Report No: P WMA
19/G10/00/2413/5

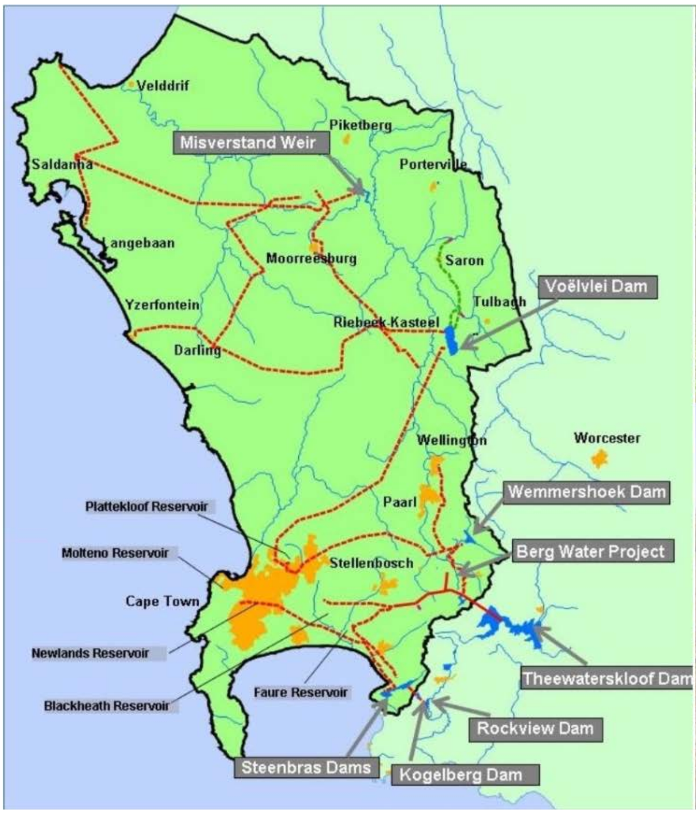
Department of Water Affairs
Directorate: Options Analysis

PRE-FEASIBILITY AND FEASIBILITY STUDIES FOR AUGMENTATION OF THE WESTERN CAPE WATER SUPPLY SYSTEM BY MEANS OF FURTHER SURFACE WATER DEVELOPMENTS

REPORT No.3 – VOLUME 1
Berg River-Voëlvlei Augmentation Scheme

APPENDIX No.4

Dispersion Modelling in Voëlvlei Dam from Berg River Water Transfers for the Berg River-Voëlvlei Augmentation Scheme




December 2012

STUDY REPORT LIST

REPORT No	REPORT TITLE	VOLUME No.	DWA REPORT No.	VOLUME TITLE
1	**ECOLOGICAL WATER REQUIREMENT ASSESSMENTS**	Vol 1	PWMA19 G10/00/2413/1	**Riverine Environmental Water Requirements**
				Appendix 1: EWR data for the Breede River
				Appendix 2: EWR data for the Palmiet River
				Appendix 3: EWR data for the Berg River
				Appendix 4: Task 3.1: Rapid Reserve assessments (quantity) for the Steenbras, Pombers and Kromme Rivers
				Appendix 5: Habitat Integrity Report – Breede River
		Vol 2	PWMA19 G10/00/2413/2	**Rapid Determination of the Environmental Water Requirements of the Palmiet River Estuary**
				Appendix A: Summary of data available for the RDM investigations undertaken during 2007 and 2008
				Appendix B: Summary of baseline data requirements and the long-term monitoring programme
				Appendix C: Abiotic Specialist Report
		Vol 3	PWMA19 G10/00/2413/3	**Berg Estuary Environmental Water Requirements**
				Appendix A: Available information and data
				Appendix B: Measurement of streamflows in the Lower Berg downstream of Misverstand Dam
				Appendix C: Specialist Report – Physical dynamics and water quality
				Appendix D: Specialist Report – Modelling
				Appendix E: Specialist Report – Microalgae
				Appendix F: Specialist Report – Invertebrates
				Appendix G: Specialist Report – Fish
				Appendix H: Specialist Report – Birds
				Appendix I: Specialist Report – The economic value of the Berg River Estuary
2	**PRELIMINARY ASSESSMENT OF OPTIONS**		PWMA19 G10/00/2413/4	Appendix 1: Scheme Yield Assessments and Diversion Functions
				Appendix 2: Unit Reference Value Calculation Sheets
				Appendix 3: Yield Analysis and Dam Size Optimization
				Appendix 4: Dam Design Inputs
				Appendix 5: Diversion Weir Layout Drawings
				Appendix 6: Voëlvlei Dam Water Quality Assessment
				Appendix 7: Botanical Considerations
				Appendix 8: Heritage Considerations
				Appendix 9: Agricultural Economic Considerations

STUDY REPORT LIST (cntd)

<table>
<tr><th>REPORT No</th><th>REPORT TITLE</th><th>VOLUME No.</th><th>DWA REPORT No.</th><th>VOLUME TITLE</th></tr>
<tr><td rowspan="15">3</td><td rowspan="15">FEASIBILITY STUDIES</td><td rowspan="6">Vol 1</td><td rowspan="6">PWMA19 G10/00/2413/5</td><td>Berg River-Voëlvlei Augmentation Scheme</td></tr>
<tr><td>Appendix 1: Updating of the Western Cape Water Supply System Analysis for the Berg River-Voëlvlei Augmentation Scheme</td></tr>
<tr><td>Appendix 2: Configuration, Calibration and Application of the CE-QUAL-W2 model to Voëlvlei Dam for the Berg River-Voëlvlei Augmentation Scheme</td></tr>
<tr><td>Appendix 3: Monitoring Water Quality During Flood Events in the Middle Berg River (Winter 2011), for the Berg River-Voëlvlei Augmentation Scheme</td></tr>
<tr><td>Appendix 4: Dispersion Modelling in Voëlvlei Dam from Berg River Water Transfers for the Berg River-Voëlvlei Augmentation Scheme</td></tr>
<tr><td>Appendix 7 - 12: See list under Volume 2 below</td></tr>
<tr><td rowspan="9">Vol 2</td><td rowspan="9">PWMA19 G10/00/2413/6</td><td>Breede-Berg (Michell’s Pass) Water Transfer Scheme</td></tr>
<tr><td>Appendix 5: Scheme Operation and Yield Analyses with Ecological Flow Requirements for the Breede-Berg (Michell’s Pass) Water Transfer Scheme</td></tr>
<tr><td>Appendix 6: Preliminary Design of Papenkuils Pump Station Upgrade and Pre-Feasibility Design of the Boontjies Dam, for the Breede-Berg (Michell’s Pass) Water Transfer Scheme</td></tr>
<tr><td>Appendix 7: Ecological Water Requirements Assessment Summary for the Berg River-Voëlvlei Augmentation Scheme, and the Breede Berg (Michell’s Pass) Water Transfer Scheme</td></tr>
<tr><td>Appendix 8: Geotechnical Investigations for the Berg River-Voëlvlei Augmentation Scheme, and the Breede-Berg (Michell’s Pass) Water Transfer Scheme</td></tr>
<tr><td>Appendix 9: LiDAR Aerial Survey, for the Berg River-Voëlvlei Augmentation Scheme, and the Breede-Berg (Michell’s Pass) Water Transfer Scheme</td></tr>
<tr><td>Appendix 10: Conveyance Infrastructure Design Report, for the Berg River-Voëlvlei Augmentation Scheme, and the Breede-Berg (Michell’s Pass) Water Transfer Scheme</td></tr>
<tr><td>Appendix 11: Diversion Weirs Design for the Berg River-Voëlvlei Augmentation Scheme, and the Breede-Berg (Michell’s Pass) Water Transfer Scheme</td></tr>
<tr><td>Appendix 12: Cost Estimates for the Berg River-Voëlvlei Augmentation Scheme, and the Breede-Berg (Michell’s Pass) Water Transfer Scheme</td></tr>
<tr><td>4</td><td colspan="2">RECORD OF IMPLEMENTATION DECISIONS</td><td>PWMA19 G10/00/2413/7</td><td></td></tr>
</table>

STUDY REPORT MATRIX DIAGRAM

PHASE 1: PRE-FEASIBILITY STUDY

ECOLOGICAL WATER REQUIREMENT ASSESSMENTS

Riverine Environmental Water Requirements
PWMA19 G10/00/2413/1
- Data (Electronic format)
- Rapid Reserves (Steenbras, Pombers, Kromme Rivers)
- Habitat Integrity (Breede River)

Rapid Determination of the Environmental Water Requirements of the Palmiet River Estuary
PWMA19 G10/00/2413/2
- Existing Data Availability
- Baseline Data Requirements and Monitoring Programme
- Abiotic Assessment

Berg Estuary Environmental Water Requirements
PWMA19 G10/00/2413/3
- Available Information and Data
- Measurement of Streamflows in the Lower Berg
- Physical Dynamics and Water Quality
- Modelling
- Microalgae
- Invertebrates
- Fish
- Birds
- Economic Value of the Estuary

PRELIMINARY ASSESSMENT OF OPTIONS
PWMA19 G10/00/2413/4
- Scheme Yield Assessments and Diversion Functions
- Unit Reference Value Calculation Sheets
- Yield Analysis and Dam Size Optimization
- Dam Design Inputs
- Diversion Weir Layout Drawings
- Voëlvlei Dam Water Quality Assessment
- Botanical Considerations
- Heritage Considerations
- Agricultural Economic Considerations

PHASE 2: FEASIBILITY STUDIES

BERG RIVER VOËLVLEI AUGMENTATION SCHEME
PWMA19 G10/00/2413/5
- Update System Analysis
- Berg River CE-Qual Water Quality Modelling
- Berg River Flood Water Quality Modelling
- Dispersion Modelling in Voëlvlei Dam
- Ecological Water Requirements Summary
- Geotechnical Investigations
- Aerial Survey
- Conveyance Infrastructure Design
- Diversion Weirs Design
- Cost Estimates

BREEDE - BERG (MICHELL'S PASS) WATER TRANSFER SCHEME
PWMA19 G10/00/2413/6
- Scheme Operation and Yield Analysis
- Preliminary Design of Papenkuils Pumpstation and Boontjies Dam
- Ecological Water Requirements Summary
- Geotechnical Investigations
- Aerial Survey
- Conveyance Infrastructure Design
- Diversion Weirs Design
- Cost Estimates

IMPLEMENTATION DECISION SUPPORT

RECORD OF IMPLEMENTATION DECISIONS
PWMA19 G10/00/2413/7

TABLE OF CONTENTS

Page No

TABLES

FIGURES

ABBREVIATIONS

CCT	City of Cape Town
DWA	Department of Water Affairs
WTW	Water Treatment Works

1. INTRODUCTION

The CE-QUAL-W2 dynamic reservoir water quality model was set up for Voëlvlei Dam to simulate the potential impacts of water transfers from the Berg River on water quality in Voëlvlei Dam, and in particular the eutrophication potential of the dam. CE-QUAL-W2 is a water quality and hydrodynamic reservoir model that simulates water quality and biological changes in two dimensions namely longitudinal (along the length of the reservoir) and vertical (in depth) (Figure 1). The model does not simulate water quality across the width of the reservoir.

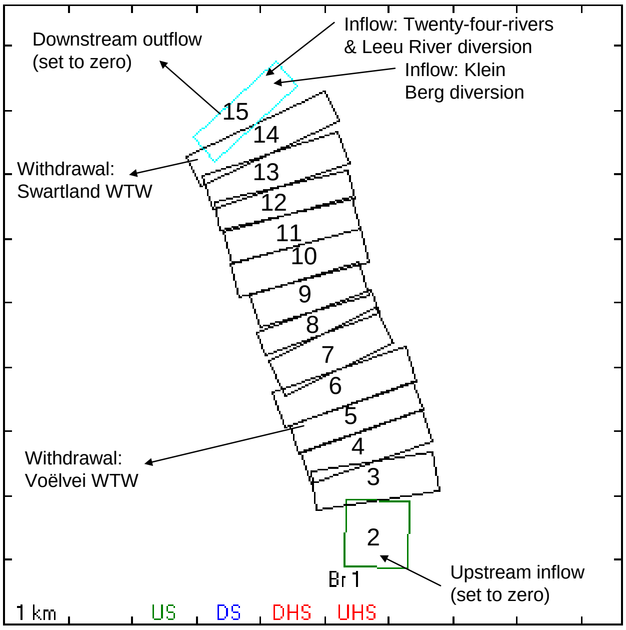


Figure 1: Diagram of Voëlvlei Dam showing the conceptual segmentation of the reservoirs for the CE-QUAL-W2 model and the location of in- and outflows from the reservoir.

The Berg River carry high microbial loads during the winter months and concerns were expressed about the impacts of this might have on the quality of water abstracted for the Swartland WTW and the City of Cape Town WTW.

2. METHODOLOGY

2.1 NEAR-SHORE BACTERIAL DIE-OFF MODEL

When concerns were raised about the near-shore effects of water transferred from the Berg River into Voëlvlei Dam, another model had to be found that could be used to estimate, at a feasibility level, the fate of bacterial contaminants at the two bulk-water abstraction points.

Near-shore models estimate the dispersion of contaminants in the vicinity of a discharge. After an initial period of mixing of the discharge due to turbulence caused by the discharge jet, the concentration of a near-shore input is dependent on the transport processes into the lake or reservoir, and on the pollutant's reaction characteristics. For the Voëlvlei application it was assumed that the water column was vertically well-mixed. Previous modelling studies found that this was indeed the case during the winter months when most of the transfers are due to take place. The coordinates used in near-shore models are illustrated in Figure 2.

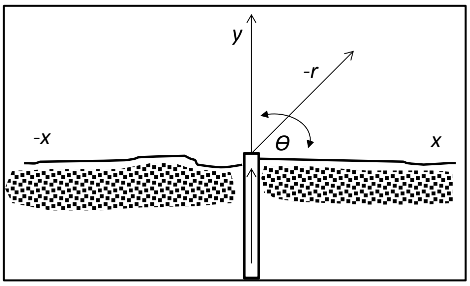


Figure 2: The cartesian (x,y) and radial (r) coordinates used for near-shore models.

To undertake a first order estimate the dispersion of bacteria that could be transferred from the Berg River via the transfer scheme, a model developed by Boyce and Hamblin (1975, cited in Capra, 1997) was used. The model estimates the concentration of a constituent at any specific x,y point in the dam as follows:

$$c = \frac{W}{\pi H E}\, e^{\frac{U_x x}{2E}}\, K_0 \left[r \sqrt{\frac{k}{E} + \left(\frac{U_x}{2E}\right)^2} \right]$$

Where:

W = Bacterial load = Flow (m^3/day) x Bacterial counts (counts per 100ml/L)
H = Water depth (m)
E = Horizontal diffusion (m^2/day)
U_x = current velocity along the shoreline (m/day)
x = distance
k = bacterial decay rate (1/day)
r = radius ($r = (x^2+y^2)^{0.5}$)

2.2 SETTING UP THE DISPERSION MODEL FOR VOËLVLEI DAM

The Voëlvlei Dam was conceptualised as a rectangular dam which is completely mixed in depth but not along its length or width. The point where the transfer water is expected to enter Vloëlvlei Dam is illustrated in Figure 3. The Swartland WTW abstraction tower is situated approximately 1400m to the north of the discharge point, and the City of Cape Town WTW abstraction works about 3100m south of the discharge point (Figure 3). At the discharge point the dam is about 2400m wide.

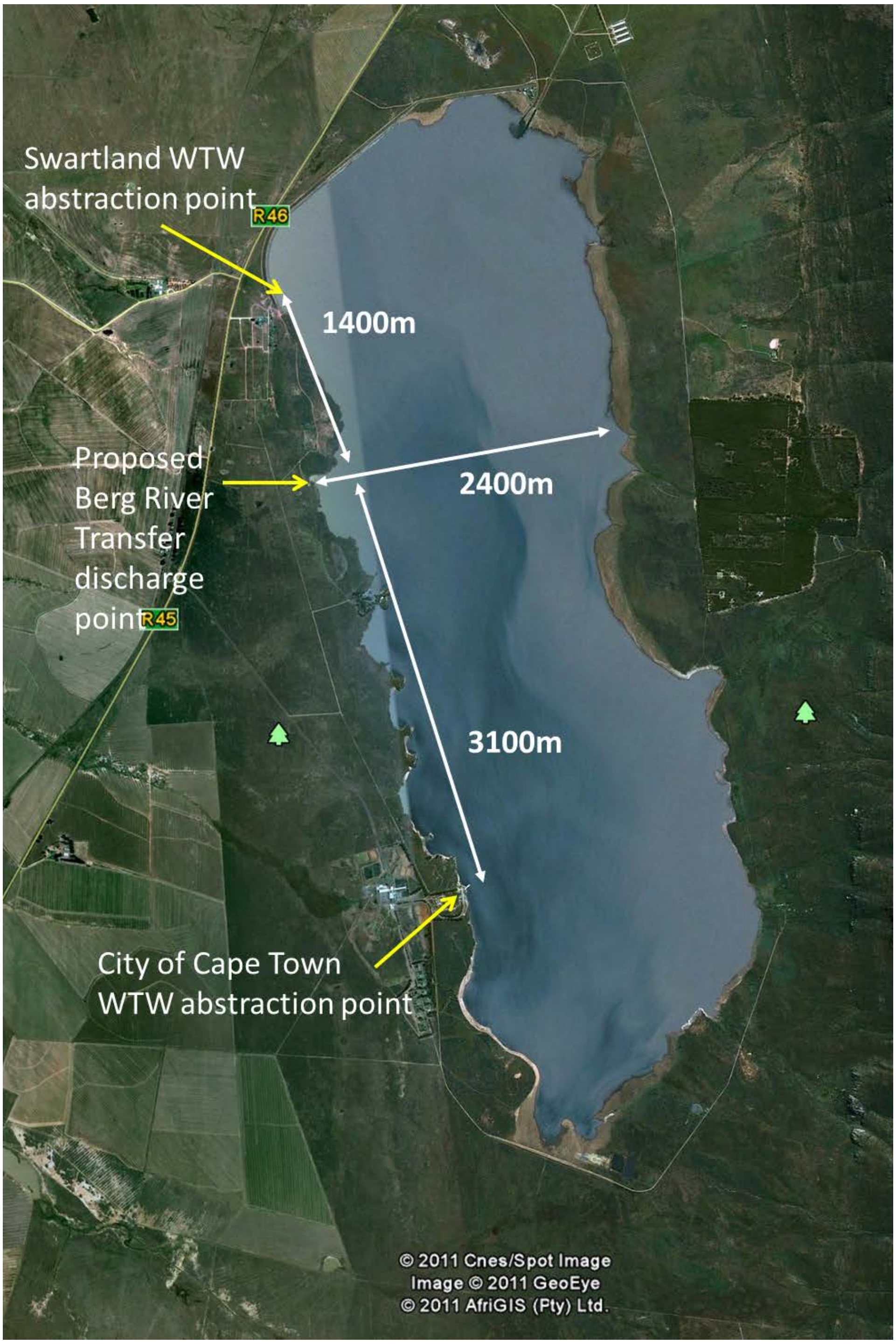


Figure 3: Image of Voëlvlei Dam showing the proposed location of the discharge point and approximate distances to the two WTW abstraction points.

A rectangular matrix (Figure 4) of 4800m by 2200m with 200m x 200m cells was set up and the bacterial concentration was calculated for each cell using the above equation.

Figure 4: Illustration of the matrix that was set up to estimate the dispersion of bacteria in the transfer water.

2.3 INPUTS TO THE MODEL

Table 1: Inputs to the dispersion model

Input	Comment
Discharge Flow (m^3/day)	This is the flow rate of the transfer. The maximum transfer rate is 6 m^3/s but the impacts of lower transfer rates, 2 m^3/s and 4 m^3/s were also assessed.
Discharge concentration (counts/100ml)	The bacterial counts in the water transferred from the Berg River. An examination of DWA E.coli data collected at Saron, the closest NMMP monitoring point to Zonquasdrift, indicate that high bacterial counts are recorded in June each year. The median E.coli counts was 1453 counts/100ml, the 75th percentile value was 2419 counts/100ml, and the 95th percentile value was 24196 counts/100ml.
Water depth (m)	This is depth of the dam. The maximum water depth is 17.65m but the impacts of transfers into different water depths were evaluated. Three water depths were selected. For the data period 1999-2009 and the months of May to September, the lowest water level was 7.6m, the average depth was 13.4m, and the highest level was 17.7m.
Current velocity along the shoreline (m/day)	A shoreline current due to wind can direct the dispersing plume either towards or away from the two off-take points. The prevailing wind direction at Voëlvlei Dam is along the longitudinal axis of the dam. Horizontal current velocities were calculated with the CE-QUAL-W2 model using observed wind data for Voëlvlei Dam. It was found that the average current velocity was about 0.03 m/s (2592 m/day) and a high current velocity was about 0.1 m/s (8640m/day). Three shoreline current velocities were therefore evaluated to illustrate the effect of wind on the discharge plume. These were no shoreline current (0 m/day) on a wind still day, an average shoreline current (2592 m/day), and a strong shoreline current (8640 m/day). The effect of current was tested in both directions (SSE and NNW).

Table 2: Parameters of the dispersion model

Parameter	Comment
Bacterial decay rate (1/day)	The bacterial decay rate describes the rate at which bacteria die off in the water. The die-off is a function of sunlight, temperature, salinity, predation, settling and resuspension of suspended sediment particles, and aftergrowth. According to Chapra (1998), the decay rate varies between 0.5/day to 3/day. The die-off rate is generally lower in turbid water than in clear water and a rate of 1.0/day was therefore used in this application.
Horizontal diffusion constant (m^2/day)	The horizontal diffusion rate refers to the movement of mass due to random water motion or mixing from a region of high to low concentration. A value of $1x10^6$ m^2/day appears to be common for reservoirs (Chapra, 1998) and was used in this application.

3. FINDINGS

3.1 CURRENT BACTERIAL STATUS IN THE BERG RIVER, KLEIN BERG RIVER AND VOËLVLEI DAM

The monthly background E.coli counts as measured in the CCT raw water intake (July 2006 to October 2011) are displayed as box-and-whisker plots in Figure 5. The highest E.coli counts tended to occur early in the rainfall season (May and June) and it then drops to very low late in the rainfall season (September and October) and there is then a slow but steady increase in E.coli counts trough summer and autumn. The high counts in May and June indicated that high bacterial loads from the Klein Berg River occurred early in the rainfall season when the first rainfalls wash pollutants form the catchment.

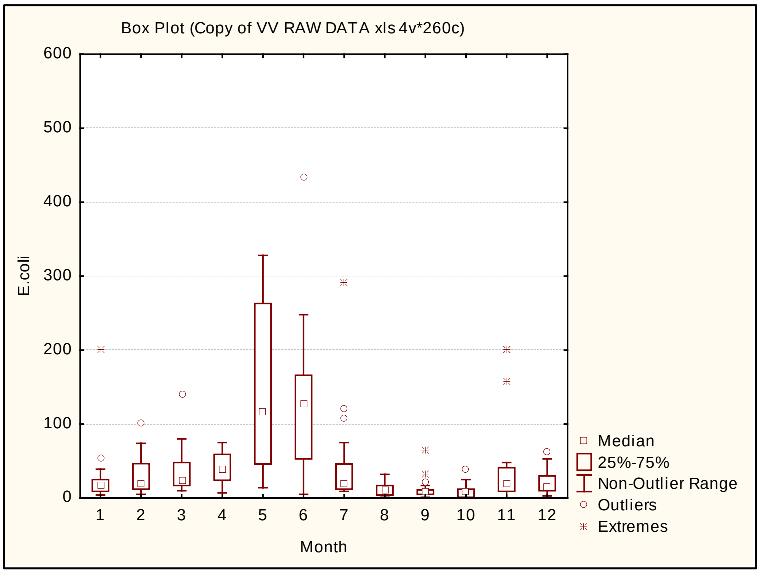


Figure 5: Monthly box-and-whisker plot of E.coli (counts/100ml) observed in the City of Cape Town raw water intake (CCT data).

An examination of DWA E.coli data collected in the Klein Berg River at Tulbach shows that median E.coli counts are not significantly higher in winter although the variability (size of the box) was very high in July (Figure 6).

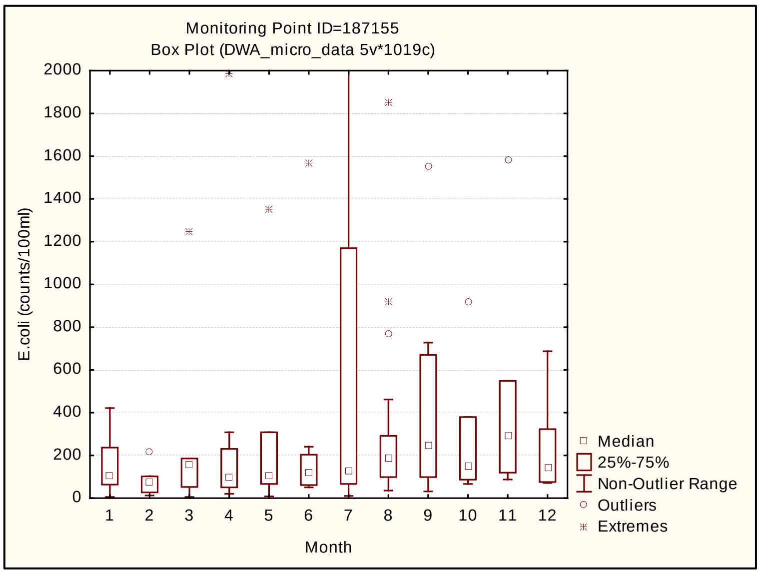


Figure 6: Monthly box-and-whisker plot of E.coli (counts/100ml) observed in the Klein Berg River at the Tulbach road bridge (DWA data)

In the Berg River near Saron there is very strong seasonal signal in the E.coli data with low counts in summer and high counts in winter, peaking in June. This indicates that non-point sources of bacteria probably dominate in this part of the Berg River (Figure 7).

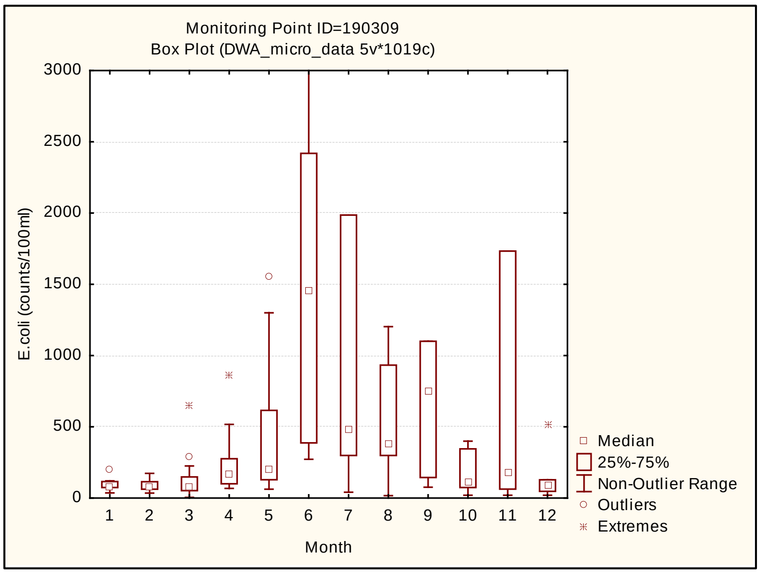


Figure 7: Monthly box-and-whisker plot of E.coli (counts/100ml) observed in the Berg River near Saron (DWA data)

3.2 ESTIMATED DISPERSION OF THE TRANSFER WATER IN VOËLVLEI DAM

The two factors that most affect the E.coli counts at the two abstraction works, are the water depth and the wind strength and direction. Water depth affects the amount of dilution that takes place at the point of discharge. Bacterial die-off is then responsible for the reduction in bacterial counts away from the discharge point. If there is no wind, then the die-off is symmetrical radiating away from the point of discharge (Figure 8). Figure 8 displays the die-off as if the reader is standing on the opposite bank of the dam. The Swartland abstraction tower is to the right of the discharge point at -1400m and the City of Cape Town abstraction is to the left of the discharge point at 3000m. Figure 8 shows that with a discharge of 6 m^3/s and median June E.coli counts of 1453/100ml, discharging into a very low dam level (7.6m), the counts at the discharge point would be between 50-60 counts/100ml, at the Swartland and CCT abstractions it would be between 0 – 10 counts/100ml above background.

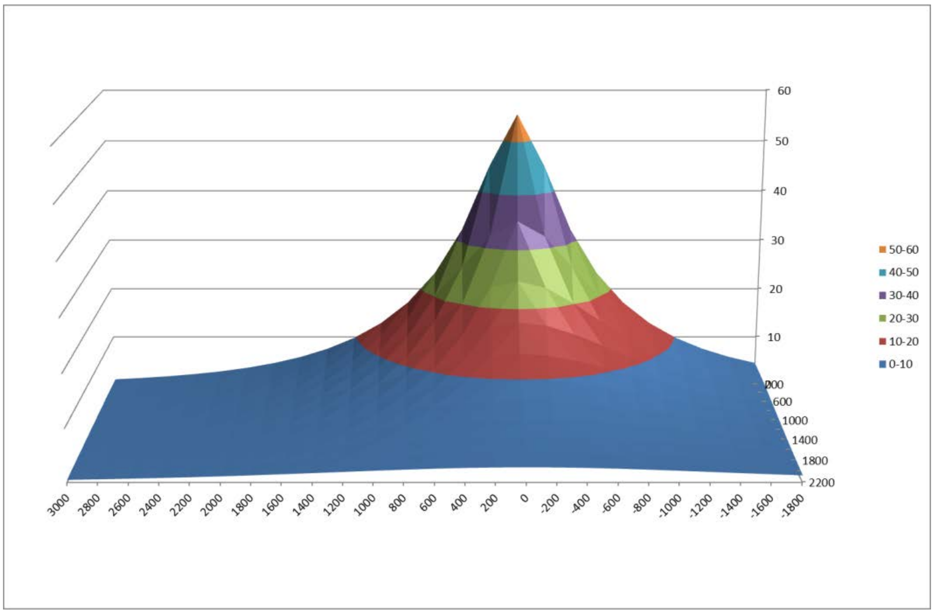


Figure 8: Surface plot of the estimated die-off of E.coli from the discharge point towards the Swartland abstraction at -1400m (right) and the CCT abstraction at 3000m (left). No wind is blowing.

If an average south-eastern wind generates surface currents of 0.03 m/s (blowing from left to right in Figure 9), then the transfer water plume would be pushed towards the Swartland abstraction point and the E.coli counts would be about between 10-15 counts/100ml above background levels and zero above background levels at the CCT abstraction.

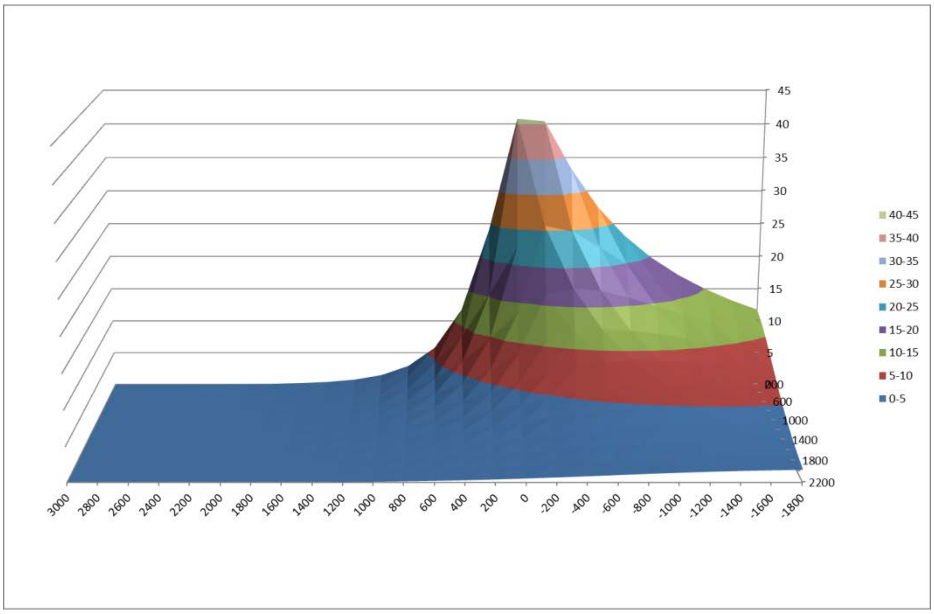


Figure 9: Surface plot of the estimated die-off of E.coli from the discharge point towards the Swartland abstraction at -1400m (right) and the CoC abstraction at 3000m (left). An average wind is blowing from left to right.

If the wind is reversed and an average north-western wind generates surface currents of 0.03 m/s (from right to left in Figure 10), then the transfer water plume would be pushed towards the CCT abstraction point and the E.coli counts would be about between 5-10 counts/100ml above background levels and 0 – 5 counts/100ml above background levels at the Swartland abstraction.

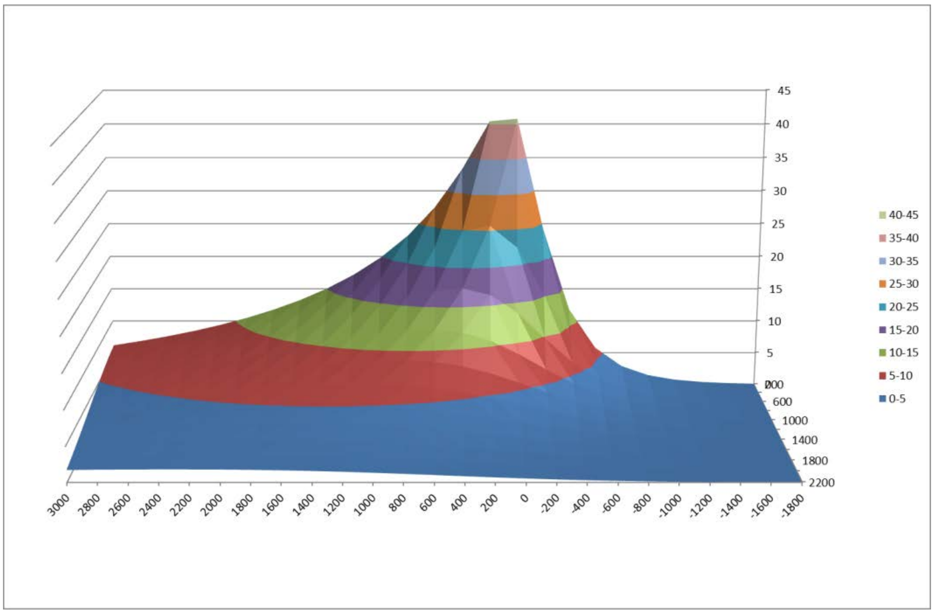


Figure 10: Surface plot of the estimated die-off of E.coli from the discharge point towards the Swartland abstraction at -1400m (right) and the CCT abstraction at 3000m (left). An average wind is blowing from right to left.

If the 75th percentile E.coli counts in June (2419 counts/100ml) was discharged into a dam that is , and south eastern wind was blowing towards the Swartland abstraction point, the E.coli counts at that point could increase by about 25 counts/100ml above background. If the wind direction is in the opposite direction, then the E.coli counts at the CCT abstraction point could increase by about 10 counts/100ml above background levels.

A worst case scenario could be if the 95th percentile E.coli counts in June (24196 counts/100ml) was discharged into the dam, and a south eastern wind was blowing towards the Swartland abstraction point. The E.coli counts at that point could then increase by about 251 counts/100ml above background levels.

4. DISCUSSION

This first order assessment indicated that under average conditions, the impacts on the bacterial counts at the CCT abstraction and the Swartland abstraction could be very low, even during the month of June when E.coli counts in the Berg River peaks. However, under extreme conditions, the E.coli counts at the Swartland abstraction could increase by as much as 251 counts/100ml above background levels. This could occur if very counts occur in the Berg River, the water level in Voëlvlei Dam is low, and there is a wind blowing towards the Swartland abstraction point.

5. REFERENCES

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