

# **The Norske Skog Waste Site Eastern Embankment: How Well It Is Functioning and What If It Fails**

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June 2006

## **Abstract**

The Norske Skog Tasman / Carter Holt Harvey pulp and paper mill has been dumping its solid waste in the primary solids disposal area in Kawerau, New Zealand since 1971. This waste material contains environmentally unfriendly chemicals which are moving into the groundwater through leachate. This groundwater is likely moving through the Lower Embankment into the Tarawera River. The Tarawera River has several contamination parameters above the recommended levels for recreational use although these high parameters are likely not due, at least not primarily, to groundwater contamination. However, in the future, it may become necessary to fix the leak from the waste site into the river. Possible methods to accomplish this goal include: reconstructing the Lower Embankment, capping the existing waste, building a new retaining wall, building a permeable reactive barrier, and isolating the Tarawera River from the disposal area.

## **Introduction**

The Tasman Pulp and Paper mill was founded in Kawerau, New Zealand in 1952. In 1954, the New Zealand government passed the “Tasman Pulp and Paper Enabling Act” which, among other things, gave the company the rights to lease land from a local Maori trust to build a waste disposal site (Tull 2008). The plant generated a significant amount of waste products during this period, so in 1971, the company leased a piece of land around and including the former Lake Rotoitipaku, from the “Responsible Trustees’ of the land” (SKM

2004). This area came to be known as the Primary Solids Disposal Area for the plant. The waste products that were dumped in this area are known to carry strong concentrations of potentially harmful chemicals (Tull 2008). However, very little preparation was undertaken to prepare the land for its intended use as a waste disposal area. The only protection the site has from the nearby Tarawera River is an earthen berm known as the Lower, or Eastern Embankment. This embankment was designed to hold back the “low solids slurry” (wastewater with low solids content) that was originally the status of the waste when entering the disposal area (SKM 2004). This embankment failed in 1983 (Tull 2008), and there is a chance that it might fail again. While this is considered unlikely because of the change in waste from low solids slurry to more solid waste (SKM 2004), there are other ways in which this embankment could fail, such as a leachate flow through or under the embankment.

Several water studies have been completed regarding both the surface water and the groundwater in and around the disposal area. Within the disposal area, the groundwater shows contamination (above Australia and New Zealand Conservation Council (ANZECC) guidelines) of certain metals and organics (Tull 2008). It is important to note here that above guideline levels of contamination do not directly translate to compromised safety of the river water, high levels just means that something about the river water may make it unsuitable for recreational usage. The fact that groundwater is contaminated here is only relevant if the groundwater is being used directly from this area or if the contamination is strong enough that dilution from spreading and entering other water sources is not enough to lower the contamination to safe levels (SKM 2007). The flow of groundwater through the site shows a general movement down gradient to the Tarawera River (SKM 2007). This is significant because the groundwater movement is indicative of the movement of leachate from the waste. If the contaminated leachate enters the Tarawera River, there is potential for an environmental hazard.

The Lower Embankment is the only protection the Tarawera River has from the waste site and a, 10 meter high by approximately 600 meter long, hill constructed of various fill materials. If contamination is entering the Tarawera River in dangerous quantities, then it may be important to further protect the river. Presently, Norske Skog Tasman is responsible for the maintenance of the site and the protection of the environment by the terms of the lease. If the embankment were to fail again or be proven to be insufficient to block the flow of contaminated groundwater, the burden would fall on Norske Skog to remediate the situation. However, the lease of the land expires in 2013 and at that point; the area again becomes the responsibility of the Maori iwi that owns the land. Even if the embankment is

not failing to the point of contamination levels exceeding ANZECC standards, it is still desirable to have the environment be kept as clean and healthy as possible. Even this could be seen as reason enough to attempt further isolation of the waste site.

This paper examines the levels of contamination in groundwater near the Lower Embankment to determine the necessity of further observation and remediation. Then the paper investigates several of the options available for remediation of the site. One option involves a liner system usually used to isolate the dumped waste from the original ground; this type of system would be set up before a site such as this is created (Chia and Muria 2002). Obviously, that was not done for the Primary Solids Disposal Area but the ideas used in the liner could be used to bolster the effectiveness of the Eastern Embankment or used as a cover system to block water movement from the surface through the waste. Another option would be to build a solid wall specifically engineered to block the flow of groundwater through the area. The last option that was considered for this paper is isolating the Tarawera River from the contaminated groundwater.

## **Background**

### **Site description**

Kawerau is city of approximately 7,000 people located in the Bay of Plenty area of the North Island of New Zealand (Figure 1). It has been the location of the Tasman Pulp and Paper Mill since the mill was built in the early 1950's. In the 1970's, a piece of land, adjacent to the property the mill is on, was leased from the local Maori iwi through a Board of Trustees. This piece of land, including Lake Rotoitipaku, then became designated the primary solids disposal area for the pulp and paper mill.

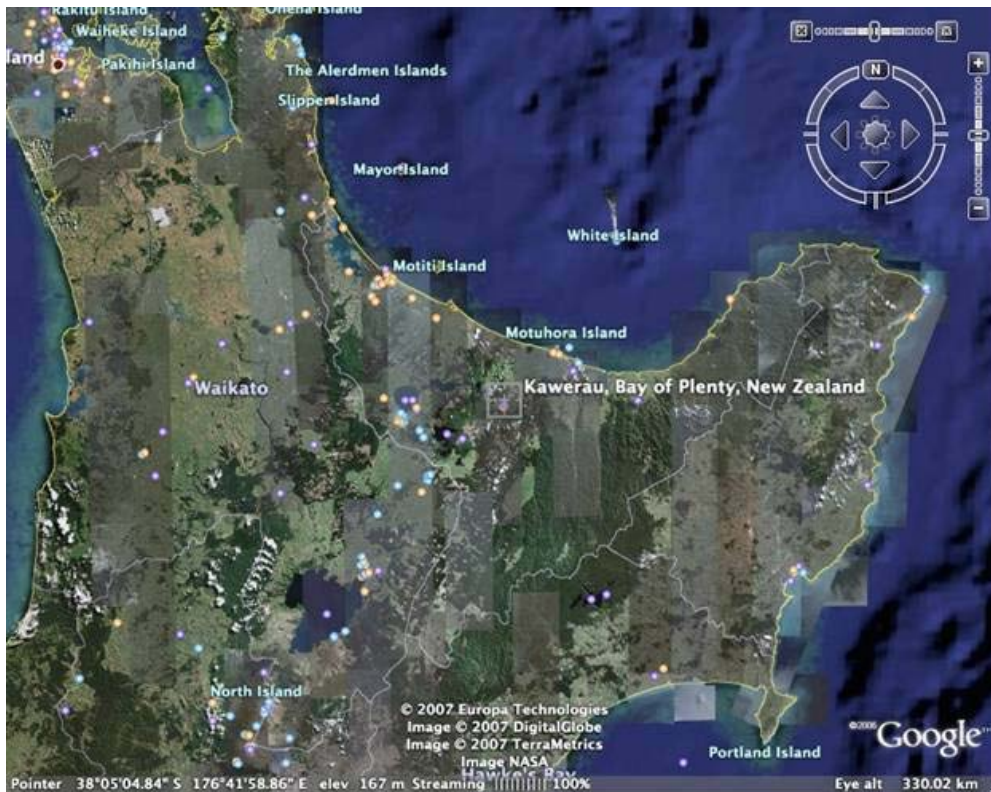


Figure 1. Location of Kawerau, North Island, New Zealand. (Image from Google Earth)

The primary solids disposal area was placed directly on top of Lake Rotoitipaku, filling it completely, to the point where the lake no longer exists today. The water has been displaced further to the southwest and is now known as the A8 pond. This pond is separated from the disposal area by the Upper Embankment. This embankment is constructed of “pumice and general mill wastes, including up to ten tonnes of zinc hydrosulphite (SKM 2004). Zinc hydrosulphite may be contained in metal drums buried in the Upper Embankment (SKM 2004). On the eastern side of the disposal site is the Lower Embankment, which is constructed of alluvial pumice gravel and fiber byproducts of the pulp and paper mill (Tull 2008). This embankment was constructed to contain the primary solid waste from migrating into the Tarawera River (Tull 2008).

It is also important to note that while most of the surface water that used to form the lake has moved to the A8 pond, the groundwater levels under the waste remain quite high. Around most of the waste site, the groundwater is within a few meters of the surface (Tull 2008). This means that the groundwater is in contact with the waste in many locations increasing the risk of leachate entering the environment.

The Tarawera River originates at Lake Tarawera and flows 65 kilometers into the Bay of Plenty. Along its path, it goes through the town of Kawerau and past the Tasman Pulp and

Paper Mill. It flows past the primary solids disposal site and then by the water treatment ponds. The water from these treatment ponds is released back into the river after treatment. For the purposes of water testing, the river is the key down-gradient receptor of any potential contamination (Tull 2008). However, there is known to be geothermal activity in the Kawerau region (SKM 2007) with some surface features occurring close to the Tarawera River. As geothermal waters often contain “elevated levels of chloride, sulfate, arsenic, antimony, boron, thallium, and mercury” (Tull 2008), it can be hard to determine what contamination is coming from the waste and what is from the geothermal waters.

### **Pulp and Paper Mill Waste Contaminants**

The process of making wood into pulp and finally paper is a chemically intensive process. There are three main stages to production: pulping, bleaching, and paper manufacture, all using various chemicals. The common contaminants used in these processes are shown in Table 1. Most of these chemicals are “discharged into pulp and paper effluent wastewaters” (Tull 2008). The solid waste of these processes then goes to the primary solids disposal area. Some of these chemicals, both organic and inorganic, can be hazardous to health even in very low concentrations (Tull 2008). It is imperative that these chemicals are kept from entering the environment in unsafe levels.

Pulping	Bleaching	Paper Manufacture
Sodium Hydroxide	Residues Hydrogen	Peroxide Waste sludge
Sulfuric/sulfurous Acid	Elemental Chlorine	Bleaching and Pulp
Hydrochloric Acid	Chlorinated Compounds	Contaminants
Hydrogen Sulfide	Sodium Hydrosulfite	SVOCs
Ammonia	Polychlorinated Biphenyls (PCBs)	VOCs
Lead	Dioxins and Furans	Slimicides Chlorinated Phenols
Cyanide		Aminos and Quarternary
Zinc		Ammonium Compounds
Chromium		Organosulfur Compounds
Resin		Silver Compounds
Unnatural Fatty Acids and Chlorinated Analogs		Titanium Residues
		Oil and Grease Discharges
		Polychlorinated Biphenyls, pesticides, dyes, asbestos fibers from agricultural residues

Table 1. Common contaminants associated with each stage of the paper manufacturing process. (Adapted from Tull, 2008)

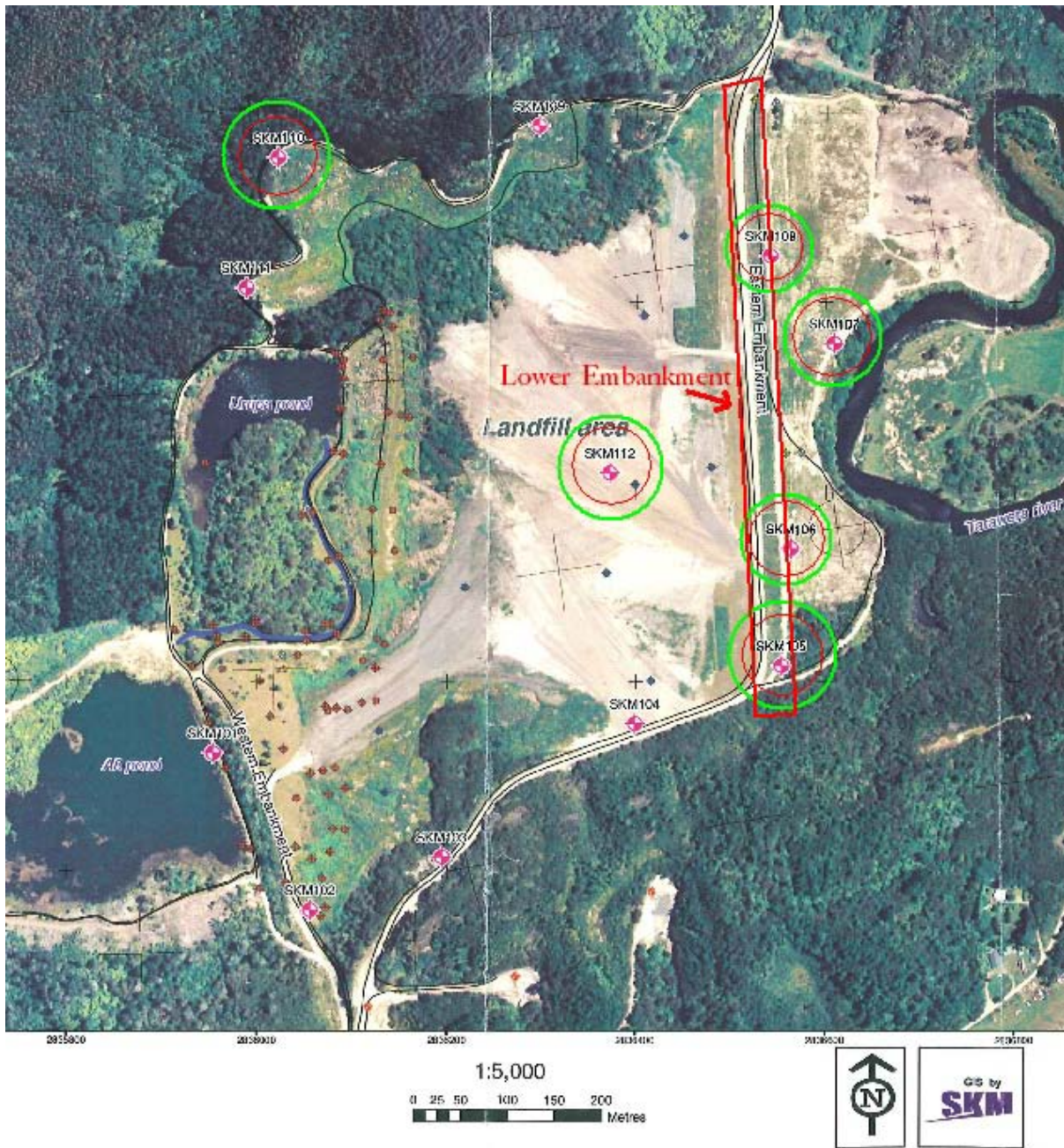


Figure 2. Aerial photograph of primary solids disposal area with boreholes and Lower Embankment marked (Image adapted from SKM report).

## Methods

Data was collected to determine levels of cations, trace metals and anions. The sample containers were prepared by soaking them in: 1N HNO<sub>3</sub> for 24 hours, then deionized water for 24 hours, then dried in a clean oven at 40°C for 24 hours. Once dry, bottles were separated into sets of four and stored in plastic ziplock bags.

Data collection occurred during the morning through late afternoon of both February 17<sup>th</sup> and February 18<sup>th</sup>. Data was collected from both surface water sites and groundwater wells in and around the dumping area. For surface water collection, the collection bottle was rinsed thoroughly with water from the collection site. Then a final sample of water was collected for testing.

For groundwater samples, a large collection bottle, foot pump and plastic tubing were thoroughly rinsed with DI water. Then the foot pump is attached to an appropriate length (governed by the depth of the borehole) of plastic tubing and lowered into the well. Water was then raised through the pipe (ideally water from halfway between the bottom of the borehole and the water level for that borehole) and pumped into the collection bottle.

Once sample water was collected in a large collection bottle, it was run through a paper towel filter into a second pre-rinsed large collection bottle. Then a 30 mL syringe fitted with a 0.45  $\mu\text{m}$  Millipore filter was used to transfer the sample water from the large collection bottle into four 125mL sample bottles to test for cations, anions, alkalinity, and boron isotope (the bottle to be used for cation testing had 2 drops of 5N nitric acid added for preservation). The four sample bottles were then put on ice for storage.

Once a sufficient quantity of water for all four sample bottles was filtered into the second bottle, field tests for pH, dissolved oxygen, temperature, and conductivity were conducted upon the water remaining in the first one liter bottle. At the ground water locations, where possible, depth and flow rate measurement / estimations were conducted. Following every procedure, all equipment was rinsed with DI water. A point was also made to take samples from sites in order of increasing known contamination as another precaution against sample contamination.

Atomic Absorption Spectroscopy (AAS) was used to measure levels of Na, K, Zn, and Ca, in the samples we took from the waste site. Each cation was tested separately using an AAS machine fitted with a specific cathode tube for each cation. The AAS machine measures “the amount of energy in the form of photons that are absorbed by a sample” (Frye 2008). Before testing commenced, the AAS machine was calibrated using three prepared standards with known cation concentrations. The software in the attached computer used the absorbency values for these from these known concentrations to compute a calibration curve. When absorbency values were taken from the samples, the value was plotted against the calibration curve and the cation concentration was interpolated.

## Results

A full set of data (Table B-1 and B-2) was collected by Sinclair Knight Merz (SKM) in 2006 and, in 2009, the Frontiers Abroad group collected data on several cation and trace metal contaminants (Table B-3). Samples were taken from boreholes SKM105-108, SKM110, and SKM112 which are located as seen on Figure 2. For the purposes of this paper, contaminant levels in boreholes SKM105-108 were averaged together to get a value representative of the mean level of contamination on the Tarawera side of the Lower Embankment. These levels were compared against the contamination level in a “clean” borehole, SKM110 (this borehole is up gradient from the waste site so it may be suggested that it is at least less contaminated by waste than the others), and the interior waste site borehole, SKM112.

It can be seen from Figure C-1 through Figure C-4, that contamination levels for Zn, Ca, K, and Na are all higher around the Lower Embankment than they are at the SKM110, the “clean” borehole. Of these four elements, only Zn and Na have ANZECC guidelines for recreational water use. All the values for sodium fell well below the guideline of 300 mg/L. For zinc, the guideline of 0.008 mg/L was exceeded in boreholes SKM106A, SKM106B, SKM108A, SKM108B, and SKM112B in 2009 and SKM112A in 2006.

Other significant results were obtained from SKM testing parameters: total phosphorus, total sulphide, dissolved manganese, dissolved arsenic, and dissolved boron. For all of these parameters, the average level of contamination on the Tarawera side of the Eastern Embankment was above the ANZECC guideline for recreational water usage. Interestingly, the levels of groundwater contamination in the SKM112 borehole (for these guideline exceeding contaminants) are all lower than the average for the Tarawera side of the embankment (except for the October 2006 testing of manganese).

The SKM surface water data (Table B-4 and B-5) shows levels of water contamination at sites on the Tarawera River upstream and downstream from the waste site. Of the previously mentioned contaminants, zinc, phosphorous, arsenic, and boron are found in the river water at levels exceeding ANZECC guidelines (Figures C-4, C-5, C-8, and C-9). Except for the zinc and boron measurements in October 2006, the contamination levels are higher downstream from the waste site.



## **Discussion**

### **Data Analysis**

The data suggests that the contaminants in the waste site are not being held to the western side of the Lower Embankment. This is inferred due to high levels of multiple contaminants existing in significant quantities in the groundwater of boreholes on both the western waste filled side (SKM 112) and on the Tarawera side (SKM 105 – SKM 108). These measurements, when compared to levels in an up-gradient, relatively clean borehole (SKM 110), suggest that contaminants are moving through the Lower Embankment to the groundwater outside the waste site and then into the Tarawera River. The SKM groundwater data also suggests that contaminants are entering the Tarawera from the waste site since many contamination levels are higher in water that has already passed by the waste site (Note: this may also be due or affected by the “treated” wastewater which enters the river after passing through the treatment ponds, also the geothermal activity of the area could affect the contamination levels).

Some of the contaminant levels exist in higher than ANZECC recreational use standards in the boreholes (on either side of the embankment). The 2007 SKM report suggests that, accounting for dilution from the river water, contamination levels in the groundwater would not be high enough to be the primary cause of unsafe (for recreational use) river water. The 2007 SKM report estimates that 1,170 cubic meters of groundwater enter the river from the landfill every day. The estimated average water flow through the Tarawera is  $1.6 \times 10^6$  cubic meters per day. This means that contaminants coming from the groundwater will be over 1,000 times more concentrated in the groundwater than they will be once entering the river (SKM 2007). From the SKM data, it is evident that the levels of contaminants that exceed ANZECC standards are usually higher both before and after passing through the waste site. This, combined with the dilution mathematics, suggests that the effect of groundwater contamination to the river from the solids disposal site is, at this point, negligible.

### **Remediation Discussion**

Despite the evidence pointing to groundwater contamination not being a significant threat to the river’s environmental health, it is still important to consider remediation options for the waste site. This is the case because, although most of the tested surface water parameters are ANZECC compliant, it is desirable for the river to be cleaner than it currently

is and removing any source of contamination is helpful in that regard. It is assumed that some of the high levels of contaminants in the river come from natural sources, like peat and geothermal activity, but some is from leachate from the waste (SKM 2007). With this in mind, it may someday become important to completely stop the leachate flow from the dump site to the river. Several options for remediation include reconstructing the Lower Embankment, capping the existing waste, building a new retaining wall, building a permeable reactive barrier, and isolating the Tarawera River from the surrounding area.

Today, typically when a new waste site is constructed, the ground beneath the proposed dumping area is prepared with a liner system (Chia and Miura 2002). These liner systems typically consist of a mineral barrier with requirements for depth ranging from half a meter to a full meter thick for municipal solid waste in Europe and America (Chia and Miura 2002). Then there is typically a requirement for either a geotextile or a HDPE geomembrane layer (sometimes both) separating the mineral barrier from the drainage layer above it. This drainage layer consists of permeable material and a piping system that is used to reduce the head difference on the liners. This system allows for leachate to flow under the landfill into a leachate collection system which relieves the pressure of water to flow through the barrier layers (Chia and Miura 2002). If reconstruction is planned for the Lower Embankment, this sort of system could be incorporated to block the majority of lateral groundwater / leachate from flowing through to the river.

To further lower the amount of leachate trying to move through the barrier layers, a cover system is used for many dumpsites in Europe and America. This lowers levels of water infiltration through the waste (by blocking rain and other surface water sources) hence reducing the total amount of leachate (Chia and Muria 2002).

A cover system could be useful at the Norske Skog waste site for reducing leachate flow to the river by reducing the flow of water down through the waste and into the groundwater. It has been shown that water moves much more slowly through the waste than through the natural soils (SKM 2007). A reduction in the amount of water trying to move through the waste and can cause a reduction in total leachate. Cover systems can be used throughout the filling of a dumpsite (as often seen in municipal waste locations) or are often used once the dumpsite has been shut down (this is often called capping and is used as a final environmental protection scheme). The final cover scheme is inappropriate in this situation as the dump site is still in use. However, capping the site now could have its advantages. A system could be set up where the current waste at the site is capped with materials conducive to being a bottom barrier for the newly produced waste. This would have the effect of

making the rest of the dumping safer environmentally and would significantly limit the amount of water leaching through the old waste into the groundwater.

An engineered retaining wall is another method for environmental protection that could be used at the Tasman solid waste site. This approach was used in the Queen City Farms Superfund site, near Seattle. This was a very large project where a 2,200 foot wall was built deep into the ground to block the movement of a large plume of contaminants moving through groundwater (USEPA 2008). It was made of a material which had very low permeability characteristics ( $1 \times 10^{-7}$  cm/s) and went over 70 feet below the ground surface in some places. This project cost 2.7 million in 1996, but did have some success in stopping the movements of the contaminants. As soon as the wall was completed, water levels within the containment area fell, evidence that the wall was stopping infiltration of the area by water (Thompson and Stamnes 1997). Still, in 2008, some of the measured contaminant levels failed to meet the 11<sup>th</sup> year post construction predictions (USEPA 2008).

A retaining wall is a valid consideration for remediation of the Tasman waste site. It would have essentially the same purpose as the Lower Embankment but would have a more solid construction and a more pointed design. At this point, it appears that the current Lower Embankment is fulfilling its purpose well enough that the Tarawera is not dangerously contaminated. A newly engineered retaining wall would have the same purpose as the Lower Embankment has now but it might be more successful in achieving it. It would completely block groundwater flowing through and, if built deep enough, drastically limit the amount of contaminated groundwater flowing below. This method would probably be most effective if combined with a drainage system to reduce the pressure of water being held by the wall. This water could then be cleaned and released into the river. At the Queen City Farms Superfund site, the wall was dug down into a layer of low permeability soil 79 feet below original ground surface (Thompson and Stamnes 2008). This created a containment area for all the contaminants by blocking the flow of groundwater. At the Tasman site, there is no guarantee of finding a soil surface with low permeability so as to block groundwater flow beneath the wall. As a result, this method may not be completely successful at blocking contaminants.

Another option would be a permeable reactive barrier (PRB). There have been experiments run where groundwater is decontaminated as it flows through a wall of reactive agents (Robertson et al. 2005). One study in particular is relevant to the Tasman waste site, Oh, Lee, and Yoon (2007) describe how they used different types of treated scrap steel to treat simulated leachate from a municipal waste dump. They found that converter slag and waste steel scrap treated with a hydrochloric acid solution were effective in removing the

majority of heavy metals from their simulated leachate (Oh et al. 2007). A PRB constructed from these materials could be a solution to the contaminated groundwater issue at the Tasman site. A barrier of sufficient depth, constructed between the waste and the river, could absorb many of the contaminants (Oh et al. 2007) feared to be entering the Tarawera River.

If the goal is simply to prevent the contamination of the Tarawera River, a method of isolation could be used. If the river was isolated from the groundwater in the area, it would not get contaminated from the solid waste. Isolation would involve placing an impermeable layer of some kind on the river bed in the vicinity of the waste site making it so the groundwater did not feed into the river. This solution has several issues; first, depending on the material used to line the river bed, the actual construction could be difficult. Second, the issue of the contaminated groundwater is still relevant, it would be important to discern where it collects if not entering the Tarawera. Given that the Tarawera is the level of groundwater in the area, the contaminated groundwater would likely collect in that region creating a sort of contaminated bog. There also would likely be other issues (such as maintenance) that would arise from this solution.

## **Conclusion**

This paper provides a discussion of the effectiveness of the Lower Embankment towards the goal of protecting the Tarawera River from groundwater contamination. It can be seen from the data that the Tarawera River, in the vicinity of the waste site, is not completely safe (for recreational use) by ANZECC standards. The data also suggests that some of this contamination is likely coming from leachate moving from the waste site, through the Lower Embankment, and into the river. It is also likely that, given the pure volume of water in the Tarawera, the groundwater contamination is diluted enough that its effect on the Tarawera River's overall contamination is negligible. Still, should it become necessary to fix the groundwater problem, possible solutions include; putting a cover system over the waste site, rebuilding the Lower Embankment, installing a PRB in the Lower Embankment area, or isolating the Tarawera River.

Future work in this area should include continued monitoring of the groundwater around the waste site as well as monitoring the contamination in the Tarawera River. It will be important to know if contamination is getting better, worse, or holding at current levels. Also, a more pointed study analyzing data from individual boreholes, as opposed to using averages, could yield for informative data and perhaps point to a more specific location

where contaminants are leaking through. Continuing from this project, the next step in discussing remediation methods would be to carry out experiments testing the effectiveness of the solutions (in particular, a permeable reactive barrier designed for this situation). Then it will be important to look at the economic side of remediation and discuss the costs of the different solutions for this situation.

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## Appendices

### Appendix A: Methods

Table A-1. Procedure for preparing sampling bottles.

1. Uncapped all bottles and soaked them in 1N HNO <sub>3</sub> solution for 24 hours.
2. Filled each bottle with ultra pure water and let soak for approximately 24 hours.
3. Dumped the ultra pure water out of the bottles.
4. Placed bottles and caps on tray and dried in a clean oven at 40°C for approximately 24 hours.

Table A-2. Procedure for collection of surface water.

1. Rinse one liter HDPE wide neck bottle with deionized water.
2. Field rinse bottle four times near the intended sampling area (careful not to disturb sediments on the bottom and disposing downstream).
3. Collect water into the one liter bottle for sampling.

Table A-3. Procedure for collection of groundwater.

1. Rinse one liter HDPE wide neck bottle with deionized water.
2. Rinse foot pump with deionized water.
3. Use foot pump to raise water from the well (ideally water from halfway between the bottom of the borehole and the water level in that borehole).
4. Pump water into wide neck bottle or bucket for sampling.

Table A-4. Procedure for moving water into sampling bottles.

1. Rinse another one HDPE liter wide neck bottle with deionized water
2. Pour water through a paper towel into the second bottle to remove the larger debris.
3. Using a 30mL syringe, remove water from filtered container.
4. Attach a 0.45 $\mu$ m Millipore filter to the syringe and then empty the contents into a 125mL sample jar.
5. Repeat until all four sample bottles have the proper amount of water in them.
6. Put sample bottles on ice for storage.

## Appendix B: Results

Table B-1. SKM Groundwater testing results for May/June 2006.

Parameter (mg/L)	SKM105B	SKM106A	SKM107A	SKM107B	SKM108A	SKM110A	SKM112A	SKM112B	ANZECC
Date sampled	6/06/06	30/05/06	29/05/06	29/05/06	30/05/06	31/05/06	1/06/06	1/06/06	-
Total Chlorine	0.02	0.06	0.28	0.01	0.03	0.04	0.00	0.00	<b>0.003</b>
TDS	1,380	729	814	557	589	135	946	561	<b>1,000</b>
Total Alkalinity	286	609	676	304	461	30	840	418	-
Bicarbonate	348	742	824	371	562	36	1020	509	-
Calcium	49.5	156	190	25.4	19.2	8.98	302	71.9	-
Magnesium	3.8	29.3	32.1	8.34	5.3	3.65	8.38	17.1	-
Sodium	375	73.5	70.2	142	166	8.9	19	83.5	<b>300</b>
Potassium	47.3	15.1	13.6	14.8	26.1	3.74	4.81	10.7	-
Chloride	259	21.4	24.9	68.5	76	15.5	13.2	27.8	<b>400</b>
Sulphate	303	0.8	<0.5	1.2	2.6	3	<0.5	<0.5	<b>400</b>
Nitrate-N	<0.002	<0.002	<0.002	<0.002	0.003	1.36	0.002	<0.002	<b>0.158</b>
Nitrite-N	<0.002	<0.002	<0.002	0.002	0.002	<0.002	<0.002	0.007	<b>1</b>
Total Phosphorus	0.169	0.299	0.71	0.501	2.88	0.015	0.122	0.404	<b>0.033</b>
Chlorate	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<b>0.8</b>
Total Sulphide	2.5	0.066	0.071	0.518	0.655	<0.002	0.231	0.117	<b>0.05</b>
Total Mercury	<0.00008	<0.00008	<0.00008	0.00071	0.0165	<0.00008	0.00016	0.00084	<b>0.0006</b>
Dissolved Manganese	0.909	2.08	3.08	1.63	1.59	0.0559	1.29	1.79	<b>0.1</b>
Dissolved Arsenic	0.171	0.007	0.053	0.01	0.063	<0.001	<0.001	0.005	<b>0.013</b>
Dissolved Boron	11.3	0.279	0.287	2.72	1.31	0.021	0.298	0.22	<b>0.37</b>
Dissolved Lithium	2.49	0.0604	0.117	0.601	0.824	0.0102	0.0202	0.128	<b>1</b>
Dissolved Barium	0.313	0.472	0.531	0.235	0.144	0.105	1.14	0.415	<b>0.7</b>
Dissolved Cadmium	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<b>0.0002</b>
Dissolved Chromium	<0.0005	<0.001	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	<0.0005	<b>0.001</b>
Dissolved Copper	0.0013	<0.0005	<0.0005	<0.0005	<0.0005	0.0018	0.001	<0.0005	<b>0.0014</b>
Dissolved Nickel	<0.0005	0.0014	0.0013	0.0066	0.0058	0.0008	0.0011	<0.0005	<b>0.011</b>
Dissolved Lead	0.0001	<0.0001	<0.0001	<0.0001	0.0004	0.0002	<0.0001	<0.0001	<b>0.0034</b>
Dissolved Selenium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<b>0.01</b>
Dissolved Zinc	<0.001	<0.001	0.003	<0.001	0.006	0.005	0.014	0.001	<b>0.008</b>

Table B-2. SKM groundwater testing results for October 2006.

Parameter (mg/L)	SKM105B	SKM106A	SKM107A	SKM107B	SKM110A	SKM110B	SKM112A	SKM112B	ANZECC
Date sampled	24/10/06	24/10/06	27/10/06	27/10/06	27/10/06	27/10/06	26/10/06	26/10/06	-
TDS	620	735	225	342	117	123	998	552	<b>1,000</b>
Total Alkalinity	513	364	103	189	17	21	897	456	-
Bicarbonate	625	444	125	230	21	26	1090	556	-
Calcium	19.4	10.5	25	59.7	5.34	1.98	342	79.1	
Magnesium	4.43	5.14	4.14	10.1	3.95	0.75	8.91	18.5	-
Sodium	148	176	24.7	23.9	9.30	13.7	20.4	88.4	<b>300</b>
Potassium	25.5	17.2	4.73	5.00	4.22	4.64	5.19	11.5	-
Chloride	81.5	128	10.2	10.9	21.7	11.7	13.9	27.5	<b>400</b>
Sulphate	3.4	6.5	25.0	48.3	3.9	4.0	<0.5	<0.5	<b>400</b>
Total Anions	12.6	8.42	2.87	5.09	1.12	0.88	18.3	9.9	-
Total Cations	11	9.04	2.78	4.98	1.10	0.87	18.8	9.61	-
Total Ammoniacal-N	40.8	13.8	0.15	0.40	<0.01	<0.01	<0.01	5.06	<b>0.021</b>
Nitrate-N	0.006	0.007	0.011	<0.002	1.19	0.616	<0.002	0.002	<b>0.158</b>
Nitrite-N	<0.002	0.003	0.012	0.022	<0.002	<0.002	<0.002	<0.002	<b>1</b>
Total Phosphorus	2.95	1.47	0.194	0.164	0.069	0.011	0.096	0.415	<b>0.033</b>
Total Sulphide	0.278	2.04	0.070	0.028	<0.002	<0.002	0.141	0.095	<b>0.05</b>
Total Mercury	0.00516	0.00036	<0.00008	<0.00008	<0.00008	<0.00008	<0.00008	0.00033	<b>0.0006</b>
Dissolved Manganese	1.38	0.803	0.556	0.853	0.0082	0.0014	1.37	1.92	<b>0.1</b>
Dissolved Arsenic	0.057	0.026	0.010	0.005	<0.001	<0.001	<0.001	0.008	<b>0.013</b>
Dissolved Boron	0.986	5.33	0.061	0.096	0.018	0.012	0.321	0.22	<b>0.37</b>
Dissolved Lithium	0.74	0.981	0.0398	0.0789	0.0072	0.0047	0.02	0.113	<b>1</b>
Dissolved Copper	<0.0005	0.0006	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<b>0.0014</b>
Dissolved Zinc	0.004	0.004	0.003	0.003	0.005	0.002	0.006	0.002	<b>0.008</b>
Formaldehyde	0.03	0.10	<0.02	0.03	0.04	<0.02	0.08	0.13	<b>1</b>

Table B-3. Frontiers abroad groundwater testing results from February 2009.

	Calcium	Potassium	Sodium	Zinc
Borehole	(mg/L)	(mg/L)	(mg/L)	(mg/L)
SKM106A	3.451	19.083	21.476	0.116
SKM106B	1.292	13.269	27.253	0.011
SKM107A	N/A	13.176	49.355	ND
SKM107B	2.076	13.782	44.061	ND
SKM108A	8.183	15.252	47.924	0.053
SKM108B	ND	27.862	56.613	0.038
SKM110B	ND	3.517	21.507	ND
SKM112B	23.154	10.937	51.674	0.035
ANZECC Guidelines	N/A	<b>300</b>	N/A	<b>0.008</b>



Table B-4. SKM surface water testing results for July 2006

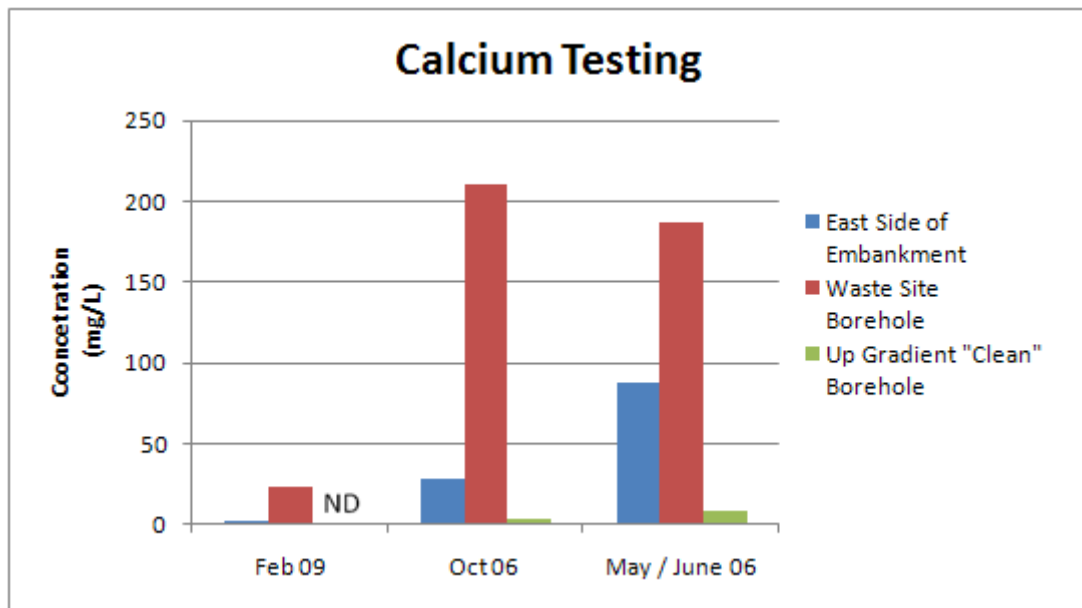
Parameter (mg/L)	River U/S	River D/S	ANZECC
Date sampled	1/06/2006	1/06/2006	-
TDS	254	243	1,000
Total Alkalinity	75	75	-
Bicarbonate	91	91	-
Calcium	6.15	6.2	-
Magnesium	4.83	4.9	-
Total Hardness	35	36	500
Sodium	49.3	48.5	300
Potassium	5.98	5.78	-
Chloride	40.1	40.6	400
Sulphate	16.5	16	400
Total Ammoniacal-N	<0.01	0.02	0.021
Nitrate-N	0.349	0.318	0.158
Nitrite-N	<0.002	<0.002	1
Total Phosphorus	0.066	0.068	0.033
Total Sulphide	0.015	0.009	0.05
Total Arsenic	0.026	0.028	0.013
Total Boron	-	-	0.37
Total Lithium	-	-	1
Total Zinc	0.004	0.013	0.008

Table B-5. SKM surface water testing results for October 2006.

Parameter (mg/L)	River U/S	River D/S	ANZECC
Date sampled	26/10/2006	26/10/2006	-
TDS	249	244	1,000
Total Alkalinity	84	84	-
Bicarbonate	102	102	-
Calcium	6.59	6.58	-
Magnesium	5.02	4.64	-
Total Hardness	37	36	500
Sodium	55.4	48.1	300
Potassium	5.98	5.85	-
Chloride	44.4	44.0	400
Sulphate	17.8	17.4	400
Total Ammoniacal-N	0.05	0.08	0.021
Nitrate-N	0.291	0.285	0.158
Nitrite-N	<0.002	<0.002	1
Total Phosphorus	0.07	0.077	0.033
Total Sulphide	0.011	0.012	.05
Total Arsenic	0.005	0.036	.013
Total Boron	0.696	0.641	0.37
Total Lithium	0.275	0.262	1
Total Zinc	0.003	0.002	0.008

Appendix C: Result graphs

Figure C-1. Sample testing results for Calcium.



\*ND denotes a level of contamination too low to be detected

Figure C-2. Sample testing results for potassium.

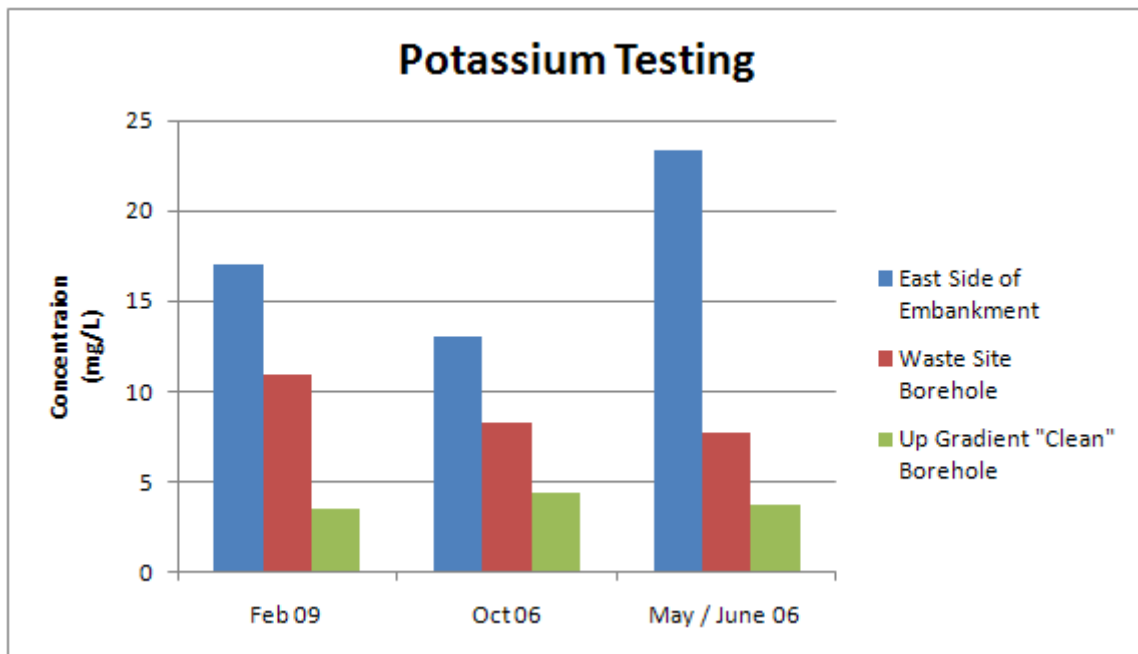


Figure C-3. Sample testing results for sodium.

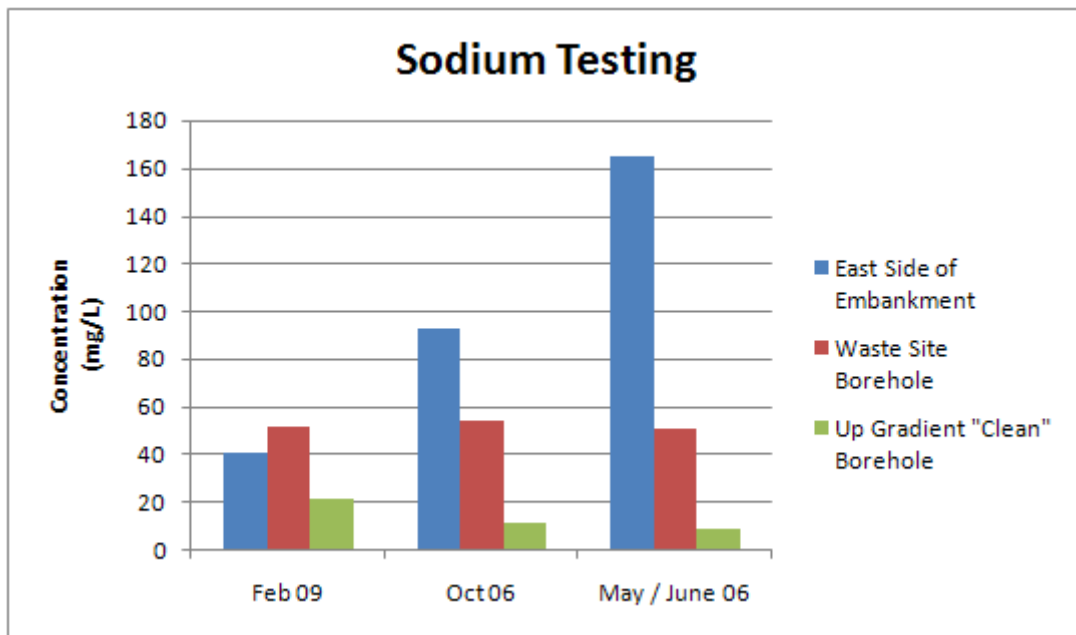
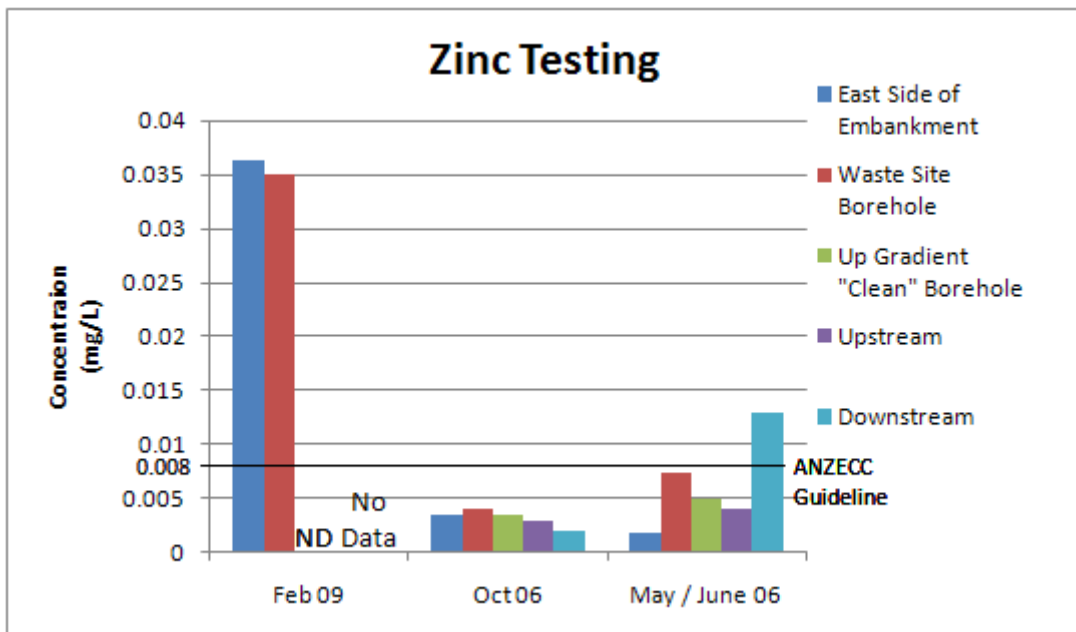


Figure C-4. Sample testing results for zinc including upstream and downstream sites.



\*ND denotes a level of contamination too low to be detected

Figure C-5. Sample testing results for total phosphorous including upstream and downstream sites.

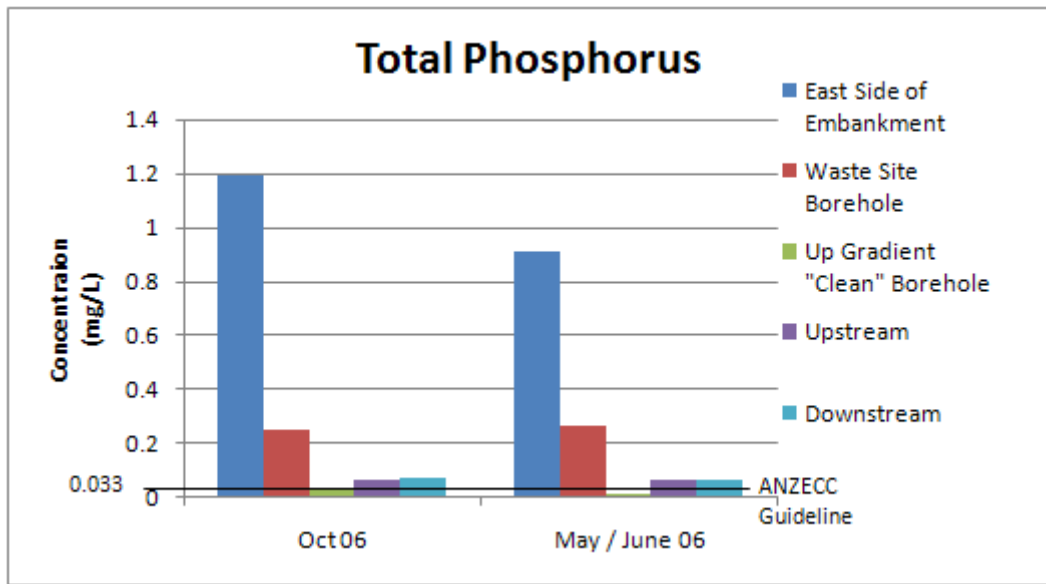
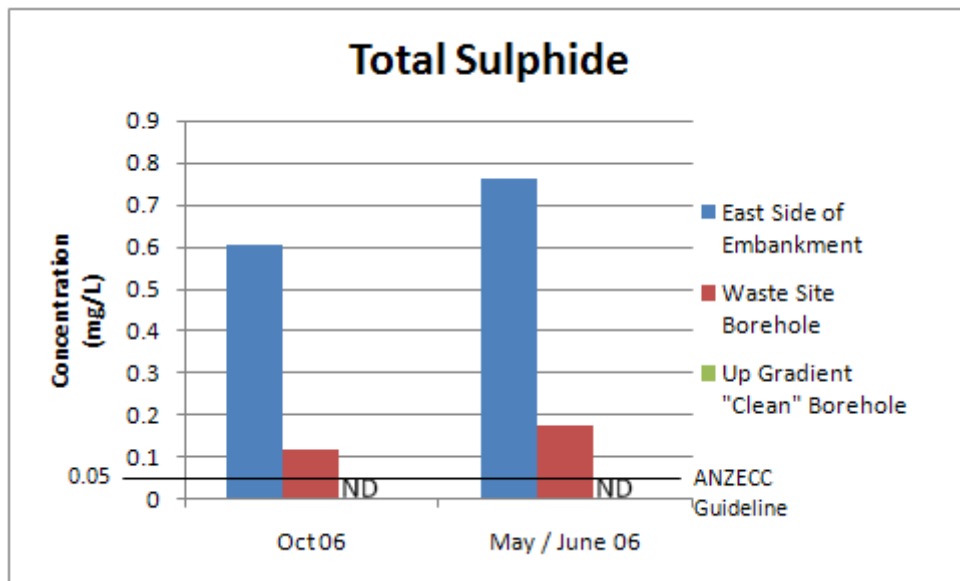


Figure C-6. Sample testing results for total sulphide.



\*ND denotes a level of contamination too low to be detected

Figure C-7. Sample testing results for dissolved manganese.

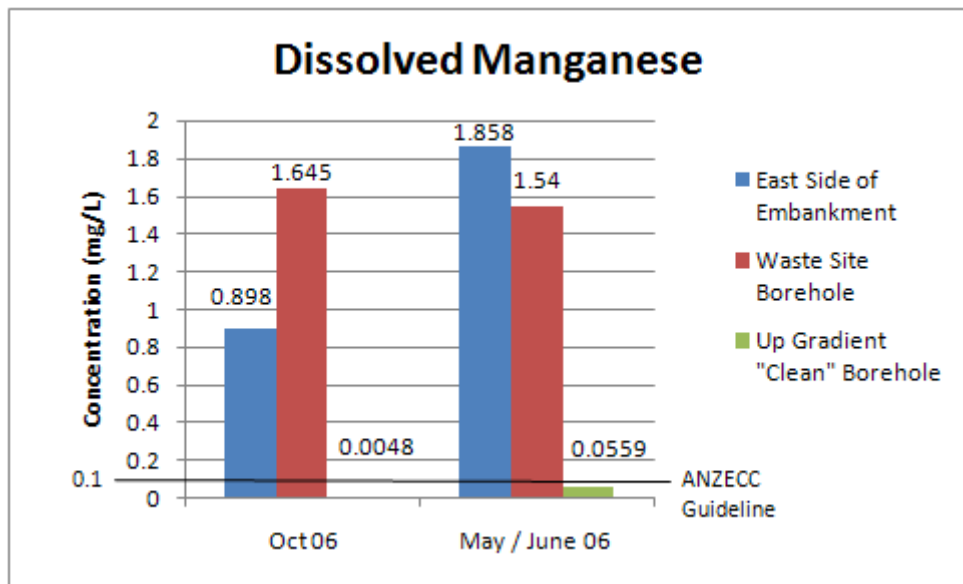
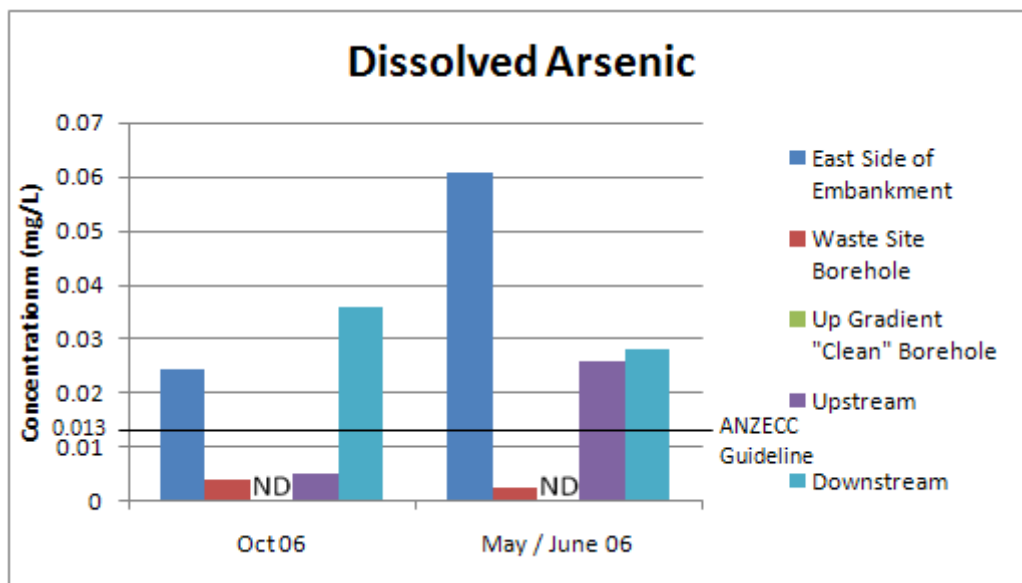


Figure C-8. Sample testing results for dissolved arsenic including upstream and downstream sites.



\*ND denotes a level of contamination too low to be detected

Figure C-9. Sample testing results for dissolved boron including upstream and downstream sites.

