μg/ℓ using the mean concentration. Taking cognisance of the above discussion on the merits of using either median of mean observed data to predict future dam TP concentrations, the mean is considered more advisable to use since it is the higher one and therefore a more precautionary prediction to use, apart from the fact that it is calculated arithmetically as is the case with application of the models.

6.3.1.1 Comparison of current and predicted dam total phosphorus concentration frequencies within selected ranges

In order to predict the possible changes from the present frequency of dam TP concentrations falling within certain ranges should Detergent Phosphate loads be removed from inflows, the historical dam concentration data sets for each dam were used to back calculate matching TP inflow concentrations using the OECD model. Since only the KZN dams had TP inflow concentration data and the majority did not, it was necessary to do this back calculation to achieve the above objective, but for uniformity, the KZN dam data were modelled similarly. Following this procedure, the sets of back calculated inflow concentrations for the dams were then adjusted downwards by reducing the inflow TP concentrations by the calculated percentages representing Detergent Phosphate loads. The model was then rerun with these lower TP inflow concentrations to establish predicted dam concentration data sets. Frequency analysis was subsequently carried out on these data sets for the dams to give the results for the frequency of dam TP concentrations falling within selected ranges. The 0-55 µg/ℓ TP range was selected as one range since it is the "threshold concentration" above which, as has been discussed above, quality problems in dams have been noted to occur. The other TP concentrations ranges were arbitrarily selected.

The results, given as percentage result frequencies are shown in Table 44. As a generalisation, the changes in percentage frequencies upwards in the 0-55 µg/ℓ TP range with the removal of Detergent Phosphate loads are not high for many of the dams. As examples, Albert Falls Dam would increase in frequency of occurrence in the 0-55 µg/ℓ TP concentration range from 86.9% to 88.5%, for Nagle Dam from 89.3% to 89.7% and for Vaal Dam from 25% to 28%. However, for those dams with significant percentages of urban areas in their catchments, and therefore the presence of WWTW effluents, the increases in predicted frequencies of concentrations in the 0-55 µg/ℓ range are greater such as from 12.3% to 27.7% for Hartbeespoort Dam and for Roodeplaat Dam from 3.3% to 5.1%. For the other ranges there are either increases or decreases in frequencies due to the changes within the data sets. Graphical representations of these frequency percentages are shown for the 0-55 µg/ℓ range below in Figure 13.

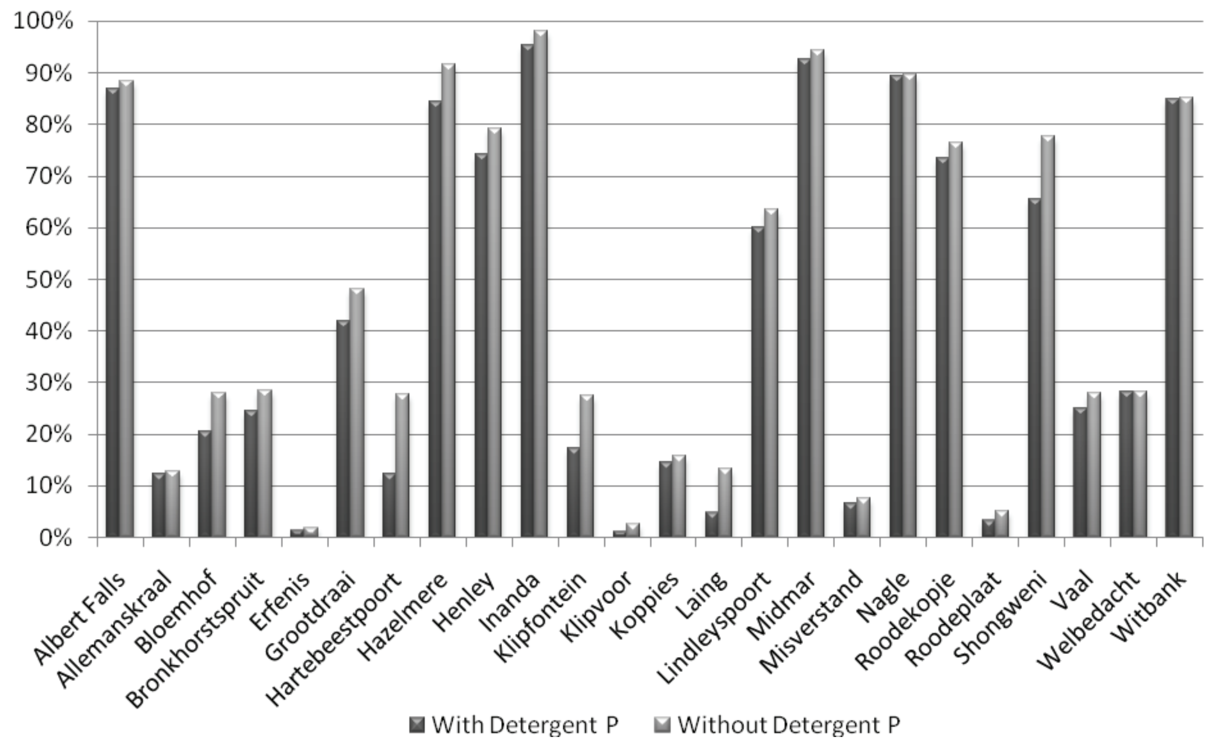

Figure 13: Frequency of predicted dam total phosphorus concentrations in the 0-55 µg/ℓ range with and without detergent phosphorus.

Table 44: Comparison of frequencies of current dam total phosphorus concentrations, with detergent p, and predicted, without detergent p loads, within concentration ranges

Detergent P	With	Without	With	Without	With	Without	With	Without	With	Without	With	Without	With	Without
TP Range	**0-55 µg/ℓ**		**56-100 µg/ℓ**		**101-200 µg/ℓ**		**201-300 µg/ℓ**		**301-400 µg/ℓ**		**401-500 µg/ℓ**		**>501 µg/ℓ**	
Albert Falls	86.9%	88.5%	9.8%	9.1%	2.8%	2.1%	0.2%	0.0%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%
Allemanskraal	12.4%	12.8%	38.0%	38.0%	25.6%	28.2%	21.4%	18.8%	1.5%	1.1%	0.4%	0.4%	0.8%	0.8%
Bloemhof	20.5%	27.9%	42.7%	45.3%	31.5%	23.5%	3.6%	1.8%	0.8%	1.0%	1.0%	0.5%	0.0%	0.0%
Bronkhorstspruit	24.6%	28.4%	47.8%	47.4%	25.4%	22.4%	0.4%	0.0%	0.4%	0.4%	0.9%	0.9%	0.4%	0.4%
Erfenis	1.5%	1.8%	6.8%	8.0%	56.6%	55.5%	29.5%	31.6%	5.3%	2.9%	0.0%	0.0%	0.3%	0.3%
Grootdraai	41.9%	48.1%	49.8%	45.1%	7.4%	5.9%	0.3%	0.3%	0.2%	0.3%	0.5%	0.3%	0.0%	0.0%
Hartbeespoort	12.3%	27.7%	35.6%	31.8%	28.3%	24.7%	11.2%	9.2%	6.7%	4.7%	4.2%	0.7%	1.8%	1.2%
Hazelmere	84.3%	91.6%	13.1%	7.0%	2.3%	1.4%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Henley	74.3%	79.2%	22.2%	17.4%	3.1%	3.5%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Inanda	95.3%	98.0%	4.0%	2.0%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Klipfontein	17.3%	27.5%	37.3%	39.7%	38.2%	28.1%	3.9%	1.8%	1.2%	2.1%	1.2%	0.3%	0.9%	0.6%
Klipvoor	1.2%	2.7%	1.8%	0.6%	1.2%	3.3%	5.8%	10.0%	7.6%	14.0%	12.8%	11.9%	69.6%	57.4%
Koppies	14.5%	15.8%	35.8%	35.2%	39.4%	39.4%	4.8%	4.2%	2.4%	3.0%	1.8%	1.2%	1.2%	1.2%
Laing	4.8%	13.4%	26.1%	36.0%	59.9%	45.5%	6.1%	3.8%	1.9%	0.6%	0.6%	0.3%	0.6%	0.3%
Lindleyspoort	60.1%	63.6%	20.8%	20.2%	17.6%	15.0%	0.9%	0.7%	0.7%	0.7%	0.0%	0.0%	0.0%	0.0%
Midmar	92.5%	94.3%	6.6%	4.9%	0.7%	0.7%	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%	0.0%	0.0%
Misverstand	6.5%	7.7%	46.3%	49.5%	36.6%	33.3%	7.0%	6.3%	1.6%	1.6%	0.7%	0.2%	1.3%	1.3%
Nagle	89.3%	89.7%	6.9%	6.5%	2.7%	2.7%	0.8%	0.8%	0.0%	0.0%	0.2%	0.2%	0.0%	0.0%
Roodekopjes	73.4%	76.4%	19.2%	18.7%	3.9%	1.5%	1.0%	1.5%	1.0%	0.5%	0.5%	0.5%	1.0%	1.0%
Roodeplaat	3.3%	5.1%	7.0%	14.9%	36.8%	52.1%	32.4%	18.2%	10.7%	3.5%	3.2%	4.2%	6.5%	2.0%
Shongweni	65.4%	77.8%	21.0%	13.6%	9.9%	6.2%	2.5%	2.5%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Vaal	25.0%	28.0%	33.8%	35.1%	31.9%	29.2%	7.2%	6.1%	0.5%	0.2%	0.6%	0.6%	1.0%	0.8%
Welbedacht	28.2%	28.2%	23.1%	28.2%	23.1%	23.1%	15.4%	10.3%	0.0%	2.6%	2.6%	0.0%	7.7%	7.7%
Witbank	84.9%	85.2%	11.4%	11.4%	2.2%	2.2%	0.6%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%

6.3.2 Modelling Dam Chlorophyll 'a' Concentrations

For the prediction of the likely decreases in dam Chlorophyll 'a' levels with the removal of Detergent Phosphate loads from the inflows, two models were employed. They are the OECD (1982) and Vollenweider (1986) models. The inputs that the OECD model uses are dam TP inflow concentration and retention time data, while in addition to these data the Vollenweider model uses dam area, mean depth and hydraulic residence time. It was considered that the outputs of these models would be complimentary and would therefore increase confidence in the mean predictions. However, it should be borne in mind that model predictions may be close to observed data for some dams and far out for others' for many reasons. Model predictions are just approximations of likely changes.

As was the case with the model predictions for dam TP concentrations with Detergent Phosphate removal from the inflow loads, the models were run for current TP loads and calculated inflow concentrations to the dams and then with the same with Detergent Phosphate loads subtracted to give reduced TP inflow concentrations. The agreement of the model predictions of Chlorophyll 'a' levels for the current dam loadings with either observed median or mean data was generally not good and highly variable, with differences ranging from just 1% to greater than 100% for some dams.

There may be a number of possible reasons why in some cases the predictions are in such poor agreement with observed data, such as sampling protocol not being representative of water quality in the dam (site positioning, frequency of sampling, surface/depth samples), inaccurate loading estimates or turbidity in dams constraining algal production through attenuation of sunlight resulting in lower algal growth and thus Chlorophyll 'a' levels. For example, Inanda Dam is 14 km long with 2 other sampling sites leading up to the main basin one, which was used for comparison with model predictions. The mean Chlorophyll 'a' concentration for the 3 sites was 9.1 µg/ℓ, which is far closer to the OECD and Vollenweider model predicted levels of 11.3 and 11.1 µg/ℓ than to the observed median and mean concentrations of just 3.6 and 5.2 µg/ℓ at the main basin site. Similarly, Albert Falls is a large dam with the sampling site close to the dam wall, which may not be truly representative of algal levels in the dam since nutrients in the inflow may be rapidly mopped up by algae en-route to the sample site. For Hazelmere Dam, the models greatly over-predict Chlorophyll 'a' concentrations compared to observed levels by about three times, but shading in the dam due to the relatively high mean turbidity in the dam of 48 NTU, and increasing up to more than 500 NTU at times, may well inhibit algal growth.

For both models, the predicted results for the dams were closer to the observed means than to the medians at counts of 22 to 3 for both, which is an indication that mean dam results are the better ones to use for modelling purposes. The average percentage differences between the observed means and predicted concentrations, using positive and negative results, were 31% for the OECD and 27% for the Vollenweider models respectively. The differences between the two models with their predictions for each dam ranged from 1% to 17% with a mean of 7.4%, which shows some consistency and therefore backup. As before, and for the same reasoning, it was decided to use the average predicted percent reductions for the models for each dam for application to observed median and mean data.

The results are given in Table 45 where predicted reductions in Chlorophyll 'a' levels range from 2.7% for Allemanskraal Dam to 30.1% for Inanda Dam. For the dams with large urban areas in their catchments and consequently significant discharges of sewage effluents with Detergent Phosphate, the predicted reductions are appreciable with 22.2% for Hartbeespoort Dam, 23.3% for Roodeplaat Dam and 23.3% for Shongweni Dam. On the other hand, reductions of less than 10% are predicted for 13 of the 24 dams, clearly dams with far lower percentages of Detergent Phosphate in their inflows. Graphical representations of the predicted changes in Chlorophyll 'a' concentrations with removal of Detergent Phosphate are shown in the Appendix in graph numbers 64 and 65 using median and mean data respectively.

A graphical representation of the predicted percentage decreases in dam TP concentrations and Chlorophyll 'a' values without detergent phosphate loads is shown in Figure 14. The graph shows that percentage reductions for both dam TP and Chlorophyll 'a' concentrations in excess of 20% are evident for 6 of the 24 dams, namely Hartbeespoort, Inanda, Klipvoor, Laing, Roodeplaat and Shongweni. For 12 dams, or 50%, the reductions predicted are less than 10%, namely Allemanskraal, Bronkhorstspruit, Erfenis, Grootdraai, Koppies, Lindleyspoort, Midmar, Misverstand, Nagle, Roodekopjes, Vaal and Witbank.

Table 45: Mean of models predicted percent reductions in dam chlorophyll 'a' concentrations without detergent phosphate loads and application to current dam median and mean concentrations

Dam	Model Predicted % Reductions	Median Dam Results µg/ℓ		Mean Dam Results µg/ℓ	
		Current	Predicted	Current	Predicted
Albert Falls	9.3%	6.8	6.2	9.1	8.3
Allemanskraal	2.7%	4.0	3.9	10.8	10.5
Bloemhof	11.9%	16.3	14.4	33.5	29.5
Bronkhorstspruit	4.1%	20.6	19.8	43.6	41.8
Erfenis	3.4%	2.0	1.9	4.5	4.3
Grootdraai	5.8%	5.0	4.7	10.0	9.4
Hartbeespoort	22.2%	28.0	21.8	72.6	56.4
Hazelmere	17.6%	1.6	1.3	2.2	1.8
Henley	10.4%	3.0	2.7	4.3	3.9
Inanda	30.1%	3.6	2.5	5.2	3.6
Klipfontein	14.6%	7.0	6.0	24.4	20.8
Klipvoor	21.3%	46.7	36.8	112.6	88.6
Koppies	2.5%	9.0	8.8	17.6	17.2
Laing	22.5%	2.1	1.6	2.7	2.1
Lindleyspoort	7.7%	4.0	3.7	6.3	5.8
Midmar	4.6%	3.0	2.9	3.5	3.3
Misverstand	5.2%	5.0	4.7	10.0	9.5
Nagle	3.8%	4.3	4.1	13.5	13.0
Roodekopjes	6.6%	7.0	6.5	10.0	9.3
Roodeplaat	23.3%	31.3	24.0	46.7	35.8
Shongweni	22.3%	34.0	26.4	53.7	41.7
Vaal	6.6%	3.0	2.8	7.2	6.7
Welbedacht	10.6%	6.6	5.9	10.4	9.3
Witbank	6.6%	4.0	3.7	6.7	6.3

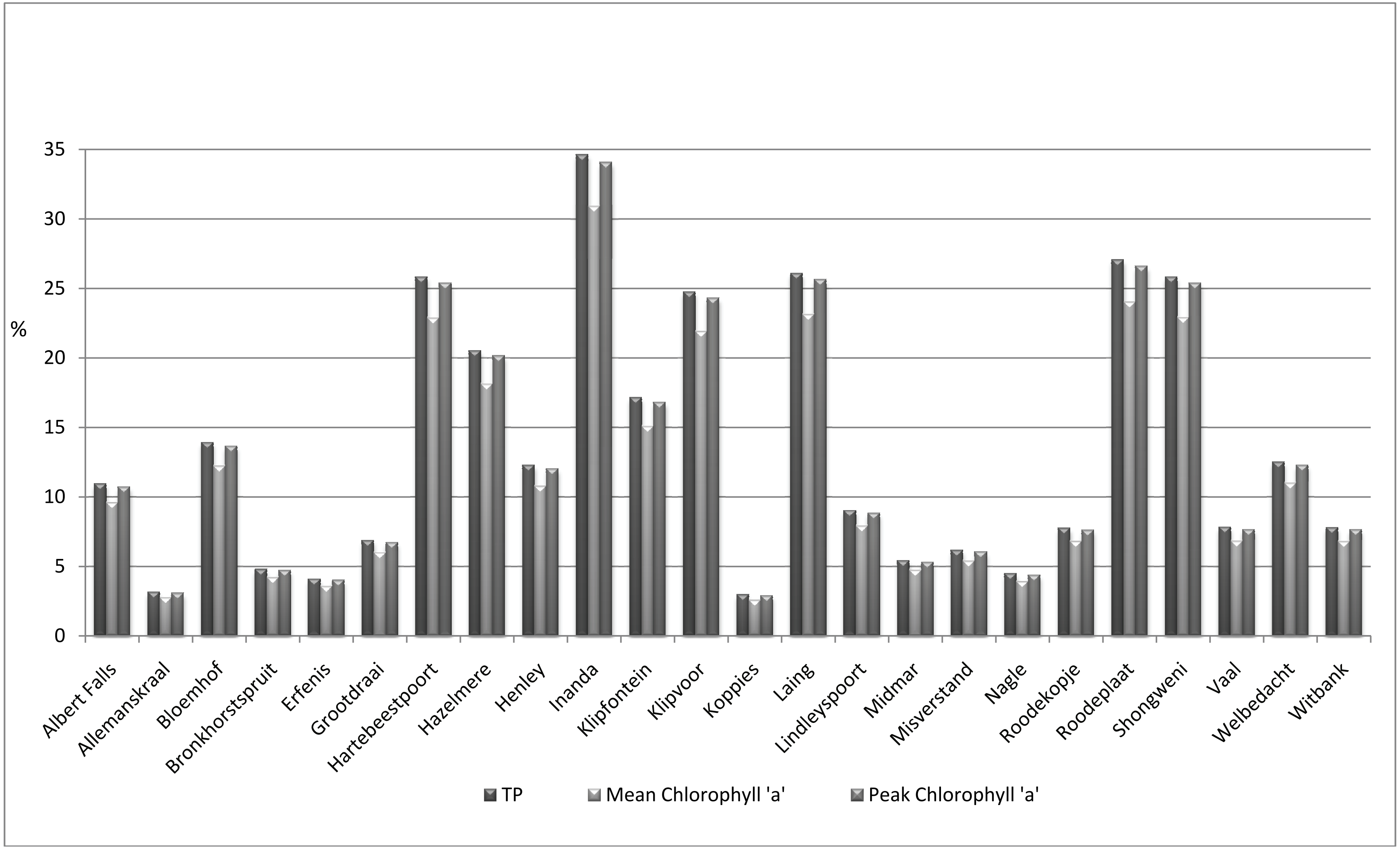

Figure 14: Predicted percentage decreases in total phosphorus dam concentrations (µg/ℓ) & chlorophyll 'a' values (µg/ℓ) with detergent phosphate removed

6.3.2.1 *Comparison of Current and Predicted Dam Chlorophyll 'a' Trophic State Frequencies*

The current trophic classifications for the dams, as discussed above, were given in Table 40 and shown in Figure 12. A prediction of the possible changes in trophic state classifications for the dams without Detergent Phosphate in the inflow loads was made using the following modelling method. As was the case for dam TP concentrations, the current observed Chlorophyll 'a' dam data were used as input to the OECD model to back calculate corresponding TP inflow concentrations. These calculated concentrations were then adjusted downwards by subtracting the Detergent Phosphate loads for each dam to give a new set of TP inflow concentrations for the same periods. The model was rerun to predict a suite of Chlorophyll 'a' values, which were then subjected to frequency analysis for comparison with the frequency analyses results for current conditions, that is inflow with Detergent Phosphate loads, Classification of the results into percentages within trophic states, as before, was then carried out. The comparisons for states with and without Detergent Phosphate are given in Table 46 and Figure 15 and Figure 16. Two graphs were necessary for clarity of viewing due to crowding by the amount of data.

The predicted changes in trophic classification states as a result of removal of detergent phosphate for most of the dams given in Table 46 are not large, and in many cases there is very little or no change at all, such as for Albert Falls, Allemanskraal, Bloemhof and Midmar dams to name a few. Some change is shown for Hartbeespoort Dam where the Oligotrophic state would increase from 26% to 31% and the Hypertrophic state decrease from 47 to 41%, while for Roodeplaat Dam the Oligotrophic state would increase from 19 to 23% and the Hypertrophic state would decrease from 51% to 44%. Other similar scale changes may be noted for Henley, Inanda, Klipvoor, Shongweni and Welbedacht dams.

Table 46: Comparison of current, with detergent P, and predicted, without detergent P, trophic classifications of dams for chlorophyll 'a' data, DWAF criteria

Dam	0-10 μg/ℓ	11-20 μg/ℓ	21-30 μg/ℓ	>30 μg/ℓ
	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Albert Falls + Det	70%	22%	4%	4%
Albert Falls - Det	73%	21%	3%	3%
Allemanskraal + Det	82%	9%	2%	7%
Allemanskraal - Det	82%	9%	2%	7%
Bloemhof + Det	39%	21%	13%	27%
Bloemhof - Det	39%	24%	15%	22%
Bronkhorstspruit + Det	37%	12%	13%	38%
Bronkhorstspruit - Det	38%	12%	12%	38%
Erfenis + Det	92%	4%	1%	3%
Erfenis - Det	92%	4%	1%	3%
Grootdraai + Det	80%	9%	3%	8%
Grootdraai - Det	80%	9%	4%	7%
Hartbeespoort + Det	26%	15%	12%	47%
Hartbeespoort - Det	32%	16%	13%	39%
Hazelmere + Det	99%	1%	0%	0%
Hazelmere - Det	99%	1%	0%	0%
Henley + Det	92%	6%	2%	0%
Henley - Det	100%	0%	0%	0%
Inanda + Det	86%	11%	2%	1%
Inanda - Det	94%	5%	1%	0%
Klipfontein + Det	59%	10%	11%	20%
Klipfontein - Det	61%	12%	11%	16%
Klipvoor + Det	15%	13%	10%	62%
Klipvoor - Det	18%	15%	12%	55%
Koppies + Det	61%	20%	5%	14%
Koppies - Det	61%	21%	5%	13%
Laing + Det	100%	0%	0%	0%
Laing - Det	100%	0%	0%	0%
Lindleyspoort + Det	87%	10%	2%	1%
Lindleyspoort - Det	88%	9%	2%	1%
Midmar + Det	97%	3%	0%	0%
Midmar - Det	97%	3%	0%	0%
Misverstand + Det	76%	13%	3%	8%
Misverstand - Det	77%	12%	4%	7%
Nagle + Det	78%	9%	3%	10%
Nagle - Det	79%	9%	3%	10%
Roodekopjes + Det	65%	25%	3%	7%
Roodekopjes - Det	66%	24%	4%	6%
Roodeplaat + Det	19%	17%	13%	51%
Roodeplaat - Det	24%	21%	14%	41%
Shongweni + Det	23%	13%	11%	53%
Shongweni - Det	29%	13%	13%	45%
Vaal + Det	88%	7%	0%	5%
Vaal - Det	89%	6%	1%	4%
Welbedacht + Det	67%	20%	5%	8%
Welbedacht - Det	77%	10%	5%	8%
Witbank + Det	86%	8%	2%	4%
Witbank - Det	87%	7%	3%	3%

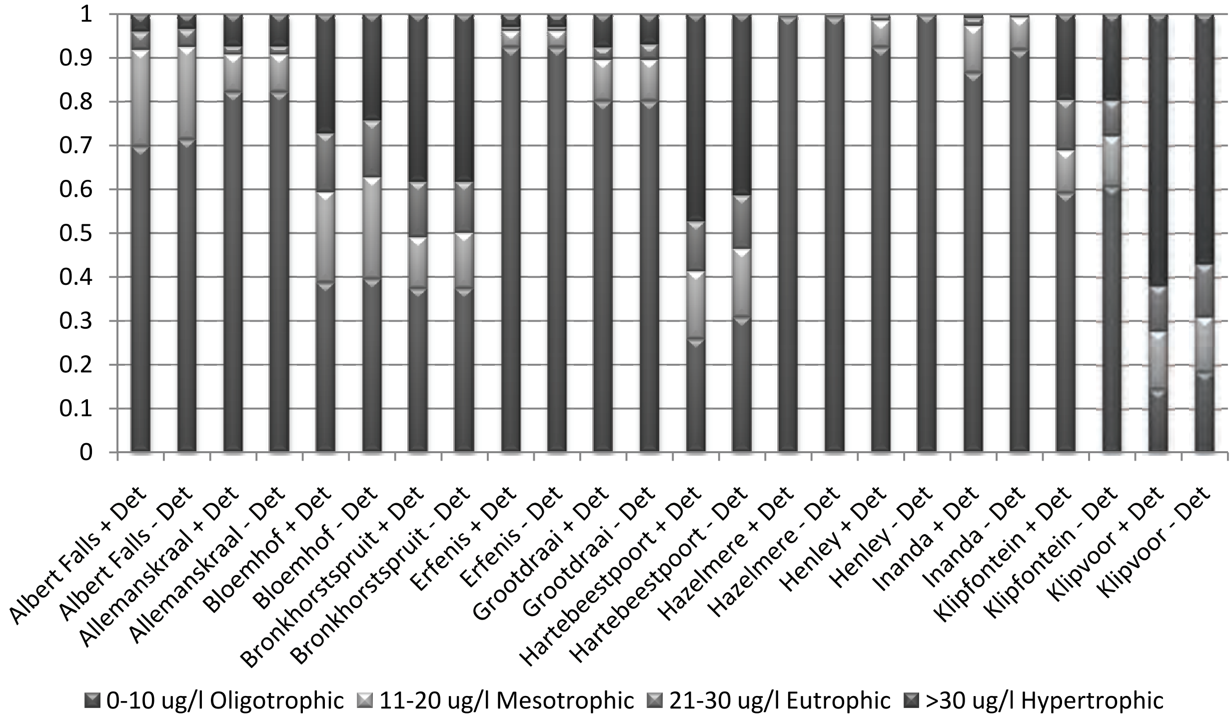

Figure 15: Comparison of current and predicted trophic classification of dams from chlorophyll 'a' data without detergent p, DWAF criteria

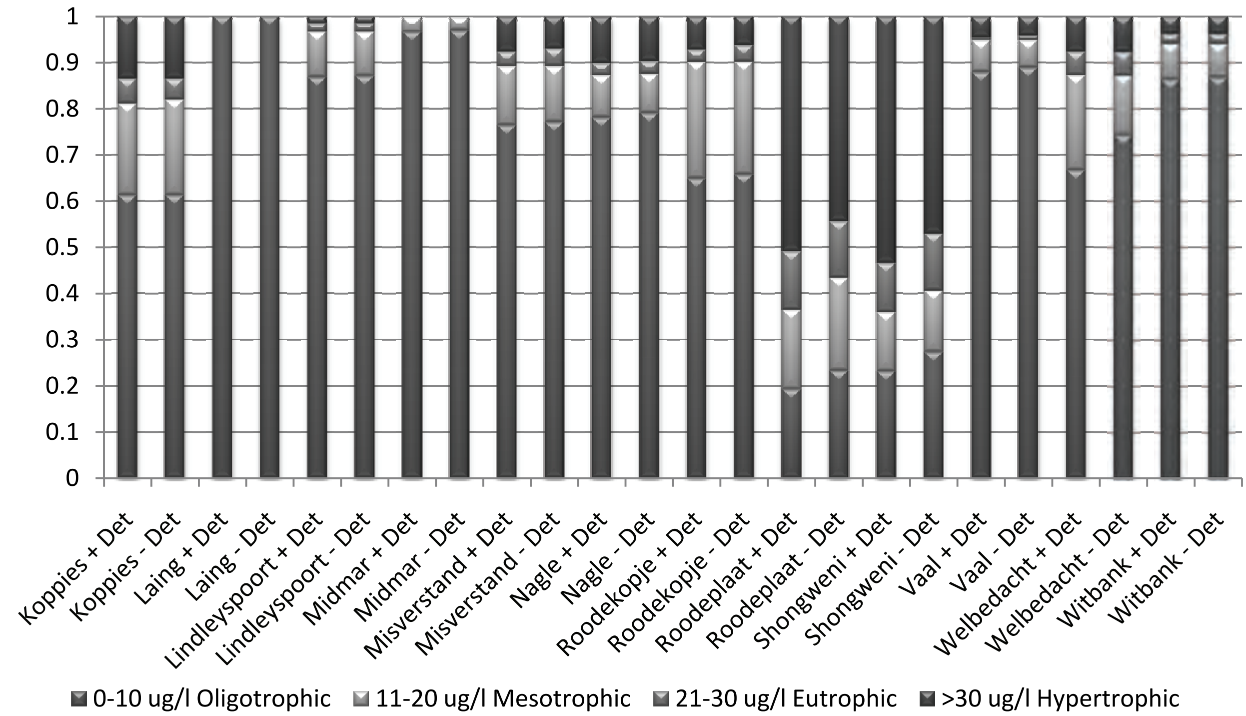

Figure 16: Comparison of current and predicted trophic classification of dams from chlorophyll 'a' data without detergent p, DWAF criteria

6.4 Summary data of current and predicted dam conditions

A summary of dam conditions with and without Detergent Phosphate loads is shown in Table 47, that is summation of current and predicted TP loads to all dams and summation of TP and Chlorophyll 'a' masses within the dams. The purpose here is to highlight the possible overall percentage reductions for these criteria for consideration of the efficacy of the proposed removal of Detergent Phosphate. Should Detergent Phosphate loads to the dams be removed, the overall TP load would be reduced by 16%, while the dam TP mass would be reduced by 11-12% and the Chlorophyll 'a' mass reduced by 12%. There is not a lot of difference between these overall percentage reductions. It would appear that the return from the percentage improvement in dam water quality, as judged by TP and Chlorophyll 'a' percentage reductions is slightly lower and not directly proportional to the corresponding reduction in TP loading. This statement does not, however, imply that the removal of detergent phosphate should not be considered as a desirable and viable option for the general improvement of dam water quality for its many users.

Table 47: Summed total phosphorus loads to all dams, dam total phosphorus masses and dam chlorophyll 'a' masses in all dams with and without detergent phosphate loads

	With Detergent P, tons	Without Detergent P, tons	Percentage Reduction
TP in Inflow	2 993	2 518	16%
TP in Dam, Model Predicted from Inflow Concentrations	805	708	12%
TP in Dam, Observed Less Model Predicted Reductions	621	554	11%
Chlorophyll 'a' in Dam, Observed Less Model Predicted Reductions	99	87	12%

Chapter 6: Findings summary

- The results of the modeling exercise show that predicted reductions in dam TP concentrations due to the elimination of detergent phosphate vary from **3%** to **35%**. Dams most affected are:
    1. Inanda – 35%
    2. Roodeplaat – 27%
    3. Hartbeestpoort – 26%
    4. Laing – 26%
    5. Shongweni – 26%
- Predicted reductions in chlorophyll 'a' vary from **2.5%** in Koppies to **30%** in Inanda
- Summed total in-dam phosphate concentration reductions across all dams is estimated to lie between **11% and 12%**
- Summed total chlorophyll 'a' concentration reductions across all dams is estimated to be **12%**

7. THE IMPACTS OF THE INTRODUCTION OF ZERO-PHOSPHATE DETERGENTS ON WATER TREATMENT COSTS

7.1 Introduction

Eutrophication is defined as the enrichment of water by nutrients, stimulating an array of symptomatic changes including increased production of algae and/or higher plants, which can adversely affect the diversity of the biological system, the quality of the water and the uses to which the water may be put (Pretty et al., 2002). It is primarily caused by high loads of phosphorus and nitrogen in the water bodies, which may be the result of natural processes of nutrient cycles and biogeochemical processes in the soil and atmosphere (natural eutrophication), or as a consequence of water pollution from domestic, industrial and agricultural activities augmenting naturally occurring nutrient levels (cultural eutrophication) (UNEP, 2005).

Amongst others, symptoms of eutrophication include an increase in water turbidity, a changed composition of the algal flora, an increased frequency of anoxic situations, and possibly more algal blooms (Söderqvist and Scharin, 2000). Eutrophication has negative consequences for the conservation status of water resources, industry, agriculture, real estate values, recreation and tourism, the provision of potable water and public health costs (Walmsley, 2000; UNEP, 2005). In the context of this project, particular focus was applied to the potential impacts that the introduction of zero-phosphate detergents may have on the cost of treating potable water abstracted from dams in South Africa.

7.2 Selection of suitable dams to determine impacts of the introduction of zero-phosphate detergents on water treatment costs

The work of Graham et al. (1998) has shown that for the most part water treatment costs are primarily driven by "base water quality" factors, e.g. turbidity, and not high algal counts or algal bye products. Only under particularly eutrophic conditions, and when for example blue-green (cyanobacterial) algal counts are high, is there a direct impact on water treatment costs (as illustrated in Harding & Paxton, 2001). Typically during these periods water treatment costs can be three to four times the base cost of treating water (Graham et al., 1998). This is largely attributable to the need to employ tertiary water treatment processes, including activated carbon, to remove taste and odour compounds generated by the algae from the raw water. From the cost of water treatment perspective, those dams which were, for the most part, not particularly eutrophic, were therefore assumed to be poor candidates to examine in terms of their response to the zero-phosphate detergents. In other words, under non eutrophic conditions (i.e. oligo and mesotrophy) water treatment costs are driven by factors not directly linked to nutrients (e.g. P) in the water or algae responding to nutrients in the water. Hence the focus of this study was on identifying those dams which could have their current and ambient eutrophication status favourably influenced by the introduction of zero-phosphate detergents. Having identified suitable candidate dams, more detailed water treatment cost modelling could be undertaken in response to likely nutrient, and hence eutrophy, regimes with a possible introduction of zero-phosphate detergents.

The previous suite of analyses highlighted a number of impoundments, which, due to their catchment detergent phosphate contribution to the total in-lake phosphate loading, appeared to be the most suitable candidates to consider in terms of potential in-lake TP reductions with the introduction of zero-phosphate detergents. These impoundments were typically those with large urban and peri-urban and industrial developments within their catchment which were contributing significant phosphate loads to the dams by way of detergent usage within their catchments.

A key figure in this respect is Figure 14, highlighting the percentage decreases in total in-dam phosphate, and hence also expected chlorophyll 'a' decreases with the introduction of zero-phosphate detergents, in dams, i.e. the removal of detergent phosphate from these systems. Figure 14 shows that some of the dams are unlikely to experience significant decreases in TP and chlorophyll 'a' concentrations with the introduction of zero-phosphate detergents. Dams such as Allemanskraal, Erfenis and Koppies, with large catchments and little urban landuse show predicted reductions of between 2% and 4%. Those dams however, with significant areas of urban landuse in their catchments do show significant reductions, the largest of which are those predicted for Inanda Dam in KZN, which may be expected to drop its TP and chlorophyll 'a' concentrations by about a third over its current status, and Hartbeespoort, Laing, Roodeplaat and Shongweni which will all experience reductions of over 25%. By visual inspection of Figure 14, the majority of dams assessed will be able to reduce their TP and chlorophyll 'a' concentrations by between 7% and 20%, or an estimated overall average of all dams assessed of 11.5% (Table 48).

From a cost of water treatment and general catchment management perspective, initial indications are that resources and efforts should be concentrated on those dams which have good potential for TP reductions based on the application of zero-phosphate detergents. Based on Figure 14 a relatively arbitrary 15% decrease in TP was used as this threshold to identify and focus on key dams with potential for TP reductions. In other words, any dams which were showing less than a potential 15% reduction in TP, based on the introduction of zero-phosphate detergents, were excluded from future modelling attention. The remaining dams (identified in Table 48) were subsequently considered as candidates for additional modelling to determine the cost of potable water treatment for water abstracted from these dams.

These potential reductions in TP and chlorophyll 'a' concentrations have, however, to be considered in the context of the current eutrophication status of the respective dams. In many instances the results of the modelling and examination of the historical water quality data from these dams indicates that they are already in an "advanced" state of eutrophication, i.e. for the most part already eutrophic or hypereutrophic (according to the DWAF/Van Ginkel et al., 2001 classification). This indicates that in many instances the introduction of zero-phosphate detergents within their catchment areas as a control measure on its own is unlikely to result in any significant reductions in their eutrophication status, due to the reasons elucidated in the above paragraph. Therefore the introduction of zero-phosphate detergents will only be successful in reducing the water treatment costs of those systems which are already eutrophic and which have the potential to show a significant decline in this status with the introduction of zero-phosphate detergents.

Table 48: Summary of mean of models predicted percent reductions in dam chlorophyll 'a' concentrations without detergent phosphate loads and application to current dam median and mean concentrations, with candidate dams suited to potential water treatment cost modelling identified

	Dam	Model Predicted % Reductions	Median Dam Chl "a" Results (µg/ℓ)		Mean Dam Results Chl "a" (µg/ℓ)		Candidate for cost modelling
			Current	Predicted	Current	Predicted	
1	Albert Falls	9.3%	6.8	6.2	9.1	8.3	No
2	Allemanskraal	2.7%	4.0	3.9	10.8	10.5	No
3	Bloemhof	11.9%	16.3	14.4	33.5	29.5	No
4	Bronkhorstspruit	4.1%	20.6	19.8	43.6	41.8	No
5	Erfenis	3.4%	2.0	1.9	4.5	4.3	No
6	Grootdraai	5.8%	5.0	4.7	10.0	9.4	No
7	Hartbeespoort	22.2%	28.0	21.8	72.6	56.4	Yes
8	Hazelmere	17.6%	1.6	1.3	2.2	1.8	Yes
9	Henley	10.4%	3.0	2.7	4.3	3.9	No
10	Inanda	30.1%	3.6	2.5	5.2	3.6	Yes
11	Klipfontein	14.6%	7.0	6.0	24.4	20.8	Yes
12	Klipvoor	21.3%	46.7	36.8	112.6	88.6	Yes
13	Koppies	2.5%	9.0	8.8	17.6	17.2	No
14	Laing	22.5%	2.1	1.6	2.7	2.1	Yes
15	Lindleyspoort	7.7%	4.0	3.7	6.3	5.8	No
16	Midmar	4.6%	3.0	2.9	3.5	3.3	No
17	Misverstand	5.2%	5.0	4.7	10.0	9.5	No
18	Nagle	3.8%	4.3	4.1	13.5	13.0	No
19	Roodekopjes	6.6%	7.0	6.5	10.0	9.3	No
20	Roodeplaat	23.3%	31.3	24.0	46.7	35.8	Yes
21	Shongweni	22.3%	34.0	26.4	53.7	41.7	Yes
22	Vaal	6.6%	3.0	2.8	7.2	6.7	No
23	Welbedacht	10.6%	6.6	5.9	10.4	9.3	No
24	Witbank	6.6%	4.0	3.7	6.7	6.3	No
	OVERALL AVERAGE	11.5%					

Based on eutrophication status data summarised in this study (Table 40 and Figure 12), the proportion of time that the dams were in a eutrophic and hypertrophic state was graphically summarized (Figure 17 below) and used to identify those dams which experience the greatest pressures through phosphate inputs arising from upstream catchment sources. Several dams were noted as being consistently eutrophic, namely Bloemhof, Bronkhorstspruit, Hartbeespoort, Klipfontein, Klipvoor, Roodeplaat, and Shongweni.

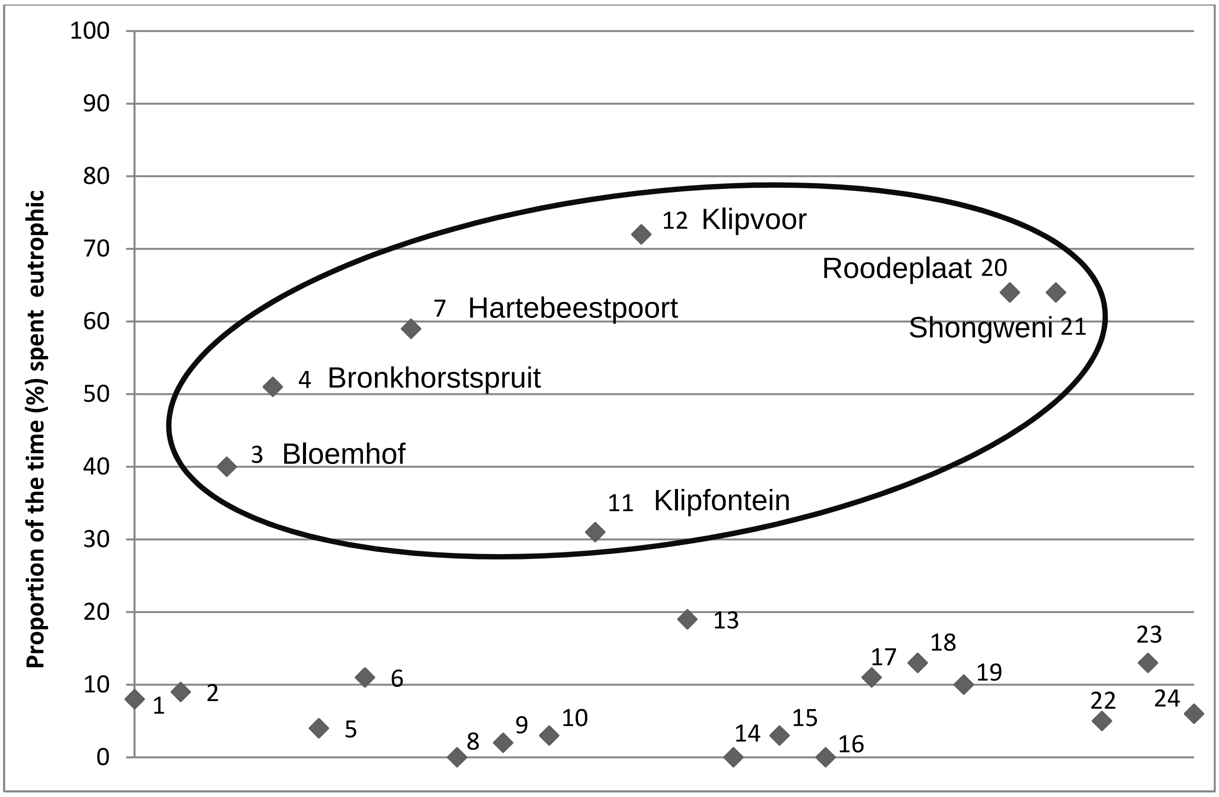

Figure 17: Diagram illustrating the proportion of time that the dams are either eutrophic or hypertrophic – dams predominantly either eutrophic or hypertrophic are named and grouped (black circle).

The next step was to refine this group and determine which of these dams had the greatest potential to reduce water treatment costs by removing additional phosphate loads from phosphate detergents. This was determined by calculating the difference in the proportion of time when dams are either eutrophic or hypertrophic under the current situation ***with*** phosphate detergents compared to the predicted situation ***without*** phosphate detergents.

Table 49 shows which of the dams have the greatest potential for improvement based on the differences that were calculated. For the purposes of this exercise, the eutrophic condition was calculated as the sum of the eutrophic and hypertrophic situations. Dams with the greatest potential for improvement, and which require further investigation, are those calculated as having the greatest reduction in percentage of time that a dam experiences eutrophic or hypertrophic conditions. The top four dams selected for further investigation were those having a low ranking in terms of being problematic but a high potential for phosphate reduction. These are the **Roodeplaat, Hartbeespoort, Klipvoor and Shongweni dams** (Table 49).

Interestingly Shongweni Dam was decommissioned as a water supply dam many years ago, principally due to its eutrophication status and problems involved in getting this highly nutrient enriched water to a suitable drinking water standard. In fairness though, the volume of water supplied by Shongweni was also found to be lacking as Durban and surrounding areas expanded, and Inanda Dam had to be built to meet this increasing demand for water. Hence in this analysis Shongweni was eliminated from further efforts to link treatment costs to eutrophication status, although arguably, the economic implications of having to partially build an entirely new water supply system to supersede Shongweni, due to eutrophication, could be seen as a severe example of the cost of eutrophication. This has to be balanced against the volume of water and surety of supply that Inanda Dam was able to provide, in superseding Shongweni.

This exercise identified Roodeplaat, Hartbeespoort and Klipvoor as being suitable candidates for determining the cost savings for water treatment that might be achieved in applying zero-phosphate detergents in their respective catchments.

Table 49: Dams selected for modelling the cost implications of removing phosphates from detergents based on their ranking as problem eutrophic/hypertrophic dams, as well as their potential for improved trophic status

	Dam	**Ranked problem dams** (1 most eutrophic, 7 least eutrophic)	**Potential improvement(% time reduction of periods under eutrophic/hypertrophic status)** (1 least potential 9- most potential)	Selected dams for costs modelling
1	Albert Falls		2	
2	Allemanskraal		0	
3	Bloemhof	6	3	
4	Bronkhorstspruit	5	1	
5	Erfenis		0	
6	Grootdraai		0	
7	Hartbeespoort	4	7	Yes
8	Hazelmere		0	
9	Henley		2	
10	Inanda		2	
11	Klipfontein	7	4	
12	Klipvoor	1	5	Yes
13	Koppies		1	
14	Laing		0	
15	Lindleyspoort		0	
16	Midmar		0	
17	Misverstand		0	
18	Nagle		0	
19	Roodekopjes		0	
20	Roodeplaat	2	9	Yes
21	Shongweni	3	6	n/a*
22	Vaal		0	
23	Welbedacht		0	
24	Witbank		0	

* Dams no longer utilised as sources of water supply and thus not applicable for cost modelling

7.3 Selection of a water treatment costing model

The literature reports on a range of methodologies used to estimate water treatment costs in relation to eutrophication. Pretty et al. (2002) estimated drinking water treatment cost by water treatment companies using Ordinary Least Squares (OLS) regression to estimate the operating and capital costs of removing nitrogen from water. Dennison and Lyne (1997) applied a different approach to a similar problem, i.e., they estimated the drinking water treatment cost for the DV Harris plant in KZN (SA) using the partial adjustment regression model This approach was subsequently used by Graham et al. (1998) for additional modelling of treatment costs within the Umgeni Water operational area in KZN. Samuel Gebremedhin (an MSc student at the University of KZN) subsequently pursued this research and the application of these methodologies as part of another WRC project (K5/1568, Development of a model to assess the costs associated with eutrophication, focusing on the cost of eutrophication in the Vaal River – in progress). His currently unpublished thesis focused on investigating the relationship between raw water quality and the chemical costs of producing potable water at two water treatment plants: Zuikerbosch Station #2 (owned by Rand Water) in the Upper Vaal Water Management Area (UVWMA), and Balkfontein (owned by Sedibeng Water) in the Middle Vaal Water Management Area (MVWMA). Descriptive statistics reveal that raw water in the Vaal River is of a poorer quality (more eutrophic) at Balkfontein compared to that at Zuikerbosch. Furthermore, the actual real chemical water treatment costs (measured in 2006 ZAR) averaged R89.90 per megalitre at Zuikerbosch and R126.31 at Balkfontein, indicating that the chemical water treatment costs of producing potable water tend to increase as raw water quality declines.

For both water treatment plants, OLS regression was used to identify the relationship between real chemical costs of water treatment and the dimensions of water quality identified through the respective Principal Components Analyses. The estimated regression models account for over 50.2% and 34.7% of variation in real chemical water treatment costs at Zuikerbosch and Balkfontein (Gebremedhin, unpublished MSc thesis), respectively. The model developed for Zuikerbosch identified that alkalinity and turbidity in raw water treated at that plant are the primary drivers of chemical costs of water treatment. On the other hand, for the Balkfontein analysis (a more eutrophic system), treatment costs appeared to increase with raw water temperature (speculated as being the effects of increased summer algal growth).

For predictive rather than explanatory purposes, a partial adjustment regression model was estimated for each of the two water treatment plants. Using this model, real chemical water treatment costs were specified as a function of real chemical water treatment costs in the previous time period and of raw water quality variables in the current period. The R^2 statistics for the two regression models were 61.4% using the data for Zuikerbosch and 59.9% using the data for Balkfontein, suggesting that both models have reasonable levels of predictive power. However for the purposes of the zero-phosphate detergent project, the focus was restricted to the Balkfontein model due to chlorophyll ‘a’ being an apparent key driver of routine water treatment costs at this plant and the need to find an appropriate water treatment cost model for eutrophic systems (where chlorophyll ‘a’ is likely to be a key driver of treatment costs).

In the Balkfontein case the current chemical cost of water treatment is predicted at R90.74 per megalitre per day. This has been shown to increase on average by 0.35% per 1% increase in the level of chlorophyll ‘a’. This sort of relationship therefore had potential to be used in estimating the likely decreases in treatment costs that could be attributed to the introduction of zero-phosphate detergents in key catchment areas. Hence in the absence of any other suitable costing model for the country to determine the impact of eutrophication on water treatment costs, the Balkfontein model of Gebremedhein (unpublished MSc thesis) was applied to generate a first order estimate of cost savings that might accrue to water authorities producing potable water abstracted from the 3 key dams, identified in the previous section, with the application of zero-phosphate detergents in their catchments.

7.4 Application of a water treatment costing model

The nature of the predictive algebraic model for Balkfontein water treatment costs (Real chm cost) was estimated as:

(Real chm cost) t = B0 + B1 (Chl-a) t +B2 (Turb) t + B3 (Colour) t +B4 (Temp) t + B5 (Cl) t + B6 (Ca) t + B7 (Fe) t + B8 (Mn) t + B9 (Thard) t + B10 (Ca2) t +B11 (Mn2) t + B12 (Cl2) t + B13 (Real chm cost) t-1

(Equation 1)

Where:

(Chl-a) t = Chlorophyll-a (µg/ℓ)

(Turb) t = Turbidity (NTU: Nephelometric Turbidity Units)

(Colour) t = Colour (Pt-co: Platinum Cobalt Standard)

(Temp) t = Temperature (degree Celsius)

(Cl) t = Chloride (mg/ℓ)

(Ca) t = Calcium (mg/ℓ)

(Fe) t = Iron (µg/ℓ)

(Mn) t = Manganese (µg/ℓ)

(Thard) t = Total hardness (mg/ℓ)

(Real chm cost) t-1 = Real water treatment cost lagged by one week(R)

Using this model it was possible to predict the chemical treatment costs associated with producing drinking water to a suitable standard based on a nutrient (P) enriched source water, such as was present in the middle Vaal River at Balkfontein.

This model was used to first predict the base treatment costs for raw water abstracted from respective dams, i.e. eutrophic water in the absence of the application of zero-phosphate detergents. Thereafter a second estimation of treatment costs was generated based on the application of zero-phosphate detergents to respective systems, which in turn would produce a concomitant reduction in chlorophyll ‘a’ in the associated system. On the assumption that all other water quality parameters would, on average, remain the same, this allowed an estimation of the likely reductions in water treatment costs associated with the introduction of zero-phosphate detergents.

Volumes of raw water abstracted from respective dams and treated at respective treatment works (Table 50) were obtained from various sources although the BKS report to DWAF was a key source of data (Water Abstractions and Return Flows), for the project, ***The assessment of water availability in the Crocodile (West) River catchment by means of water resource related models in support of the planned future licensing process***, (DWAF Report No: P WMA 03/000/00/2108, August 2008). Additional and confirmatory data was sourced from the Magalies Water Annual Report (2007/2008). This volumetric estimate was needed in the cost of treatment models as these models were configured to estimate costs based on a per mega litre per day. Actual volumes abstracted and used in water treatment would then have to be scaled to account for the volumes used and hence costs incurred in treating that water.

Table 50: Summary of water volumes (mega litres/day) abstracted for potable water from respective dams, and treated in respective water treatment works

Supply Dam	Water Treatment Works	Volume (Mℓ/d)	Total/dam (Mℓ/d)
Hartbeespoort	Vaalkop	90	90
Roodeplaat	Wallmannsthal	12	90
	Roodeplaat	60	
	Klipdrift	18	
Klipvoor	Projected	5	5

7.5 Results

Based on the aforementioned costing model, and volumes of water treated, it was possible to estimate the current base level, and reduction to water treatment costs, associated with water abstracted from respective dams. This was based on their current levels of eutrophication, and likely reductions that would be expected with the introduction of zero-phosphate detergents. Water treatment costs under these scenarios are summarised in Table 51

Table 51: Summary of water treatment costs (and savings) for selected dams on the basis of the application of zero-phosphate detergents

Dam	Hartbeespoort	Roodeplaat	Klipvoor	Total
Volume treated (ML/day)	90	90	5	
Predicted decline in Chl 'a' concentration (%)	22.2	23.3	21.3	
Base treatment cost (no P reduction)	R 108	R 90	R 134	
Reduced treatment cost (zero-phosphate detergents used in respective catchment)	R 97	R 83	R 118	
Estimated annual cost saving	R 350,516	R 236,641	R 28,978	R 616,134

These results are likely to be highly conservative and based to a large degree on basic treatment of water, i.e. to simply remove algae and sediments present in the raw water. It is well known that tertiary treatment of drinking water is necessary if there are taste and odour (T&O) problems in the raw water supply.

These sorts of problems are generally largely associated with problematic/T&O algae, a manifestation of eutrophication. Graham et al. (1998) showed that water treatment costs could double (from a 1996 base price of R25/Mℓ to R65/Mℓ) when powdered activated carbon (PAC) had to be dosed into the water during periods of taste and odour problems at Durban Heights WTW in KZN. These problems resulted from blooms of Anabaena or Microcystis (classical indicator algae associated with eutrophic conditions) in Nagle Dam.

Under the current trajectories of eutrophication then in South Africa (see Tables 47), water treatment costs have the potential to be significantly affected by increased eutrophication.

Chapter 7: Findings summary

1. Water treatment costs at dams which are predominantly oligotrophic or mesotrophic are driven by factors other than nutrients, or algae responding to nutrients. Water treatment costs in these dams are thus unlikely to be affected by a reduction in phosphate loading.

2. Dams selected for cost modeling were those which showed a high potential for improvement in phosphate loading and those which spent a significant amount of time in a eutrophic state – Hartbeestpoort, Roodeplaat, Klipvoor and Shongweni. Shongweni was discarded as it is no longer used as a potable water supply dam.

3. Based on modeling of reduced algal concentrations, a combined total predicted saving of **R616, 134 per year** was estimated for treating water from Hartbeestpoort, Roodeplaat and Klipvoor. This is likely to be conservative estimate of total treatment costs associated with eutrophic water. Projected eutrophication levels in South Africa suggest treatment costs may be significantly affected by eutrophication in the future.

8. COST BENEFIT ANALYSIS

8.1 Determination of the economy-wide costs of zero-phosphate detergents

One of the most important considerations in the debate as to whether or not to introduce zero-phosphate detergents to South Africa is the impact that these detergents will have on the economy as a whole and consumers in particular. South Africa is a developing country, with a highly skewed income distribution and a large percentage of the population living in poverty. Any action which may thus affect the pricing or effectiveness of a mass consumed product such as laundry detergent should be very carefully considered.

There are five main factors which need to be taken into account when evaluating the effect that zero-phosphate or phosphate-free detergents may have on consumers and the overall economy:

1. the price of zero-phosphate detergents relative to the price of the current phosphate detergents available on the market,
2. the effectiveness, the ease of use, and the safety of zero-phosphate detergents,
3. the effect of zero-phosphate detergents on the functioning / lifespan of washing machines,
4. the impact of zero-phosphate detergents on clothing and fabrics.
5. the impact of zero-phosphate detergents on the broader environment.

8.1.1 The price of zero-phosphate detergents

The price difference between current detergents and zero-phosphate detergents will be driven by the cost of the inputs necessary to substitute the phosphate builder. The most likely alternative to STPP is zeolite, combined with soda ash (R. Plumbley – Pers comm). In the past, zeolite was considered more expensive than STPP. This situation however has recently changed. Phosphorus rock is becoming increasingly scarce (see information box 1 below), with some authors predicting that the world phosphorus stocks might only last another one hundred years or less at the current rate of consumption (Tangsubkul, Moore & Waite, 2005), with some major producing countries' stocks possibly being depleted in the next 20 years (FAO, 2004).

In addition, the demand for phosphorus in the agriculture sector has grown; and the detergent industry, which accounts for about ten percent of world-wide phosphate demand, does not have sufficient market power to compete with the demand in the agriculture sector. This is has led to the price of phosphorus, and STPP, increasing substantially. Additionally, China has begun to guard her phosphate rock reserves by placing a 135% export tariff on phosphate products (timesonline 2008). As the world's leading STPP producer, this tariff has contributed to the exponential increase in its price.

Information box 1: World Phosphate use and reserves

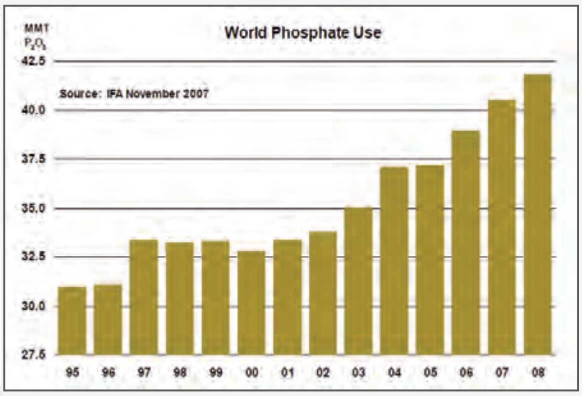

Figure 18: Map of economic and potentially economic phosphate deposits of the world (FAO 2004) and

Figure 19: World phosphate use (Mosaic 2008)

Figure 18 above shows a map of Phosphate Rock (PR) deposits currently being mined, those that have been mined in the recent past, and those that have been shown to be potentially economic, while Figure 19 shows the extraordinary growth in world demand for phosphate in the last 8 years. Based on current extraction rates, rising world demand and economic conditions in the 1990s, more than half of the top ten producing countries will have exceeded the life of their reserves in less than 20 years (FAO 2004).

According to scientists at the University of Technology in Sydney, global reserves will be depleted in the next 50 – 100 years. China, one of the world's leading producers, in response to global shortages has recently imposed a 135% export tariff on phosphate fertilizer, with the intent of retaining its reserves in the country for the use of its own farmers (Timesonline 2008). As China is the world's leading producer of STPP, this product has seen a significant increase in price over the last two years (see Figure 20 below).

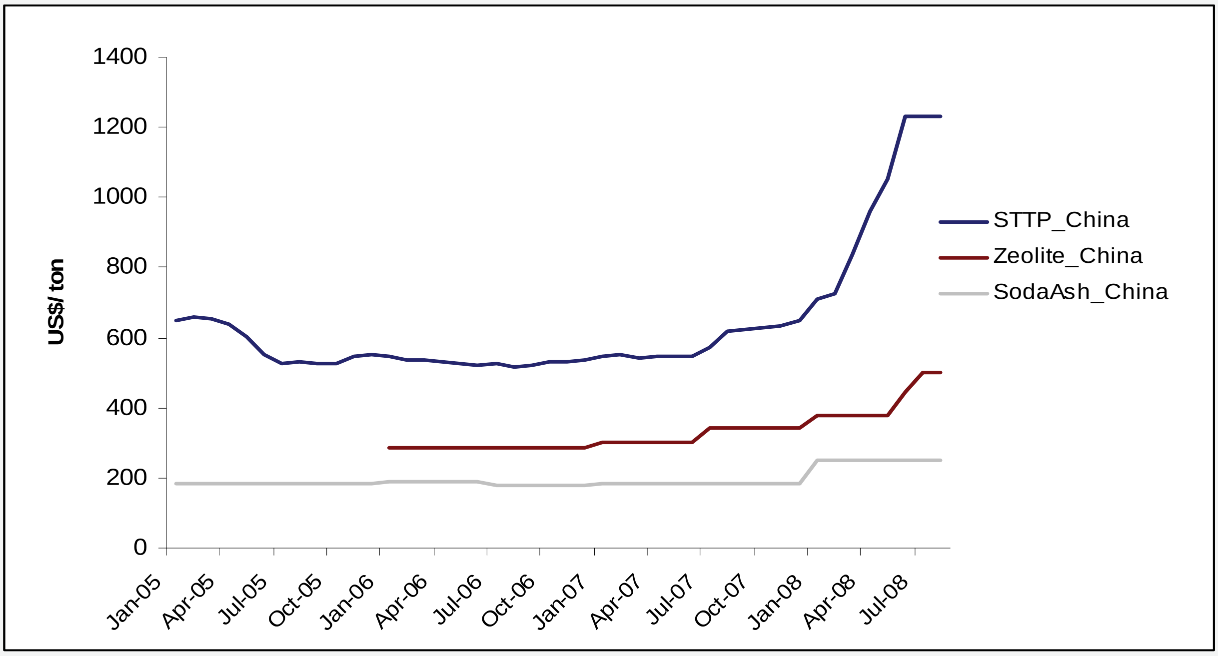

Figure 20: The price of STPP and its zeolite alternative (components) over time (Unilever)

Information box 1 above indicates the exponential rise in the cost of STPP over the last year. Regardless of the negative environmental impact of STPP, the price increase in itself makes seeking an STPP alternative a sensible option, which may not have been the case as recently as two years ago. This differential is also very likely to increase as phosphorus becomes increasingly scarce.

Data received from Unilever on the current cost differential between zeolite and STPP formulations of detergents shows that zeolite detergent formulations are on average fifty-eight Euros per ton cheaper than STPP formulations, mainly due to the sharp increase in the price of phosphate (based on data from the third quarter of 2008). Based on these market forces and international trends it is foreseen by manufacturers that, in the near future, STPP will most likely be substituted by zeolite in their laundry detergents (R. Plumbley – pers comm.). Currently, thirty-percent of phosphate-free detergents in Europe are zeolite-based (Fruijter-Pölloth, 2008).

In order to accommodate the change from phosphate detergents to zeolite detergents, detergent manufacturers will need to purchase new machinery and fund new production methods. In the case of Unilever, South Africa's largest detergent manufacturer, this capital investment is expected to amount to approximately 1.7 million Euros, which should be seen against the backdrop of a South African detergent market worth an estimated 350 million Euros. It is anticipated that this proportionally small cost will not affect the pricing of detergents at all, and will thus have no effect on consumers (R. Plumbley – pers comm.).

A further cost consideration of a switch to zero-phosphate detergents is the cost of marketing a product with a new look and feel. Advertising will need to be conducted in order to inform and acclimatise consumers to the new product. Though this is the case, it is felt there will be no need to re-brand the new detergents (i.e. remarket detergents under another name) and manufacturers will be able to use their current advertising budget to market zero-phosphate detergents under existing brand names (R. Plumbley pers comm.).

In summary, it is anticipated that there will be no difference in the shelf price of zero-phosphate detergents in comparison with the price of phosphate formulated detergents. Consumers thus will not have to spend any more on purchasing detergents if zero-phosphate detergents are legislated.

8.1.2 The effectiveness, practicality and safety of zero-phosphate detergents

The effectiveness of zero-phosphate detergents in relation to existing products is obviously crucial to the assessment of the costs and benefits of such a product. In the USA, a survey by the Consumers Union found that six out of the top ten detergents were in fact phosphate free detergents (Hartig et al., 1990). Manufacturers, who have evaluated the difference in efficacy locally and internationally, have shown and reported that zeolite formulated detergents have produced acceptable results for the last twenty years (R. Plumbley – Pers comm.). Additionally, it is anticipated that manufacturers will formulate zero-phosphate detergents such that consumer washing habits will in no way need to be altered, with the same dose achieving the same results.

In terms of the possible health effects of zeolite detergents on consumers, Fruijter-Pölloth (2008), found that zeolite would not affect consumers *via* inhalation or skin contact when using the detergent under normal conditions. Additionally, the study found that the chance of an individual experiencing a negative health impact as a result of exposure to zeolite residue on garments they are wearing was minimal. Overall, the study found zeolite detergents to be safe for consumers, if they are used as recommended.

8.1.3 The impact of zero-phosphate detergents on washing machines

It has been reported that zero-phosphate detergents may cause some precipitation in washing machines. In the long term, this can lead to the clogging of pipes and possible pump failure. This is dependent on a number of factors, such as the chemical composition of the water used and the concentration of the phosphate alternative in the detergent (Gouws, 2008).

However, from previous phosphate to zero-phosphate detergent conversion studies conducted internationally, it was found that zeolite detergents have a similar effect on washing machines to that of their phosphate counterparts. It is thus anticipated that there will be no extra wear and tear on washing machines as a result of zero-phosphate detergents being used (R. Plumbley – Pers comm.).

8.1.4 The effect of zero-phosphate detergents on garments

From previous studies on the impact of zero-phosphate detergents on clothing and fabric in Europe, it was found that phosphate-free detergents perform on par with their phosphate counterparts, and that there is no increased wear and tear on fabrics and clothes as a result of low phosphate detergents (R. Plumbley – Pers comm.).

This was confirmed in a confidential Unilever report on the impact of zero- phosphate detergents. In comparing zero-phosphate detergents to phosphate detergents it found that the two detergents performed on a par and no additional wear and tear was attributed to the alternative formulation (confidential report provided by Unilever).

It has however been suggested that there may be the possibility of some residue ("white specks") left on coloured garments as a result of zeolite detergents. This varies with the composition of the detergent, the amount and temperature of water used and the type of fabric (Fruijter-Pӧlloth, 2008). However this is reported as only being a problem when the detergent is used incorrectly and can easily be remedied by brushing the residue away, or rewashing the item of clothing. It may however represent a small negative cost to consumers in terms of time and expense associated with re-washing the garment.

8.1.5 Environmental costs and benefits associated with zero-phosphate detergents

The environmental effects of phosphate rich detergents have been alluded to throughout this report. This section provides a brief summary of their effects and the environmental impact of a switch to zero-phosphate detergents in order to introduce the subject in terms of the Cost Benefit Analysis.

It has already been noted that many WWTWs are inefficient in removing phosphates from waste water. Phosphates that are not removed are consequently discharged into the aquatic environment. Detergents used by people directly in rivers and dams in more rural areas also introduce a significant amount of phosphate into the environment in addition to that emanating from WWTWs. The obvious environmental benefit of zero-phosphate detergents would thus be to lower the amount of phosphate being introduced into sensitive aquatic environments.

The environmental impacts of elevated phosphate concentrations in water bodies are most commonly linked to water resource eutrophication or nutrient enrichment. Nutrient enrichment of water bodies is frequently associated with increased growth of algae, sometimes known as algal blooms. These growth events have several important impacts on the environment and those utilizing it.

Nutrient enriched water is often related to a shift towards dominance of the phytoplankton by blue-green algae (cyanobacteria) some of which are known to be extremely toxic (Smith et al., 1999). This threatens the health of people and livestock and limits the recreational and amenity value of a waterbody. Even without blooms of cyanobacteria, massive blooms of harmless green algae can be sufficient to significantly reduce the environmental services offered by the water body. Few people are willing to fish, boat, or swim in a 'pea soup' reservoir.

Algal blooms are also known to lower dissolved oxygen (DO) levels in water bodies. If sudden and severe enough, algal blooms can reduce DO concentrations sufficiently to result in the mass deaths of other aquatic biota, such as fish. Over a sustained period however, lower DO levels result in reductions in the levels of biodiversity that can be sustained by the waterbody (Correll, 1998).

Depending on lake conditions, a portion of the phosphates entering the lake are deposited on the floor of the lake and retained there. Anoxic or hypoxic conditions caused by algal growth can result in phosphates being released from the sediment layer, further increasing the water's phosphate load and exacerbating the problem (Correll, 1998).

It has been shown earlier in this report that a reduction in phosphate loading of waterbodies is likely to result in a reduction in algal growth. This will decrease the impact that algal growth has on the environment. This constitutes the bulk of the environmental **benefits** which would result from the introduction of zero-phosphate detergents.

Conversely, should zero-phosphate detergents be introduced, the resultant reduction in nutrients may result in some environmental **costs** such as a reduction in the bio-productivity of waterbodies. Anecdotal evidence suggests that reductions in nutrient loading have, in some cases, decreased fish populations in particular lakes and streams. This is however likely to be limited to specific situations.

8.2 Implications of zero-phosphate detergents for the waste discharge charge system (WDCS)

8.2.1 What is a WDCS?

According to the South African Department of Water Affairs and Forestry (DWAF), a WDCS is "… a framework for charging for the discharge of waste into water sources" (DWAF undated). It has been provided for in Section 56 of the National Water Act (36/1998), forming part of the Pricing Strategy for Water Use Charges (DWAF, 2003b). Many developed and developing countries have implemented a Waste Discharge Charge System (WDCS) with much success, such as Brazil, Canada, Colombia, India, Italy and France (DWAF undated:31).

A WDCS is grounded in the *polluter pays principle* (DWAF, 2000), whereby the creator of a negative externality has to cover the costs associated with that externality. This principle is efficient for two main reasons. Firstly, the *free-rider* problem is curbed (this is when a benefit is enjoyed by a certain party without having to pay for it (Black, Calitz & Steenkamp, 2005)). Secondly, pollution is reduced in the long run, as firms alter their waste production activities in order to reduce their costs of having to pay for pollution discharging (Goodstein, 2008).

This section studies the Department of Water Affair's rationale and intended application of a WDCS in South Africa, and also how the introduction of zero-phosphate detergents could impact this system, once it is implemented.

8.2.2 The aims of the WDCS

The goal of the WDCS is to reduce the overall volume of discharges to aquatic environments, and to internalise some of the costs associated with water discharges, such as environmental, social and economic costs (DWAF undated). It is a direct payment for the services rendered in using the water source, and covers the costs experienced by any other party downstream utilising the polluted water. It is not a tax, levy or duty, and dischargers will pay directly for their own pollutant emissions (DWAF, 2003b).

According to the document, *Development of a Waste Discharge Charge System* (DWAF, 2000), the WDCS has the following specific aims:

- To encourage sustainable and efficient use of water resources
- To encourage the internalising of environmental costs by those who cause environmental damage
- To cover some of the financial costs that are associated with the discharging of wastewater
- To act as an incentive for the efficient use of water sources and to minimise waste discharge.

With the introduction of a WDCS, certain activities can be encouraged, such as the abatement of pollution and the recycling of wastewater. Also, industries may be encouraged to recycle waste (such as certain nutrients, for example phosphorus) and return water to its original source. Overall water conservation will be incentivised through this system. (DWAF, 2003b)

8.2.3 The impact of zero-phosphate detergents on the WDCS

There are four main sectors that will be responsible in paying a waste discharge charge: the agricultural, mining, manufacturing and municipal sectors.

The agricultural sector contributes to phosphate pollution by using fertiliser which is very high in phosphates. It is thought though, that individually, farmers do not contribute significantly to the phosphate pollution of water resources due to the fact that fertiliser is expensive and farmers tend to be frugal with its application (Bekker – pers comm). It is also only applied when necessary (in general) and applying it when heavy rain is predicted (which will wash the fertiliser away before it has a chance to enter the ground) is avoided. The mining and manufacturing sectors are not considered to be significant phosphate polluters of water resources (Bekker – pers comm).

Without doubt, the sector that contributes the most to phosphate pollution is the municipal sector (Bekker – pers comm). This is reflected in the landuse export coefficients used earlier in the study which estimated 'urban residential' as the highest phosphate exporting landuse (see appendix 1). The growing number of housing developments and increasing levels of sanitation provision have put municipal WWTWs under immense pressure in trying to keep up with the increased volumes of sewage influent. An indicator of this problem is that many WWTWs are currently unable to meet the 1 mg/ℓ phosphate concentration standard in their treated effluent (Freese, 2008). This is largely due to WWTWs being undercapacitated, outdated or through poor management (Bekker, 2008). Taking the above into account, the municipal sector will be focused on as the most significant phosphorus polluter.

8.2.4 WDCS scenarios

Since the WDCS has not yet been implemented, there is no data against which the impact of the introduction of zero-phosphate detergents on the WDCS can be evaluated. Therefore, this impact is evaluated using policy evaluation of three scenarios, namely:

- Scenario 1: Phosphate detergents remain on the market
- Scenario 2: Zero-phosphate detergents are introduced and the impact this will have on:
    - municipalities from a WDCS perspective
    - other phosphate polluters

Scenario 1: Phosphate detergents remain on the market

In the case that zero-phosphate detergents are not introduced, the problem of eutrophication will still need to be addressed. The costs of this may partially be covered by the WDCS. The revenue raised through the WDCS from phosphate pollution may be used towards activities which may help reduce eutrophication, since, in addition to the primary aim of discouraging pollution, a further aim of the WDCS is to use the funds generated to address water quality related issues (Machaba, 2008).

Investment in WWTWs regarding their ability to remove phosphorus and perhaps the development of new WWTWs may be necessary (DWAF, 2008). A significant step in addressing the eutrophication problem would be to identify the WWTWs that are not meeting the phosphorus discharge standard of 1 mg/ℓitre. These WWTWs could then be targeted with investment in new technologies, or improving existing methods (Dr von der Heyden – pers comm.). Similarly, investment in WTWs may be necessary to improve algal removal.

Scenario 2: Zero-phosphate detergents are introduced.

Municipalities

The introduction of zero-phosphate detergents and the related economy-wide costs that are borne by consumers may be seen as an extension of the *polluter pays principle* (Van der Westhuizen, 2008). In other words, the costs of eutrophication which were previously borne by the environment will be shifted to phosphorus polluters (households).

The direct impact of the introduction of zero-phosphate detergents on the WDCS would be a reduction in the revenue of DWAF received from the waste discharge charges levied on municipalities. However, the aim of the WDCS is not to generate revenue for DWAF, but its primary role is to discourage pollution and to enforce the management of water resources. If the phosphate discharge from WWTWs were to be reduced, this aim will have been partially achieved, and there will be no change in the way charges are levied to municipal WWTWs despite the reduction in monies received (Machaba, pers comm).

The approach of DWAF regarding the WDCS is that the system is built on a set of principles which are not meant to be variable. The impact of phosphate-free detergents on the WDCS will be at an operational level only, in other words, WWTWs will be paying lower charge fees (von der Heyden – pers comm).

It has been determined that detergents contribute approximately 32% of the total phosphorus in domestic sewage. If detergent phosphates were to be removed from the influent at WWTW facilities, and if the effluent concentration of phosphorus were consequently to be reduced, it can be assumed that municipalities will benefit from paying lower waste discharge charges. The expected charge for a phosphorus discharge is R1.35 per cubic meter of water discharged (2009 rate).

Other phosphorus polluters

According to DWAF, the WDCS will not change its approach to the principal phosphorus polluters if zero-phosphate detergents were to be introduced. The WDCS will still continue to charge any particular polluter for phosphate pollution at the same rate as is established, in order to discourage any form of phosphate pollution. The charge will thus remain the same for other phosphorus polluters regardless of the decision as to whether or not to introduce zero-phosphate detergents (Machaba, pers comm.).

Importantly, industries have expressed a desire to see the revenue from the WDCS “ring-fenced”, i.e. specifically set aside for water quality management.

8.3 Assessment of the costs and benefits associated with the introduction of zero-phosphate detergents

8.3.1 Aims

The aim of this section of the study was to determine the economic impact of the introduction of zero-phosphate detergents if they were to become legislated in South Africa. The following areas received focus:

- consumers,
- detergent manufacturers,
- water treatment works,
- wastewater treatment works
- the environment and
- the Waste Discharge Charge System.

8.3.2 Approach

A qualitative assessment of potential costs and benefits in the sectors listed above was carried out by scoring particular issues which may have positive or negative impacts on the sector under review. Issues were identified based on information and data obtained from various parties, most importantly, from the preceding chapters of this report, DWAF and various detergent manufacturers (predominantly Unilever).

Using evidence from these sources, issues were weighted according to their importance in the context of the sector being assessed, with weighting scores ranging between 1 (unimportant) and 5 (very important). The impact that zero-phosphate detergents would have on the issue was indicated by a positive or negative score. Impact scores ranged between a strong negative (-2) and a strong positive impact (+2). The weighting and impact scores were then multiplied to arrive at a cost benefit product for each issue. These have been used to draw conclusions.

8.3.3 Results

Table 52 below presents the qualitative cost benefit analysis based on issues that were identified in this study per sector. The Product of each issue (right hand column) represents the Weighting score multiplied by the Impact score. The weighting and impact scores used in Table 52 are keyed as follows:

Weighting		*Impact*	
1	*Unimportant*	*-2*	*A strong negative impact*
2	*Of Slight Importance*	*-1*	*Negative impact*
3	*Moderately Important*	*0*	*No impact*
4	*Important*	*1*	*Positive impact*
5	*Very Important*	*2*	*A strong positive impact*

Table 52: Weighted combined qualitative and quantitative evaluation of the introduction of zero-phosphate detergents

The Environment (see chapters 2, 5 & 6)					
ISSUE	WEIGHT	REASON	IMPACT	REASON	PRODUCT
Environmental impact of the toxicity level of zeolite	5	The impact on the environment is the major issues in introducing low-phosphate detergents.	0	International literature review has not revealed any reports of negative impacts caused by existing products, however, according to the Helsinki Commission (2003) its toxicity is regarded as 'unknown'.	0
Reduced eutrophication due to reduced phosphorus levels / cleaner water resources	5	It is the aim of introducing zero-phosphate detergents. Clean water is a necessity.	2	Strong positive impact of zero-phosphate detergents.	10
Aesthetic quality of water resources	3	Impacts tourism, recreation and property prices.	1	Small positive impact of zero-phosphate detergents.	3
Improved health of humans and animals	5	Affects health and livelihoods of individuals and communities.	1	Small positive impact of zero-phosphate detergents.	5
Depleting stock of phosphorus	3	Phosphorus is a scare resource which is necessary to many other industries.	1	Phosphorus stocks are depleting rapidly.	3
Recreation	3	Affects activities such as fishing, boating and swimming, as well as tourism.	1	Positive impact of zero-phosphate detergents in reducing eutrophication.	3
Reduction in loss of biodiversity associated with phosphate	3	Too much phosphate in water bodies inhibits the growth of many species.	1	The positive impact of zero-phosphate detergents on amount of phosphates in water bodies.	3
Lower fish production in rivers and lakes	3	High levels of phosphate are required for certain fish species.	0	The impact of zero-phosphate detergents is likely to be highly site-specific and isolated.	0
SUM PRODUCT					**27**
RANGE					**(-80;80)**
CONCLUSION: The introduction of zero-phosphate detergents will have a net positive impact on the environment					

Water Treatment Works (See chapter 7)					
ISSUE	**WEIGHT**	**REASON**	**IMPACT**	**REASON**	**PRODUCT**
Water treatment cost savings	4	Less infrastructure and fewer chemicals may be required for treatment of water.	1	There will be cost-savings at certain WTW's.	4
Fewer occurrences of filter blockage	3	Filter blockages affect operational efficiency of WTWs.	1	Improved water quality will decrease the chance of filter blockages.	3
SUM PRODUCT					**7**
RANGE					**(-20:20)**
CONCLUSION: The introduction of zero-phosphate detergents will have a net positive impact on water treatment works					

Wastewater Treatment Works (see chapters 3 & 4)					
ISSUE	**WEIGHT**	**REASON**	**IMPACT**	**REASON**	**PRODUCT**
Inability to recycle zeolite	4	Affects operational costs of WWTWs.	-1	Zeolite cannot be recycled and therefore will have to be removed and transported.	-4
Need for fewer chemicals	4	Affects operational costs of WWTWs.	1	The need for aluminium sulphate may be reduced at certain facilities if they continue to target the 1 mg/ℓ standard.	4
Ability to meet discharge limits	3	May reduce WDCS fees.	1	May be easier to meet the 1 mg/ℓ limit for phosphorus, due to reduced loads.	3
Loss of potential to recycle phosphate rich sludge for fertiliser	1	In some WWTWs, the sludge is recycled as fertiliser.	-1	Due to phosphate loads to WWTWs being reduced, the sludge will be less phosphate-rich.	-1
Loss of nutrients feeding the WWTW treatment process	1	Bacteria are used in the wastewater treatment process, which feed on phosphates.	0	Unlikely, as there are other sources of phosphates.	0
SUM PRODUCT					**2**
RANGE					**(-50;50)**
CONCLUSION: The introduction of zero-phosphate detergents will have no net impact on wastewater treatment works					

Consumers (see chapter 8)					
ISSUE	**WEIGHT**	**REASON**	**IMPACT**	**REASON**	**PRODUCT**
Price of new detergent	5	Affects income of consumers.	0	The price of zeolite detergent will be the same as the price of phosphate detergent.	0
Effectiveness of detergent	4	Affects consumer satisfaction when using the detergent.	0	Zeolite detergents perform on par with phosphate detergents.	0
Spotting of clothing	4	Impacts income and can be a nuisance to consumers.	-1	Unlikely to happen, but will have a negative impact in situations where it does occur.	-4
Damage to washing machines	4	Impact on life-span and running costs of washing machines.	0	Zeolite detergents have a similar effect as phosphate detergents.	0
Limited consumer choice if legislated	2	Affects consumer satisfaction.	-1	Consumers will only be able to use zero-phosphate washing powders, but may also opt to use laundry bars.	-2
Health impacts of zeolite	5	Health of users of detergent is a highly important issue.	0	Fruijter-Pölloth (2008) found zeolite detergents to be safe for consumers.	0
Increasing price of phosphorus	5	Impact on income of consumers purchasing phosphate detergents.	1	The increasing scarcity of phosphorus may push up the price of phosphate detergents.	5
SUM PRODUCT					**-1**
RANGE					**(-70;70)**
CONCLUSION: The introduction of zero-phosphate detergents will have no net impact on consumers					

Detergent industry					
ISSUE	**WEIGHT**	**REASON**	**IMPACT**	**REASON**	**PRODUCT**
Cost of zeolite versus cost of phosphate	5	Affects variable costs of manufacturers.	2	The price of phosphate is higher than zeolite and this difference is increasing.	10
Plant upgrading	3	Affects fixed costs/ need for investment.	-1	For example: Unilever will need to invest 1.7 million Euro's to upgrade plants.	-3
Re-branding / marketing	4	Affects advertising/ marketing budget.	0	The industry's current advertising budget will be used.	0
Impact on sales	2	The perception that the old detergents have been lost may affect sales.	-1	Consumers may be resistant to zeolite detergents as it may looks and feel different to phosphate detergents.	-2
SUM PRODUCT					**5**
RANGE					**(-40;40)**
CONCLUSION: The introduction of zero-phosphate detergents will have a <u>negligible net positive impact</u> on the detergent industry					

Waste discharge charge system (WDCS)					
ISSUE	**WEIGHT**	**REASON**	**IMPACT**	**REASON**	**PRODUCT**
Decline in fees collected and thus revenue	1	Revenue is not a concern of the WDCS.	0	Increasing revenue is not one of the aims of the WDCS.	0
Simplification of regulatory system	2	Reducing "red-tape" is beneficial as it reduces the costs of adhering to regulation.	0	The WDCS will not be altered.	0
SUM PRODUCT					**0**
RANGE					**(-20;20)**
CONCLUSION: The introduction of zero-phosphate detergents will have <u>no net impact</u> on the WDCS					

8.4 Conclusion

The monetary value of some of the costs and benefits of zero-phosphate detergents are potentially calculable, but there are many others to which monetary value cannot easily be attached, or which may only be fully realised in the years after zero-phosphate detergents are introduced. For this reason, a qualitative assessment of issues within sectors has proved to be the most appropriate approach. The sums of the cost benefit products within each sector (see Table 52) provide an indication of the overall impact of zero-phosphate detergents per sector.

Values close to zero (zero represents neither positive nor negative impact value) indicates negligible impacts, or indifference in the opinion of the party concerned. Values further away from zero indicate more significant impacts, either positive or negative. The number of issues considered for each sector influences the range of possible values, and a percentage value has thus been calculated to facilitate comparison of scores.

Positive impact values were derived for the following sectors.

- **The Environment** (+27/80 or +40%). This positive value has been generated largely through the findings that the removal of detergent phosphate will result in a significant reduction in phosphorus loading of rivers and dams. This in turn has been shown to result in a significant reduction in eutrophication and algal growth. This reduction is anticipated to have benefits for biodiversity conservation, aesthetic and amenity value of water bodies and human and livestock health.
- **WTWs** (+7/20 or +35%), it is anticipated, will benefit by being required to spend less on purification chemicals, and by experiencing fewer filter blockages as a result of lower levels of algal growth. They will therefore experience greater operational efficiency.
- **Detergent manufacturers** (+5/40 or +12.5%) will experience a minor benefit by eliminating the rising cost of phosphate from their production expenses.

Negligible impacts were determined for the following sectors.

- **WWTWs** (+2/50 or +0.04%) will experience a benefit where the reduced phosphate load may result in less expenditure on treatment chemicals at certain facilities and a reduction in charges paid according to the WDCS, but this will be largely negated by the fact that non-recyclable zeolite may produce greater volumes of sludge which will need to be disposed of.
- **Consumers** (-1/70 or -0.01%) will experience a benefit where the use of phosphate alternatives will eliminate the increase in cost of detergents that is likely to occur due to rising phosphate costs. However, that is negated by the possibility of residue/spotting occurring on clothing and a limitation of product choice in the event that phosphate rich detergents are banned.
- **WDCS** (0) will see neither benefit nor cost, since a reduction in phosphate pollution is seen as the achievement of a goal, and thus will not affect the charging system at any level.

Based on the results outlined above, it is concluded that, on the whole, the introduction of zero-phosphate detergents is likely to have a **net beneficial effect**.

Chapter 8: Findings summary

1. The costs associated with the manufacture of phosphate containing detergents are increasing due to increasing scarcity of, and increasing demand for, phosphate. This has had the effect of nullifying the differential in the cost of manufacture of phosphate detergents and zero-phosphate detergents. In the shop, zero-phosphate detergents will cost the same as, or will be cheaper than phosphate detergents.
2. Costs previously associated with zero-phosphate detergents causing damage to washing machines and fabrics have been shown to be essentially nil.
3. Negative costs attributed to a switch to zero-phosphate detergents are associated with:
   - The inability to recycle zeolite, and its consequent transport and disposal
   - The capital expenditure of manufacturers that will be required to adapt the manufacturing process
   - The limitation of the consumer's choice of products
4. Positive benefits attributed to a switch to zero-phosphate detergents are associated with:
   - Better water quality as a result of reduced eutrophication and potential cost savings at WTWs.
   - Reduced influent phosphate loading at WWTWs means that either effluent concentration is reduced or treatment cost savings are realised.
   - Increased opportunity for water based recreation due to better water quality
   - Reduced reliance on a dwindling resource.
   - Increasing cost of phosphate means zero-phosphate detergents will be cheaper than phosphate detergents in the future.
5. Overall, a shift to zero-phosphate detergents is qualitatively seen as being **beneficial** and is recommended by the cost benefit analysis. The scores calculated per sector are as follows:
   - The Environment = **+27** (range of -80 to +80 or **+34%**),
   - WTWs = **+7** (range of -20 to +20 or **+35%**) and
   - Manufacturers = **+5** (range of -40 to +40 or **+12.5%**).
   - WWTWs = **+2** (range of -50 to +50 or **+0.04%**),
   - Consumers = **-1** (range of -70 to +70 or **-0.01%**) and
   - The WDCS = **0** (range of -20 to +20).

9. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Limiting the use of phosphates in detergents is a popular method of combating rising levels of nutrients in water resources around the world. A review of local and international literature has shown that countries or regions in which the eutrophication of water resources is a problem, have in many cases at least partially remediated the problem through either legislated or voluntary limiting of phosphates in detergents. This approach to reducing phosphorus in effluent has gained popularity in both Europe and the USA and has set a strong precedent which countries and regions with limited water resources are likely to follow.

Because zero-phosphate detergents have been in use for a reasonable length of time now (internationally), this study has been able to gain insight into the costs and benefits associated with them that were not available to prior studies that have been reviewed. Significantly, it has been shown that if correctly formulated and correctly used, zero-phosphate detergents can perform just as well as phosphate containing detergents, and are no more likely to cause damage to washing machines or fabrics than their phosphate rich counterparts. This fact has shed new light on the findings of previous studies which had asserted that the switch to zero-phosphate detergents is more costly than beneficial, a conclusion which was based mostly on these costs.

There can be little argument concerning the impact phosphates have on the water resources in South Africa, and given that a large proportion of WWTWs are struggling to meet even the relatively lenient 1 mg/ℓ effluent phosphate concentration limit, a 15-50% (depending on the make-up of waste water) reduction in SRP loading at WWTWs is considered extremely significant. This is especially true in small WWTWs where phosphate removal is generally inefficient. This reduction would not only go a long way to assist WWTWs in achieving effluent concentration targets, but it would also help alleviate the problems created by the overflow of WWTWs during heavy rains or because of equipment failure, and the use of detergents in water bodies in rural settings where detergent phosphates are introduced directly into water courses.

In addition to the impacts on WWTWs, the indications are that as much as 35% of dam TP loading (such as is the case at Inanda) could be eliminated through the removal of detergent phosphorus, resulting in an estimated reduction in algal growth of up to 30%. In dams where algal growth is resulting in significant costs (such as reductions in biodiversity, loss in dam-side property values, increased water treatment costs and loss of recreational amenity value) a reduction of this nature must be regarded as important.

It should also be noted that the predictive results of this study are considered conservative estimates, based on the fact that Darvill WWTW was used as a case study and represents a reasonably efficient phosphate removal facility. The effluent of many other WWTWs would show considerably higher phosphate loading values.

According to South African manufacturers, some products on the market are already phosphate free (C. de Lange pers comm.). This has introduced the concept of zero-phosphate detergents to the South African market place. Based on international trends, Unilever (South Africa's largest manufacturer) has already prepared itself for a change to zero-phosphate detergents, and they feel that if the decision were taken to move to phosphate free detergents, it would take them as little as 3-5 years to adapt their process (H. Boolah – Pers comm and R. Plumbley pers comm). These facts, when seen against the backdrop of the exponential increase in the cost of phosphate, can be seen as an indication of the willingness of manufacturers to move away from phosphate rich detergents.

Finally, it is important to note that the environmental benefits of eliminating phosphate from detergents will only be fully realised if the resulting reduction in WWTWs' influent phosphate loading is translated into a reduction in their effluent loading. This will not necessarily occur at efficient facilities (where the 1 mg/ℓ standard is routinely achieved) if they merely enjoy the reduction in treatment costs that would accompany a reduced phosphate loading and continue to target the 1 mg/ℓ effluent concentration standard.

However, in the cases of those WWTWs where the 1 mg/ℓ standard is currently not being attained, the benefit will indeed be transferred to the downstream environment in addition to the facility being better able to comply with the legal standard. Of note is that there are increasing pressures to review the philosophy of the 1 mg/ℓ standard and to reduce this target, which would be eased by the reduction in loading of phosphorus due to the introduction of zero-phosphate detergents.

Based on the arguments developed through this report and summarized in this section, the following recommendations have been made:

Recommendations

1. The **elimination of phosphorus from detergents is both beneficial and desirable**, and it is thus recommended that the replacement of phosphate containing detergents with zero-phosphate alternatives should be carried out as soon as is feasible.

2. It is also the recommendation of this study that negotiations be entered into between the DWA and detergent manufacturers to **establish a mutually agreeable process for this transition to be achieved**.

3. Although it is recommended that this process be approached in a co-operative manner that **allows manufacturers to take a leading role** (and thus achieve a maximum benefit from the process through marketing and public relations exercises), it is important that **the change to zero-phosphate detergents be consolidated through legislation**. This would mean that, should a change in world markets result in phosphate rich detergents once again providing a competitive advantage, that the possibility of manufacturers returning to them is negated.

4. It is also recommended that the efficacy and implementation of **the 1 mg/ℓ phosphate effluent standard be reviewed**. This is specifically important given the predicted reductions in influent phosphate loading at WWTWs that will result from the elimination of detergent phosphate, and the importance of transferring that benefit to downstream aquatic environments.

10. REFERENCES

Please note: Personal communications and online resources are listed separately at the end of this section.

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11. APPENDICES

Appendix 1 – Landuse Phosphorus Export Coefficients

Export coefficients were extracted from literature sources and collated in order to establish a full set of coefficients to match the CSIR landuse categories. The “Urban residential” coefficient was calculated by combining data from Darvill WWTW with a surface runoff value drawn from literature.

Landuse Type	Harding (2008) (kg/Ha/Yr)	Pegram and Gorgens (kg/Ha/Yr) **Max**	Pegram and Gorgens (kg/Ha/Yr) **Min**	Pegram and Gorgens (kg/Ha/Yr) **Med**	Hoffman 1995 (kg/Ha/Yr)	Enongene & Rossouw kg/Ha/Yr) (2007)	Simpson kg/Ha/Yr) (combined)	Project Case Studies	Cullis Gorgens and Rossouw (2005)	**Composite** kg/Ha/Yr)
cultivated: permanent -commercial dryland	0.1	8	0.2	4.1			0.085		0.01	0.1
cultivated: permanent -commercial irrigated	1.2	8	0.2	4.1			0.085		0.12	1.2
cultivated: permanent -commercial sugarcane	1.2	8	0.2	4.1			0.085		0.12	0.12
cultivated: temporary - commercial dryland	0.1	8	0.2	4.1			0.085		0.01	0.08
cultivated: temporary - commercial irrigated	1.2	8	0.2	4.1			0.085		0.01	1.2
cultivated: temporary - semi-commercial/subsistence dryland	0.1	0.45	0.45	0.45	0.83			0.07		0.1
Degraded -forest and woodland	0.1	0.8	0.02	0.41		0.02				0.02
Degraded -shrubland and low Fynbos	0.02	0.8	0.02	0.41		0.08				0.08
Degraded -thicket and bushland	0.02	0.8	0.02	0.41						0.02
Degraded -unimproved grassland	0.1	0.8	0.02	0.41		0.013				0.1
Forest	0.1	0.8	0.02	0.41		0.02				0.02
Forest and woodland	0.1	0.8	0.02	0.41		0.02				0.02
Forest plantations	0.1	0.8	0.02	0.41		0.02				0.02
Herbland	0.02	0.8	0.02	0.41						0.02
Improved grassland	0.1	0.7	0.1	0.4						0.1
Mines and quarries	0.8	0.8	0	0.4						0.8
Shrubland and low Fynbos	0.02	0.8	0.02	0.41		0.08				0.08
Thicket and bushland, etc.	0.02	0.8	0.02	0.41						0.02
Unimproved grassland	0.1	0.1	0.02	0.06		0.013				0.1
Urban - commercial	0.8	0.9	0.1	0.5	0.25		1.7			1.7
Urban - industrial/transport	0.8	4.1	0.9	2.5	0.25		2.7			2.7
Urban - residential	2.5	1.3	0.4	0.85	2.34		0.6	5.0		5.0
Urban - smallholdings - bushland	0.1	0.1	0.4	0.25						0.1
Urban - smallholdings - grassland	0.1	0.1	0.4	0.25						0.1
Urban - smallholdings - woodland	0.1	0.1	0.4	0.25						0.1
Urban - smallholdings - shrubland	0.1	0.1	0.4	0.25						0.1
Waterbodies	0	0	0	0	0	0	0	0	0	0
Wetlands	0	0	0	0	0	0	0	0	0	0
Dongas	0	0	0	0	0	0	0	0	0	0
Barren rock	0	0	0	0	0	0	0	0	0	0

Appendix 2 – Individual Catchment Phosphorus export calculations

	P Export Coefficient	Albert Falls			
Landuse	**kg/Ha/Yr**	**Area (Ha)**	**%**	**Export**	**%**
cultivated: permanent -commercial dryland	0.1			0.00	0.00
cultivated: permanent -commercial irrigated	1.2	110.67	0.15	132.80	1.43
cultivated: permanent -commercial sugarcane	0.12	126.91	0.17	15.23	0.16
cultivated: temporary - commercial dryland	0.08	4817.76	6.63	385.42	4.14
cultivated: temporary - commercial irrigated	1.2	90.23	0.12	108.28	1.16
cultivated: temporary - semi-commercial/subsistence dryland	0.1	74.70	0.10	7.47	0.08
Degraded -forest and woodland	0.02			0.00	0.00
Degraded -shrubland and low Fynbos	0.08			0.00	0.00
Degraded -thicket and bushland	0.02			0.00	0.00
Degraded -unimproved grassland	0.1			0.00	0.00
Forest	0.02	3323.47	4.57	66.47	0.71
Forest and woodland	0.02			0.00	0.00
Forest plantations	0.02	27166.50	37.37	543.33	5.84
Herbland	0.02			0.00	0.00
Improved grassland	0.1	2093.65	2.88	209.37	2.25
Mines and quarries	0.8			0.00	0.00
Shrubland and low Fynbos	0.08			0.00	0.00
Thicket and bushland, etc.	0.02	5919.40	8.14	118.39	1.27
Unimproved grassland	0.1	25559.16	35.16	2555.92	27.47
Urban - commercial	1.7	110.94	0.15	188.60	2.03
Urban - industrial/transport	2.7			0.00	0.00
Urban - residential	5	988.27	1.36	4941.35	53.12
Urban - smallholdings - bushland	0.1	302.09	0.42	30.21	0.32
Urban - smallholdings - grassland	0.1			0.00	0.00
Urban - smallholdings - woodland	0.1			0.00	0.00
Urban - smallholdings - shrubland	0.1			0.00	0.00
Waterbodies	0	2017.57	2.78	0.00	0.00
Wetlands	0			0.00	0.00
Dongas	0			0.00	0.00
Barren rock	0			0.00	0.00
	Total	72701.32	100.00	9302.8	100.0
Urban residential detergent contribution (kg)				1625.7	
Rural settlement detergent contribution (kg)				1.7	
Total detergent contribution (kg)				1627.4	
Percentage of total phosphorus export is detergent P (%)				**17.5**	

	P Export Coefficient	Allemanskraal			
Landuse	**kg/Ha/Yr**	**Area (Ha)**	**%**	**Export**	**%**
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	153660.75	42.30	12292.9	35.0
cultivated: temporary - commercial irrigated	1.2	221.29	0.06	265.5	0.8
cultivated: temporary - semi-commercial/subsistence dryland	0.1			0.0	0.0
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1	4756.45	1.31	475.6	1.4
Forest	0.02			0.0	0.0
Forest and woodland	0.02	212.53	0.06	4.3	0.0
Forest plantations	0.02	84.44	0.02	1.7	0.0
Herbland	0.02			0.0	0.0
Improved grassland	0.1			0.0	0.0
Mines and quarries	0.8			0.0	0.0
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	10409.97	2.87	208.2	0.6
Unimproved grassland	0.1	181483.69	49.96	18148.4	51.7
Urban - commercial	1.7			0.0	0.0
Urban - industrial/transport	2.7			0.0	0.0
Urban - residential	5	737.04	0.20	3685.2	10.5
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	1845.45	0.51	0.0	0.0
Wetlands	0	1505.82	0.41	0.0	0.0
Dongas	0	7850.21	2.16	0.0	0.0
Barren rock	0	485.01	0.13	0.0	0.0
	Total	363252.65	99.99	35081.8	100.0
Urban residential detergent contribution (kg)				1212.4	
Rural settlement detergent contribution (kg)				0.0	
Total detergent contribution (kg)				1212.4	
Percentage of total phosphorus export is detergent P (%)				**3.5**	

Landuse	P Export Coefficient kg/Ha/Yr	Bloemhof Area (Ha)	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12	8.97	0.00	1.1	0.0
cultivated: temporary - commercial dryland	0.08	2383514.36	41.23	190681.1	16.5
cultivated: temporary - commercial irrigated	1.2	25476.69	0.44	30572.0	2.6
cultivated: temporary - semi-commercial/subsistence dryland	0.1	397.93	0.01	39.8	0.0
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02	604.62	0.01	12.1	0.0
Degraded -unimproved grassland	0.1	4980.69	0.09	498.1	0.0
Forest	0.02	84.71	0.00	1.7	0.0
Forest and woodland	0.02	50210.60	0.87	1004.2	0.1
Forest plantations	0.02	12371.47	0.21	247.4	0.0
Herbland	0.02			0.0	0.0
Improved grassland	0.1	5625.89	0.10	562.6	0.0
Mines and quarries	0.8	51656.84	0.89	41325.5	3.6
Shrubland and low Fynbos	0.08	31.39	0.00	2.5	0.0
Thicket and bushland, etc.	0.02	199609.24	3.45	3992.2	0.3
Unimproved grassland	0.1	2796981.63	48.38	279698.2	24.2
Urban - commercial	1.7	8996.27	0.16	15293.7	1.3
Urban - industrial/transport	2.7	19632.40	0.34	53007.5	4.6
Urban - residential	5	106879.51	1.85	534397.6	46.2
Urban - smallholdings - bushland	0.1	217.35	0.00	21.7	0.0
Urban - smallholdings - grassland	0.1	54374.75	0.94	5437.5	0.5
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	16964.97	0.29	0.0	0.0
Wetlands	0	41150.19	0.71	0.0	0.0
Dongas	0	60.32	0.00	0.0	0.0
Barren rock	0	1197.27	0.02	0.0	0.0
	Total	5781028.06	99.99	1156796.4	100.0
Urban residential detergent contribution (kg)				175816.8	
Rural settlement detergent contribution (kg)				9.0	
Total detergent contribution (kg)				175825.8	
Percentage of total phosphorus export is detergent P (%)				**15.2**	

Landuse	P Export Coefficient kg/Ha/Yr	Bronkhorstspruit Area (Ha)	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	64052.41	50.83	5124.2	34.9
cultivated: temporary - commercial irrigated	1.2	572.36	0.45	686.8	4.7
cultivated: temporary - semi-commercial/subsistence dryland	0.1			0.0	0.0
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08	18.67	0.01	1.5	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02			0.0	0.0
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	1327.82	1.05	26.6	0.2
Herbland	0.02			0.0	0.0
Improved grassland	0.1	57.63	0.05	5.8	0.0
Mines and quarries	0.8	222.81	0.18	178.2	1.2
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	492.81	0.39	9.9	0.1
Unimproved grassland	0.1	54329.85	43.11	5433.0	37.0
Urban - commercial	1.7	38.45	0.03	65.4	0.4
Urban - industrial/transport	2.7	200.88	0.16	542.4	3.7
Urban - residential	5	469.13	0.37	2345.7	16.0
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1	2586.25	2.05	258.6	1.8
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	753.44	0.60	0.0	0.0
Wetlands	0	902.57	0.72	0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	126025.08	100.00	14677.9	100.0
Urban residential detergent contribution (kg)				771.7	
Rural settlement detergent contribution (kg)				0.0	
Total detergent contribution (kg)				771.7	
Percentage of total phosphorus export is detergent P (%)				**5.3**	

Landuse	P Export Coefficient kg/Ha/Yr	Erfenis Area (Ha)	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	131397.25	27.77	10511.8	21.9
cultivated: temporary - commercial irrigated	1.2	186.38	0.04	223.7	0.5
cultivated: temporary - semi-commercial/subsistence dryland	0.1	1336.57	0.28	133.7	0.3
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1	9537.51	2.02	953.8	2.0
Forest	0.02			0.0	0.0
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	59.95	0.01	1.2	0.0
Herbland	0.02			0.0	0.0
Improved grassland	0.1			0.0	0.0
Mines and quarries	0.8			0.0	0.0
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	31687.49	6.70	633.7	1.3
Unimproved grassland	0.1	290791.41	61.46	29079.1	60.6
Urban - commercial	1.7			0.0	0.0
Urban - industrial/transport	2.7			0.0	0.0
Urban - residential	5	1283.14	0.27	6415.7	13.4
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	2413.18	0.51	0.0	0.0
Wetlands	0	1168.86	0.25	0.0	0.0
Dongas	0	2240.84	0.47	0.0	0.0
Barren rock	0	1056.52	0.22	0.0	0.0
	Total	473159.10	100.00	47952.6	100.0
Urban residential detergent contribution (kg)				2110.8	
Rural settlement detergent contribution (kg)				30.3	
Total detergent contribution (kg)				2141.1	
Percentage of total phosphorus export is detergent P (%)				**4.5**	

	P Export Coefficient	Grootdraai			
Landuse	**kg/Ha/Yr**	**Area (Ha)**	**%**	**Export**	**%**
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	214700.82	26.93	17176.1	16.9
cultivated: temporary - commercial irrigated	1.2	558.55	0.07	670.3	0.7
cultivated: temporary - semi-commercial/subsistence dryland	0.1	2305.41	0.29	230.5	0.2
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02			0.0	0.0
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	3155.12	0.40	63.1	0.1
Herbland	0.02			0.0	0.0
Improved grassland	0.1	201.35	0.03	20.1	0.0
Mines and quarries	0.8	1588.86	0.20	1271.1	1.3
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	1644.66	0.21	32.9	0.0
Unimproved grassland	0.1	561153.19	70.38	56115.3	55.3
Urban - commercial	1.7	96.94	0.01	164.8	0.2
Urban - industrial/transport	2.7	1012.35	0.13	2733.3	2.7
Urban - residential	5	4600.74	0.58	23003.7	22.7
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	5197.96	0.65	0.0	0.0
Wetlands	0	1082.51	0.14	0.0	0.0
Dongas	0	16.19	0.00	0.0	0.0
Barren rock	0			0.0	0.0
	Total	797314.65	100.02	101481.2	100.0
Urban residential detergent contribution (kg)				7568.2	
Rural settlement detergent contribution (kg)				52.3	
Total detergent contribution (kg)				7620.6	
Percentage of total phosphorus export is detergent P (%)				**7.5**	

Landuse	P Export Coefficient kg/Ha/Yr	Hartbeespoort Area (Ha)	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2	87.38	0.02	104.9	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	64794.76	15.77	5183.6	1.6
cultivated: temporary - commercial irrigated	1.2	5272.76	1.28	6327.3	2.0
cultivated: temporary - semi-commercial/subsistence dryland	0.1			0.0	0.0
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02			0.0	0.0
Forest and woodland	0.02	41958.25	10.21	839.2	0.3
Forest plantations	0.02	5218.91	1.27	104.4	0.0
Herbland	0.02			0.0	0.0
Improved grassland	0.1	4072.56	0.99	407.3	0.1
Mines and quarries	0.8	3038.22	0.74	2430.6	0.8
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	35974.09	8.75	719.5	0.2
Unimproved grassland	0.1	124895.49	30.39	12489.5	3.9
Urban - commercial	1.7	4097.43	1.00	6965.6	2.2
Urban - industrial/transport	2.7	2230.36	0.54	6022.0	1.9
Urban - residential	5	54723.87	13.32	273619.4	85.1
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1	54037.76	13.15	5403.8	1.7
Urban - smallholdings - woodland	0.1	8048.06	1.96	804.8	0.3
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	2026.28	0.49	0.0	0.0
Wetlands	0	496.30	0.12	0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	410972.48	100.00	321421.7	100.0
Urban residential detergent contribution (kg)				90020.8	
Rural settlement detergent contribution (kg)				0.0	
Total detergent contribution (kg)				90020.8	
Percentage of total phosphorus export is detergent P (%)				**28.0**	

Landuse	P Export Coefficient kg/Ha/Yr	Hazelmere Area	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12	2047.94	5.45	245.8	7.0
cultivated: temporary - commercial dryland	0.08			0.0	0.0
cultivated: temporary - commercial irrigated	1.2			0.0	0.0
cultivated: temporary - semi-commercial/subsistence dryland	0.1	12521.68	33.31	1252.2	35.8
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02	13450.11	35.78	269.0	7.7
Degraded -unimproved grassland	0.1	121.47	0.32	12.1	0.3
Forest	0.02	586.74	1.56	11.7	0.3
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	602.35	1.60	12.0	0.3
Herbland	0.02			0.0	0.0
Improved grassland	0.1			0.0	0.0
Mines and quarries	0.8			0.0	0.0
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	7101.21	18.89	142.0	4.1
Unimproved grassland	0.1	710.33	1.89	71.0	2.0
Urban - commercial	1.7			0.0	0.0
Urban - industrial/transport	2.7			0.0	0.0
Urban - residential	5	296.56	0.79	1482.8	42.4
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	157.56	0.42	0.0	0.0
Wetlands	0			0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	37595.95	100.01	3498.7	100.0
Urban residential detergent contribution (kg)				487.8	
Rural settlement detergent contribution (kg)				284.2	
Total detergent contribution (kg)				772.1	
Percentage of total phosphorus export is detergent P (%)				**22.1**	

	P Export Coefficient	Henley			
Landuse	kg/Ha/Yr	Area	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	324.6300	1.48	26.0	1.3
cultivated: temporary - commercial irrigated	1.2			0.0	0.0
cultivated: temporary - semi-commercial/subsistence dryland	0.1	7786.4100	35.50	778.6	39.7
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02	220.0500	1.00	4.4	0.2
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	1672.9200	7.63	33.5	1.7
Herbland	0.02			0.0	0.0
Improved grassland	0.1	72.3800	0.33	7.2	0.4
Mines and quarries	0.8			0.0	0.0
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	880.3300	4.01	17.6	0.9
Unimproved grassland	0.1	10939.6400	49.88	1094.0	55.8
Urban - commercial	1.7			0.0	0.0
Urban - industrial/transport	2.7			0.0	0.0
Urban - residential	5			0.0	0.0
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	34.9000	0.16	0.0	0.0
Wetlands	0			0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	21931.26	99.99	1961.3	100.0
Urban residential detergent contribution (kg)				0	
Rural settlement detergent contribution (kg)				176.8	
Total detergent contribution (kg)				176.8	
Percentage of total phosphorus export is detergent P (%)				**9.0**	

Landuse	P Export Coefficient kg/Ha/Yr	Inanda Area	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12	11194.74	8.78	1343.4	2.2
cultivated: temporary - commercial dryland	0.08	225.25	0.18	18.0	0.0
cultivated: temporary - commercial irrigated	1.2			0.0	0.0
cultivated: temporary - semi-commercial/subsistence dryland	0.1	8561.07	6.71	856.1	1.4
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02	11955.40	9.38	239.1	0.4
Degraded -unimproved grassland	0.1	155.70	0.12	15.6	0.0
Forest	0.02	1316.45	1.03	26.3	0.0
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	5116.93	4.01	102.3	0.2
Herbland	0.02			0.0	0.0
Improved grassland	0.1	1107.73	0.87	110.8	0.2
Mines and quarries	0.8	28.51	0.02	22.8	0.0
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	47033.69	36.89	940.7	1.5
Unimproved grassland	0.1	25070.50	19.66	2507.1	4.0
Urban - commercial	1.7	570.61	0.45	970.0	1.6
Urban - industrial/transport	2.7	897.07	0.70	2422.1	3.9
Urban - residential	5	10436.41	8.19	52182.1	84.1
Urban - smallholdings - bushland	0.1	2210.34	1.73	221.0	0.4
Urban - smallholdings - grassland	0.1	339.48	0.27	33.9	0.1
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	1279.98	1.00	0.0	0.0
Wetlands	0			0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	127499.86	99.99	62011.3	100.0
Urban residential detergent contribution (kg)				17167.9	
Rural settlement detergent contribution (kg)				194.3	
Total detergent contribution (kg)				17362.2	
Percentage of total phosphorus export is detergent P (%)				**28.0**	

Landuse	P Export Coefficient kg/Ha/Yr	Klipfontein Area	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08			0.0	0.0
cultivated: temporary - commercial irrigated	1.2			0.0	0.0
cultivated: temporary - semi-commercial/subsistence dryland	0.1	4600.45	13.54	460.0	5.5
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02			0.0	0.0
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	7171.33	21.11	143.4	1.7
Herbland	0.02			0.0	0.0
Improved grassland	0.1	53.86	0.16	5.4	0.1
Mines and quarries	0.8	154.25	0.45	123.4	1.5
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	1059.52	3.12	21.2	0.3
Unimproved grassland	0.1	19122.52	56.29	1912.3	22.9
Urban - commercial	1.7	61.84	0.18	105.1	1.3
Urban - industrial/transport	2.7	428.43	1.26	1156.8	13.8
Urban - residential	5	885.16	2.61	4425.8	53.0
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	416.60	1.23	0.0	0.0
Wetlands	0			0.0	0.0
Dongas	0	19.37	0.06	0.0	0.0
Barren rock	0			0.0	0.0
	Total	33973.33	100.01	8353.4	100.0
Urban residential detergent contribution (kg)				1456.1	
Rural settlement detergent contribution (kg)				104.4	
Total detergent contribution (kg)				1560.5	
Percentage of total phosphorus export is detergent P (%)				**18.7**	

Landuse	P Export Coefficient kg/Ha/Yr	Klipvoor Area	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	46540.31	8.54	3723.2	1.8
cultivated: temporary - commercial irrigated	1.2	8480.98	1.56	10177.2	4.9
cultivated: temporary - semi-commercial/subsistence dryland	0.1	33710.06	6.18	3371.0	1.6
Degraded -forest and woodland	0.02	89980.70	16.50	1799.6	0.9
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02	39.63	0.01	0.8	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02			0.0	0.0
Forest and woodland	0.02	220610.29	40.46	4412.2	2.1
Forest plantations	0.02	926.10	0.17	18.5	0.0
Herbland	0.02			0.0	0.0
Improved grassland	0.1	913.00	0.17	91.3	0.0
Mines and quarries	0.8	1378.54	0.25	1102.8	0.5
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	32780.64	6.01	655.6	0.3
Unimproved grassland	0.1	46539.33	8.54	4653.9	2.2
Urban - commercial	1.7	1609.26	0.30	2735.7	1.3
Urban - industrial/transport	2.7	2082.75	0.38	5623.4	2.7
Urban - residential	5	33551.60	6.15	167758.0	80.5
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1	11.61	0.00	1.2	0.0
Urban - smallholdings - woodland	0.1	22958.79	4.21	2295.9	1.1
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	1161.02	0.21	0.0	0.0
Wetlands	0	1815.86	0.33	0.0	0.0
Dongas	0	158.52	0.03	0.0	0.0
Barren rock	0			0.0	0.0
	Total	545248.99	100.00	208420.4	100.0
Urban residential detergent contribution (kg)				55192.4	
Rural settlement detergent contribution (kg)				765.2	
Total detergent contribution (kg)				55957.6	
Percentage of total phosphorus export is detergent P (%)				**26.8**	

	P Export Coefficient	Koppies			
Landuse	**kg/Ha/Yr**	**Area**	**%**	**Export**	**%**
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	61618.84	28.49	4929.5	21.6
cultivated: temporary - commercial irrigated	1.2	269.38	0.12	323.3	1.4
cultivated: temporary - semi-commercial/subsistence dryland	0.1			0.0	0.0
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02			0.0	0.0
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	9.24	0.00	0.2	0.0
Herbland	0.02			0.0	0.0
Improved grassland	0.1	38.13	0.02	3.8	0.0
Mines and quarries	0.8			0.0	0.0
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	675.40	0.31	13.5	0.1
Unimproved grassland	0.1	150437.09	69.55	15043.7	66.1
Urban - commercial	1.7	128.03	0.06	217.7	1.0
Urban - industrial/transport	2.7			0.0	0.0
Urban - residential	5	447.83	0.21	2239.2	9.8
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	1398.57	0.65	0.0	0.0
Wetlands	0	1200.86	0.56	0.0	0.0
Dongas	0	77.43	0.04	0.0	0.0
Barren rock	0			0.0	0.0
	Total	216300.80	100.01	22770.8	100.0
Urban residential detergent contribution (kg)				736.7	
Rural settlement detergent contribution (kg)				0.0	
Total detergent contribution (kg)				736.7	
Percentage of total phosphorus export is detergent P (%)				**3.2**	

Landuse	P Export Coefficient kg/Ha/Yr	Laing Area	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	275.20	0.30	22.0	0.1
cultivated: temporary - commercial irrigated	1.2	181.87	0.20	218.2	0.5
cultivated: temporary - semi-commercial/subsistence dryland	0.1	8065.36	8.71	806.5	1.9
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02	174.35	0.19	3.5	0.0
Degraded -unimproved grassland	0.1	17850.34	19.28	1785.0	4.2
Forest	0.02	8513.36	9.20	170.3	0.4
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	4389.84	4.74	87.8	0.2
Herbland	0.02			0.0	0.0
Improved grassland	0.1	66.83	0.07	6.7	0.0
Mines and quarries	0.8	63.14	0.07	50.5	0.1
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	21516.38	23.24	430.3	1.0
Unimproved grassland	0.1	23723.24	25.62	2372.3	5.5
Urban - commercial	1.7	150.56	0.16	256.0	0.6
Urban - industrial/transport	2.7	130.08	0.14	351.2	0.8
Urban - residential	5	7259.79	7.84	36299.0	84.7
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	211.34	0.23	0.0	0.0
Wetlands	0			0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0	8.76	0.01	0.0	0.0
	Total	92580.44	100.00	42859.3	100.0
Urban residential detergent contribution (kg)				11942.4	
Rural settlement detergent contribution (kg)				183.1	
Total detergent contribution (kg)				12125.4	
Percentage of total phosphorus export is detergent P (%)				**28.3**	

Landuse	P Export Coefficient	Lindleyspoort			
	kg/Ha/Yr	Area (Ha)	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	25394.88	35.81	2031.6	33.9
cultivated: temporary - commercial irrigated	1.2	103.48	0.15	124.2	2.1
cultivated: temporary - semi-commercial/subsistence dryland	0.1	241.76	0.34	24.2	0.4
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02			0.0	0.0
Forest and woodland	0.02	3986.27	5.62	79.7	1.3
Forest plantations	0.02	190.99	0.27	3.8	0.1
Herbland	0.02			0.0	0.0
Improved grassland	0.1			0.0	0.0
Mines and quarries	0.8	326.55	0.46	261.2	4.4
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	29147.03	41.10	582.9	9.7
Unimproved grassland	0.1	10759.00	15.17	1075.9	17.9
Urban - commercial	1.7	17.06	0.02	29.0	0.5
Urban - industrial/transport	2.7			0.0	0.0
Urban - residential	5	356.50	0.50	1782.5	29.7
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	64.22	0.09	0.0	0.0
Wetlands	0	327.87	0.46	0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	70915.61	99.99	5995.1	100.0
Urban residential detergent contribution (kg)				586.4	
Rural settlement detergent contribution (kg)				5.5	
Total detergent contribution (kg)				591.9	
Percentage of total phosphorus export is detergent P (%)				**9.9**	

	P Export Coefficient	Midmar			
Landuse	**kg/Ha/Yr**	**Area (Ha)**	**%**	**Export**	**%**
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12	28.26	0.03	3.4	0.0
cultivated: temporary - commercial dryland	0.08	6084.40	6.60	486.8	3.0
cultivated: temporary - commercial irrigated	1.2	6759.36	7.33	8111.2	49.4
cultivated: temporary - semi-commercial/subsistence dryland	0.1	5.30	0.01	0.5	0.0
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02	2011.40	2.18	40.2	0.2
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	15262.82	16.55	305.3	1.9
Herbland	0.02			0.0	0.0
Improved grassland	0.1	3225.20	3.50	322.5	2.0
Mines and quarries	0.8			0.0	0.0
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	1591.50	1.73	31.8	0.2
Unimproved grassland	0.1	54592.43	59.18	5459.2	33.3
Urban - commercial	1.7			0.0	0.0
Urban - industrial/transport	2.7			0.0	0.0
Urban - residential	5	328.90	0.36	1644.5	10.0
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	2087.30	2.26	0.0	0.0
Wetlands	0	270.90	0.29	0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	92247.77	100.02	16405.5	100.0
Urban residential detergent contribution (kg)				541.0	
Rural settlement detergent contribution (kg)				0.1	
Total detergent contribution (kg)				541.2	
Percentage of total phosphorus export is detergent P (%)				**3.3**	

Landuse	P Export Coefficient	Misverstand			
	kg/Ha/Yr	Area (Ha)	%	Export	%
cultivated: permanent -commercial dryland	0.1	177.46	0.04	17.7	0.0
cultivated: permanent -commercial irrigated	1.2	53732.66	13.12	64479.2	55.9
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	206691.18	50.48	16535.3	14.3
cultivated: temporary - commercial irrigated	1.2			0.0	0.0
cultivated: temporary - semi-commercial/subsistence dryland	0.1			0.0	0.0
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08	2023.11	0.49	161.8	0.1
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1	95.23	0.02	9.5	0.0
Forest	0.02			0.0	0.0
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	12171.01	2.97	243.4	0.2
Herbland	0.02			0.0	0.0
Improved grassland	0.1	278.77	0.07	27.9	0.0
Mines and quarries	0.8	267.60	0.07	214.1	0.2
Shrubland and low Fynbos	0.08	111095.01	27.13	8887.6	7.7
Thicket and bushland, etc.	0.02	9055.60	2.21	181.1	0.2
Unimproved grassland	0.1	6190.19	1.51	619.0	0.5
Urban - commercial	1.7	193.08	0.05	328.2	0.3
Urban - industrial/transport	2.7	18.25	0.00	49.3	0.0
Urban - residential	5	4729.52	1.16	23647.6	20.5
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1	293.18	0.07	29.3	0.0
Waterbodies	0	2218.11	0.54	0.0	0.0
Wetlands	0	228.40	0.06	0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0	15.18	0.00	0.0	0.0
	Total	409473.54	99.99	115431.1	100.0
Urban residential detergent contribution (kg)				7780.1	
Rural settlement detergent contribution (kg)				0.0	
Total detergent contribution (kg)				7780.1	
Percentage of total phosphorus export is detergent P (%)				**6.7**	

Landuse	P Export Coefficient kg/Ha/Yr	Nagle Area (Ha)	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12	26201.14	28.23	3144.1	39.1
cultivated: temporary - commercial dryland	0.08	1706.83	1.84	136.5	1.7
cultivated: temporary - commercial irrigated	1.2			0.0	0.0
cultivated: temporary - semi-commercial/subsistence dryland	0.1	2827.63	3.05	282.8	3.5
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02	505.50	0.54	10.1	0.1
Degraded -unimproved grassland	0.1	313.45	0.34	31.3	0.4
Forest	0.02	1794.78	1.93	35.9	0.4
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	24837.35	26.76	496.7	6.2
Herbland	0.02			0.0	0.0
Improved grassland	0.1	590.31	0.64	59.0	0.7
Mines and quarries	0.8			0.0	0.0
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	15295.71	16.48	305.9	3.8
Unimproved grassland	0.1	18228.67	19.64	1822.9	22.7
Urban - commercial	1.7			0.0	0.0
Urban - industrial/transport	2.7			0.0	0.0
Urban - residential	5	341.39	0.37	1707.0	21.3
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	173.69	0.19	0.0	0.0
Wetlands	0			0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	92816.45	100.01	8032.3	100.0
Urban residential detergent contribution (kg)				561.6	
Rural settlement detergent contribution (kg)				64.2	
Total detergent contribution (kg)				625.8	
Percentage of total phosphorus export is detergent P (%)				**7.8**	

Landuse	P Export Coefficient kg/Ha/Yr	Roodekopjes Area (Ha)	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2	303	0.15	363.5	0.4
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	17437	8.65	1395.0	1.5
cultivated: temporary - commercial irrigated	1.2	50713	25.16	60856.2	65.8
cultivated: temporary - semi-commercial/subsistence dryland	0.1	1640	0.81	164.0	0.2
Degraded -forest and woodland	0.02	160	0.08	3.2	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02	402	0.20	8.0	0.0
Forest and woodland	0.02	44826	22.24	896.5	1.0
Forest plantations	0.02	23	0.01	0.5	0.0
Herbland	0.02			0.0	0.0
Improved grassland	0.1	55	0.03	5.5	0.0
Mines and quarries	0.8	1673	0.83	1338.1	1.4
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	67407	33.44	1348.1	1.5
Unimproved grassland	0.1	10980	5.45	1098.0	1.2
Urban - commercial	1.7	18	0.01	30.2	0.0
Urban - industrial/transport	2.7	457	0.23	1234.6	1.3
Urban - residential	5	4753	2.36	23767.4	25.7
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	750	0.37	0.0	0.0
Wetlands	0			0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	201596.75	100.02	92508.7	100.0
Urban residential detergent contribution (kg)				7819.5	
Rural settlement detergent contribution (kg)				37.2	
Total detergent contribution (kg)				7856.7	
Percentage of total phosphorus export is detergent P (%)				**8.5**	

	P Export Coefficient	Roodeplaat			
Landuse	**kg/Ha/Yr**	**Area (Ha)**	**%**	**Export**	**%**
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	4325.92	6.34	346.1	0.5
cultivated: temporary - commercial irrigated	1.2	789.91	1.16	947.9	1.5
cultivated: temporary - semi-commercial/subsistence dryland	0.1			0.0	0.0
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02			0.0	0.0
Forest and woodland	0.02	16429.04	24.07	328.6	0.5
Forest plantations	0.02	1227.20	1.80	24.5	0.0
Herbland	0.02			0.0	0.0
Improved grassland	0.1	394.88	0.58	39.5	0.1
Mines and quarries	0.8	213.43	0.31	170.7	0.3
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	1707.33	2.50	34.1	0.1
Unimproved grassland	0.1	22285.85	32.65	2228.6	3.5
Urban - commercial	1.7	272.04	0.40	462.5	0.7
Urban - industrial/transport	2.7	585.20	0.86	1580.0	2.5
Urban - residential	5	11479.29	16.82	57396.5	89.2
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1	3934.18	5.76	393.4	0.6
Urban - smallholdings - woodland	0.1	4261.16	6.24	426.1	0.7
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	356.42	0.52	0.0	0.0
Wetlands	0			0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	68261.85	100.01	64378.5	100.0
Urban residential detergent contribution (kg)				18883.4	
Rural settlement detergent contribution (kg)				0.0	
Total detergent contribution (kg)				18883.4	
Percentage of total phosphorus export is detergent P (%)				**29.3**	

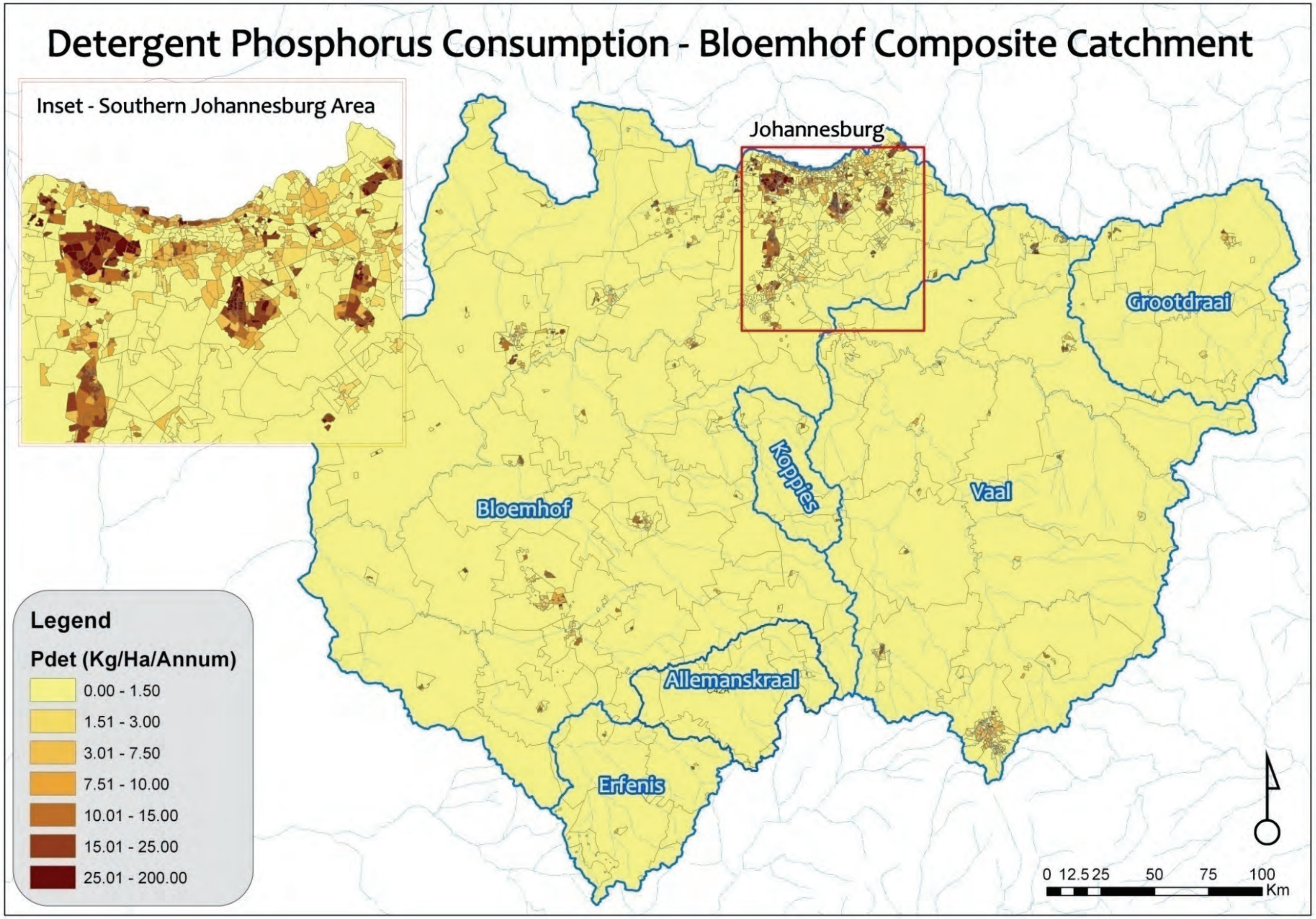
	P Export Coefficient	Shongweni			
Landuse	**kg/Ha/Yr**	**Area (Ha)**	**%**	**Export**	**%**
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12	12746.34	16.24	1529.6	7.0
cultivated: temporary - commercial dryland	0.08	2312.20	2.95	185.0	0.8
cultivated: temporary - commercial irrigated	1.2	1544.48	1.97	1853.4	8.4
cultivated: temporary - semi-commercial/subsistence dryland	0.1	3181.99	4.05	318.2	1.5
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1	504.63	0.64	50.5	0.2
Forest	0.02	756.24	0.96	15.1	0.1
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	9786.66	12.47	195.7	0.9
Herbland	0.02			0.0	0.0
Improved grassland	0.1	820.59	1.05	82.1	0.4
Mines and quarries	0.8			0.0	0.0
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	11158.34	14.22	223.2	1.0
Unimproved grassland	0.1	32148.24	40.96	3214.8	14.7
Urban - commercial	1.7			0.0	0.0
Urban - industrial/transport	2.7	161.41	0.21	435.8	2.0
Urban - residential	5	2757.76	3.51	13788.8	62.8
Urban - smallholdings - bushland	0.1	4.60	0.01	0.5	0.0
Urban - smallholdings - grassland	0.1	515.27	0.66	51.5	0.2
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	82.25	0.10	0.0	0.0
Wetlands	0			0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	78481.00	100.00	21944.1	100.0
Urban residential detergent contribution (kg)				4536.5	
Rural settlement detergent contribution (kg)				72.2	
Total detergent contribution (kg)				4608.7	
Percentage of total phosphorus export is detergent P (%)				**21.0**	

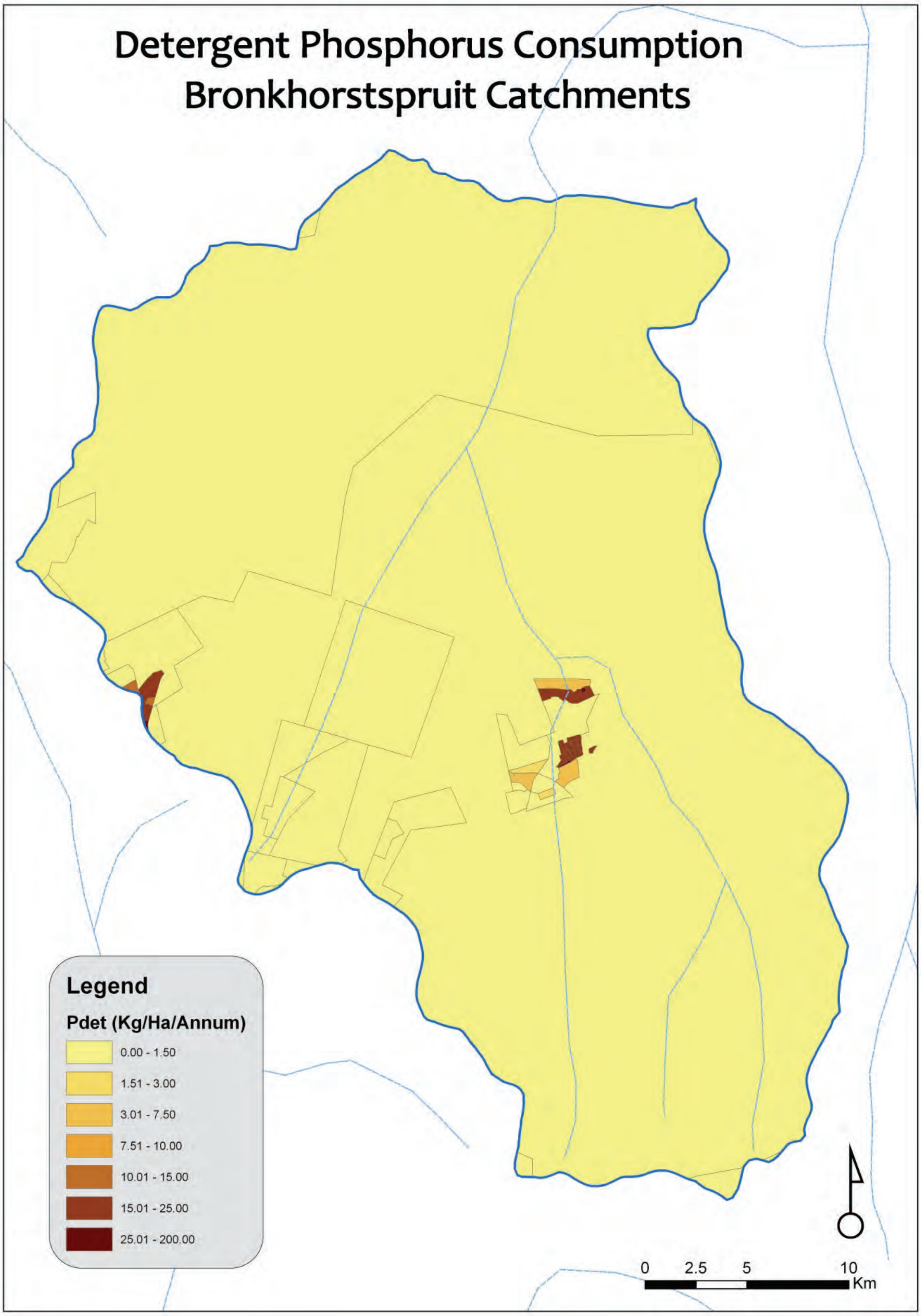
Landuse	P Export Coefficient kg/Ha/Yr	Vaal Area (Ha)	%	Export	%
cultivated: permanent -commercial dryland	0.1	281.01	0.01	28.1	0.0
cultivated: permanent -commercial irrigated	1.2	32.93	0.00	39.5	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	1011972.21	33.03	80957.8	20.6
cultivated: temporary - commercial irrigated	1.2	4845.64	0.16	5814.8	1.5
cultivated: temporary - semi-commercial/subsistence dryland	0.1	1325.05	0.04	132.5	0.0
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08	23.02	0.00	1.8	0.0
Degraded -thicket and bushland	0.02	241.90	0.01	4.8	0.0
Degraded -unimproved grassland	0.1	16083.77	0.52	1608.4	0.4
Forest	0.02	66.09	0.00	1.3	0.0
Forest and woodland	0.02	197.54	0.01	4.0	0.0
Forest plantations	0.02	6663.91	0.22	133.3	0.0
Herbland	0.02			0.0	0.0
Improved grassland	0.1	597.44	0.02	59.7	0.0
Mines and quarries	0.8	3144.81	0.10	2515.8	0.6
Shrubland and low Fynbos	0.08	1416.83	0.05	113.3	0.0
Thicket and bushland, etc.	0.02	25124.96	0.82	502.5	0.1
Unimproved grassland	0.1	1924572.73	62.82	192457.3	48.9
Urban - commercial	1.7	541.80	0.02	921.1	0.2
Urban - industrial/transport	2.7	2126.43	0.07	5741.4	1.5
Urban - residential	5	20435.16	0.67	102175.8	26.0
Urban - smallholdings - bushland	0.1	212.72	0.01	21.3	0.0
Urban - smallholdings - grassland	0.1	864.70	0.03	86.5	0.0
Urban - smallholdings - woodland	0.1	87.07	0.00	8.7	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	30242.88	0.99	0.0	0.0
Wetlands	0	6651.77	0.22	0.0	0.0
Dongas	0	431.35	0.01	0.0	0.0
Barren rock	0	5404.49	0.18	0.0	0.0
	Total	3063588.21	100.01	393329.7	100.0
Urban residential detergent contribution (kg)				33615.8	
Rural settlement detergent contribution (kg)				30.1	
Total detergent contribution (kg)				33645.9	
Percentage of total phosphorus export is detergent P (%)				**8.6**	

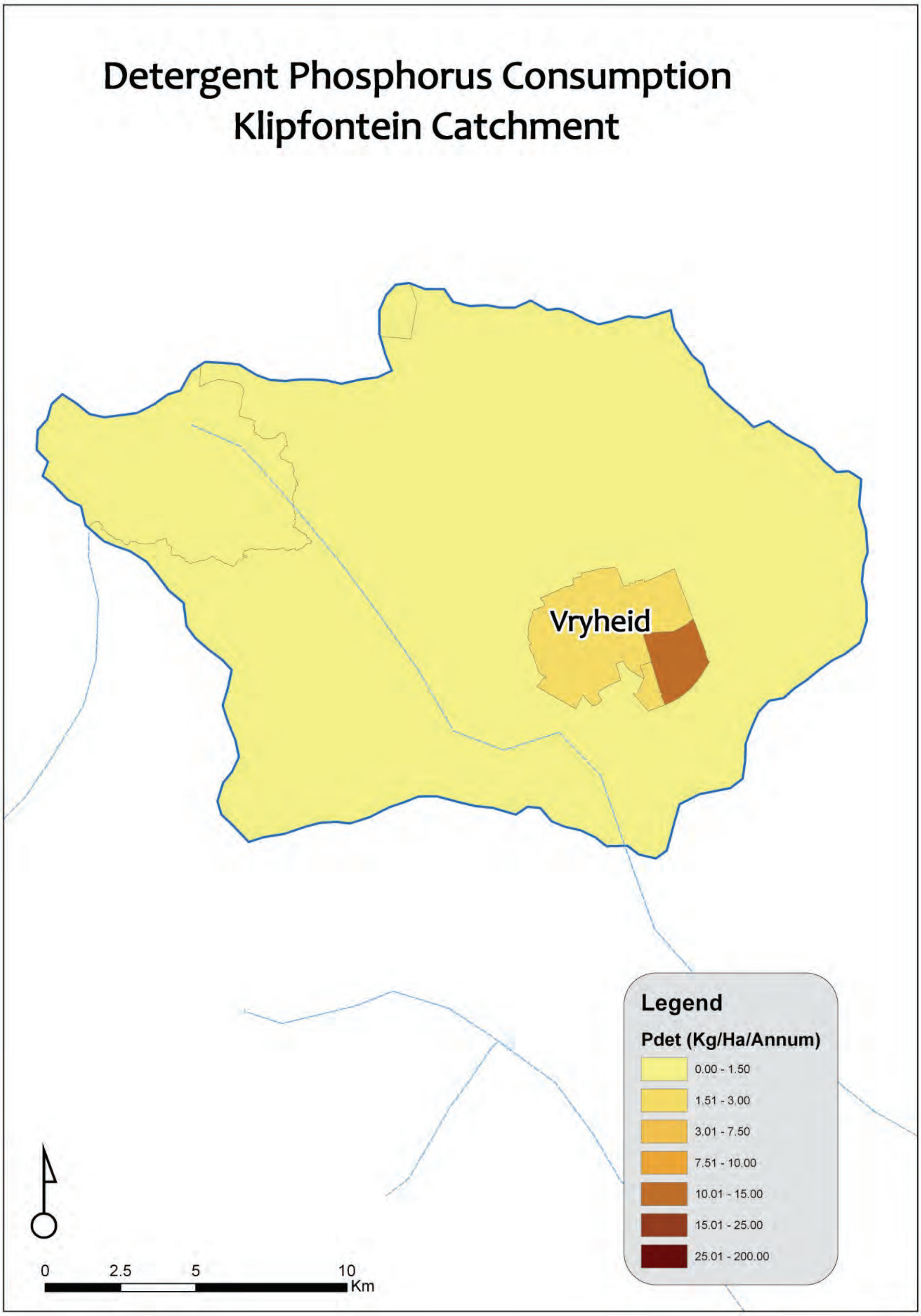
	P Export Coefficient	Welbedacht			
Landuse	kg/Ha/Yr	Area (Ha)	%	Export	%
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	266783.56	17.44	21342.7	11.0
cultivated: temporary - commercial irrigated	1.2	2142.51	0.14	2571.0	1.3
cultivated: temporary - semi-commercial/subsistence dryland	0.1	403318.14	26.37	40331.8	20.7
Degraded -forest and woodland	0.02	6.39	0.00	0.1	0.0
Degraded -shrubland and low Fynbos	0.08	12.08	0.00	1.0	0.0
Degraded -thicket and bushland	0.02	831.02	0.05	16.6	0.0
Degraded -unimproved grassland	0.1	93537.29	6.12	9353.7	4.8
Forest	0.02			0.0	0.0
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	2036.71	0.13	40.7	0.0
Herbland	0.02	314.51	0.02	6.3	0.0
Improved grassland	0.1	320.46	0.02	32.0	0.0
Mines and quarries	0.8			0.0	0.0
Shrubland and low Fynbos	0.08	2813.46	0.18	225.1	0.1
Thicket and bushland, etc.	0.02	78971.95	5.16	1579.4	0.8
Unimproved grassland	0.1	644997.76	42.17	64499.8	33.2
Urban - commercial	1.7	94.31	0.01	160.3	0.1
Urban - industrial/transport	2.7	505.90	0.03	1365.9	0.7
Urban - residential	5	10602.72	0.69	53013.6	27.2
Urban - smallholdings - bushland	0.1	212.40	0.01	21.2	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1	62.83	0.00	6.3	0.0
Waterbodies	0	4826.72	0.32	0.0	0.0
Wetlands	0	3943.43	0.26	0.0	0.0
Dongas	0	738.92	0.05	0.0	0.0
Barren rock	0	12374.62	0.81	0.0	0.0
	Total	1529447.69	99.98	194567.7	100.0
Urban residential detergent contribution (kg)				17441.5	
Rural settlement detergent contribution (kg)				9155.3	
Total detergent contribution (kg)				26596.8	
Percentage of total phosphorus export is detergent P (%)				**13.7**	

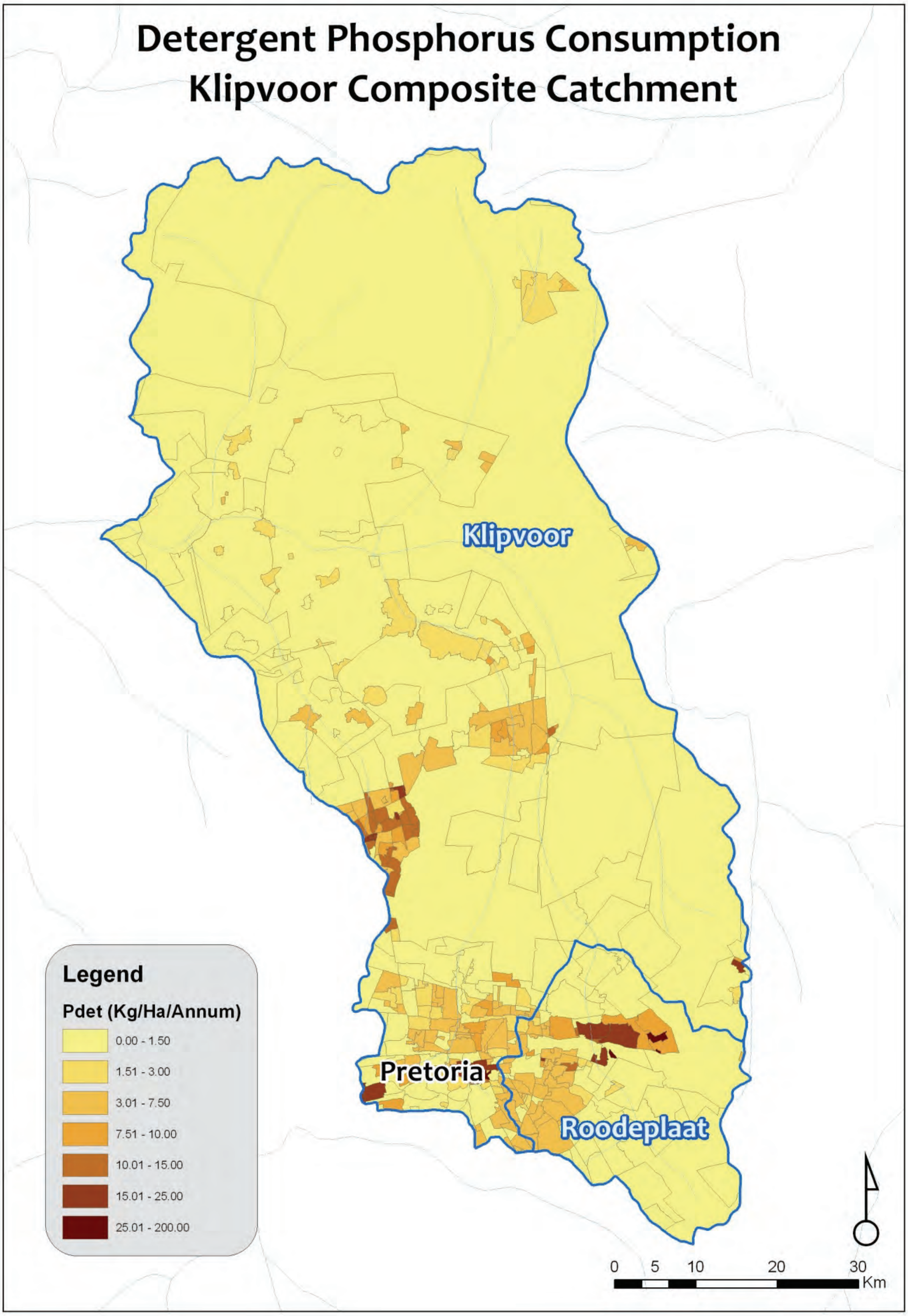
	P Export Coefficient	Witbank			
Landuse	**kg/Ha/Yr**	**Area (Ha)**	**%**	**Export**	**%**
cultivated: permanent -commercial dryland	0.1			0.0	0.0
cultivated: permanent -commercial irrigated	1.2			0.0	0.0
cultivated: permanent -commercial sugarcane	0.12			0.0	0.0
cultivated: temporary - commercial dryland	0.08	136331.68	38.07	10906.5	17.1
cultivated: temporary - commercial irrigated	1.2	702.46	0.20	843.0	1.3
cultivated: temporary - semi-commercial/subsistence dryland	0.1			0.0	0.0
Degraded -forest and woodland	0.02			0.0	0.0
Degraded -shrubland and low Fynbos	0.08			0.0	0.0
Degraded -thicket and bushland	0.02			0.0	0.0
Degraded -unimproved grassland	0.1			0.0	0.0
Forest	0.02			0.0	0.0
Forest and woodland	0.02			0.0	0.0
Forest plantations	0.02	2088.51	0.58	41.8	0.1
Herbland	0.02			0.0	0.0
Improved grassland	0.1	1261.14	0.35	126.1	0.2
Mines and quarries	0.8	18169.89	5.07	14535.9	22.8
Shrubland and low Fynbos	0.08			0.0	0.0
Thicket and bushland, etc.	0.02	520.62	0.15	10.4	0.0
Unimproved grassland	0.1	192212.77	53.67	19221.3	30.2
Urban - commercial	1.7			0.0	0.0
Urban - industrial/transport	2.7	543.35	0.15	1467.0	2.3
Urban - residential	5	3299.14	0.92	16495.7	25.9
Urban - smallholdings - bushland	0.1			0.0	0.0
Urban - smallholdings - grassland	0.1			0.0	0.0
Urban - smallholdings - woodland	0.1			0.0	0.0
Urban - smallholdings - shrubland	0.1			0.0	0.0
Waterbodies	0	2545.16	0.71	0.0	0.0
Wetlands	0	439.32	0.12	0.0	0.0
Dongas	0			0.0	0.0
Barren rock	0			0.0	0.0
	Total	358114.04	99.99	63647.7	100.0
Urban residential detergent contribution (kg)				5427.1	
Rural settlement detergent contribution (kg)				0.0	
Total detergent contribution (kg)				5427.1	
Percentage of total phosphorus export is detergent P (%)				**8.5**	

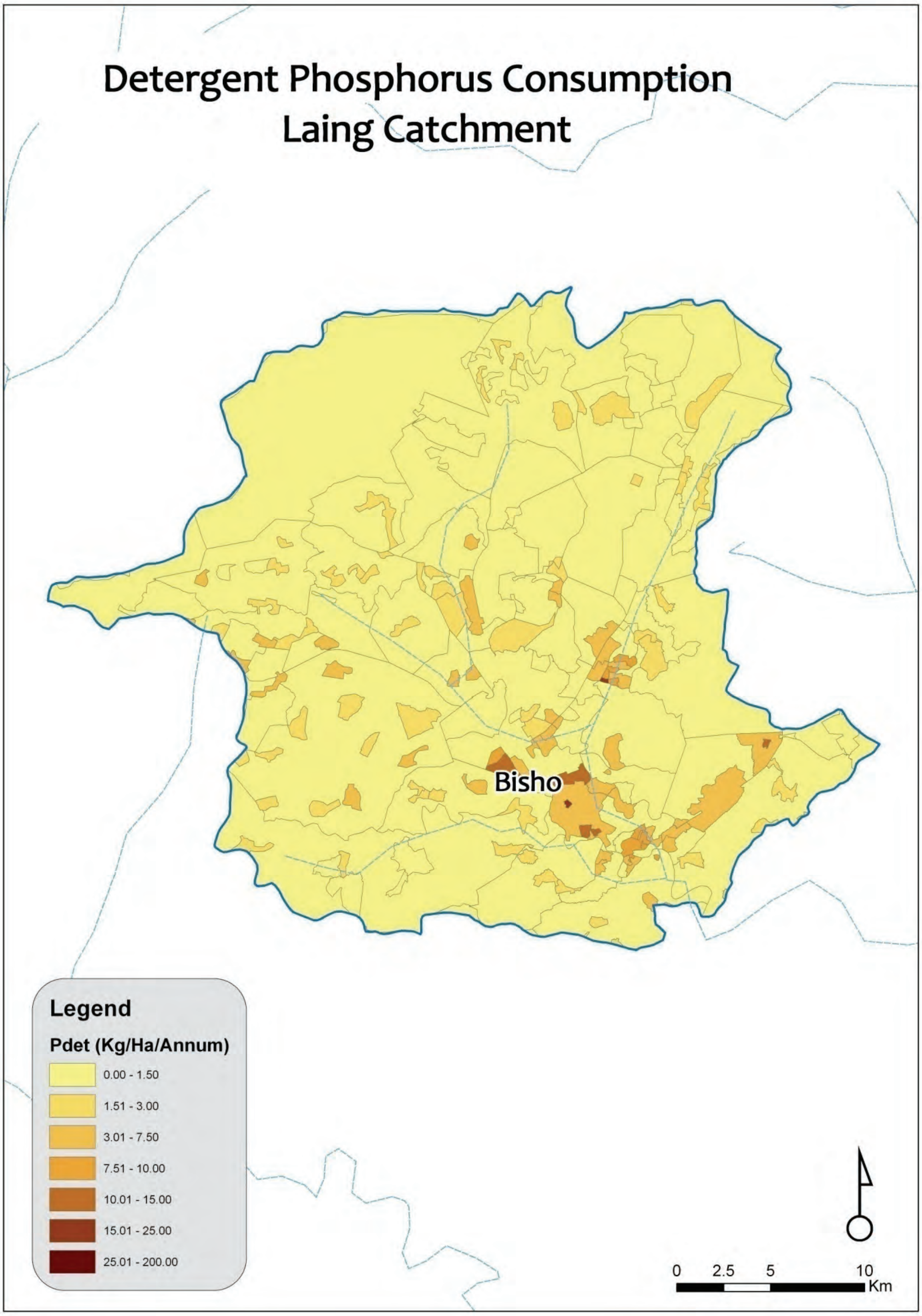
Appendix 3 – Detergent Phosphate Consumption Intensity Maps


Detergent Phosphorus Consumption - Bloemhof Composite Catchment
Inset - Southern Johannesburg Area
Johannesburg
Grootdraai
Koppies
Vaal
Bloemhof
Allemanskraal
Erfenis
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
0 12.5 25 50 75 100
Km

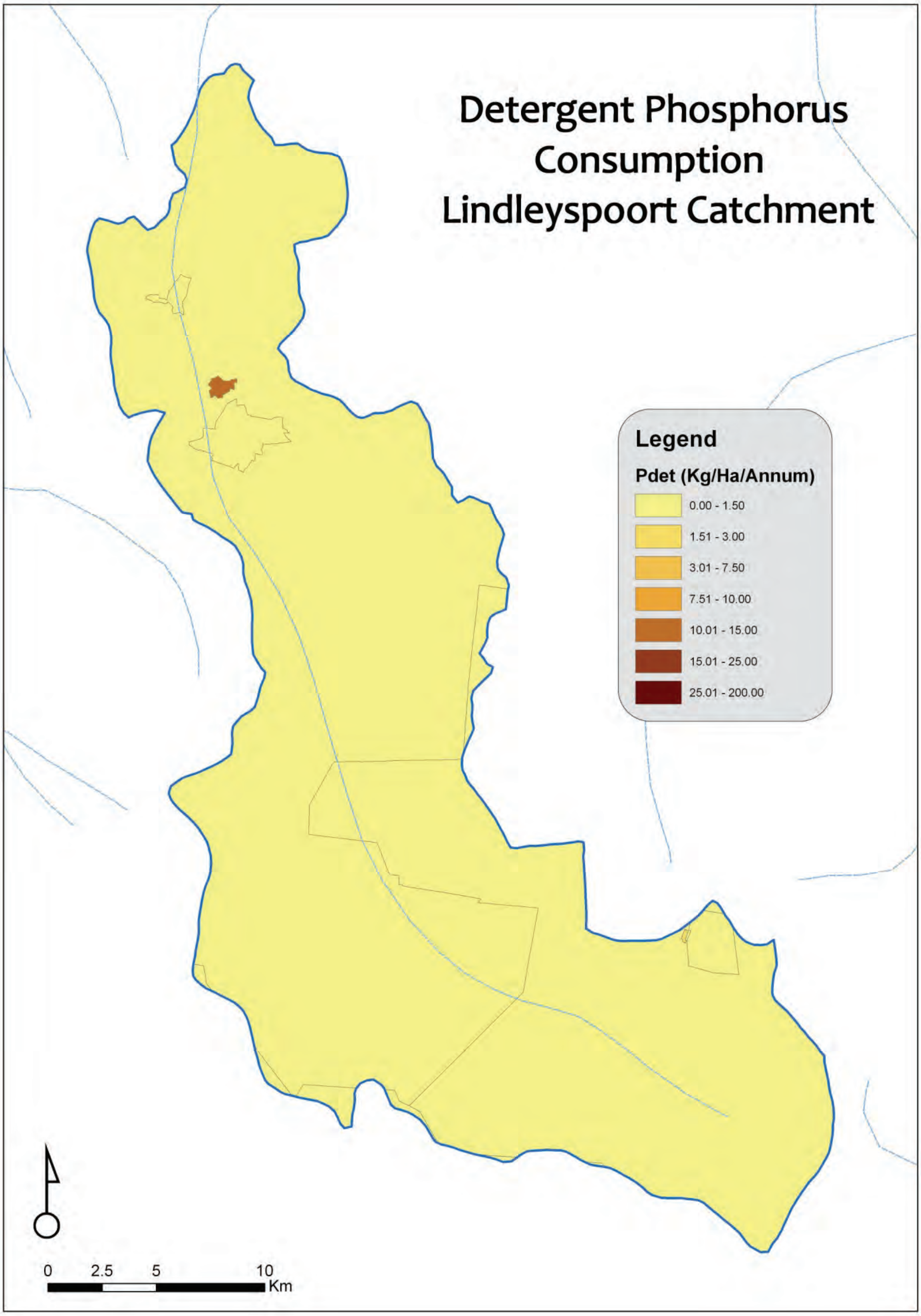

Detergent Phosphorus Consumption
Bronkhorstspruit Catchments
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
0
2.5
5
10
Km

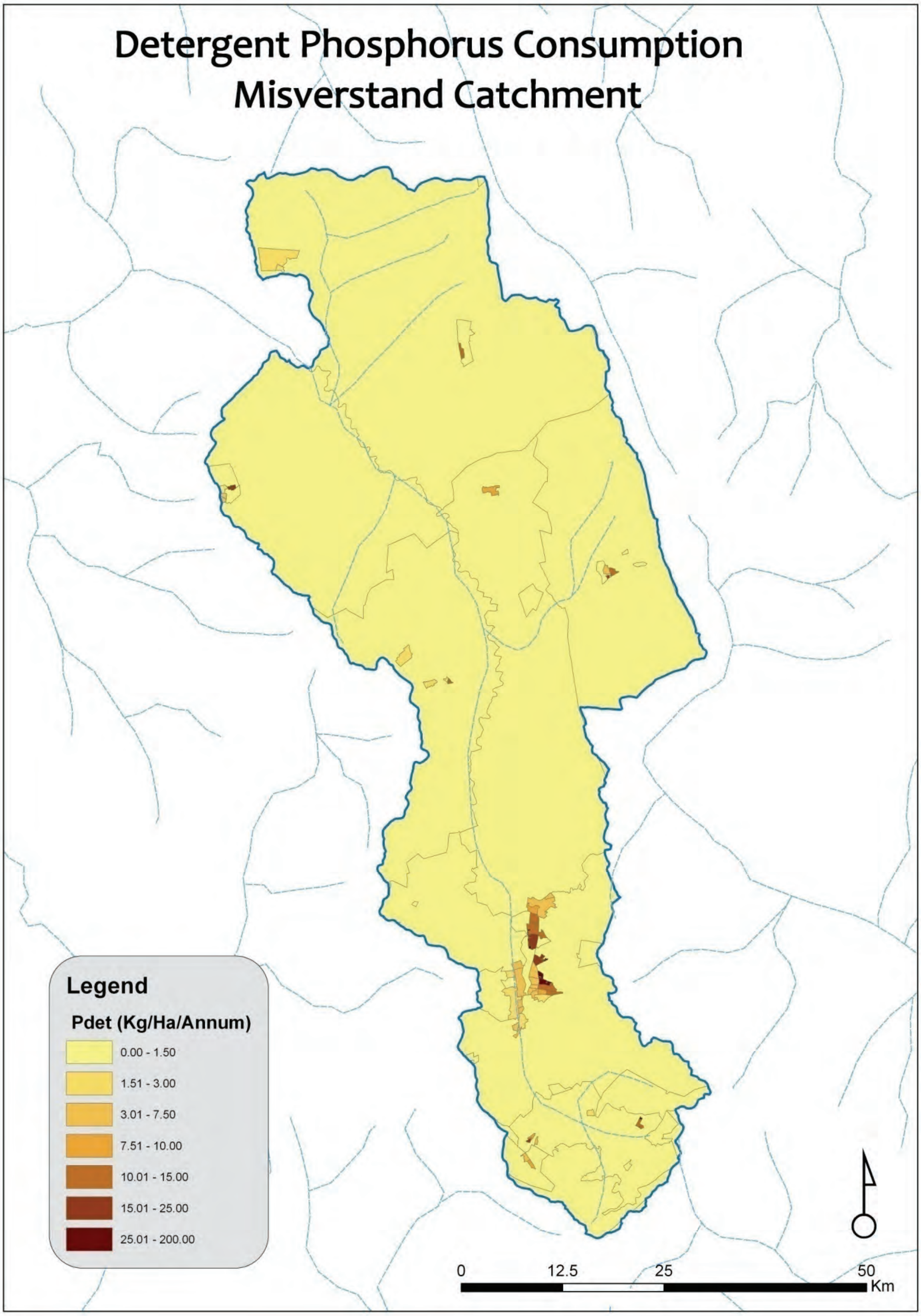

Detergent Phosphorus Consumption
Klipfontein Catchment
Vryheid
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
0
2.5
5
10
Km

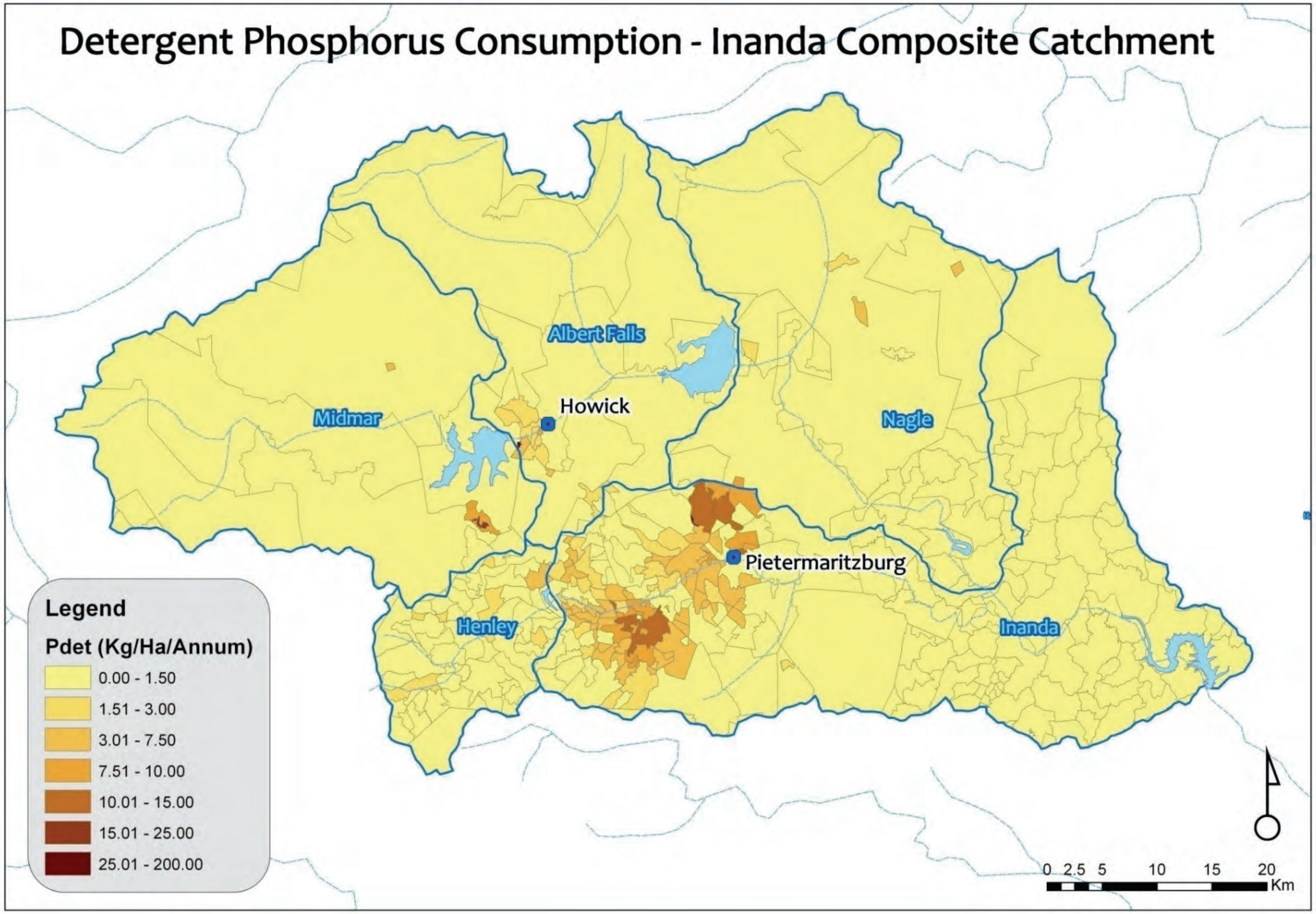

Detergent Phosphorus Consumption
Klipvoor Composite Catchment
Klipvoor
Pretoria
Roodeplaat
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
0
5
10
20
30
Km

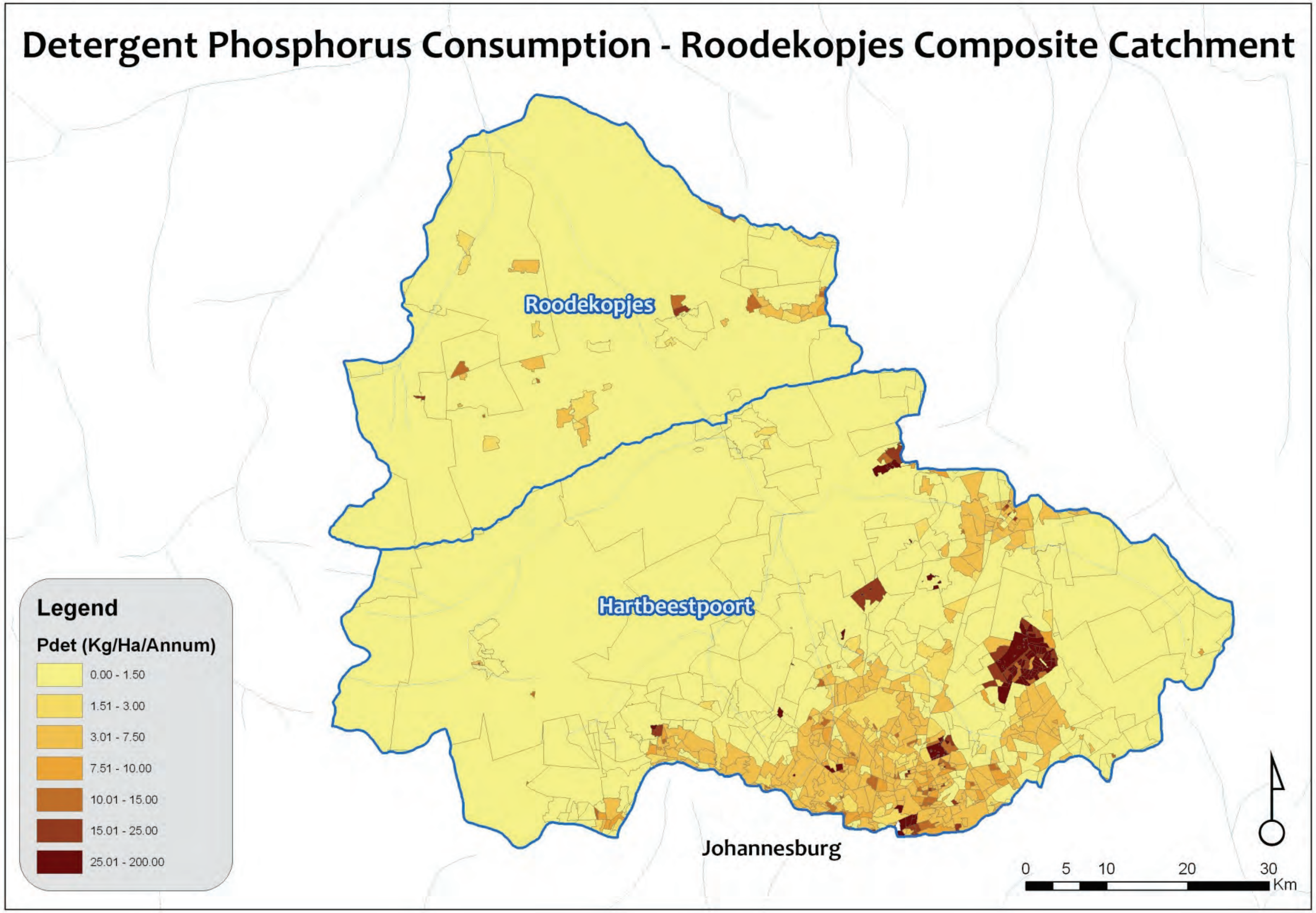


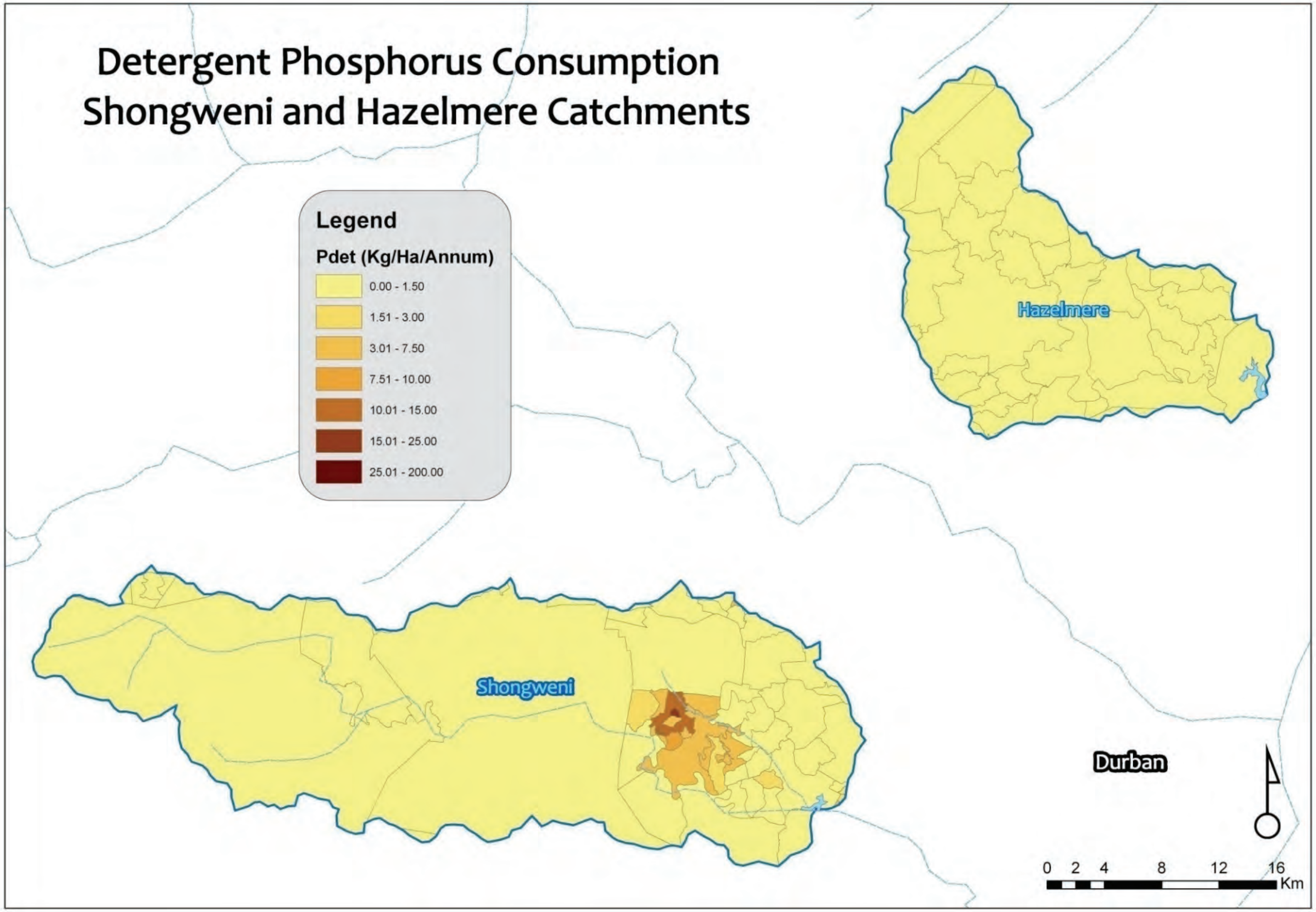
Detergent Phosphorus Consumption
Laing Catchment
Bisho
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
0 2.5 5 10
Km

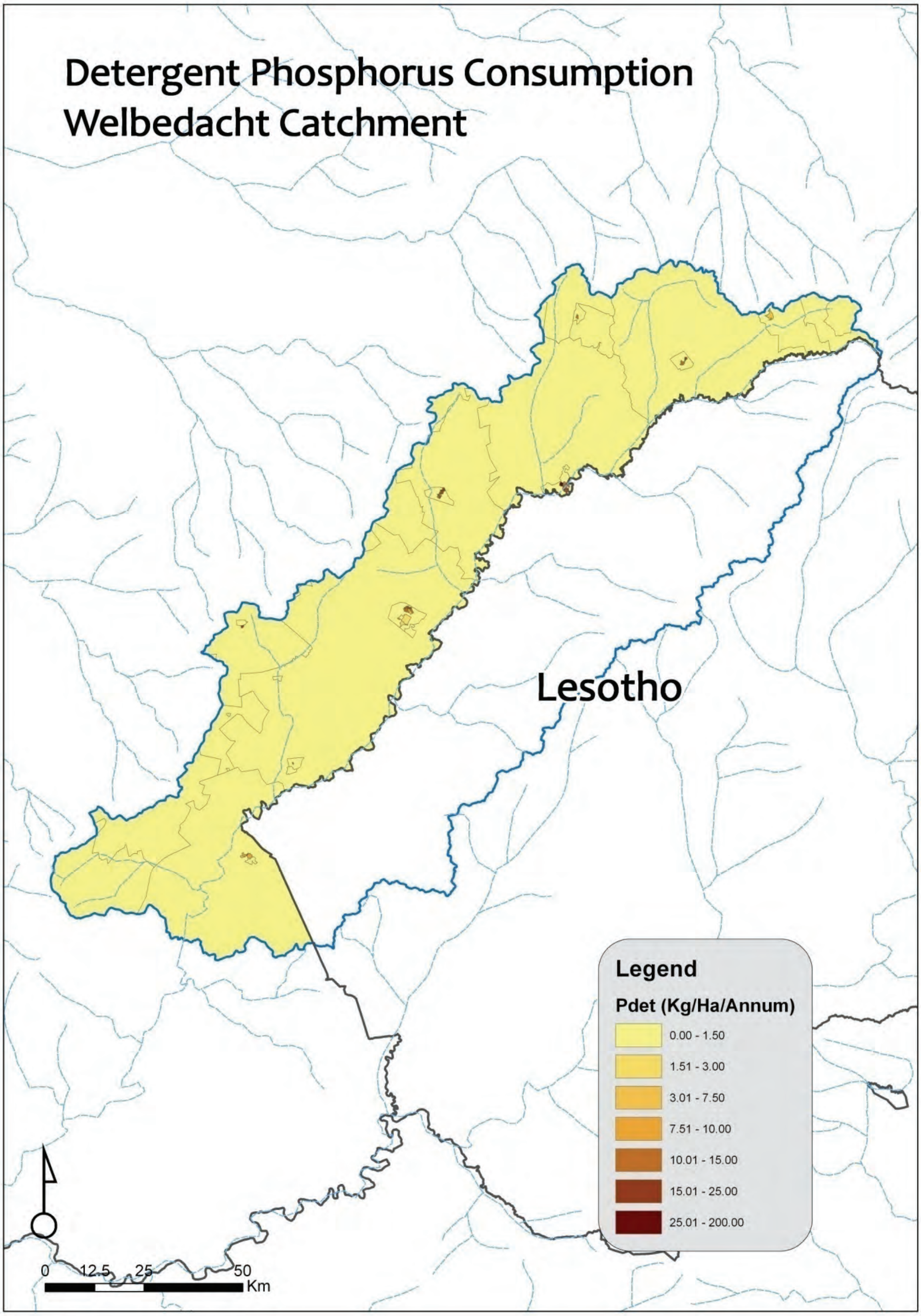

Detergent Phosphorus
Consumption
Lindleyspoort Catchment
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
0
2.5
5
10
Km

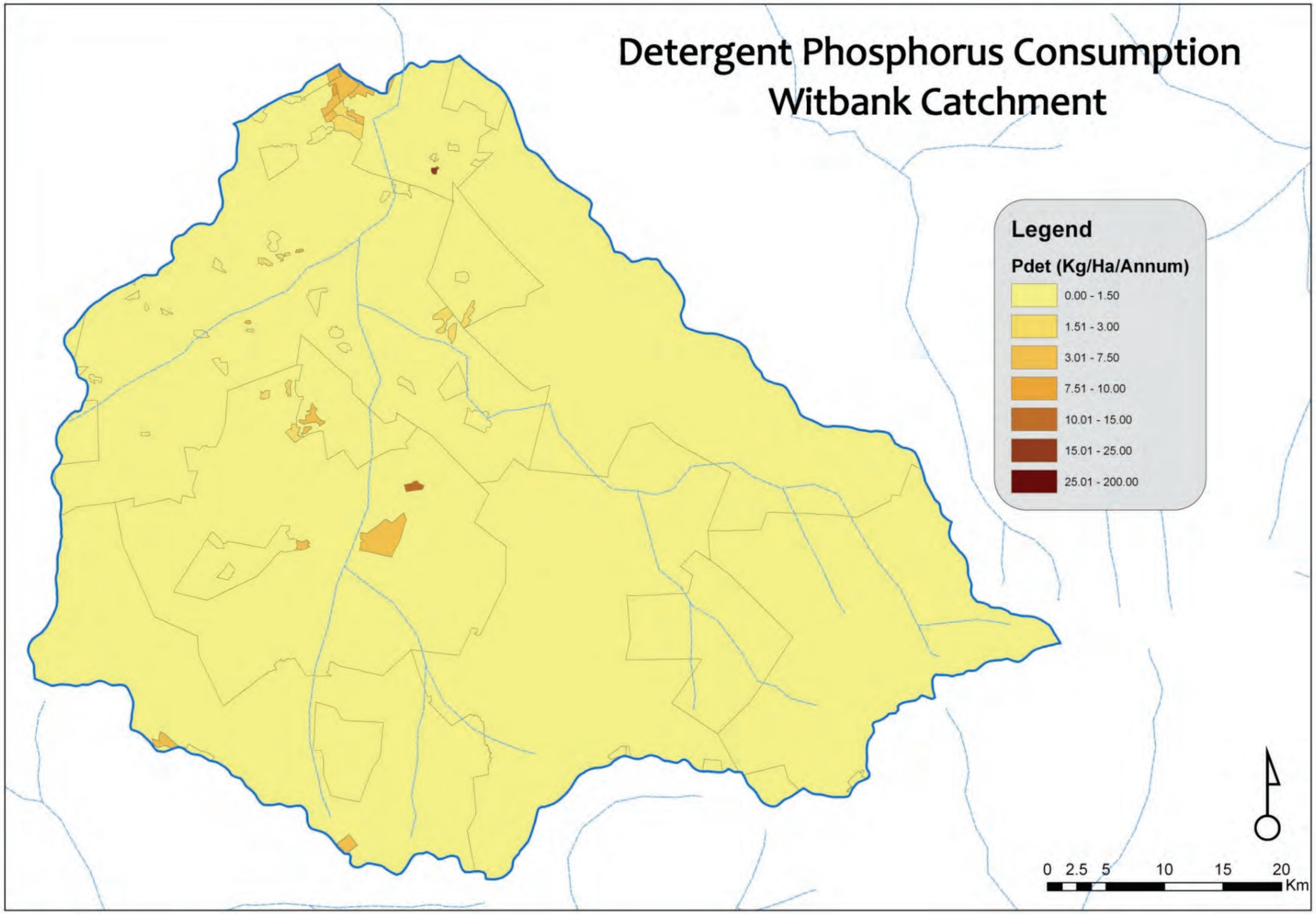

Detergent Phosphorus Consumption
Misverstand Catchment
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
0
12.5
25
50
Km


Detergent Phosphorus Consumption - Inanda Composite Catchment
Albert Falls
Howick
Midmar
Nagle
Pietermaritzburg
Henley
Inanda
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
0 2.5 5 10 15 20
Km


Detergent Phosphorus Consumption - Roodekopjes Composite Catchment
Roodekopjes
Hartbeestpoort
Johannesburg
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
0 5 10 20 30
Km


Detergent Phosphorus Consumption
Shongweni and Hazelmere Catchments
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
Hazelmere
Shongweni
Durban
0 2 4 8 12 16
Km


Detergent Phosphorus Consumption
Welbedacht Catchment
Lesotho
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
0
12.5
25
50
Km


Detergent Phosphorus Consumption
Witbank Catchment
Legend
Pdet (Kg/Ha/Annum)
0.00 - 1.50
1.51 - 3.00
3.01 - 7.50
7.51 - 10.00
10.01 - 15.00
15.01 - 25.00
25.01 - 200.00
0 2.5 5 10 15 20
Km

Appendix 4 –Detergent Phosphate Contributions to JHB Water WWTWs

Bushkoppies

WWTW Data		
No of Stands	69,481	
Average inflow volume	222.00	M ℓ /day
Average Concentration	4.43	PO_4 (mg/ℓ)
Average Concentration	4429.31	PO_4 (µg/ℓ)
Variance (on mg/ℓ)	2.05	
Std Dev	1.43	

Detergent Consumption Data		
Number of households	69,481	
Average use of Detergent	17.30	kg/annum
Tons Detergent use per annum	1202.02	T/annum
P content	5.30	%
Tons Phosphate use per annum	63.71	T/annum
kg Phosphate use per day	174.54	kg/day

Pdet composition calculation		
Total SRP intake	983.31	kg/day
Pdet Consumption	174.54	kg/day
Percentage Composition	17.75	%

Goudkoppies

WWTW Data		
No of Stands	30,937	
Average inflow volume	128	M ℓ /day
Average Concentration	3.94	PO_4 (mg/ℓ)
Average Concentration	3941.38	PO_4 (µg/ℓ)
Variance (on mg/ℓ)	0.75	
Std Dev	0.87	

Detergent Consumption Data		
Number of households	30,937	
Average use of Detergent	17.30	kg/annum
Tons Detergent use per annum	535.21	T/annum
P content	5.30	%
Tons Phosphate use per annum	28.37	T/annum
kg Phosphate use per day	77.72	kg/day

Pdet composition calculation		
Total SRP intake	504.50	kg/day
Pdet Consumption	77.72	kg/day
Percentage Composition	15.40	%

Driefontein

WWTW Data		
No of Stands	12,532	
Average inflow volume	30	M ℓ /day
Average Concentration	6.95	PO_4 (mg/ℓ)
Average Concentration	6950.00	PO_4 (µg/ℓ)
Variance (on mg/ℓ)	16.55	
Std Dev	4.07	

Detergent Consumption Data		
Number of households	12532.00	
Average use of Detergent	17.30	kg/annum
Tons Detergent use per annum	216.80	T/annum
P content	5.30	%
Tons Phosphate use per annum	11.49	T/annum
kg Phosphate use per day	31.4811	kg/day

Pdet composition calculation		
Total SRP intake	208.5	kg/day
Pdet Consumption	31.4811	kg/day
Percentage Composition	15.1	%

Ennerdale

WWTW Data		
No of Stands	7,502	
Average inflow volume	6.3	M ℓ /day
Average Concentration	5.09	PO_4 (mg/ℓ)
Average Concentration	5085.49	PO_4 (µg/ℓ)
Variance (on mg/ℓ)	11.90149	
Std Dev	3.45	

Detergent Consumption Data		
Number of households	7,502	
Average use of Detergent	17.30	kg/annum
Tons Detergent use per annum	129.78	T/annum
P content	5.30	%
Tons Phosphate use per annum	6.88	T/annum
kg Phosphate use per day	18.84544	kg/day

Pdet composition calculation		
Total SRP intake	32.03856	kg/day
Pdet Consumption	18.84544	kg/day
Percentage Composition	58.8	%

Oliphantsvlei

WWTW Data		
No of Stands	144,295	
Average inflow volume	220.00	M ℓ /day
Average Concentration	5.86	PO_4 (mg/ℓ)
Average Concentration	5858.54	PO_4 (μg/ℓ)
Variance	5.54	
Std Dev	2.35	

Detergent Consumption Data		
Number of households	144,295	
Average use of Detergent	17.30	kg/annum
Tons Detergent use per annum	2496.30	T/annum
P content %	5.30	%
Tons Phosphate use per annum	132.30	T/annum
kg Phosphate use per day	362.48	kg/day

Pdet composition calculation		
Total SRP intake	1288.88	kg/day
Consumption	362.48	kg/day
Percentage composition	28.12	%

Northern

WWTW Data		
No of Stands	213,040	
Average inflow volume	401	M ℓ /day
Average Concentration	4.68	PO_4 (mg/ℓ)
Average Concentration	4678.56	PO_4 (μg/ℓ)
Variance	1.738737542	
Std Dev	1.32	

Detergent Consumption Data		
Number of households	213040.00	
Average use of Detergent	17.30	kg/annum
Tons Detergent use per annum	3685.59	T/annum
P content %	5.30	%
Tons Phosphate use per annum	195.34	T/annum
Kg Phosphate use per day	535.1681534	kg/day

Pdet composition calculation		
Total SRP intake	1876.100778	kg/day
Consumption	535.1681534	kg/day
Percentage composition	28.53	%