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

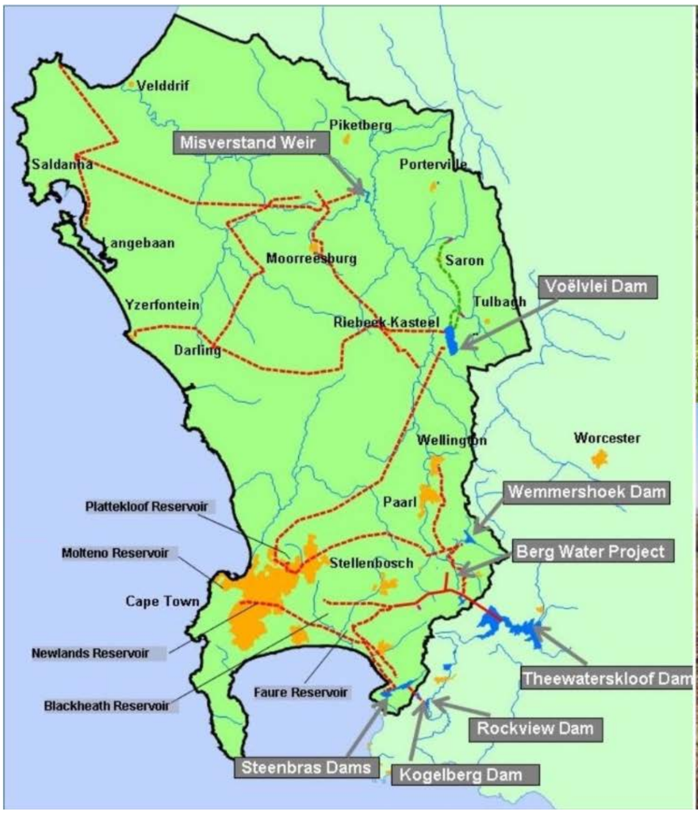
Department of Water Affairs
Directorate: Options Analysis

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.3

Monitoring Water Quality During Flood Events in the Middle Berg River (Winter 2011), for the Berg River-Voëlvlei Augmentation Scheme




December 2012

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1. INTRODUCTION

1.1 PURPOSE OF THIS REPORT

During Phase 1 of the Pre-feasibility and Feasibility Studies for Augmentation of the Western Cape Water Supply System, transfer of water from the Berg River into Voëlvlei Dam was identified as one of the options to augment water supply to the Western Cape Water Supply System. The transfers would occur during the high flow winter rainfall months but concerns were expressed about the quality of water and how it varied over a typical season or flood event.

In the Inception Report to Phase 2 of the project the following was stated with regard to water quality investigations:

> *Quality and flow data from the waste water treatment works at Paarl and Wellington would be obtained to ascertain what benefits there would be from the upgrade of these works. The Paarl WWTW is currently being upgraded and the same is proposed for Wellington in due course. Three flood events during the winter months in the Berg River would be sampled for nutrients at short time intervals so as to determine whether there would be any water quality benefit in timing the abstractions from the rivers into Voëlvlei Dam. The cost of upgrading these waste water treatment works will be taken into consideration as well as the possible improvements in water quality of the Berg River downstream. The additional water quality data would be used to improve the estimates of nutrient loadings, and if required, the CE-QUAL-W2 model for Voëlvlei would be rerun. This information together with that available would also be used to determine the capital and operating costs of additional water treatment requirements that may be required at the CCT WTW at Voëlvlei Dam and particularly the need for treatment with activated carbon to remove tastes and odours.*

At the WCWSS Recon Support Meeting on 14 March 2011 the water quality monitoring during low and high flow events was discussed with Ashia Petersen (DWA Regional Director), Derril Daniëls (Acting Berg River Catchment Manager for DWA), Nick Faasen (West Coast District Municipality) and Peter Flower (City of Cape Town). The DWA Regional Office (Derril Daniëls) indicated that the Department had a contract with West Coast District Municipality and they would be willing to arrange for staff at the Swartland WTW to collect water samples during selected flood events. The samples would be analysed at the laboartories of the Cape Town City Council for chemical constituents and at the Withoogte laboratory for microbiological constituents.

2. METHODOLOGY

2.1 MONITORING OBJECTIVES

The objectives of the winter water quality monitoring were as follows:

- Baseline survey - To characterise the water quality at three gauges in the Berg River at the end of the dry season just prior to the rainy season. Water quality includes the salinity, nutrient, microbial, and turbidity status.
- Early-season floods - To characterise the water quality in the Berg River at Zonquasdrift during the first flood events to determine if there was a significant first flush effect.
- Mid-season floods - To characterise the water quality in the Berg River at Zonquasdrift during a mid rainy season flood events to determine what the quality was when the flow in the Berg River exceeds at least 6 m^3/s.
- End-season floods - To characterise the water quality in the Berg River at Zonquasdrift during a flood event at the end of the rainfall season.

2.2 BASELINE SURVEY

End-of-dry season water samples were collected on the 18th of May 2011 at G1H020 (Berg at Dal Josafat) just upstream of the Lang street bridge over the Berg River, G1H036 (Berg at Hermon) and G1H079 (Berg at Zonquasdrift).

Duplicate water samples (two simultaneous samples at each of three locations) were collected for analysis, one set was sent to the WCDM Laboratory at Withoogte and one set was sent to CCT Scientific Services laboratory at Athlone. These samples were analysed for the water quality constituents listed below.

2.3 FLOOD EVENT MONITORING

It was recommended that at least three flood events be sampled at Zonquasdrift (G1H079) only. One during the first floods of the season (May 2011), one midway into the rainfall season (July 2011), and one towards the end of the rainfall season (end of August or early September 2011).

A sampling objective was to collect water samples more frequently during the rising limb of a flood to determine if there was a first flush effect and fewer samples during the receding limb of the flood. An analysis was done of historical flood events to determine the typical magnitude of early season flood events, and the travel time between G1H020 and G1H036/G1H079 to determine when samplers should start collecting samples, and the typical duration of the rising limb of a flood.

An analysis of flood events in 2009 and 2010 showed that early winter flows were generally below 7 m^3/s and that the discharge would rise above this level during the first flood. It was recommended that the trigger value for an early season flood be set at 7 m^3/s as measured at G1H020 (Paarl). The travel time between Paarl (G1H020) and Zonquasdrift (G1H079) for a small early season flood was calculated to be about 24 hrs. This was used give the samplers at Swartland Water Treatment Works sufficient warning to prepare for sample collection when the flood arrives (refer to sampling logistics below).

2.4 MONITORING VARIABLES

Online monitoring

The DWA has online flow and water quality recording equipment installed at G1H020 (Berg at Dal Josafat), G1H036 (Berg at Hermon) and G1H079 (Berg at Zonquasdrift). Flow, electrical conductivity and water temperature is recorded continuously at these gauges and sent via a scada or cell phone system to the DWA Western Cape Regional Office.

Chemical and microbial analysis

Table 1: Constituents the water samples were analysed for by the City of Cape Town and the Western Cape District Municipality

Constituent	Motivation
Electrical conductivity	Electrical conductivity is an indicator of salinity. Salinisation refers to the build-up of salts in a river system. This is a particular concern to irrigation farmers because it affects crop yield of salt sensitive crops. At very high levels it affects the palatability of drinking water.
Ortho-phosphate	The enrichment of rivers and dams with plant nutrients leads to excessive growth of rooted and free-floating aquatic plants and algae. It is a concern to irrigation farmers where aquatic plants block irrigation equipment and algal blooms cause taste and odour problems in water treated for drinking water purposes. It was recommended that the methods employed to analyse the phosphate concentrations have a detection limit below 0.1 mg/l. The historical mean PO_4-P concentration at G1H036 was 0.168mg/l (Standard deviation of 0.088 mg/l).
Total phosphate	Total phosphate is the sum of the dissolved phosphates and the particulate phosphates in a water sample. The particulate phosphate can be phosphates adhered onto sediment particles, algae or organic matter in the water. This is generally unavailable for algal growth. However, when the water is transferred into a dam like Voëlvlei Dam, organic matter can decay releasing P into the water column, or dissociate from sediment participles and becoming available for algal growth. Total-P is an indication of the P that can potentially be available for algal growth.
Nitrate-nitrite nitrogen	Nitrate plus nitrite nitrogen is also a plant nutrient and excessive concentrations can lead to eutrophication problems. It was recommended that the methods employed to analyse the nitrate plus nitrite nitrogen concentrations have a detection limit below 1.0 mg/l. The historical mean NO_3+NO_2-N concentration at G1H036 was 0.941mg/l (Standard deviation of 0.681mg/l).
Ammonium nitrogen	Ammonium nitrogen is also a plant nutrient and excessive concentrations can lead to eutrophication problems.

Constituent	Motivation
	It is highly recommended that the methods employed to analyse the nitrate plus nitrite nitrogen concentrations have a detection limit below 0.1 mg/l. The historical mean NH_4-N concentration at G1H036 was 0.046mg/l (Standard deviation of 0.0.026mg/l).
Turbidity	Turbidity is a measure of the amount of suspended material in a water sample. It provides information on how the suspended sediment loads change and is affected by floods. It also affects water clarity which is an important parameter for algae and aquatic plants that need sunlight for photosynthesis.
Total suspended solids	Total suspended solids measures the mass of suspended material in the water. TSS is known to increase during floods and is related to turbidity.
Escherichia coli	E.coli is a measure of the microbial water quality of the Berg River. Poor microbial water quality of a river can lead to high incidents of water borne diseases in people using the water without treatment or contact recreation users. Farmers are concerned about polluted irrigation water because it affects their ability to secure certification to export their products to Europe. It was recommended that the Colilert™ method be used for the analysis of the microbial water samples because the DWA, City of Cape Town, and Drakenstein Municipality have standardised on the Colilert™ method for detecting E.coli.
Dissolved organic carbon	Dissolved organic carbon is an indicator of the amount of organic material in the water. Organic matter consumes oxygen when it decomposes and large concentrations in the transfer water can have an impact on the dissolved oxygen concentrations in Voëlvlei Dam. It also affects water treatment processes.

2.5 SAMPLING LOGISTICS

Baseline survey – it was recommended that water samples be collected in April or early May, and on a Sunday or Monday morning when no or little irrigation releases are generally made. This represented the most vulnerable state for the river when the least dilution of point source discharges was available. The sampling design called for a duplicate set of samples to be collected for chemical and microbial analysis at G1H020 in Paarl, G1H036 at Hermon and G1H079 at Zonquasdrift (Appendix D). One set of samples was sent to Withoogte, and one set to the Scientific Services laboratories of the City of Cape Town.

Table 2: Protocol followed to initiate a sampling event

Action	Responsibility
Identification of potential flood events based on the weather forecast.	Aurecon
Giving advance warning to samplers at the Swartland WTW that a flood is expected and that sampling may be required.	Aurecon to inform WCDM representative
Track the real-time flood hydrograph at G1H020, SMS notification when flow exceeds the trigger value (7 m^3/s for first flood)	DWA arrange SMS notification

	Aurecon track flow online
If a flood event is confirmed, activate sampling at Zonquasdrift by providing samplers at Swartland WTW with a schedule when sampling should start, how many samples should be collected, and at what sampling intervals.	Aurecon to inform WCDM representative
Collection of duplicate sets of water samples at Zonquasdrift at the scheduled times. Refer to the sampling collection protocol below.	WCDM representative Swartland WTW staff
Transport one set of water samples to the Withoogte Laboratory for chemical and microbial analysis of the samples. Transport the other set of water samples to the City of Cape Town WTW at Voëlvlei Dam for transport to Scientific Services laboratory in Cape Town for chemical and microbial analysis of the samples.	WCDM representative to arrange transport City of Cape Town to arrange transport
Send the analysis results to the Aurecon project team	WCDM CCT Scientific Services

2.6 WATER SAFETY

It was stressed that the collection of water samples during floods could be dangerous for samplers (Appendix D). It was recommended that samplers be equipped with a sample collection staff (refer to sampling protocol below) or bucket to allow them not to venture too close to the rapidly flowing water in the river. Samplers were also instructed to wear life jackets when sampling during flood events. All water samples were collected from the river bank and samplers were instructed not to wade into the river to collect the water samples. The samplers were instructed to work in pairs, and that they have cell phones or two-way radios with them when sampling.

2.7 COLLABORATING ORGANISATIONS

Table 3: Collaborating organisations

Organisation	Envisaged role and responsibility
Department of Water Affairs Western Cape Regional Office	Recoding of real time flow and electrical conductivity data at the following gauging weirs • G1H020 (Berg River Dal Josafat) • G1H036 (Berg River at Hermon) • G1H079 (Berg River at Zonquasdrift) SMS notification when flow exceeds trigger value (7 m^3/s).
West Coast District Municipality	Samplers from Swartland WTW to collect water samples at Zonquasdrift Transport of water samples to the Withoogte Treatment works laboratory Chemical analysis of water samples at the Withoogte laboratory
City of Cape Town Scientific Services	Transport of water samples to the CCT Scientific Services laboratory Chemical analysis of water samples at the CCT Scientific Services laboratory
Aurecon	Design of the sampling programme Sample coordination

	Interpretation and reporting of sampling results

3. RESULTS

3.1 FLOOD MONITORING

The aim of the flood monitoring was to collect water samples early in the rainfall season (May), in the middle of the rainfall season (end July/early August), and late in the rainfall season (end September/early October).

The water heights recorded at G1H079 – Berg River at Zonquasdrift during the winter rainfall season of 2011 is illustrated in FIGURE. The days on which samples were collected are also presented. The team managed to sample the second flood in the Berg River at the end of May (31 May to 2 June) and a flood early in August (5 – 9 August 2011) (Figure 1). The intention was to sample a flood late in September or early October but such a flood never materialised and this component of the project was therefore terminated at the end of October.

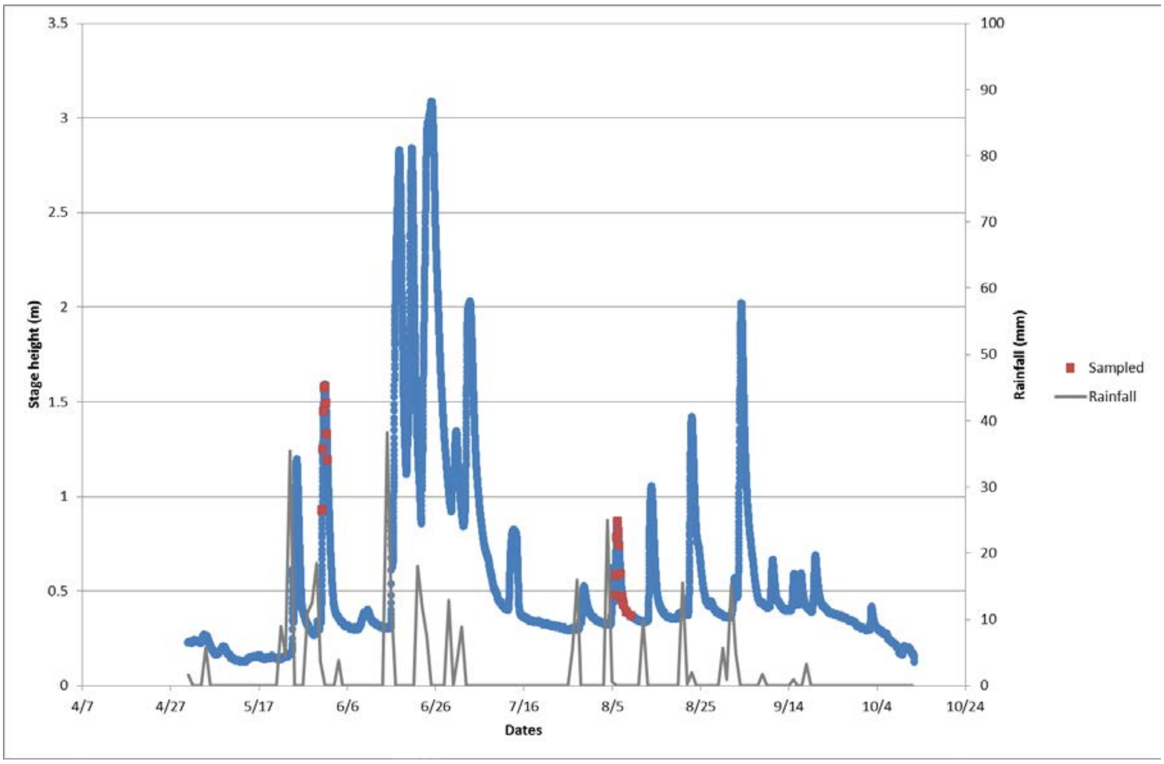


Figure 1: Time series plot stage heights recorded at G1H079 – Berg River at Zonquasdrift, and rainfall recorded at Voëlvlei Dam, and the two flood events that were sampled.

The sampling team collected water samples during the rising limb and the receding limb of the flood that took place at the end of May 2011 but the sampling was terminated too early (Figure 2). The sampling strategy was modified for the August 2011 flood to sample for a longer period after the peak has passed.

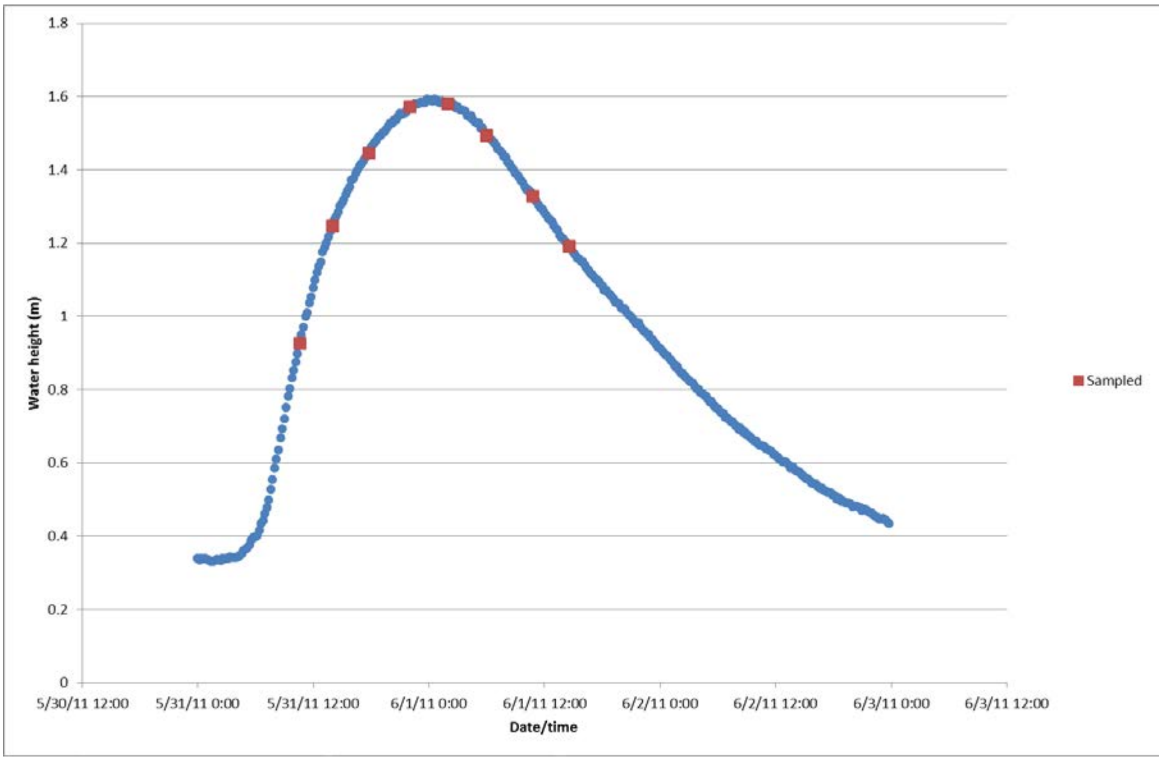


Figure 2: Hydrograph of the flood at the end of May 2011 showing the times water samples were collected.

In the August 2011 flood the sampling team managed to collect samples during the rising limb of the flood and to after the receding limb of the flood (Figure 3).

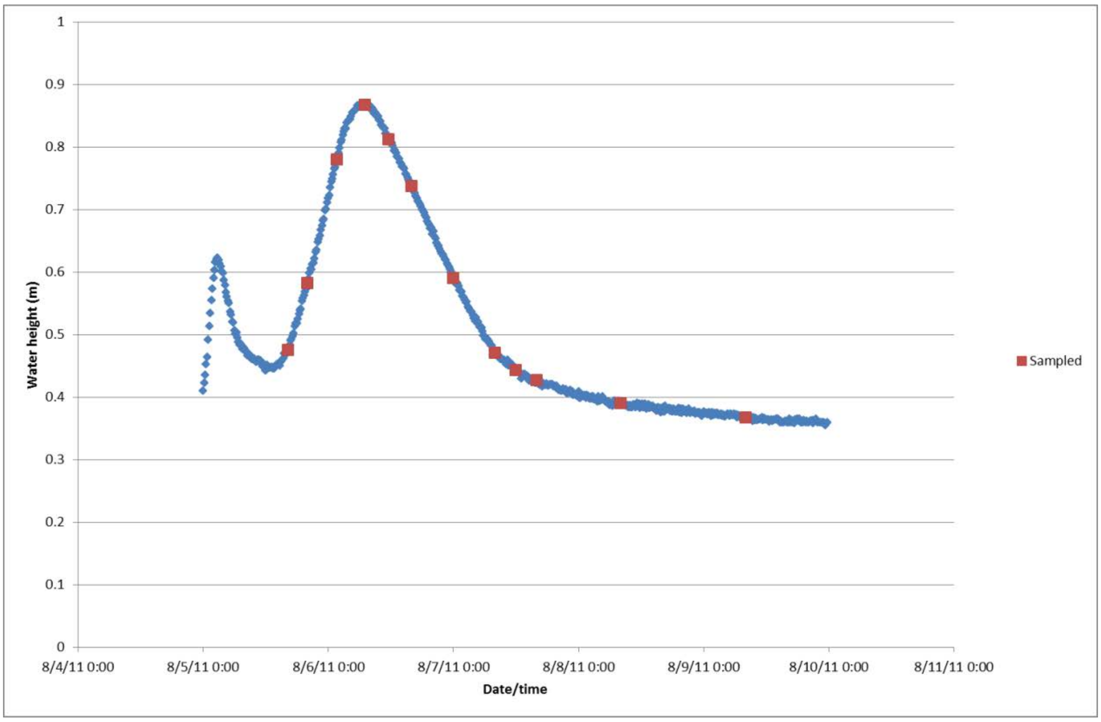


Figure 3: Hydrograph of the flood at early in August 2011 showing the times water samples were collected.

The graphs () show the stage height (m) recorded at G1H079 (Berg River at Zonquasdrift). It was the intention to show the change in quality with a change in flow (m^3/s) but the rating curve for G1H079 only goes up to a stage height of 0.6m or 17.86 m^3/s as illustrated in Figure 4. It was therefore not possible to estimate constituent loads as part of this project.

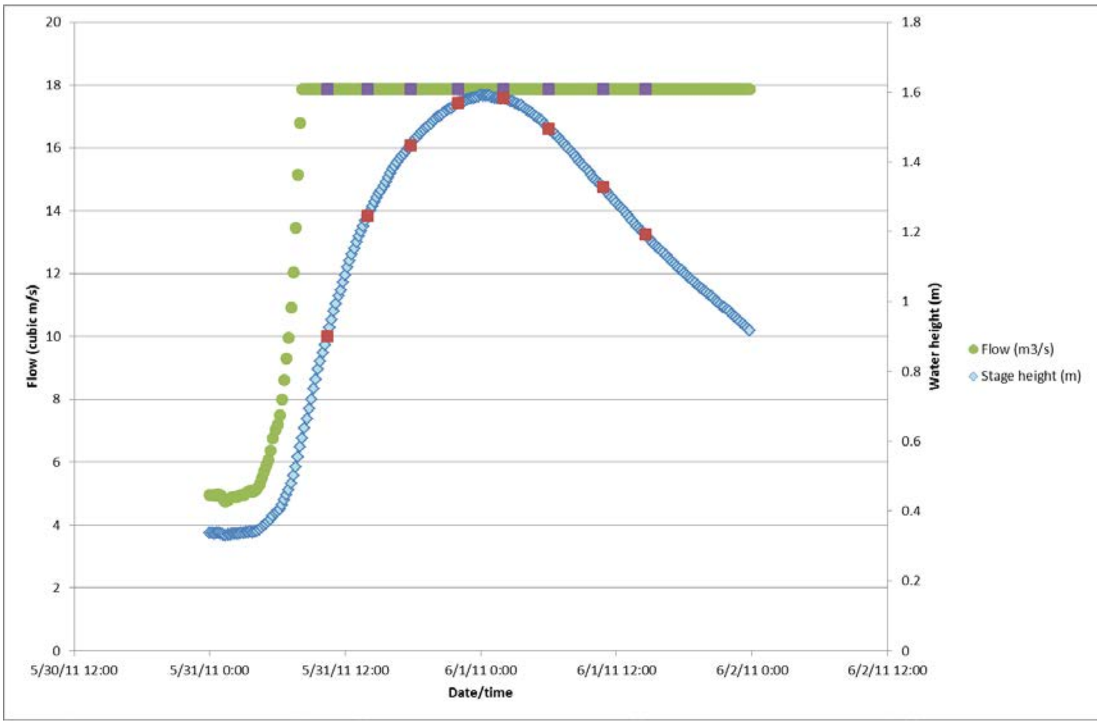


Figure 4: Flood hydrograph of stage height and the flow derived from the stage height: discharge relationship. The stage height: discharge relationship was only determined up a height of 0.6m.

3.2 WATER CHEMISTRY

The monitoring was design to explore two aspects of the behaviour of water quality in the Berg River during the rainfall season:

- Change in quality during a flood to determine if there was a peak in pollution that should be avoided when transferring water to Voëlvlei Dam, and
- Changes in quality over the winter rainfall season to determine if the early season runoff should be avoided because the quality may be poorer than later in the season.

The full chemical and microbiological analysis results are presented in Appendix A.

3.3 CHANGE IN QUALITY DURING A FLOOD

Conventional thinking on the change in quality during a flood is that the concentration starts out low in the rising limb of a flood, increases rapidly as constituents are washed off the catchment, and during the receding limb of the flood, the concentration starts decreasing again. A hysteresis effect is also sometimes evident. That is, for the same flow, a higher concentration is recorded during the rising limb of a flood that during the receding limb of the flood (Figure 5).

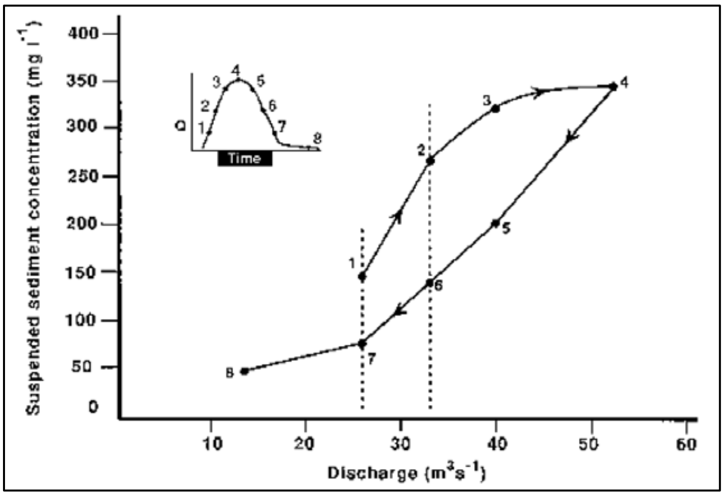


Figure 5: A typical hysteresis effect observed in suspended sediment sampling (Bartram and Ballance, 1996)

Time series plots of all the constituents were prepared and are presented in Appendix B and C. During an examination of the change in water quality during a flood, we found that there was no significant increase during the rising limb of the flood but that, in general, concentrations decreased as the flood passed by Zonquasdrift.

3.3.1 Electrical conductivity

In both floods the salinity, measured as electrical conductivity, were reduced during the flood rather than increasing during the rising limb and decreasing during the receding limb of the flood (Figure 6).

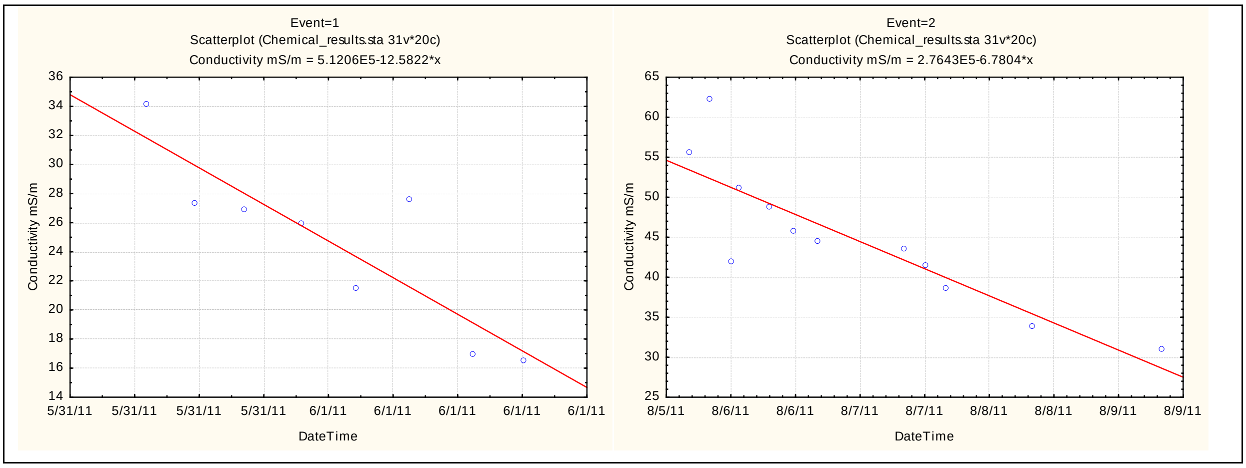


Figure 6: Electrical conductivity (mS/m) recorded at G1H079 (Zonquasdrift) during the May/June 2011 flood (Event 1) and the August 2011 flood (Event 2)

3.3.2 Aluminium

During the May/June 2011 flood the aluminium concentrations display a step change – Al concentrations were low during the rising limb of the flood. It then increased rapidly and then remained constant during the receding limb of the flood. During the August flood there was a constant decrease in Al concentrations during the rising and the receding limbs of the flood (Figure 7). The laboratory measures total Aluminium which includes Al adhered onto sediment particles. The step increase coincided with a step increase in turbidity. The increase in Al was probably the result of an increase in fine sediment particles (turbidity).

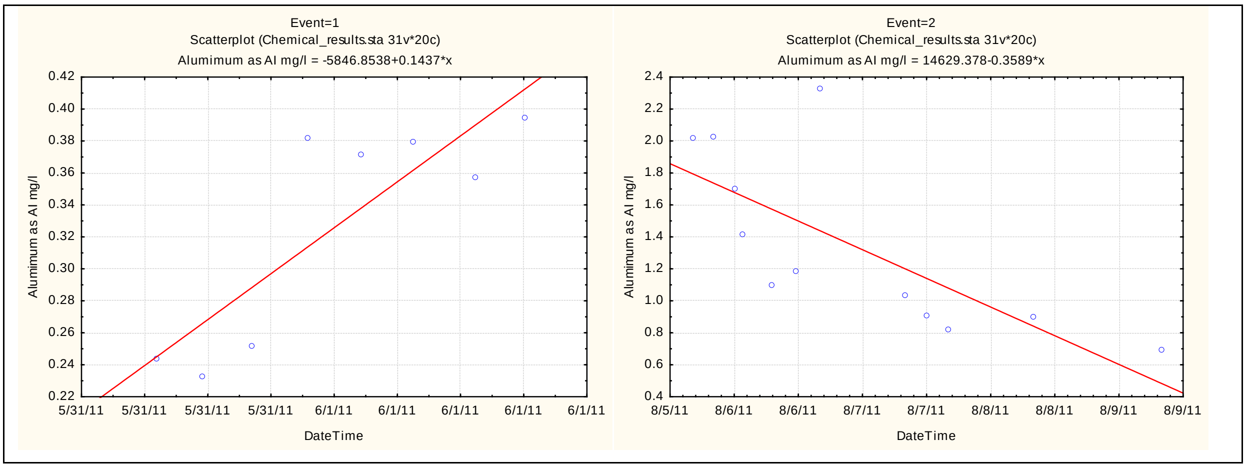


Figure 7: Aluminium concentrations (mg/l) recorded at G1H079 (Zonquasdrift) during the May/June 2011 flood (Event 1) and the August 2011 flood (Event 2)

3.3.3 Iron

Iron displayed the same patterns as aluminium, Fe concentrations were low during the rising limb of the flood. It then increased rapidly and then started to drop again during the receding limb of the flood. During the August flood there was a constant decrease in Fe concentrations during the rising and receding limbs of the flood (Figure 8).

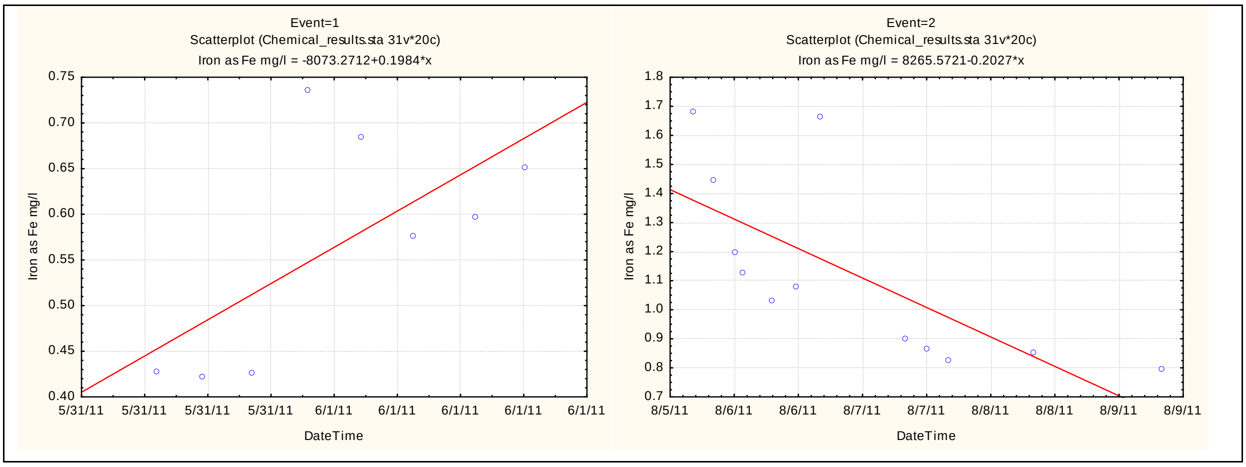


Figure 8: Iron concentrations (mg/l) recorded at G1H079 (Zonquasdrift) during the May/June 2011 flood (Event 1) and the August 2011 flood (Event 2)

3.3.4 Nitrogen

Nitrogen concentrations displayed a constant decrease during May/June flood but during the August flood it first increased during the rising limb o the flood and then decreased during the receding limb of the flood (Figure 9).

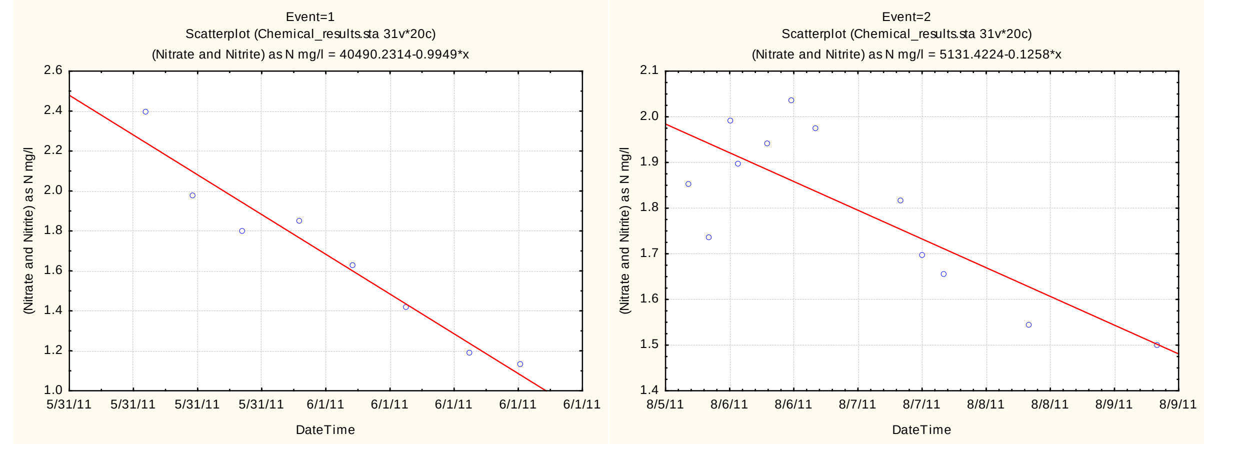


Figure 9: Nitrogen concentrations (mg/l) recorded at G1H079 (Zonquasdrift) during the May/June 2011 flood (Event 1) and the August 2011 flood (Event 2)

3.3.5 Phosphate

Phosphate concentrations creased during the flood of May/June 2011. During the August flood there appeared to be a drop in concentration and during the receding limb of the flood concentrations started to increase again (Figure 10).

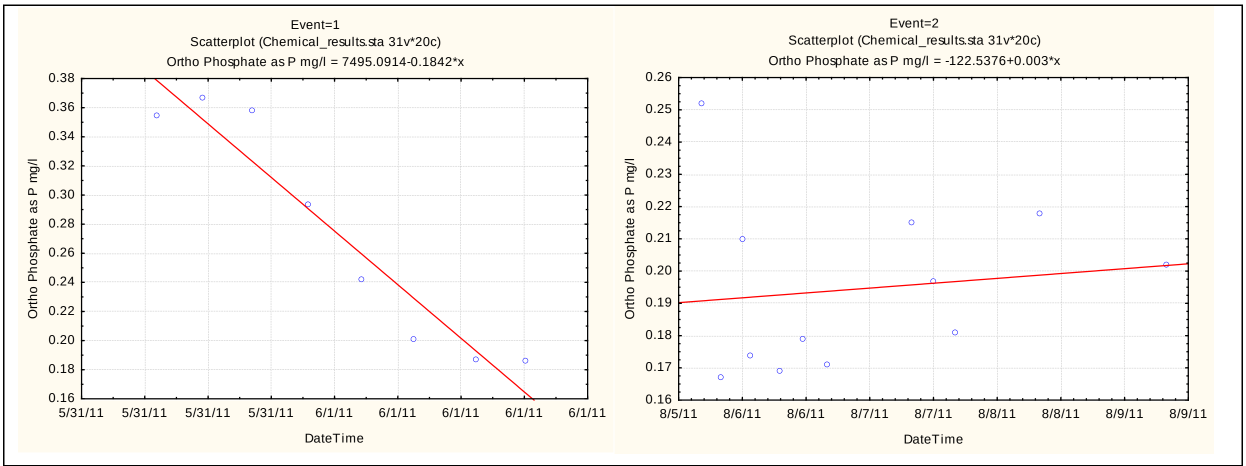


Figure 10: Phosphate concentrations (mg/l) recorded at G1H079 (Zonquasdrift) during the May/June 2011 flood (Event 1) and the August 2011 flood (Event 2)

3.3.6 Suspended solids

During the May/June 2011 flood, suspended solids concentrations reduced during the rising limb of the flood, but the rate of decrease slowed down after the peak of the flood passed by. During the August flood, the concentrations decreased throughout the flood (Figure 11).

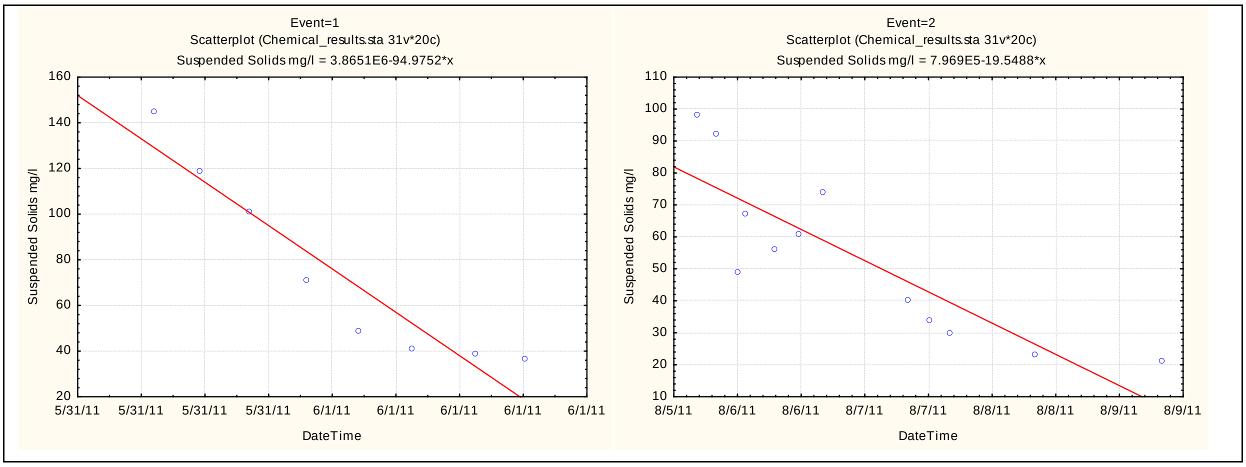


Figure 11: Suspended sediment concentrations (mg/l) recorded at G1H079 (Zonquasdrift) during the May/June 2011 flood (Event 1) and the August 2011 flood (Event 2)

3.3.7 E.coli

During the May/June flood there appeared to be an initial drop in E. coli counts during the rising limb of the flood, there was then an increase up to the flood peak and it then started to decrease again. During the August flood there was an initial drop in E. coli counts during the rising limb of the flood followed by a slow decease in counts during the receding limb of the flood (Figure 12).

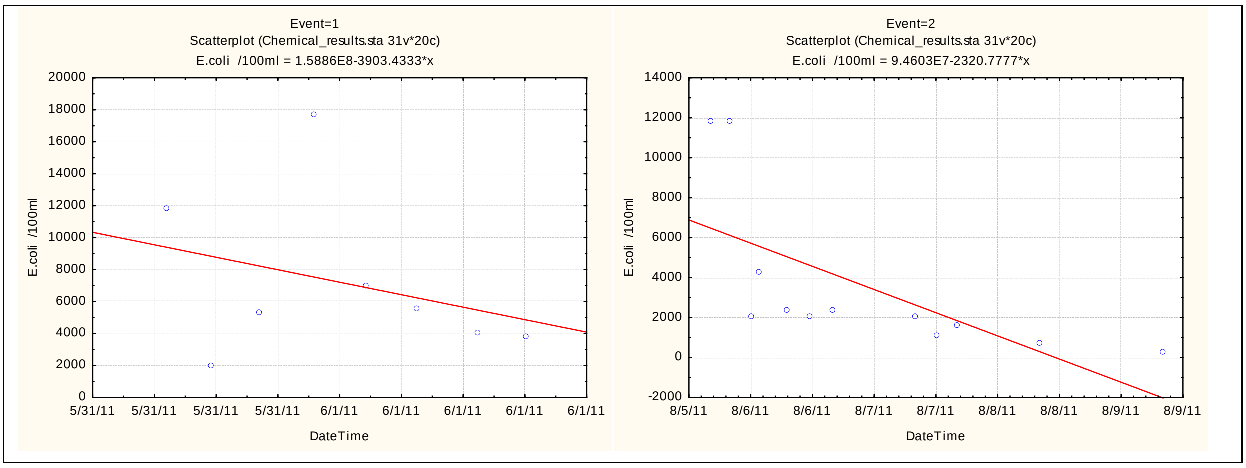


Figure 12: E coli counts (counts/100ml) recorded at G1H079 (Zonquasdrift) during the May/June 2011 flood (Event 1) and the August 2011 flood (Event 2)

3.4 CHANGE IN QUALITY OVER THE 2011 RAINFALL SEASON

The expectation was that in general, concentration would be high during the early part of the rainfall season and it would decrease as the season progresses and the system is flushed with rain water.

3.4.1 Electrical conductivity

The salinities recorded during the August flood were higher than those observed during the May/June flood (Figure 13).

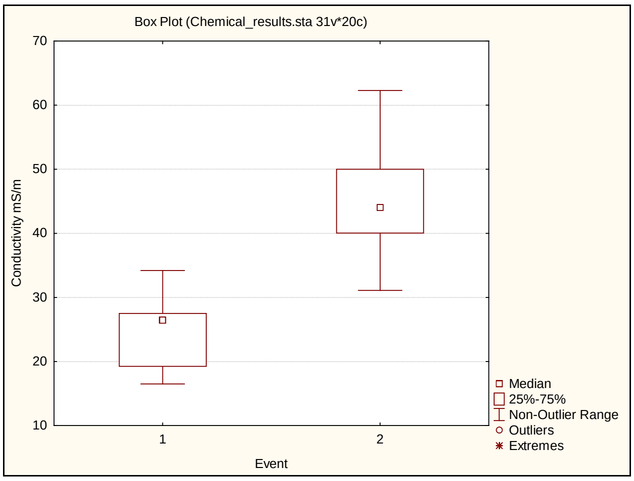


Figure 13: Box-and-whisker plot of electrical conductivity (mS/m) recorded during the May/June 2011 flood and during the August 2011 flood at G1H079

3.4.2 Aluminium

Aluminium concentrations were substantially higher during the August flood when compared to the May/June flood (Figure 14).

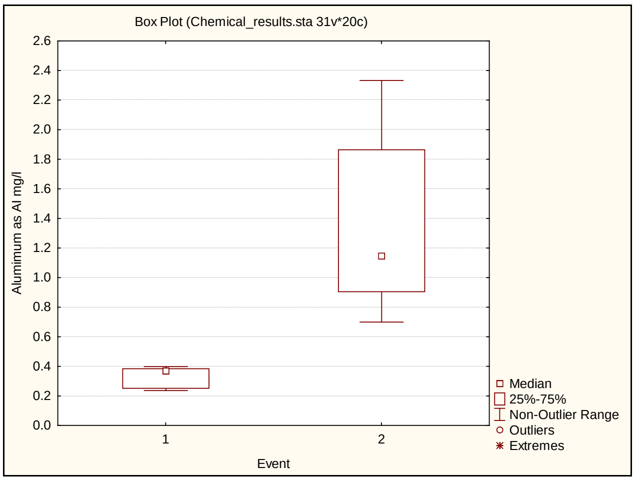


Figure 14: Box-and-whisker plot of aluminium concentrations (mg/l) recorded during the May/June 2011 flood and during the August 2011 flood at G1H079

3.4.3 Iron

Iron concentrations displayed a pattern similar to aluminium with much higher concentrations being observed during the August flood in comparison with the May/June flood (Figure 15).

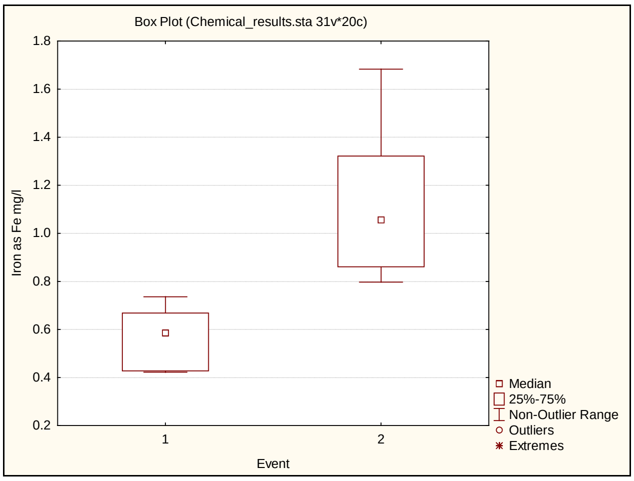


Figure 15: Box-and-whisker plot of iron concentrations (mg/l) recorded during the May/June 2011 flood and during the August 2011 flood at G1H079

3.4.4 Nitrogen

Although the median dissolved nitrogen concentrations were not that different between the floods, the variability (size of the box) in dissolved nitrogen concentrations during the May/June flood was much greater than the variability observed during the August flood (Figure 16). Higher N concentrations were therefore observed during the August floods.

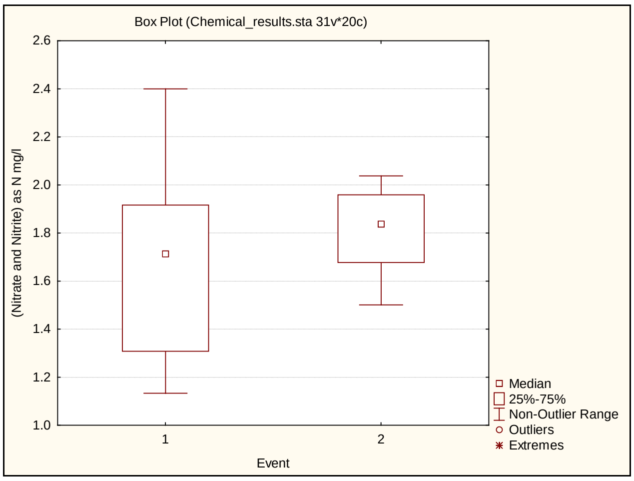


Figure 16: Box-and-whisker plot of nitrate + nitrite - nitrogen concentrations (mg/l) recorded during the May/June 2011 flood and during the August 2011 flood at G1H079

3.4.5 Phosphate

Higher phosphate concentrations were observed during the May/June 2011 flood than during the August 2011 flood. The concentrations in the May/June flood were also much more variable than during the flood later in the season (Figure 17).

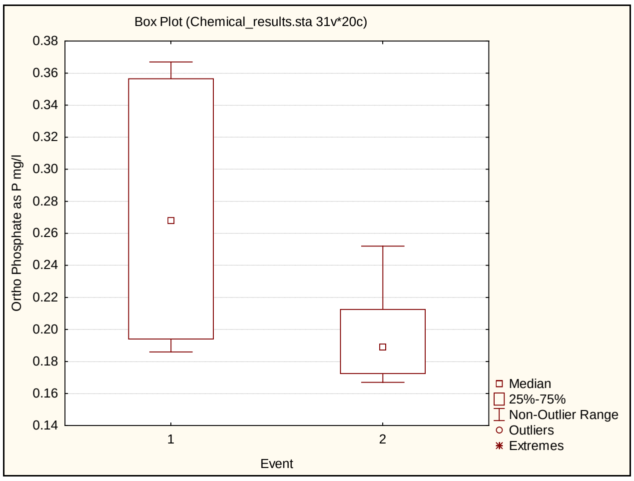


Figure 17: Box-and-whisker plot of ortho-phosphate concentrations (mg/l) recorded during the May/June 2011 flood and during the August 2011 flood at G1H079

3.4.6 Suspended solids

Suspended solids concentrations were higher and more variable during the May/June flood than during the August flood (Figure 18).

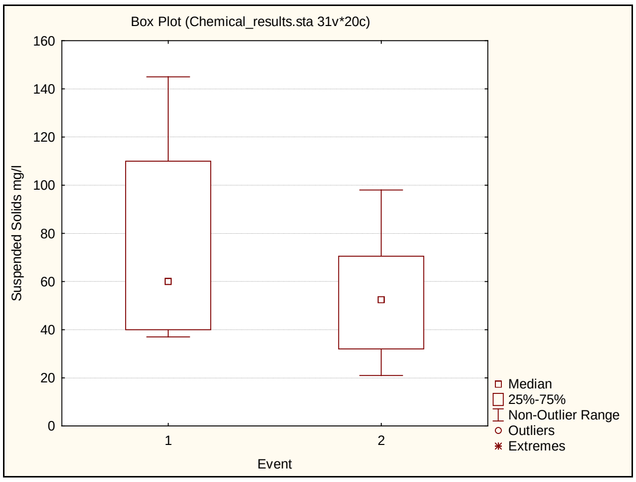


Figure 18: Box-and-whisker plot of suspended solids concentrations (mg/l) recorded during the May/June 2011 flood and during the August 2011 flood at G1H079

3.4.7 E.coli

E.coli counts were higher and more variable during the May/June flood than during the August flood (Figure 19).

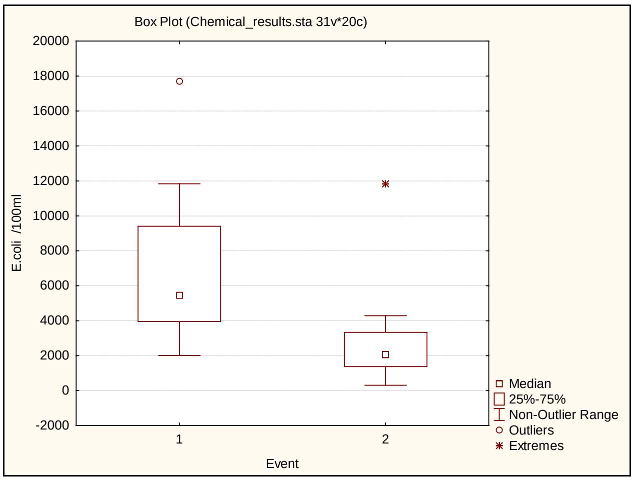


Figure 19: Box-and-whisker plot of E.coli (counts/100 ml) recorded during the May/June 2011 flood and during the August 2011 flood at G1H079

4. DISCUSSIONS AND CONCLUDING REMARKS

The fact that conservative substances (constituents such as sodium and chloride) increase from low concentrations early in the rainfall season to higher concentrations later in the rainfall season is a well-known phenomenon in the middle and lower Berg River. The reason for this is that Malmesbury shales dominate in the catchment downstream from about Wellington. These soils leach salts during the rainfall season resulting in an increase in concentrations as the rainfall season progresses. The same trend is true for nitrogen. Non-conservative substances and nitrogen concentrations are controlled by non-point source, catchment processes during the winter rainfall season.

Phosphates concentrations and E.coli counts on the other hand decrease during the rainfall season, following a pattern that is typically associated with point source processes. Phosphates from upstream WWTW's are high at the end of the dry season when there is little dilution of the wastewater effluent. The same true for E.coli from dry-weather storm water inflows into the Berg River. An increase in flow dilutes the phosphate concentrations and E.coli counts, resulting in lower concentrations as the rainy season progresses.

It is not clear whether there is a first flush effect that should be avoided. It is clear that phosphates and bacterial are high early in the season due to point source inputs but the concentrations are quickly halved during a flood event.

At this stage there is probably not sufficient evidence of a particular period during which water transfers should be avoided.

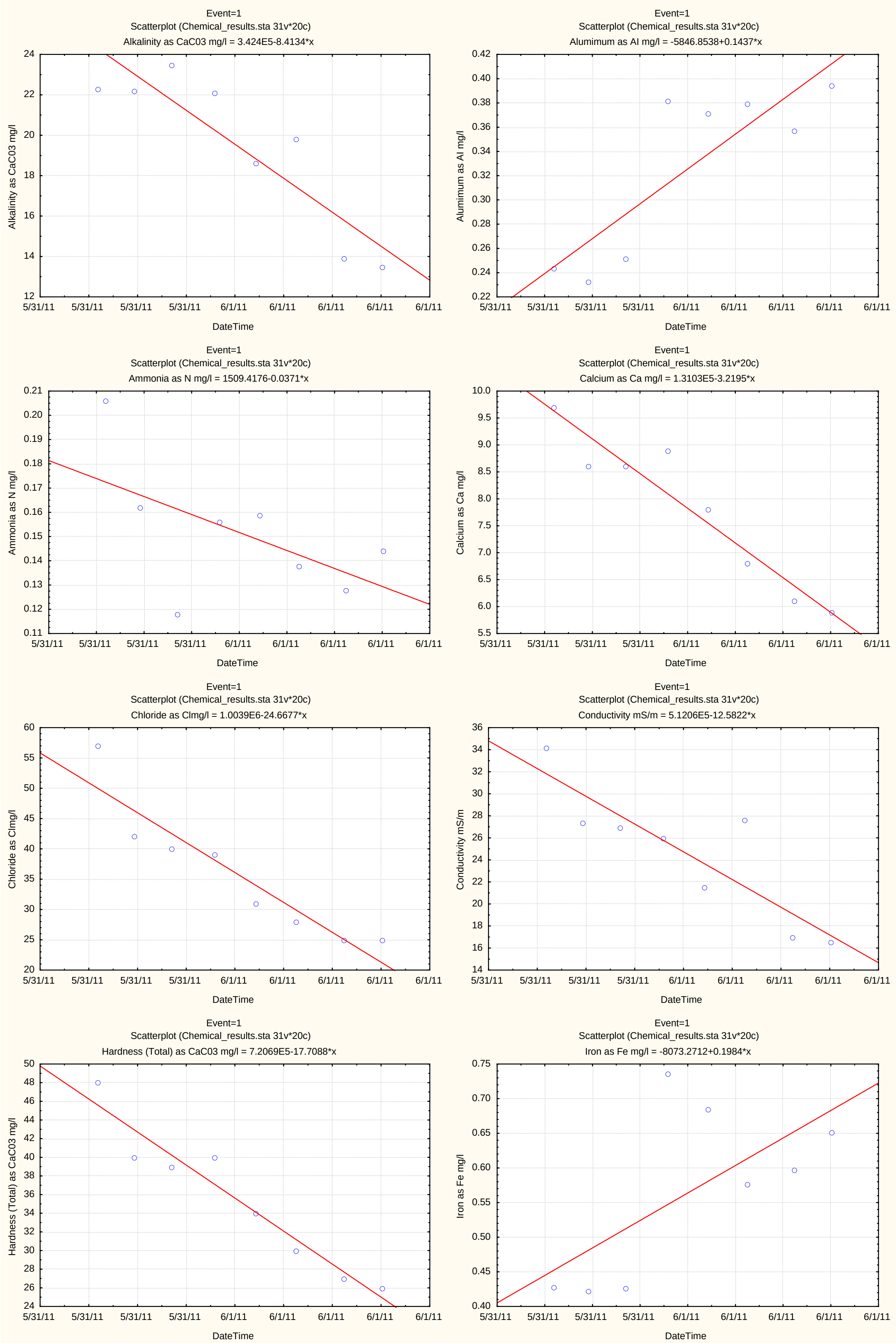
5. REFERENCES

Bartram, J., and Balance, R. (1996). Water Quality Monitoring: A practical guide to the design and implementation of freshwater quality studies and monitoring programmes. Published on behalf of UNEP and WHO. Taylor & Francis, London.

APPENDIX A
ANALYSIS RESULTS OF THE WATER SAMPLES COLLECTED IN MAY/JUNE 2011 and AUGUST 2011

DateTime	CaC03 mg/l	Al mg/l	NH4-N mg/l	Ca mg/l	Cl mg/l	Colour mg/l Pt	EC mS/m	Hardness CaC03 mg/l	Fe mg/l	Mg mg/l	Mn mg/l	NO3+NO2-'N mg/l	PO4-P mg/l	pH	K mg/l	PV4 mg/l	Na mg/l	S04 mg/l	TSS mg/l	TP mg/l	Turbid NTU	UV	Turb NTU	EC mS/m	E.coli /100ml
5/31/11 10:30	22.3	0.244	0.206	9.7	57	35	34.2	48	0.428	5.85	0.019	2.399	0.355	7.03	5.52	5.334	38.8	29	145	0.76	69.8	0.655	120	30	11840
5/31/11 14:00	22.2	0.233	0.162	8.6	42	31	27.4	40	0.422	4.5	0.019	1.981	0.367	7.15	5.03	4.538	28.4	24.8	119	0.69	60.5	0.555	83.8	25	2005
5/31/11 17:45	23.5	0.252	0.118	8.6	40	32	26.9	39	0.427	4.24	0.015	1.799	0.358	7.15	5.24	4.323	27.6	24.9	101	0.668	39.4	0.528	68.2	24	5310
5/31/11 22:00	22.1	0.382	0.156	8.9	39	32	26	40	0.736	4.25	0.045	1.85	0.294	7.14	5.12	4.586	26	24.6	71	0.546	137	0.561	102	25	17700
6/1/11 2:00	18.6	0.372	0.159	7.8	31	30	21.5	34	0.685	3.47	0.04	1.627	0.242	7.14	4.24	4.554	22	20.5	49	0.421	106	0.557	83.7	19	6970
6/1/11 6:00	19.8	0.38	0.138	6.8	28	38	27.6	30	0.576	3.1	0.031	1.422	0.201	6.83	4.21	4.45	35.2	18.3	41	0.287	75.6	0.544	59.2	18	5600
6/1/11 10:45	13.9	0.357	0.128	6.1	25	35	17	27	0.597	2.74	0.029	1.192	0.187	7.5	3.49	4.331	17	16.5	39	0.267	68.4	0.529	54.7	15	4060
6/1/11 14:30	13.5	0.395	0.144	5.9	25	36	16.5	26	0.652	2.67	0.032	1.132	0.186	7.33	3.29	4.689	16.6	15.9	37	0.264	65.6	0.574	47.4	14	3840
8/5/11 16:15	37.8	2.021	0.248	13.2	132	60	55.7	79	1.683	11.13	0.182	1.854	0.252	7.27	5.91	6.353	78.7	33.4	98	0.422	144	0.783	126	53	11840
8/5/11 20:00	39.9	2.028	0.17	14	155	53	62.3	88	1.445	12.87	0.048	1.736	0.167	7.3	5.49	5.955	90.2	36	92	0.275	135	0.733	125	59	11840
8/6/11 1:30	37.4	1.415	0.197	12.6	120	41	51.2	73	1.127	10.07	0.03	1.898	0.174	7.36	5.31	4.18	70.3	32.4	67	0.258	73	0.51	55.3	48	4290
8/6/11 7:00	38.1	1.099	0.243	12.4	110	40	48.8	70	1.032	9.38	0.029	1.942	0.169	7.38	5.41	3.997	67.5	32.6	56	0.25	55.7	0.487	48.6	46	2380
8/6/11 11:30	37.1	1.186	0.166	12.3	95	38	45.8	67	1.081	8.72	0.031	2.037	0.179	7.37	5.59	3.949	62.1	30.8	61	0.264	65.1	0.481	55.6	43	2070
8/6/11 16:00	36.9	2.33	0.142	12.1	92	39	44.5	64	1.665	8.18	0.04	1.974	0.171	7.35	5.43	3.742	57.8	27.1	74	0.269	98.1	0.455	91.9	42	2380
8/6/11 0:00	37.4	1.702	0.265	11.7	86	36	42	60	1.198	7.51	0.027	1.992	0.21	7.3	5.39	3.901	53.6	25.5	49	0.27	65.3	0.475	57.4	39	2070
8/7/11 8:00	34.6	1.034	0.264	11.9	91	34	43.6	61	0.9	7.7	0.025	1.818	0.215	7.42	5.3	3.694	57.4	26.2	40	0.264	46.7	0.449	40.2	41	2070
8/7/11 12:00	32.1	0.905	0.146	11.2	86	34	41.5	58	0.867	7.37	0.025	1.698	0.197	7.32	4.99	3.352	54.3	24.7	34	0.246	35.5	0.406	32.8	38	1110
8/7/11 16:00	29.7	0.821	0.129	10.3	81	33	38.6	54	0.827	6.92	0.024	1.655	0.181	7.33	4.74	3.463	49.3	22.6	30	0.235	30.4	0.42	25.3	36	1640
8/8/11 8:00	30	0.898	0.167	9.6	68	38	33.9	49	0.855	6.15	0.019	1.544	0.218	7.39	4.76	3.861	42.4	20.3	23	0.249	29.7	0.47	22.9	31	750
8/9/11 8:00	28.7	0.696	0.096	9.3	61	40	31.1	47	0.797	5.84	0.035	1.5	0.202	7.4	4.37	3.941	38.1	19	21	0.233	22.5	0.48	19.7	28	310

APPENDIX B
TIME SERIES PLOTS OF THE MAY/JUNE 2011 WATER CHEMISTRY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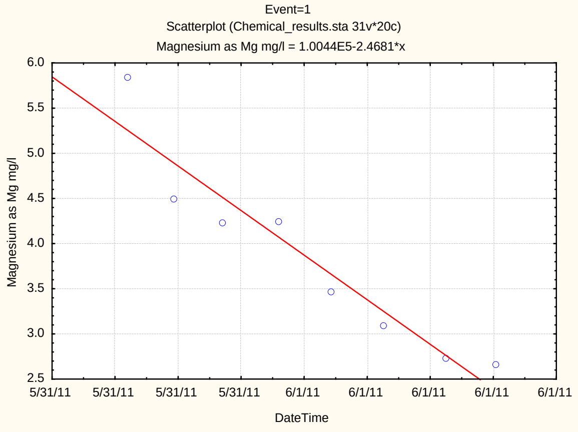
Scatterplot (Chemical_results.sta 31v*20c)
Alkalinity as CaC03 mg/l = 3.424E5-8.4134*x
Alkalinity as CaC03 mg/l
DateTime
Event=1
Scatterplot (Chemical_results.sta 31v*20c)
Alumimum as Al mg/l = -5846.8538+0.1437*x
Alumimum as Al mg/l
DateTime
Event=1
Scatterplot (Chemical_results.sta 31v*20c)
Ammonia as N mg/l = 1509.4176-0.0371*x
Ammonia as N mg/l
DateTime
Event=1
Scatterplot (Chemical_results.sta 31v*20c)
Calcium as Ca mg/l = 1.3103E5-3.2195*x
Calcium as Ca mg/l
DateTime
Event=1
Scatterplot (Chemical_results.sta 31v*20c)
Chloride as Clmg/l = 1.0039E6-24.6677*x
Chloride as Clmg/l
DateTime
Event=1
Scatterplot (Chemical_results.sta 31v*20c)
Conductivity mS/m = 5.1206E5-12.5822*x
Conductivity mS/m
DateTime
Event=1
Scatterplot (Chemical_results.sta 31v*20c)
Hardness (Total) as CaC03 mg/l = 7.2069E5-17.7088*x
Hardness (Total) as CaC03 mg/l
DateTime
Event=1
Scatterplot (Chemical_results.sta 31v*20c)
Iron as Fe mg/l = -8073.2712+0.1984*x
Iron as Fe mg/l
DateTime


Event=1
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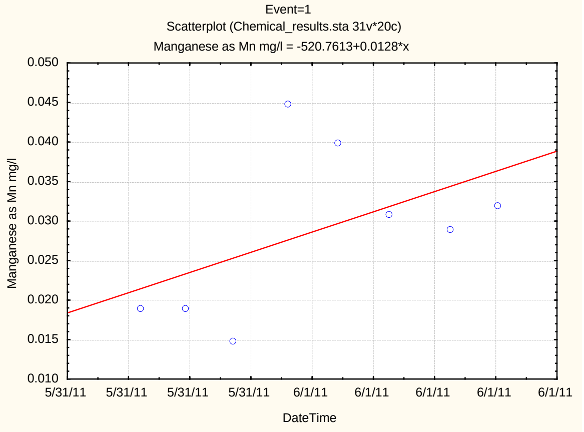
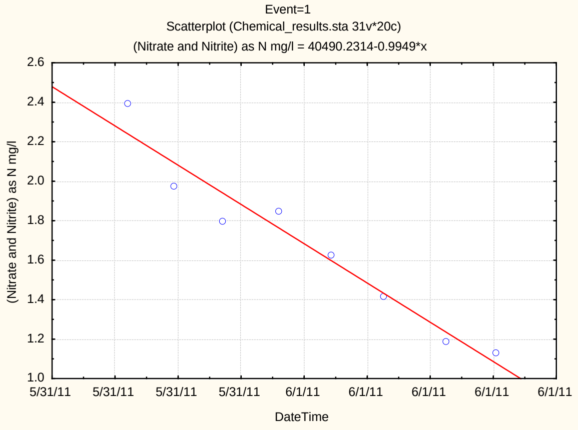
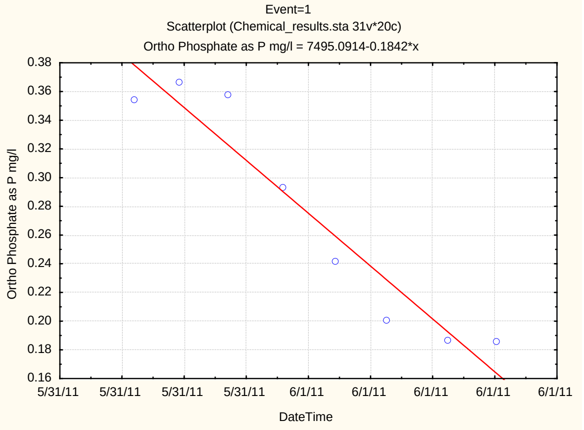
Magnesium as Mg mg/l = 1.0044E5-2.4681*x
Magnesium as Mg mg/l
DateTime


Event=1
Scatterplot (Chemical_results.sta 31v*20c)
Manganese as Mn mg/l = -520.7613+0.0128*x
Manganese as Mn mg/l
DateTime


Event=1
Scatterplot (Chemical_results.sta 31v*20c)
(Nitrate and Nitrite) as N mg/l = 40490.2314-0.9949*x
(Nitrate and Nitrite) as N mg/l
DateTime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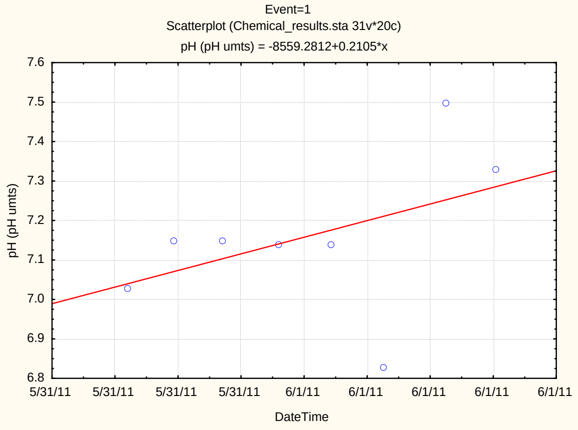
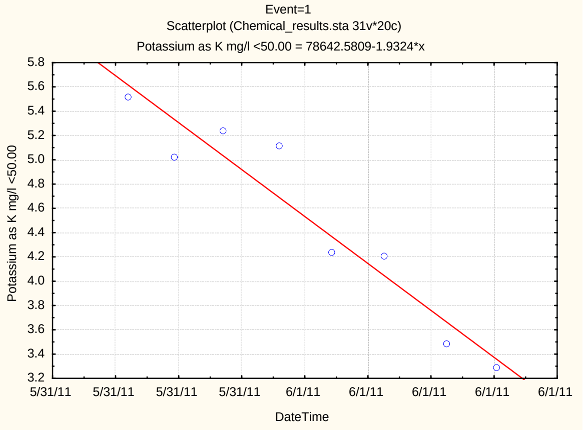
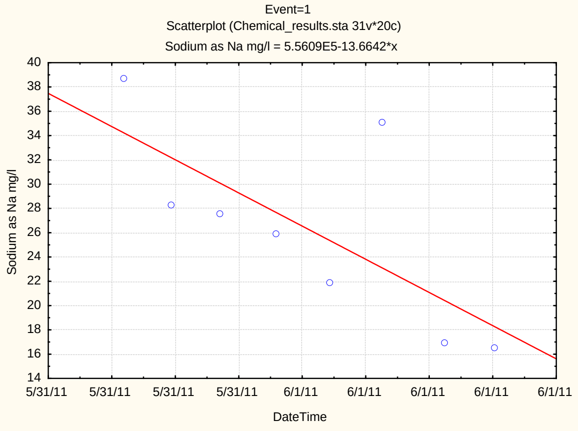
Scatterplot (Chemical_results.sta 31v*20c)
Ortho Phosphate as P mg/l = 7495.0914-0.1842*x
Ortho Phosphate as P mg/l
DateTime


Event=1
Scatterplot (Chemical_results.sta 31v*20c)
pH (pH umts) = -8559.2812+0.2105*x
pH (pH umts)
DateTime


Event=1
Scatterplot (Chemical_results.sta 31v*20c)
Potassium as K mg/l <50.00 = 78642.5809-1.9324*x
Potassium as K mg/l <50.00
DateTime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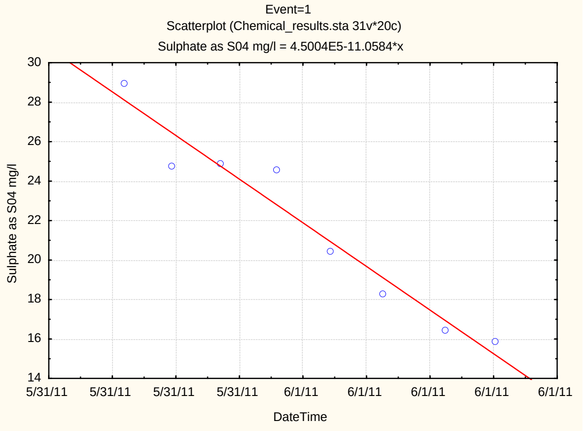
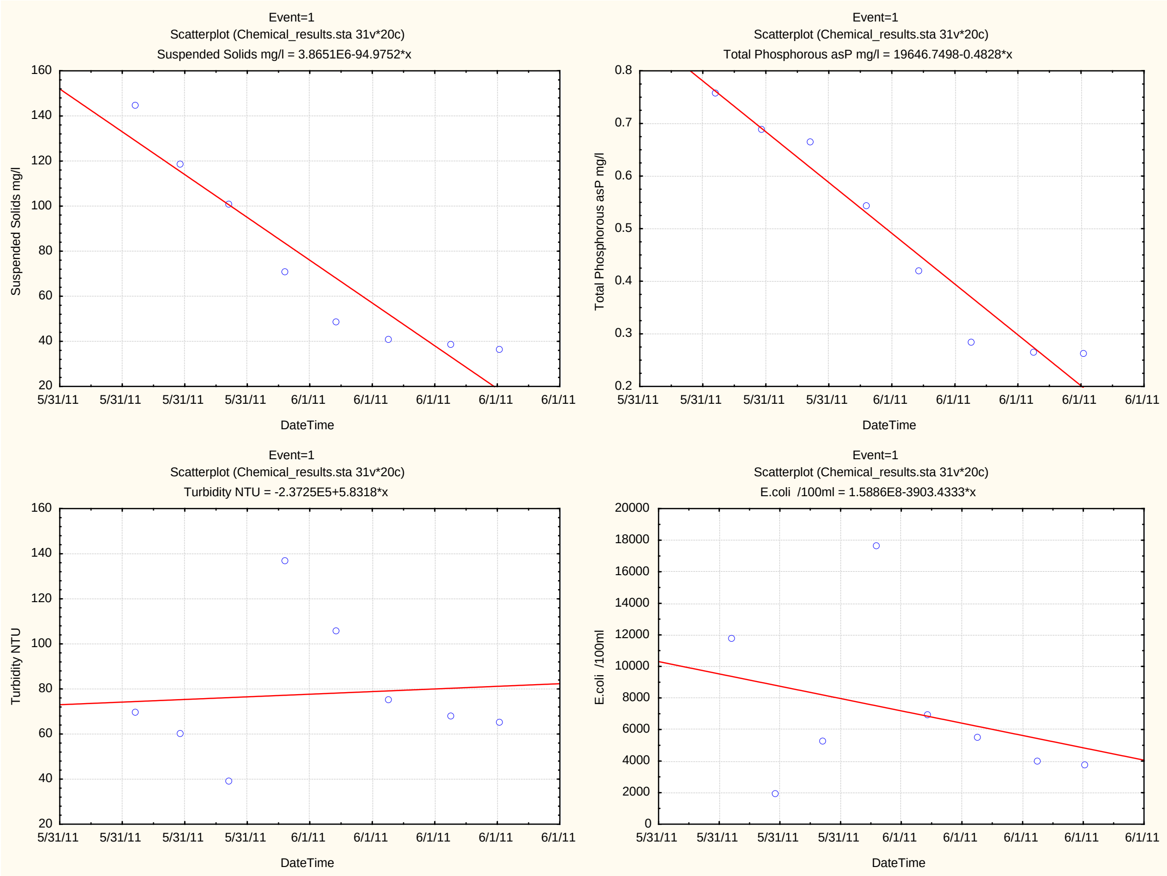
Sodium as Na mg/l = 5.5609E5-13.6642*x
Sodium as Na mg/l
DateTime


Event=1
Scatterplot (Chemical_results.sta 31v*20c)
Sulphate as S04 mg/l = 4.5004E5-11.0584*x
Sulphate as S04 mg/l
DateTime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Suspended Solids mg/l = 3.8651E6-94.9752*x
Suspended Solids mg/l
DateTime
Event=1
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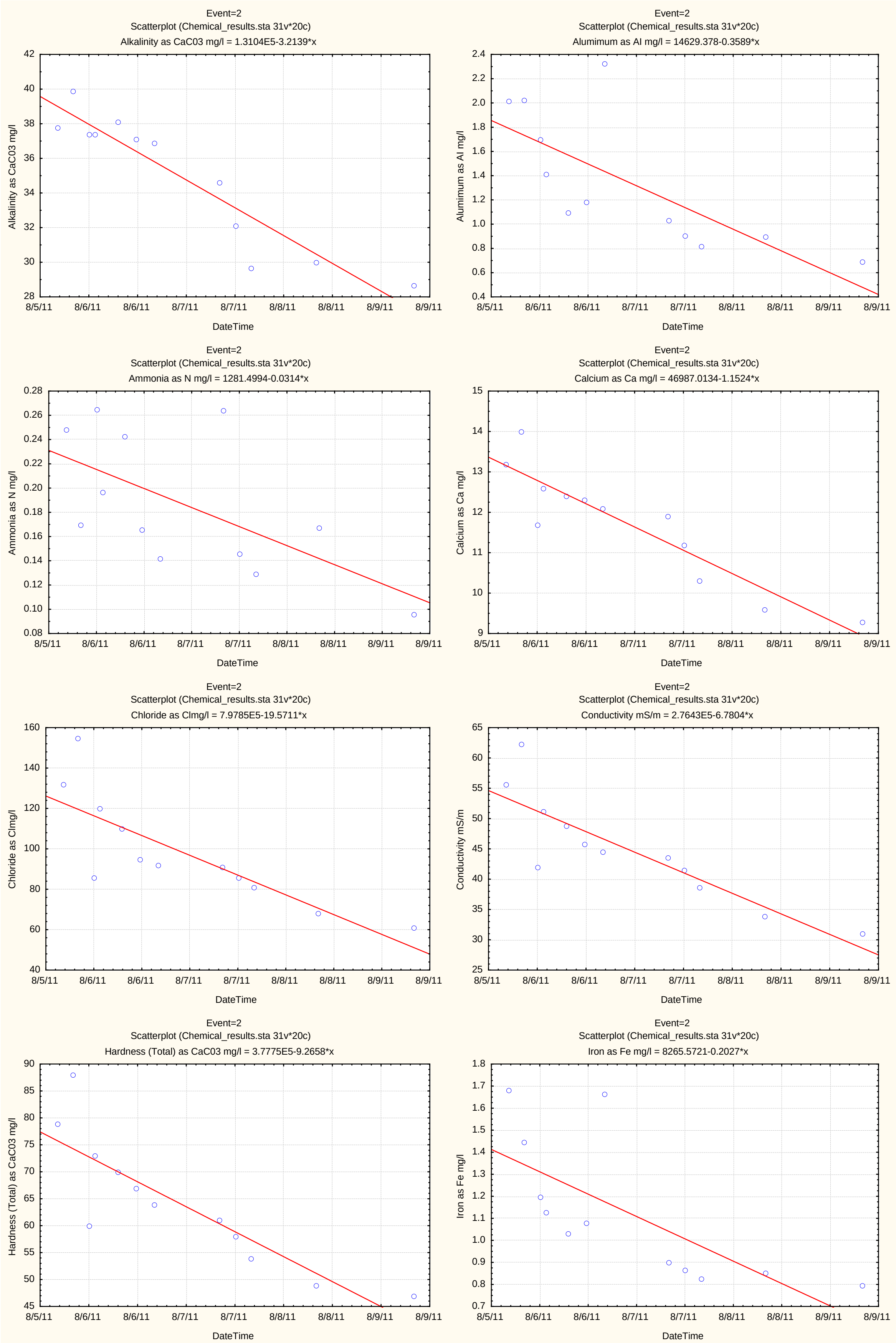
Total Phosphorous asP mg/l = 19646.7498-0.4828*x
Total Phosphorous asP mg/l
DateTime
Event=1
Scatterplot (Chemical_results.sta 31v*20c)
Turbidity NTU = -2.3725E5+5.8318*x
Turbidity NTU
DateTime
Event=1
Scatterplot (Chemical_results.sta 31v*20c)
E.coli /100ml = 1.5886E8-3903.4333*x
E.coli /100ml
DateTime

APPENDIX C

TIME SERIES PLOTS OF THE AUGUST 2011 WATER CHEMISTRY


Event=2
Scatterplot (Chemical_results.sta 31v*20c)
Alkalinity as CaC03 mg/l = 1.3104E5-3.2139*x
Alkalinity as CaC03 mg/l
DateTime
Event=2
Scatterplot (Chemical_results.sta 31v*20c)
Alumimum as Al mg/l = 14629.378-0.3589*x
Alumimum as Al mg/l
DateTime
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Ammonia as N mg/l = 1281.4994-0.0314*x
Ammonia as N mg/l
DateTime
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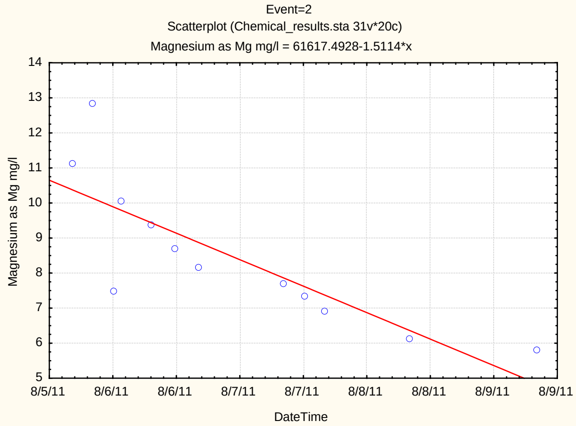
Calcium as Ca mg/l = 46987.0134-1.1524*x
Calcium as Ca mg/l
DateTime
Event=2
Scatterplot (Chemical_results.sta 31v*20c)
Chloride as Clmg/l = 7.9785E5-19.5711*x
Chloride as Clmg/l
DateTime
Event=2
Scatterplot (Chemical_results.sta 31v*20c)
Conductivity mS/m = 2.7643E5-6.7804*x
Conductivity mS/m
DateTime
Event=2
Scatterplot (Chemical_results.sta 31v*20c)
Hardness (Total) as CaC03 mg/l = 3.7775E5-9.2658*x
Hardness (Total) as CaC03 mg/l
DateTime
Event=2
Scatterplot (Chemical_results.sta 31v*20c)
Iron as Fe mg/l = 8265.5721-0.2027*x
Iron as Fe mg/l
DateTime
8/5/11 8/6/11 8/6/11 8/7/11 8/7/11 8/8/11 8/8/11 8/9/11 8/9/11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Magnesium as Mg mg/l = 61617.4928-1.5114*x
Magnesium as Mg mg/l
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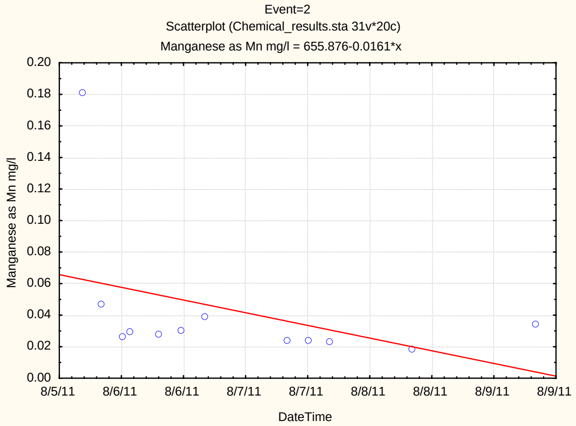
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Manganese as Mn mg/l = 655.876-0.0161*x
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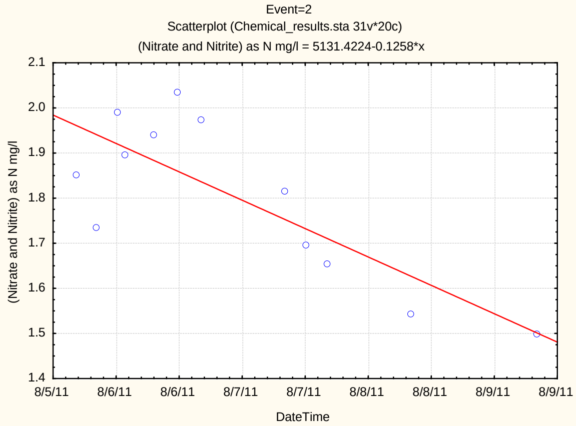
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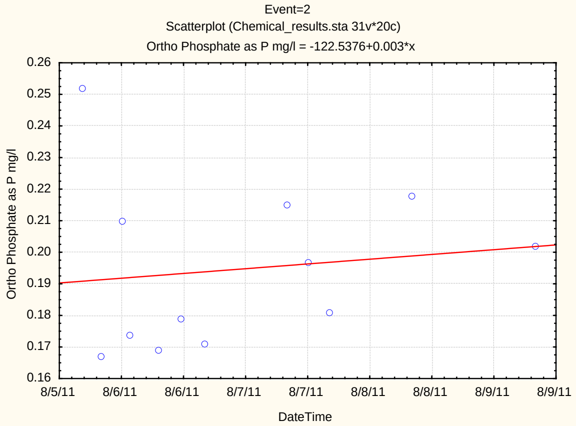
(Nitrate and Nitrite) as N mg/l
DateTime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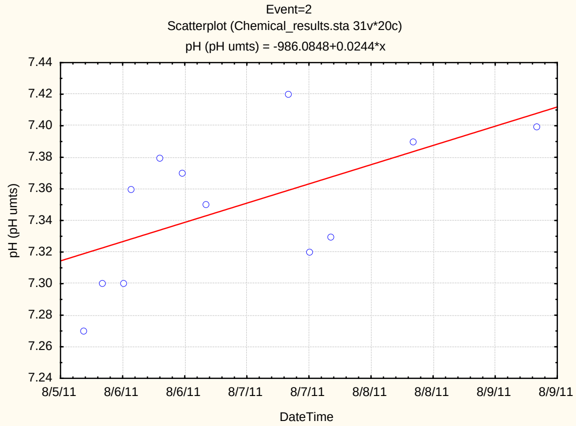
Ortho Phosphate as P mg/l = -122.5376+0.003*x
Ortho Phosphate as P mg/l
DateTime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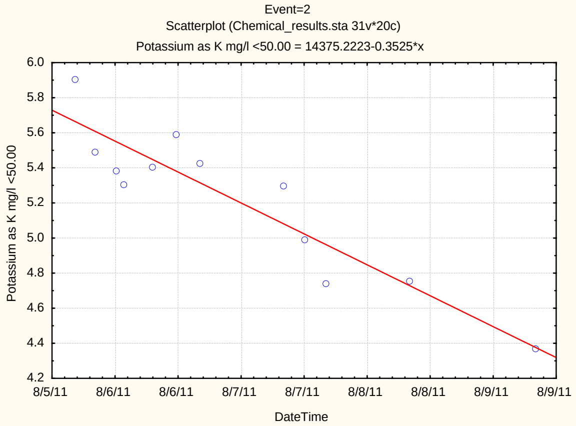
DateTime


Event=2
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Potassium as K mg/l <50.00 = 14375.2223-0.3525*x
Potassium as K mg/l <50.00
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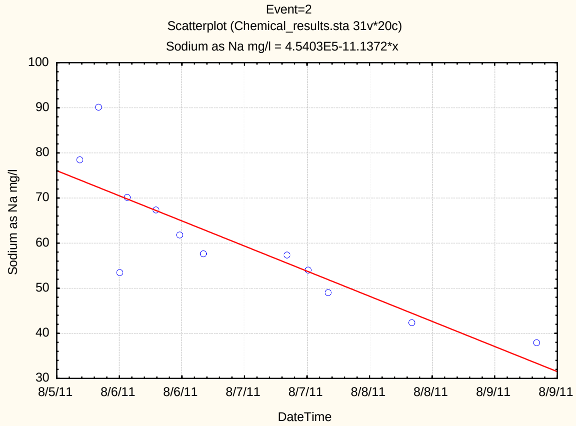
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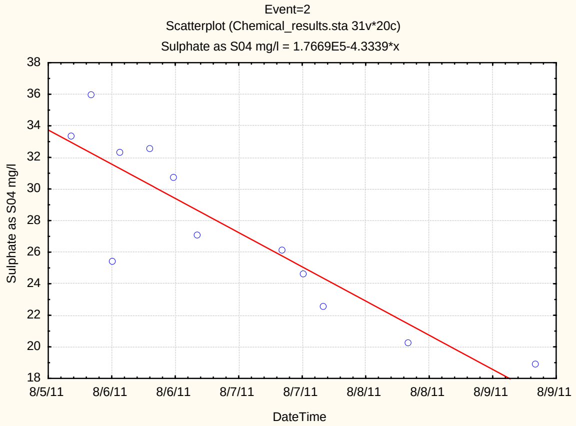
Sodium as Na mg/l = 4.5403E5-11.1372*x
Sodium as Na mg/l
DateTime


Event=2
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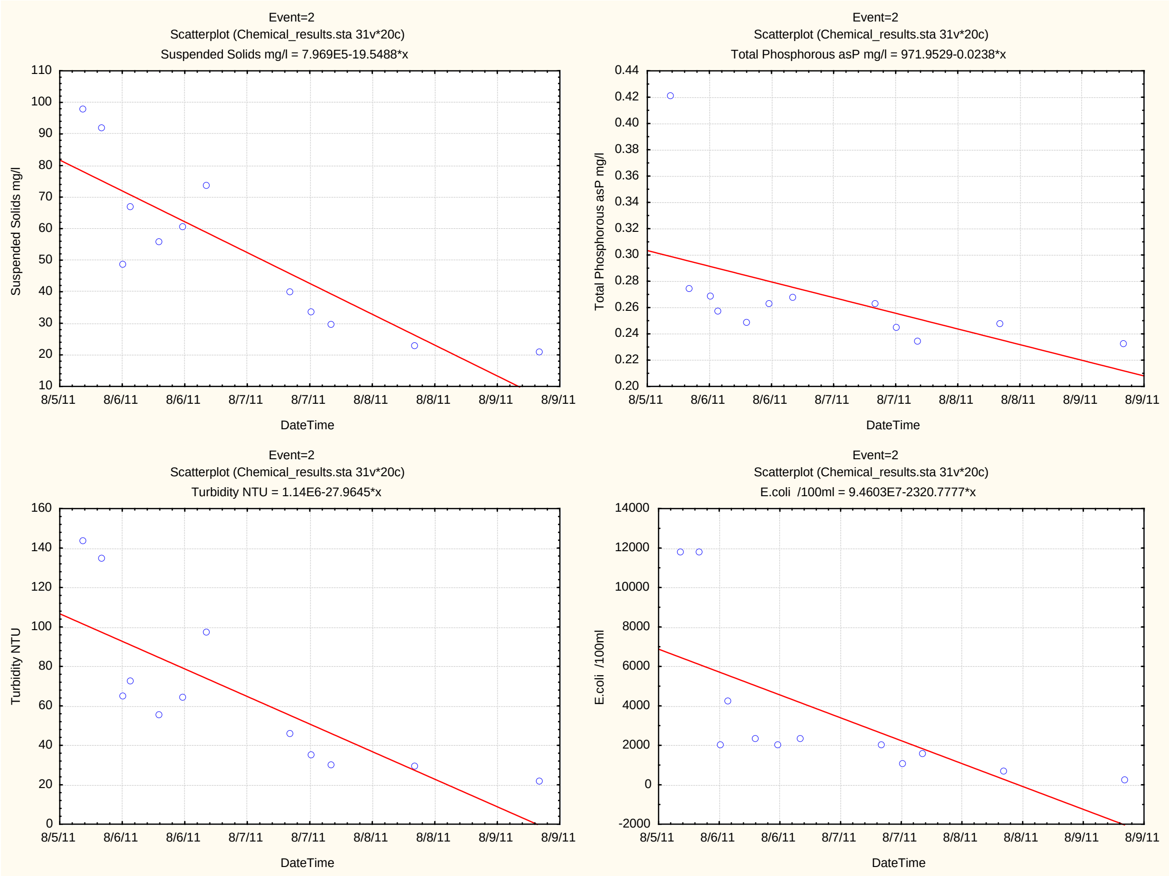
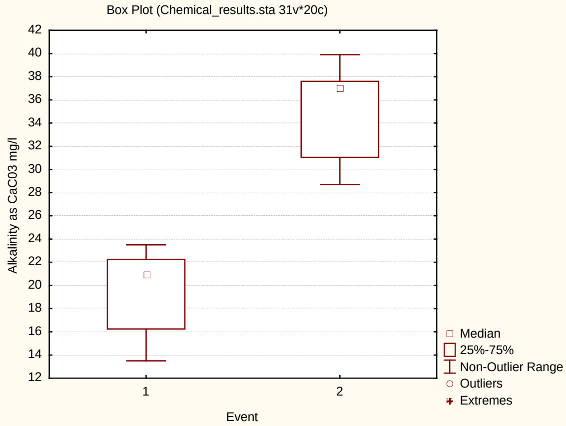
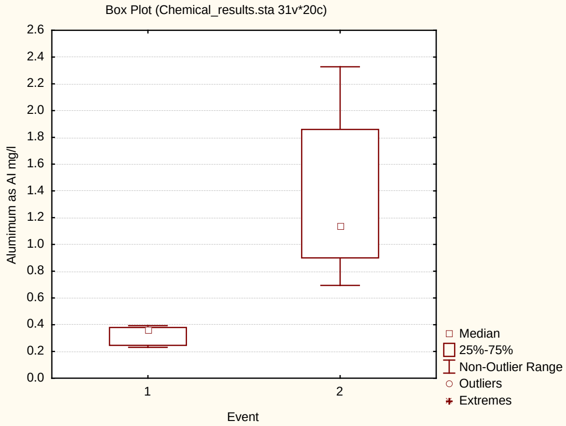
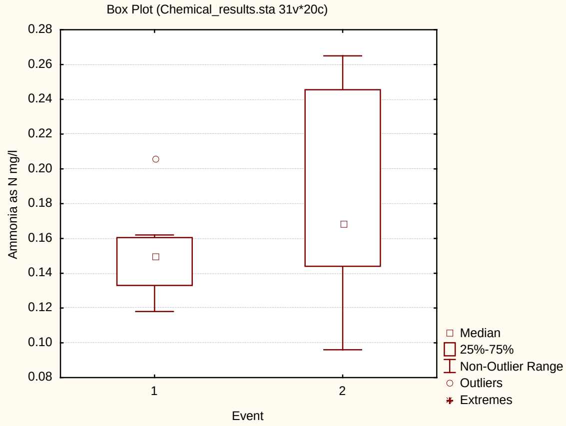
Sulphate as S04 mg/l = 1.7669E5-4.3339*x
Sulphate as S04 mg/l
DateTime

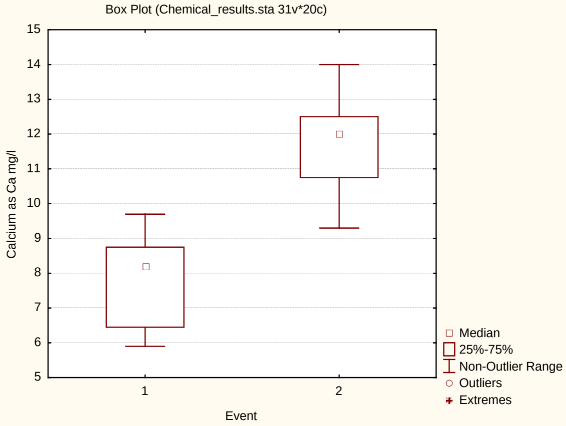

Event=2
Scatterplot (Chemical_results.sta 31v*20c)
Suspended Solids mg/l = 7.969E5-19.5488*x
Suspended Solids mg/l
DateTime
Event=2
Scatterplot (Chemical_results.sta 31v*20c)
Total Phosphorous asP mg/l = 971.9529-0.0238*x
Total Phosphorous asP mg/l
DateTime
Event=2
Scatterplot (Chemical_results.sta 31v*20c)
Turbidity NTU = 1.14E6-27.9645*x
Turbidity NTU
DateTime
Event=2
Scatterplot (Chemical_results.sta 31v*20c)
E.coli /100ml = 9.4603E7-2320.7777*x
E.coli /100ml
DateTime

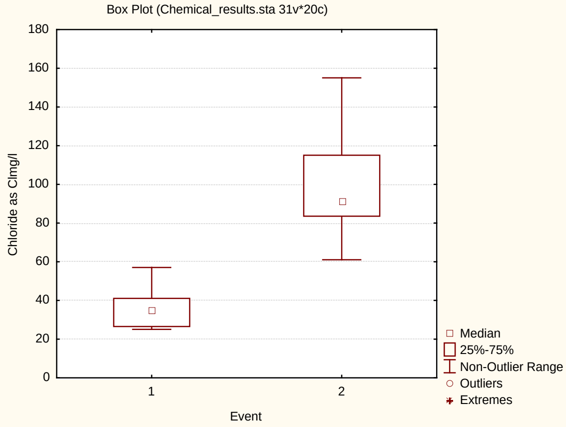
APPENDIX D
BOX AND WHISKER PLOTS COMPARING THE WATER CHEMISTRY OF THE MAY/JUNE (EVENT 1) AND AUGUST 2011 (EVENT 2) FLOODS

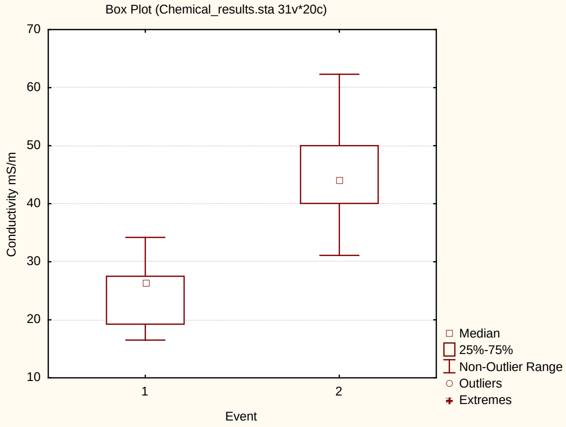

Box Plot (Chemical_results.sta 31v*20c)
Alkalinity as CaCO3 mg/l
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes

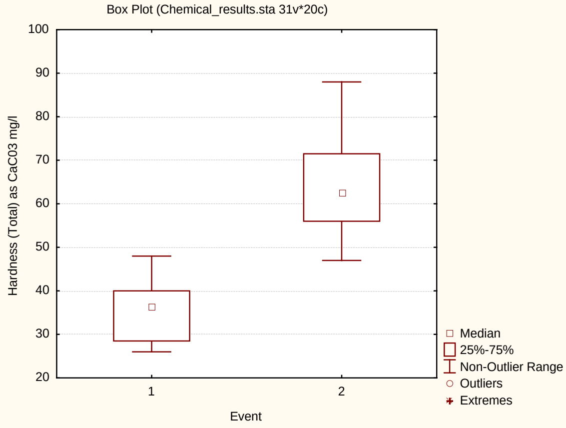

Box Plot (Chemical_results.sta 31v*20c)
Alumimum as Al mg/l
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes

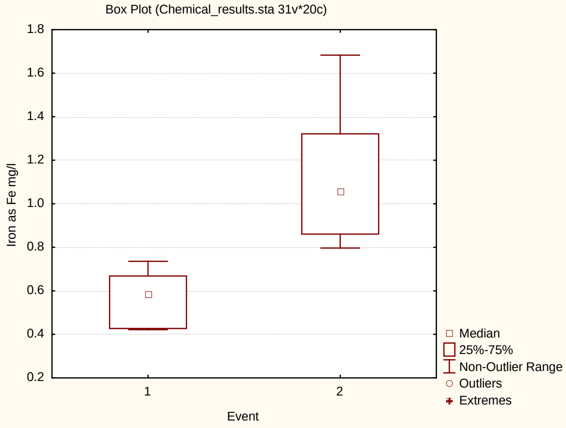

Box Plot (Chemical_results.sta 31v*20c)
Ammonia as N mg/l
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes

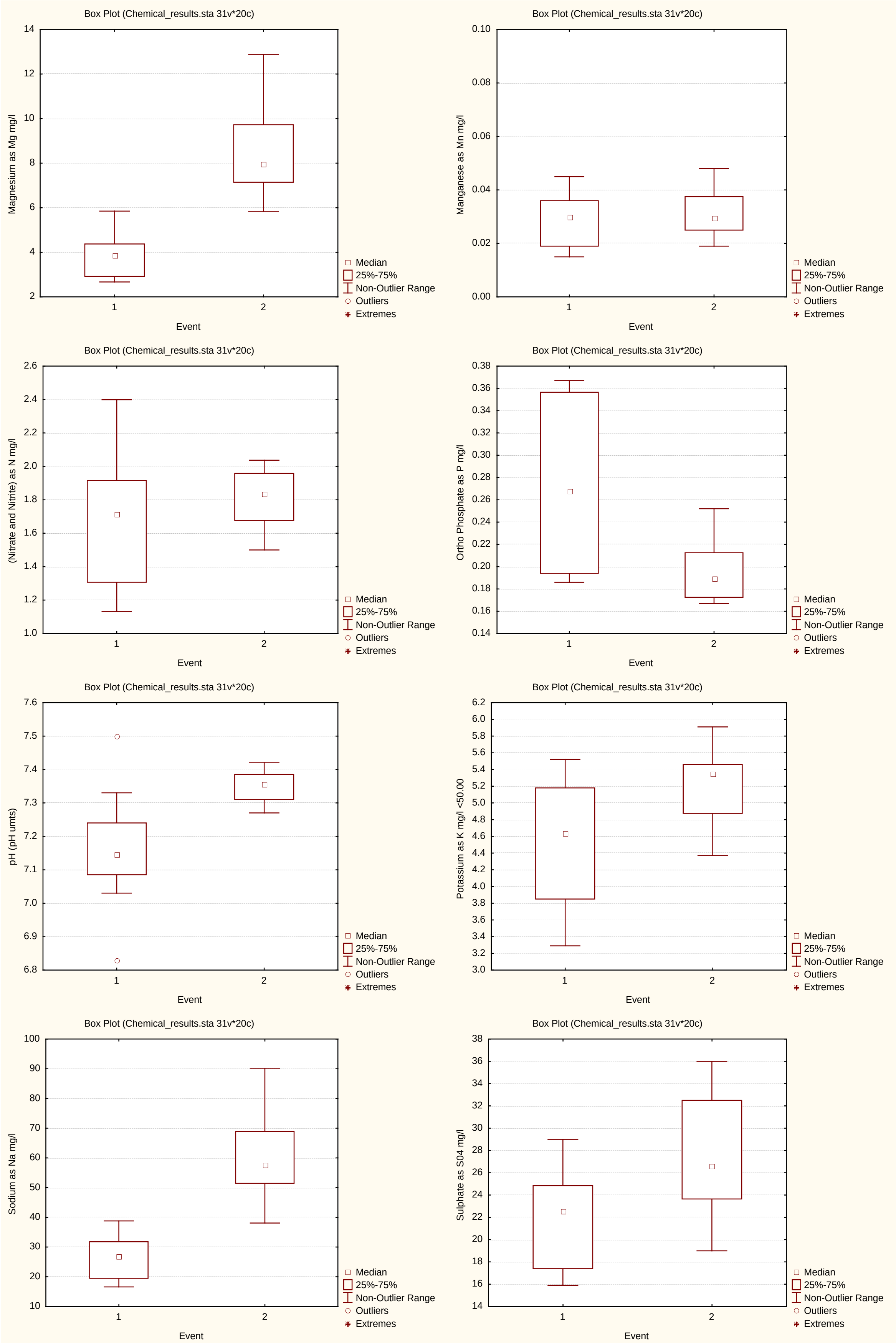

Box Plot (Chemical_results.sta 31v*20c)
Calcium as Ca mg/l
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes

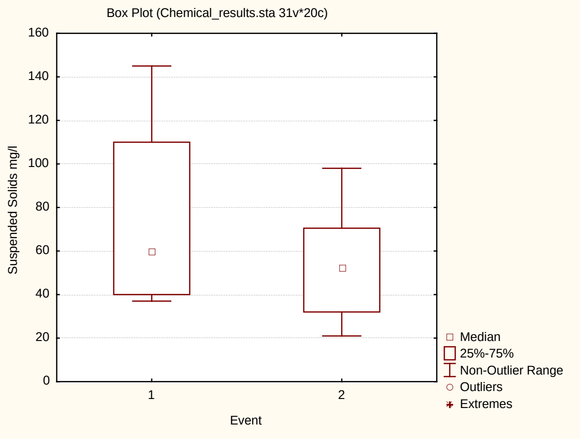

Box Plot (Chemical_results.sta 31v*20c)
Chloride as Clmg/l
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes

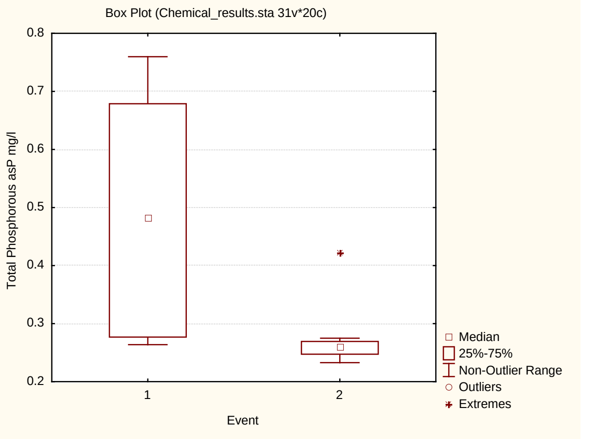

Box Plot (Chemical_results.sta 31v*20c)
Conductivity mS/m
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes

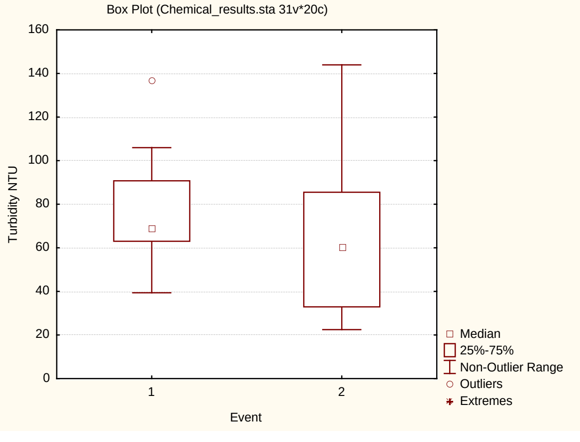

Box Plot (Chemical_results.sta 31v*20c)
Hardness (Total) as CaC03 mg/l
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes

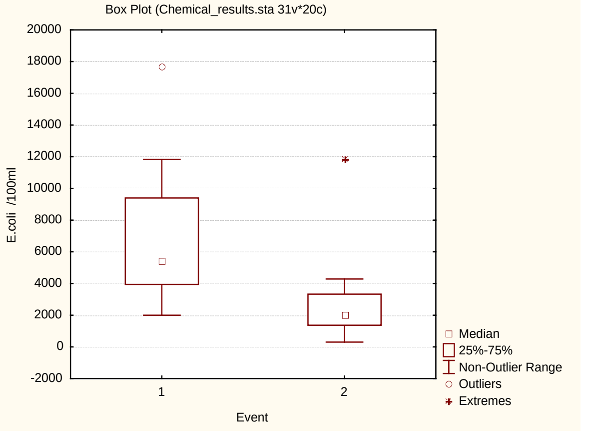

Box Plot (Chemical_results.sta 31v*20c)
Iron as Fe mg/l
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes


Box Plot (Chemical_results.sta 31v*20c)
Magnesium as Mg mg/l
Event
Box Plot (Chemical_results.sta 31v*20c)
Manganese as Mn mg/l
Event
Box Plot (Chemical_results.sta 31v*20c)
(Nitrate and Nitrite) as N mg/l
Event
Box Plot (Chemical_results.sta 31v*20c)
Ortho Phosphate as P mg/l
Event
Box Plot (Chemical_results.sta 31v*20c)
pH (pH units)
Event
Box Plot (Chemical_results.sta 31v*20c)
Potassium as K mg/l <50.00
Event
Box Plot (Chemical_results.sta 31v*20c)
Sodium as Na mg/l
Event
Box Plot (Chemical_results.sta 31v*20c)
Sulphate as S04 mg/l
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes


Box Plot (Chemical_results.sta 31v*20c)
Suspended Solids mg/l
160
140
120
100
80
60
40
20
0
1
2
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes


Box Plot (Chemical_results.sta 31v*20c)
Total Phosphorous asP mg/l
0.8
0.7
0.6
0.5
0.4
0.3
0.2
1
2
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes


Box Plot (Chemical_results.sta 31v*20c)
Turbidity NTU
160
140
120
100
80
60
40
20
0
1
2
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes


Box Plot (Chemical_results.sta 31v*20c)
E.coli /100ml
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
1
2
Event
Median
25%-75%
Non-Outlier Range
Outliers
Extremes

APPENDIX E
SAMPLING PROTOCOLS RECOMMENDED TO SWARTLAND WATER TREATMENT PLANT SAMPLERS

Recommended Sampling Protocols

Sample collection

1. Before departing for Sonquas Drift, ensure that the following equipment has been packed:
    a. Duplicate sampling bottles for chemical and microbial analysis
    b. Labels for the bottles
    c. Marker pen to label bottles
    d. Cooler box
    e. Clean bucket and rope
    f. Sampling staff
    g. Life jackets
    h. Cell phones or two-way radios
    i. Torch if sampling at night
2. Drive to Zonquasdrift and park the vehicle where it is safe to turn around.
3. Mark the sampling bottles with the date & time, name of the sampler, sampling point (G1H079), and laboratory (Withoogte or CCT) the sample will be sent to. The sampling time is very important because it will be used to retrieve the river flow from the hydrograph.
4. Walk to the middle of the low water bridge and collect the water sample on the upstream side of the bridge.
5. If the water level is close to the deck of the bridge, use the sampling pole to collect water samples directly into the sampling bottles by clamping the bottles onto the sampling pole (see illustration below). Push the sampling bottle about 10cm below the water surface with the opening facing upstream. Allow the bottle to fill, retrieve it, and replace the bottle cap. Repeat for the other bottles.
6. If the water level is too low for the sampling staff, then use a bucket to collect water. Lower the bucket with a rope into the water and allow it to fill. Retrieve the bucket. Swirl the water in the bucket and fill the sampling bottles by emerging each bottle below the water surface in the bucket. Retrieve and recap the bottle. Repeat until all the bottles have been filled.
7. If the low water bridge is over-topped by the flood water, park a safe distance away from the bridge and use the sampling staff to collect a water sample from the side of the river. **DO NOT** wade into the river under these conditions.
8. Pack the bottles in a cooler box and transport it back to the Swartland WTW. Store in a refrigerator until the sampling has been completed, usually within 24 hours after the first sample was collected.
9. Transport the samples in cooler boxes to the respective laboratories.

Sampling rod

A simple sampling rod can be constructed from an extendable aluminium pole with a C clamp screwed onto the pole as illustrated below.

Uitvoerbaarheidstudie vir die aanvulling van die Weskaapse Watervoorsiening stelsel deur middel van verder water ontwikkelings: Fase 2

Watergehalte Moniteringsprogram van vloede in die middel Bergrivier (2011)

Doel

Om watergehalte monsters te neem tydens drie vloede in die winter van 2011; een vroeg in die seisoen (Mei 2011); een in die middel van die seisoen (Julie 2011); en een laat in die seisoen (Sept. 2011). Die doel is om te bepaal hoe watergehalte tydens hierdie vloede verander veral tydens die stygende en dalende been van 'n vloed.

Prosedure

1. Voor vertrek na Zonquasdrift, maak seker dat die volgende toerusting in 'n krat gepak is:
   a. Duplikaat monster bottels vir chemiese analises en vir bakteriologiese analises (net Withoogte laboratorium).
   b. Plakkers vir die bottels.
   c. Merkpen om op die plakkers te skryf.
   d. Koelboks.
   e. Monsterpaal.
   f. Veiligheidsbaadjies.
   g. Selfone or twee-rigting radio's
   h. Flits indien monsters in die nag geneem word
2. Ry na Sonquadrift en parkeer die voertuig waar dit veilig is om terug te draai.
3. Merk die monster bottles met die datum, tyd, naam van die monsternemer, monsterpunt nommer (G1H079) en laboratorium (Withoogte of Kaapstad).
   NB Die tyd wat die monster geneem word, is baie belangrik omdat dit gebruik gaan word om die riviervloei af te lees van die vloeirekord.
4. Stap na die middel van die laagwater brug en neem die watermonsters aan die stroomop kant van die brug.
5. As die watervlak naby aan die dek van die brug is, gebruik die monsterpaal om water direk in die monsterbottels te neem daar dit aan die paal vas te klem. Druk die monsterbottel sowat 10cm onder die oppervlakte van die water met die bek in 'n stroomop rigting. Laat die bottel vol loop, haal dit uit en sit die prop op. Vul ook die ander bottels.
6. Gebruik 'n emmer om die water te versamel as die watervlak te laag is om die monsterpaal te gebruik. Laat sak die emmer tot in die water, laat dit toe om vol te loop en trek dit weer op. Meng die water in die emmer en vul elke bottel deur dit in die emmer te druk. Haal uit as dit vol is en draai die prop op. Maak die res van die bottels uit die emmer vol.
7. As die laagwaterbrug oorstroom is, parkeer 'n veilige afstand weg van die rivier en gebruik die monsterpaal om water van die kant te versamel. MOET NIE onder sulke omstandighede in die river instap nie.
8. Pak die bottels terug in 'n koelboks en vervoer dit terug na die Swartland Waterwerke. Bewaar die bottels in 'n yskas tot die monsterneming klaar is, gewoonlik binne 24 uur nadat die eerste monster geneem is.
9. As monsterneming voltooi is, neem een stel monsterbottels na die Kaapstad Waterwerke toe (vir aandag Graham Alexander). Die ander stel monsters moet gestuur word aan die Withoogte laboratorium (vir aandag Garnet Titus).

As jy onseker is wat om te doen, kontak asseblief vir:

Garnet Titus:	WCDM	022 433 2352 of 083 347 1531
Of Nico Rossouw	Aurecon	021 481 2451 of 082 493 1570