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The uMkhomazi Water Project Phase 1: Module 1: Technical Feasibility Study: Raw Water

ENGINEERING FEASIBILITY DESIGN REPORT

WRITE-UP 2: WATER QUALITY AND LIMNOLOGICAL REVIEW

FINAL

JANUARY 2014

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UMGENI WATER

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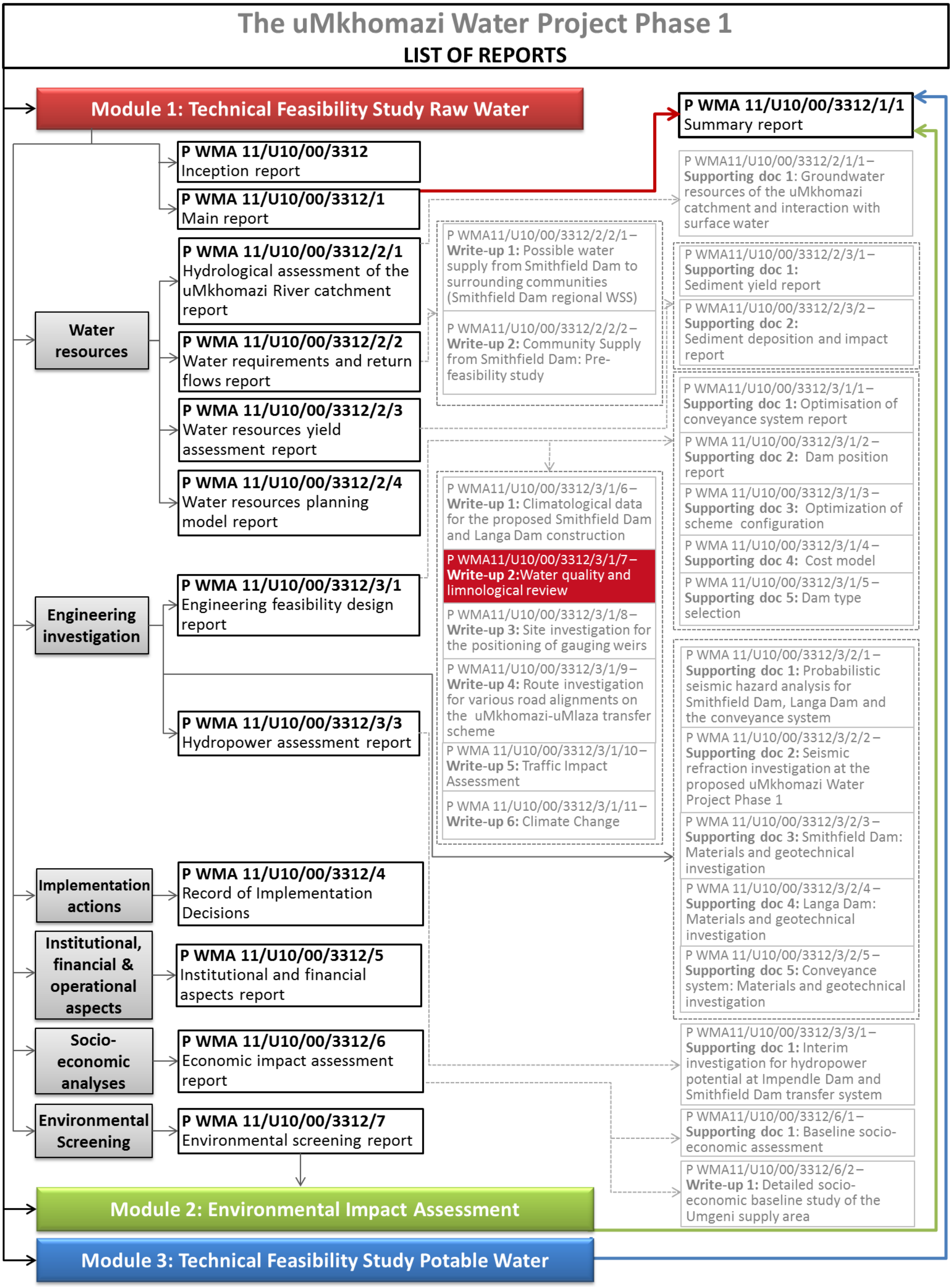
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Executive summary

The current water resources of the Mgeni and the upper Mooi System are insufficient to meet the long-term water demands for both domestic and industrial use in the Durban-Pietermaritzburg area. The Department of Water Affairs (DWA) is therefore exploring possible augmentation options to ensure a sustainable water supply for KwaZulu-Natal. Initial studies considered eight augmentation options to meet the long-term system requirements, and the prefeasibility investigation recommended that the Smithfield Scheme be taken to a detailed feasibility level investigation.

The DWA is currently implementing a Technical Feasibility Study as part of Phase 1 of the uMkhomazi Water Project (a dam at Smithfield on the uMkhomazi River, a tunnel and a raw water pipeline to a water treatments works and a gravity pipeline to the Umgeni Water bulk distribution system at Umlaas Road and further distribution into the eThekwini Metropolitan Municipal area). A balancing dam will also be constructed on the Mbangweni River in the Baynesfield area to comply with the 21 day water supply requirement for tunnel inspection and maintenance.

This report contains the water quality component of the Technical Feasibility Study, and includes a water quality assessment of the water in the uMkhomazi River and the proposed Smithfield Dam. Limited consideration was also given to the water quality in the proposed balancing dam. The report focuses primarily on the water quality implications of Phase 1 of the uMkhomazi Water Project.

The overall aim of this water quality assessment is to document the current water quality in the uMkhomazi and uMlaza Rivers, to predict the water quality in the proposed Smithfield Dam and the balancing dam and to establish whether any serious water quality constraints exist regarding the feasibility of Phase 1 of the uMkhomazi Water Project.

The conclusions of the Water Quality Assessment for the proposed impoundment on the uMkhomazi River are as follows:

- *The dominant land uses in the Smithfield Dam catchment are unimproved grasslands and bushland (some degraded) primarily used for animal grazing and some forestry plantations. There is a significant population (approximately 200 000), with some associated subsistence farming, but no significant industry or mining. Overall, the Smithfield Dam catchment is considered to be in moderately good condition, with low potential for serious pollution issues in the proposed dam,* *largely as a result of the lack of large population numbers and industry. The greatest risk to water quality in the Smithfield impoundment is from the significant soil erosion occurring in the catchment. This accelerated erosion is associated with livestock related erosion (trails and overgrazing), subsistence farming practices, loss of indigenous vegetation and colonization by invasive species (which bind the soil less well), disturbed lands associated with forestry and clear-felling of trees, and erosion associated with compaction of the soils in the road network. High intensity rain events also occur in this catchment. Management plans are recommended to be developed to limit erosion from this catchment.*

- *The very small Langa balancing dam catchment which comprises natural bush and grassland with forestry plantations appears in good condition with very limited potential for significant pollution issues in this dam.*
- *In terms of potential future land uses, if the proposed mining activities involving gas drilling through a process of hydraulic fracturing go ahead, this may impact water quality and the required water treatment process.*
- *Good long-term data records indicated that water quality measured to date in the Smithfield Dam catchment is generally satisfactory, with the exception of elevated turbidity, total organic carbon and phosphorus concentrations recorded during high intensity rainfall events (particularly the first flush of the summer rainfall period). Low conductivity results reflect that this water is likely to be aggressive and will require lime stabilization during treatment. There are no indications of elevated heavy metals such as copper, cobalt, lead or mercury and there are no known mining activities (other than for sand or stone). Similarly, the limited data record so far available indicated good water quality in the balancing dam catchment, but with elevated total phosphorus results in the summer high rainfall period.*
- *In-dam processes such as sedimentation of suspended material, biological processing of nutrients, predation and natural mortality of potential pathogens, and ultra-violet light disinfection are anticipated to improve surface water quality between the uMkhomazi Smithfield inflow and the proposed Smithfield Dam wall. Significant improvements will thus occur in recorded concentrations of suspended materials and the bacteriological quality of the river water, despite relatively short impoundment residence times.*
- *The algal response models predicted an average chlorophyll 'a' concentration from 5.7 – 5.8 µg/ℓ and a peak chlorophyll 'a' concentration of 16 µg/ℓ for the proposed Smithfield Dam. The anticipated trophic status of the proposed Smithfield*

Dam is mesotrophic - moderately enriched with nutrients, with occasional blooms of nuisance algal species.

- *The Smithfield Dam is likely to stratify thermally during summer (from October), with dam turnover (destratification) occurring around April, dependent on air temperatures and impoundment drawdown. The most severe stratification can be expected during February and will result in ca. 8-10 m of surface aerobic water being available for optimal abstraction. Water abstracted from below the oxycline is likely to cause treatment problems. At the onset of the annual impoundment turnover, anoxic water will be mixed into the water column, reducing dissolved oxygen concentrations throughout the water column. Elevated concentrations of metals which will be liberated from the sediments under anoxic conditions will thus be mixed through the water column at turnover. These metals may require additional treatment for removal and to avoid post-precipitation in final drinking waters. From information at impoundments in adjacent or nearby catchments, elevated concentrations of both iron and manganese may present a risk at these times.*
- *The impoundment size is relatively small compared to the Mean Annual Runoff and significant rain events are likely in the catchment at times. Under very severe storm conditions, inflows of highly turbid water may be sufficient to reach the abstraction zone or temporarily mix the dam (particularly if the impoundment is drawn-down). Under these conditions, significantly elevated turbidities are possible in the raw water abstracted from the impoundment.*
- *In order to allow abstraction from the aerobic zone as well as abstraction when the proposed Smithfield impoundment is significantly drawn-down, it is recommended that a number of abstraction levels are constructed at 6-8m intervals from Full Supply Level. Selection of the most favourable abstraction level will optimise raw water quality at the water works, reduce water treatment costs and facilitate compliance with potable water quality standards.*
- *In addition, a number of levels (at 10-15 m intervals) are recommended to be constructed for the proposed Smithfield Dam outlet works to minimise the impact of the dam and its management on the downstream aquatic life.*
- *A dam scour/river release is recommended to be constructed to be able to release dam bottom water during high summer inflows. Sleeve valves with dispersers are recommended to oxygenate the water used for environmental releases.*
- *Spilling is the recommended release mechanism when algal numbers are high and water levels permit. As far as possible, water for environmental flows is recommended to be distributed according to the natural flow patterns. The bottom*

scour/river release valves should be big enough to emulate natural flood events downstream.

- *A variable abstraction/environmental release mechanism is not recommended for Langa Dam.*
- *Water quality and biological (SASS) monitoring is recommended during the pre-construction, construction and operational phase of the proposed Smithfield Dam and the Langa balancing dam to assess impacts on the environment, and to optimise dam management.*

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ASPT	Average Score per Taxon
DRDLR	Department of Rural Development and Land Reform
DWA	Department of Water Affairs
E. coli	*Escherichia coli*
FSL	Full Supply Level
IDP	Integrated Development Plan
ITB	Ingonyama Trust Board
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
masl	metres above sea level
NEMP	National Eutrophication Monitoring Programme
SANS	South African National Standard
SASS5	South African Scoring System (version 5
SDF	Spatial Development Framework
SRP	Soluble Reactive Phosphorus (orthophosphate)
TOC	Total Organic Carbon

1 INTRODUCTION

The current water resources of the uMgeni System are insufficient to meet the long-term water demand for both domestic and industrial use in the Durban-Pietermaritzburg area. The Department of Water Affairs (DWA) is therefore exploring possible options to meet the vision of a reliable, efficient and sustainable water supply for the economic hub of KwaZulu-Natal.

Initial studies considered eight augmentation options to meet the long-term system requirements, with the Smithfield and Impendle Scheme options taken forward to the prefeasibility stage. The prefeasibility investigation, which concluded in 1999, recommended that the Smithfield Scheme be taken to a detailed feasibility level investigation.

In this regard, DWA is currently implementing a Technical Feasibility Study as part of Phase 1 of the uMkhomazi Water Project. Phase 1 of the uMkhomazi Water Project is proposed to comprise:

- A dam at Smithfield on the uMkhomazi River with a storage volume of 241 million m^3;
- Water conveyance infrastructure through a 32 km long tunnel and a raw water pipeline to a water treatments works in the uMlaza River catchment, and
- A gravity pipeline to the Umgeni Water bulk distribution system at Umlaas Road and further distribution under gravity through existing infrastructure to the eThekwini Metropolitan Municipal area.

A balancing dam will also be constructed on the Mbangweni River in the Baynesfield area to comply with the 21 day water storage requirement for tunnel inspection/maintenance. However, this balancing dam will only be used once in 5 years on average (abnormal operating conditions).

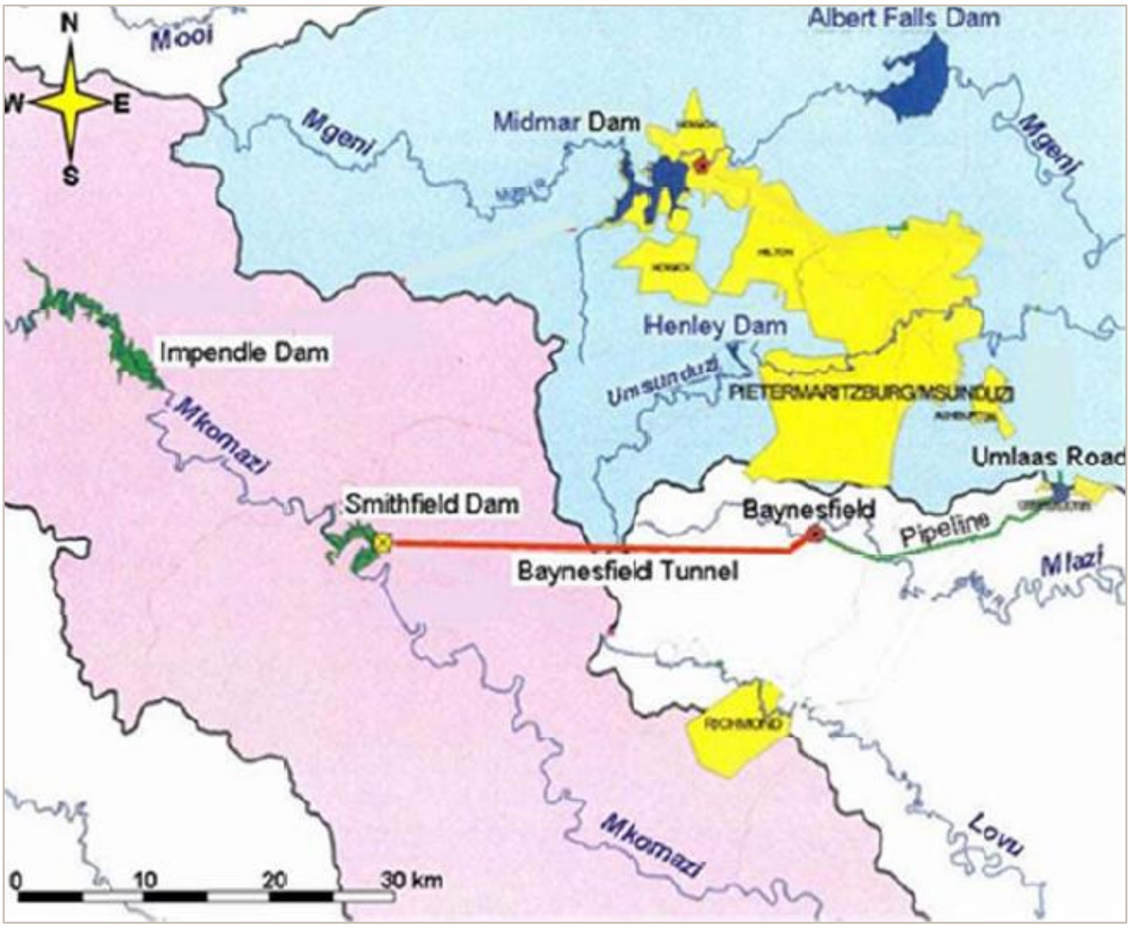

Figure 1.1: Overview of the proposed uMkhomazi Water Project

Phase 2 of the uMkhomazi Water Project comprises the construction of a second much larger storage dam at Impendle to release water to the downstream Smithfield Dam, and will only be implemented when needed.

This report contains the water quality component of the Technical Feasibility Study, and includes a water quality assessment of the water in the uMkhomazi River and predictions for the proposed Smithfield storage dam. Some consideration is also given to the water quality in the proposed balancing dam. The report thus focuses primarily on the water quality implications of Phase 1 of the uMkhomazi Water Project.

2 OBJECTIVES

The overall aim of this water quality assessment is to document the current water quality in the uMkhomazi and uMlaza Rivers, to predict the water quality in the proposed Smithfield Dam and the balancing dam and to establish whether any serious water quality constraints exist regarding the feasibility of Phase 1 of the uMkhomazi Water Project. Specific objectives are to:

- Assess the catchment land uses and activities upstream of the proposed impoundments and their potential impacts on water quality;
- Assess the water quality of the uMkhomazi raw water source and implications for water treatment;
- Predict the water quality of impounded water, implications for treatment and river release to the downstream environment, and recommend best management practices for abstraction, storage, fill and release, and
- Provide water quality information needed for the preliminary design of the proposed Smithfield and Langa Dams.

3 PROPOSED DAM CHARACTERISTICS

The characteristics of the proposed impoundments are listed in **Table 3.1** and the footprints of the proposed dams are shown in **Figure 3.1** and **Figure 3.2**.

Table 3.1: The characteristics of the proposed Smithfield Dam and Langa balancing dam

	Smithfield Dam	Balancing dam
Altitude of spillway (masl)	930	923
MAR (million m^3)	730.3	2.9
Catchment area (km^2)	2050	5
Gross storage (million m^3)	251	10.6
Retention time (storage/MAR – years	0.33	3.9
Flushing (times per year)	3.01	0.27
Surface area at FSL (km^2)	7.52	0.25
Maximum water depth at FSL (m)	82	38

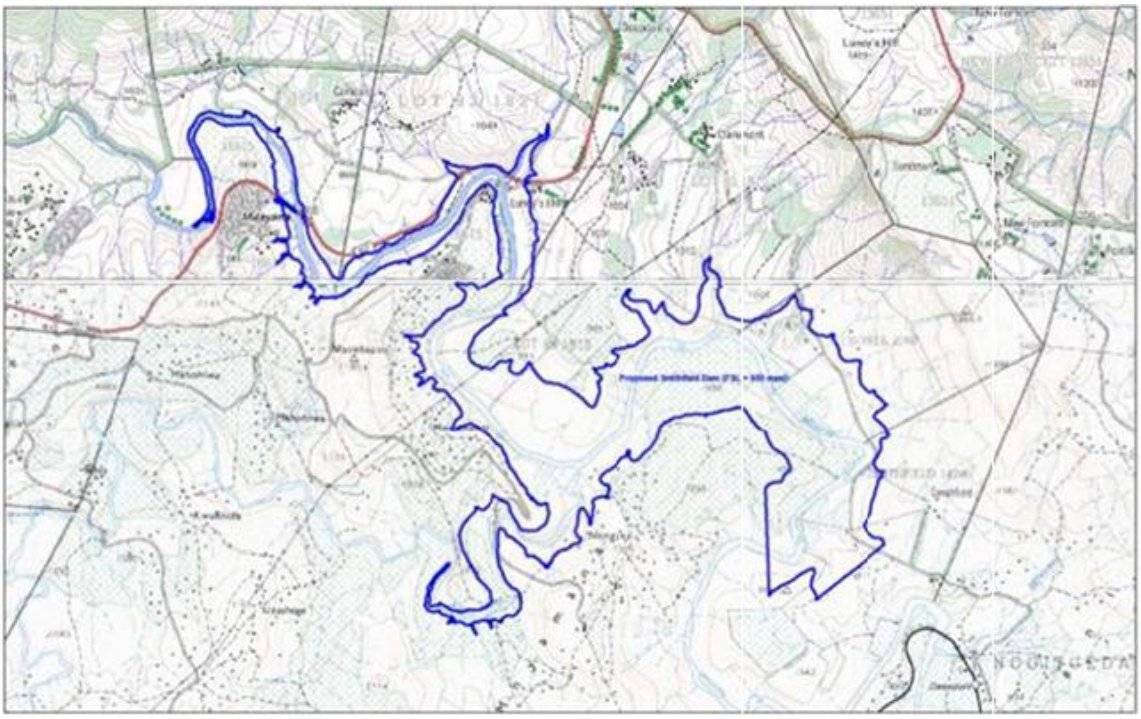

Figure 3.1: Footprint of the proposed Smithfield Dam

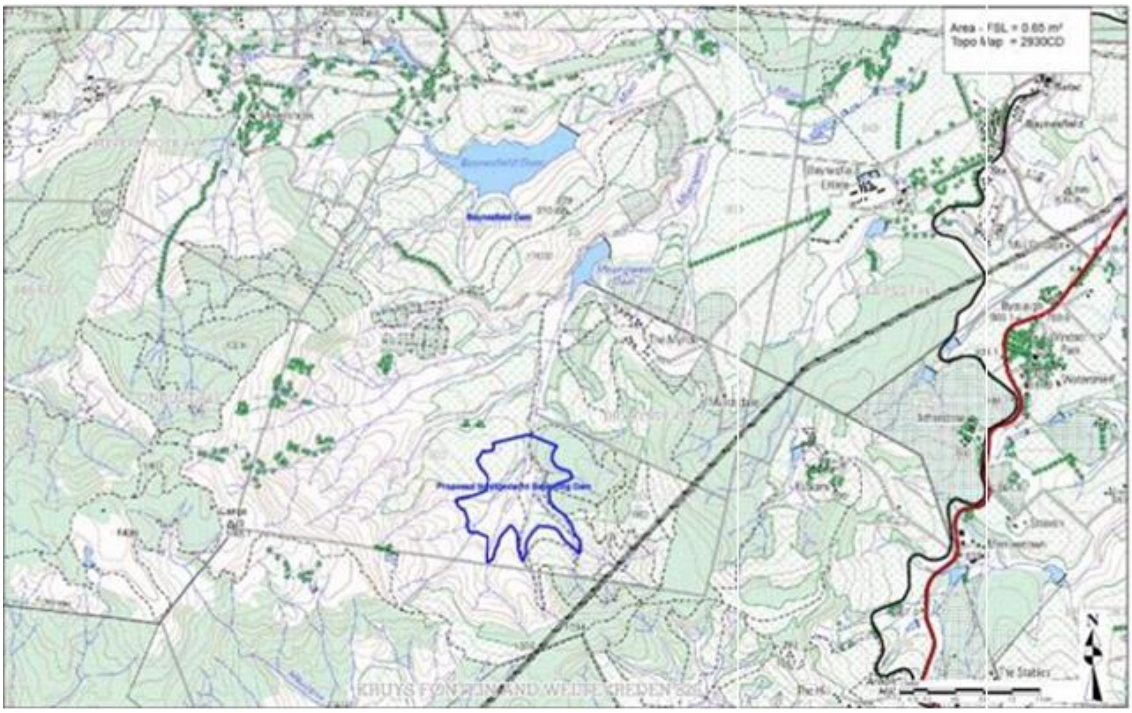

Figure 3.2: Footprint of the proposed balancing dam

4 CATCHMENT ASSESSMENT

4.1 CATCHMENT LAND COVER

The land cover maps in **Figure 4.2** and **Figure 4.3** show the major land use categories in the catchments of the proposed dams (*Source: Department of Agriculture, 2008*). The actual areas of each category of land cover and the percentage breakdowns are given in **Table 4.1**.

Table 4.1: Land cover in the proposed Smithfield Dam and Langa balancing dam catchments

Land cover	Smithfield Dam		Balancing dam	
	km^2	%	km^2	%
Unimproved (natural) grassland	1498.33	73.10	0.10	1.93
Degrade unimproved (natural) grassland	174.04	8.49	0.03	0.59
Thicket, bushland, bush clumps	137.03	6.69	2.36	46.92
Forestry: Plantations	101.33	4.94	0.93	18.50
Cultivated, temporary, subsistence, dryland	86.00	4.20	-	-
Indigenous forest	19.46	0.95	-	-
Waterbodies and wetlands	14.61	0.71	-	-
Urban/built-up (rural cluster)	8.49	0.41	-	-
Shrubland	6.96	0.34	-	-
Improve grassland	1.76	0.09	1.38	27.52
Bare rock and soil	1.55	0.08	-	-
Cultivated, temporary, commercial,	-	-	0.23	4.56
Totals	2049.57	100	5.02	100

The dominant land cover in the Smithfield Dam catchment is unimproved grasslands (some degraded). The catchment also comprises approximately 100 km^2 of plantations and some small areas of indigenous forest. The population is scattered in rural clusters in the catchment and some cultivated land with subsistence crops are also present. Limited riparian wetlands are found in the Smithfield Dam catchment.

The dominant land cover in the small balancing dam catchment is natural thicket and bushland, with some improved grasslands. Some acacia and eucalyptus plantations also occur in the catchment.

It should however, be noted that the Department of Agriculture 2008 land cover dataset does not accurately represent current land cover, and that wetlands are estimated to comprise at least 1% of the balancing dam catchment area.

Figure 4.1: Balancing dam catchment

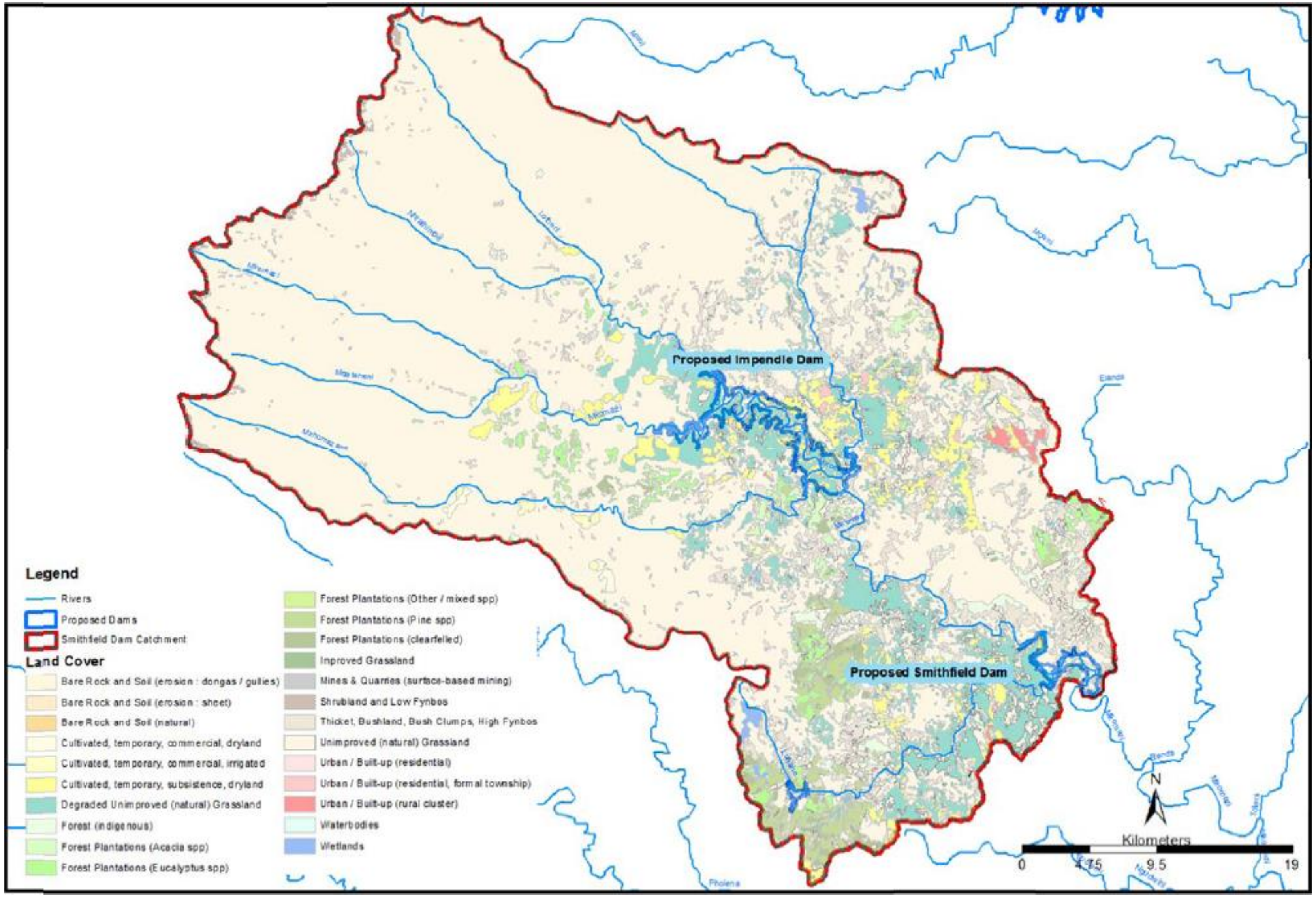

Figure 4.2: Land cover in the proposed Smithfield Dam catchment

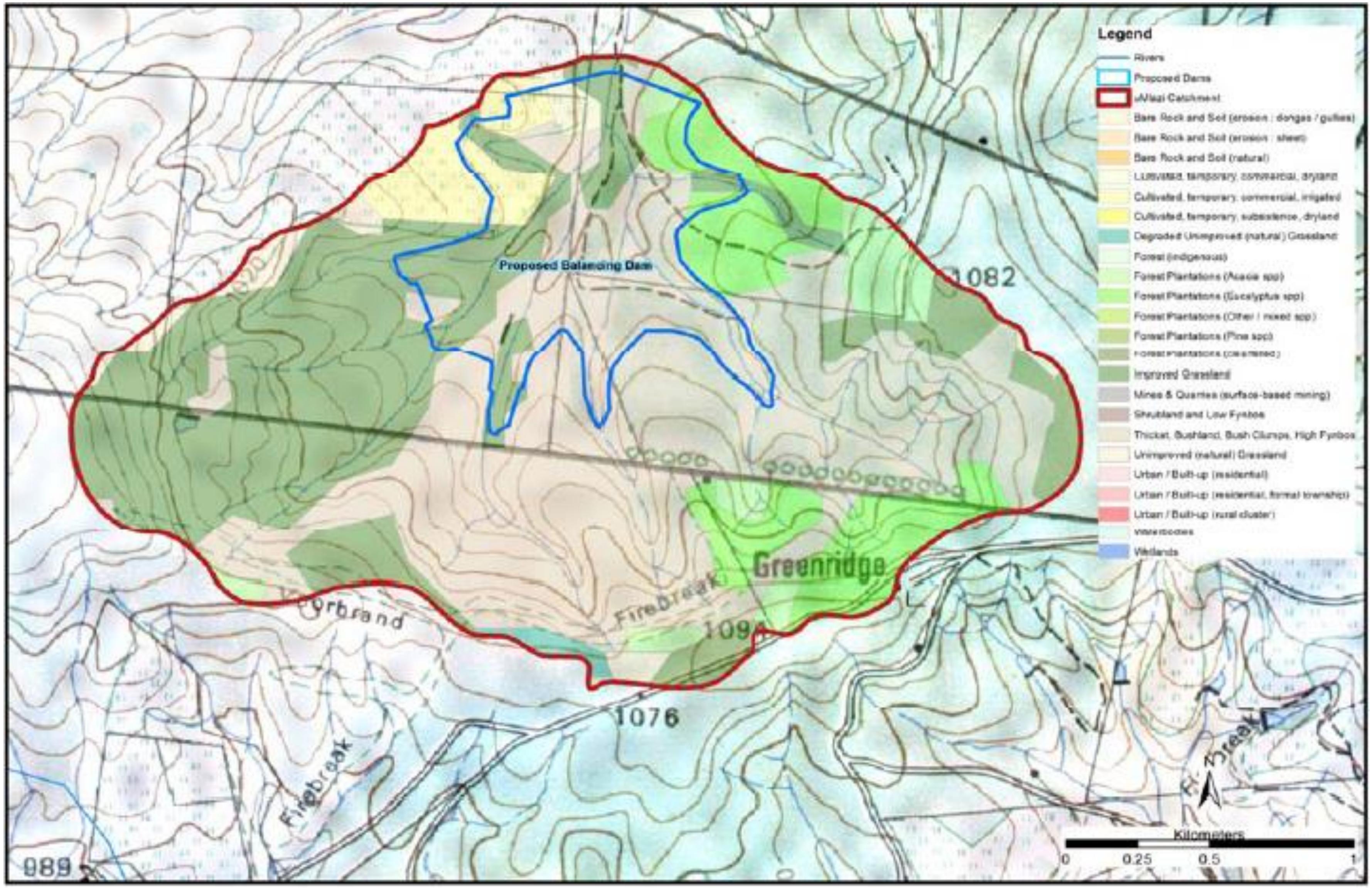

Figure 4.3: Land cover in the proposed Langa balancing dam catchment

4.2 CATCHMENT CONDITION AND POLLUTION POTENTIAL

4.2.1 uMkhomazi catchment

Maps, previous land cover assessments and historical reports were reviewed for background information. Google Earth images were also used, and areas of particular interest or representative of a board usage were identified. A suitable route was determined and a catchment assessment was undertaken on 16 April 2013 to consider catchment land uses and activities upstream of the proposed Smithfield impoundment that could potentially impact water quality. It should be noted that this catchment assessment was undertaken at the end of an above average rainfall summer period, with the implication that grass cover was likely to be at its peak and may have obscured some details.

Specific areas of the catchment were visited, including the proposed impoundment basin, the lower Luhane catchment and the uMkhomazana, uMkhomazi and the Nzinga catchments near their confluence. This was considered to be the area of the catchment most likely to determine water quality in the proposed impoundment.

The uMkhomazi River catchment originates within the Drakensberg at an elevation of approximately 3 300 m, with much of the upper reaches of the catchment above an altitude of 1 500 m. A significant component of the upper uMkhomazi, uMkhomazana and Lotheni catchments is uKhahlamba Reserve, a protected World Heritage Site. While some erosion does occur in these areas, it is limited by the restricted land uses in this protected area.

The remainder of the upper uMkhomazi River catchments and its main tributaries the uMkhomazana, Lotheni and Nzinga Rivers comprises narrow, incised river valleys and mountains with relatively steep slopes. Gradients become gentler towards the proposed Smithfield Dam site as can be seen in **Figure 4.4**.

Figure 4.4: Panoramic view of the vicinity of the proposed Smithfield Dam basin

The geology of the uMkhomazi catchment comprises mainly sandstones and shales as well as some intrusive Karoo dolerite outcrops. No significant heavy metals are known or likely. Soils observed during the catchment assessment were generally well-leached and evidence of clay content was observed in some rivers (particularly the Luhane tributary), where finer colloidal material was visible suspended in the river water.

The Mean Annual Precipitation (MAP) of the uMkhomazi River catchment reaches a maximum of 1 500 mm in the upper reaches of the Drakensberg. The central regions are generally the drier with an average MAP of 1 200 mm. In general, the catchment has a moderate climate, with summer rainfall characterised by afternoon thunder showers.

Significant areas of erosion were immediately obvious in the catchment. These included sheet and rill erosion as well as gully erosion. Some minor erosion control structures were observed in the Nzinga catchment. Areas of sheet erosion / bare soil and rock exposures were also noted on some steep slopes. A slope stability analysis of the dam basin will be undertaken as part of the uMkhomazi Water Project.

Figure 4.5: Sheet and rill erosion in the proposed Smithfield Dam basin

Figure 4.6: Gully erosion in the upper uMkhomazi catchment

While the overall human population of the proposed Smithfield Dam catchment is relatively low (approximately 200 000 (*Source: Statistics South Africa (Census 2011*), but with possible additional migratory workers returning on weekends/holidays), there are some areas of significant settlement, specifically in the Nzinga catchment (see **Figure 4.8**). These main settlement areas are generally dispersed, and of low to moderate density. Settlements are mostly along roads and on upland areas and the ridgelines at a significant distance from the main river channels.

Figure 4.7: Panoramic view of the upper uMkhomazi catchment looking towards the Drakensburg source, showing typical dispersed settlement patterns, pasturage and erosion

Figure 4.8: Panoramic view of the lower Nzinga catchment showing more dense settlement patterns

Service provision is at a low level. There are no significant sewage works in the catchment (with the exception of a package plant for the town of Bulwer on the Luhane River catchment boundary, and also possibly package plants at clinics/hospitals). Sanitation is mainly onsite in nature, and pit latrines predominate. However, due to the relatively low housing density, and also the location of most dwellings either high on ridgelines or else at the foot of slopes at some distance from surface water resources, the likelihood of serious direct pit latrine contamination remains low, even in cases of pits overfilling or being exposed to the surface runoff ingress problems. Pathogen contamination from human sources to surface water is not anticipated to be significant.

Some areas have power supplies, and limited communities have reticulated water. More remote settlement areas have neither. Rainwater harvesting and spring protection schemes dominate as water supply. Roads are mostly gravel and the road network density is moderate through the catchment. Some road related erosion was observed (**Figure 4.9**). The R617 main road is a significant transport corridor and undoubtedly carries hazardous loads, potentially affecting the catchment as a result of any spills. The most vulnerable area in this regard is the R617 immediately upstream of the impoundment basin, which would result in direct contamination in the case of spillages

Figure 4.9: Erosion associated with the road network in the Luhane catchment

Significant areas of subsistence agriculture were observed in the catchment assessment, with crops of maize, beans and potatoes being grown. High inputs of fertilizer and biocides are unlikely, so related contamination is likely to be minor. However, while not extensive in nature, in the lower Luhane catchment some pockets of formal agriculture were observed where maize crops were grown, likely as a small scale cash crop to supply the local community. Some usages of fertilizers and pesticides would be probable to ensure profitable yields from these crops.

Figure 4.10: Panoramic view of the lower Luhane catchment showing local cash crop agriculture

Communal gazing is practiced and animal densities (primarily cattle and goats, with some sheep also noted) were moderate to high relative to the carrying capacity of the land, and there were some indications of the significant over-gazing in some areas.

There are a number of dip tanks present in the catchment, but the risk of pesticide contamination is not perceived to be significantly high.

The loss of protective vegetation through deforestation, over-gazing, ploughing and fire makes soil vulnerable being swept away by wind and water. In addition, over-cultivation and compaction cause the soil to lose its structure and cohesion and it becomes more easily eroded. Erosion will remove the top soil first. Once this nutrient rich layer of soil is gone, few plants will grow in the soil again. Without soil and plants the land becomes dessert-like and unable to support life. Erosion associated with livestock was noticeable in several parts of the catchment, primarily as a result of animal and human trails eroding on the slopes, especially where there was access to water points from upland areas (see **Figure 4.12**).

On steeper slopes, some general over-gazing was observed and will be contributing to more general sheet erosion. As livestock watering is directly from surface streams (see **Figure 4.13**), there is some potential for pathogen introduction, likewise from overland transport during rain events. Protection of the riparian margins of streams is recommended.

Figure 4.11: Dip tank observed in the uMkhomazana catchment

Figure 4.12: Cattle trails contributing to soil erosion in the lower Luhane catchment

Figure 4.13: Cattle watering in the uMkhomazana catchment

While pockets of indigenous vegetation were observed on the steeper slopes in the catchment, there is significant invasion of alien species including Lantana (*Lantana camara*), Mauritius thorn (*Caesalpinia decapetala*), silver and black wattle (*Acacia dealbata* and *Acacia mearnsii*), peanut butter bush (*Cassia didymobotrya)* and syringe ((*Melia azedarach).*These alien invasive species represent a significant consumptive water use, and also contribute to destabilization of soils and exacerbating soil erosion (see Figure 4.14).

Figure 4.14: Alien invasive tree woodlot associated with significant erosion

Formal/commercial agriculture comprises mainly of forestry, particularly in the uMkhomazana catchment.

Figure 4.15: Panoramic view of the uMkhomazana catchment showing steeper slopes and timber plantations

Catchment practices associated with forestry that may affect water quality include burning of firebreaks in the winter period as well as trash burning along clear-felled areas. Runoff from these areas is likely to contribute to the elevated total organic carbon concentrations measured after heavy rainfall. Clear-felling also disturbs the land surface, leaving exposed areas of soil and increasing the potential for erosion.

Adequate setback distances from water courses were not always complied with (particularly in areas surrounding Bulwer), and alien invasive species were observed in water courses in the forestry areas.

Some limited and narrow riparian wetlands were noted, but are not a significant feature of the upper uMkhomazi catchment (estimated at 0.5% of the proposed Smithfield Dam catchment area).

Figure 4.16: Poor land cover after clear-felling in the uMkhomazi catchment in the Bulwer area

In summary, the most significant land uses and activities that present a risk to current or future water quality in the upper uMkhomazi catchment are presented in **Table 4.2**.

Table 4.2: Summary of current land cover issues affecting water quality of the proposed Smithfield impoundment

Land use/issue	Extent & severity	Water quality impact	Recommended remedial/ Preventative measures
Erosion (natural and accelerated)	Significant extent, moderate to major severity.	Increased impoundment turbidity and treatment costs, Sedimentation of impoundment.	Implement soil conservation measures and management plans to limit soil erosion. Educate communities on the economic benefit of soil conservation.
Animal Husbandry: associated overgrazing and livestock-related soil erosion	Extensive, Moderate-high severity relative to carrying capacity of land.	Increased impoundment turbidity and treatment costs, Sedimentation of impoundment, potential pathogen risk.	
Population-associated sewage provision, refuse removal, road network and potential for contaminated runoff	Low extent (approximately 8.5 km^2 in total and 0.4% of catchment) and low severity. Potential for increase in the next 20 years.	Pathogen contamination from human sources is anticipated to be low. The road network has an impact on soil erosion, and associated an increase in turbidity in the rivers and dam.	Improved managed of solid waste within urban municipal areas. Design of road networks to be correctly designed to limit erosion from embankments and storm water drains. Ensure adequate sanitation (Ventilated improved Pit latrines) for higher density housing and schools.
Timber	Moderate extent (approximately 100 km^2 and 5% of catchment) and low severity.	Increased impoundment turbidity and treatment costs, Sedimentation of impoundment associated with clear-felling. Elevated total organic carbon results associated with burning.	Improve setback distances from water resources where non-compliance with the 30m setback requirement.
Alien invasive terrestrial weeds	Extensive, moderate severity (but do tend to colonise river courses).	Consumptive water use and destabilization of soils, leading to increased soil loss and elevated river and dam turbidity.	Recommend a DWA Working for Water intervention upstream of the proposed Smithfield Dam.
Dryland farming	Limited extent (approximately 86 km^2 and 4% of catchment) and low severity.	Impacts of fertilisers and pesticides are limited. Some soil loss does occur.	Implement soil conservation methods and improve setback distances from rivers where necessary.
Transport Spillages	Unknown.	Potentially high, depending on substance transported.	An Incident Management Plan (as for the N3) is recommended to be developed, so that adequate reporting and mitigation can be taken.

4.2.2 Potential future land uses that could impact water quality

In consideration of the impact of climate change in the uMkhomazi catchment, the probable increase in the number of high intensity – short duration rainfall events that occur in this area, coupled with over-grazing, steep topography and limited wetlands poses a potentially serious detrimental impact on the land cover and soil erosion in the catchment and sedimentation in the impoundment in the future.

The uMkhomazi catchment is included in the area under threat of a mining activity involving gas drilling through a process of hydraulic fracturing, (see **Figure 4.17**). Water concerns associated with general natural gas and shale gas extraction including hydraulic fracturing, are already well known.

Figure 4.17: Map showing operator permits in the Karoo basin, South Africa for shale gas exploration and prospecting

Potential risk to surface and underground sources of drinking water might occur at various points in the hydraulic fracturing process. Contaminants of concern to drinking water include fracturing fluid chemicals and degradation products and naturally occurring materials in the geologic formation (for example metals, radionuclides) that are mobilized and brought to the surface during the hydraulic fracturing process. The likelihood of such activity in this area needs to be confirmed.

In terms of future land use planning in the Smithfield Dam catchment, relevant Integrated Development Plans and Spatial Development Frameworks were considered and revealed the following:

- The western portion of the proposed dam site is Ingonyama Trust Board (ITB) land. ITB land is also located in Impendle Municipality on the eastern and northern banks of the uMkhomazi River as well as on the Mgatsheni River, a tributary on the uMkhomazi River upstream of the proposed dam site. There are two leases for health centres from ITB as well as some commercial leases which are predominantly taverns (*ITB, 2013*).
- Impendle Municipality has its primary node at Impendle which is the area in which primary commercial and residential development will be focused. An urban edge has been defined for the Impendle town and secondary nodes are Lower Lotheni, Stepmore, Nzinga, Stoffelton and Boston. Nzinga and Stoffelton are proposed to be "rural economic nodes with a focus on general commercial and market activity together with basic services". Lower Lotheni is proposed to develop a "specialist tourism node which will allow for the development of eco-tourism related economic activity, bringing tourists in through a mini-gateway to this section of the Drakensberg World Heritage Site" (*Impendle Municipality, 2013*).
- Impendle's Spatial Development Framework (SDF) identified the above-mentioned nodes and the land uses of "protected areas", "environmental/limited grazing", "arable land" and grazing/limited arable" (*Impendle Municipality, 2013: 48*).
- KwaSani's SDF identifies the proposed land uses of "environmental priority zone", "areas of conservation" and "commercial agricultural areas" (*KwaSani Municipality, 2013: 25*).
- Within Ingwe Municipality, the EKZN-W "Impendle" Conservation site is located upstream of the proposed dam site.
- The proposed land uses identified in Ingwe's SDF are "agriculture/tourism" and "traditional authorities" (*Ingwe Municipality, 2012: 191*).
- The proposed dam site is located on land that is subject to a land claim (*DRDLR, 2012*).
- The proposed Bulwer Dam (Greater Bulwer-Donnybrook Bulk Water Supply Scheme) is located on the Luhane River which is a tributary of the

uMkhomazi River (the proposed Smithfield Dam is located at the confluence of the Luhane and uMkhomazi Rivers). The Greater Bulwer- Donnybrook Bulk Water Supply Scheme is proposed to provide an assured supply of potable water for the settlements within Ingwe Municipality.

Overall, these proposed development plans do not present a substantial risk in terms of their likely impact on water quality. However, the provision of an assured water supply in the Bulwer area is likely to promote development in that area, and may have some impacts on water quality.

Generally, the upper uMkhomazi catchment is considered to be in moderately good condition, with low potential for serious pollution issues in the proposed dam. The greatest danger to water quality in the Smithfield impoundment would be from an increase in the current erosion, and if there were any significant changes in land use from the natural to either cultivated or urban land.

Protection of the water quality of the resource will ultimately depend on wise catchment management initiatives and decisions being taken. Multi-stakeholder involvement and cooperation of regulatory bodies, including the Department of Water Affairs and the Department of Agriculture, will be necessary, and particular emphasis is recommended to be placed on soil conservation and agricultural extension activities to control animal populations and cultivated lands. Management plans are recommended to be developed to limit erosion from this catchment.

Once the upstream Impendle Dam is constructed, a number of potential risks at Smithfield Dam will be significantly reduced, as the Impendle Dam will act as a substantial barrier to movement, and increase retention time and assimilative capacity.

4.2.3 uMlaza catchment

The Langa balancing dam catchment, which comprises mainly natural bush and grassland with some plantations and alien vegetation, appears in reasonable condition with limited potential for significant pollution issues in this balancing dam. Some areas of sugar cane are also present in this catchment. The Google Earth images do not indicate significant erosion.

Figure 4.18: Google Earth image of the balancing dam catchment

5 WATER QUALITY ASSESSMENT

5.1 WATER QUALITY MONITORING

Water quality samples have been collected by Umgeni Water for a wide range of constituents at a number of sample points in the uMkhomazi catchment in the vicinity of the proposed Smithfield Dam (see **Figure 5.3**):

- RMK002 – uMkhomazi River at Lundy's Hill weir (also known as the uMkhomazi Smithfield inflow), at varying frequencies:
  - Mar-1996 to Nov-2000: Weekly
  - Dec-2000 to Sep-03: Fortnightly
  - Oct-2003 to Feb-07: Annual
  - Mar-07 to present: Fortnightly

This is the most relevant sample point used for this uMkhomazi Water Project Phase 1 Water Quality Assessment.

- RMK009 – Luhane Smithfield inflow at a monthly frequency from mar-07 to present.

In the upper uMkhomazi catchment in the vicinity of the proposed Impendle Dam, three sample points at varying frequencies (between weekly and annual frequency since 1996):

- RKZ001 - uMkhomazana upstream of uMkhomazi confluence
- RNZ001 - Nzinga upstream of uMkhomazi confluence
- RMK001 - uMkhomazi at confluence of uMkhomazana and Nzinga

In the receiving uMlaza River catchment, water quality monitoring was set up in October 2012 at a monthly frequency at the following sites:

- RBY001 – uMlaza Baynesfield Dam inflow
- DBY001 – Baynesfield Dam integrated
- RMBG001 – Mbangweni Dam inflow

Figure 5.1: Sample point at uMkhomazi River at Lundy's Hill weir

Figure 5.2: Sample point at Luhane Smithfield inflow

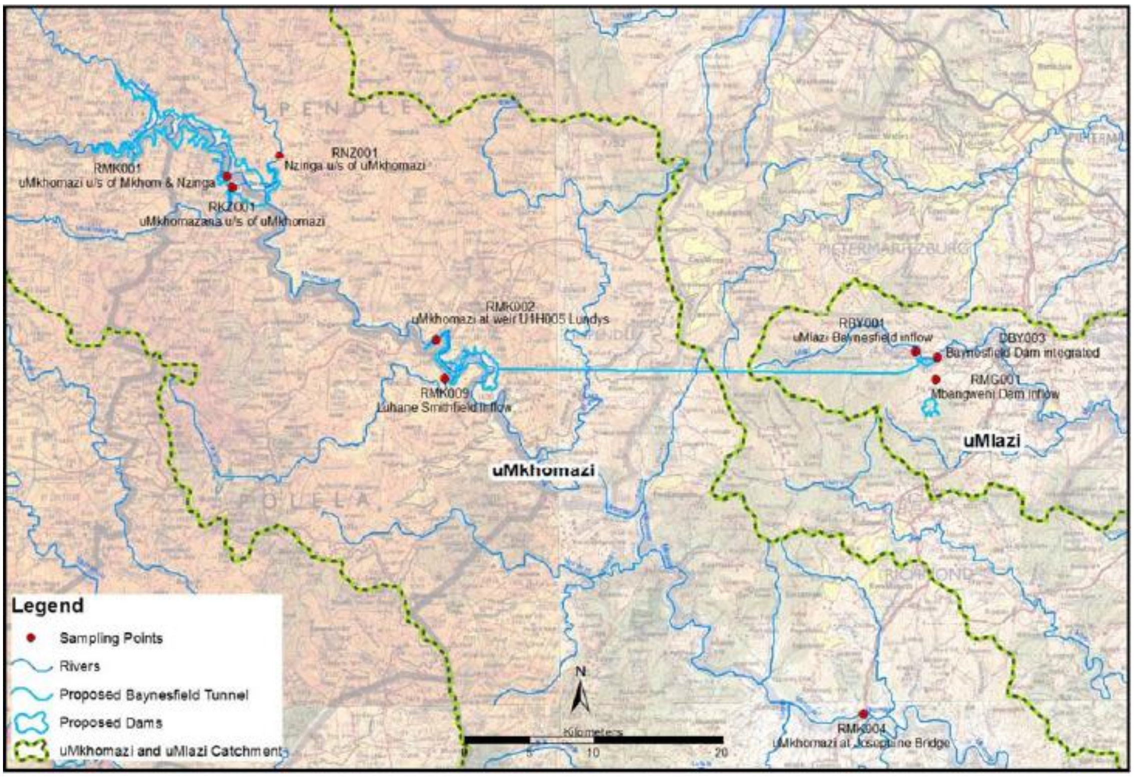

Figure 5.3: Location of routine water quality sample points

In the uMkhomazi catchment, there are thus good water quality data available for the water quality assessment, with samples that were taken over both the drier winter period and the summer high rainfall period, thus providing an indication of the average and some of the poorest water quality conditions. However, it should be noted that the more frequent weekly sampling period between 1996 and 2000 generally indicates higher peak values compared to the more recent fortnightly sampling frequency, suggesting that the impact of extreme events is not as well qualified in the more recent sampling period.

In the uMlaza receiving catchment for the balancing dam, only limited data are available and as the statistics are based on few results, the findings must be viewed with caution.

Summary statistics and times series, percentile and box-and whisker plots of relevant data for key water quality determinands are presented in **Annexures 1** to **4**. Where data were below the analytical detection limit, half of the detection limit was used to calculate statistics, unless all results were below the detection limit.

5.2 CURRENT WATER QUALITY STATUS

5.2.1 uMkhomazi catchment

a) *pH*

pH values ranged between 6.3 and 8.9, with a median pH at the uMkhomazi River at Lundy's Hill weir site of 7.8, which is in the range of the most natural waters. Very similar pH values were recorded at the Luhane Smithfield inflow site.

b) *Microbiology*

The E.coli counts (used as an indicator of potential pathogen risks) recorded at the uMkhomazi River at Lundy's Hill weir site were low-moderate, with a median of 110 per 100 mℓ and the 95th percentile of 2500 per 100 mℓ. Faecal contamination is primarily associated with rainfall-related run-off during the summer high rainfall months and is thus likely to be linked to sporadic faecal contamination from human and animal sources. Slightly higher E.coli counts were recorded at the Luhane Smithfield inflow, with a median of 240 per 100 mℓ and a 95th percentile of 2612 per 100 mℓ, possibly due to significant cattle numbers observed at this sample point.

Figure 5.4: Numerous cattle observed in the vicinity of the Luhane Smithfield inflow sample point

The median *E. coli* count recorded at the at the uMkhomazi Smithfield inflow (110 per 100 mℓ) was lower than the DWAF *E. coli* target water quality guideline for full contact recreation (median of 130 per 100 mℓ), thus posing a low risk of gastrointestinal illnesses among potential swimmers and bathers in the uMkhomazi River. Impoundment storage will further reduce numbers significantly. Similarly, pathogen numbers are likely to be low in abstracted water, but there may still be potential for cattle borne *Cryptospordium* and *Giardia* to be present in low numbers during times of high rainfall/flushing.

c) ***Conductivity and dissolved salts***

The median conductivity value recorded at the uMkhomazi Smithfield inflow site (6.3 mS/m) indicates very low dissolved salt concentrations. Median calcium and magnesium concentrations are also low (6.3 and 2.6 mg/ℓ respectively) reflecting a soft water which is likely to be aggressive and will require lime stabilisation. Conductivity results were higher during the winter period and decreased with dilution after the summer rains. Slightly higher conductivity values were recorded at the Luhane Smithfield inflow (median 9.3 mS/m, 95^{th} percentile 12.7 mS/m).

d) ***Total organic carbon***

Total organic carbon (TOC) results were low to moderate (median 1.9 mg/ℓ, 95^{th} percentile 4.3 mg/ℓ), but some very high results (up to a maximum of 19.6 mg/ℓ) were recorded at the uMkhomazi Smithfield inflow. In all cases, these significantly elevated concentrations were clearly associated with rainfall patterns, and in particular, the first significant rainfall event and flush of contaminants off the catchment. Since there is significant burning in the upper uMkhomazi catchment by both the community (for improved grazing after the spring rains) and the commercial forestry sector (large fire breaks) during the winter period, the elevated TOC concentrations associated with the first flush are likely to be related to the wash off of carbon compounds resulting from burning, and as such, are unlikely to pose a problem for the impoundment or water treatment.

Slightly lower TOC concentrations were recorded at the Luhane Smithfield inflow (median 1.9 mg/ℓ, 95^{th} percentile 3.9 mg/ℓ).

e) *Colour*

Colour results were generally low to moderate (with a median of 5.8 °H and a 95^{th} percentile of 37.5 °H), but elevated results were highly associated with rainfall patterns. Some very high colour results and were recorded during the first significant summer rainfall (up to a maximum of 147 °H). Elevated colour results are related to the wash off of humic compounds from the soils and vegetation. Tillage and planting into previously fallow fields which exposes partially decomposed organic compounds would exacerbate the runoff into the river and elevate the water colour.

f) *Turbidity and suspended solids*

Significant and severe soil erosion was noted some parts of the in the proposed Smithfield Dam catchment and would contribute to moderate median turbidity and suspended solids concentrations of 13 NTU and 21.6 mg/ℓ respectively. The upper catchment steep slopes and erodible soils are associated with natural soil erosion and the production of sediments, but a number of catchment practices and activities contribute to accelerated soil erosion in the uMkhomazi catchment. These practices include cattle/goat related erosion (trails, overgrazing and pasture burning), subsistence farming practices carried out by the local communities on tribal land, loss of indigenous vegetation and colonization by invasive species (which bind the soil less well), disturbed lands associated with forestry and clear-felling of trees, and erosion associated with compaction of the soils in the road network.

However, as with total organic carbon, there was a strong relationship between turbidity/suspended solids and rainfall as seen by high 95th percentile values of 328 NTU and 104 mg/ℓ and the elevated concentrations during the summer period. Most transport into the proposed dam will thus occur during times of heavy rainfall and high inflow. Turbidity results from the Luhane Smithfield inflow indicated a lower 95th percentile value (150 NTU), but this is more likely to be associated with a shorter data record and lower frequency monitoring than a significant lower turbidity from this subcatchment. Notably elevated 95th percentile values of 646 NTU and 585 mg/ℓ were measured in the uMkhomazi River upstream of the uMkhomazana and Nzinga confluence.

The bed load of sand is unknown but is presumed to be significant; although it should not directly influence water quality, it will lead to infilling of the basin.

The catchment assessment also indicated relatively high clay content in the soils in places, and this fine colloidal material may remain suspended in the impounded water in the dam.

g) ***Iron and manganese***

Relatively low manganese concentrations were recorded at the uMkhomazi Smithfield inflow site (median 0.03 mg/ℓ, 95th percentile 0.14 mg/ℓ). Iron concentrations, however, were elevated (median 0.32 mg/ℓ, 95th percentile 1.48 mg/ℓ) and strongly associated with summer rainfall and high turbidity values.

Dam sediments are thus likely to produce soluble iron and manganese under anaerobic summer conditions, which could affect abstracted water.

h) ***Nutrients - Phosphorus***

The DWAF Aquatic Ecosystems Guidelines (1996) state that an average summer soluble reactive phosphorus concentration between 5 and 25 µg/ℓ is indicative of mesotrophic conditions. The average summer soluble reactive phosphorus concentration was calculated as 6.6 µg/ℓ at the uMkhomazi Smithfield inflow site. Hence the Smithfield Dam catchment can be classified as a mesotrophic system, which means that it is likely to have high levels of biodiversity, and low to moderate algal growth. Some elevated soluble reactive phosphorus results were recorded when samples were taken after heavy rainfall (up to 50 µg/ℓ). If elevated soluble reactive phosphorus concentrations are maintained, this may lead to algal blooms developing at times, with nuisance algal species (*Microcystis* and *Anabaena*).

Elevated total phosphorus results were also associated above average rainfall recorded in the proposed Smithfield dam catchment over the past summer period (95^{th} percentile 157 µg/ℓ, but a first flush related maximum of 1988 µg/ℓ).

i) ***Nutrients - Nitrogen***

Average summer inorganic nitrogen concentrations were calculated to be 0.18 mg/ℓ at the uMkhomazi inflow to the proposed Smithfield Dam site, indicating oligotrophic trophic conditions (*DWAF Aquatic Ecosystem Guidelines, 1996*). Oligotrophic systems (average summer inorganic nitrogen concentrations of <0.5 mg/ℓ) usually have moderate levels of biodiversity, and low algal growth. This trophic status classification does not correspond to the classification for phosphorus, and an overall classification of oligo-mesotrophic is considered to be representative of the overall nutrient status of the proposed Smithfield Dam catchment.

In addition, an evaluation of the inorganic nitrogen to inorganic phosphorus ratio yielded an N: P ratio of 37:1, which confirms a generally unimpacted system. The DWAF Aquatic Ecosystem Guidelines (*DWAF, 1996*) states that unimpacted systems typically have an N:P ratio greater than 25-40:1.

j) ***Toxics – un-ionised ammonia***

Un-ionised ammonia can be highly toxic above certain concentrations in that it affects the respiratory systems of many animals by inhibiting cellular metabolism and decreasing the oxygen permeability of cell membranes (DWAF Aquatic Ecosystem Water Quality Guidelines, 1996). Un- ionised ammonia concentrations (which are directly related to water temperature and pH) were low at the proposed Smithfield Dam inflow site, with a median concentration of 0.7 µg/ℓ. The 90^{th} percentile value used to evaluate the effects of free ammonia on aquatic ecosystems was 3.57 µg/ℓ, thus within the Target Water Quality Range of $\leq$ 7 µg/ℓ, indicating a low risk of toxicity to aquatic life.

k) ***Toxics - metals***

Heavy metal concentrations were generally very low at the proposed Smithfield Dam inflow site with many results below the analytical detection limit. All heavy metal results measured at the uMkhomazi weir at Lundy's Hill were below the SANS 241: 2011 drinking water limit for final waters, with the exception of a single lead (29.9 µg/ℓ on 12-Mar-07) and cadmium (5.5 µg/ℓ on 08- Dec-11) result, both associated with elevated turbidity. The underlying geology of the catchment is thus unlikely to contain significant amounts of these metals, and they should not be a risk factor for abstracted water.

l) ***Aquatic ecosystem status - river health***

The South African Scoring System (SASS5) Average Score per Taxon (ASPT) was used to assess aquatic organism diversity at the uMkhomazi River at Lundy's Hill weir. The uMkhomazi River at Lundy's Hill weir falls in the South Eastern Uplands-Upper Ecoregion of KwaZulu Natal and the scores indicated in **Annexure 1** were used to classify the ecological category. The median value of the ASPT was 7.4, indicating an *unmodified natural* score for the majority of the time. At times, however, the river health was modified, with a 10th percentile value of 6.5.

Overall, the uMkhomazi River at the proposed dam site is considered to be in a natural ecological condition, and the DWA scoring system for assigning sites to a River Class places the uMkhomazi River at Lundy's Hill in a Class A.

m) ***uMlaza catchment***

Since monthly monitoring only commenced in Oct-2012, only six samples have been considered for this assessment and as the statistics are based on few results, the findings must be viewed with caution. However, since the samples were taken in an above average summer rainfall period, they will generally be biased towards elevated results for determinands associated with significant rainfall-runoff events.

The most relevant sample point for the proposed balancing dam is the Mbangweni inflow sample point which is located approximately 1 km downstream of the proposed balancing dam. However, the Baynesfield Dam inflow will also provide comparable results.

- All pH results ranged from 7 to 8.2, within the range of natural waters;
- *E. coli* counts were moderate with summer median values of 250 and 343 per 100 mℓ at the Mbangweni and Baynesfield Dams inflows respectively. 95th percentile *E. coli* counts ranged between 350 and 662 per 100 mℓ. Significant in-dam improvement of bacteriological quality was recorded with

median counts of 18 per 100 mℓ, and 95th percentile count of 98 per 100 mℓ at the Baynesfield Dam integrated sample point;

- Low conductivity results were recorded in the upper uMlaza catchment (< 8 mS/m), associated with low dissolved salt concentrations;
- Moderate total organic carbon results were recorded with median concentrations of 2.37 and 2.26 mg/ℓ at the Mbangweni and Baynesfield Dams inflows respectively. However, the first flush of significant rainfall in the catchment, recorded elevated TOC concentrations of up to 4.75 mg/ℓ.
- A low median colour result of 3.95 °H was noted at both inflow sites. Significant catchment rainfalls resulted in elevated colour results of up to 11.8 °H.
- Turbidity results collected in summer in the upper uMlaza catchment were moderate. The Mbangweni Dam inflow turbidity results (median 25.8 NTU, 95th percentile 45.4 NTU) were higher than the Baynesfield Dam inflow results (median 10.9 NTU, 95th percentile 27.1 NTU).
- In terms of nutrient trends, average summer soluble reactive phosphorus concentrations were 3.7 and 5.4 µg/ℓ for the Baynesfield Dam inflow and Mbangweni Dam inflow respectively, indicating oligo-mesotrophic conditions. However, the average total phosphorus concentration was significantly higher at the Mbangweni Dam inflow (69 µg/ℓ) compared to the Baynesfield Dam inflow (41 µg/ℓ). Average summer inorganic nitrogen concentrations were calculated to be 0.6 and 0.5 mg/ℓ at the Baynesfield Dam inflow and Mbangweni Dam inflow respectively, indicating mesotrophic conditions.
- In terms of toxic metals, all results were less than the analytical detection limit, with the exception of a single chromium result (9.65 µg/ℓ) at the Baynesfield Dam inflow, significantly less than the SANS 241: 2011 limit of 50 µg/ℓ for drinking water.

Overall, the quality of water flowing into the proposed balancing dam (relevant only under abnormal operating conditions when the tunnel is being inspected or maintained) was good to satisfactory.

5.3 PREDICTED WATER QUALITY STATUS ON IMPOUNDMENT

5.3.1 Water quality improvement

The proposed Smithfield impoundment is of similar basin morphology to Inanda Dam – relatively long and sinuous, with resulting water quality benefits. In-dam processes such as sedimentation of suspended material will improve surface water quality between the uMkhomazi and Luhane inflows and the proposed Smithfield Dam wall. Significant reductions in concentrations of turbidity, suspended solids, iron, manganese and total phosphorus are expected with impoundment.

Based on measured data from other impoundments in the Umgeni Water operational area (paired data from the past three hydrological years), annual median, average and 95th percentile percentage reduction in turbidity results between the inflow and main basin integrated sample ranged from:

- Inanda Dam (average retention time 1.5 years, impounded river length 17.7 km):
  - Median 90% - 93%, average 93% - 94%, 95th percentile 94% - 95%
- Midmar Dam (average retention time 1.25 years, impounded river length 7.7 km):
  - Median 72% to 83%, average 70 – 81%, 95th percentile 62% - 83%
- Nagle Dam (average retention time 2 months, impounded river length 6.3 km):
  - Median 30% - 54%, average 35% - 53%, 95th percentile 23% - 53%

With a retention time of 0.3 years and an impounded river length of 11.6 km at full supply level for the proposed Smithfield impoundment, median, average and 95th percentile turbidity (and associated determinands) are anticipated to decrease by at least 50% from the uMkhomazi Smithfield inflow to the main basin site under most conditions.

Table 5.1: Predicted turbidity statistics the proposed Smithfield Dam

	Measured uMkhomazi Smithfield inflow	Predicted Smithfield impoundment integrated
Median turbidity (NTU)	13.3	6.7
Average turbidity (NTU)	90.8	45.4
95th percentile turbidity (NTU)	328	164

However, while the dam should be well flushed during in the summer high rainfall period with a water residence time of several months, significant flood event warmer water inflows during the summer period may ride over cooler in-dam water, and possibly form a density current of more turbid water that may reach abstraction intakes directly. The impoundment size is relatively small compared to the MAR and under very severe storm conditions, inflows of highly turbid water may be sufficient to reach the abstraction zone or temporarily mix the dam (particularly if the impoundment is drawn-down). Under these conditions, significantly elevated turbidities are possible in the raw water abstracted from the impoundment.

For this reason, it is not appropriate to apply a 50% reduction to the maximum turbidity measured at the uMkhomazi Smithfield inflow to the main basin site. Maximum turbidities predicted in the Smithfield impoundment may therefore only decrease between 10 - 25% from the maximum turbidity measured at the uMkhomazi Smithfield inflow (5 530 NTU at the river inflow to between 4 000 and 5 000 NTU at the impoundment main basin as a worst case for a short duration). This prediction should, however, be treated with caution for design purposes since it is dependent on how representative the historical data record is.

Also, it should be noted that the catchment assessment highlighted clay content in some of the soils, and this fine colloidal material may remain suspended in the impounded water in the dam and may not flocculate naturally or sediment easily. This is particularly relevant in summer when the majority of the sediment load will be entering the dam, and the impoundment retention time will be low (approximately 3 months) – but may result in the advantage of not requiring bentonite dosing at the water works to improve coagulation.

The bacteriological quality of the river water is also predicted to improve significantly on impoundment. This improvement in bacteriological quality is associated with bacteriological removal due to sedimentation, predation and natural mortality and ultra-violet light disinfection. Based on measured data from other impoundments in the Umgeni Water operational area, annual median and average percentage reduction in *E. coli* between the inflow and main basin integrated sample range from:

- Inanda Dam (average retention time 1.5 years, impounded river length 17.7 km):
  - Inanda Dam: median 99% - 100%, average 91% - 100%, 95th percentile 49% - 96%
- Midmar Dam (average retention time 1.25 years, impounded river length 7.7 km):

- Midmar Dam : median 98% to 99%, average 91 – 99%, 95th percentile 93% - 99%

- Nagle Dam (average retention time 2 months, impounded river length 6.3 km):
  - Nagle Dam: median 74% - 90%, average 15% - 74%, 95th percentile 3% - 59%

Median, average and 95th percentile *E. coli* counts are anticipated to decrease by at least 75% from the uMkhomazi Smithfield inflow to the main basin site.

Table 5.2: Predicted E.coli statistics in the proposed Smithfield Dam

	Measured uMkhomazi Smithfield inflow	Predicted Smithfield impoundment integrated
Median *E. coli* (per 100 mℓ)	110	28
Average *E. coli* (per 100 mℓ)	559	140
95th percentile *E. coli* (per 100 mℓ)	2500	625

As with turbidity, maximum *E. coli* counts cannot be predicted using a 75% reduction from the uMkhomazi Smithfield inflow to the main basin site since major rainfall runoff events are likely to cause some "short circuiting" of inflow water through to the abstractions and reduce the impoundment residence times significantly. A 25% reduction in maximum *E.coli* counts recorded at the uMkhomazi Smithfield inflow (13 000 per 100 ml) is a more likely worst-case scenario, resulting in a prediction of a maximum *E. coli* of approximately 10 000 per 100 ml at the impoundment main basin site for a limited duration. It is also possible that protozoan parasites (*Cryptosporidium* and *Giardia*) may be present at these times.

Proposed balancing dam: Sedimentation of suspended material and improvement in bacteriological quality will also occur in the proposed balancing dam, but the degree of improvement will depend on the way in which this impoundment is operated. However, considering the long retention time (storage/MAR) in this proposed impoundment (3.9 years), the assimilative capacity and associated improvement in water is anticipated to be very significant.

5.3.2 Algal response

Algal growth in impoundments in South Africa is primarily limited by the amount of phosphorus available for uptake. However, flushing or retention time is also considered to play a major role in limiting algal growth in the impoundment.

Empirical OECD models, that predict average and peak chlorophyll 'a' concentrations from the inflow total phosphorus concentration and retention time in the impoundment, were used to predict the algal response in the proposed Smithfield Dam (*OECD, Eutrophication of Waters, 1982*). The Updated Vollenweider – OECD model was also used to verify the predictions of the OECD model (*Jones & Lee, 1986*). While these models were not specifically developed for use in South African or southern hemisphere conditions, previous work has indicated that the OECD model is relevant for South African conditions (*Harding, 2004; Thornton and Harding, 2005*).

Table 5.3: Results of the Algal Response modelling exercise for the proposed Smithfield Dam

Average Inflow Total Phosphorus (μg/ℓ)	50.3#
Predicted Average Chlorophyll '*a*' (μg/ℓ) – OECD model	5.7
Predicted Average Chlorophyll '*a*' (μg/ℓ) – Updated Vollenweider-OECD model	5.8
Predicted Peak Chlorophyll '*a*' (μg/ℓ) – OECD model	16.0

* *Measured Average Total Phosphorus concentration*

The OECD and the Updated Vollenweider – OECD model predict an average chlorophyll '*a*' concentration of 5.7 - 5.8 μg/ℓ for the proposed Smithfield Dam using the measured total phosphorus data. The OECD model predicted peak chlorophyll '*a*' concentration of 16.0 μg/ℓ. Based on the OECD classification, the anticipated trophic status of the proposed Smithfield Dam is mesotrophic. Mesotrophic systems are moderately enriched with nutrients and have occasional blooms of nuisance algal species (average chlorophyll '*a*' concentration 2.5 - 8.0 μg/ℓ, maximum chlorophyll a concentration 8.0 - 25.0 μg/ℓ).

However, the DWA National Eutrophication Monitoring Programme (NEMP) classification system classifies an average chlorophyll '*a*' concentration of 5.7 - 5.8 μg/ℓ and a peak chlorophyll '*a*' concentration of 16.0 μg/ℓ as **oligotrophic** with a **negligible** nuisance value of algal bloom productivity.

Table 5.4: Trophic Status Classification for National Eutrophication Monitoring Programme

Trophic Status				
Mean annual chlorophyll ‘ a’ (µg/ℓ)	0 < x ≤ 10	10 < x ≤ 20	20 < x ≤ 30	> 30
	Oligotrophic (low)	Mesotrophic (moderate)	Eutrophic (significant)	Hypertrophic (serious)
Nuisance value of algal bloom production				
% of time chlorophyll *a* *>30* µg/ℓ	0	0 < x ≤ 10	0 < x ≤ 10	> 50
	Negligible	Moderate	Significant	Serious

To covert chlorophyll ‘*a’* into algal biomass as cells per ml, a mean ratio was calculated using algal data for Midmar dam. Based on this ratio, average algal counts of approximately 3 000 per ml and peak algal counts of 8 300 per ml are anticipated in the proposed Smithfield Dam. These predicted algal counts are unlikely to be problematic for a well operated water treatment process, but could increase treatment costs and backwashing requirements.

Based on experience with other impoundments in the Umgeni Water operational area, the following are likely to apply to the proposed Smithfield impoundment:

- The maximum algal counts are likely to occur during the January to April period, particularly after the main input of nutrients and when impoundment spilling and flushing have reduced somewhat. This may, however, be limited by high impoundment turbidities during the summer period, which would limit light penetration.
- A secondary, lesser, algal peak may also occur in the early spring period (September-October), when water temperatures increase and nutrients are available from internal nutrient recycling (after dam turnover) or the ‘first-flush’ (after the first significant rainfall event).
- The algal genera likely to dominate during periods of low nutrient loading (most of the time) are the less problematic green algae and diatoms (such as *Chlorella*, *Melosira* and *Cryptomonas*). However, during the higher rainfall period and during periods of excessive nutrient enrichment, problematic blue-green genera such as *Microcystis* and *Anabaena* may occur.
- The proposed Smithfield Dam is long enough, and with a sinuous morphology, that most algal blooms will be limited to the inflow area (except under very high inflow conditions).

- Since there is likely to be significant sedimentation in the dam inflow and also in-dam sedimentation, this is likely to limit endogenous phosphorus cycling in the proposed Smithfield Dam.
- From limited sampling, silica appears to be present in the uMkhomazi river water in reasonable concentrations (5.7 – 13.7 mg/ℓ), and so diatoms, including potential filter clogging genera such as *Fragilaria*, may dominate at times.

It should be noted that during the filling phase of the proposed Smithfield impoundment, algal counts might be relatively higher than predicted due to the decay of vegetation and flooding of soils, and subsequent release of nutrients. This is also likely to reduce initial dissolved oxygen results in the impoundment. This will, however, stabilise relatively quickly, particularly if initial impoundment flushing is good.

Proposed Langa balancing dam: The algal response in the proposed balancing dam was also predicted to be mesotrophic, despite an elevated average inflow total phosphorus concentration of 69 µg/ℓ. Average chlorophyll '*a'* concentrations of 4.5 – 5.7 µg/ℓ were predicted and a peak chlorophyll '*a'* concentration of 12.4 µg/ℓ.

5.3.3 Thermal and chemical stratification

Prediction of stratification patterns and hydrodynamics in the proposed Smithfield Dam is important from the water treatment perspective in that it will guide the siting of abstraction levels to ensure abstraction of aerobic water for treatment. While anoxic water can be treated, it is both more difficult and expensive to treat to potable water standards.

Recorded temperature, dissolved oxygen and chemical patterns in other impoundments in the Umgeni Water operational area were used to predict stratification patterns and hydrodynamics in the proposed Smithfield Dam. The proposed dam basin is at a similar altitude to Midmar Dam, and while in a significantly deeper valley, behaviour is likely to be similar. The following stratification patterns are predicted in the proposed Smithfield Dam:

- Initial dissolved oxygen concentrations may be reduced due to the inundation of submerged vegetation and soils during the filling of the impoundment.

- The dam is likely to stratify thermally during summer (from October), with dam turnover or destratification occurring around April, dependent on air temperatures, weather events and impoundment drawdown.
- The most severe stratification can be expected during February and will result in approximately 8 m of aerobic water being available.
- Below the oxycline, there will be anoxic waters containing reduced metal species (iron particularly, and possibly manganese).
- Between May and October, the water column will generally be isothermal and well oxygenated throughout.
- Despite the dam being stratified, summer rainfall high inflows may cause additional mixing events and temperature/density currents could 'short-circuit' the impoundment and deliver turbid water directly to some of the abstraction levels.
- Since the impounded volume is not very large with respect to its catchment, larger flood events could mix the dam contents at any time.

At the onset of impoundment turnover in the proposed Smithfield dam, anoxic water will be mixed into the water column, reducing dissolved oxygen concentrations throughout the water column. Elevated concentrations of metals which will be liberated from the sediments under anoxic conditions are also mixed through the water column at turnover. These metals may require additional treatment for removal and to avoid precipitation in final drinking waters.

Proposed Langa balancing dam: With a maximum water depth of 38m and long retention times, the proposed balancing dam will also display thermal and chemical stratification during the summer period. This is particularly likely due to its sheltered location, low inflows and likely low wind mixing. Consideration will thus need to be given to the abstraction of aerobic water (from the uppermost 6-8 m of the water column) if the balancing dam will be used to supply raw water for treatment during the summer stratified period. The preferred time of year to undertake tunnel maintenance would therefore be during the winter isothermal period.

5.3.4 Impact of impoundment on downstream aquatic environment and users

In summer, the proposed Smithfield impoundment may be subject to algal blooms and the bottom water will be significantly cooler than the water temperature of the inflow to the dam. Scour water releases will also be anaerobic. The combined impact, without mitigation, would be a reduction in river health for a significant distance downstream. Mitigation of these impacts is detailed in **Section 6**, but the use of sleeve valves (with dispersers) to oxygenate the bottom scour water, balancing the use of spill water / upper abstraction release water versus bottom scour water, and releasing water for environmental flows according to the natural flow patterns over a hydrological year, is recommended.

In terms of recreation in the proposed Smithfield Dam:

- Predicted chlorophyll ‘a’ concentrations (approximately 6 µg/ℓ) are within the Target Water Quality Range for full contact recreation (0-6 µg/ℓ). However, at times, and particularly in sheltered bays at the inflow to the proposed impoundment, algal blooms (particularly if the problematic blue-green genera such as *Microcystis* and *Anabaena* dominate) may cause skin irritations on contact recreation. Under these circumstances, recreational users should avoid contact with scums and notices warning users to avoid algal scums should be posted. In the unlikely occurrence of severe blooms, alternate animal watering sites should be sought if possible, since consumption of water high in algal toxins is detrimental to livestock health.
- The median *E. coli* count predicted in the proposed Smithfield impoundment (28 per 100 ml) is significantly lower than the DWAF *E. coli* target water quality guideline for full contact recreation (median of 130 per 100 ml), thus posing a low risk of gastrointestinal illnesses among potential swimmers and bathers in the proposed impoundment.

6 RECOMMENDATIONS FOR DAM INFRASTRUCTURE AND OPERATION

Recommendations are provided for Smithfield and Langa Dams to optimise water quality from a raw water treatability perspective as well as for downstream environmental releases.

6.1 SMITHFIELD DAM – RAW WATER TREATABILITY

The following recommendations are provided for the proposed Smithfield Dam infrastructure to ensure that the best possible raw water quality is abstracted at the tunnel inlet for the water treatment works:

- The dam will stratify thermally during summer (from October), with dam turnover or destratification occurring around April, dependent on air temperatures, weather events and impoundment drawdown.
- The most severe stratification can be expected during February and will result in approximately 8 m of aerobic water being available.
- Below the oxycline, there will be anoxic waters containing reduced metal species (iron particularly, and possibly manganese).
- Between May and October, the water column will generally be isothermal and well oxygenated throughout.
- The first four abstraction levels are recommended to be constructed at 6 m intervals from Full Supply Level (930 masl). This interval could be increased to 8 m from Level 5 at 32 m below Full Supply Level, since these levels would primarily be used under drought conditions when the dam is significantly drawn down. However, this may result in the requirement for additional treatment chemicals at the water works when abstracting from these lower abstraction levels (**Table 6.1**).

Table 6.1: Abstraction level

Abstraction level	Meters above sea level	Intervals (m)
FSL	930	
L1	924	6
L2	918	6
L3	912	6
L4	906	6
L5	898	8
L6	890	8
Tunnel inlet	881	

- This will allow aerobic water to be abstracted for treatment at all times, and allow selection to reduce the algal load abstracted. Selection of the most favourable abstraction level will optimise raw water quality at the water works and thereby reduce water treatment costs and facilitate compliance with potable water quality standards.
- Should algal counts increase above specified warning limits in the dam, it is recommended that this algal-laden water be spilled from the dam (if possible) in preference to release of scour water, to ensure optimal raw water quality for treatment. These warning limits are recommended to be 15 000 cells/ml of total algae, 3 000 cells/ml of *Microcystis* and 1 000 cells/ml of *Anabaena*.

6.2 SMITHFIELD DAM – ENVIRONMENTAL RELEASES

A number of levels are recommended for the proposed Smithfield Dam outlet works to minimise the impact of the dam and its management on the downstream aquatic life. Two of the most significant water quality variables that can affect downstream aquatic life are temperature and dissolved oxygen.

- The South African Water Quality Guidelines (SAWQG) for Aquatic Life (1996) recommend that water temperatures do not vary from the background daily water temperature (river inflow) by >2 °C or 10% whichever estimate is more conservative. The Midmar impoundment river and impoundment temperature data were reviewed to establish the level that the best compliance with this temperature guideline could be achieved. During the most significantly stratified period (January to March), the best compliance was achieved at 8 - 10 m below the surface of the impoundment. The first two environmental release levels (which will be used for the majority of the time) are therefore located at 10 m intervals from the Fully Supply Level; thereafter a 15 m interval was applied (**Table 6.2**).

Table 6.2: Environmental release levels

Environmental release level	Meters above sea level	Intervals (m)
FSL	930	
L1	920	10
L2	910	10
L3	895	15
L4	880	15
River release/scour to river	855	

- Optimizing environmental releases between the spill, variable environmental release levels and the bottom scour/river release is recommended to minimise the impact on aquatic life by following the natural river temperatures as far as possible.
- In addition, the use of some form of infrastructure (for example sleeve valves with dispensers) is recommended to oxygenate this scour water for environmental releases.
- Water for environmental flows is recommended to be distributed according to the natural flow patterns over a hydrological year. This will minimise the impact on aquatic life by mimicking the natural flood hydrograph. Where possible, any changes in dam operating rules should be made gradually (over a number of days) to allow the biota to adapt and minimise the impact on aquatic life.

Figure 6.1: Sleeve valves reoxygenate water released from Hazelmere dam

6.3 Langa Dam – Abstraction for water treatment & environmental releases

With a maximum water depth of 38 m and long retention times, the proposed balancing dam will also display thermal and chemical stratification during the summer period. This is particularly likely due to its sheltered location, low inflows and likely low wind mixing. However, a variable abstraction/environmental release mechanism in Langa Dam is not recommended because:

- Langa Dam is only planned to be used every 5 years for a period of 3 weeks;
- The preferred time of year to undertake tunnel maintenance would be during the winter isothermal period;
- During the 3 week duration of tunnel maintenance, the majority of the water in Langa Dam will be used for water treatment, making a variable abstraction mechanism redundant;
- Even if, under emergency conditions, the water from Langa Dam is required to be abstracted for treatment during the summer stratified period, the activated carbon dosing facility planned for the water works should be able to treat the water to potable water standards.

In terms of environmental releases from Langa Dam:

- Since the Langa Dam is located in a very small, upper uMlaza catchment, once the dam has been filled, it is likely to remain full until used. Under these conditions, the natural spilling from the dam is likely to satisfy the environmental releases from a quality and quantity perspective. However, a dam scour/river release mechanism will be required to supplement environmental releases if necessary and ensure that adequate water of acceptable quality for environmental flows is released at all times.
- Consideration will have to be given to environmental releases immediately after the tunnel maintenance period since the retention time is this dam is long (3.9 years) and thus would take a long time to refill, during which time only scour releases would be possible if Langa Dam was not supplemented from the proposed Smithfield Dam.

Water quality and biological (SASS) monitoring is recommended during the pre-construction, construction and operational phase of the proposed Smithfield Dam and the Langa balancing dam:

- During the pre-construction and construction phase, monitoring of the proposed impoundment site, as well as the uMkhomazi and uMlaza Rivers up- and downstream of all construction activities is recommended to assess impacts of activities on the environment. Water quality monitoring is recommended to be undertaken at a monthly frequency and to include pH, temperature, bacteria, nutrients, turbidity, iron & manganese, conductivity, colour, total organic carbon and oil & grease at a minimum. SASS monitoring is recommended at a 3- monthly frequency.
- During the operational phase, water quality monitoring of the impoundment and abstraction levels is recommended to optimise dam management as well as raw water quality for treatment. It is also recommended to monitor the water quality and SASS of the uMkhomazi and Mbangweni Rivers up- and downstream of the dams to assess the impact of the dam management on the downstream aquatic environment. Water quality monitoring is recommended to be undertaken at a monthly frequency and SASS monitoring at a 3-monthly frequency. Water quality monitoring is recommended to include the monthly minimum list specified above (with the exclusion of oil & grease, and the inclusion of *Cryptosporidium* and *Giardia* until an adequate baseline is achieved) as well as a comprehensive list of determinands at an annual frequency.

7 CONCLUSIONS

The conclusions of the Water Quality Assessment for the proposed Smithfield impoundment on the uMkhomazi River and balancing dam in the uMlaza catchment are as follows:

a) *Catchment Assessment - Overview of Pollution Potential*

Table 7.1: Summary of climatology for the proposed Smithfield Dam and Langa Balancing Dam sites

MAP (mm)	Number of days with rainfall > 10 mm	MAE (mm)	Number of days with minimum air temp. less than 0°C
Proposed Smithfield Dam site			
809(1)	28(1)	1 300(3)	12(5)

b) *Current Water Quality Status*

- Good long-term data records indicated that water quality measured to date in the Smithfield Dam catchment is generally satisfactory, with the exception of elevated turbidity, total organic carbon and phosphorus concentrations recorded during high intensity rainfall events (particularly the first flush of the summer rainfall period). Low conductivity results reflect that this water is likely to be aggressive and will require lime stabilization during treatment. There are no indications of elevated heavy metals such as copper, cobalt, lead or mercury and there are no known mining activities (other than for sand or stone).
- Similarly, the limited data record so far available indicated good water quality in the balancing dam catchment, but with elevated total phosphorus results in the summer high rainfall period.

c) *Predicted Water Quality Impact on Impoundment*

- In-dam processes such as sedimentation of suspended material, biological processing of nutrients, predation and natural mortality of potential pathogens, and ultra-violet light disinfection are anticipated to improve surface water quality between the uMkhomazi Smithfield inflow and the proposed Smithfield Dam wall. Significant improvements will thus occur in recorded concentrations of suspended materials and the bacteriological quality of the river water, despite relatively short impoundment residence times.

- The algal response models predicted an average chlorophyll ‘a’ concentration from 5.7 – 5.8 µg/ℓ and a peak chlorophyll ‘a’ concentration of 16 µg/ℓ for the proposed Smithfield Dam. The anticipated trophic status of the proposed Smithfield Dam is mesotrophic – moderately enriched with nutrients, with occasional blooms of nuisance algal species.
- The Smithfield Dam is likely to stratify thermally during summer (from October), with dam turnover (destratification) occurring around April, dependent on air temperatures and impoundment drawdown. The most severe stratification can be expected during February and will result in *ca.* 8 – 10 m of surface aerobic water being available for optimal abstraction. Water abstracted from below the oxycline is likely to cause treatment problems. At the onset of the annual impoundment turnover, anoxic water will be mixed into the water column, reducing dissolved oxygen concentrations throughout the water column. Elevated concentrations of metals which will be liberated from the sediments under anoxic conditions will thus be mixed through the water column at turnover. These metals may require additional treatment for removal and to avoid post-precipitation in final drinking waters. From information at impoundments in adjacent or nearby catchments, elevated concentrations of both iron and manganese may present a risk at these times.
- The impoundment size is relatively small compared to the MAR and significant rain events are likely in the catchment at times. Under very severe storm conditions, inflows of highly turbid water may be sufficient to reach the abstraction zone or temporarily mix the dam (particularly if the impoundment is drawn-down). Under these conditions, significantly elevated turbidities are possible in the raw water abstracted from the impoundment.

d) *Recommendations for Dam Infrastructure and Operation*

- In order to allow abstraction from the aerobic zone as well as abstraction when the proposed Smithfield impoundment is significantly drawn-down, it is recommended that a number of abstraction levels are constructed at 6-8m intervals from Full Supply Level. Selection of the most favourable abstraction level will optimise raw water quality at the water works, reduce water treatment costs and facilitate compliance with potable water quality standards.
- In addition, a number of levels (at 10-15 m intervals) are recommended to be constructed for the proposed Smithfield Dam outlet works to minimise the impact of the dam and its management on the downstream aquatic life.

- A dam scour/river release is recommended to be constructed to be able to release dam bottom water during high summer inflows. Sleeve valves with dispersers are recommended to oxygenate the water used for environmental releases.
- Spilling is the recommended release mechanism when algal numbers are high and water levels permit. As far as possible, water for environmental flows is recommended to be distributed according to the natural flow patterns. The bottom scour/river release valves should be big enough to emulate natural flood events downstream.
- A variable abstraction/environmental release mechanism is not recommended for Langa Dam.
- Water quality and biological (SASS) monitoring is recommended during the pre-construction, construction and operational phase of the proposed Smithfield Dam and the Langa balancing dam to assess impacts on the environment, and to optimise dam management.

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Appendix A

uMkhomazi River at Lundy's Hill weir

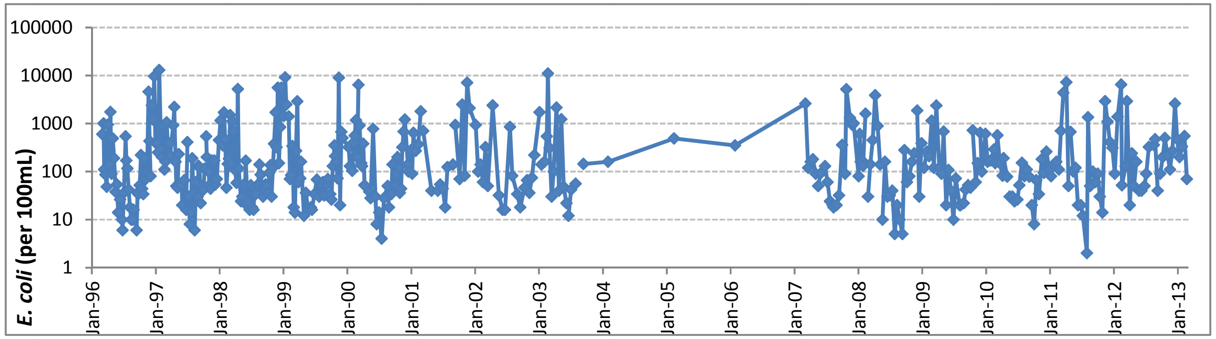
ANNEXURES

ANNEXURE 1: UMKHOMAZI RIVER AT LUNDY'S HILL WEIR

TIME SERIES PLOTS OF KEY DETERMINANDS

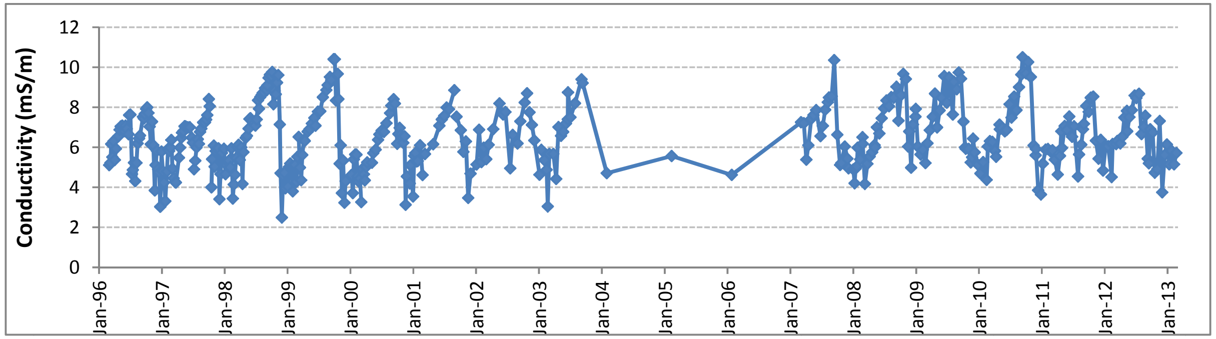
E. coli (per 100 mL)

N	431.00
Minimum	2.00
5-percentile	14.00
25-percentile	40.00
Median	110.00
Average	558.97
75-percentile	350.00
95-percentile	2500.00
Maximum	13000.00



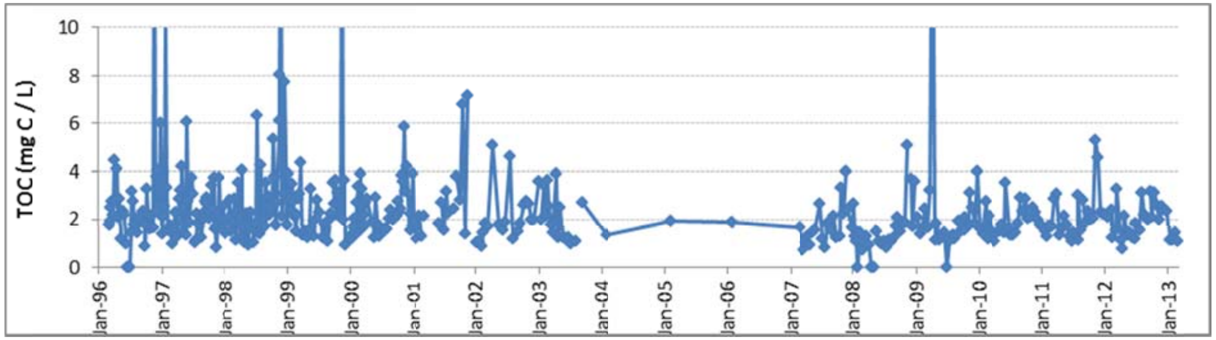
Conductivity (mS/m)

N	448
Minimum	2.49
5-percentile	4.17
25-percentile	5.33
Median	6.33
Average	6.47
75-percentile	7.49
95-percentile	9.39
Maximum	10.5



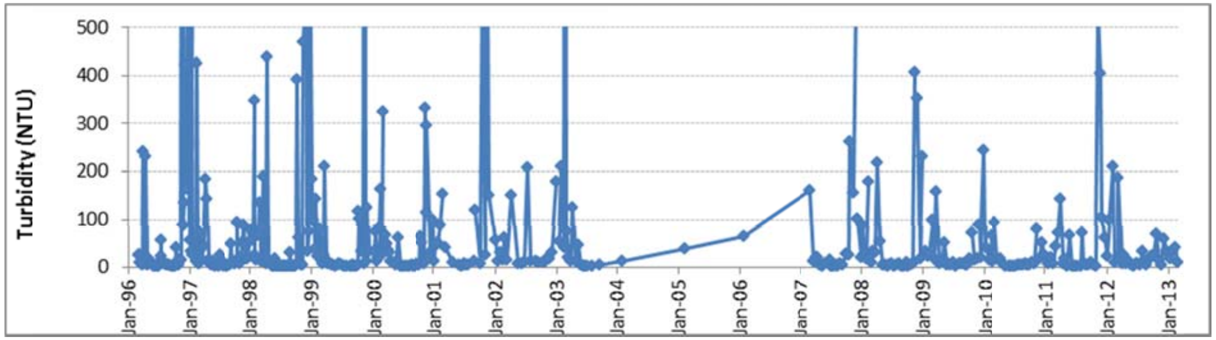
Total Organic Carbon (mg/L)

N	430
Minimum	0.35
5-percentile	0.99
25-percentile	1.46
Median	1.945
Average	2.30
75-percentile	2.67
95-percentile	4.23
Maximum	19.6



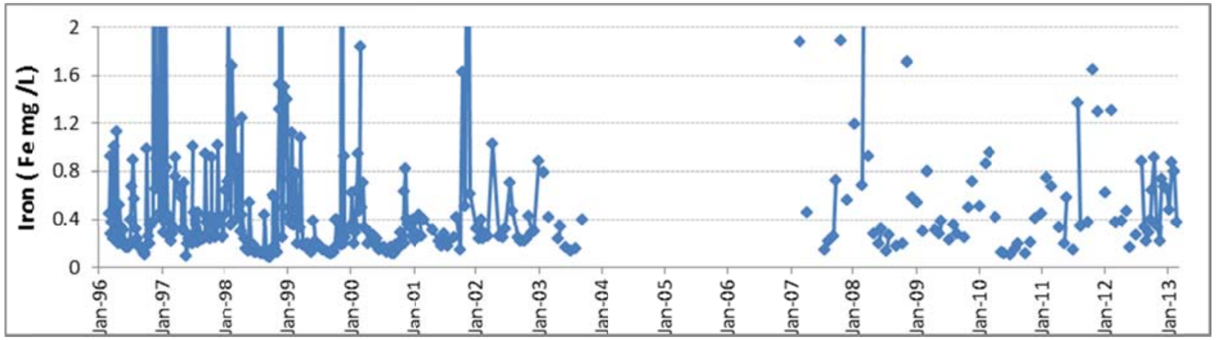
Turbidity (NTU)

N	432
Minimum	1.86
5-percentile	2.682
25-percentile	5.535
Median	13.3
Average	90.78
75-percentile	51.575
95-percentile	328.05
Maximum	5530



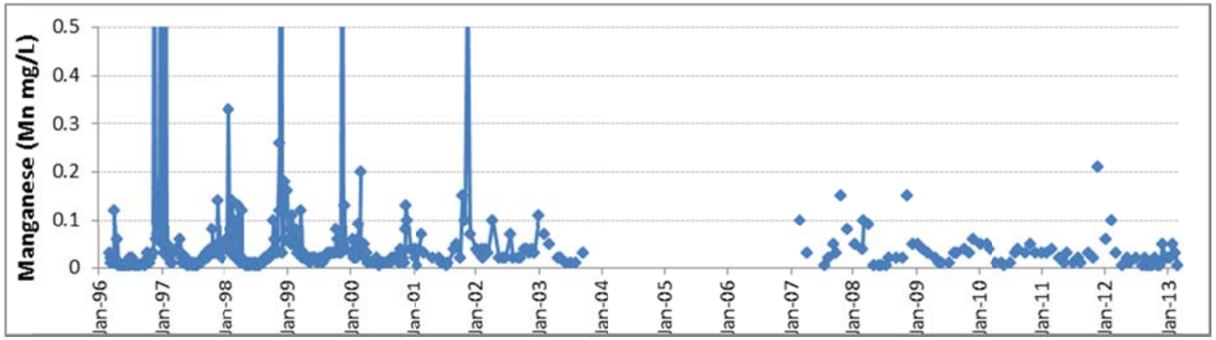
Iron (Fe mg/L)

N	346.00
Minimum	0.08
5-percentile	0.12
25-percentile	0.20
Median	0.32
Average	0.58
75-percentile	0.58
95-percentile	1.48
Maximum	14.10



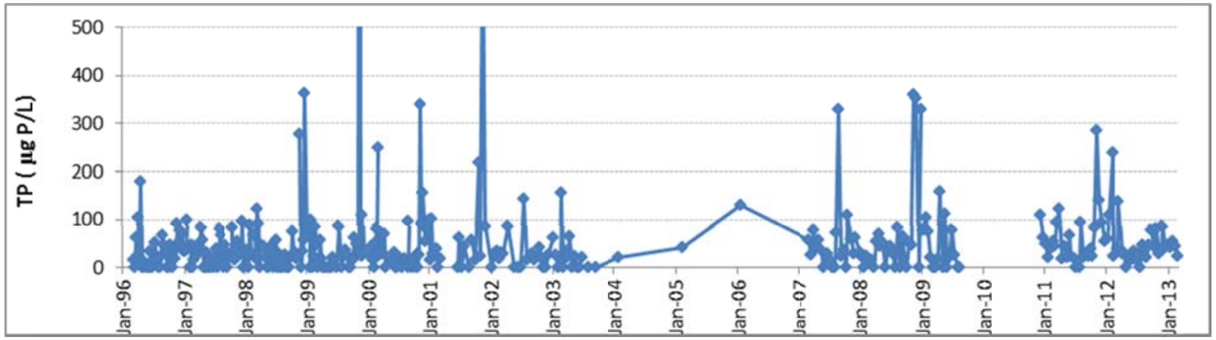
Manganese (Mn mg/L)

N	346.00
Minimum	0.01
5-percentile	0.01
25-percentile	0.01
Median	0.03
Average	0.06
75-percentile	0.04
95-percentile	0.14
Maximum	2.54



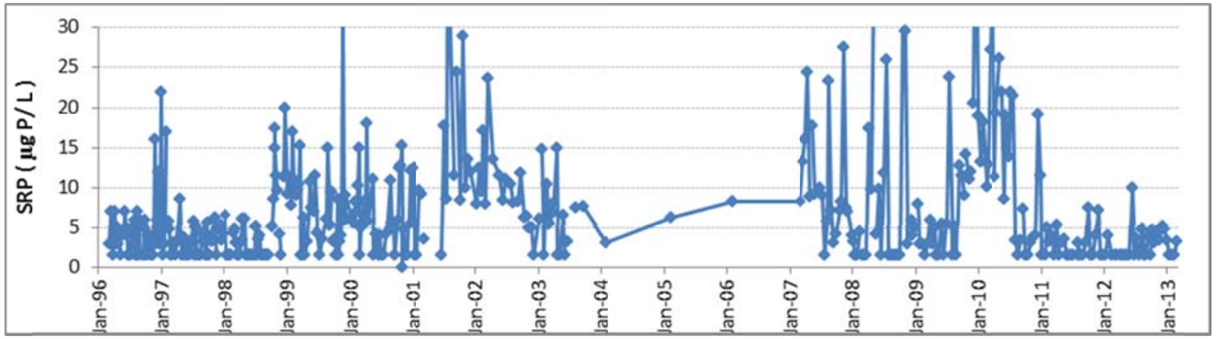
Total Phosphorus (µg/L)

N	391
Minimum	7.5
5-percentile	7.5
25-percentile	7.5
Median	27
Average	50.31
75-percentile	54.25
95-percentile	133.86
Maximum	1988



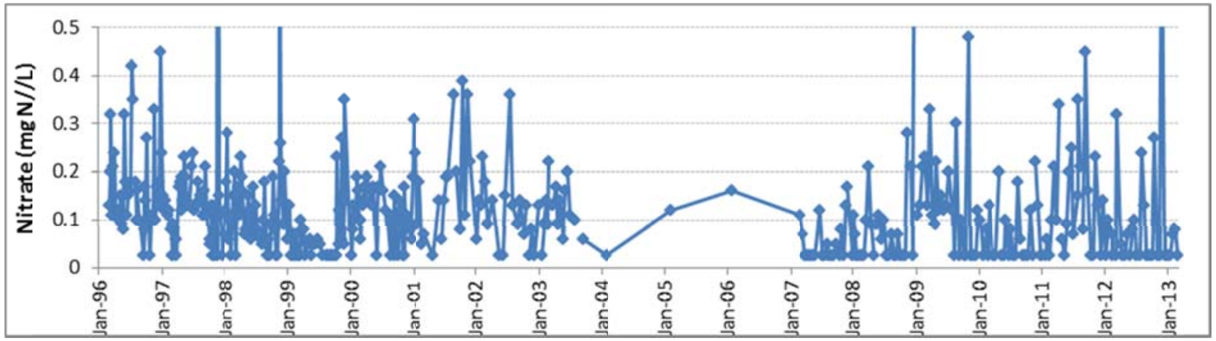
Soluble Reactive Phosphorous (µg P/L)

N	423
Minimum	1.5
5-percentile	1.5
25-percentile	1.5
Median	4.16
Average	6.67
75-percentile	8.57
95-percentile	21.39
Maximum	50



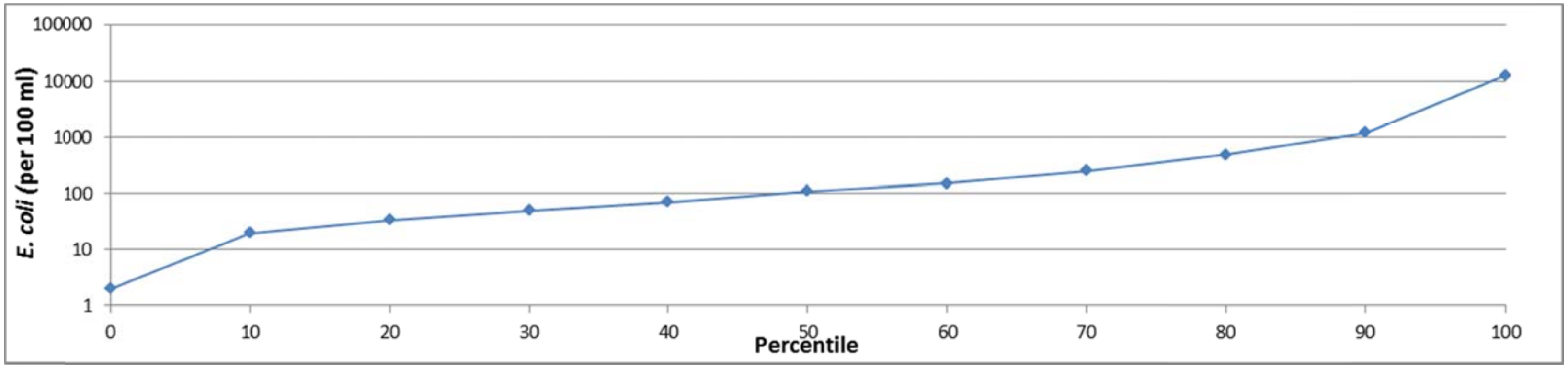
Nitrate (mg N/L)

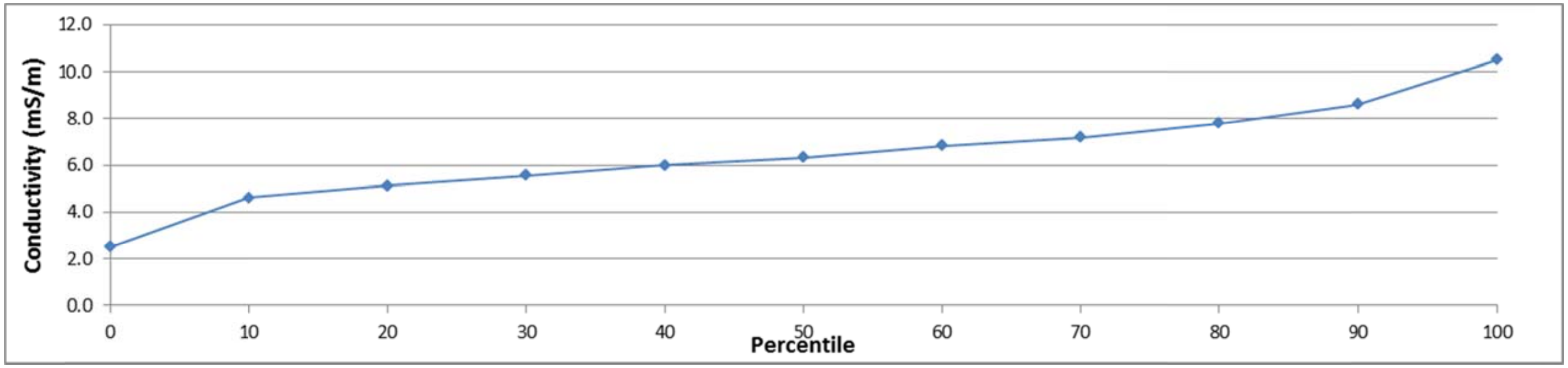
N	432.00
Minimum	0.03
5-percentile	0.03
25-percentile	0.03
Median	0.10
Average	0.12
75-percentile	0.15
95-percentile	0.30
Maximum	1.46

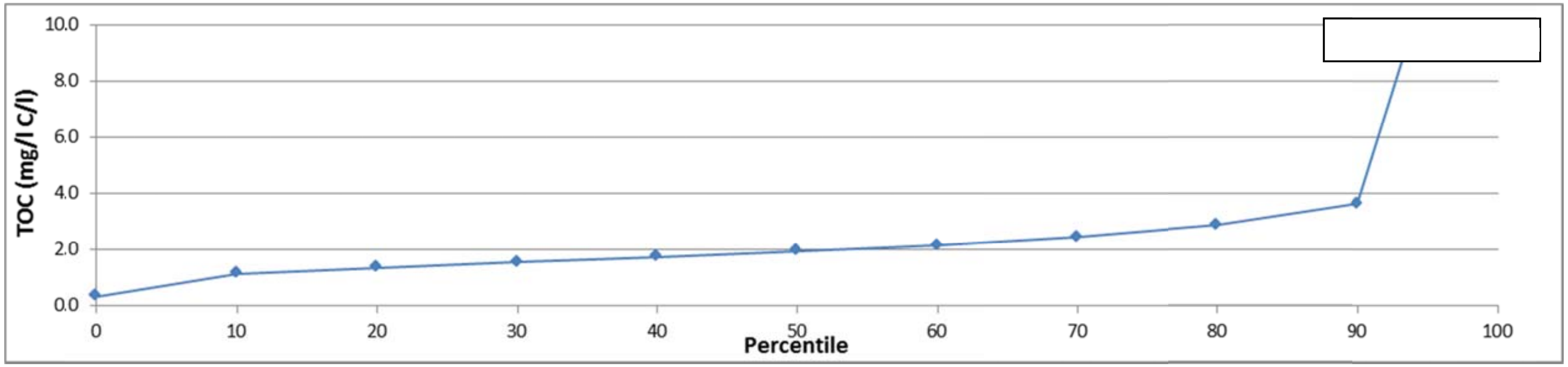


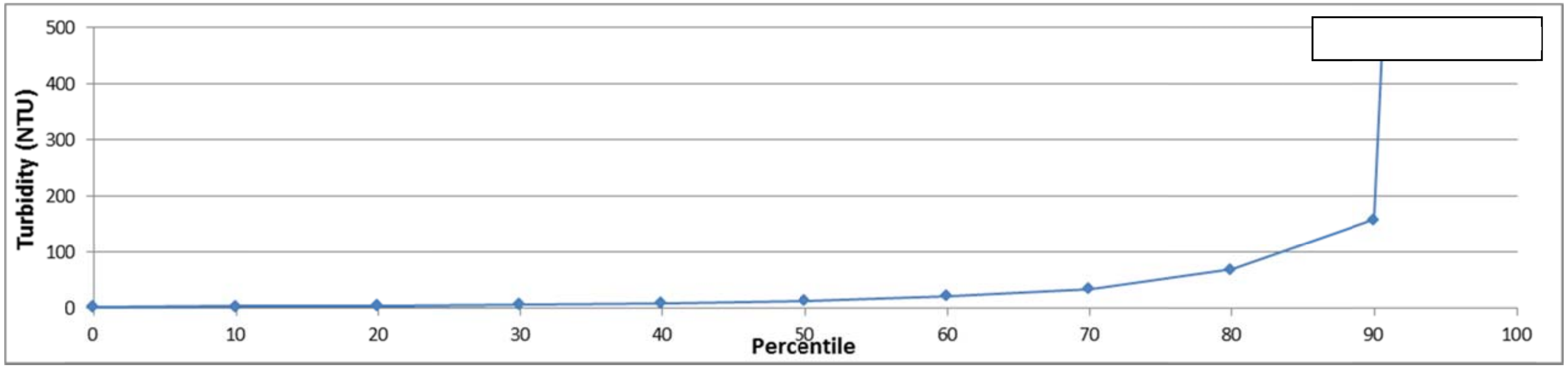
In cases of results below the detection limit, statistics and time series plots indicate half the detection limit.

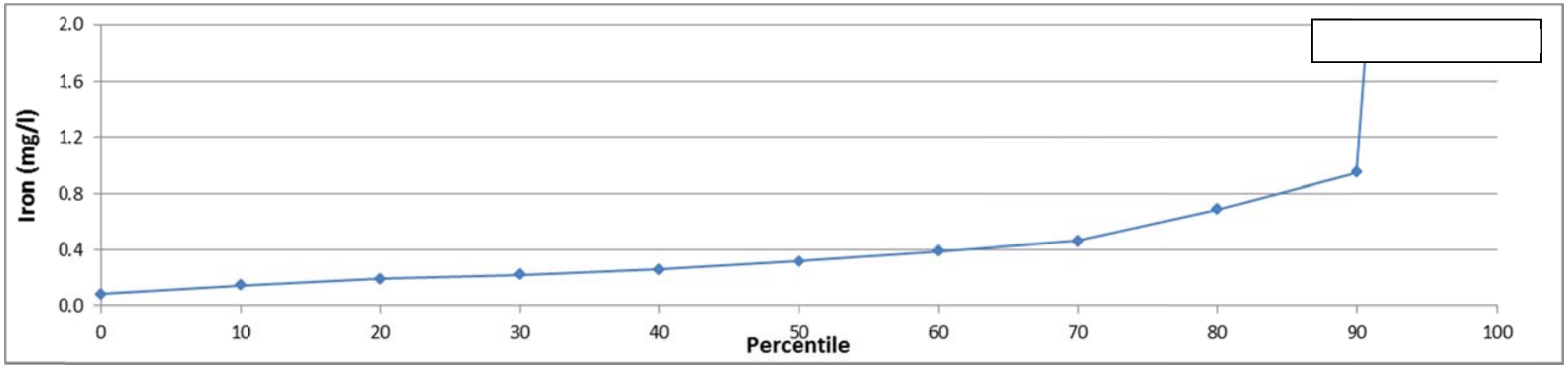
PERCENTILE PLOTS - UMKHOMAZI RIVER AT LUNDY'S HILL WEIR

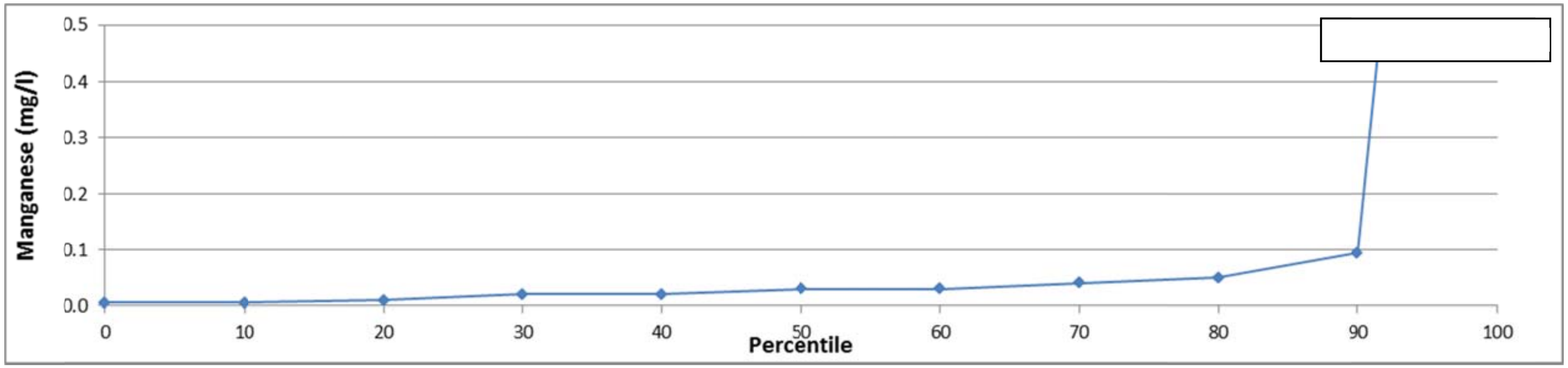


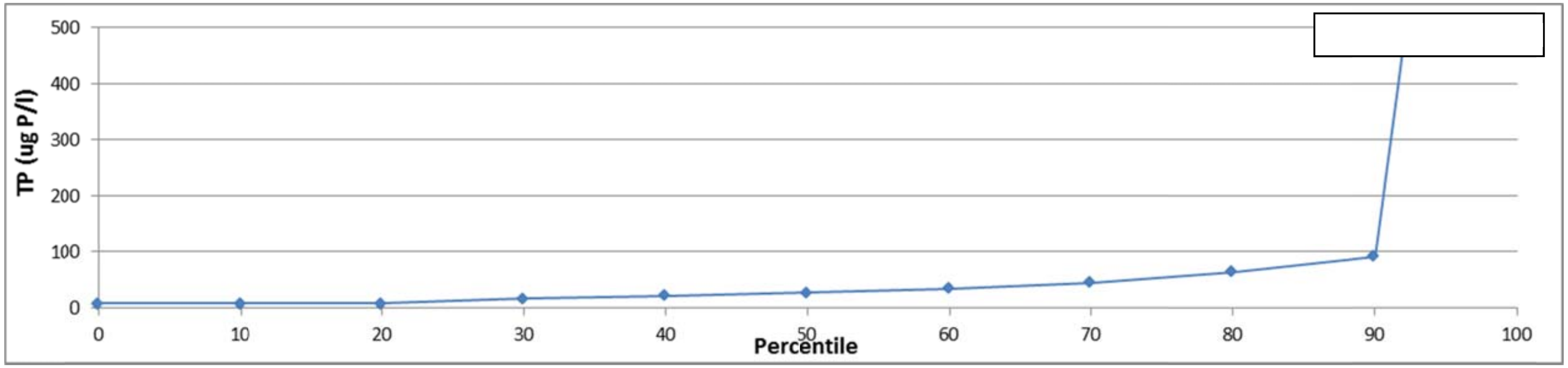


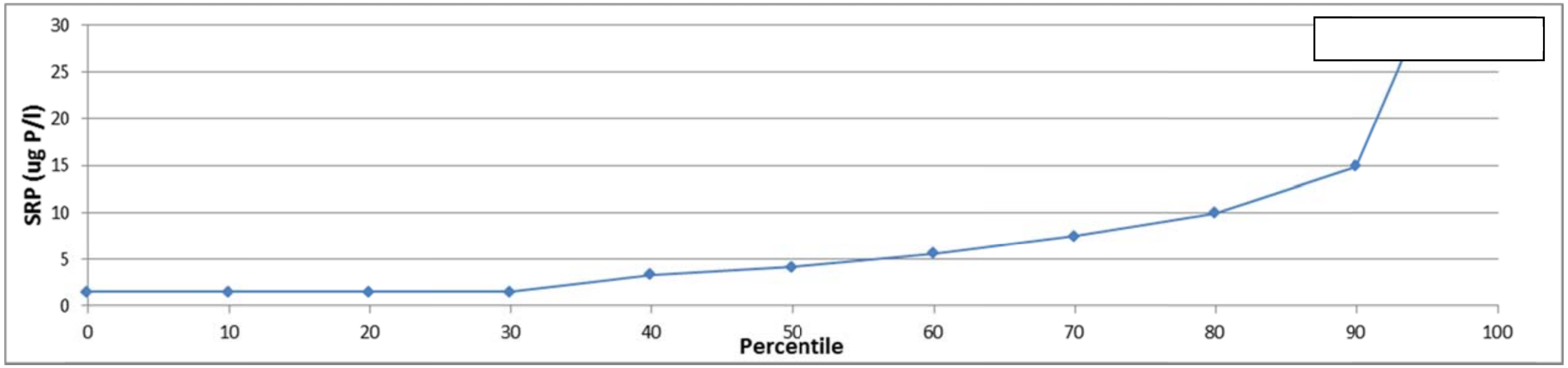


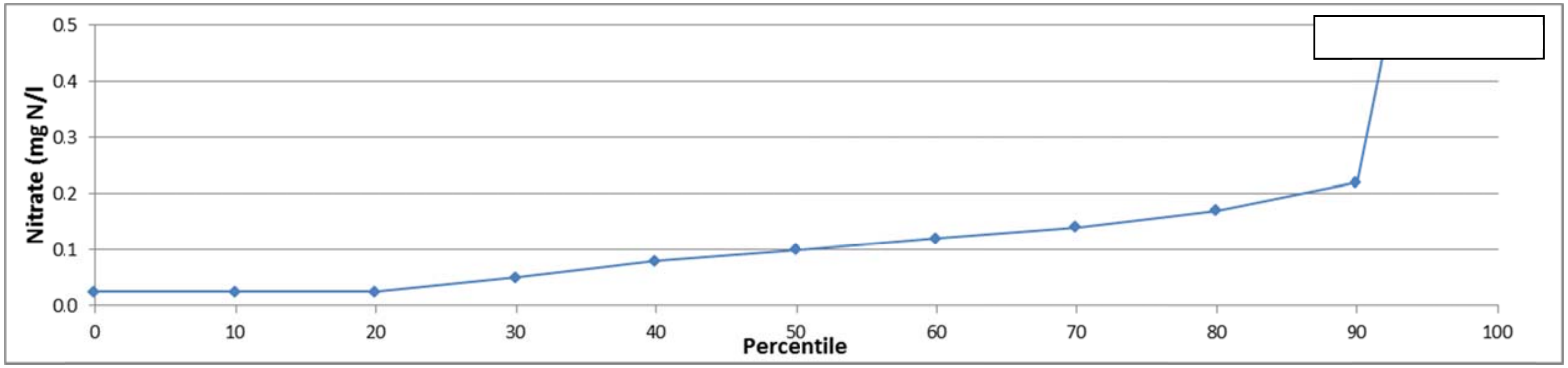

Turbidity (NTU)
500
400
300
200
100
0
0 10 20 30 40 50 60 70 80 90 100
Percentile


Iron (mg/l)
2.0
1.6
1.2
0.8
0.4
0.0
0 10 20 30 40 50 60 70 80 90 100
Percentile


Manganese (mg/l)
0.5
0.4
0.3
0.2
0.1
0.0
0 10 20 30 40 50 60 70 80 90 100
Percentile

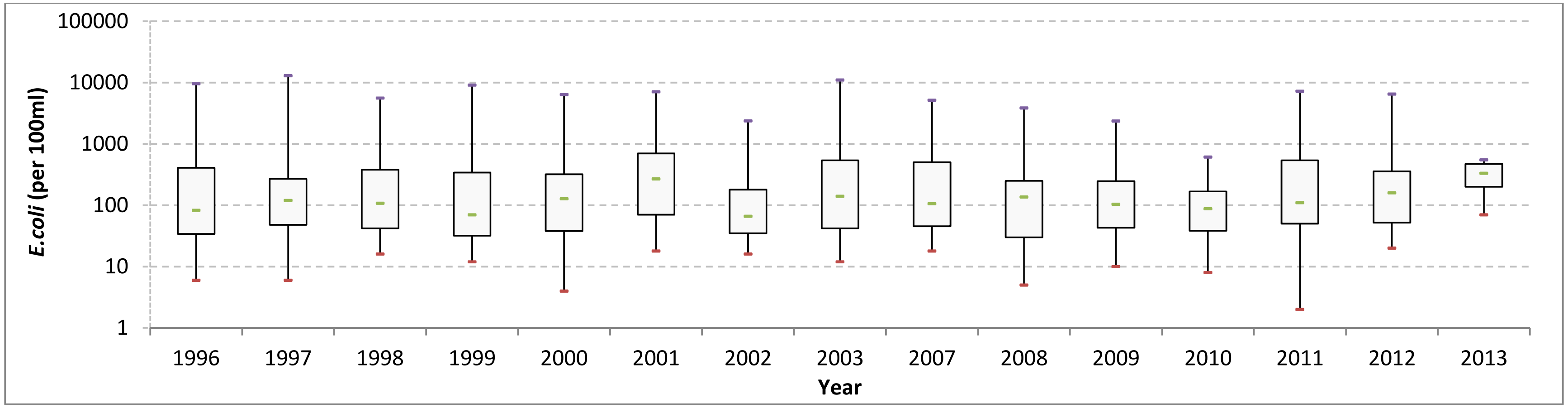

TP (ug P/l)
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
Percentile

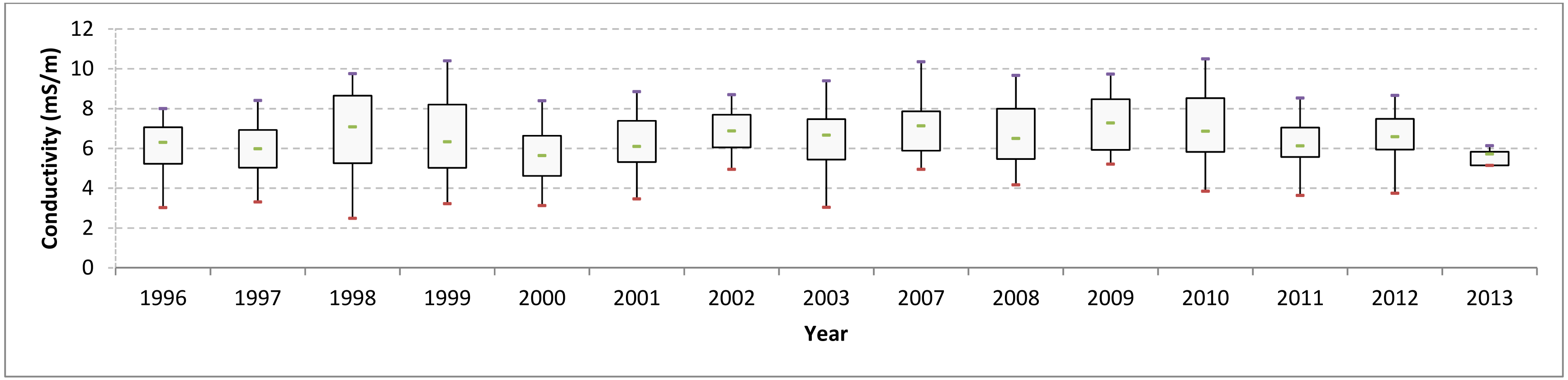

SRP (ug P/l)
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Percentile

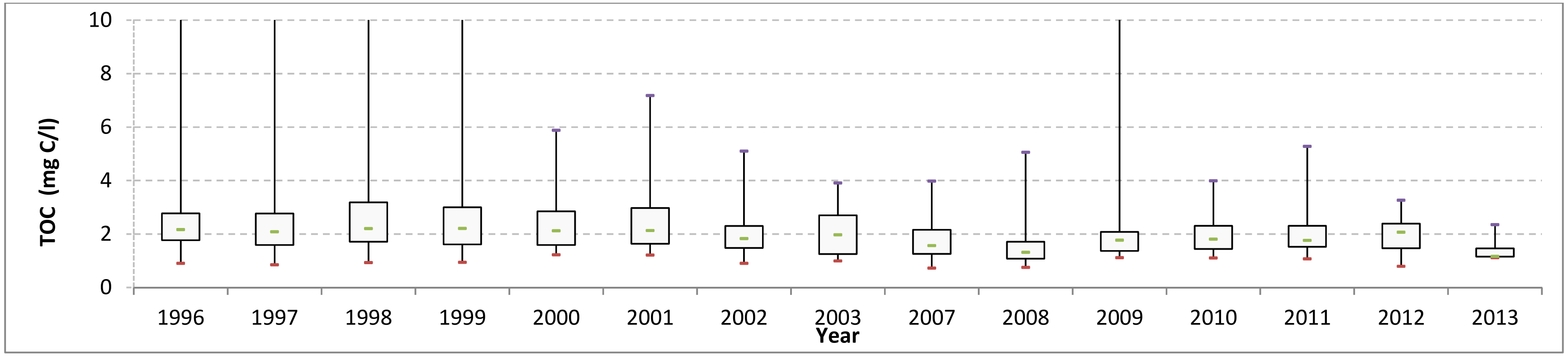

Nitrate (mg N/l
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
70
80
90
100
Percentile

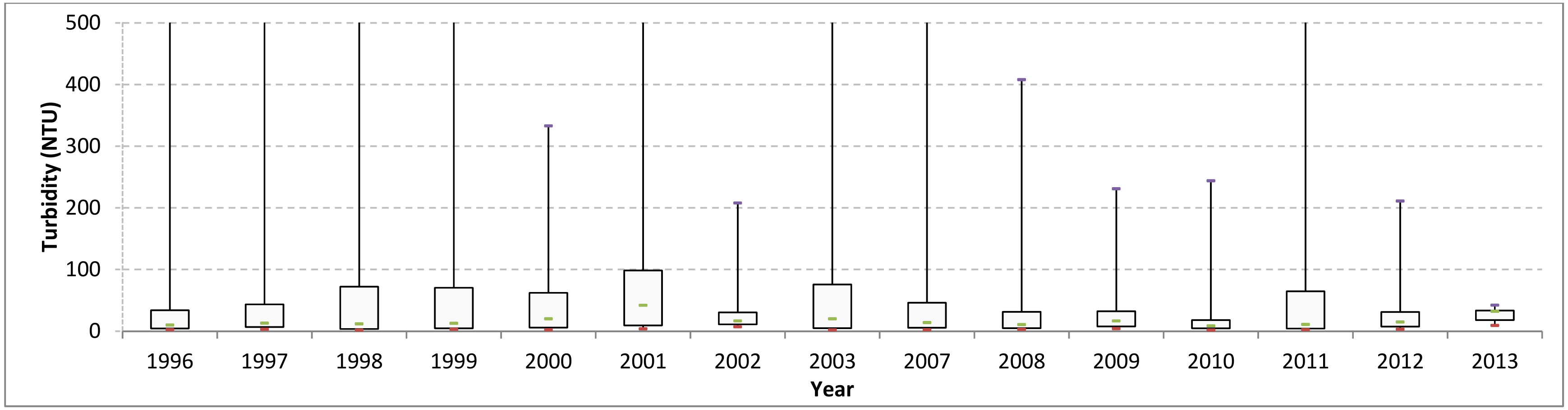
BOX AND WHISKER PLOTS - UMKHOMAZI RIVER AT LUNDY'S HILL WEIR

(Insufficient data was available to draw Box-and-Whisker plots for the years 2004-2006)

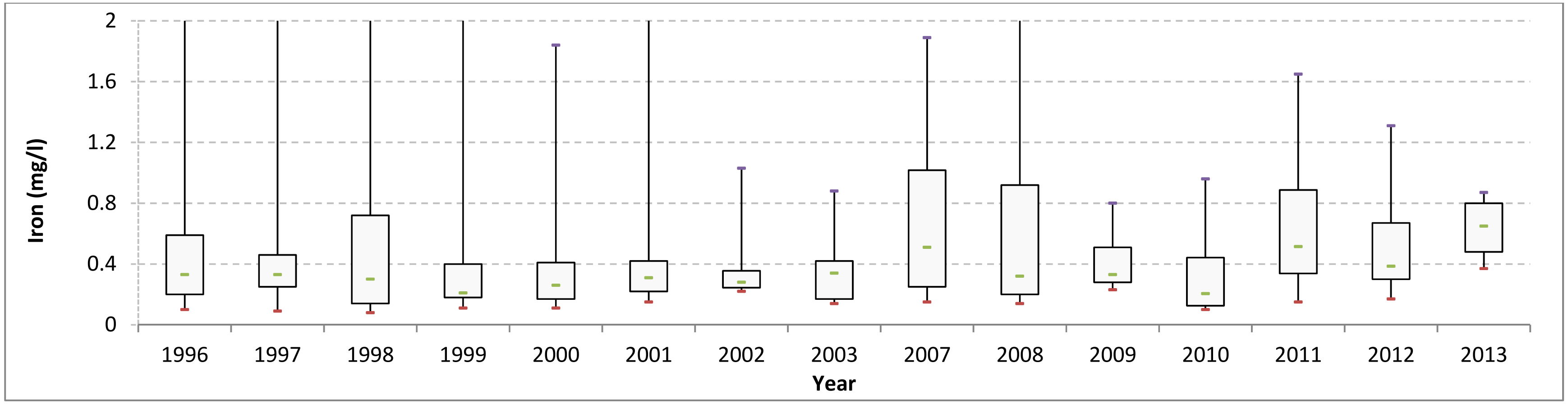




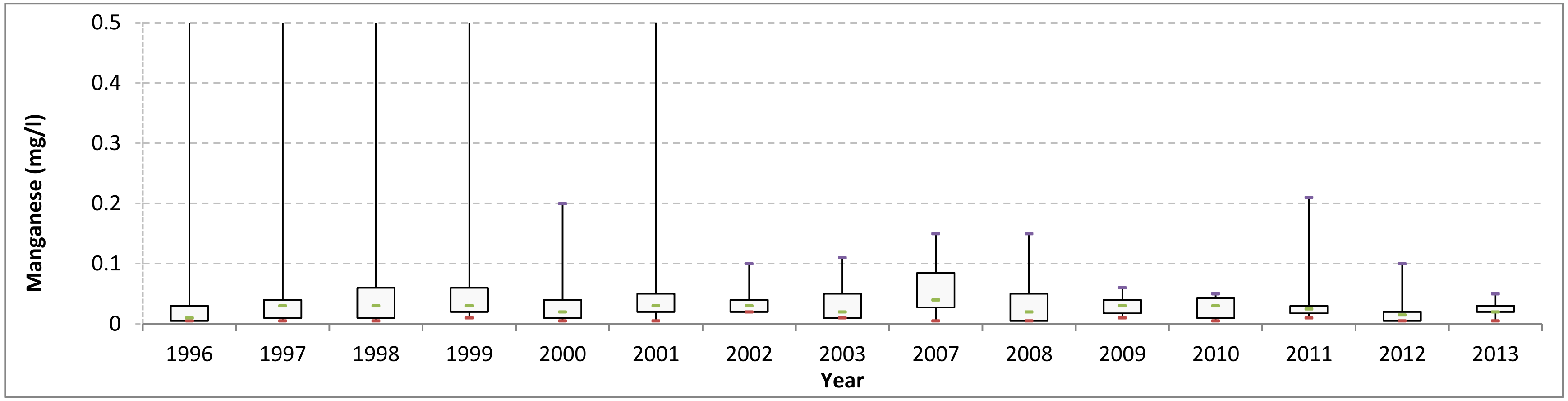




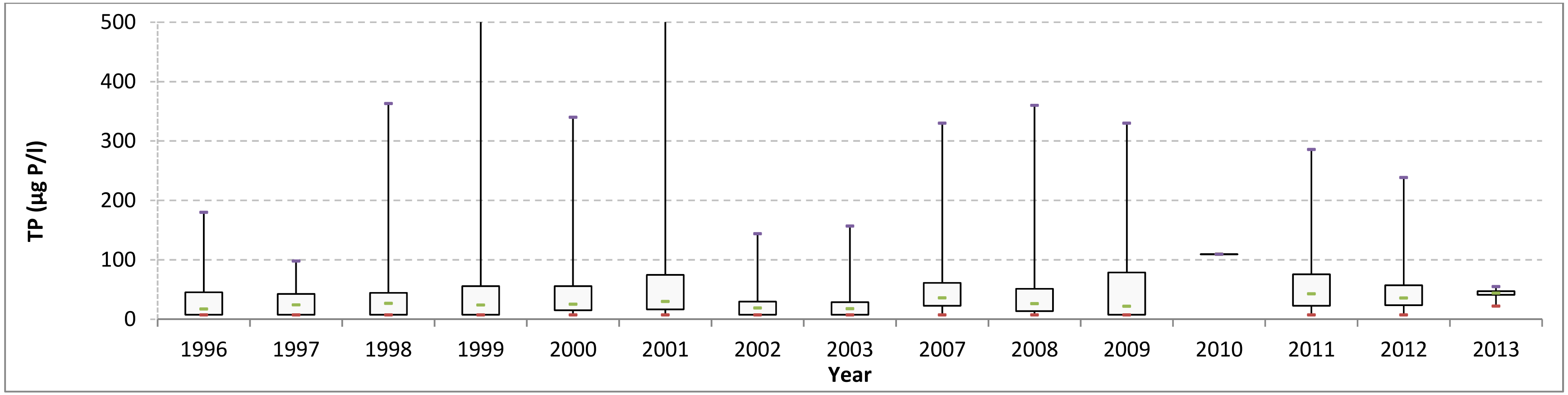
Turbidity (NTU)
500
400
300
200
100
0
1996 1997 1998 1999 2000 2001 2002 2003 2007 2008 2009 2010 2011 2012 2013
Year

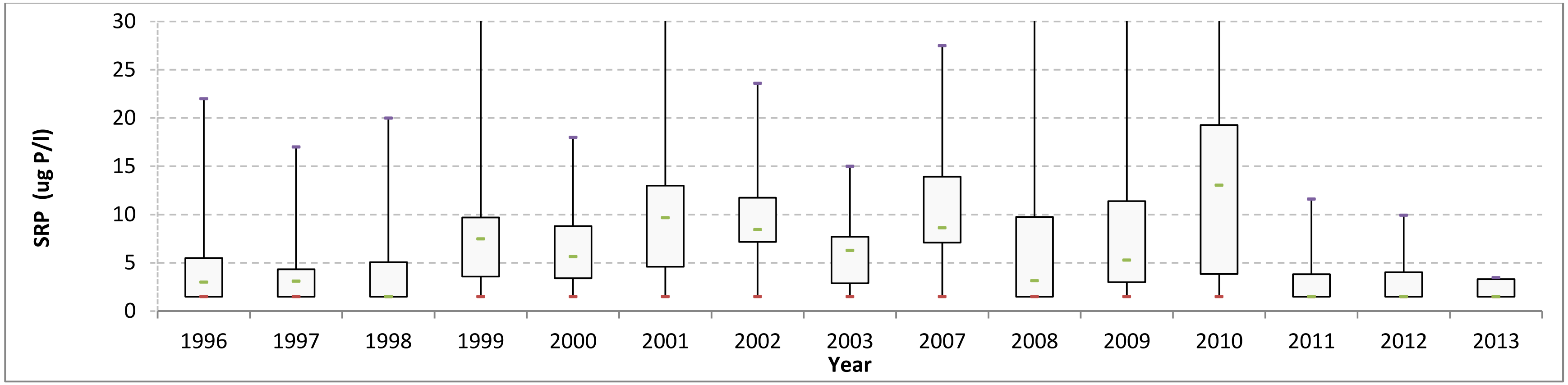


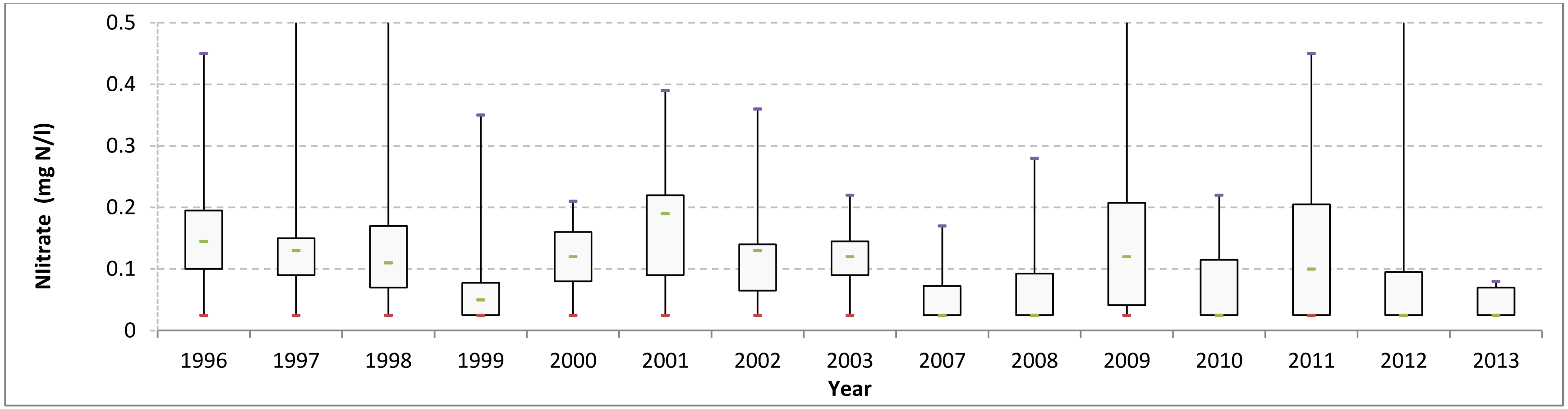
Iron (mg/l)
2
1.6
1.2
0.8
0.4
0
1996 1997 1998 1999 2000 2001 2002 2003 2007 2008 2009 2010 2011 2012 2013
Year



Manganese (mg/l)
0.5
0.4
0.3
0.2
0.1
0
1996 1997 1998 1999 2000 2001 2002 2003 2007 2008 2009 2010 2011 2012 2013
Year


TP (µg P/l)
500
400
300
200
100
0
1996 1997 1998 1999 2000 2001 2002 2003 2007 2008 2009 2010 2011 2012 2013
Year


SRP (µg P/l)
30
25
20
15
10
5
0
1996 1997 1998 1999 2000 2001 2002 2003 2007 2008 2009 2010 2011 2012 2013
Year


Nitrate (mg N/l)
0.5
0.4
0.3
0.2
0.1
0
1996 1997 1998 1999 2000 2001 2002 2003 2007 2008 2009 2010 2011 2012 2013
Year

SUMMARY STATISTICS - UMKHOMAZI RIVER AT LUNDY'S HILL WEIR

Determinands	Sample Count	Minimum	Median	Average	95th percentile	Maximum
Aluminium µg/l	61	33.00	204.50	293.85	842.80	1071
Algal count cells/ml	182	0	205	1147	6390	22103
Alkalinity mg CaCO3/l	218	12.90	31.60	32.64	47.74	60.90
Arsenic µg/l	49	<2.0	<2.0	<2.0	<2.0	<2.0
Atrazine ng/l	16	1.00	1.00	4.81	10.00	10.00
Boron µg/l	12	<20	<20	<20	<20	<20
Barium µg/l	11	5.0	24.0	53.0	193.5	270.0
Calcium mg/l	219	3.10	6.30	6.33	8.95	11.50
Cadmium µg/l	65	0.50	0.50	0.58	0.50	5.5
Chlorophyll a µg/l	14	0.45	0.45	0.64	1.56	2.46
Chloride mg/l	219	0.47	1.22	1.29	2.17	4.11
Cyanide (F) µg/l	26	<10	<10	<10	<10	<10
Cyanide (T) µg/l	40	<10	<10	<10	<10	<10
Cobalt µg/l	6	<10	<10	<10	<10	<10
Chemical Oxygen Demand mg /l	8	10.00	10.00	15.17	31.90	34.80
Coliforms /100ml	24	42	355	612	2024	3300
Coliphages PFU/10ml	1	507	507	507	507	507
Colour `H	346	0.50	5.81	11.85	37.53	147.00
Conductivity mS/m	448	2.49	6.33	6.47	9.39	10.50
Chromium µg/l	64	1.00	1.50	2.12	4.93	9.40
Copper mg/l	66	0.03	0.03	0.03	0.03	0.09
Dissolved Oxygen	30	6.00	8.35	8.51	10.17	14.50
E.coli /100ml	431	2	110	559	2500	13000
Endosulfan ug/l	1	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoride µg/l	118	50	50.0	50.5	50.0	114
Iron mg/l	346	0.08	0.32	0.58	1.48	14.10
Hardness (T) mg CaCO3/l	31	14.83	25.92	25.56	35.75	37.75
Mercury µg/l	40	0.25	0.25	0.29	0.80	0.80
Potassium mg/l	108	0.16	0.50	0.50	1.45	1.52
Magnesium mg/l	219	1.4	2.60	2.71	3.81	8.36
Manganese mg/l	346	0.005	0.03	0.06	0.14	2.54
Sodium mg/l	109	1.00	3.26	3.56	5.01	28.00
Ammonia mg N/l	426	0.005	0.04	0.06	0.17	0.94
Nickel µg/l	41	0.50	1.50	2.16	5.00	5.00
Nitrite mg N/l	53	<0.05	<0.05	<0.05	<0.05	<0.05
Nitrate mg N/l	432	0.025	0.10	0.12	0.30	1.46
Lead µg/l	66	1.0	2.0	2.5	4.0	29.9
pH	445	7.8	7.80	-	8.40	8.90
Phenols µg/l	13	2.50	2.50	3.65	5.00	5.00
Antimony µg/l	18	<2.00	<2.00	<2.00	<2.00	<2.00
Selenium µg/l	49	0.5	0.5	0.6	1.0	1.6

Determinands	Sample Count	Minimum	Median	Average	95th percentile	Maximum
Silica mg/l	23	5.70	7.00	7.22	8.94	13.70
Sulphate mg/l	212	0.27	1.01	1.06	1.60	2.51
Soluble Reactive Phosphorus µg P/l	423	1.50	4.16	6.67	21.39	50.00
Suspended Solids mg/l	354	2.00	16.40	91.56	267.35	4240.00
Total Dissolved Solids mg/l	141	24.00	52.80	53.96	76.00	188.00
Temperature `C	448	6.20	18.60	17.65	24.20	28.90
Total Kjeldahl Nitrogen mg N/l	240	0.01	0.44	0.67	2.09	5.67
Total Organic Carbon mg C/l	430	0.35	1.95	2.30	4.23	19.6
Total Phosphorus µg P/l	391	7.50	27.00	50.31	133.86	1988.00
Turbidity NTU	432	1.86	13.30	90.78	328.05	5530.00
Vanadium µg/l	6	<10.00	<10.00	<10.00	<10.00	<10.00
Zinc mg/l	57	0.02	0.03	0.03	0.03	0.03

AQUATIC ECOSYSTEM DATA

Determinands	N	Minimum	Median	Average	95th percentile	Maximum
Average Score Per Taxon	33	4.75	7.36	7.27	8.44	8.7
SASS score	34	68.00	119.00	123.94	173.20	183.00

ASPT and SASS Ecological Category scores for the South Eastern Uplands - UPPER

Description	Seriously/ critically modified	Poor - largely modified	Fair - Moderately modified	Good - largely natural / few mods	Natural
Ecological category	E/F	D	C	B	A
ASPT Score	<5.8	5.8 - 6.4	6.5 - 6.6	6.7 - 7.3	>7.3
SASS score	<125	126 - 156	157 - 175	176 - 200	>200

Interpretation is based on the premise that if either SASS5 Score or ASPT is above the Category value it will fall into the Category.

Ecological categories used to interpret SASS 5 data

Ecological Categories	Ecological Category Name	Description
A	Natural	Unmodified natural
B	Good	Largely natural with few modifications
C	Fair	Moderately modified
D	Poor	Largely modified
E	Seriously modified	Seriously modified
F	Critically modified	Critically or extremely modified

Appendix B

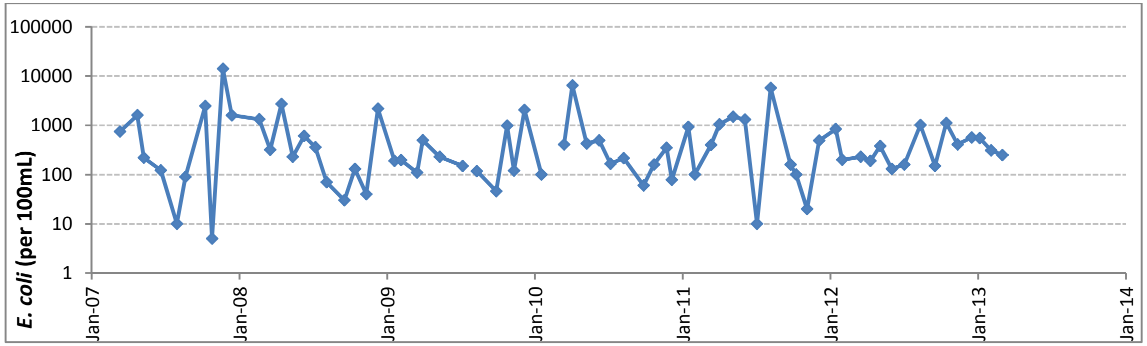
Luhane Smithfield inflow

ANNEXURE 2: LUHANE SMITHFIELD INFLOW

TIME SERIES PLOTS

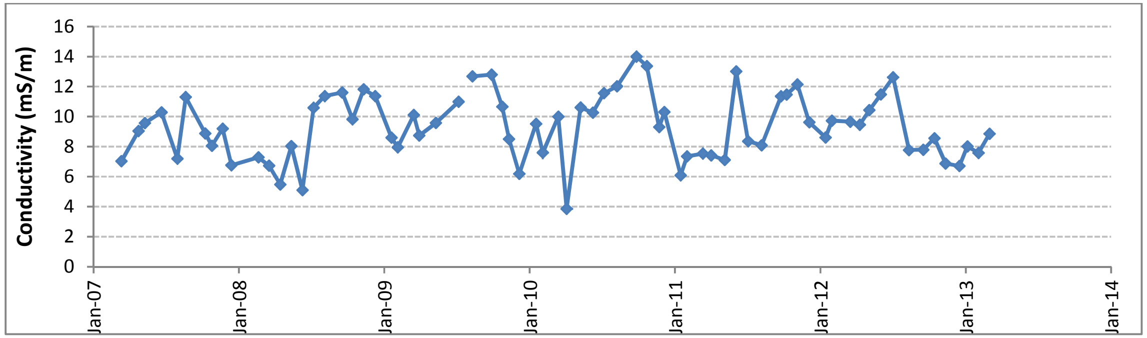
E. coli (per 100 mL)

N	70
Minimum	<10
5-percentile	24.50
25-percentile	124
Median	240
Average	873
75-percentile	818
95-percentile	2612
Maximum	14140



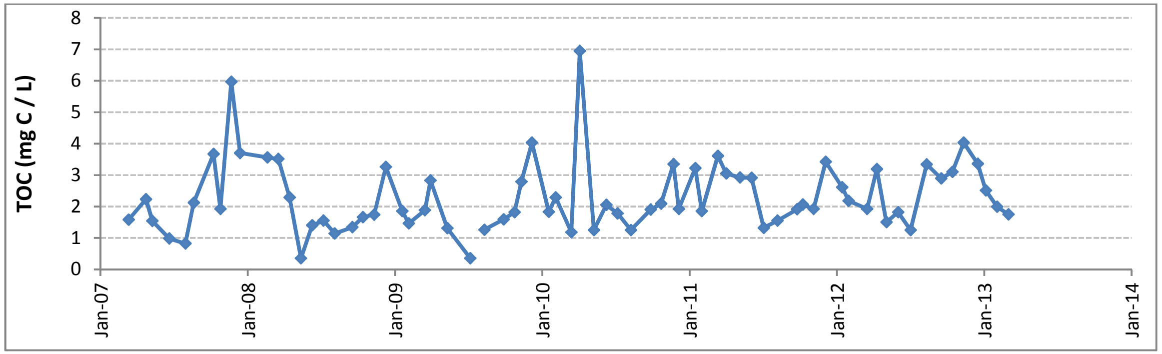
Conductivity (mS/m)

N	71
Minimum	3.86
5-percentile	6.14
25-percentile	7.69
Median	9.30
Average	9.29
75-percentile	10.83
95-percentile	12.74
Maximum	14



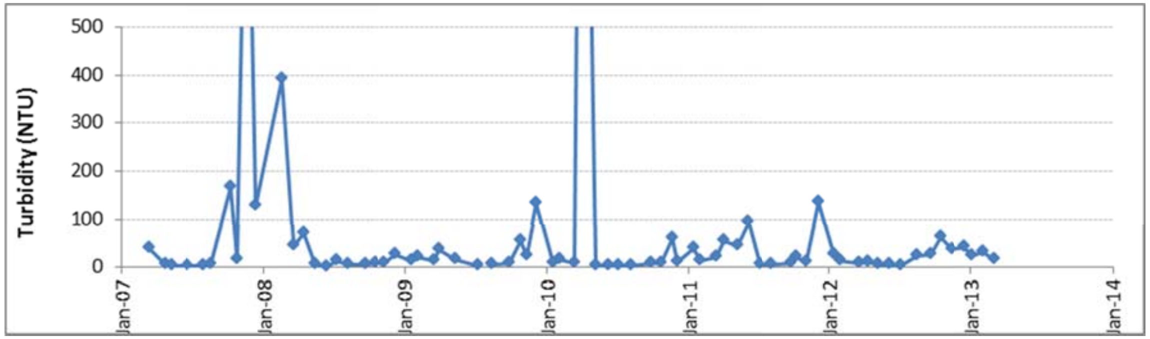
Total Organic Carbon (mg /L)

N	71
Minimum	<0.70
5-percentile	1.06
25-percentile	1.55
Median	1.92
Average	2.29
75-percentile	2.99
95-percentile	3.87
Maximum	6.95



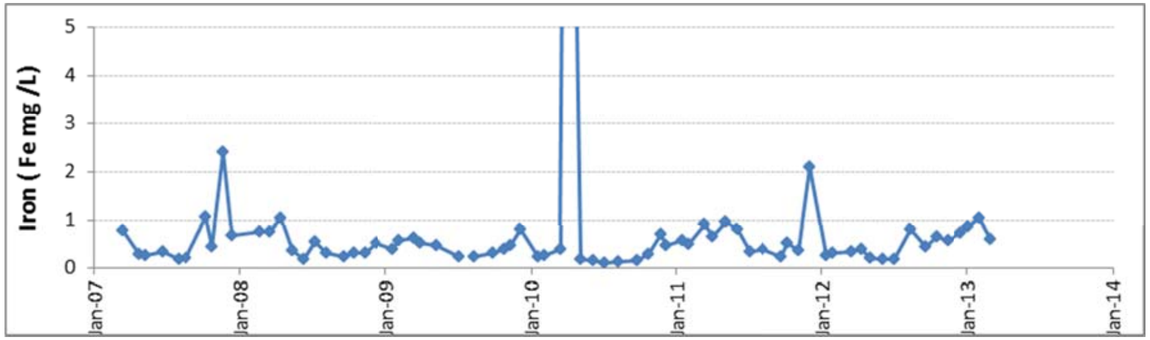
Turbidity (NTU)

N	71
Minimum	1.39
5-percentile	2.41
25-percentile	6.15
Median	13.90
Average	70.40
75-percentile	37.80
95-percentile	150.00
Maximum	1761.00



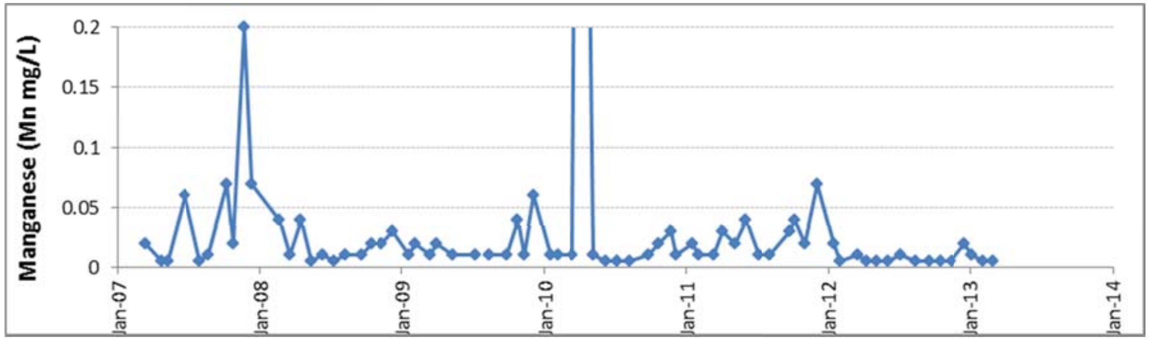
Iron (mg/L)

N	71
Minimum	0.10
5-percentile	0.17
25-percentile	0.27
Median	0.40
Average	0.76
75-percentile	0.67
95-percentile	1.06
Maximum	18.30

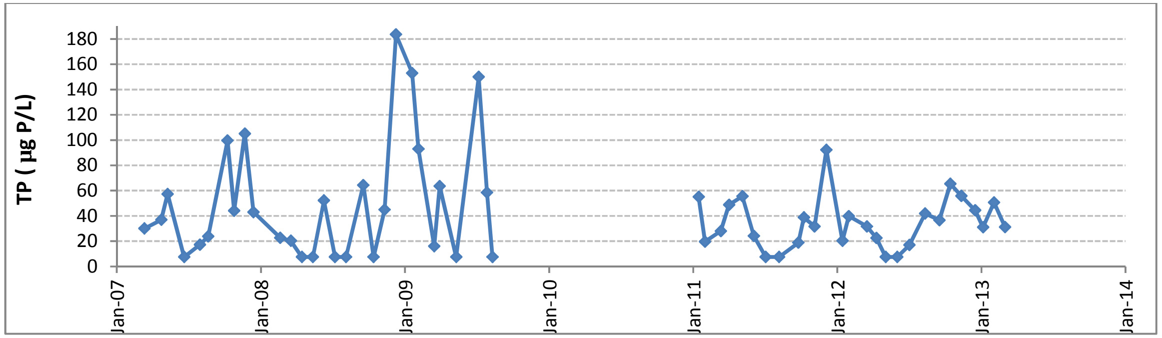


Manganese (mg/L)

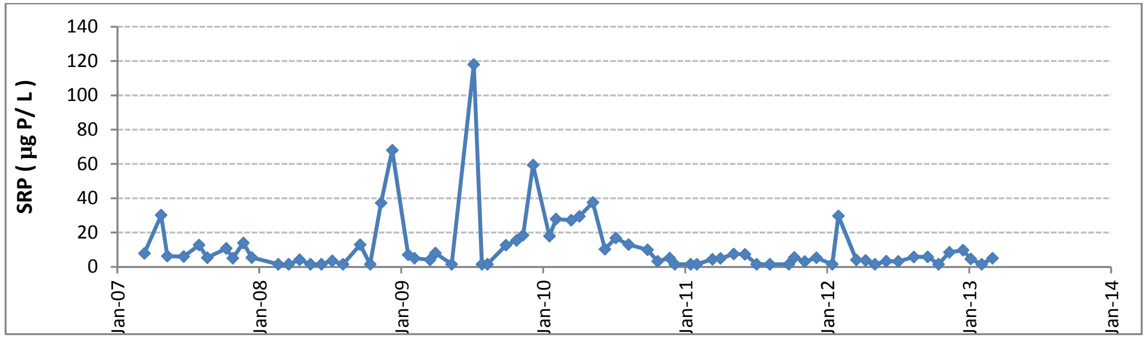
N	71
Minimum	<0.01
5-percentile	0.01
25-percentile	0.01
Median	0.01
Average	0.03
75-percentile	0.02
95-percentile	0.07
Maximum	0.95



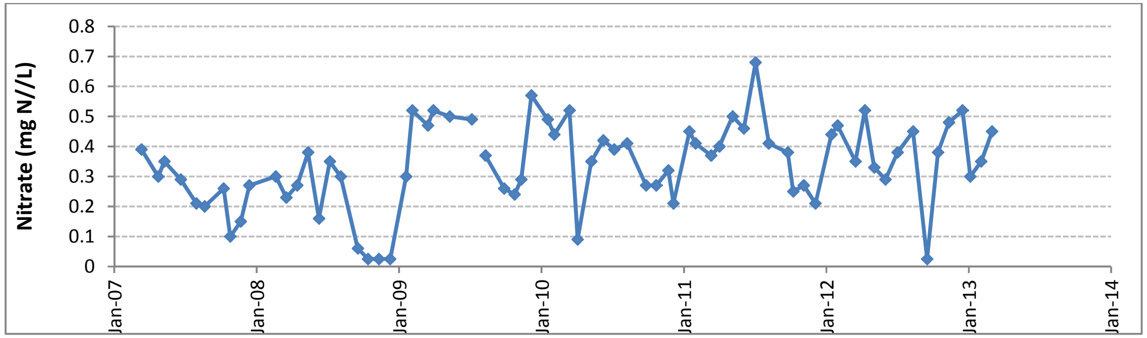
Total Phosphorus (µg/L)	
N	56
Minimum	<15.00
5-percentile	7.50
25-percentile	17.15
Median	31.70
Average	42.32
75-percentile	55.13
95-percentile	116.25
Maximum	183.60



Soluble Reactive Phosphorous (µg/L)	
N	72
Minimum	<3.00
5-percentile	1.50
25-percentile	1.50
Median	5.27
Average	11.44
75-percentile	12.63
95-percentile	37.34
Maximum	118.00



Nitrate (mg/L)	
N	71
Minimum	<0.05
5-percentile	0.04
25-percentile	0.27
Median	0.35
Average	0.34
75-percentile	0.45
95-percentile	0.52
Maximum	0.68



In cases of results below the detection limit, time series plots indicate half the detection limit.

SUMMARY STATISTICS – LUHANE SMITHFIELD INFLOW

Determinands	Sample Count	Minimum	Median	Average	95th percentile	Maximum
Conductivity mS/m	71	3.9	9.3	9.3	12.7	14.0
E.coli /100ml	70	5	240	873	2612	14140
Iron mg/l	71	0.10	0.40	0.76	1.06	18.30
Manganese mg/l	71	0.01	0.01	0.03	0.07	0.95
Ammonia mg N/l	72	0.01	0.09	0.07	0.21	0.79
Nitrate mg N/l	71	0.03	0.35	0.34	0.52	0.68
pH	71	6.8	7.9	-	8.5	8.7
Soluble Reactive Phosphorus ug P/l	72	1.5	5.3	11.4	37.3	118.0
Suspended Solids mg/l	71	2.0	9.2	53.2	116.4	1716.8
Temperature `C	71	6.7	18.1	17.0	24.4	25.6
Total Organic Carbon mg C/l	71	0.35	1.90	2.30	3.90	6.95
Total Phosphorus ug P/l	56	7.50	31.70	42.32	116.25	183.60
Turbidity NTU	71	1.39	13.90	70.40	150.00	1761.00

Summary statistics have been calculated using the half the detection limit, except in cases when all results are below the detection limit

Appendix C

Upper uMkhomazi catchment

ANNEXURE 3: UPPER UMKHOMAZI CATCHMENT

SUMMARY STATISTICS – UMKHOMAZI UPSTREAM OF UMKHOMAZANA AND NZINGA CONFLUENCE

Determinands	Sample Count	Minimum	Median	Average	95th percentile	Maximum
Colour 'H	227	0.5	4.4	11.7	51.1	210.1
Conductivity mS/m	244	2.4	6.0	6.0	8.4	15.2
E.coli /100ml	244	0	83	592	3385	12000
Iron mg/l	231	0.03	0.20	0.40	1.41	4.49
Manganese mg/l	231	0.01	0.01	0.04	0.20	0.78
Ammonia mg/l	242	0.01	0.04	0.05	0.11	0.39
Nitrate mg/l	247	0.03	0.03	0.08	0.22	1.31
pH	242	6.5	7.8	-	8.1	9.0
Soluble Reactive Phosphorus µg/l	241	1.5	3.5	5.1	14.8	3.1
Suspended Solids mg/l	244	2.0	9.6	95.7	585.5	2339.0
Total Kjeldahl Nitrogen mg/l	221	0.10	0.37	0.57	1.65	5.52
Total Organic Carbon mg/l	245	3.4	1.8	2.2	4.4	17.7
Total Phosphorus µg/l	243	7.5	18.7	48.7	160.8	1011.0
Turbidity NTU	245	1.1	7.8	116.2	646.4	3244.0

SUMMARY STATISTICS – NZINGA UPSTREAM OF UMKHOMAZI CONFLUENCE

Determinands	Sample Count	Minimum	Median	Average	95th percentile	Maximum
Colour 'H	221	0.5	7.4	11.6	34.0	102.0
Conductivity mS/m	236	2.4	4.8	4.9	7.4	8.1
E.coli /100ml	234	6	161	496	2205	7900
Iron mg/l	223	0.09	0.33	0.43	0.95	2.83
Manganese mg/l	223	0.01	0.02	0.03	0.08	0.30
Ammonia mg/l	234	0.01	0.04	0.05	0.14	0.44
Nitrate mg/l	238	0.03	0.19	0.20	0.38	1.55
pH	235	6.5	7.8	-	8.1	9.1
Soluble Reactive Phosphorus µg/l	230	1.5	3.0	4.2	12.1	33.8
Suspended Solids mg/l	235	2.0	11.2	34.6	135.5	528.0
Total Kjeldahl Nitrogen mg/l	210	0.01	0.35	0.59	2.06	4.22
Total Organic Carbon mg/l	236	0.35	2.2	2.6	5.1	12.6
Total Phosphorus µg/l	232	7.5	20.6	34.7	95.6	366.0
Turbidity NTU	236	2.0	10.8	35.2	169.8	663.0

SUMMARY STATISTICS – UMKHOMAZANA UPSTREAM OF UMKHOMAZI CONFLUENCE

Determinands	Sample Count	Minimum	Median	Average	95th percentile	Maximum
Colour 'H	223	0.5	6.5	11.6	37.3	154.0
Conductivity mS/m	242	2.8	6.5	6.6	10.4	12.7
E.coli /100ml	239	0	110	629	3021	35000
Iron mg/l	228	0.06	0.26	0.50	1.23	12.10
Manganese mg/l	228	0.01	0.01	0.03	0.11	0.91
Ammonia mg/l	239	0.01	0.04	0.05	0.12	0.65
Nitrate mg/l	245	0.03	0.03	0.07	0.23	0.50
pH	238	6.7	7.8	-	8.2	9.0
Soluble Reactive Phosphorus µg/l	236	1.5	3.8	5.5	14.9	31.4
Suspended Solids mg/l	240	2.0	10.8	49.0	173.2	2.5
Total Kjeldahl Nitrogen mg/l	216	0.01	0.35	0.60	1.91	4.22
Total Organic Carbon mg/l	241	0.4	2.2	2.6	5.2	15.5
Total Phosphorus µg/l	238	7.5	20.7	32.8	95.9	372.0
Turbidity NTU	240	1.0	8.1	63.7	205.1	5160

Appendix D

uMlaza receiving catchment

ANNEXURE 4: UMLAZI RECEIVING CATCHMENT

SUMMARY STATISTICS – BAYNESFIELD DAM INFLOW

Determinands	Number	Minimum	Median	Average	95th Percentile	Maximum
Aluminium µg/l	6	160.5	245.0	278.8	414.5	421.0
Algal count cells/ml	6	0	13	17	42	46
Alkalinity mg CaCO3/l	6	19.3	21.4	21.5	23.3	23.4
Arsenic µg/l	6	<2	<2	<2	<2	<2
Calcium mg/l	6	2.29	3.41	3.18	3.72	3.74
Cadmium µg/l	6	<1	<1	<1	<1	<1
Chlorophyll *a* µg/l	6	0.45	0.45	0.74	1.45	1.58
Chloride mg/l	6	4.62	6.01	6.05	7.53	7.60
Cyanide (T) µg/l	6	<10	<10	<10	<10	<10
Cobalt µg/l	5	<10	<10	<10	<10	<10
Colour `H	6	2.40	3.95	3.73	4.75	4.80
Conductivity mS/m	6	6.02	6.54	6.54	7.15	7.28
Chromium µg/l	6	2.50	2.50	3.69	7.86	9.65
Copper mg/l	6	<0.05	<0.05	<0.05	<0.05	<0.05
E.coli /100ml	6	288	343	400	662	760
Fluoride µg/l	6	<100	<100	<100	<100	<100
Iron mg/l	6	0.48	0.67	0.99	2.07	2.34
Mercury µg/l	6	<0.50	<0.50	<0.50	<0.50	<0.50
Potassium mg/l	6	<1.00	<1.00	<1.00	<1.00	<1.00
Magnesium mg/l	6	2.28	2.54	2.58	2.89	2.96
Manganese mg/l	6	0.005	0.03	0.04	0.08	0.08
Sodium mg/l	6	3.25	5.10	5.52	7.85	7.96
Ammonia mg N/l	6	0.02	0.02	0.03	0.06	0.06
Nickel µg/l	6	<10	<10	<10	<10	<10
Nitrite mg N/l	6	<0.05	<0.05	<0.05	<0.05	<0.05
Nitrate mg N/l	6	0.36	0.42	0.56	0.95	1.01
Lead µg/l	6	<4	<4	<4	<4	<4
pH	6	7.20	7.50	-	7.58	7.60
Phenols µg/l	6	<10	<10	<10	<10	<10
Antimony µg/l	6	<2	<2	<2	<2	<2
Selenium µg/l	6	<2	<2	<2	<2	<2
Sulphate mg SO4/l	6	1.14	1.52	1.54	2.05	2.20
Soluble Organic Carbon mg C/l	6	1.20	2.13	2.27	3.52	3.75
Soluble Reactive Phosphorus µg P/l	6	1.50	4.23	3.67	5.39	5.51
Suspended Solids mg/l	6	4.80	14.60	16.27	30.40	34.00
Total Dissolved Solids mg/l	5	2.00	55.00	59.52	121.16	136.20
Temperature `C	6	18.00	19.05	19.03	20.05	20.10
Total Kjeldahl Nitrogen mg N/l	6	0.50	0.80	0.84	1.27	1.32
Total Organic Carbon mg C/l	6	1.52	2.26	2.51	3.89	4.13
Total Phosphorus ug P/l	6	16.44	37.42	40.91	73.64	82.41
Turbidity NTU	5	7.93	10.85	14.63	27.08	30.00
Vanadium µg/l	5	<10	<10	<10	<10	<10
Zinc mg/l	6	<0.03	<0.03	<0.03	<0.03	<0.03

SUMMARY STATISTICS - MBANGWENI DAM INFLOW

Determinands	Number	Minimum	Median	Average	95th Percentile	Maximum
Algal count cells/ml	6	0	41	40.67	77	79
Alkalinity mg $CaCO_3$/l	6	18.60	21.30	21.68	25.55	26.20
Calcium mg/l	6	1.96	2.52	2.82	3.96	4.10
Chlorophyll *a* µg/l	6	0.45	0.45	0.84	2.18	2.76
Chloride mg/l	6	5.08	5.55	6.12	7.69	7.72
Colour `H	6	2.40	3.95	5.02	10.08	11.80
Conductivity mS/m	6	6.02	6.65	6.57	6.93	6.95
E.coli /100ml	6	130	250	252	350	360
Fluoride µg/l	6	<100	<100	<100	<100	<100
Iron mg/l	6	0.63	1.47	1.60	2.87	3.03
Potassium mg/l	6	<1	<1	<1	<1	<1
Magnesium mg/l	6	2.35	2.71	2.65	2.89	2.90
Manganese n mg/l	6	0.03	0.05	0.06	0.11	0.11
Sodium mg/l	6	4.48	5.34	5.85	7.72	7.94
Ammonia mg N/l	6	<0.04	<0.04	<0.04	<0.04	<0.04
Nitrite mg N/l	6	<0.05	<0.05	<0.05	<0.05	<0.05
Nitrate mg N/l	6	0.18	0.44	0.46	0.81	0.89
pH	6	7.10	7.35	-	8.05	8.2
Sulphate mg SO_4/l	6	1.14	1.73	1.92	2.82	2.91
Soluble Organic Carbon mg C/l	6	1.15	1.78	2.29	4.29	4.72
Soluble Reactive Phosphorus µg P/l	6	1.50	5.52	5.38	8.61	9.25
Suspended Solids mg/l	6	7.20	25.40	28.53	50.00	50.40
Total Dissolved Solids mg/l	6	48.80	66.80	73.80	107.55	117.2
Temperature `C	6	15.70	18.65	19.22	22.90	23.50
Total Kjeldahl Nitrogen mg N/l	6	0.50	0.91	0.97	1.58	1.66
Total Organic Carbon mg C/l	6	1.34	2.37	2.76	4.43	4.75
Total Phosphorus µg P/l	6	33.37	70.08	68.76	104.63	110.27
Turbidity NTU	6	13.60	25.80	27.85	45.35	47.50

SUMMARY STATISTICS – BAYNESFIELD DAM INTEGRATED

Determinands	Number	Minimum	Median	Average	95th Percentile	Maximum
Algal count cells/ml	6	304	387	482	767	817
Alkalinity mg CaCO3/l	6	19.10	21.65	21.70	24.15	24.40
Calcium mg/l	6	3.30	3.43	3.51	3.85	3.91
Chlorophyll *a* µg/l	6	4.04	5.29	6.11	8.67	8.67
Chloride mg/l	6	4.74	5.24	5.27	5.70	5.76
Colour `H	6	3.60	4.65	4.80	6.10	6.50
Conductivity mS/m	6	5.96	6.36	6.35	6.62	6.62
E.coli /100ml	6	2	18	32	98	122
Fluoride µg/l	6	<100	<100	<100	<100	<100
Iron mg/l	6	0.36	0.51	0.47	0.54	0.54
Magnesium mg/l	6	2.12	2.32	2.33	2.52	2.54
Manganese mg/l	6	0.01	0.02	0.02	0.04	0.04
Ammonia mg N/l	6	0.02	0.02	0.03	0.06	0.07
Nitrate mg N/l	6	0.20	0.24	0.25	0.31	0.31
pH	6	7.0	7.35	-	7.50	7.5
Phenols µg/l	6	<10	<10	<10	<10	<10
Sulphate mg SO4/l	6	1.29	1.82	2.00	2.91	3.08
Soluble Organic Carbon mg C/l	6	1.51	2.47	2.56	3.66	3.89
Soluble Reactive Phosphorus µg P/l	6	1.10	2.54	2.64	3.99	4.09
Suspended Solids mg/l	6	2.00	5.00	6.93	14.70	15.60
Total Dissolved Solids mg/l	5	28.40	40.00	45.99	73.11	81.00
Temperature `C	6	18.10	22.25	21.78	23.20	23.20
Total Kjeldahl Nitrogen mg N/l	6	0.50	0.77	0.79	1.13	1.14
Total Organic Carbon mg C/l	6	1.78	2.75	2.88	4.05	4.20
Total Phosphorus µg P/l	5	7.50	18.42	33.98	86.93	99.39
Turbidity NTU	6	1.85	5.99	7.29	14.43	15.20

Summary statistics have been calculated using the half the detection limit, except in cases when all results are below the detection limit