ERWAT

WELGEDACHT WATER CARE WORKS 50 Ml/d and 100 Ml/d EXTENSIONS

HYDROLOGY

WATER QUALITY IMPACTS

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EXECUTIVE SUMMARY

An overview has been carried out of the potential effects on water quality of the proposed Module 2 and Module 3 (50 Ml/d each) extensions of the Welgedacht Water Care Works. The evaluation is confined to the baseline effluent disposal option, comprising discharging to the Blesbokspruit at site above the R555 road crossing. The time periods considered include present day, after the first 50 Ml/d extension reaches capacity (in about 2020) and after the following 50 Ml/d extension reaches capacity (in about 2034). Grootvlei Gold Mine has been assumed to continue discharging effluent to the wetland. The WQ2000 model was used to simulate the effects on salinity, while the DECAY model was used to simulate the effect on phosphate levels.

The main findings are as follows:

Effect on salinity

- For present day (2010) conditions the simulated median TDS concentration at the head of the wetland is in the Tolerable guideline range (455 – 780 mg/l) but moves into the Unacceptable range (above 780 mg/l) below Grootvlei gold mine and through the remainder of the Blesbokspruit and lower Suikerbosrand River.

- TDS concentrations show a 6% to 9% improvement at all points by 2020 and a 11% to 18% improvement by 2034. This results in the median concentration in the lower Suikerbosrand River near the Vaal River confluence improving to the Tolerable guideline range.

- The present day 95-percentile peak TDS concentrations above and below Grootvlei gold mine are only 9% higher than the median. This is attributable to the dominance of point source discharges. The difference increases to 21% near the Suikerbosrand-Vaal River confluence due to the increasing influence of catchment runoff. The 95-percentile TDS concentration remains in the Tolerable guideline range above Grootvlei and deteriorates into the Unacceptable range further downstream.

- 95-percentile peak TDS concentrations show a 7% to 11% improvement at all points by 2020 and a 12% to 20% improvement by 2034. Despite this improvement, the 95-percentile peak TDS concentration remains in the Unacceptable guideline range below the Grootvlei gold mine point of discharge for all simulated time horizons.

- Seasonal distributions of TDS concentrations show remarkably little variation due to the dominance of point discharges.

- The elevated TDS concentrations in the Blesbokspruit and Suikerbosrand River are far higher than those of the Welgedacht WCW and are attributable to other pollution sources. Indeed, increasing treated effluent flows from Welgedacht have the beneficial effect of diluting salt concentrations.

Effect on phosphate concentrations

- For present day conditions the simulated median phosphate concentrations in the upper portion of the wetland between the R555 and Daggafontein are in the

Unacceptable guideline range (>0.6 mg/l). This may be attributable to diffuse sources or unrepresentative sampling during the calibration period, since the wetland is very wide and some of the monitoring sections are located close to incoming streams and point sources. The remainder of the wetland and beyond to below Nigel at Poortjie Road the median concentrations improves to the Tolerable Interim Target range (0.4 – 0.6 mg/l). Median concentrations improve further to the Acceptable Management Target range (0.2 - 0.4 mg/l) in the lower Suikerbosrand River, reverting back to the Tolerable Interim Target range near the confluence with the Vaal River, presumably due to local diffuse pollution sources in the vicinity of Vereeniging.

- A steady improvement in median phosphate concentrations over time is expected due to increasing dilution of diffuse sources by treated sewage effluent. The biggest improvement occurs in the upstream portion of the wetland between the R555 and Daggafontein, with a simulated 13% improvement at the R555 by 2020 and a 22% improvement by 2034. However, the median phosphate concentration in this region remains in the Unacceptable range. Smaller improvements are noticeable further downstream, averaged at 6% by 2020 and 10% by 2034. A larger improvement is simulated in the Suikerbosrand River near Vereeniging (15% to 26%) due to dilution of the local diffuse sources.

Note that these changes over time are based on the assumption that the diffuse source loads will not change. Better controls may improve them, while growth over time could have the opposite effect.

Phosphate breakthrough

- Phosphate breakthrough from the Blesbokspruit wetland is not expected by 2034. However, this conclusion is based on the unproven simplifying assumption that the aerial phosphate loading rate is the dominant factor controlling the ability of both the Olifantsvlei and Blesbokspruit wetlands to accumulate phosphate.

Phosphate load on Vaal Barrage

- The 2010 phosphate export at weir C2H004 was estimated at 103 kg/day, growing to 114 kg/day by 2034. Welgedacht WCW accounts for about half of the point source phosphate load discharged to the Blesbokspruit and the proportional contribution to the export at C2H004 is further reduced by diffuse inputs.

Overall conclusion

- The development of Modules 2 and 3 of the Welgedacht WCW has the beneficial effect of diluting salt concentrations. The development does not appear to hold new adverse impacts with regard to the primary nutrient, phosphate, for the Blesbokspruit and the downstream Vaal Barrage. Phosphate breakthrough from the wetland is not indicated by the analysis, although further research on the dynamics of the wetland is recommended.

Recommendations

1. **Implement Welgedacht WCW Module 2** Since the extensions are expected to be largely beneficial, implementation of Welgedacht Module 2 is recommended, discharging at or near to the existing outlet works.

2. **Future improvements** While the relatively coarse evaluations that were made are considered sufficient to support the main conclusion to proceed with Welgedacht Module 2, the following actions by DWA are recommended to provide greater confidence with regard to further catchment developments.

- ***Revise salinity model calibration*** The WQT hydro-salinity model on which WQ2000 is based needs to be re-calibrated to take account of new catchment developments and the water quality data collected over the last 16 years.

- ***Improve estimation of phosphate concentrations*** The newly developed and much more versatile WQDOWN model should be more fully tested and applied to evaluate the effect of future developments.

- ***Investigate phosphate dynamics of Blesbokspruit wetland*** It is strongly recommended that a detailed investigation of the dynamics of the Blesbokspruit wetland be undertaken to determine its continued ability to assimilate nutrient loads (especially phosphate) before breakthrough occurs.

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1. INTRODUCTION

This report provides an overview of the potential effects on water quality of the proposed Module 2 and Module 3 (50 Ml/d each) extensions of the Welgedacht Water Care Works (WCW). The evaluation is confined to the baseline effluent disposal option, comprising discharging to the Blesbokspruit at site above the R555 road crossing. The time periods considered include present day, after the first 50 Ml/d extension (Module 2) reaches capacity (in about 2020) and after the following 50 Ml/d extension (module 3) reaches capacity (in about 2034). Grootvlei Gold Mine has been assumed to continue discharging effluent to the wetland throughout the period. The WQ2000 model was used to simulate the effects on salinity, while the DECAY model was used to simulate the effect on phosphate levels.

1.1 Background

Most of the flow passing down the Blesbokspruit comprises of point discharges consisting of treated sewage effluent, underground water pumped from Grootvlei Gold Mine and Sappi's industrial effluent. Since resuming pumping, the Grootvlei Gold Mine has had to pump at a much higher rate than previously due to the cessation of dewatering by closed mines in the Rietspruit catchment and the migration of underground water entering adjacent mines towards the Grootvlei Gold Mine workings. Not only have the quantities increased dramatically (up to 120 Ml/d), the salinity has also risen considerably to reflect the poorer quality of the water in the surrounding region. While the salinity of water pumped from Grootvlei Gold Mine has gradually improved (from an EC of 405 mS/m for the first year, 1996/7, to 244 mS/m for the last year, 2009) the salinity is still high and is of concern with regard to the RAMSAR wetland site and has a significant impact on Vaal Barrage and the downstream Vaal River. Growing treated sewage effluent discharges have an increasing beneficial effect on salinity concentrations in the Blesbokspruit wetland.

At present the high nutrient concentrations in various point discharges to the upper Blesbokspruit are improved by the wetland. There is concern that the assimilative capacity of the wetland may be nearing exhaustion with the subsequent break-through of phosphate. The main concern is a potential rise in the phosphate load entering the Vaal Barrage, leading to increased eutrophication problems. Elevated concentrations of other pollutants could occur closer to the point of discharge, but high decay rates in the wetland should confine such impact to a relatively short reach of the Blesbokspruit.

1.2 Status quo option

The status quo option has been evaluated for three time horizons corresponding to current conditions and those expected when Modules 2 and 3 of the Welgedacht WCW reach full capacity. Growth in other WCW discharges have been accounted for, taking due cognisance of the known development plans. The assumption has been made that Sappi will continue to discharge at current rates and water quality. Grootvlei Gold Mine has been assumed to discharge at its permitted rate of 80 Ml/d with water quality levels similar to those of the last five years. The current elevated pumping rate was not used in the analyses since exceptional wet conditions do not represent the long term mean. No attempt has been made to predict future changes in the concentration of the Grootvlei Gold Mine salt concentrations.

The option of cessation of the Grootvlei Gold Mine discharge before the Welgedacht extensions reach full capacity, due to the implementation of direct reclamation or decanting downstream of the wetland at Nigel, have not been considered.

2. HYDROLOGICAL FACTORS

2.1 Urbanisation

The WR2005 study (Middleton and Bailey, 2009) gives estimates of the paved urban areas for 1990 and 2005. Linear extrapolation was used to estimate the paved urban areas for 2010, 2020 and 2034 conditions. These are shown in Table 2.1

Table 2.1: Paved urban areas based on WR2005 study

Quaternary		C21D	C21E	C21F	C21G
Paved urban area (km^2)	1990(1)	15.2	6.9	0	0
	2005(1)	18.3	8.2	0	0
	2010(2)	19.3	8.6	0	0
	2020(2)	21.4	9.4	0	0
	2034(2)	24.3	10.6	0	0

Notes: (1) WR2005 data
(2) linear extrapolation

2.2 Irrigated areas

Irrigated areas were assumed to remain constant at levels similar to those used in the previous studies. This is based on the WR2005 data, which shows no historical growth over several years. This assumption is thought to be reasonable since the available river base flow has been large for a number of years and most of the irrigable land has already been brought under irrigation. Table 2.2 gives the irrigation areas used in the WR2005 study (Middleton and Bailey, 2009).

Table 2.2: Default irrigated areas used in WQ2000

Quaternary	C21D	C21E	C21F	C21G
Irrigated area (km^2)	4.66	6.57	4.45	4.36

It should be noted that earlier studies (Herold, 1981) showed considerably more irrigation in the C21G quaternary catchment. An investigation of the discrepancies could not be investigated within the constraints of this study.

2.3 Diffuse source salt recharge

Catchment salt recharge rate plays an important role in hydro-salinity modelling. Once again, the study stopped short of the evaluation of growth in diffuse source salt generation rates. The effect of growth would affect present day conditions and future time horizons. However, the impact for median and drier flow conditions is expected to be small since then catchment runoff would be small compared with the large point source inflows.

2.4 Effluent Flow

The effluent point discharges to the Blesbokspruit system are described in Table 2.3.

Table 2.3: Effluent point sources to the Blesbokspruit system

Source	Discharged to
Benoni WCW	Benoni canal
Rynfield WCW	Rynfield Dam (tributary of Benoni canal)
Jan Smuts WCW	Jan Smuts Lake (tributary of Benoni canal)
J P Marais WCW	Tributary of Benoni canal
Sappi	Cowles Dam (Benoni canal)
Daveyton WCW	Blesbokspruit (above wetland)
Welgedacht WCW	Blesbokspruit (above wetland)
Grootvlei Gold Mine	Blesbokspruit (wetland)
Ancor WCW	Klein Blesbokspruit (into wetland)
Grundlingh WCW	Tributary of Blesbokspruit (below wetland)
Bickley WCW	Blesbokspruit (below wetland)
Tsakane WCW	Kaydalespruit (below wetland)
Heidelberg WCW	Blesbokspruit (below wetland)
Ratanda WCW	Blesbokspruit (below wetland)

The locations of the effluent sources are shown in Figure 2.1.

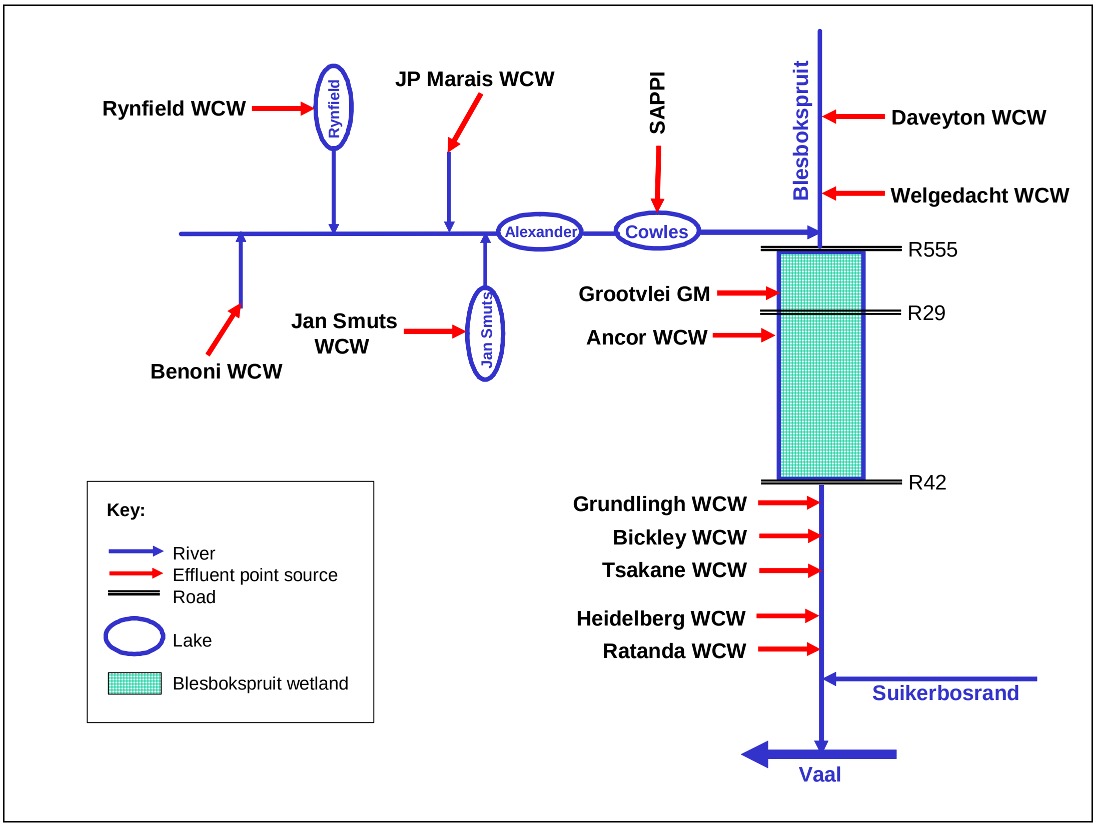

Figure 2.1: Locations of effluent point sources

The Status Quo option point source flows for the three selected time horizons are shown in Table 2.4.

Table 2.4: Current and projected discharges to the Blesbokspruit

Source	**Discharge (Ml/d)**		
	Current	**Mod 2 @ capacity**	**Mod 3 @ capacity**
	2010	**2020**	**2034**
Above Blesbokspruit wetland			
Benoni WCW	9.4	11.5	15.0
Rynfield WCW	7.2	8.7	11.5
Jan Smuts WCW	8.3	9.0	9.0
J P Marais WCW	14.0	14.0	14.0
Sappi (1)	22.7	22.7	22.7
Daveyton WCW (2)	6.0	16.0	16.0
Welgedacht WCW	65.0	85.0	135.0
Total above wetland	**132.6**	**166.9**	**223.2**
Into Blesbokspruit wetland			
Grootvlei Gold Mine (3)	80.0	80.0	80.0
Ancor WCW	23.0	28.0	37.5
Total into wetland	**103.0**	**108.0**	**117.5**
Below Blesbokspruit wetland			
Grundlingh WCW	1.8	2.2	3.0
Bickley WCW	17.0	23.0	23.0
Tsakane WCW	15.4	17.0	17.0
Heidelberg WCW	7.8	10.0	14.0
Ratanda WCW	2.4	3.3	4.9
Total below wetland	**44.4**	**55.5**	**61.9**
TOTAL POINT SOURCE FLOW	**280.0**	**330.4**	**402.6**

Notes: (1) Discharge from Sappi is assumed to remain constant.
(2) Inlet works at Daveyton WCW are assumed repaired to allow it to run at capacity.
(3) Grootvlei Gold Mine is currently discharging at above 80 Ml/d due to excessive rainfall. For comparative purposes the discharge is assumed to average the permitted rate of 80 Ml/d.

3. EFFECT ON SALT CONCENTRATIONS

3.1 Modelling approach

The WQ2000 model (Herold and le Roux, 2004 and Herold et al, 2006) was used to evaluate salt concentrations and loadings. This model makes use of the comprehensive WQT hydro-salinity model (Allan and Herold, 1988) and a database comprising calibration parameters for every quaternary catchment of the Vaal River system. WQ2000 facilitates updating of the effluent point source flows and concentrations to match the time horizon to be simulated and suitable urban paved areas and irrigation areas can be specified. The modelling system incorporates powerful simulation features, such as the ability to update existing major and minor dam features, water importation quantity and quality, water demands, mining inputs and the proportions of the catchment runoff commanded by major and minor dams. Hence the model is well able to simulate the options at hand.

A drawback is that WQ2000 deals with relatively large quaternary sized sub-catchments. Although relatively coarse, this is sufficient to evaluate the major impacts.

3.2 Model calibration

The WQ2000 model database contains calibration parameters for each quaternary catchment of the Vaal River system, which facilitates rapid simulation of a wide range options.

The WQT model calibrations are based on the 70 years of processed monthly hydrology and water quality data from October 1925 to September 1995 used in the Vaal River System Analysis Update Study (Herold, 1999).

The 70-year calibration period is long enough to provide a representative range of hydrological fluctuations for simulating water quality. However, previous modelling (Herold, 1981; Herold 1988; Herold 1999) showed that diffuse sources contributed a significant proportion of the total salt load export from the C21D and C21E catchment area and that considerable growth in the diffuse source salt recharge rate had taken place. It can therefore be anticipated that further growth in diffuse source salt generation has taken place since 1995 and will continue over the next 34 years of the study period. Therefore failure to calibrate the hydro-salinity model using the water quality data gathered over the last 16 years represents a significant knowledge gap.

The much needed re-calibration of the salinity models for the Vaal Barrage catchment is a considerable undertaking that is beyond the scope of this study. This knowledge gap needs to be accounted for when interpreting the model simulation results. The main implication is that the model results will tend to under-estimate the absolute salinity values due to not taking account of increasing catchment diffuse source salt recharge. However, the model results do show the relative changes in salt concentration that are anticipated. The simulation results have therefore also been expressed as percentage changes (see Tables 4.2 and 4.3).

3.3 Point source discharge salinity

Figure 3.2 shows the major point sources relative to the quaternary catchments.

C21D The modelled output represents conditions at the downstream boundary of each quaternary catchment. Hence the results for C21D include the inputs for the entire upstream catchment until just upstream of the discharge from Grootvlei Gold Mine, which is located in the C21E quaternary. The C21D results give a reasonable approximation of salinity conditions at the head of the main wetland at the R55 road crossing since there are no intervening point sources and the salinity in this region is dominated by point sources for median flow conditions.

Since the Grootvlei Gold Mine discharge has such a profound effect on salinity levels, greater definition was sought. This was achieved by running WQ2000 twice. In the second run the Grootvlei Gold Mine discharge was artificially included in the C21D quaternary to simulate conditions immediately downstream of the saline mine input. This was necessary because normal quaternary scale modelling would only show the sharp rise in salinity at the lower boundary of the C21E quaternary and would also miss the peak salinity below Grootvlei Gold Mine since the results for C21E include dilution by point sources (most notably the Ancor WCW) and incremental catchment runoff.

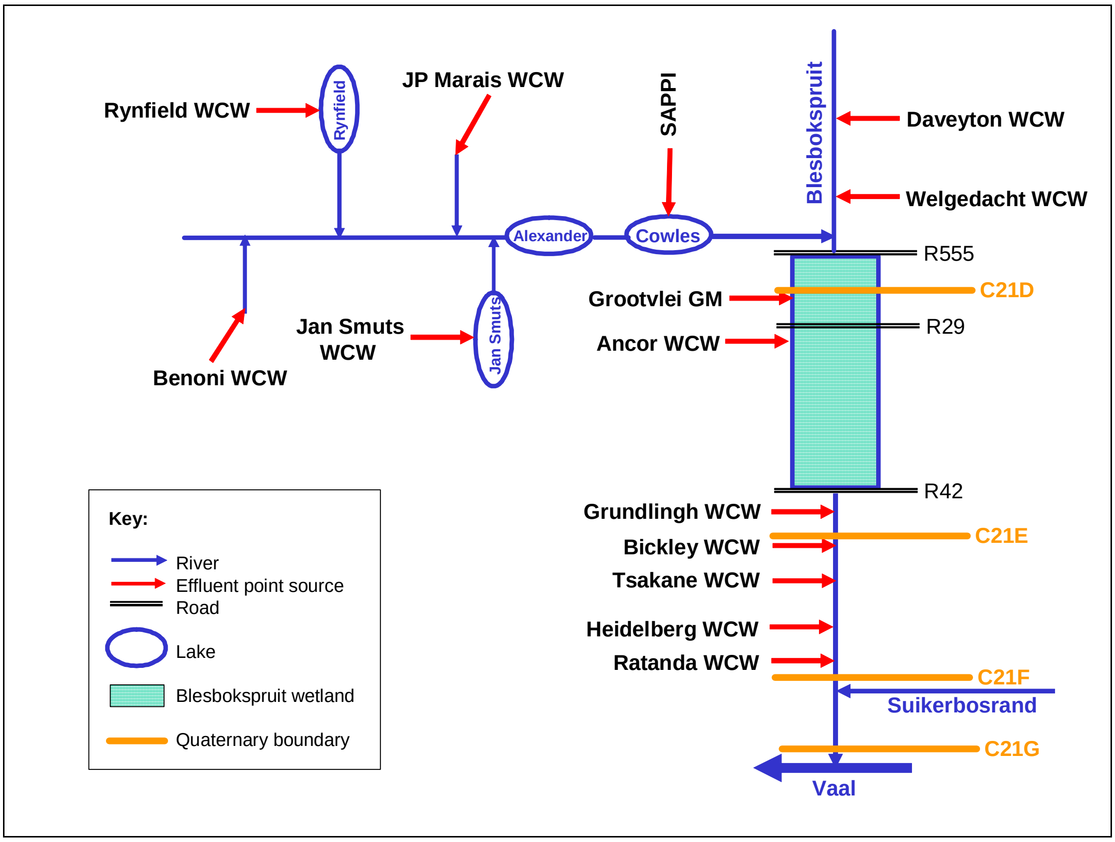

Figure 3.1: Locations of quaternary catchment boundaries

C21E The C21E quaternary presents results downstream of Nigel. This includes Grootvlei Gold Mine, the Ancor and Carl Grundlingh WCWs and incremental C21E quaternary catchment runoff. (Although the latter has little effect at the 50-percentile level since under such conditions point sources have by far the biggest effect.)

C21F The lower boundary of quaternary C21F is strategically located to represent the salinity at the end of the Blesbokspruit just upstream of its confluence with the Suikerbosrand River. This quaternary includes point inflows from the Tskane, Bickley, Heidelberg and Ratanda WCWs and runoff from the C21F quaternary catchment.

C21G Finally, the simulation results for quaternary C21G represent conditions in the Suikerbosrand River immediately upstream of its confluence with the Vaal River. There are significant point sources in this region. Salinity is affected by incremental catchment runoff, including dilution by the inflow from the Suikerbosrand River (from quaternaries C21A, C21B and C21C).

The model was run three times with different effluent flows to represent present day and projected 2020 and 2034 conditions.

Point source effluent salt concentrations were based on the averages for the last 5 years derived from the DWA's WMS data base. Since there are more electrical conductivity (EC) samples than DMS (Dissolved Mineral Salts) analyses, the average DMS/EC ratio for samples where both are recorded was multiplied with the average for all of the EC values to estimate the salt concentration.

Table 3.1 gives the average point source salt concentrations used in the simulation, which were assumed to remain unaltered.

Table 3.1: Effluent point source salt concentrations

Source	**Period**	**DMS/EC**		**Average EC (mS/m)**		**DMS (mS/m)**
		N	**Ratio**	**N**	**EC**	
Above Blesbokspruit wetland						
Benoni WCW⁽¹⁾	2005-2009		6.244	62	70.8	442
Rynfield WCW	2005-2009	22	5.934	135	64.4	382
Jan Smuts WCW	2005-2006	21	6.244	51	66.9	418
J P Marais WCW	2005-2009	22	6.729	49	56.6	381
Sappi combined	2005-2009	21	7.121	48	154	1097
Daveyton WCW	2005-2009	21	5.767	49	55.1	318
Welgedacht WCW	2005-2009	21	6.614	47	70.6	467
Into Blesbokspruit wetland						
Grootvlei HDS	2005-2009	19	8.288	49	260	2155
Ancor WCW	2005-2009	32	7.416	149	103.7	769
Below Blesbokspruit wetland						
Grundlingh WCW⁽²⁾	2005-2009		6.546	62	91.2	597
Bickley WCW	2005-2009	34	6.546	54	83.4	546
Tsakane WCW	2005-2009	31	7.354	52	50.0	368
Heidelberg WCW	2005-2009	33	7.271	111	66.2	481
Ratanda WCW	2005-2009	33	6.070	56	67.7	411

Note: (1) No data for Benoni WCW was found in the WMS database. EC data was taken from ERWAT records and the Jan Smuts WCW DMS/EC ratio was used.
(2) No data for the Grundlingh WCW was found in the WMS database. EC was taken from ERWAT records and the Bickley WCW DMS/EC ratio used.

3.3 Simulated salt concentrations

Simulated median salt concentrations are given in Table 3.2 for the following key points:

- The downstream boundary of the C21D quaternary catchment, which is located in the Blesbokspruit immediately upstream of Grootvlei Gold Mine

- Immediately downstream of Grootvlei Gold mine in the Blesbokspruit.

- The downstream boundary of the C21E quaternary in the Blesbokspruit downstream of Nigel.

- The downstream boundary of the C21F quaternary in the Blesbokspruit immediately upstream of the Suikerbosrand River confluence.

- The downstream boundary of the C21G quaternary in the Suikerbosrand River immediately upstream of its confluence with the Vaal River.

The simulated median TDS concentrations are listed in Table 3.2.

Table 3.2: Simulated median TDS concentrations at key points

Location	TDS concentration (mg/l)		
	Current	**Module 2 at capacity**	**Module 3 at capacity**
	2010	**2020**	**2034**
C21D (upstream of Grootvlei GM)	603	564 (-6%)	537 (-11%)
Downstream of Grootvlei GM)	**1123**	**1027** (-9%)	**925** (-18%)
C21E (downstream Nigel)	**1128**	**1025** (-9%)	**920** (-18%)
C21F (upstream of Suikerbosrand)	**1021**	**930** (-9%)	**849** (-17%)
C21G (upstream Vaal River)	**896**	**834** (-7%)	778 (-13%)

Note: TDS concentrations exceeding the tolerable water quality guideline are shown in bold.

Figures 3.2, 3.3 and 3.4 show the simulated median catchment salt concentrations for 2010, 2020 and 2034 conditions. Catchment diffuse source salt generation has been assumed to remain constant.

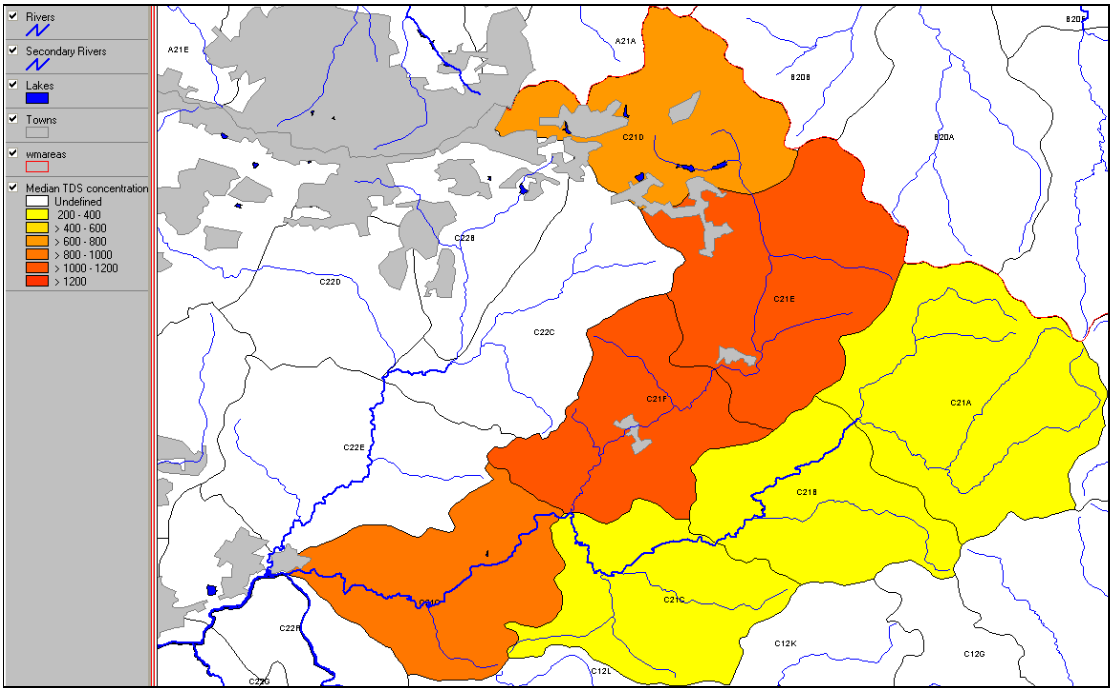

Figure 3.2: Simulated median quaternary TDS concentrations in the Blesbokspruit/Suikerbosrand River for 2010 conditions

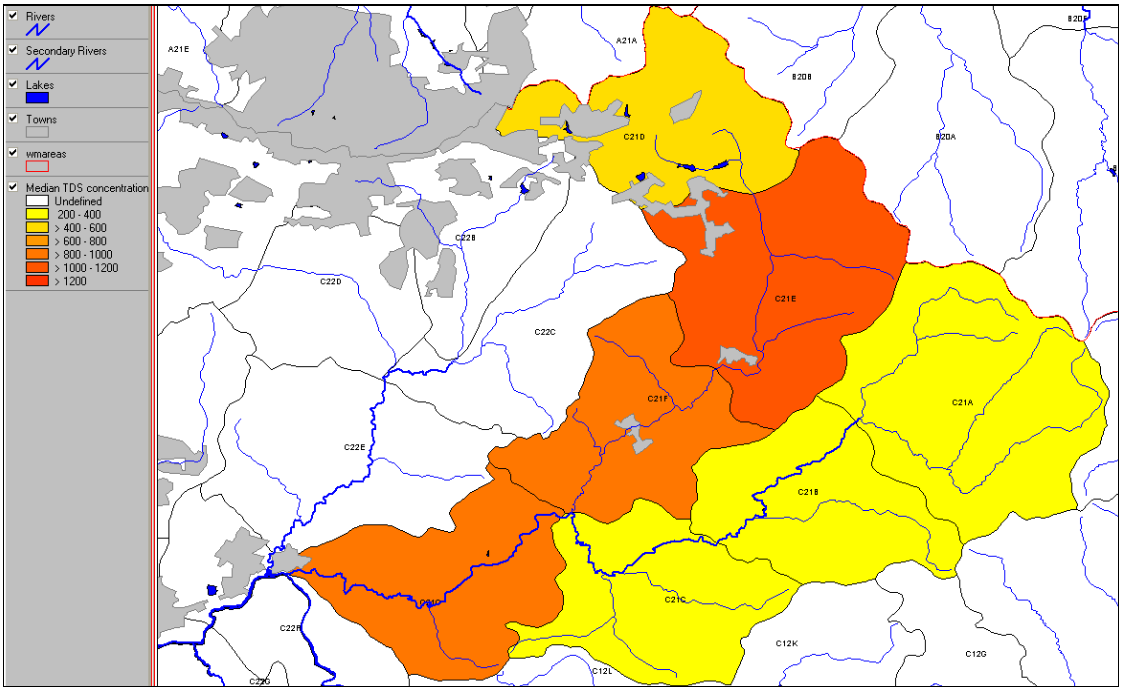

Figure 3.3: Simulated median quaternary TDS concentrations in the Blesbokspruit/Suikerbosrand River for 2020 conditions

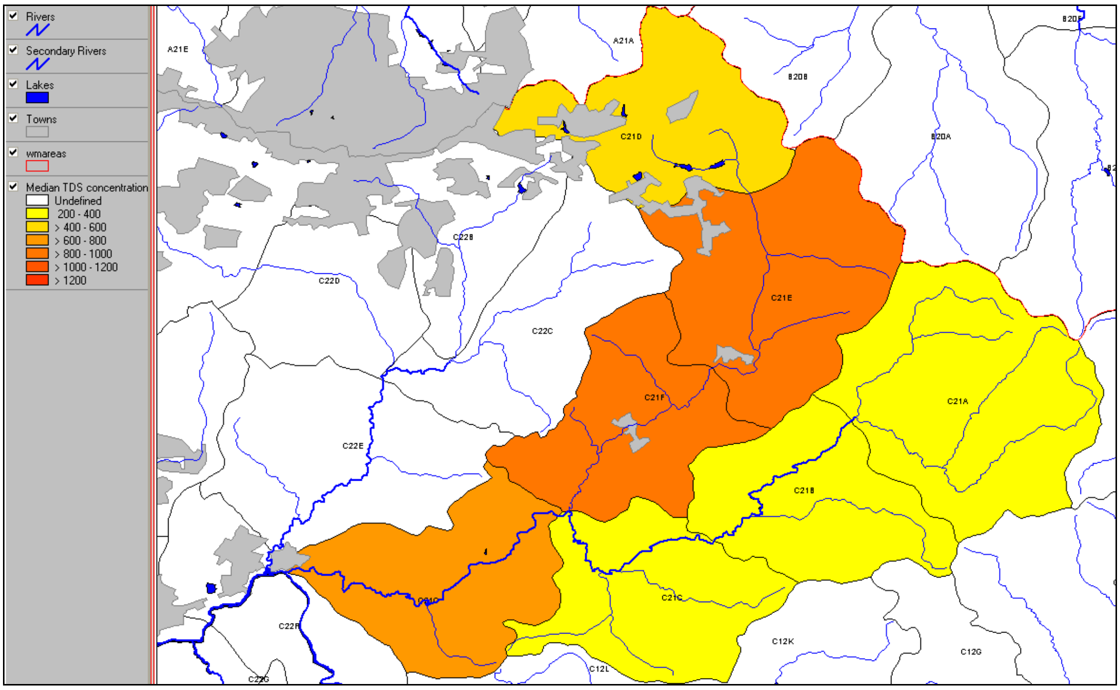

Figure 3.4: Simulated median quaternary TDS concentrations in the Blesbokspruit/Suikerbosrand River for 2034 conditions

The results indicate a steady reduction in salt concentrations at all points in the system over time. By the 2020 improvements of between 6% and 9% can be expected, while by the time module 3 reaches capacity in 2034 the reduction in salt concentrations should vary between 11% and 18%.

It is significant that 2010 salt concentration below Grootvlei Gold Mine is 30% lower than that simulated in 1997 (Herold et al, 1997). This is attributable to a marked 40% reduction in the salt concentration of the water pumped from underground since 1996/97, together with a large reduction in the average mine dewatering rate.

The results show that for all time horizons the median TDS concentration in the wetland upstream of the Grootvlei gold mine discharge falls within the Tolerable Interim Target electrical conductivity range of 70 to 120 mS/m (Khwinana, 2010), i.e. 455 mg/l to 780 mg/l, assuming a TDS/EC ratio of 6.5. The salinity rises abruptly to the Unacceptable range (TDS > 780 mg/l) at all points downstream of Grootvlei gold mine for all time horizons, with the exception of the C21G quaternary in 2034, by which time the dilution factor would have grown enough to attain the Tolerable Interim Target salinity range.

Simulated 95-pecentile peak salt concentrations are given in Table 3.3.

Table 3.3: Simulated 95-percentile TDS concentrations at key points

Location	**TDS concentration (mg/l)**		
	Current	**Module 2 at capacity**	**Module 3 at capacity**
	2010	**2020**	**2034**
C21D (upstream of Grootvlei GM)	657	614 (-7%)	581 (-12%)
Downstream of Grootvlei GM)	**1209**	**1096** (-9%)	**977** (-18%)
C21E (downstream Nigel)	**1285**	**1150** (-11%)	**1022** (-20%)
C21F (upstream of Suikerbosrand)	**1198**	**1098** (-8%)	**1007** (-16%)
C21G (upstream Vaal River)	**1082**	**994** (-8%)	**919** (-15%)

Note: TDS concentrations exceeding the Tolerable Interim Target guideline are shown in bold.

Figures 3.5, 3.6 and 3.7 show the simulated average, median, 95-percentile and 98-percentile salt concentrations at the outlet of each of the quaternary catchments at different time horizons.

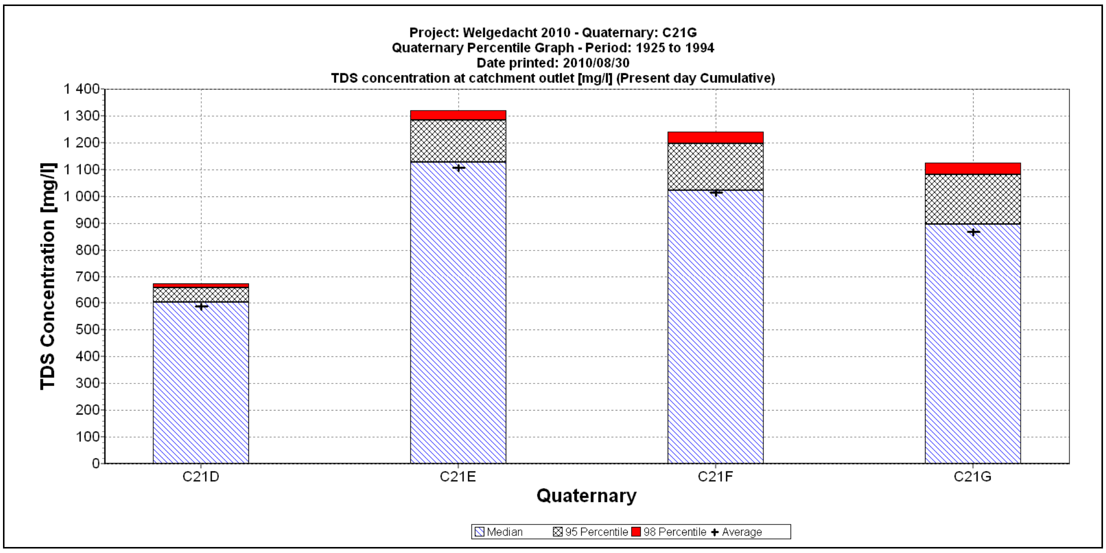

Figure 3.5: Simulated average, median, 95-percentile and 98-percentile quaternary TDS concentrations for 2010 conditions

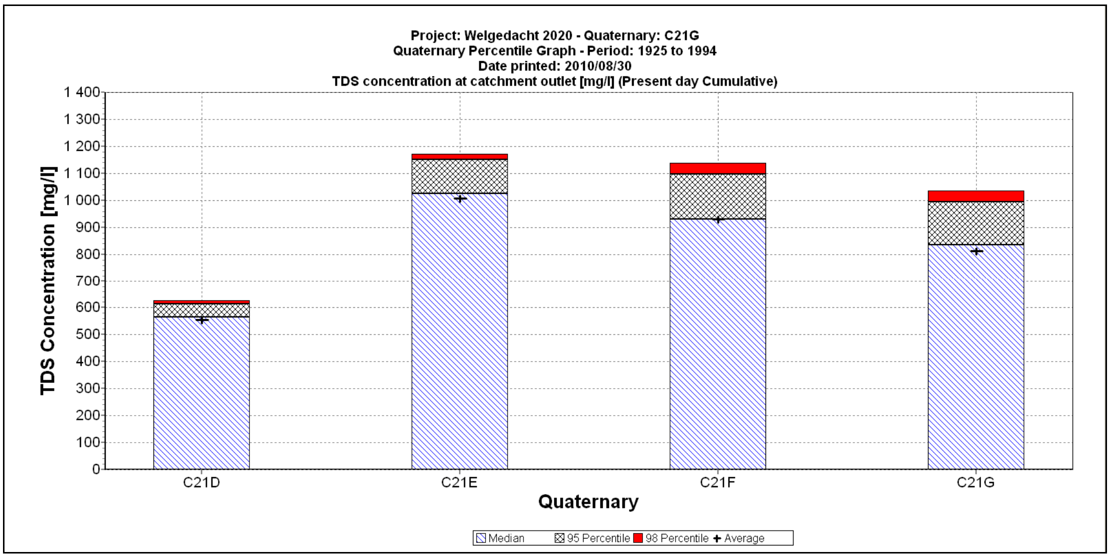

Figure 3.6: Simulated average, median, 95-percentile and 98-percentile quaternary TDS concentrations for 2020 conditions

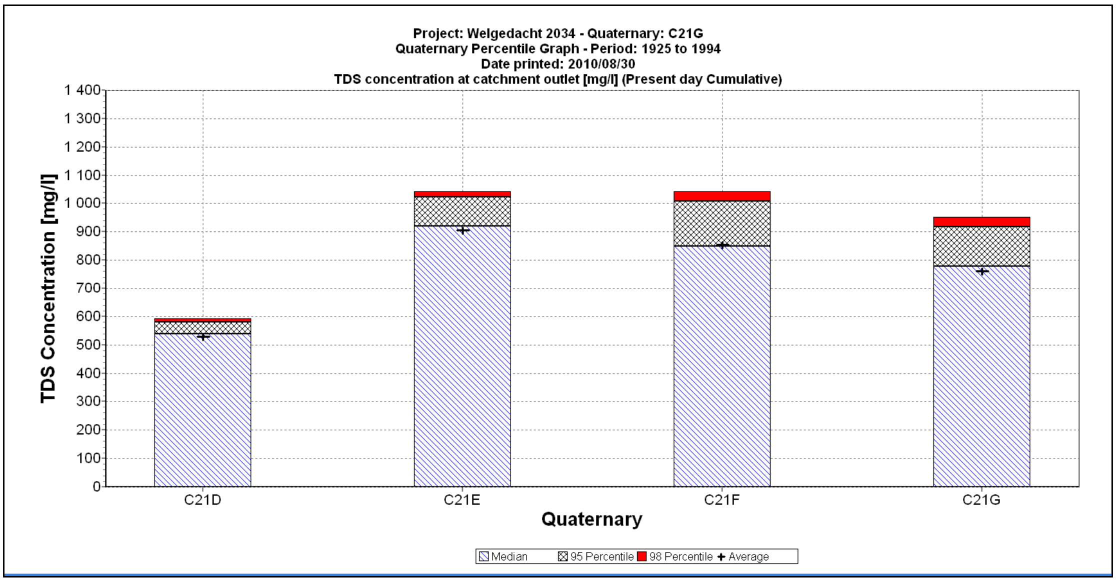

Figure 3.7: Simulated average, median, 95-percentile and 98-percentile quaternary TDS concentrations for 2034 conditions

The results show that for all time horizons the 95-percentile TDS concentration in the wetland upstream of the Grootvlei gold mine discharge remain within the Tolerable Interim Target salinity range. The 95-percentile salinity exceeds the Tolerable limit at all points downstream of Grootvlei gold mine for all time horizons.

The 95-percentile peak concentrations also show a steady improvement over time, ranging from 7% to 11% reductions in 2020 and 12% to 20% reductions by 2034.

The improvement in salinity is attributable to increases in the flow of diluting treated sewage effluent flows. Additional reductions that may arise from further improvement in the Grootvlei Gold Mine discharge quality have not been modelled, since investigation of trends in the quality of the mine discharge is beyond the scope of this study. Instead the simplifying assumption has been made that the salinity of Grootdraai Gold Mine’s discharge would remain constant at the average for the last 5 years.

Conversely, increasing catchment diffuse source salt recharge can be expected to increase salt concentrations. This effect has not been simulated since the major investigation required to estimate the magnitude of the change in diffuse source salt export is beyond the scope of this study.

However, irrespective of the direction and magnitude of the change induced by these competing trends, Welgedacht modules 2 and 3 can be expected to have the beneficial effect of significantly reducing salt concentrations by about 9% by 2020 and 16% by 2034.

Figure 3.8 shows the 2020 simulated seasonal distribution of average TDS concentrations in the Blesbokspruit at the lower boundary of the C21D quaternary.

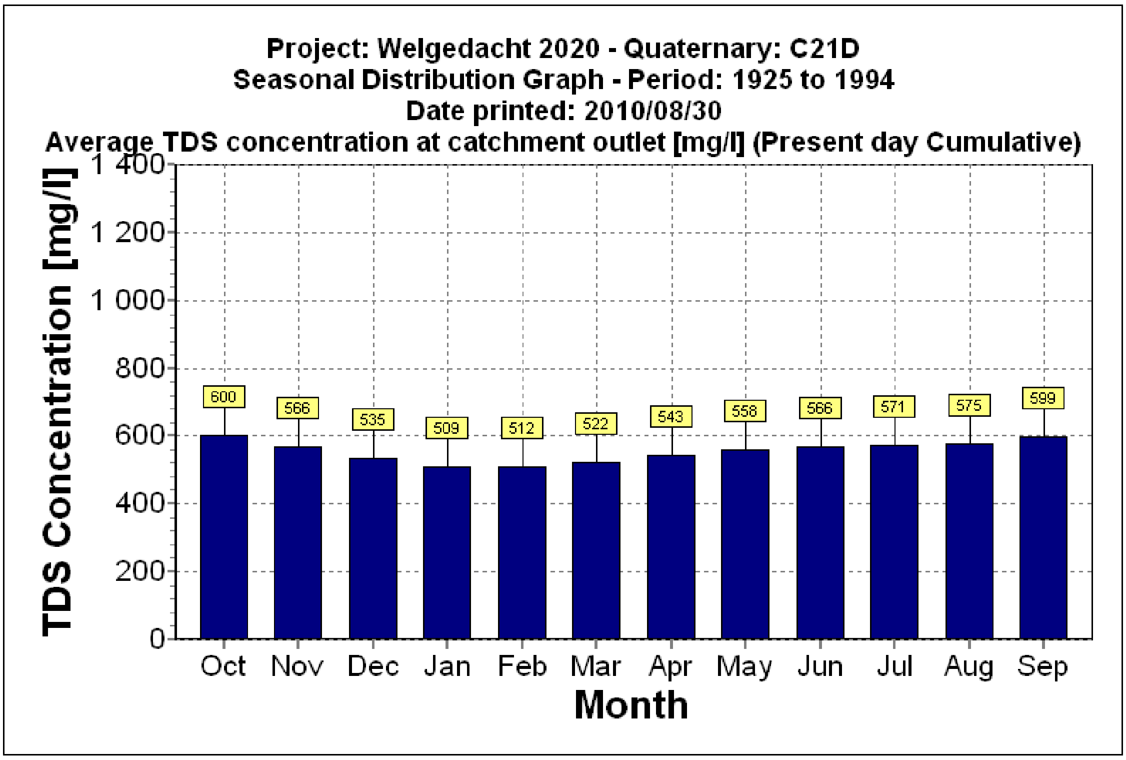

Figure 3.8: Simulated seasonal distribution of average TDS concentrations for the lower boundary of the C21D quaternary for 2020 conditions

Very little seasonal change is evident, with only a 15% difference between the maximum and minimum month's TDS concentration. This is symptomatic of the fact that river flows to the B21D quaternary are dominated by point inflows.

The difference between peak and minimum seasonal monthly TDS concentrations reduces marginally from 17% in 2010 to 14% in 2034. The general seasonal distribution is similar to that shown for 2010. The reducing percentage difference implies increasing dominance of point discharges, despite the increase in runoff from urban surfaces (see Table 2.1) during the period.

Figure 3.9 shows the 2020 simulated seasonal distribution of average TDS concentrations in the Blesbokspruit at the lower boundary of the C21E quaternary.

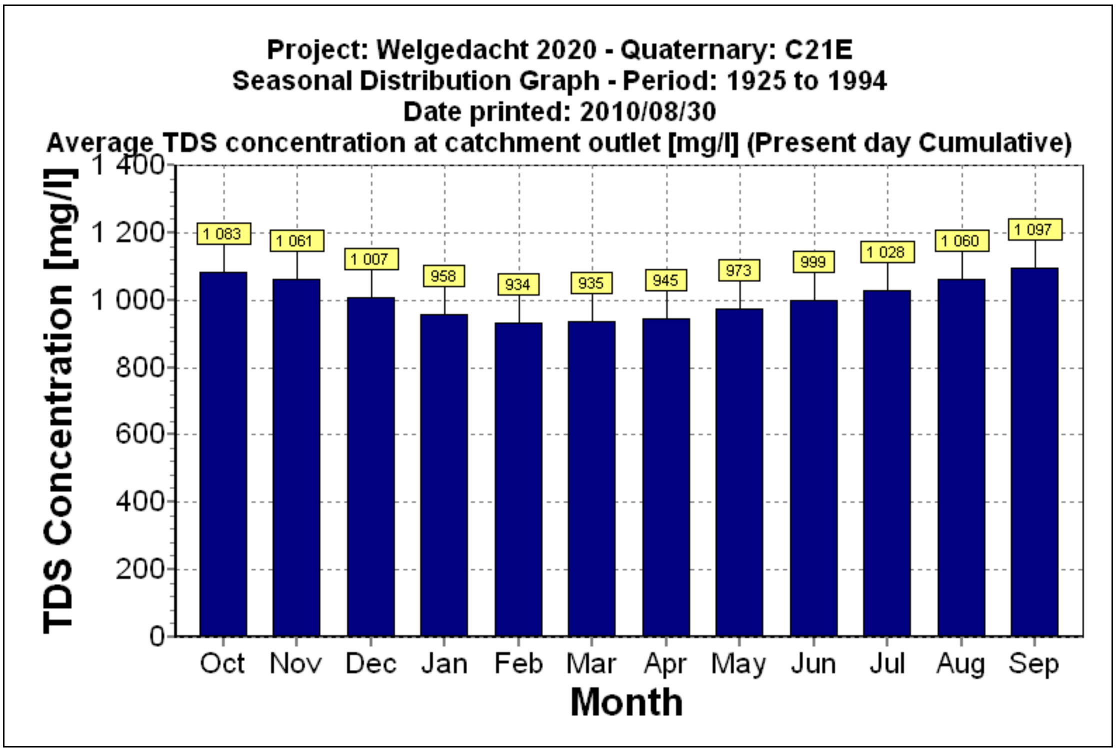

Figure 3.9: Simulated seasonal distribution of average TDS concentrations for the lower boundary of the C21E quaternary for 2020 conditions

It is immediately apparent that the saline Grootvlei Gold mine discharge brings about a sharp rise in TDS concentrations. Under 2020 conditions the difference between the peak and minimum average monthly seasonal TDS concentrations is only 15%, again indicative of the dominance of point flows. The difference between the simulated peak and minimum monthly TDS concentrations drops from 18% to 13% during the period from 2010 to 2034, indicating the growing dominance of point discharges.

Similar seasonal trends occur further downstream at the downstream end of the C21F quaternary, where point discharges remain the dominant component of the flow.

At the lower boundary of the C21G quaternary the 2020 difference between the maximum and minimum average TDS concentrations increases to 22%, due to an increase in the wet weather runoff due to the substantially increased catchment area that includes three quaternary catchments in the relatively undeveloped portion of the Suikerbosrand River. However, despite this the flows are dominated by point sources for most flow conditions lower than larger floods.

It is important to observe that the elevated TDS concentrations are far higher than those of the Welgedacht WCW and are attributable to other pollution sources.

4. EFFECT ON NUTRIENTS

4.1 General considerations

The phosphate dynamics differ markedly from those for TDS since phosphate behaves in a distinctly non-conservative fashion. (Although phosphorous is a conservative constituent, it's presence in the water column exhibits distinctive decay characteristics since it adheres to sediment particles that are removed by deposition and is taken up by organic matter that is also subject to sedimentation. These processes are particularly pronounced in slow moving water bodies, such as lakes and wetlands. Much of the sediment appears to be semi-permanently trapped under successive layers of sediment, especially in lakes and wetlands. Biological processes can slowly re-introduce phosphate into the water column, but these processes are very slow compared with sedimentation and are therefore not noticeable except at quite low concentrations.

Large wetlands such as the Blesbokspruit are likely to keep on trapping phosphate in their flat reed-covered flood plains, where flow velocities seldom rise high enough to mobilise sediments. Here periodic scouring is probably confined to relatively narrow central channels, especially in the vicinity of bridges and culverts. This is born out by the historical records shown in Teurlings et al (1998), which display marked reductions in phosphate concentration between the R555 road crossing near the start of the wetland and the Marivale Bird Sanctuary, with the median phosphate concentration dropping to less than 0.1 mg/l.

In normal river sections that are in regime (i.e. the river bed is not aggrading with time) there should be a long-term balance between the sediment (and hence phosphate) load deposited and taken up. However, even here there is a re-distribution in time, with a pronounced deposition loss apparent during low flow conditions (i.e for most of the time) and phosphate re-mobilisation confined mainly to the more extreme flood conditions when significant scouring occurs. However, these events are associated with large flow volumes which tend to dilute the phosphate, except for a brief “first flush” effect that can occur on the early rising limbs of floods. Such effects are seldom detected since they are usually missed by routine sampling programmes based on periodic grab samples. However, they can move significant loads of phosphate down the river system, where it is usually trapped in the sediments of downstream dams.

4.2 Inferred impact of Welgedacht developments

The lower Blesbokspruit and lower Suikerbosrand River from the R42 road bridge to the confluence with the Vaal River near weir C2H004 represents a long river reach that is largely devoid of storage elements such as wetlands or lakes. It can therefore be assumed that this river reach is in regime, with the long-term export roughly in balance with the phosphate input, other than the load removed via irrigation abstractions. But a seasonal or longer phase difference can be anticipated, with a net accumulation of phosphate in river bed sediments during low flow conditions and scouring during high flows. The relatively low frequency sampling intervals at upstream and downstream monitoring points make it very difficult to quantity this effect. Since low flows occur for more than half the year, it follows that median flow conditions represent low flow conditions. Hence, despite the fact that the median phosphate concentration at C2H004 is relatively low, it is expected that a significant phosphate load is still contributed to Vaal Barrage.

Vaal Barrage in turn is a long shallow reach of the Vaal River backed up by Vaal Barrage, some 53 km further downstream. Although technically a long thin lake, this reach of the Vaal River is subject to periodic scouring and can be considered to be in a state of dynamic equilibrium. The phosphate load entering Vaal Barrage can therefore be considered to remain in play, since it can continue to contribute nutrients to feed local eutrophication problems, as well as promoting eutrophication down the entire length of the Middle Vaal River, until it is trapped in the sediments of Bloemhof Dam.

The Status Quo Welgedacht development option is associated with a gradual increase in nutrient loading on the Blesbokspruit wetland over time, attributable to the growth in effluent flow. This will be mitigated by an easing of the current overloading of works (including Welgedacht Module 1 itself). This should make it possible to deliver a better quality of effluent from the affected works. Although the conservative approach has been adopted that only the Welgedacht effluent will benefit from this improvement.

4.3 Effect on phosphate concentrations

The study did not warrant calibration of a sophisticated nutrient model. Instead the impact on phosphate levels has been approximated using the DECAY model that was developed when Welgedacht Module 1 was assessed (Herold et al, 1997). This model was run for median flow conditions.

Figure 4.1 shows the model configuration used for the DECAY model.

The system has been divided into 15 reaches, each with a river water quality sampling point at its downstream end, the data for which was obtained from the DWA’s WMS system. 14 effluent point sources are also indicated, for each of which WMS water quality data is available.

Table 4.1 shows the observed median phosphate concentrations at the downstream end of each reach and for each of the effluent point sources derived from the WMS.

The DECAY model requires the end of reach flow and reach flow velocity data. The NACL daily time step hydro-salinity model was run for the system setup used in the precious study (Herold et al 1997) to obtain daily flows and velocities for the calibration period and for projected 2010, 2020 and 2034 flow conditions. The median flow velocities that were abstracted are shown in Table 4.2.

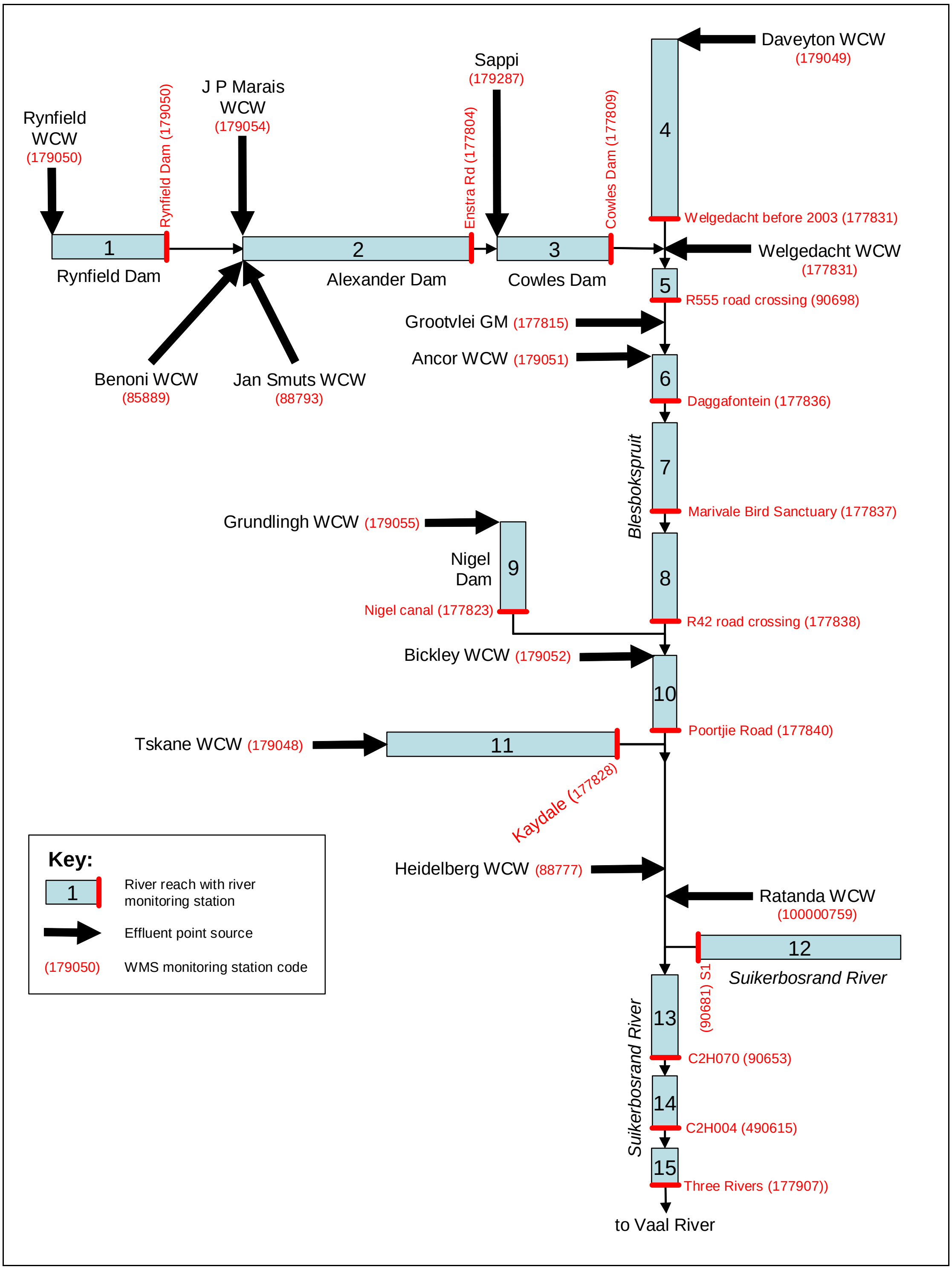

Figure 4.1: DECAY model configuration

Table 4.1: Median effluent phosphate concentrations (2003-2009)

River reach			Effluent point source		
Description	**PO4 (mg/l)**	**N**	**Description**	**PO4 (mg/l)**	**N**
1 Rynfield Dam	0.05	58	Rynfield WCW	0.60	743
2 Alexander Dam	0.05	60	JP Marais WCW	0.05	955
			Benoni WCW(1)	0.28	40
			Jan Smuts WCW	0.50	847
3 Cowles dam	0.20	60	Sappi	0.42	244
4 Welgedacht(2)	0.30	59	Daveyton WCW	0.20	750
5 R555 road	0.80	57	Welgedacht WCW	0.60	779
6 Daggafontein	0.70	52	Grootvlei GM	0.05	58
			Ancor WCW	0.40	900
7 Marivale Bird Sanctuary	0.50	54	-		
8. R42 road	0.40	56	-		
9 Nigel canal	0.05	34	Grundlingh WCW	0.05	783
10 Poortjie Road	0.04	58	Bickley WCW	0.05	827
11 Kaydale	1.30	55	Tsakane WCW	0.80	1196
12. Suikerbosrand at S1	0.05	49	-		
13 C2H070	0.30	56	Heidelberg WCW	0.05	876
			Ratanda WCW	0.05	873
14 C2H004	0.30	58	-		
15 Three Rivers	0.06	47	-		

Note: (1) Benoni WCW data is for the period 9/1995 to 12/1999.
(2) The WMS data for Welgedacht was taken for the period prior to 2003 to emulate conditions before the Welgedacht WCW was commissioned. Data after this date could not be used since this river monitoring station is located downstream of the Welgedacht WCW.

Table 4.2: Median flows and velocities simulated by NACL model

River reach	Calibration period		2010		2020		2034	
	Median Flow (m^3/s)	**Velocity (m/s)**	**Median Flow (m^3/s)**	**Velocity (m/s)**	**Median Flow (m^3/s)**	**Velocity (m/s)**	**Median Flow (m^3/s)**	**Velocity (m/s)**
1 Rynfield Dam	0.09	.003	0.11	.003	0.13	.003	0.17	.003
2 Alexander Dam	0.35	.014	0.20	.011	0.24	.012	0.31	.011
3 Cowles dam	0.58	.017	0.44	.015	0.48	.016	0.54	.017
4 Welgedacht(1)	0.19	.114	0.05	.067	0.16	.108	0.16	.108
5 R555	1.0	.044	1.32	.050	1.73	.056	2.39	.063
6 Daggafontein	2.16	.249	2.43	.268	2.88	.298	3.66	.343
7 MBS	2.16	.249	2.43	.268	2.88	.298	3.66	.343

River reach	Calibration period		2010		2020		2034	
	Median Flow (m^3/s)	Velocity (m/s)	Median Flow (m^3/s)	Velocity (m/s)	Median Flow (m^3/s)	Velocity (m/s)	Median Flow (m^3/s)	Velocity (m/s)
8 R42	2.09	.245	2.36	.264	2.81	.294	3.58	.340
9 Nigel canal	0.09	.003	0.08	.003	0.10	.003	0.13	.003
10 Poortjie Road	2.13	.504	2.39	.526	2.87	.560	3.64	.609
11 Kaydale	0.13	.185	0.18	.204	0.20	.209	0.20	.209
12 S1	0.03	.091	0.03	.091	0.03	.091	0.03	.091
13 C2H070	2.39	.389	2.79	.410	3.39	.438	4.34	.470
14 C2H004	2.18	.377	2.58	.399	3.19	.428	4.03	.463
15 Three Rivers	2.18	.377	2.58	.399	3.19	.428	4.03	.463

Note: (1) The median flow and velocity values for Welgedacht are in the Blesbokspruit upstream of the Welgedacht WCW.

The median phosphate concentrations simulated using the DECAY model at the downstream end of each river reach are shown in Table 4.3.

Table 4.3: Simulated end of reach median phosphate concentrations (mg/l)

River reach	2010	2020	2034
1 Rynfield Dam	0.04	0.04	0.04
2 Alexander Dam	0.04	0.04	0.05
3 Cowles dam	0.24	0.23	0.21
4 Welgedacht (upstream of STW)	0.54	0.32	0.32
5 R555	0.83	0.72	0.65
6 Daggafontein	0.72	0.67	0.62
7 Marivale Bird Sanctuary	0.53	0.5	0.49
8 R42	0.43	0.42	0.41
9 Nigel canal	0.05	0.05	0.05
10 Poortjie Road	0.41	0.38	0.37
11 Kaydale	1.07	1.01	1.01
12 S1	0.05	0.05	0.05
13 C2H070	0.31	0.29	0.28
14 C2H004	0.29	0.26	0.24
15 Three Rivers	0.54	0.46	0.4

The median phosphate concentrations have been colour coded according to the in-stream water quality guidelines for the Blesbokspruit catchment (Khwinana, 2010), which are given in Table 4.4.

Table 4.4: Blesbokspruit in-stream phosphate water quality guidelines (mg/l)

Ideal Background	Acceptable Management Target	Tolerable Interim Target	Unacceptable
< 0.2	0.2 - 0.4	0.4 - 0.6	> 0.6

The assumption has been made that the calibrated decay rates and (where indicated by the data) diffuse input loads to each reach would remain unaltered between 2010 and 2034. The underlying assumptions are subject to error and hence the absolute values listed in Table 4.3 cannot be taken as definitive. However, the general trends are considered reasonable.

The simulated median phosphate concentration falls within the Tolerable Interim Target range or better for all points on the main stem of the Blesbokspruit and downstream Suikerbosrand River for all of the time horizons, with the exception of the R555 and Daggafontein.

Note that the improvements over time reflected in Table 4.3 are based on the assumption that the diffuse source loads will not change. Better controls may improve them, while growth over time could have the opposite effect.

The reasons for the higher phosphate concentrations at the R555 and Daggafontein are discussed below in sections 4.3.3 and 4.3.4.

4.3.1 Cowles Dam

The simulated median concentrations in the outflow from Cowles Dam (reach 3) show a gradual decrease over time. This is attributable to increasing dilution of those point sources showing higher phosphate concentrations. This despite increasing flow rates that reduce detention times, which in turn reduce the in-stream decay. Increasing urban areas have very little effect since the increased catchment runoff is confined to wet weather, which is not applicable to median flow conditions.

4.3.2 Blesbokspruit at Welgedacht

The median phosphate concentration at Welgedacht (reach 4) shows a large 40% reduction from 0.54 mg/l to 0.32 mg/l by 2020. This result appears counter intuitive since the reduced detention time associated with the substantial increase in flow velocity could be expected to reduce the decay, leading to an increase in concentration. However, during the calibration period the median concentration at the upstream end of reach 4 was higher than that observed at Welgedacht, resulting necessitating the introduction of a diffuse input to the river reach. Since the median phosphate concentration at Daveyton is only 0.2 mg/l, the increasing flow from this source (from 6 Ml/d to 16 Ml/d) has the effect of diluting the diffuse input.

4.3.3 Blesbokspruit at R555 road crossing

Similar effects are evident at the R555 road crossing (reach 6), where the observed median phosphate concentrations of the upstream river reaches and the Welgedacht STW discharge (0.60 mg/l) are all lower than the observed downstream median concentration. This required the inclusion of a diffuse source phosphate input.

4.3.4 Blesbokspruit at Daggafontein

The 2010 median phosphate concentration at Daggafontein is only 13% lower than that at the R555. This reduction is lower than expected since both Grootvlei Gold mine and the Anchor STW have median concentrations that are significantly lower than those at the R555 and these two sources comprise 44% of the total effluent flow above Daggafontein. Once again this is reflected in a calibrated diffuse source salt load entering the Blesbokspruit. Gradually diminishing median phosphate concentrations from 2010 (0.72 mg/l) to 2034 (0.62 mg/l) are attributable to increasing dilution by upstream effluent discharges. The cause of the diffuse input is not known. It may be due to actual physical sources, or due to unrepresentative sampling. Examination of the data at other sites revealed large inconsistencies due to poor lateral mixing in the Blesbokspruit downstream of the Klein Blesbokspruit into which the Ancor WCW discharges. The mixing should be better resolved further downstream at Daggafontein, but there may still be residual inconsistencies.

4.3.5 Blesbokspruit at Marivale Bird Sanctuary

Simulated median phosphate concentrations at the Marivale Bird Sanctuary are reduced by between 26% (2010) and 21% (2034), due to decay in the wetland.

4.3.6 Blesbokspruit at R42 road crossing

A further 19% (2010) to 16% (2034) reduction in the median phosphate concentration is expected between the Marivale Bird Sanctuary and the R42 road crossing at the downstream end of the Blesbokspruit wetland. There are no simulated diffuse load inputs to the Blesbokspruit between Daggafontein and the R42, nor are there any effluent point sources. There is an overall 40% (2010) to 34% (2034) reduction in the median phosphate concentration between Daggafontein and the R42.

4.3.7 Blesbokspruit at Poortjie road crossing

The simulated median phosphate concentration shows a relatively small reduction of between 5% and 10% between the R42 and Poortjie Road. This low reduction may reflect higher velocities in the river below the wetland reducing the decay. However, a more important factor is that a diffuse source of phosphate was required to entering the Blesbokspruit along this river reach. This may arise from the vicinity of Nigel, or it may be due to unrepresentative monitoring during the calibration period.

4.3.8 Suikerbosrand River at C2H004

In the long 46 km reach of the Blesbokspruit between Poortjie Road and the RW weir at C2H004 the median phosphate concentrations dropped to 0.29 mg/l (29% lower than at Poortjie) for 2010 conditions. By 2034 a 25% reduction is evident with the median concentration reducing to 0.24 mg/l. The modelled median phosphate concentrations at C2H004 for all three time horizons are nearly one third of those at the R555 road bridge at the head of the wetland just downstream of Welgedacht.

4.3.9 Suikerbosrand River at Three Rivers

Six km further downstream at Three Rivers near to the Vaal River confluence the 2010 median phosphate concentration rises abruptly to 0.54 mg/l (an increase of 86%). This is indicative of diffuse sources in the vicinity of Vereeniging.

5. PHOSPHATE BREAKTHROUGH

The possibility of phosphate breakthrough from the Blesbokspruit wetland was assessed during the 1998 Welgedacht study (Teurlings et al, 1998) by comparing unit loading on the Blesbokspruit wetland with that on the Olifantsvlei. A similar approach has been adopted, since the alternative of investigating the phosphate balance and sediment dynamics of the Blesbokspruit wetland would require a long-term comprehensive research project, which would yield useful results only long after a decision has to be made regarding the Welgedacht extensions.

An earlier study of the neighbouring Klip River system indicated that during the period September 1994 to June 1995 a 5.84 km^2 portion of the Olifantsvlei wetland removed about 30 percent of the phosphate load discharged by the Goudkoppies and Olifantsvlei WCWs. (It must be stressed that the percentage phosphate removal of 30 percent is a first order estimate inferred from very limited *ad hoc* flow gauging.) The average discharge from these two WCWs was 107 Ml/d during this period, with a corresponding phosphate load of 121 kg/day. Hence, while this does not indicate at what loading phosphate breakthrough would occur, it does indicate that effective phosphate removal could still be expected when the aerial loading reaches 20.7 kg/day per km^2 of wetland.

Extrapolation of the relationship to the larger 14.2 km^2 Blesbokspruit wetland implies that a phosphate loading rate of at least 293 kg per day should be accommodated without breakthrough. (This if course assumes similarity of the two wetland systems and similar conditions arising with regard to hydraulic short circuiting.)

The estimated daily phosphate loadings from point sources on the Blesbokspruit wetland for the three time horizons are given in Table 5.1.

Table 5.1: Calculated point source phosphate loading on Blesbokspruit wetland

Reach		Point source	Effluent flow (m^3/s)			Ave. PO4 (mg/l)	PO4 load (kg/day)		
No.	Description		2010	2020	2034		2010	2020	2034
3	Cowles Dam outflow(1)	-	0.48	0.51	0.56	0.300	12.4	13.3	14.5
4	Welgedacht	Daveyton STW	0.07	0.19	0.19	0.684	4.1	10.9	10.9
5	R555	Welgedacht STW	0.75	0.98	1.56	1.054	68.5	89.6	142.3
6	Daggafontein	Grootvlei GM	0.93	0.93	0.93	0.113	9.0	9.0	9.0
		Ancor STW	0.27	0.32	0.43	0.530	12.2	14.8	19.9
7	MBS	-							
8	R42	-							
TOTAL			2.49	2.93	3.67	-	106.2	137.7	196.7

Note (1) The point sources into the chain of lakes above Cowles Dam have not been used since most of the phosphate load from these sources is deposited in the dam sediments. Instead the outflow from Cowles Dam was used.

The estimated 2034 phosphate load of 197 kg/day is lower than 293 kg/day, while those for the earlier period are even lower. It can therefore be assumed that phosphate breakthrough is not expected to occur during this period.

However, it must be stressed that this is an extremely coarse first order approximation that is dependent on the as yet unproven assumption that the aerial phosphate loading rate is the dominant factor controlling the ability of both the Olifantsvlei and the Blesbokspruit wetlands to accumulate phosphate. If this proves not to be the case for either wetland, then the evaluation would have to be abandoned in favour of a more appropriate set of relationships.

A number of other factors are also likely to play a role, including:
- hydraulic loading;
- flow velocity;
- morphology (especially short circuiting via channels);

- sediment accumulation (i.e. successive layers of sediment burying accumulated phosphate);
- biological processes causing re-suspension of phosphate);
- cumulative effects (i.e. breakthrough might be induced by the increasing concentration of accumulated phosphate in the sediment); and
- biomass uptake and release (although in the absence of harvesting, it is hard to visualise a process that can make a substantial contribution to the long-term removal of phosphate from the wetland).

The above factors could not be addressed in the current level of investigation but introduce a number of uncertainties to the results. Potential breakthrough of phosphates is of critical importance to nutrient loads entering Vaal Barrage and the downstream Middle Vaal River. It is therefore imperative to initiate a more comprehensive investigation to identify and quantify the key processes governing the removal of phosphate by the Blesbokspruit wetland. A similar recommendation was made in 1998 when the Comprehensive Environmental Impact Assessment for the first 35 Ml/d phase of the Welgedacht WCW was investigated.

6. PHOSPHATE LOAD ON VAAL BARRAGE

Assessment of the impact on Vaal Barrage stopped short of a detailed evaluation since this would require simulation of the entire Vaal River system. This is because the flow regime of the Vaal River is a complex function of the upstream and downstream hydrology and the Vaal River system operating rules. In addition, complex phosphate modelling would be required. This would be a most demanding task, seeing as previous attempts at modelling phosphate dynamics in the Vaal River have met with only limited success.

Instead the phosphate load export from the Suikerbosrand River to the Vaal River was estimated.

This is of importance since eutrophication of Vaal Barrage and the downstream Middle Vaal River is a major concern and phosphate is the limiting nutrient fuelling the eutrophication.

The phosphate export at the Suikerbosrand River weir C2H004 was estimated using the following steps.

6.1 Regression analysis

First the program MOVE was used to estimate the phosphate load at C2H004 for the period October 2003 to September 2009. A power regression between observed phosphate concentrations and the corresponding observed daily flows at gauge C2H004 was used. As expected for this variable the linear correlation between regressed and observed concentrations was low at only 0.202. The power regression was applied to the observed daily flows to patch daily concentrations for periods when the observed flow exceeded 4.0 m^3/s and linear interpolation was used for lower flows. This approach was adopted since the low flow relationship differs from that prevalent during flood events.

This analysis yielded an average daily phosphate export of 122 kg/day for the 6-year calibration period. The flow-weighted average phosphate concentration was calculated from the load and average observed MAR ($152.84 \times 10^6 m^3$) for the calibration period as 0.291 mg/l.

6.2 Estimation of future average phosphate concentrations

The assumption was made that the flow-weighted average phosphate concentration can be scaled from the calibration period to future time horizons according to the ratios of the simulated median concentrations. The results are given in Table 6.1.

Table 6.1: Estimated flow-weighted average PO_4 concentrations at C2H004

Parameter	Units	Calibration	2010	2020	2034
Regressed flow-weighted PO_4	mg/l	0.29			
Median PO_4	mg/l	0.30(1)	0.29	0.26	0.24
Projected flow-weighted PO_4	**mg/l**	**0.29**	**0.28**	**0.25**	**0.23**

Note (1) The observed median during the calibration period.

The projections made in Table 6.1 are a simplification that depends on the relationship between the ratio between the flow-weighted and median phosphate concentrations remaining constant. This relationship may alter as the contribution of point sources to the MAR grows with time.

6.3 Estimation of phosphate loading on Vaal Barrage

Finally, the annual phosphate load exported to Vaal Barrage was calculated by multiplying the projected flow-weighted phosphate concentrations by the longer-term MAR simulated using the NACL daily time step model.

Table 6.2: Estimated annual phosphate load passing C2H004

Parameter	Units	2010	2020	2034
PO4 concentration	mg/l	0.28	0.25	0.23
MAR	$10^6 m^3$	133.80	153.47	181.09
PO_4 load	**t/year**	**37.4**	**38.4**	**41.7**
	kg/day	**103**	**105**	**114**

While the observed phosphate concentrations at Three Rivers are higher than those at C2H004, the increase is thought to be attributable to local sources in Vereeniging and as such is not attributable to sources in the Blesbokspruit.

Note that the Welgedacht WCW contributes only about half of the phosphate load discharged by point sources in the Blesbokspruit catchment. This proportional contribution is further reduced by the influence of diffuse sources.

7. CONCLUSIONS

The effect on water quality of implementing modules 2 and 3 of the Welgedacht WCW, each of which would add 50 Ml/d, has been evaluated for present day conditions and the time horizons (2020 and 2034) when each module would reach capacity, assuming that the treated effluent would be discharged to the Blesbokspruit at site. The evaluations were carried out assuming that Grootvlei gold mine continues to discharge underground water. Salinity and phosphate have been evaluated since these are expected to have the greatest impact on the Blesbokspruit and Vaal Barrage.

The WQ2000 model was used to evaluate salinity impacts and the DECAY model was used to evaluate phosphate effects on the Blesbokspruit. The possibility of phosphate breakthrough from the Blesbokspruit wetland was assessed and phosphate loading on Vaal Barrage evaluated.

7.1 Effect on salt concentrations

- For present day (2010) conditions a median TDS concentration of 603 mg/l is simulated in the wetland downstream of the R555 road bridge, rising to 1123 mg/l downstream of Grootvlei gold mine. Little change in TDS concentration occurs through the remainder of the wetland to below Nigel. Upstream of the Suikerbosrand River confluence the median TDS concentration reduces by 9% to 1021 mg/l, and falls a further 12% to 896 mg/l above the confluence of the Suikerbosrand River with the Vaal River. The median TDS concentration is in the Tolerable Interim Target guideline range (455 - 780 mg/l) above Grootvlei and moves into the Unacceptable range (>780 mg/l) below this point due to the influence of saline underground dewatering.

- Median TDS concentrations show a 6% to 9% improvement at all points by 2020 and a 11% to 18% improvement by 2034, so much so that by 2034 the median concentrations in the lower Suikerbosrand River near the Vaal River confluence are expected to revert to the Tolerable Interim Target guideline range.

- The present day 95-percentile peak TDS concentrations above and below Grootvlei gold mine are only 9% higher than the median. This is attributable to the dominance of point source discharges. The difference further downstream increases due to the increasing influence of catchment runoff, reaching 21% near the Suikerbosrand-Vaal River confluence. The 95-percentile TDS concentration remains in the Tolerable Interim Target guideline range above Grootvlei and deteriorates into the Unacceptable range further downstream.

- 95-percentile peak TDS concentrations show a 7% to 11% improvement at all points by 2020 and a 12% to 20% improvement by 2034. Despite this improvement, the 95-percentile peak TDS concentration remains in the Unacceptable guideline range below the Grootvlei gold mine point of discharge for all time horizons.

- Seasonal distributions of TDS concentrations show remarkably little variation due to the dominance of point discharges.

- The elevated TDS concentrations in the Blesbokspruit and Suikerbosrand River are far higher than those of the Welgedacht WCW and are attributable to other pollution sources, such a industrial and mining effluent. Indeed, increasing treated effluent flows from Welgedacht have the beneficial effect of diluting salt concentrations.

7.2 Effect on phosphate concentrations

- For present day conditions the simulated median phosphate concentration at Cowles Dam meets the Acceptable Management Target (0.2 to 0.4 mg/l) and that in the Blesbokspruit above Welgedacht is in the Tolerable Interim Target range (0.4 - 0.6 mg/l), where it remains through most of the wetland and beyond Nigel to Poortjie Road. However, the median phosphate concentrations in the upper portion of the wetland between the R555 and Daggafontein extend into the Unacceptable guideline range (> 0.6 mg/l). This may be attributable to diffuse sources or unrepresentative sampling during the calibration period, since the wetland is very wide and some of the monitoring sections are located close to incoming streams and point sources. Median concentrations improve to the Acceptable Management Target range in the lower Suikerbosrand River, regressing to the Tolerable Interim Target range near the confluence with the Vaal River, presumably due to local diffuse pollution sources in the vicinity of Vereeniging.

- A steady improvement in median phosphate concentrations over time is expected due to increasing dilution of diffuse sources by treated sewage effluent. The biggest improvement occurs in the upstream portion of the wetland between the R555 and Daggafontein, with a simulated 13% improvement at the R555 by 2020 and a 22% improvement by 2034. However, the median phosphate concentration in this region remains in the Unacceptable range. Smaller improvements are noticeable further downstream, averaged at 6% by 2020 and 10% by 2034. A larger improvement is expected in the Suikerbosrand River near Vereeniging (15% to 26%) due to dilution of the local diffuse sources.

Note that these changes in time are based on the assumption that the diffuse source loads will not change. Better controls may improve them, while growth over time could have the opposite effect.

7.3 Phosphate breakthrough

- Based on comparisons with investigations of the neighbouring Olifantsvlei wetland on the Kip River, by 2034 the point source loading on the Blesbokspruit wetland should not reach the stage of phosphate breakthrough. However, it must be stressed that this conclusion is an extremely coarse first order approximation that is based on the unproven simplifying assumption that the aerial phosphate loading rate is the dominant factor controlling the ability of both the Olifantsvlei and Blesbokspruit wetlands to accumulate phosphate.

7.4 Phosphate load on Vaal Barrage

- The 2010 phosphate export at weir C2H004 was estimated at 103 kg/day, growing to 114 kg/day by 2034. Welgedacht WCW accounts for about half of the point source phosphate load discharged to the Blesbokspruit and the proportional contribution to the export at C2H004 is further reduced by diffuse inputs.

7.5 Overall conclusion

- The development of Modules 2 and 3 of the Welgedacht WCW has the beneficial effect of diluting salt concentrations. The development does not appear to hold new adverse impacts with regard to the primary nutrient, phosphate, for the Blesbokspruit and the downstream Vaal Barrage. Phosphate breakthrough from the wetland is not indicated by the analysis, although further research on the dynamics of the wetland is recommended.

8. RECOMMENDATIONS

8.1 Implement Welgedacht WCW Module 2

The results show that the discharge of purified effluent above the R555 at the current Welgedacht WCW point of discharge has a beneficial impact on salinity at all points in the Blesbokspruit wetland and downstream river system. Modelled phosphate concentrations also show improvement due to reduced loading on WCWs and the planned treatment specifications at Welgedacht. The Module 2 extensions are not expected to cause phosphate breakthrough in the wetland and the phosphate export to Vaal Barrage would show only a moderate 2% increase, with a 11% improvement of the average concentration, by 2020 when Module 2 is running at capacity. Since the extensions are expected to be largely beneficial, it is recommended that the Welgedacht Module 2 be implemented, discharging at or near to the existing outlet works.

8.2 Improvements to support future developments

While these relatively coarse evaluations are considered sufficient to support the main conclusion to proceed with Welgedacht Module 2, the following actions are recommended by the DWA to provide greater confidence with regard to further catchment developments.

8.1.1 Revise salinity model calibration

The WQ2000 hydro-salinity model used in this study is based on calibrations up to the end of September 1995. This is considered barely adequate to make first order comparisons of the salinity implications of options and time horizons, as was done in this study. However, 16 years have now elapsed since the underlying WQT model was last calibrated, during which time the catchment has undergone considerable development and much new water quality data has been accumulated . It is therefore recommended that the hydro-salinity model calibrations be extended to better simulate diffuse salt loads, which play a significant role in the salinity regime of the catchment. This task is beyond the scope of the current study.

8.1.2 Improve estimation of phosphate concentrations

Since this work was undertaken an improved model to evaluate phosphate concentrations, WQDOWN, has been developed (Herold and Le Roux, 2010). This model goes much further than the DECAY model and permits evaluation of full duration curves of phosphate and other concentrations taking account of varying catchment and effluent flow rates during the calibration period and the effect of runoff variation when simulating options. In addition to the decay and diffuse inputs used in the DECAY model, stochastic variations are also simulated. Initial development has shown the value of this model. It is recommended that this model be more fully tested and applied to future developments.

8.1.3 Investigate phosphate dynamics of Blesbokspruit wetland

The evaluation of phosphate breakthrough discussed in Chapter 7 is highly simplistic and raises a number of questions regarding the processes taking place. It is strongly recommended that a detailed investigation of the dynamics of the Blesbokspruit wetland be undertaken to determine its continued ability to assimilate nutrient loads (especially phosphate) before breakthrough occurs.

Factors that need to be taken into account include:
- Aerial loading;
- hydraulic loading;
- flow velocity and scour;
- morphology (especially short circuiting via channels);
- sediment accumulation (i.e. successive layers of sediment burying accumulated phosphate);
- biological and other processes causing re-suspension of phosphate);
- cumulative effects (i.e. breakthrough might be induced by the increasing concentration of accumulated phosphate in the sediment); and
- biomass uptake and release (although in the absence of harvesting, it is hard to visualise a process that can make a substantial contribution to the long-term removal of phosphate from the wetland).

Such a study was recommended when Module 1 was investigated and the need for it is now even more pressing. A comprehensive study of this nature is best handled by the WRC.

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