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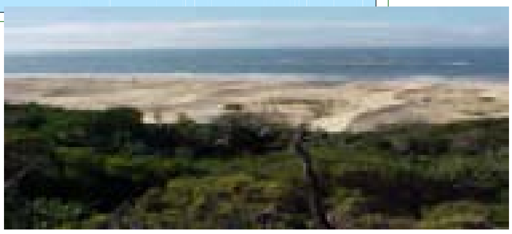
DEPARTMENT OF WATER AFFAIRS AND FORESTRY

Directorate: National Water Resource Planning

ALBANY COAST SITUATION ASSESSMENT STUDY



Water Quality

Final

December 2004

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DEPARTMENT OF WATER AFFAIRS AND FORESTRY
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ALBANY COAST SITUATION ASSESSMENT STUDY

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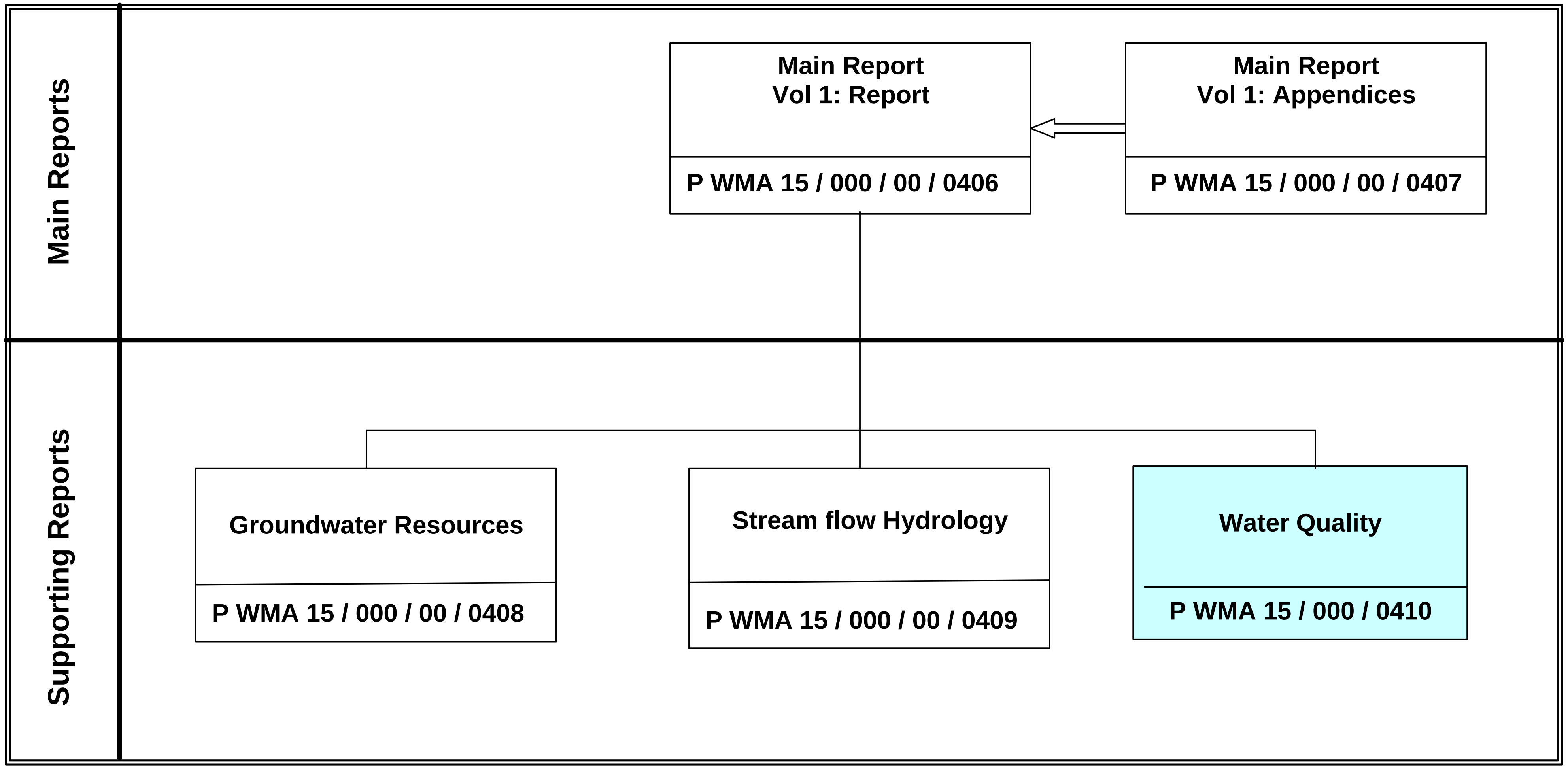

EXECUTIVE SUMMARY

Introduction: Much of Region P is underlain by rocks of marine origin that contribute a significant salt load to runoff, especially during low flow periods. TDS levels in the rivers can exceed 2 000 mg/l due to leaching of these salts. As a result, dams with catchment areas in these strata provide poor quality water. *The purpose of the desk top study* is to calculate the expected salt loads and TDS levels in the proposed dam reservoirs.

Study area geology: The strata in the area belong to the Cape Supergroup (Bokkeveld and Witteberg Groups) the Karoo Supergroup (Dwyka Group), Cretaceous age silcretes of the Grahamstown Formation, and Quaternary sediments of the Algoa Group.

Study area drainage: The main rivers draining the region are the Bushman's (P10), Boknes (P20), Kariega (p30), Kowie (P40A-C), and the Kleinemonde (P40D). There is no significant groundwater baseflow in the rivers and runoff consists of storm runoff and throughflow from drainage of the weathered zone immediately following rain events.

Surface water quality: Rainfall on the Bokkeveld and other marine terrains results in flushing of surficial salts released by weathering, and the leaching of salts by water percolating through the soil and weathered zone. In general, water leaching over Bokkeveld shales results in 0.3 g salt/kg of rock, whereas soils developed over Bokkeveld yield 0.8-4 g/kg. As a result, 25-50 tons of salt are expected to be leached per mm of rain, resulting in surface runoff having a TDS of over 2 200 mg/l, given rainfalls of 600 mm/a.

Over 73% of the salt load is derived from the coastal Nanaga and inland Weltevrede Formations, which occupy 70% of the area. By comparison, nearly 16% of the salt load is derived from Bokkeveld shales, which occupy only 2.3 % of the area. The Dwyka tillites, although containing saline groundwater, contribute only 2% of the salt load and generate primarily fresh surface runoff in the headwater catchments due to their low permeability.

High salt loads for the Weltevrede Formations in Quaternary catchments P30B and P40B can be attributed to significant irrigation return flows on the Kariega and Bloukrans rivers. Over much of catchments P20A, P20B, P30B, P10E and P10F the

Nanaga Formation overlies Bokkeveld shales, hence produces more saline than elsewhere. High salinities are also recorded in boreholes drilled in the Nanaga in these catchments. As a result, runoff from the Nanaga in these catchments generally produces high salt loads.

The quality of runoff is categorised according to the DWAF drinking water classification. In general, only the Witpoort quartzites, and the Dwyka tillites in the headwater region, produce Class 0 water.

Predicted runoff quality: In the Bushman's river, good water quality (Class 1) can be expected down stream to include Quaternaries P10A-D, which are the New Year's and upper Bushman's rivers to Alicedale. *South of Alicedale*, water quality deteriorates rapidly due to significant salt loads originating from the Nanaga and Weltevrede Formations. Runoff continues to become progressively more saline downstream.

In the Kariega catchment acceptable water quality is only present in the head waters of the Kariega, P10A and the headwaters of the Assegai, P30B, which is partially underlain by Witpoort quartzites. *Below the Settler's dam* in catchment P30B water quality deteriorates rapidly due to salt loads from the Weltevrede shales and irrigation return flows.

In the Kowie River, water quality is acceptable in the headwaters, which are underlain by Dwyka, Lake Mentz and Witpoort rocks (P40A). Water quality deteriorates once the *river flows over Weltevrede rocks* north of Bloukrans pass. Salinisation is also expected due to irrigation in the Belmont valley of the Bloukrans, SE of Grahamstown.

In the Boknes catchment, good quality water can only be expected from springs emanating from the Alexandria Formation at the base of the Nanaga Formation at its contact with the Bokkeveld. The Boknes River itself flows over Bokkeveld rocks and *water quality deteriorates rapidly down channel*.

The Diepkloof is an intermittent river with internal drainage into the back dunes regions. Water quality of springs draining the Nanaga is *generally poor*.

Conclusion: The development of dams to produce acceptable quality water is generally not possible, except in those upstream areas underlain by Witpoort quartzites and Dwyka tillites.

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1 INTRODUCTION

1.1 BACKGROUND

Much of Region P is underlain by rocks of marine origin that contribute a significant salt load to runoff, especially during low flow periods. TDS levels in the rivers can exceed 2000 mg/l due to leaching of these salts. This problem is exacerbated where the natural geological profile has been disturbed by agricultural practice, where tillage exposes more of the profile to leaching, or where removal of vegetation increases infiltration.

As a result, dams in the region that have their catchments underlain by marine sediments provide poor quality water due to excessive salt loads in the inflow water. In order to quantify salt loads at potential dam sites, the water quality of groundwater seepage and natural runoff is characterised by lithology and by Quaternary catchment in order to provide a means to characterise water quality at potential dam sites underlain by variable portions of marine lithologies.

1.2 TERMS OF REFERENCE

WSM was approached by UWP regarding potential water quality problems that could arise in proposed dam sites for Ndlambe Municipality in the Eastern Cape. WSM was appointed by UWP Ref. No. 23821/RW/06.

1.3 SCOPE OF WORK

The scope of work includes calculating salt loads and approximate TDS in water at a reconnaissance scale for proposed dam sites when varying proportions of the dam catchment are underlain by marine deposits. This objective requires:

- Characterising surface and subsurface water quality for the Bokkeveld and Witteberg Groups.
- Estimating runoff coefficients and groundwater seepage for the above geological Groups
- Estimate final water quality for varying proportions of Bokkeveld catchment area using a geochemical mixing model.

- Determining maximum proportions of a catchment that could be underlain by saline marine deposits before unacceptable water quality occurs.

1.4 DATA SOURCES

The study will be at a desk top level based on available data and limited field investigation. Data sources consulted include:

- Water quality from local dams established on Bokkeveld and Witteberg Group rocks
- Local borehole and surface runoff collected while undertaking the Albany Coast Water Situation Assessment
- Water quality data from the DWAF ZQM data base
- Runoff coefficients derived from WSAM

2 THE STUDY AREA

2.1 GEOLOGY

The strata in the area belong to the Cape Supergroup (Bokkeveld and Witteberg Groups) the Karoo Supergroup (Dwyka Group), Cretaceous age silcretes of the Grahamstown Formation, and Quaternary sediments of the Algoa Group (Table 1 and Map 1).

The oldest rocks are of the Bokkeveld Group that lies conformably over the Table Mountain Group and comprises the lower Ceres subgroup, which consists of 3 inter-bedded mudrock and 3 thin sandstone layers, and the upper Traka subgroup, which consist of shales and siltstones. These are overlain by the Witteberg Group, of which the lowest member is the Weltevrede Formation, consisting of shale, phyllite and sandstone, and the Witpoort Formation, consisting of quartzite.

The Bokkeveld Group generally lies in synclinal valleys in between mountain ranges consisting of quartzite. Resistant steeply folded beds of shales and siltstones and sandstones form sharp hogsback ridges V ridges at the noses of anticlines and synclines and elongated basins and domes that trends ESE parallel to river valleys.

The shales are generally dark grey to black and have a high carbon content, seen as graphite flakes in cleavage zones. They contain a high iron sulphide fraction in the form of pyrite and sericite. Although these rocks have a low permeability, groundwater from these rocks can have a TDS exceeding 4000 mg/l and up to 9000 mg/l.

Sandstone formations are generally thin and fine grained and also contain sericite mica. The sandstones contain much sericite mica and have well developed jointing that provide channels for groundwater movement, therefore the sandstone beds are of significantly lower salinity.

The Bokkeveld is of marine origin and formed under deltaic conditions. Rocks are generally of very low permeability due to the high degree of rock induration, and pore spaces have been effectively sealed due to secondary crystallisation during periods of dynamic metamorphism, orogenesis and tectogenesis. The presence of well developed micaceous cleavage and graphite confirms high pressures were active in sealing these rocks.

Groundwater flow is restricted to joints, fractures and faults that have a variable degree of openness and marine salts have therefore not been leached from the rock matrix over geological time. Shales of the Bokkeveld Group therefore contain highly saline connate water due to high concentrations of sodium chloride sorbed on to clays micas and graphite platlets, or held immobile in pores until weathering of the rock matrix allows leaching and drainage. Salts are generally released from broken fragments in the weathered zone from material rich in sericite mica and graphite.

When leached, magnesium, calcium, iron and aluminium oxides are leached out of the rock, co-releasing sorbed Cl. Oxidation of sulphide minerals also produces large amounts of sulphate. Cation exchange from weathered clays sorbs the released magnesium and calcium in exchange for sodium, resulting in strongly sodium-chloride type water.

The Witteberg Group consists of the Weltevrede and, Witpoort Formations, and the Lake Mentz Subgroup. The Weltevrede consists of shales deposited under similar conditions to the Bokkeveld, hence is expected to have a similar saline character. The Witpoort quartzites represent deltaic or fluviatile deposits and do not produce saline marine water. The Lake Mentz subgroup represent offshore marine deposits, hence also yield brackish water. Te Witteberg Group lies conformably over the Bokkeveld and builds a series of foothills.

The Dwyka Group consists of glacial tills deposited in deep marine water by ice-rafting. It is generally present in valley bottoms of the New Years and Bloukrans rivers near Grahamstown.

The Nanaga Formation consists of Pliocene-Pleistocene Aeolian deposits deposited in coastal dune fields; hence do not have a marine origin.

Table 1 Stratigraphy of Region P.

Supergroup	Group	Subgroup	Formation	Lithology
	Algoa		Nanaga	Calcareous sandstone, sandy limestone
			Grahamstown	Silcrete
	Uitenhage		Kirkwood	Mudstone
Karoo	Dwyka		Elandsvlei	Diamictite
Cape	Witteberg	Lake Mentz	Waaipoort	Mudrock, sandstone

			Floriskraal	Mudrock, sandstone
			Kweekvlei	Mudrock
			Witpoort	Quartzite
			Weltevrede	Shale, quartzite
	Bokkeveld	Traka	Sandpoort Adolphspoort Karies	Shale, siltstone
		Ceres	BoPlaas Tra-Tra Hex River Voorstehoek Gamka Ghydo	Mudrock, shale, sandstone

2.2 DRAINAGE

The main rivers draining the region are the Bushman's (P10), Boknes (P20), Kariega (p30), Kowie (P40A-C), and the Kleinemonde (P40D). The Quaternary catchments, runoff and baseflow, as given in WSAM, are listed in Table 2 and shown on Map 1.

Table 2 Runoff and baseflow

Quaternary	Area (km^2)	MAP (mm)	MAR (Mm^3/a)	Baseflow (mm/a)	MAR (mm/a)
P10A	126	600	4.51	11.31	35.79
P10B	508	531	12.25	8.07	24.11
P10C	281	386	2.38	2.99	8.47
P10D	564	432	7.01	4.48	12.43
P10E	466	493	8.71	0.75	18.69
P10F	469	557	13.67	2.21	29.15
P10G	343	550	9.76	1.79	28.45
P20A	422	715	30.27	12.91	71.73
P20B	332	635	15.43	5.14	46.48
P30A	176	623	6.95	12.72	39.49
P30B	403	559	11.67	2.30	28.96
P30C	68	536	1.69	0.00	24.85
P40A	312	635	13.58	14.23	43.53
P40B	264	570	8.17	2.03	30.95
P40C	342	616	14.18	4.20	41.46
P40D	246	666	13.36	6.24	54.31

There is no significant groundwater baseflow in the rivers and runoff consists of storm runoff and throughflow from drainage of the weathered zone immediately following rain events.

Due to the widespread presence of alien invasive vegetation and farm dams, significant runoff reduction has occurred. Estimated runoff due to runoff reduction is given in table 3.

Table 3 Runoff due to runoff reduction by alien invasives

Quaternary	Alien Invasives (km^2)	Estimated runoff (Mm^3)
P10A	5.27	3.09
P10B	4.51	9.78
P10C	0	1.54
P10D	0.26	4.60
P10E	0.78	8.56
P10F	11.2	12.63
P10G	0.41	9.23
P20A	51.10	24.82
P20B	57.19	13.72
P30A	22.12	4.71
P30B	5.49	10.74
P30C	0.38	1.69
P40A	40.11	9.14
P40B	5.62	7.63
P40C	10.98	12.71
P40D	13.51	11.83

2.3 QUATERNARY CATCHMENT GEOLOGY

The proportion of each Quaternary catchment underlain by the various geological Formations is given in table 4.

Due to the difficulties in establishing the contacts between some of the various Formations, the areas underlain by the various lithologies must be considered approximate.

2.4 QUATERNARY CATCHMENT GROUNDWATER QUALITY

Borehole and surface water quality data found in the National ZQM water quality data base was clipped using Quaternary and geological formation boundaries to identify the range of TDS values in each Formation per quaternary catchment. The average TDS value was used to categorise each Formation (table 5). Where no data was present, TDS was extrapolated from an adjacent Quaternary catchment. A weighted mean catchment groundwater TDS was subsequently derived according to lithological type areas and their percentage distribution. The results are shown in table 5.

2.5 QUATERNARY CATCHMENT SURFACE WATER QUALITY

Rainfall on Bokkeveld and other marine terrains results in flushing of surficial salts released by weathering, and the leaching of salts by water percolating through the soil and weathered zone. In general, water leaching over Bokkeveld shales results in 0.3 g salt/kg of rock, whereas soils developed over Bokkeveld yield 0.8-4 g/kg. As a result, 25-50 tons of salt are expected to be leached per mm of rain, resulting in surface runoff having a TDS of over 2200 mg/l, given rainfalls of 600 mm/a.

Peak TDS is encountered during the first flush of runoff, with a lowering of TDS generally appearing several days after peak flows. The recorded TDS of runoff is shown in figures 1-7.

2.5.1 Bushman's River – P10

In the headwater regions of the New Year's river (P10A, figure 1), TDS is generally less than 200 mg/l and has a mean value of 140 mg/l, except during rainfall events, when a first flush of higher TDS of up to 500 mg/l can be expected. Following these events, lower TDS values are recorded.

Higher TDS values are recorded downstream in catchment P10B (figure 2), where TDS averages approximately 500 mg/l. During flood events, TDS rises to over 3500 mg/l.

TDS continues to rise downstream (P10E, figure 3), and the Bushman's river has an average TDS of 2200 mg/l, rising to over 4000 mg/l during flood events. Immediately after floods flush salts from the catchment TDS values drop to as low as 500 mg/l.

Pools sampled in the Bushman's and the Bega river tributary that originates on Bokkeveld shales had TDS values of 4400 mg/l, and over 10 000 mg/l respectively.

2.5.2 Kariega River – P30

The headwaters of the Kariega (P30A figure 4) generally have an average TDS of 250-400 mg/l, which rises up to 1400 mg/l during floods. Downstream in P30B the Kariega has an average TDS of 2500 mg/l, rising to over 5500 mg/l during floods (figure 5).

2.5.3 Kowie River – P40

In the headwaters of the Kowie (P40A figure 6) average TDS values are 750-900 mg/l, rising to over 1300 mg/l during floods. TDS values increase downstream to an average of 1700 mg/l in P40C (figure 7).

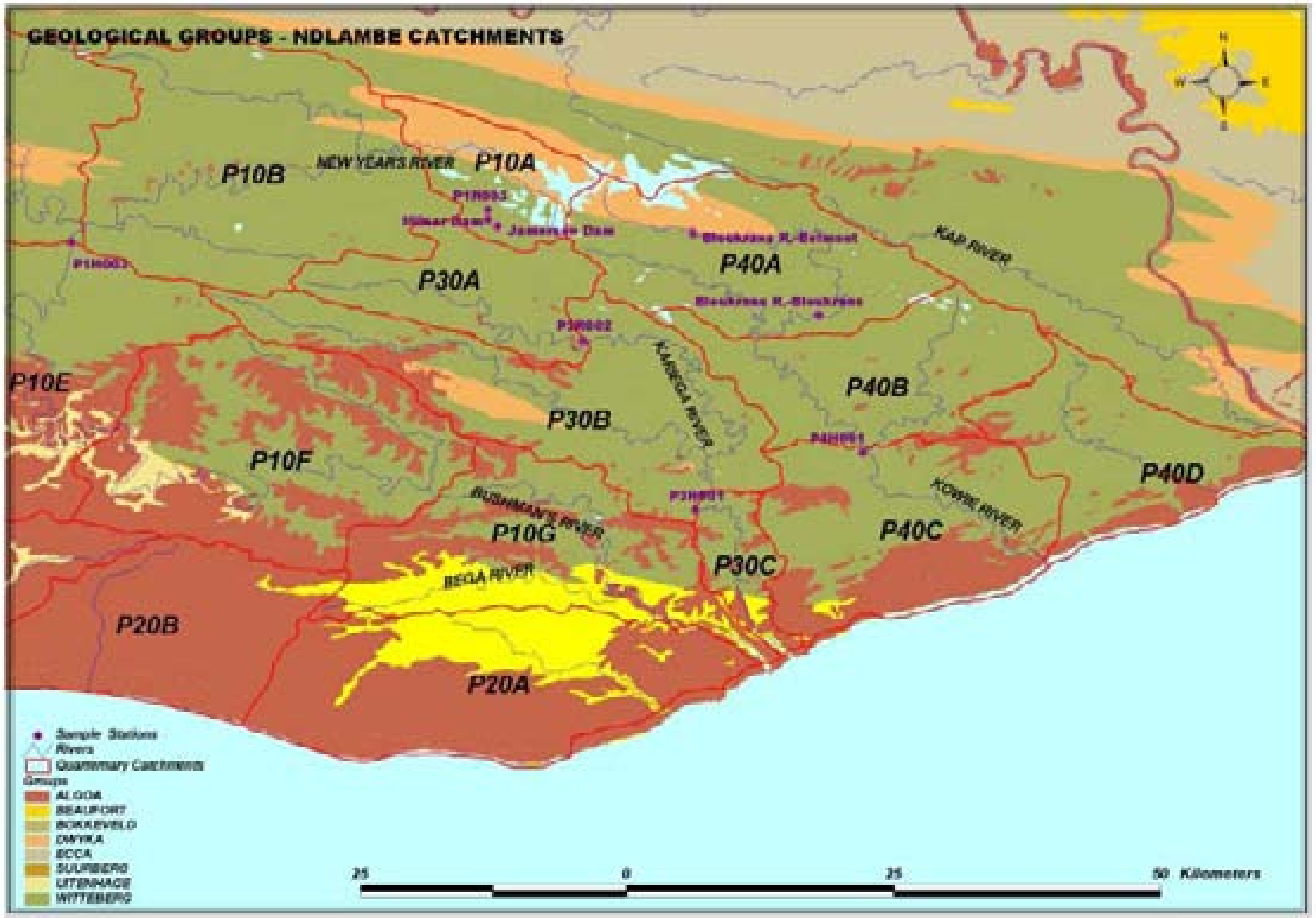
2.6 SALT LOADS

To calculate salt loads, the average TDS of runoff was obtained from the WSAM model. The weighted mean groundwater TDS times baseflow volumes were used to calculate the annual salt load contributed by subsurface drainage. The remainder of the total salt load was attributed to the flushing of salts by surface runoff (table 6). TDS values for runoff in catchments P10E, F and G were not available from WSAM and were estimated based on recorded discharges (figure 3).

Salt loads per mm of rainfall and runoff are shown in table 7, together with the estimated weighted mean TDS in runoff calculated from runoff and estimated total salt loads.

Quaternary	Weltevrede	Witpoort	Nanaga	Grahamstown	Lake Mentz	Bokkeveld	Dwyka	Basalt	Kirkwood	Sand	Limestone
P10A	10.57	27.00		8.73	13.40		40.30				
P10B	18.38	50.00			18.81		12.81				
P10C	43.50				44.09		12.40				
P10D	53.50				32.52		13.98				
P10E	39.95		49.00	0.09	1.67			2.15	7.12	0.02	
P10F	10.62		70.00	0.38	6.18	6.00	3.00	1.13	0.84	1.85	
P10G	26.64		46.00		12.36	15.00					
P20A			84.26			10.96				4.78	
P20B			90.21			3.94				5.15	
P30A	60.00		40.00		0.00						
P30B	71.00		19.00		6.00		4.00				
P30C	26.00		60.60		10.80	1.10				1.50	
P40A	57.00			3.80	23.50		15.10				0.60
P40B	94.40				0.00						5.60
P40C	42.20		42.10		8.70	1.80				4.80	0.40
P40D	50.20		33.30		13.80					1.90	0.80

Table 4 Percentage distribution of Formations by Quaternary catchment



Map 1 Geological Map of region P, showing Quaternary catchments and water quality sampling points.

Quaternary	Weltevrede	Witpoort	Nanaga	Grahamstown	Lake Mentz	Bokkeveld	Dwyka	Basalt	Kirkwood	Sand	Limestone	Mean TDS (mg/l)
P10A	600	552		106	666		106					353.66
P10B	900	963			1192		3677					1342.07
P10C	800	963			1400		992					1088.38
P10D	800				1014		992					896.43
P10E	3761	1394	2629	1394	1394			1520	1520	2629		2956.64
P10F	3188	3188	2838	1394	1600	3929	3188	600	1520	2600		2828.33
P10G	2557		1881		1875	3929				2360		2641.93
P20A			2417			2358				819		2334.15
P20B			2578			3828				819		2536.66
P30A	600		600									600.00
P30B	2498	2498	915		2489		2498					2196.69
P30C	1233	1420	994		927	8123				2600		1151.41
P40A	2600	588		1394	2400		2500				800	2481.27
P40B	2609	656					2500				800	2507.70
P40C	2442	2255	2255		2500	2034				2600	1337	2364.14
P40D	2509	1473	1473		2500					2600	813	2150.93

Table 5 Average TDS in mg/l per Formation and weighted mean groundwater TDS in mg/l per Quaternary catchment.

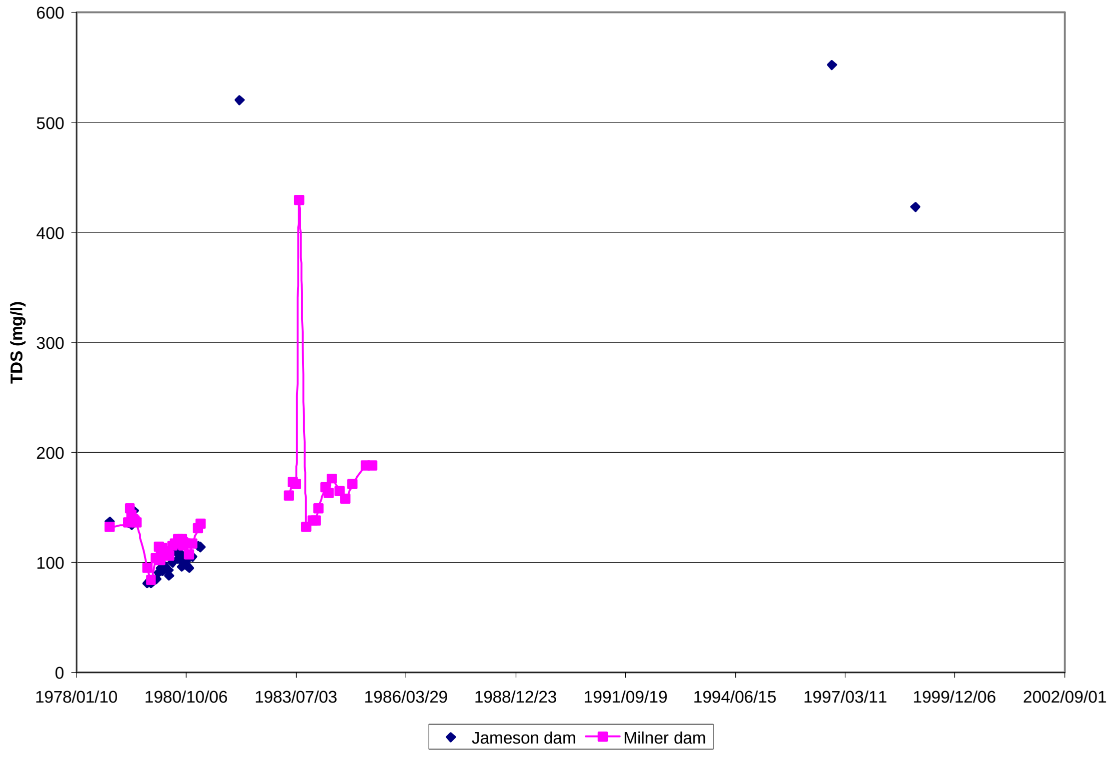


Figure 1 TDS values in Jameson and Milner dams, P10A

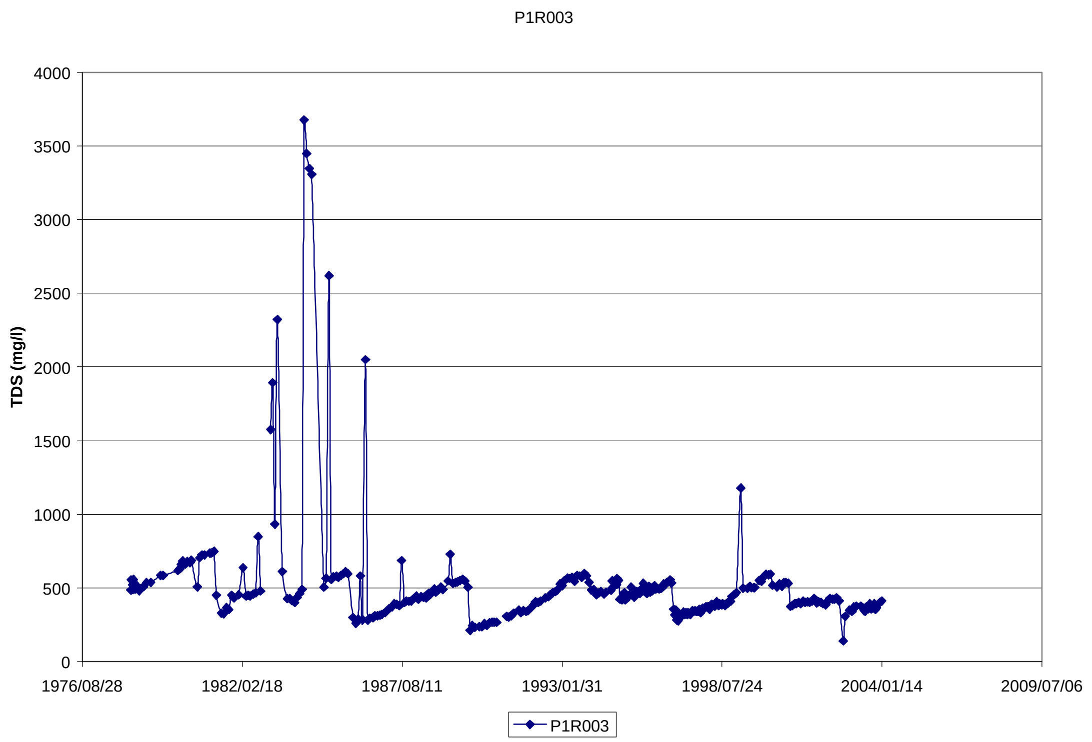


Figure 2 TDS values at gauge P1R003, P10B.

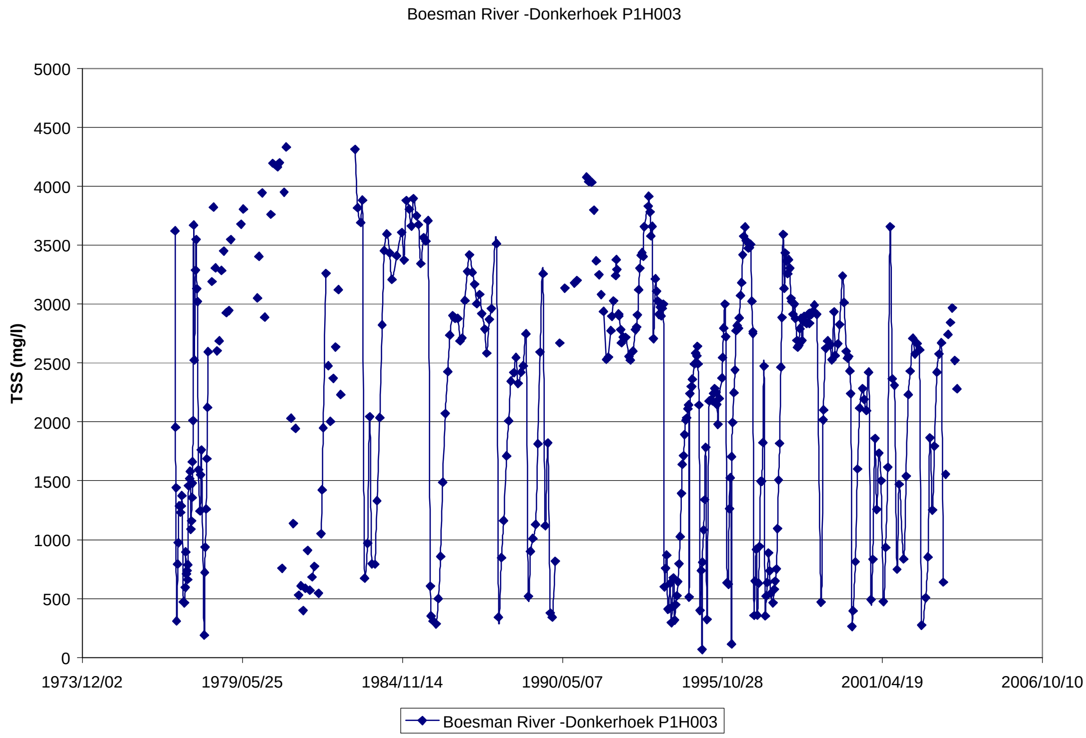


Figure 3 TDS values in the Bushman's river, P10E

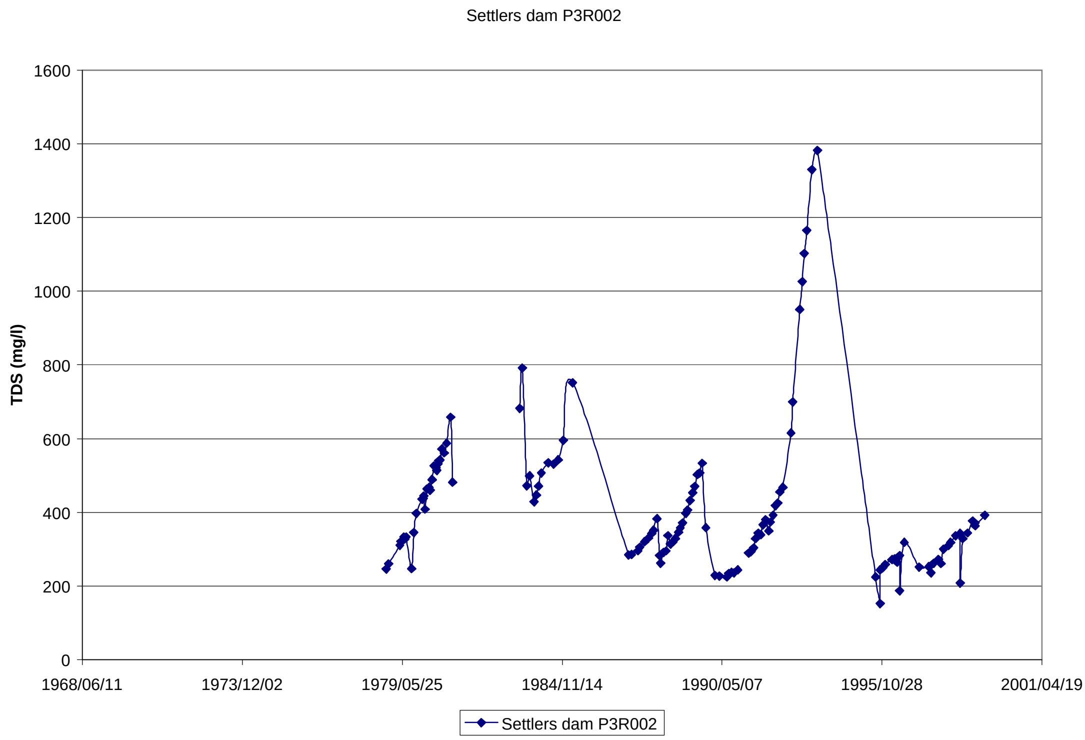


Figure 4 TDS values in Settler's dam, P30A

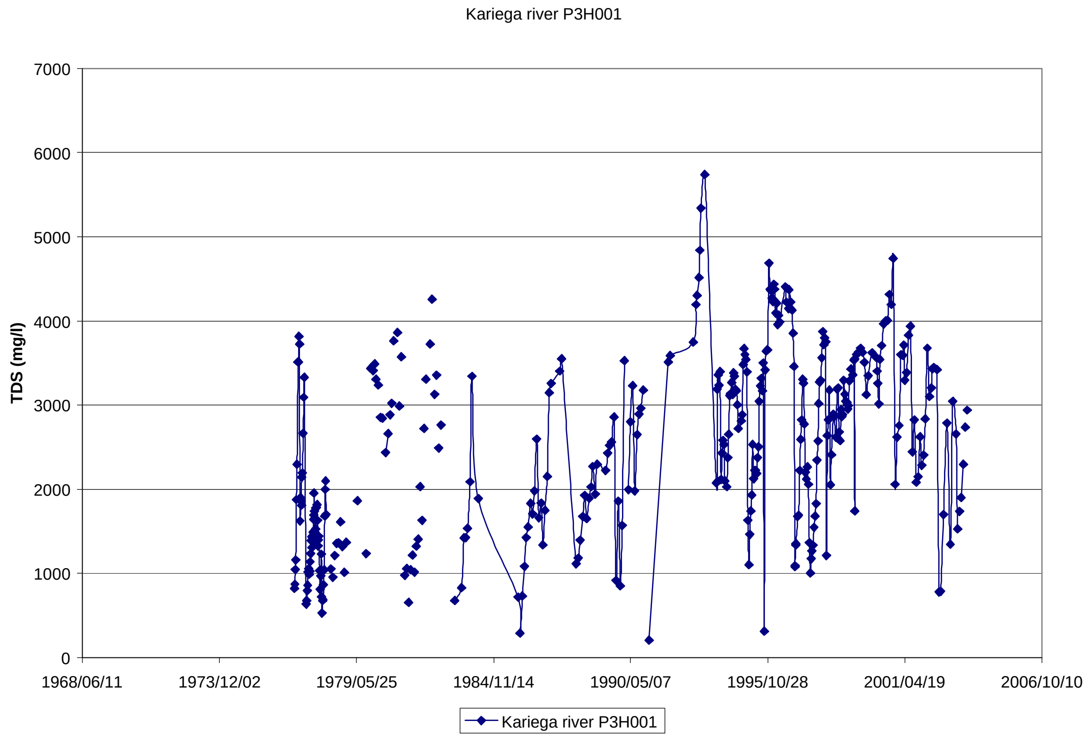


Figure 5 TDS values in the Kariega river, P3H001, P30B

Figure 6 TDS values in the Blaukrans river, P40A

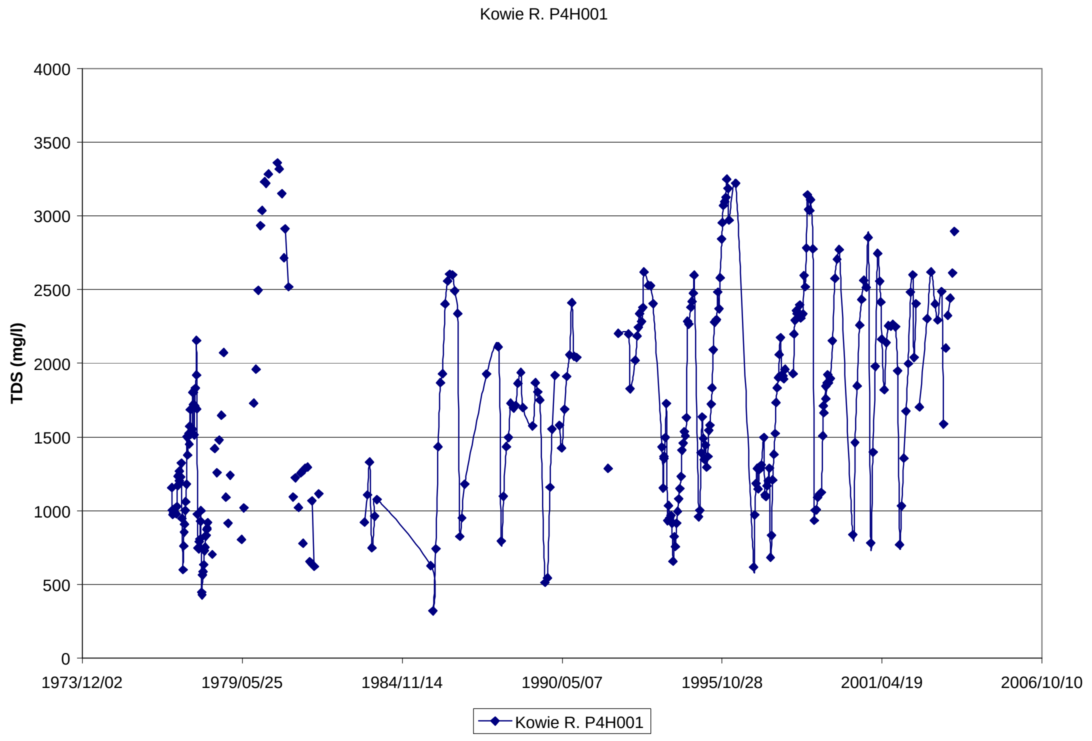


Figure 7 TDS values in the Kowie River, P4H001, P40C.

Table 6 Surface and subsurface runoff salt loads by Quaternary catchment

Quaternary	Runoff TDS (mg/l)	Groundwater TDS(mg/l)	Groundwater load (tonnes/a)	Surface runoff load (tonnes/a)	Surface runoff TDS (mg/l)	Total load (tonnes/a)
P10A	121	353	503	43	26	546
P10B	510	1342	5502	746	131	6248
P10C	418	1088	914	80	114	994
P10D	343	896	2264	139	67	2403
P10E	2300	2956	1033	19000	2315	20033
P10F	2300	2858	2962	28479	2456	31441
P10G	2300	2641	1621	20827	2418	22448
P30A	214	580	1298	192	77	1490
P30B	2361	2196	2035	25513	2599	27548
P30C	442	1151	0	747	442	747
P40A	891	2481	11015	1085	231	12100
P40B	1582	2507	1344	11579	1631	12922
P40C	1770	2364	3396	21697	1924	25093

P40D	1566	2150	3300	17620	1712	20920
P20A	781	2334	12716	10934	564	23650
P20B	593	2536	4325	4829	402	9154

Table 7 Estimated salt loads per unit rainfall and runoff.

Quaternary	Tonnes/ mm rain/a	Tonnes/ mm runoff/a	Discharge (Mm3/a)	Est. average TDS (mg/l)
P10A	0.9	22.3	3.09	177
P10B	11.8	324.4	12.87	528
P10C	2.6	181.3	1.54	645
P10D	5.6	294.5	6.14	553
P10E	40.6	1091.1	27.57	1096
P10F	56.4	1167.3	40.20	1534
P10G	40.8	834.4	49.43	1702
P30A	2.4	55.6	4.71	316
P30B	49.3	1033.4	15.46	1879
P30C	1.4	30.0	17.15	1737
P40A	19.1	413.0	9.14	1324
P40B	22.7	446.9	16.77	1492
P40C	40.7	675.0	29.49	1700
P40D	31.4	435.2	11.83	1769
P20A	33.1	402.1	24.82	953
P20B	14.4	221.4	13.72	667

2.7 RUNOFF COEFFICIENTS

Runoff coefficients for both surface and subsurface drainage as a percentage of rainfall per Formation and per Quaternary were derived to estimate salt loads from each Formation. Runoff coefficients (table 8) were calibrated against total Quaternary runoff (table 3) to derive an estimate of runoff per Formation (table 9).

Quaternary	Weltevrede	Witpoort	Nanaga	Grahamstown	Lake Mentz	Bokkeveld	Dwyka	Basalt	Kirkwood	Sand	Limestone
P10A	2.1	4.9		2.5	1.0		5.5			10.0	
P10B	2.1	4.9			1.0		5.5			10.0	
P10C	1.2				1.0		4.0			10.0	
P10D	1.8				1.0		4.5			10.0	
P10E	2.0		5.8	2.5	1.0			2.0	0.0	10.0	
P10F	1.7		5.8	2.5	1.0	4.0	4.0	2.0	0.0	10.0	
P10G	2.1		6.2	2.5	1.0	9.0	4.5	2.0	0.0	10.0	1.0
P20A			8.0			9.0				10.0	
P20B			6.3			9.0				10.0	
P30A	3.0		6.2							10.0	
P30B	4.0		8.0		3.0	9.0	5.7	2.0	0.0	10.0	3.0
P30C	3.0		5.8		1.5	9.0	5.7	2.0	0.0	10.0	3.0
P40A	5.5	7.0	7.0	3.0	2.0	13.0	5.7	2.0	0.0	10.0	3.0
P40B	5.2	7.0	7.0	3.0	2.0	13.0	5.7	2.0	0.0	10.0	3.0
P40C	4.6	7.0	7.0	3.5	5.0	13.0	5.7	2.0	0.0	10.0	3.0
P40D	7.5	8.0	8.0	4.0	5.0	13.0	5.7	2.0	0.0	10.0	3.0

Table 8 Calibrate runoff coefficients per Formation

Quaternary	Weltevrede	Witpoort	Nanaga	Grahamstown	Lake Mentz	Bokkeveld	Dwyka	Basalt	Kirkwood	Sand	Limestone	Total (Mm^3/a)
P10A	0.17	1.00	0.00	0.17	0.10	0.00	1.68	0.00	0.00	0.00	0.00	3.11
P10B	1.04	6.61	0.00	0.00	0.51	0.00	1.90	0.00	0.00	0.00	0.00	10.06
P10C	0.57	0.00	0.00	0.00	0.48	0.00	0.54	0.00	0.00	0.00	0.00	1.58
P10D	2.35	0.00	0.00	0.00	0.79	0.00	1.53	0.00	0.00	0.00	0.00	4.67
P10E	1.84	0.00	6.53	0.01	0.04	0.00	0.00	0.10	0.00	0.00	0.00	8.51
P10F	0.47	0.00	10.61	0.02	0.16	0.63	0.31	0.06	0.00	0.48	0.00	12.75
P10G	1.06	0.00	5.38	0.00	0.23	2.55	0.00	0.00	0.00	0.00	0.00	9.22
P20A	0.00	0.00	8.48	0.00	0.00	1.24	0.00	0.00	0.00	0.60	0.00	10.33
P20B	0.00	0.00	14.66	0.00	0.00	0.91	0.00	0.00	0.00	1.32	0.00	16.88
P30A	0.76	0.00	1.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.81
P30B	4.95	0.00	2.65	0.00	0.31	0.00	0.40	0.00	0.00	0.00	0.00	8.32
P30C	1.10	0.00	4.97	0.00	0.23	0.14	0.00	0.00	0.00	0.21	0.00	6.66
P40A	6.81	0.00	0.00	0.25	1.02	0.00	1.87	0.00	0.00	0.00	0.04	9.98
P40B	6.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	7.12
P40C	5.05	0.00	7.66	0.00	1.13	0.61	0.00	0.00	0.00	1.25	0.03	15.73
P40D	8.32	0.00	5.89	0.00	1.53	0.00	0.00	0.00	0.00	0.42	0.05	16.21

Table 9 Mean annual runoff per Formation in Mm^3/a.

2.8 ORIGIN OF SALTS

Estimated runoff from each Formation (table 9) and the water quality of runoff from each Formation (table 10) were used to estimate salt loads emanating from each Formation per Quaternary (Table 11). Runoff water quality was calibrated against total salt loads from each catchment (table 6). Water quality from each Formation is expressed as a percentage of the total Quaternary and Region P salt load in table 12.

Over 73% of the salt load is derived from the coastal Nanaga and inland Weltevrede Formations, which occupy 70% of the area. By comparison, nearly 16% of the salt load is derived from Bokkeveld shales, which occupy only 2.3 % of the area. The Dwyka tillites, although containing saline groundwater, contribute only 2% of the salt load and generate primarily fresh surface runoff in the headwater catchments due to their low permeability.

Salt loads expressed as tonnes/a/km^2 per Formation are given in Table 13. High salt loads for the Weltevrede Formations in Quaternary catchments P30B and P40B can be attributed to significant irrigation return flows on the Kariega and Bloukrans rivers. Over much of catchments P20A, P20B, P30B, P10E and P10F the Nanaga Formation overlies Bokkeveld shales, hence produces more saline than elsewhere. High salinities are also recorded in boreholes drilled in the Nanaga in these catchments (Table 5). As a result, runoff from the Nanaga in these catchments generally produces high salt loads.

The quality of runoff is categorised according to the DWAF drinking water classification in table 14. In general, only the Witpoort quartzites, and the Dwyka tillites in the headwater region, produce Class 0 water.

Quaternary	Weltevrede	Witpoort	Nanaga	Grahamstown	Lake Mentz	Bokkeveld	Dwyka	Basalt	Kirkwood	Sand	Limestone
P10A	750	150		200	700		100				
P10B	1500	300			1500		1000				
P10C	850	150			850		200				
P10D	750	150			700		100				
P10E	2950	300	2200	1394	2500			1520	1520	2629	
P10F	3000	300	2200	1394	2500	7000	1000	600	2000	2600	
P10G	3000		700		1875	6000				2360	
P20A			1450			8000				2600	
P20B			500			1200				800	
P30A	1000	150	700								
P30B	4100	300	2200		3000		1000				
P30C	250	100	100		250	1000				200	
P40A	1350	150		1394	1300		700				800
P40B	1850	150					700			2600	800
P40C	1700	100	1100		1200	6000				2600	1337
P40D	1550	100	900		1200					2400	1300

Table 10 Calibrated TDS of weighted surface and subsurface runoff in mg/l per Formation and Quaternary catchment

Quaternary	Weltevrede	Witpoort	Nanaga	Grahamstown	Lake Mentz	Bokkeveld	Dwyka	Basalt	Kirkwood	Sand	Limestone	Total (tonnes/a)
P10A	126	150	0	33	71	0	168	0	0	0	0	547
P10B	1562	1983	0	0	761	0	1900	0	0	0	0	6206
P10C	481	0	0	0	407	0	108	0	0	0	0	995
P10D	1760	0	0	0	555	0	153	0	0	0	0	2468
P10E	5415	0	14364	8	96	0	0	150	0	10	0	20043
P10F	1415	0	23333	34	403	4389	313	35	0	1255	0	31179
P10G	3166	0	3766	0	437	15281	0	0	0	0	0	22650
P20A	0	0	12300	0	0	9930	0	0	0	1564	0	23794
P20B	0	0	7328	0	0	1089	0	0	0	1054	0	9472
P30A	763	0	735	0	0	0	0	0	0	0	0	1498
P30B	20308	0	5832	0	942	0	398	0	0	0	0	27480
P30C	276	0	497	0	57	140	0	0	0	42	0	1013
P40A	9191	0	0	345	1327	0	1308	0	0	0	31	12203
P40B	12734	0	0	0	0	0	0	0	0	0	188	12922
P40C	8579	0	8427	0	1357	3650	0	0	0	3244	42	25298
P40D	12904	0	5301	0	1831	0	0	0	0	1008	69	21113

Table 11 Estimated annual salt load per Formation and Quaternary in tonnes/a.

Quaternary	Weltevrede	Witpoort	Nanaga	Grahamstown	Lake Mentz	Bokkeveld	Dwyka	Basalt	Kirkwood	Sand	Limestone
P10A	22.98	27.41		6.03	12.96		30.62				
P10B	25.17	31.95			12.26		30.62			0.00	
P10C	48.35				40.84		10.81			0.00	
P10D	71.31				22.48		6.21			0.00	
P10E	27.02		71.67	0.04	0.48			0.75		0.05	
P10F	4.54		74.84	0.11	1.29	14.08	1.01	0.11		4.03	
P10G	13.98		16.63		1.93	67.46				0.00	
P20A			51.69			41.73				6.57	
P20B			77.37			11.50				11.13	
P30A	50.90		49.10							0.00	
P30B	73.90		21.22		3.43		1.45			0.00	
P30C	27.24		49.09		5.66	13.83				4.19	
P40A	75.32			2.83	10.87		10.72			0.00	0.26
P40B	98.54									0.00	1.46
P40C	33.91		33.31		5.36	14.43				12.82	0.16
P40D	61.12		25.11		8.67					4.78	0.33
% of total load (Region P)	35.95	0.97	37.41	0.19	3.77	15.75	1.99	0.08	0.00	3.74	0.15

Table 12 Percent of total salt load derived from each Formation for each Quaternary catchment.

Quaternary	Weltevrede	Witpoort	Nanaga	Grahamstown	Lake Mentz	Bokkeveld	Dwyka	Basalt	Kirkwood	Sand	Limestone
P10A	1.00	1.19		0.26	0.56		1.33				
P10B	3.07	3.90			1.50		3.74				
P10C	1.71				1.45		0.38				
P10D	3.12				0.98		0.27				
P10E	11.62		30.82	0.02	0.21			0.32		0.02	
P10F	3.02		49.75	0.07	0.86	9.36	0.67	0.08		2.68	
P10G	9.23		10.98		1.27	44.55					
P20A			69.89			56.42				8.89	
P20B			18.18			2.70				2.62	
P30A	11.21		10.82								
P30B	65.09		18.69		3.02		1.27				
P30C	1.05		1.88		0.22	0.53				0.16	
P40A	26.87			1.01	3.88		3.83				0.09
P40B	51.76										0.77
P40C	20.33		19.97		3.22	8.65				7.69	0.10
P40D	38.87		15.97		5.51					3.04	0.21

Table 13 Salt loads in tonnes/a/km^2 per Formation.

Quaternary	Weltevrede	Witpoort	Nanaga	Grahamstown	Lake Mentz	Bokkeveld	Dwyka	Basalt	Kirkwood	Sand	Limestone
P10A	1	0		0	1		0				
P10B	2	0			2		2				
P10C	1				1		0				
P10D	1				1		0				
P10E	3		3	2	3			2		3	
P10F	4		3	2	3	4	2	1		3	
P10G	4		1		2	4					
P20A			2			4				3	
P20B			1			2				1	
P30A	2		1								
P30B	4		3		4		2				
P30C	0		0		0	2				0	
P40A	2			2	2		1				1
P40B	2										1
P40C	2		2		2	4				3	2
P40D	2		1		2					3	2

Table 14 Category of runoff TDS in terms of DWAF classification

3 PREDICTED RUNOFF QUALITY AND CONCLUSIONS

Estimated salt loads from each Quaternary were incremented down channel to derive estimates of mean water quality that could be expected in dams (table 15).

Table 15 Predicted water quality in main river channels of Quaternary catchments

Quaternary	Discharge Mm^3/a	TDS Mg/l
P10A	3.09	177
P10B	12.87	528
P10C	1.54	645
P10D	6.14	553
P10E	27.57	1096
P10F	40.20	1534
P10G	49.43	1702
P30A	4.71	316
P30B	15.46	1879
P30C	17.15	1737
P40A	9.14	1324
P40B	16.77	1492
P40C	29.49	1700
P40D	11.83	1769
P20A	24.82	953
P20B	13.72	667

3.1 BUSHMAN'S RIVER - P10

In the Bushman's river, good water quality (class 1) can be expected down stream to include Quaternaries P10A-D, which are the New Year's and upper Bushman's rivers to Alicedale. South of Alicedale, water quality deteriorates rapidly due to significant salt loads originating from the Nanaga and Weltevrede Formations. Runoff continues to become progressively more saline downstream.

3.2 KARIEGA RIVER – P30

In the Kariega catchment acceptable water quality is only present in the head waters of the Kariega, P10A and the headwaters of the Assegai, P30B, which is partially underlain by Witpoort quartzites. Below the Settler's dam in catchment P30B water quality deteriorates rapidly due to salt loads from the Weltevrede shales and irrigation return flows.

3.3 KOWIE RIVER - P40

In the Kowie River, water quality is acceptable in the headwaters, which are underlain by Dwyka, Lake Mentz and Witpoort rocks (P40A). Water quality deteriorates once the river flows over Weltevrede rocks north of Bloukrans pass. Salinisation is also expected due to irrigation in the Belmont valley of the Bloukrans, SE of Grahamstown.

3.4 BOKNES AND DIEPKLOOF RIVERS – P20

In the Boknes catchment, good quality water can only be expected from springs emanating from the Alexandria Formation at the base of the Nanaga Formation at its contact with the Bokkeveld. The Boknes River itself flows over Bokkeveld rocks and water quality deteriorates rapidly down channel.

The Diepkloof is an intermittent river with internal drainage into the back dunes regions. Water quality of springs draining the Nanaga is generally poor.

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