Groundwater Monitoring Review Following Soil Remediation at the Mapua FCC Site

Prepared for

Tasman District Council

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1.0 Introduction

The Site Auditor's report for the remediation of the former Fruitgrowers Chemical Company (FCC) site at Mapua included the following recommendations regarding groundwater beneath and adjacent to the site:

- the installation of additional monitoring bores;
- monitoring of these bores at quarterly intervals for a 12 month period, with a review of the results and recommendations for ongoing monitoring at the end of the 12 month period;
- use all the available information to update the hydrogeological model for the site.

Tasman District Council (TDC) have managed the installation of the new monitoring bores and have undertaken sampling during November 2009, February 2010, May 2010, July 2010 and November 2010. Therefore, the purpose of this report is to review all the available information and to recommend a future monitoring regime to address ongoing groundwater issues at the site.

This report provides the following information:

- a description of the hydrogeologic model for the site and adjacent areas;
- the occurrence of contaminants within the strata;
- the results of the groundwater sampling that has occurred to date;
- recommendations to deal with ongoing groundwater issues.

Figure 1 shows the site location and the boreholes present within the site. Appendix B presents details from TDC of those boreholes that have been drilled most recently in response to the audit report.

2.0 Hydrogeologic Model

The natural strata that were originally present beneath this site comprised sandy gravels deposited within a marine and beach environment to a depth of around 2.3-8.5 metres. This strata forms a shallow unconfined aquifer that is underlain by lower permeability claybound strata of the Moutere Gravel. Groundwater levels fluctuate from around 0.5-3.0 m deep.

Figure 2 is a plan showing the original site layout and Figure 3 is a schematic geological cross-section from west to east showing the pre-remediation geology. Much of the natural strata located above and close to the water table has been excavated and reconstituted as part of the site remediation process.

Figure 4 shows the range of long-term groundwater level measurements that have been made at six on-site bores, along with an indicative measure of daily rainfall recharge, calculated from daily rainfall minus daily evapotranspiration as measured at the Mapua site on NIWA's cliflo database (located near Mapua Drive opposite the Seaton Valley Road intersection).

The relationship between rainfall recharge and groundwater is not precise, because groundwater levels were only measured on the site at either monthly or quarterly intervals and because there are many variable factors that influence the movement of rainfall down into the underlying groundwater. However, the data provides a useful indication of how infiltrating rainfall within the wider area causes the water table beneath the site to rise during times of higher rainfall (particularly during the low evaporation periods of winter and spring) and how the water table declines due to the process of natural groundwater throughflow when there is less infiltration recharge occurring.

The data within Figure 4 also shows the timing of two piezometric surveys that indicate the direction of groundwater flow. These are plotted in Figure 5a (early May 2010, a time of low groundwater levels) and Figure 5b (late July 2010, a time of high groundwater levels).

The piezometric surveys indicate the following groundwater flow characteristics:

- groundwater enters the site from throughflow from the land to the north of Aranui Road, as well as from the direct infiltration of rainwater from within the site soils;
- groundwater moves through the site and exits it to the following locations:
  - to the Mapua channel to the east;
  - to the western site drain and the Waimea Inlet to the south-west;
  - a small proportion of the site contributes to groundwater flow across the southern boundary of the site, which moves towards the west and eastern coastal margins of the Mapua peninsula.

The water table has a relatively flat hydraulic gradient across the northern inland part of the site (i.e. the northern section of the site adjacent to and west of Tahi Street) at around $2\text{-}3 \times 10^{-3}$. Towards the coastal discharge sections of the site, the hydraulic gradient steepens considerably to values of around 2×10^{-2} under low water level conditions (Figure 5a) and 5×10^{-2} at times of high groundwater levels (Figure 5b).

Values of hydraulic conductivity of the on-site strata have been measured using two different methods. Firstly, TDC undertook a series of slug tests at a number of the observation bores on-site. This involved the insertion or removal of a solid rod (the slug), which caused an instantaneous change in water levels. A summary plot of the water level changes is presented in Figure 6. This test involves only a small volume of aquifer strata and may be influenced by the backfill and filter fabric sock that was placed around the standpipes, particularly for those tests where the displacement of water is quite small.

Analysis of this test data reveals the hydraulic conductivity values shown in Table 1 and plotted in Figure 7.

Table 1. Summary of Slug Test Analyses

Bore	Initial Water Level (mbgl)	Displacement Falling Head (m)	Displacement Rising Head (m)	Top of Screen (mbgl)	Base of Screen (mbgl)	Kr (m/day) for falling head test (NB: Kr is for a well that terminates at the lower impermeable boundary)	Kr (m/day) for rising head test (NB: Kr is for a well that terminates at the lower impermeable boundary)
BH113	1.362	0.254	-0.554	1	6	0.59	0.83
BHL	0.58	0.703	-0.844	1	6	0.89	1.62
BH 105	1.249	0.401	-0.818	1	6	0.31	0.42
BH1A	2.101	0.988	-0.959	1	6	0.53	0.58
BH 106	1.627	0.257	-0.272	1	6	0.70	0.85
BH 103	0.898	0.469	-0.486	1	6	0.18	0.25
BH 108	1.855	0.69	-0.449	1	6	0.20	0.27
BH 107	1.519	0.348	-0.224	1	6	6.87	8.88
BH 111	2.972	0.593	-0.734	1	7	0.19	0.16
BH D	2.16	1.012	-0.214	1	6	1.86	0.39
BH 2A	1.83	0.905	-1.059	1	6	0.36	0.37
BH 110	2.381	0.471	-0.892	1	6	0.08	0.11
BH 5A	1.018	0.98	-1.188	1	6	0.14	0.08
BH102	0.665	0.557	-0.554	1	6	0.33	0.25

The highest hydraulic conductivity of 6-9 m/day in BH107 may be attributed to the occurrence of a nearby permeable rubble filled zone of backfill in the area and a notable loss of drilling circulation water at a depth of 1.8 m. Other monitoring bores have lower and more consistent hydraulic conductivities in the range from 0.08-1.9 m/day with a geometric mean of 0.35 m/day.

A larger scale check on these hydraulic conductivity values has been obtained by monitoring the range of tidally induced water level fluctuations between the Mapua channel and three nearby monitoring wells: BHD, BH1A and BH110. The measured levels are plotted in Figure 8 and indicate a significantly larger tidal wave amplitude in the sea (around 3.06 m) compared to that observed in the groundwater. The details of the groundwater level records are summarised in Table 2.

Table 2: Summary of Tidally Induced Water Level Fluctuations

Monitoring Borehole	**BHD**	**BH1A**	**BH110**
Typical distance from coast (m)	17	24	65
Typical amplitude of tidally induced fluctuation (m)	0.36	0.30	0.05
Apparent tidal efficiency (ratio of groundwater fluctuation to sea level fluctuation)	11.8%	9.9%	1.5%
Average lag time between sea and groundwater peaks and troughs (minutes)	78	92	199

The data has been analysed using a method for an unconfined aquifer which is bounded on one side by a changing head boundary, as shown in Appendix D.

If a typical storage coefficient value for an unconfined aquifer of 0.1 is assumed, the analysis indicates a hydraulic conductivity of the strata in the range from 7 m/day to 85 m/day, which is around an order of magnitude greater than the slug test results.

To check on the appropriateness of these values, an indicative water balance calculation of annual water throughflow has been undertaken. The discharge across the coastal boundaries of the site occurs over a length of 130 m for each of the coastal boundaries and a typical hydraulic gradient for much of the site is around 3 x 10^{-3}. Assuming a mid-range hydraulic conductivity of 50 m/day (as indicated by the analysis of the tidal fluctuations) gives an annual rate of throughflow of 14,235 m^3/year per m thickness of strata or 71,175 m^3/year for the 5 m thick aquifer.

As a further check on the overall water balance, the annual rainfall for the site over the last seven years is around 950 mm and an indicative water balance suggests that the infiltration recharge to the groundwater for an undeveloped vegetated site would be around 350 mm per annum. Over the 3.6 ha site, this corresponds to 12,600 m^3 per annum, with the majority of infiltration occurring during the winter and spring months. These water balance numbers suggest that the higher hydraulic conductivity values indicated by the tidal analysis are more likely to be correct for the bulk groundwater flow values because the lower slug test numbers would not be able to accommodate the annual rate of infiltration recharge.

Therefore, an indicative water balance for the site would suggest that typical throughflow from areas upgradient of the site is in the order of 60,000 m^3/year, with additional input of local rainfall of around 12,000 m^3/year.

It is inferred that the slug test results indicate the hydraulic conductivity of the localised strata immediately surrounding the well screens showing values of 0.08-9 m/day, equivalent to what would be expected for a silty sand. The tidal analysis provides a measure of the bulk strata including some high permeability rubbly zones which were placed as backfill, resulting in bulk average hydraulic conductivity values for all the strata in the range of 10-100 m/day, equivalent to clean sand deposits.

3.0 Occurrence of Contaminants Within the Strata

The main contaminants of concern that are present within the site soils are:

- organochloride pesticides (OCPs) from the original FCC activities (particularly DDT, DDD and DDE (DDX) and aldrin, dieldrin and lindane (ADL));
- nitrogen compounds (due to the use of diammonium phosphate and urea as re-agents in the remediation process).

The main contaminants occur in two different soil types within the site:

- the original site soils with concentrations of contaminants that meet the "Soil Acceptance Criteria" for areas of commercial land use (i.e. DDX <200mg/kg and ADL <60mg/kg). These soils are referred to as "Commercial" material;
- soils that have passed through the MCD remediation process. These soils are referred to as "Treated Fines" because pre-processing of the soils ensured that only the finer fraction (<5mm) entered the MCD reactor.

Table 3 shows the measured concentration of the main contaminants in the soils that have been distributed across the site as a result of the remediation process.

Table 3: Soil Concentrations at the Remediated Site (mg/kg)

	Commercial	Treated Fines	Treated Fines + Oversize	Treated Fines + Oversize + Commercial	Treated Fines + Oversize + Foreshore Sediments
DDX - samples collected prior to their placement within the remediated site	41[1]	123[2]	141[3]	79[3]	-
- *validation samples[4]*					
(average)	*75*	*96*	-	*64*	*56.5*
(range)	*(16-199)*	*(60-110)*	-	*(1.3-107)*	*(27-104)*
(# of samples)	*14*	*6*	-	*22*	*5*
ADL - samples collected prior to their placement within the remediated site	4[1]	12[2]	-	8[3]	-
- *validation samples[4]*					
(average)	*10*	*10*	-	*5*	*4*
(range)	*(1-24)*	*(6-13)*	-	*(0.3-14.3)*	*(2.4-8)*
(# of samples)	*14*	*6*	-	*22*	*5*
Ammonia-N					
- *validation samples[4]*					
(average)	-	*4084*	-	*933*	*776*
(range)	-	*(2110-8300)*	-	*(189-2000)*	*(229-1700)*
(# of samples)	-	*5*	-	*16*	*4*
Nitrate-N					
- *validation samples[4]*					
(average)	-	*90*	-	*43*	*9.6*
(range)	-	*(12-200)*	-	*(2.5-250)*	*(2.0-22)*
(# of samples)	-	*5*	-	*16*	*4*
Total N					
- *validation samples[4]*					
(average)	-	*4967*	-	*1890*	*1400*
(range)	-	*(3500-6900)*	-	*(600-3600)*	*(1200-1600)*
(# of samples)	-	*3*	-	*10*	*2*

Notes for Table 3:

1. From Mapua site spreadsheet entitled "Reburial with commercial 18 August 2007".
2. From Mapua site spreadsheet entitled "MWH DE table – 21 July 07 with averages".
3. Calculated using the approach set out in Peter Nadebaum's memo to Kim Morgan dated 19 September 2007.
4. Concentrations from in situ validation samples collected by MfE and GHD on 30/04/2007.

Figures 9, 10 and 11 have been prepared to provide an indication of the placement of these main contaminant source materials relative to the water table, based on the reasonable interpretation of the currently available information and the piezometric contour maps at times of low and high groundwater levels (Figures 5a and 5b).

Figure 9 shows the position of the Treated Fines cells with no mixing from other site materials. This is the most concentrated source of contaminants, as shown in Table 3. Figure 9 indicates that to the east of Tahi Street these materials mostly occur above the lowest water table location, but are present in some locations at elevations where they can be inundated by the water table. They also occur in a small area of the western site, where they are often inundated by groundwater.

Figure 10 shows the placement of Treated Fines materials which are mixed with other site materials (oversize, commercial or foreshore sediments). As shown in Table 3, this mixing reduces the overall contaminant concentration. Figure 10 indicates that these Treated Fines mixtures represent a larger volume that occurs below the water table or at a depth where they can be inundated by the water table from time to time, particularly in the eastern part of the site, but not the soils closest to the Mapua Channel.

Figure 11 shows the placement of Commercial material with no Treated Fines present. This represents a lower concentration source material of OCPs compared to the Treated Fines and is not expected to contain significant quantities of nitrogen. The commercial material is placed on the eastern side of the site, with around half of the area containing this material indicated to contain some material below the water table.

Table 4 summarises the placement of the backfill contaminant sources relative to the water table. It provides a preliminary indication of the likely contaminant sources in each cell and whether they are likely to be an intermittent source (placed above the range of water table fluctuations) or a more continuous source of contaminants leaching into the groundwater.

Table 4: Summary of Ongoing Sources of Groundwater Contamination Based on Indicative Water Table Information						
Backfill Cells (as shown in Figures 9-11)	**Contaminant Source for:**		**Placement Location**			**Timing of Placement**
	OCPs	**N**	**Permanently Below Water Table**	**Intermittently Below Water Table**	**Above Water Table**	
FCC East						
Treated Fines (Unmixed)						
SG2	Yes	Yes	No	Yes	No	April 2005
SG6	Yes	Yes	No	No	Yes	July 2005
SG20	Yes	Yes	No	Yes	Yes	May 2005
Treated Fines Mixed with Other Materials						
SG3	Yes	Yes	No	No	Yes	May 2005
SG4	Yes	Yes	Yes	Yes	No	June 2005
SG7	Yes	Yes	No	Yes	Yes	July 2005
SG8	Yes	Yes	Yes	Yes	No	October 2005
SG12	Yes	Yes	Yes	No	No	November 2005
SG14	Yes	Yes	No	No	Yes	August 2005
SG16	Yes	Yes	No	Yes	Yes	November 2005
SG17	Yes	Yes	Yes	No	No	?
SG20	Yes	Yes	Yes	Yes	No	May 2005
Commercial Material						
SG2	Yes	No	Yes	No	No	April 2005
SG4	Yes	No	Yes	No	No	June 2005
SG5A	Yes	No	No	No	Yes	June 2005
SG5B	Yes	No	No	No	Yes	June 2005
SG5C	Yes	No	No	No	Yes	June 2005
SG6	Yes	No	No	No	Yes	July 2005
SG7	Yes	No	No	No	Yes	July 2005
SG9	Yes	No	No	No	Yes	July 2005
SG11	Yes	No	No	No	Yes	July 2005
SG17	Yes	No	Yes	No	No	?
FCC West						
Treated Fines (Unmixed)						
SG19A	Yes	Yes	Yes	Yes	No	February 2007
SG19B	Yes	Yes	Yes	Yes	No	February 2007
SG19C	Yes	Yes	Yes	No	No	March 2007
Treated Fines Mixed with Other Materials						
SG18	Yes	Yes	Yes	Yes	No	?

The location of the MCD reactor was in the vicinity of BH106 and associated stockpiling of re-agents and treated soils provide another, more temporary, source of contaminants that could have leached into the underlying soils and groundwater (although the most affected soils have now been removed from this area).

In addition to the main OCP and nitrogen species contaminants, phosphorous, copper and iron are also present in the Treated Fines as a result of the remediation process.

All these contaminants are attached to soil particles, but will leach into groundwater as water passes across the soil surface either as rainfall infiltrating downward through the soil or as saturated groundwater that inundates the soil. Once in the groundwater, the contaminants will migrate with the groundwater flow in the direction shown in Figures 5a and 5b. The concentrations in groundwater will vary depending on the rate of groundwater movement across the affected soils and the relative chemical composition of the soil and the groundwater. The movement of the contaminants within the groundwater creates the following issues:

- migration of contaminants onto the mudflat and marine environments of the Waimea Inlet and the Mapua Channel;
- migration of contaminants into the western drain and then to the Waimea Inlet;
- migration of contaminants to other properties to the south of the site, some of which contain abstraction bores, although none of these bores are used for potable purposes as TDC have provided the area with a reticulated drinking water supply.

The results of the monitoring bore sampling provides a measure of the contaminant migration that is occurring in the groundwater.

4.0 Results of Groundwater Sampling

4.1 Regularly Sampled Bores

Five bores located within and adjacent to the site have been sampled to determine long-term trends during and following the remediation process. Figure 1 shows the location of these longer term monitoring bores. BH1A and BH2A are upgradient of the eastern groundwater discharge to the Mapua channel. BH5A and BH9A are upgradient of the south-western groundwater discharge into the Waimea Inlet. The bore at 13 Tahi Street is the nearest private bore downgradient of the site.

Figures 12-19 show the long-term water quality trends in these bores. Earlier sampling that was carried out in January and April 2008 has included three nearby pairs of boreholes: BH1/BH1A, BH5/BH5A and BH9/BH9A. On occasions when both pairs of bores have been sampled, the points from these adjacent boreholes have been joined by a vertical line to indicate how similar or different they are. The following comments apply to these long-term trends:

- Figure 12 shows nitrate-nitrogen concentrations. Three boreholes have historically shown elevated concentrations: BH2, BH5 and BH9. Since late 2007, concentrations have decreased substantially, which coincides with the cessation of the MCD reactor in mid-2007. Despite this general decline, BH5 continues to show significantly elevated concentrations. At the present time, only BH9 and BH5 currently have nitrate-N concentrations above the Maximum Acceptable Value in the Drinking Water Standards for New Zealand 2005 (Revised 2008). BH5 is located downgradient of an area of mixed Treated Fines (Figure 10). From 2004 until late 2007 BH9 is reported to have had a broken well casing and received direct inflows of stormwater around the well casing which will have impacted on groundwater quality data from this borehole around that time. In more recent times, BH9 could be showing the effects from the Treated Fines buried in the western portion of the site (Figure 9). Figure 12a shows the boreholes that have typically displayed lower nitrate-N concentrations. Both BH1 and 13 Tahi Street remain at stable, low concentrations;
- Figure 13 shows ammonia-nitrogen concentrations. BH1, BH2 and BH5 have all had elevated concentrations which have reduced significantly from those peaks since 2006-2008. Despite these declines, BH1 and BH2 still show high concentrations of 60 g/m^3 and 32 g/m^3 relative to guidelines for drinking water aesthetics (0.3 g/m^3) and ecosystems (0.71 g/m^3). Both these boreholes are located downgradient of the Treated Fines placed in the eastern site (Figures 9 and 10). Those bores with lower ammonia-N concentrations (Figure 13a) show decreasing concentrations in BH5, BH9 and 13 Tahi Street. BH9 currently shows the highest concentration of this group at 1.8 g/m^3;
- Figure 14 shows dissolved reactive phosphorous concentrations, which are most elevated in BH2, currently at 7.7 g/m^3, but have decreased from their former peak;
- Figure 15 shows DDX concentrations for the isomers 2,4'-DDD, 4,4'-DDD, 4,4'-DDE and 4,4'-DDT. Most bores show decreasing concentrations, although BH1 and BH5 remain elevated above the Drinking Water Standards health based MAV of 0.001 g/m^3 for DDT and its isomers, with BH2 showing lower but variable concentrations;
- Figure 16 shows ADL concentrations. These concentrations continue to show a relatively stable pattern, with no significant declining trend. BH5 and BH2 show the most elevated concentrations, with BH9 at lower values. All values in Figure 16 currently sit above the Drinking Water Standards health based MAV of 0.00004 g/m^3 for aldrin and dieldrin, the most elevated concentrations occurring in BH2 and BH5;
- Figure 17 shows electrical conductivity values, which are a general indicator of all the chemicals dissolved in the water. These show a decrease from high values that occurred from 2005-2008 with relatively lower stable values over the last 12 months. The comparison between current values at 13 Tahi Street (235 μS/cm) relative to the on-site bores (1,373-2,780 μS/cm) indicates the significantly higher concentration of chemicals dissolved in groundwater beneath the site;

- Figure 18 shows dissolved copper concentrations. Copper was one of the reagents used in the MCD process. The results show currently stable concentrations at values that are generally above the ANZECC marine ecosystem guidelines of 0.0013 g/m³;
- Iron was also utilised in the MCD process, but has only been sampled since January 2008. The results are shown in Figure 19. Detectable concentrations only occur in BH1A, which has shown quite variable but decreasing concentrations.

The results generally show some highly elevated groundwater concentrations during the period from 2006-2008, with decreasing and more stable concentrations since the end of the remediation works in late 2007. In the post remediation period, fluctuations in chemical concentrations show variable trends with regard to groundwater levels.

Figure 20 shows the variation in groundwater levels and DDX, indicating that following the completion of the MCD treatment process (mid-2007), higher concentrations occur at times of higher groundwater levels, which is most likely due to a greater degree of leaching by infiltrating rainwater and a greater volume of Treated Fines and commercial grade soils inundated below the water table.

In contrast, Figure 21 suggests that in the post-remediation period, higher concentrations of ammonia occur at times of lower groundwater levels. It is assumed that these different patterns relate to the differing factors affecting the inputs of leachate from the affected soils and the diluting effect of throughflow that has not passed through the contaminants. In particular, the nitrogen species are more readily leached into the groundwater and at times of low water levels, those chemicals present in the groundwater will be more concentrated. Furthermore, redox conditions are more likely to favour the occurrence of nitrogen in ammoniacal form. DDX compounds are likely to preferentially adsorb onto the soil particles and so will be most prevalent in groundwater during the most active conditions of water throughflow.

4.2 Sampling of Additional Bores

The installation of additional bores and the more stable pattern of chemical concentrations over the last 12 months allows a more detailed picture of the distribution of chemicals within the area to be defined. Figures 22-30 have been prepared to show the patterns that exist. In addition to the borehole samples, data is also presented of samples collected from groundwater seepage on the coastal mudflats at the eastern and south-western boundaries of the site. There is a degree of uncertainty about the mixing and dilution of these samples with sea water in the seepage areas, therefore the results only provide a very broad scale indication of potential contaminant movement into the coastal environment.

In most of these plots, the highest concentrations occur at BH101, which is located within the former landfill area that now contains commercial grade material, including Treated Fines. BH101 is located immediately west of the clay bund that bounds the former landfill area and is not considered representative of groundwater moving beneath most of the site. Therefore, the following comments relate to other bores.

- **Nitrate-Nitrogen**

  Figure 22 shows the nitrate-nitrogen concentrations, which have been colour coded as follows:

  - green – less than half the Maximum Acceptable Value (MAV) in the Drinking Water Standards (<5.7 mg/L);
  - orange – between half the MAV and the full MAV of 11.3 mg/L;
  - red – greater than the MAV.

  Low nitrate concentrations generally occurring within the eastern part of the site. More elevated nitrate-nitrogen concentrations occur within the western portion of the site, in areas downgradient of Treated Fines placed on the western portion of the site (Figures 9 and 10). The exception to this is the elevated value at BH108 on the eastern part of the site adjacent to the northern end of Tahi Street, which is located adjacent to Treated Fines shown in Figures 9 and 10. The highest concentration during the November 2010 sampling round was 310 g/m^3 in BH102.

  Only very low nitrate concentrations were present in the west and east seepage samples collected from groundwater seepage on the exposed mudflats.

- **Ammonia-Nitrogen**

  Figure 23 shows the ammonia-nitrogen concentrations, which have been colour coded as follows:

  - green – less than the aesthetic guideline value in the Drinking Water Standards (<0.3 mg/L);
  - orange – between the aesthetic guideline value in the Drinking Water Standards and a significantly elevated value of 10 mg/L of aquatic ecosystems;
  - red – above a significantly elevated value of 10 mg/L.

  The results show elevated concentrations occur in both the east and west of the site, with the highest concentration of 620 mg/L occurring at BH111.

  Elevated ammonia-N at a concentration of 2 mg/L was collected from groundwater seepage from the mudflats of the Waimea Inlet. This is above the ANZECC marine guideline of 0.71 g/m^3. It is interesting to note that the concentration in the seepage sample is higher than the ammonia-N concentration of boreholes BH3A and BH5a. These two boreholes do however show elevated nitrate concentrations, particularly BH5a and it is possible that conversion of nitrogen from nitrate to ammonia is occurring in the mudflat environment.

  A comparison between Figures 22 and 23 indicates a predominance of ammonia in the eastern part of the site, suggesting a more reducing chemical environment, possibly due to the greater amount of Treated Fines in that area (Figures 6 and 7). Figures 22 and 23 also indicate no significant migration of nitrate or ammonia in a southerly direction to affect bores further down Tahi Street.

- **Total Nitrogen**

  Figure 24 shows the total Nitrogen concentrations, which have been colour coded as follows:

  - green – <5 mg/L, which is above the ANZECC guideline value for marine water of 0.12 mg/L;
  - orange – between 5 and 20 mg/L;
  - red – greater than 20 mg/L.

  As with the ammonia-nitrogen concentrations, there have been variable changes between the boreholes.

  The results indicate that the vast majority of on-site bores have elevated nitrogen concentrations.

- **Dissolved Reactive Phosphorous**

  Phosphorous is the other nutrient (in addition to nitrogen) that contributes to algal growth problems in surface waterways. Diammonium phosphate was used as one of the re-agents used in the remediation process (along with urea).

  Figure 25 shows the DRP concentrations, which have been colour coded as follows:

  - green – less than the ANZECC guideline value for marine water (<0.01 mg/L);
  - orange – between the ANZECC guideline value and one hundred times the ANZECC guideline value;
  - red – more than 100 times above the ANZECC guideline value (>1.0 mg/L).

  Variable concentrations occur across the site, with some low and non-detectable values, and the bores showing localised high concentrations (up to 31 mg/L at BH110). The upgradient bore (BH113) and bores to the south of the site indicate that naturally occurring DRP concentrations can occur in this area up to 10-20 times above the marine water guideline.

  DRP seepage on the eastern mudflats was measured at 0.036 g/m^3, which is above the ANZECC guidelines.

- **DDX**

  Figure 26 shows the DDX concentrations (for six isomers), which have been colour coded as follows:

  - green – close to or less than the laboratory detection limit (<0.00006 mg/L);
  - orange – greater than the laboratory detection limit and below the MAV in the Drinking Water Standards;
  - red – greater than the MAV in the Drinking Water Standards (>0.001 mg/L).

  The results show variable DDX concentrations within the site. The highest concentrations occur in the east, where both Treated Fines and commercial grade soils are located (Figures 9-11). Elevated concentrations also occur in the west in

BH4a and BH5a, downgradient of the Treated Fines shown in Figures 9 and 10. The highest concentration occurs in BH108 at 0.0083 g/m³.

Only low concentrations (<0.00008 g/m³) were recorded in the coastal seepage sampling.

- **ADL**

Figure 27 shows the ADL concentrations, which have been colour coded as follows:

- green – close to or less than the laboratory detection limit (<0.000006 mg/L);
- orange – above the laboratory detection limit but below a value midway between the MAV in the Drinking Water Standards for aldrin and diedlrin and the MAV for lindane;
- red – elevated concentrations above 0.001 g/m³.

As with DDX, the results show variable concentrations within the site, but with higher values on the eastern side of the site. The highest concentration occurs at BH103 (0.014 g/m³) located at the southern end of the site near Tahi Street. There is no reported placement of Treated Fines or commercial soil near this site, and the elevated ADL may be related to residual effects from stockpiled soils in this area and/or due to the original FCC activities that occurred in the area – the solution mixing sump is reported to have been located in the south-east corner of the FCC West site. Also, these original site activities included the installation of a subsurface gravel drain near BH107, under Tahi St , that reportedly allowed factory stormwater from the south-east corner of the FCC East site to pass across into the western site.

Only low concentrations of ADL (<0.00005 g/m³) were collected in the coastal seepage samples.

During the November 2010 sampling round, five of the bores to the south of the site have shown low concentrations of Lindane (0.000013-0.000021 g/m³), which is close to the laboratory detection limit of 0.00001 g/m³. This is a higher concentration than has been measured previously, but it is not expected that Lindane would have migrated from the site in the absence of other more mobile chemicals (such as the nitrogen species). It seems most likely that some sample contamination has occurred, either from the sampling procedures (all the affected samples were collected at a similar time from 13:05-14:35 on 09/11/2010) or from the laboratory equipment.

A rinsate blank was collected at 13:20 on 10/11/2010 using tap water pumped from plastic water containers into sample bottles in the same manner as the collection of the groundwater samples. This showed a detection of Lindane at a concentration of 0.00005 g/m³ and provides further indication that some contamination within the sample collection system has occurred. Analysis of a trip blank showed no detectable Lindane, indicating that the problem did not originate in the bottles sent out from the laboratory.

It would be prudent to re-sample these bores for Lindane during the next sampling round, using rigorous sampling protocols, to confirm that these detections are not part of the groundwater system.

- **Conductivity**

  Figure 28 shows the pattern of electrical conductivity values in the groundwater. This is a general indication of all the chemicals dissolved in the groundwater. The following colour coding has been used:

  - green – typical background values (<30mS/m);
  - orange – moderately elevated values (30-100 mS/m);
  - red – highly elevated values (>100 mS/m).

  This plot demonstrates the presence of elevated values beneath the site and in 15 Tahi Street (adjacent to the site). Some slightly elevated conductivity values occur in some boreholes to the south of the site (21, 23 and 29 Tahi Street). They could be affected by local land use influences around the bores, seawater effects and/or the general movement of groundwater from the site, although based on Figures 22-27, there are no specific chemicals from the site works that are causing elevated conductivity values in any of the Tahi Street bores that show elevated conductivities.

  The coastal seepage samples have very high electrical conductivity values, indicating the presence of sea water within the samples that have been collected.

- **Copper**

  Figure 29 shows the pattern of copper concentrations, which have been colour coded as follows:

  - green – less than the ANZECC guideline value for protection of 95% of species in marine water (<0.0013 mg/L);
  - orange – between the ANZECC guideline value and ten times the ANZECC guideline value;
  - red – greater than 10 times above the ANZECC guideline value.

  The results show low to moderate concentrations generally occur within the groundwater beneath the site, with an elevated hot spot at BH108. Whilst some of the off-site bores show copper concentrations above the ANZECC marine guideline values, these are not expected to be due to site activities due to the similar, or lower, concentrations beneath the site and the absence of elevated concentrations of more mobile species that are present beneath the site such as nitrate and/or ammonia.

  No detectable copper concentrations were present in the coastal seepage samples.

- **Iron**

  Figure 30 shows the pattern of iron concentrations in the groundwater, which have been colour coded as follows:

  - green – below the laboratory detection limit (<0.02 mg/L);
  - orange – above the laboratory detection limit, but below the aesthetic guideline value in the Drinking Water Standards;
  - red – greater than the aesthetic guideline value in the Drinking Water Standards (>0.2 mg/L).

  The results show generally low concentration across the site, although significantly higher values occurred at BHG and BH111. Elevated iron can occur if any suspended sedimentary particles become incorporated into the sample, and both these bores show elevated values at 260 and 650 NTU respectively. Anoxic groundwater conditions associated with organic rich sediments can also contribute to iron being dissolved in the groundwater.

  The detectable iron concentrations in wells further down Tahi St indicate the natural occurrence of iron within this groundwater system (TDC report that this is a common issue with the general Mapua area) and there are no significant off-site effects expected due to the use of iron in the MCD process.

  No detectable iron was present in the coastal seepage samples.

4.3 Overview of Groundwater Sampling Results

The patterns shown in Figures 22-30 indicate a continuing impact from the site soils on the underlying groundwater within the site boundaries. In particular:

- nitrogen (mostly nitrate in the west and ammonia in the east);
- DDX;
- ADL

are all elevated within the site groundwater.

Isolated occurrences of elevated concentrations of phosphorous, copper and iron also occur within the site, but are less significant, less widespread and may in part be present in the natural groundwater and/or sediment of the area.

There is no indication of significant downgradient migration effects into private bores to the south of the site. It is expected that most of the chemicals dissolved in the groundwater migrate into the marine environments of the Mapua channel (east of the site) and the Waimea Inlet (south west of the site).

4.4 Mass Flux

Based on the assessment of groundwater throughflow and measured concentrations, an estimate of the mass flux discharging from the site can be made. In Section 2.0, it was noted that the field testing for hydraulic conductivity indicated two different ranges of values, one representative of the finer grained strata around the boreholes (around 0.35 m/day) and a larger bulk value representing the overall groundwater flow through the site, including permeable rubbly zones that were placed as backfill around the remedial works. When considering the mass flux of contaminants that may be emanating from the site, it is considered most appropriate to use the lower hydraulic conductivity values that are representative of the strata from where the contaminant concentrations have been measured. Based on that approach, the following mass flux values have been estimated from the following assumptions:

- Throughflow:
  - East to the Mapua channel = 0.35 m/day x 3 x 10^{-3} x 130 m x 5 m

    = 0.68 m^3/day
  - South-west to the Waimea inlet = 0.35 m/day x 3 x 10^{-3} x 130 m x 5 m

    = 0.68 m^3/day
- Groundwater concentration:
  - East to the Mapua channel = average of BHD, BH112, BH1, BH2
  - South-west to the Waimea inlet = average of BH3, BH5, BHG, BH9.

These assumptions lead to the following mass fluxes based on the November 2010 sampling round.

Table 5: Mass Flux Estimates at November 2010

Contaminant	Eastern Discharge to Mapua Channel		South-Western Discharge to Waimea Inlet	
	Average Concentration (g/m³)	Mass Flux (g/year)	Average Concentration (g/m³)	Mass Flux (g/year)
Total Nitrogen	91	22,600	47	11,700
DDX	0.0008	0.2	0.0016	0.4
ADL	0.0011	0.3	0.0008	0.2

There are a number of assumptions that are made in these calculations which make their accuracy no more than a very broad ballpark indication. However, it is instructive to demonstrate that the major contaminants carried by the groundwater are the nitrogen species, with the organo-chlorine compounds at much lower loadings. It is also worth noting that the rate of groundwater seepage entering the Mapua channel and the Waimea inlet is very small compared to the tidally controlled surface water flows within those water bodies. Therefore, there is significant dilution within the surface water environment. The main environmental issues that could require consideration from the discharges are likely to arise on the beach and mudflat environments (prior to significant sea water dilution) where nitrogen could contribute to algal growths and the organo-chlorine compounds could accumulate due to adsorption onto sediments, albeit at a very low and slow rate.

If the infiltration of rainwater through the site soils could be reduced during future site re-development work, it should lessen the mass of contaminants leaching into groundwater and discharging to the coastal environment. This reduction in infiltration is likely to be achieved to some extent through the site re-development which will lead to less permeable ground cover as a result of increased roofs and paved surfaces. It will be important to ensure that any works undertaken as part of the site development do not create a more direct discharge pathway for water to infiltrate into the ground. Furthermore, any excavations that expose shallow contaminated groundwater must include special management measures to ensure that exposure to, or spread of, those contaminants is avoided

5.0 Recommendations for Ongoing Monitoring

The Site Auditor's report recommends that the groundwater monitoring information that has been gathered to date should be used to review the frequency of sampling to be undertaken in the future. The bores that have been monitored to date can be placed in the following groups:

1. **Upgradient control:**
   - BH113
2. **Long-term monitoring sites:**
   - East: BH1a, BH2a, 13 Tahi Street
   - West: BH5a, BH9a
3. **Internal site monitoring bores:**
   - East: BH108, BH109, BH110, BH111
   - West: Old BH1, BH101, BH102, BH104, BH105, BH106

4. **Monitoring of water exiting the site:**
   - To the east (into the Mapua channel)

     BHD

     BH112

     East estuary coastal seepage
   - To the south (down Tahi Street)

     BH103

     BH107

     BHH
   - To the south-west (to the Waimea Inlet)

     BH3a

     BH4a

     BHG

     West estuary coastal seepage
5. **Nearby bores to the south of the site:**
   - BHL
   - 15 Tahi Street
   - 21 Tahi Street
   - 23 Tahi Street
   - 26 Tahi Street
6. **More distant private bores:**
   - 27 Tahi Street
   - 29 Tahi Street
   - 36 Tahi Street
   - 39 Tahi Street

It is recommended that the future monitoring should have the following structure:

(i) installation of a transducer to continuously monitor water levels and the electrical conductivity of the water in one monitoring bore within the site;

(ii) quarterly monitoring at a small subset of bores across the site;

(iii) a more comprehensive sampling of on-site and off-site bores once a year.

To assist in the consideration of which bores are placed into which group, the time series data from all the groundwater monitoring bores over the last five sampling rounds is presented in Appendix C to indicate the variability that occurs in the different bores throughout the year.

With regard to the annual survey, it is proposed that the following bores can be removed from the sampling round:

- BHD, BH107 and BH3a, because they tend to show lower concentrations than other nearby bores, and are not on significant flow paths from areas of contaminant sources relative to other bores;
- BH105 and BH106 are upgradient of contaminant sources and their general area can be covered by bore BH104, which is more centrally located;
- 39 Tahi Street is the most southerly bore and is sufficiently remote from the site that it no longer needs to be sampled, particularly due to the number of bores that are monitored closer to the site.

All other bores should continue to be included in the annual sampling survey. This includes BH101, which typically shows the highest concentrations that are representative of groundwater within the bunded former landfill area which is proposed for use as a reserve in the future. Monitoring of BH101 also provides a contrast with BH102 on the other side of the bund.

Based on the information in Appendix C, it appears that many concentrations are at, or close to, their seasonally highest values during the spring period, where rainfall infiltration and groundwater levels are at their highest. Therefore, it is recommended that the more comprehensive annual sampling round of both on-site and off-site bores should be undertaken in November each year.

Quarterly sampling should be carried out at a subset of bores within the site located both adjacent to and downgradient of the major contaminant sources shown in Figures 9-11 of this report. It is proposed that the following bores should be used:

- East BH108
  BH109
  BH 110
  BH1A;
- West BH101
  BH102
  BH5A
  BH9A.

Both these groupings of bores represent migration paths from the contaminant sources shown in Figures 9, 10 and 11 through the discharge points to the east (BH1a), south (BH9a) and south-west (BH5a). It also maintains the long-term monitoring record in BH1A, BH5A and BH9A. It is suggested that if cost is of concern, the list of analytes could be reduced by removing those analytes from the quarterly sampling round that appear to be less significant, such as copper, iron, DRP, nitrite-N, TKN and total N.

To provide further understanding of the generation of contaminant leachate into the groundwater, it is recommended that a transducer to monitor both the water levels and electrical conductivity at one hourly intervals should be installed in BH110. This bore is located in and adjacent to the eastern area where Treated Fines and commercial material has been placed and the plot in Appendix C shows good variability in conductivity, indicating that it is responsive to change due to the different concentrations of dissolved chemicals that are migrating through the site during times of differing recharge and groundwater level conditions.

On that basis, the proposed future monitoring programme is:

(i) a transducer to monitor water levels and electrical conductivity in BH110;

(ii) quarterly monitoring in:

- BH108
- BH109
- BH110
- BH1A
- BH101
- BH102
- BH5A
- BH9A

These quarterly samples need only be analysed for:

- turbidity
- pH
- electrical conductivity
- nitrate-N
- ammoniacal-N
- DDX
- ADL

(iii) annual monitoring in:

- BH1A
- BH2A
- BH4A
- BH5A
- BH9A
- Old BH1
- BHG
- BHH
- BHL
- BH101
- BH102

- BH103
- BH104
- BH108
- BH109
- BH110
- BH111
- BH112
- BH113
- 13 Tahi Street
- 15 Tahi Street
- 21 Tahi Street
- 23 Tahi Street
- 26 Tahi Street
- 27 Tahi Street
- 29 Tahi Street
- 36 Tahi Street
- East estuary coastal seepage
- West estuary coastal seepage

These annual samples should be analysed for the full suite of parameters included in the previous sampling rounds.

In addition, it is recommended that the next quarterly sampling round should also include the analysis of lindane from the bores at 21, 23, 29 and 36 Tahi Street as a one-off extra sample to confirm that the low level of detections present in the November 2010 sampling are not present in the groundwater. This sampling should include collection of a rinsate blank before and after sampling that group of bores, analysis of the water used to create the rinsate blank and analysis of a trip blank.

6.0 Conclusion

A period of detailed groundwater quality monitoring has been carried out in and around the former Fruitgrowers Chemical Company site at Mapua, both during and following the soil remediation activities. Groundwater occurs beneath the site at depths of around 0.5-3.0 m deep and is recharged by throughflow from areas to the north of the site and from rainfall infiltration within the site. The groundwater from the site discharges primarily into the Mapua channel to the east and the Waimea Inlet to the south-west, with a smaller component migrating south down Tahi Street.

Significantly elevated concentrations of nitrogen, DDX and ADL occurred in the groundwater during 2006-2008 (i.e. the period during and immediately following the remedial works) and have decreased since then, but still remain high in some monitoring boreholes. Other contaminants used in the remediation process (phosphorous, copper, iron) show more variable patterns.

The primary issue arising from these contaminants in the groundwater is their emergence as seepage on the foreshore of the Mapua channel and the Waimea Inlet where they bound the site, prior to the significant dilution of groundwater seepage when it mixes with these surface water bodies. This foreshore seepage could add a nutrient source which could facilitate algal growths and there could be a very slow accumulation of organo-chlorine compounds adsorbed onto foreshore muds.

Future site development should aim to reduce the amount of rain water infiltration within the site, which should cause a corresponding reduction in the mass of contaminants leaching into groundwater and migrating through to the surface water environment. Site development activities should avoid crating any increased infiltration and if any development activities encounter groundwater then special management measures need to be implemented to avoid exposure to, or spreading of, this groundwater.

Due to the elevated chemical concentrations, it is recommended that regular groundwater monitoring should continue at the site, with the results reviewed annually. Further modifications to the monitoring programme should be considered based on the results of this review.

Appendix A

Figures

Figure 1 : Groundwater Monitoring Wells

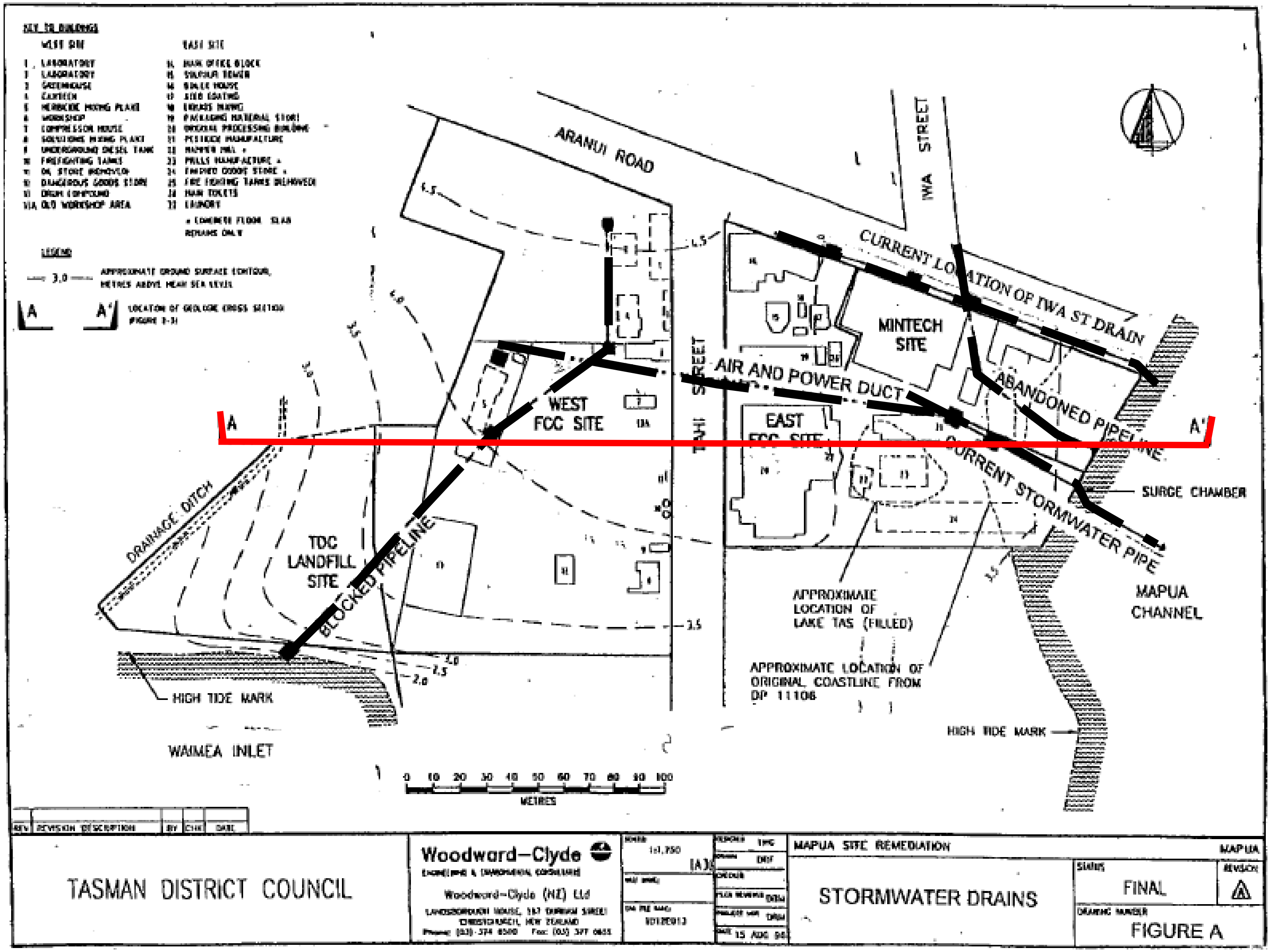

Figure 2: Original Site Layout and Location of Cross-section Line A-A' in Figure 3

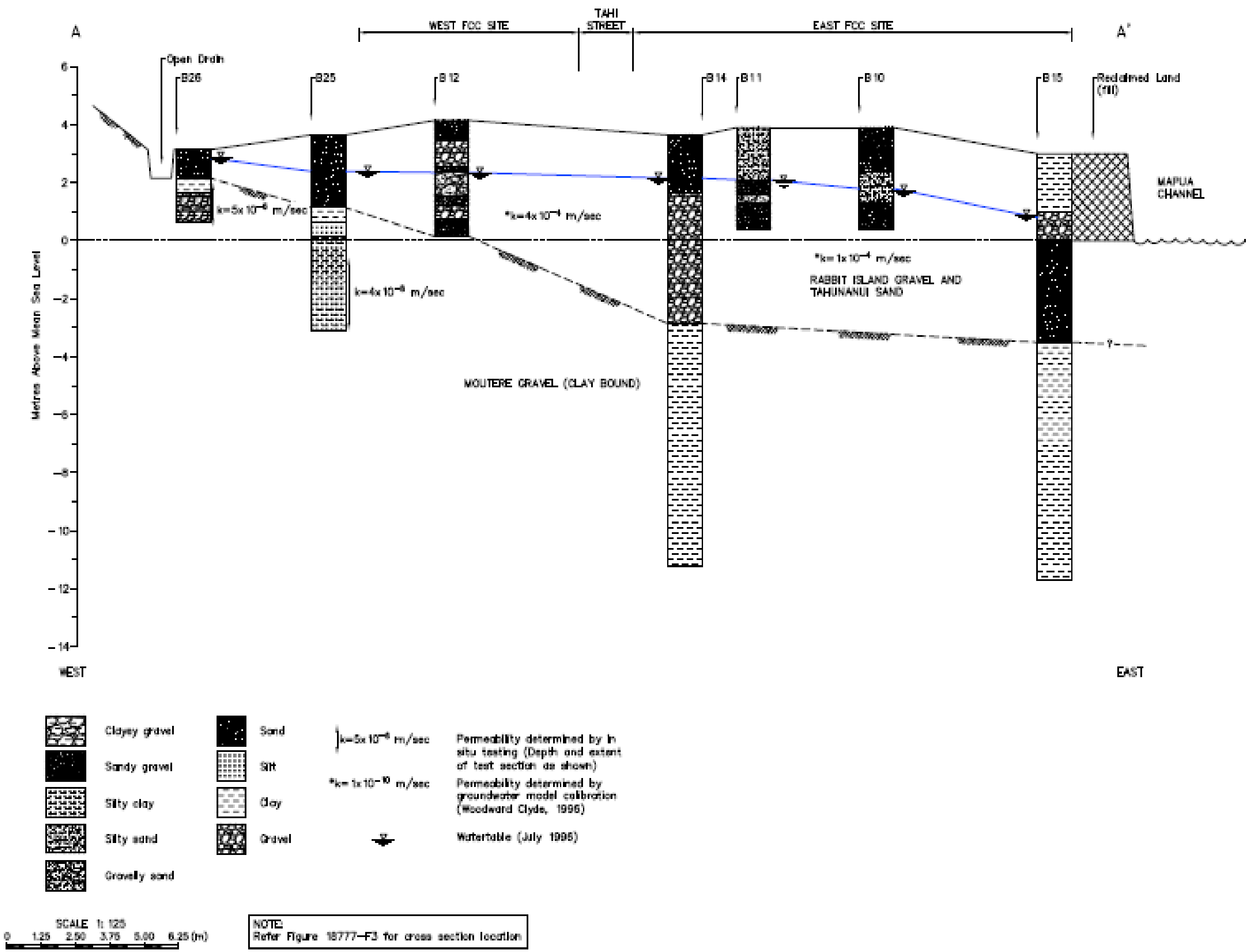

Figure 3: Pre-Remediation Geological Cross-section

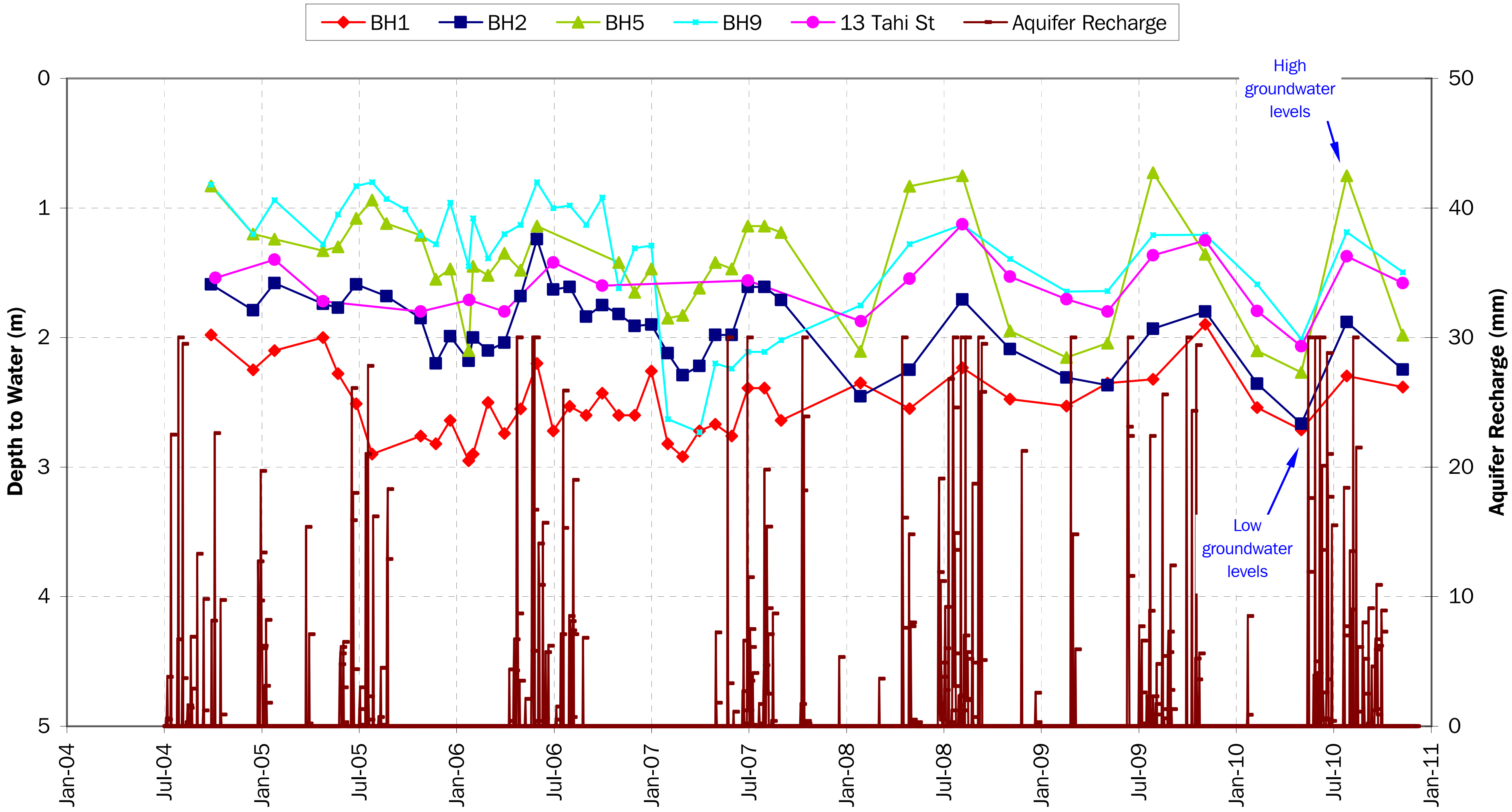

Figure 4: Depth to Groundwater Table in On-site Monitoring Wells

Mapua

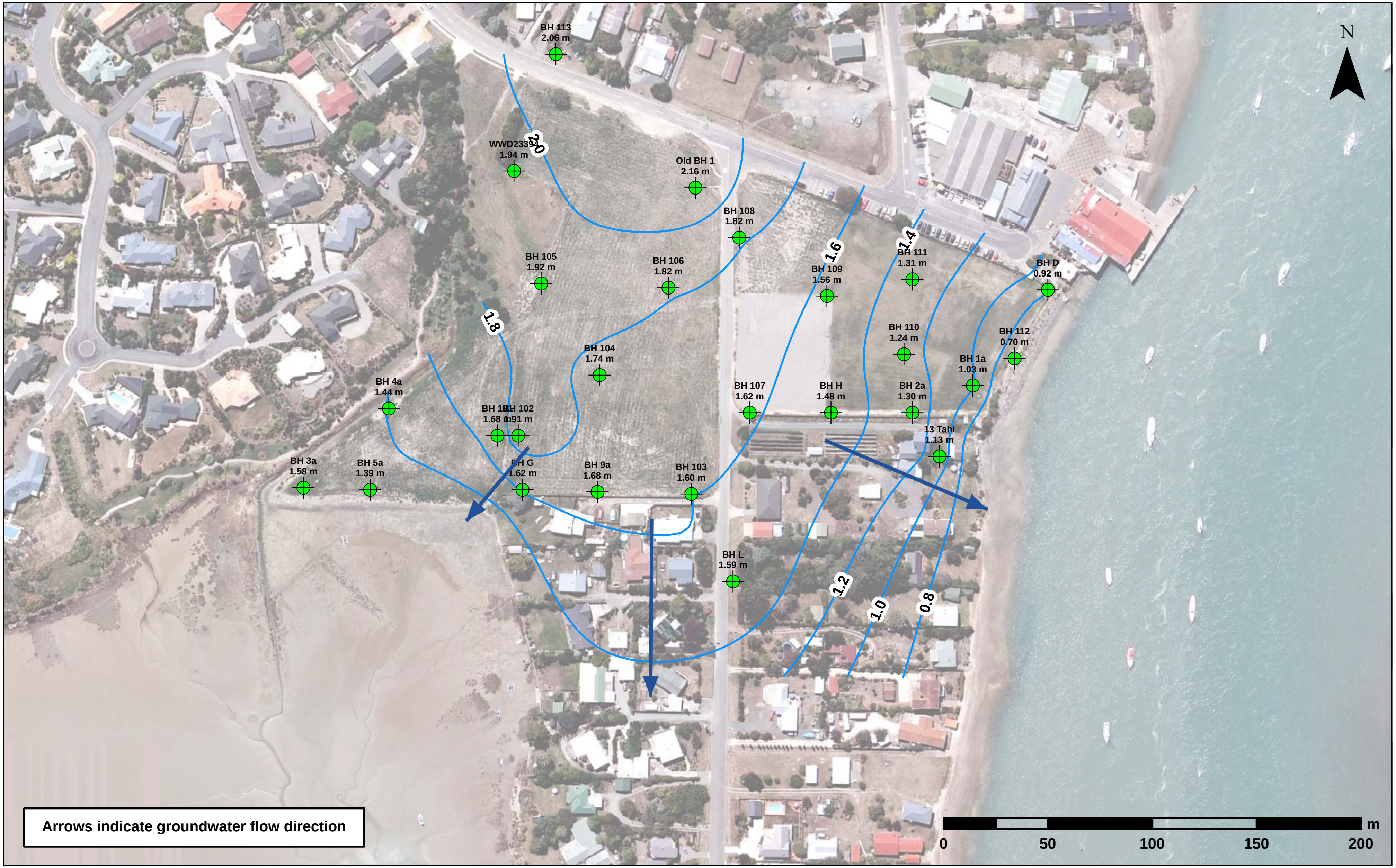

Figure 5a : Piezometric contours at times of low groundwater levels (early May 2010)

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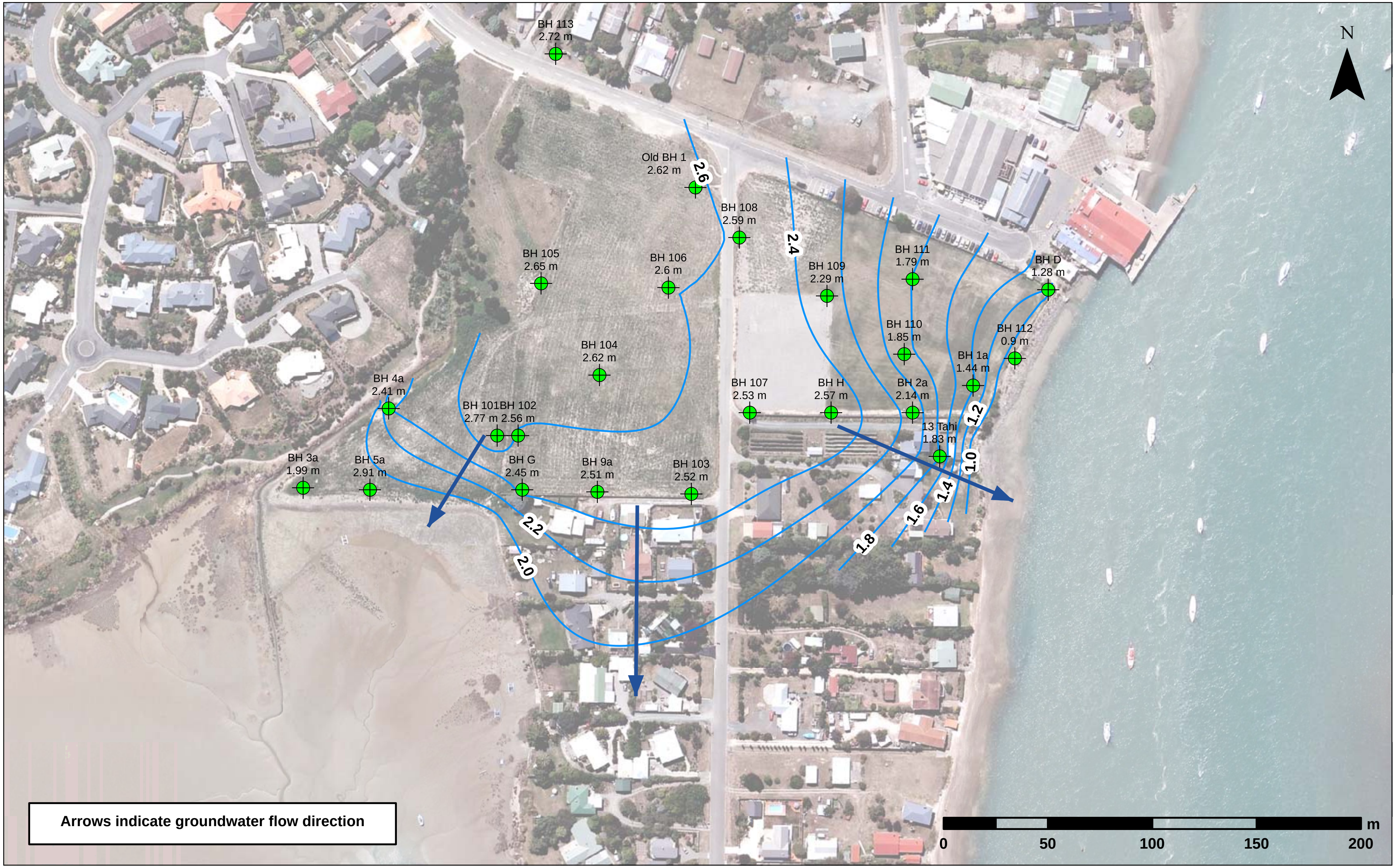


Figure 5b : Piezometric contours at times of high groundwater levels (late July 2010)

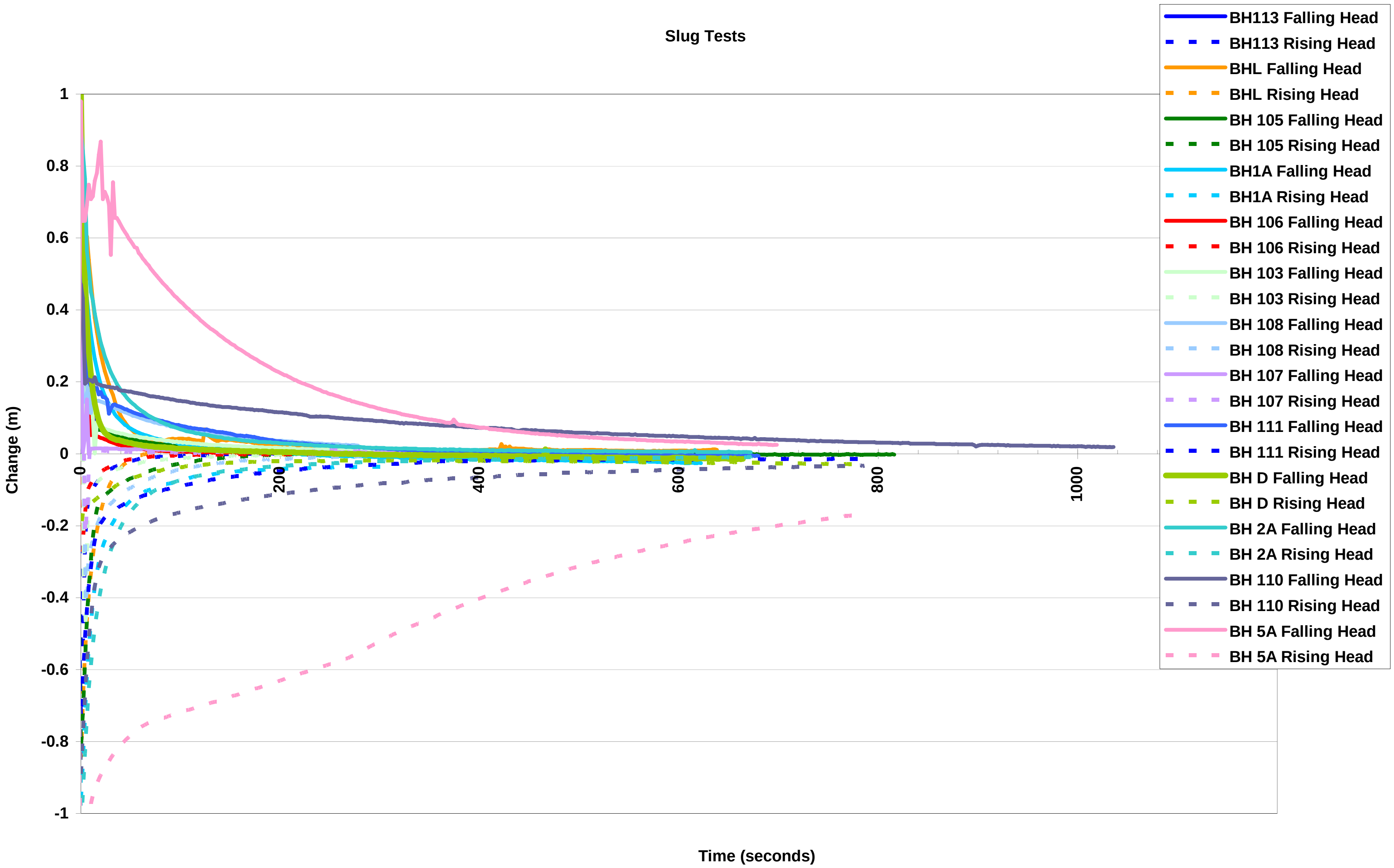


Figure 6: Summary Plot of Slug Tests

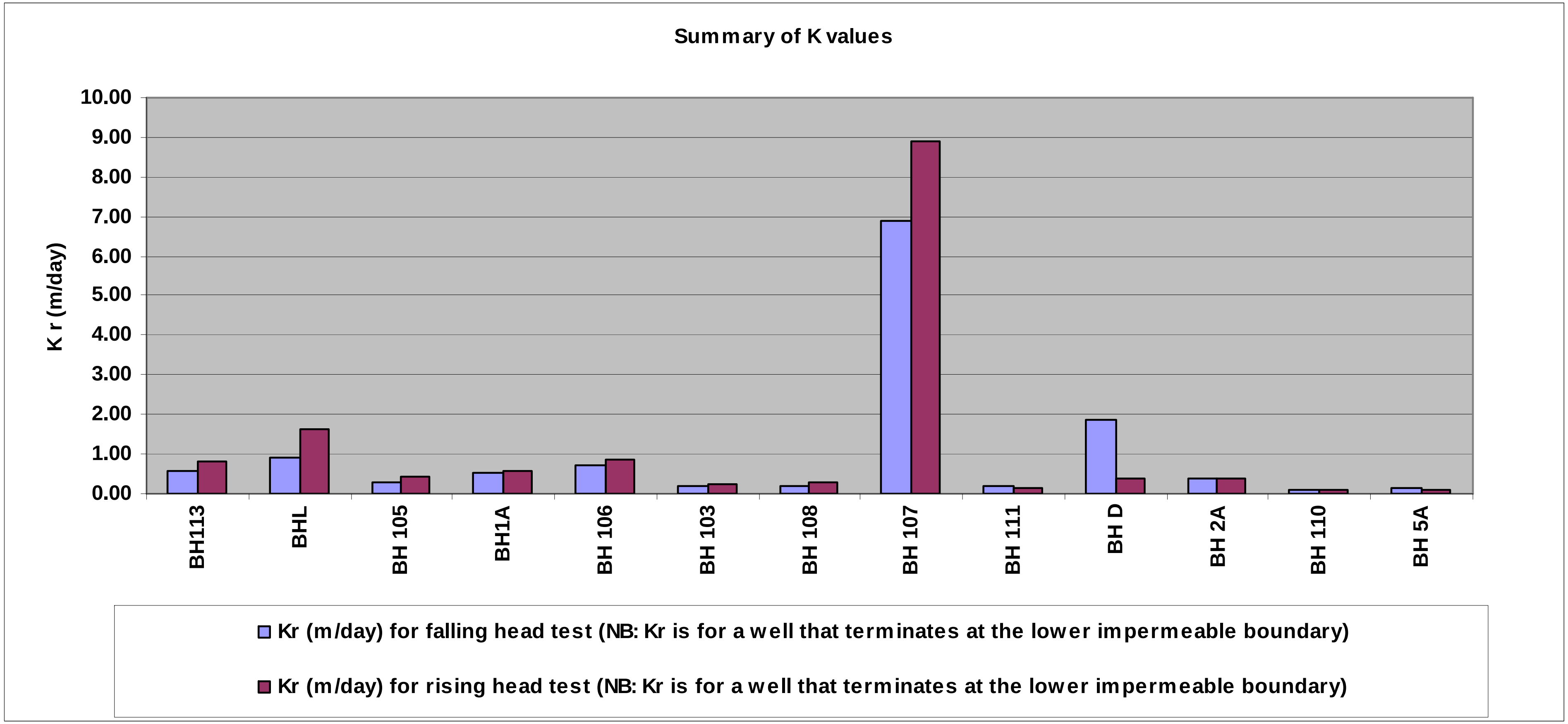


Figure 7: Summary of Hydraulic Conductivity Values from Slug Tests

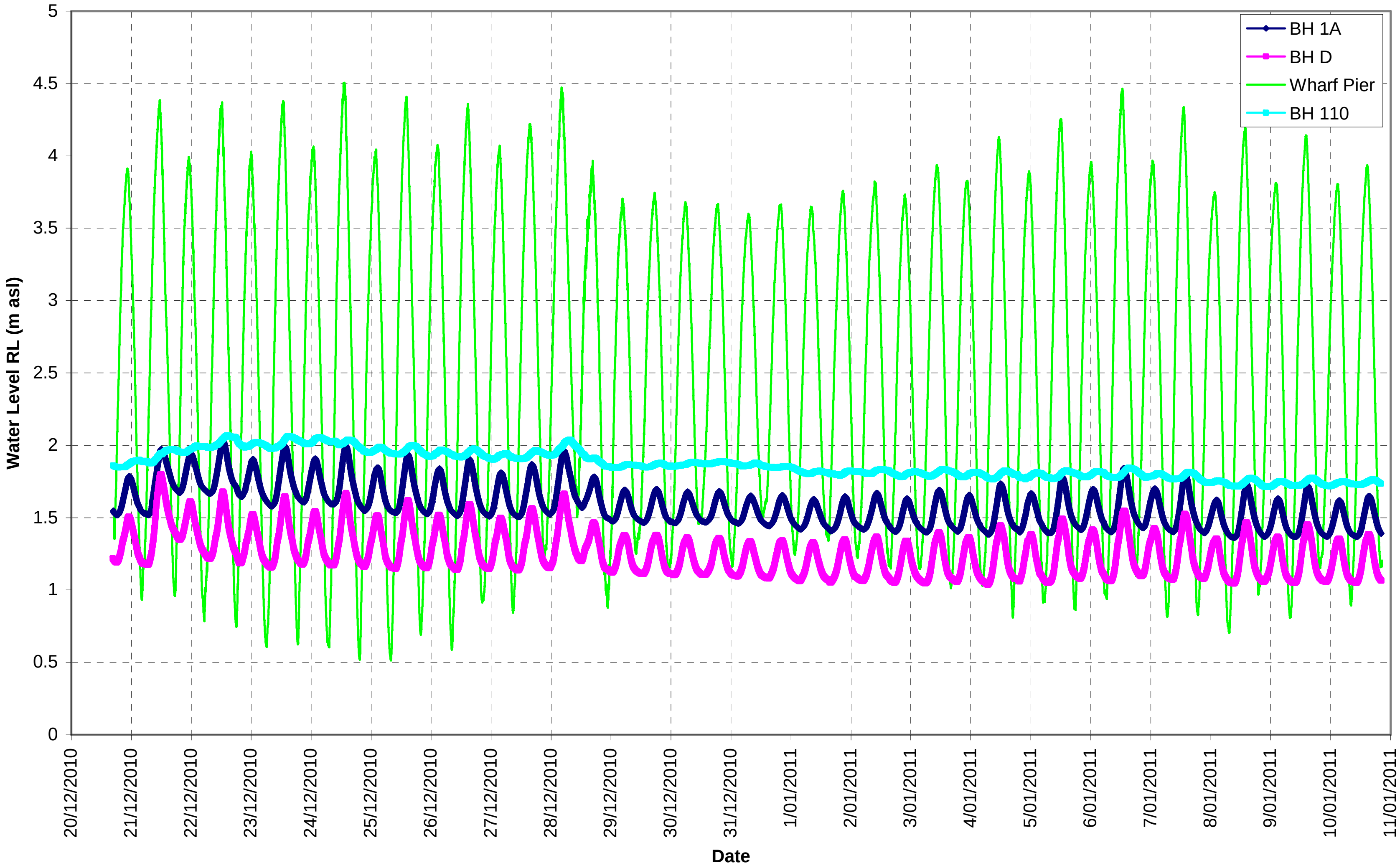
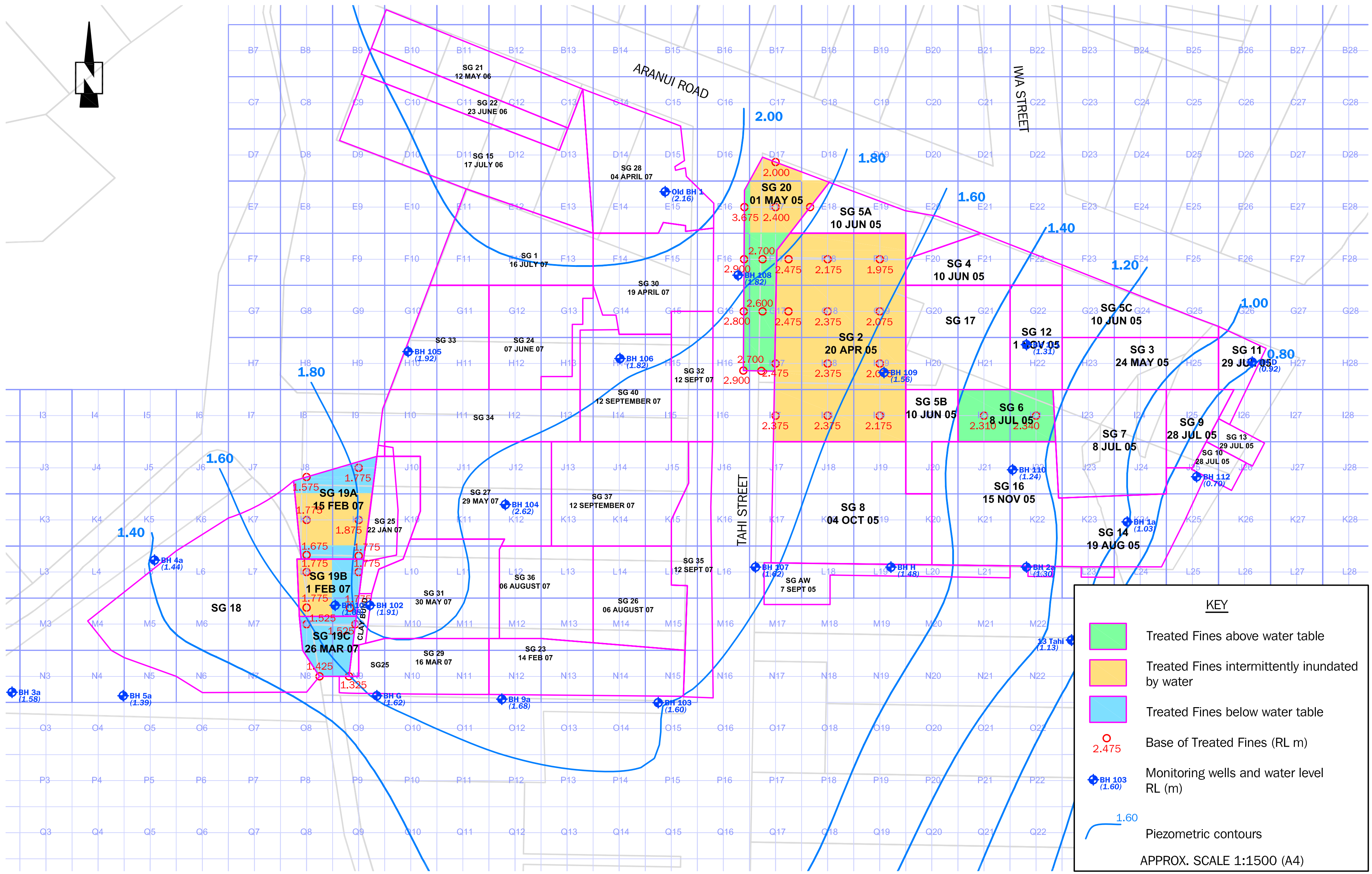


Figure 8: Water Level Fluctuations Near Waimea Channel

MAPUA GROUNDWATER ASSESSMENT – AT COMPLETION OF MCD SOIL REMEDIATION



Source: Cadastral information derived from LINZ data.

Figure 9 : POSITION OF TREATED FINES (UNMIXED WITH OTHER MATERIALS) RELATIVE TO THE WATER TABLE

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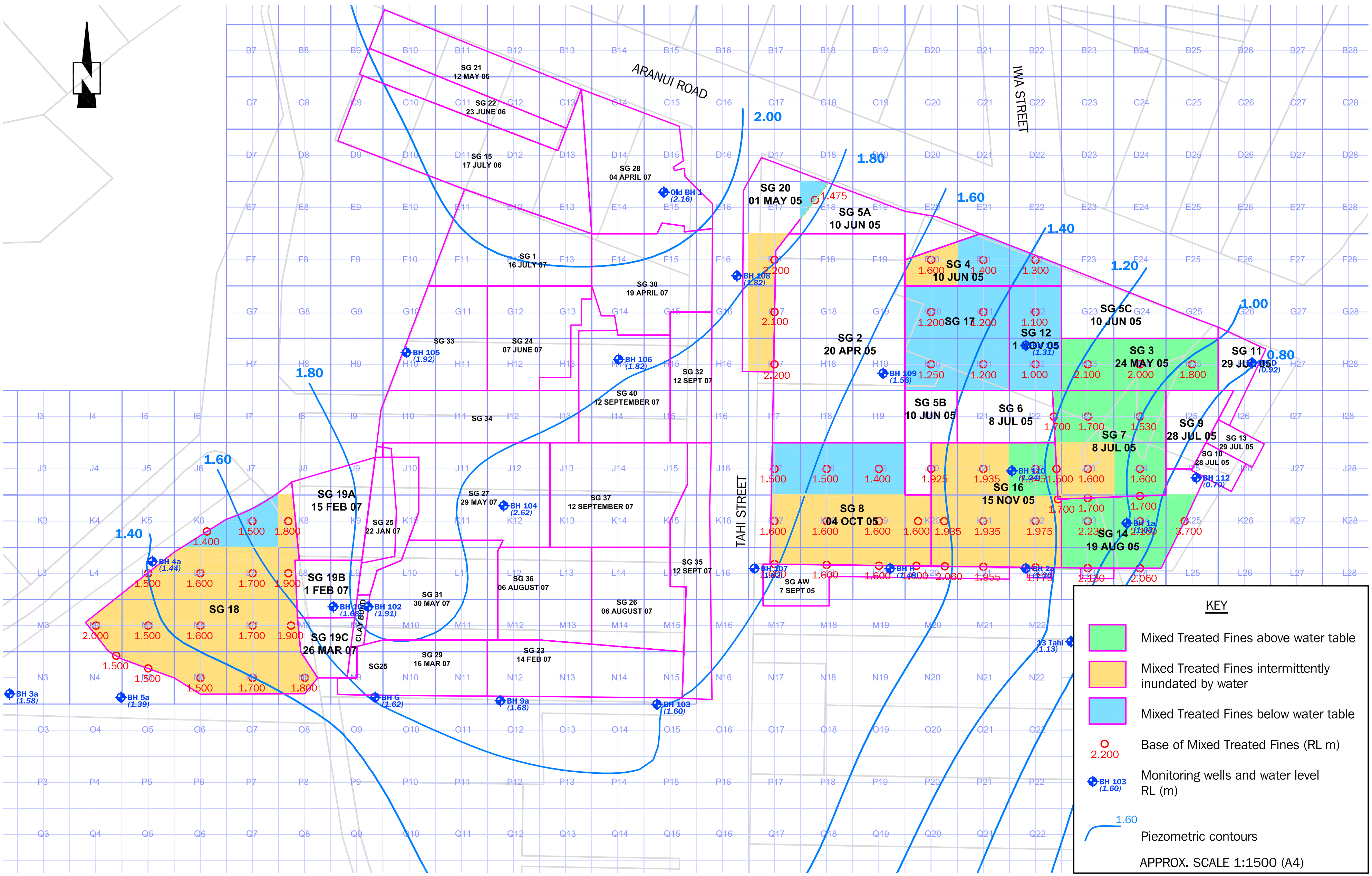
MAPUA GROUNDWATER ASSESSMENT–AT COMPLETION OF MCD SOIL REMEDIATION



Source: Cadastral information derived from LINZ data.

Figure 10 : POSITION OF TREATED FINES (MIXED WITH OTHER MATERIALS) RELATIVE TO THE WATER TABLE

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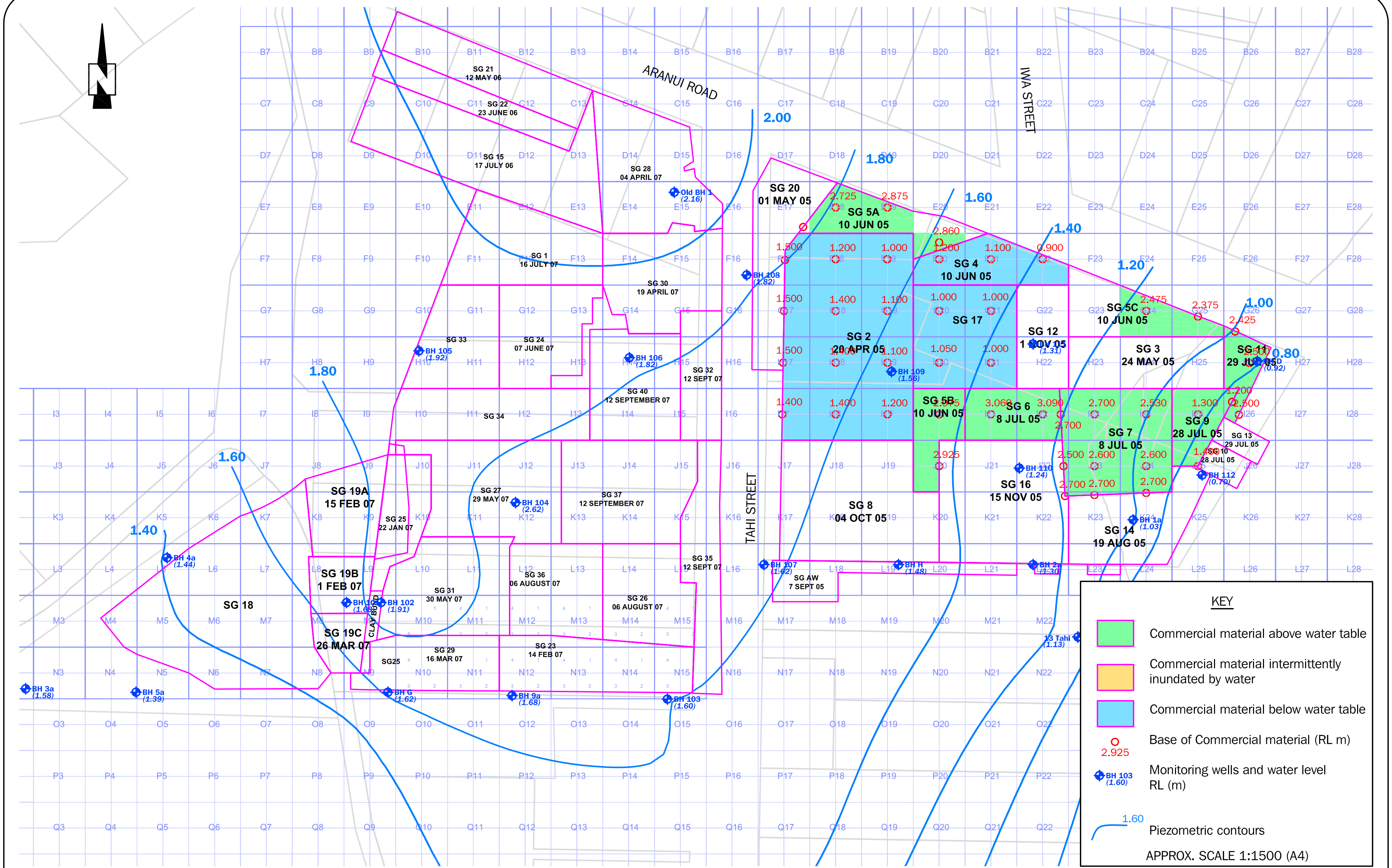
MAPUA GROUNDWATER ASSESSMENT – AT COMPLETION OF MCD SOIL REMEDIATION



Source: Cadastral information derived from LINZ data.

Figure 11 : POSITION OF COMMERCIAL MATERIAL, WITH NO TREATED FINES, RELATIVE TO THE WATER TABLE

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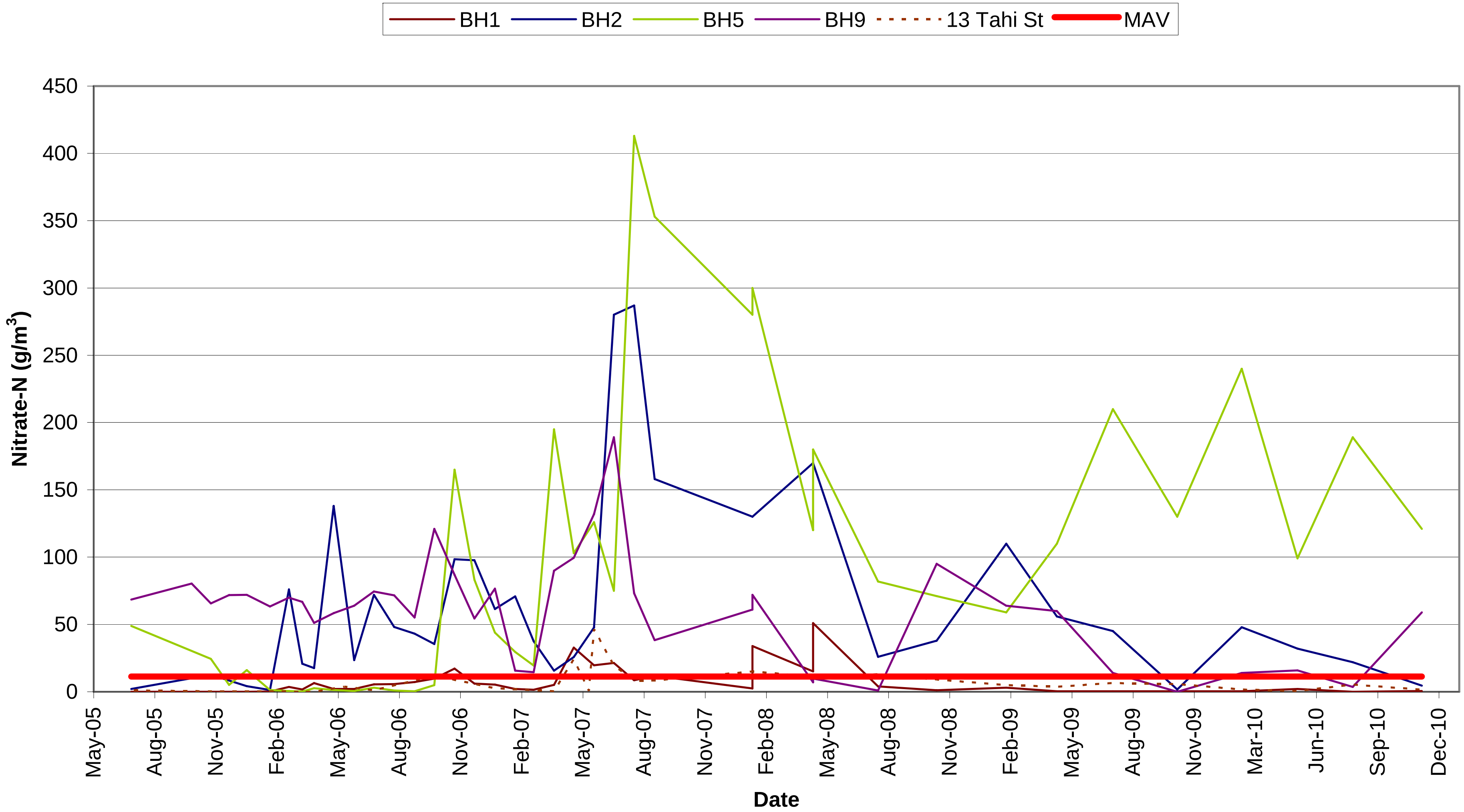


Figure 12: Nitrate-N
MAV DWSNZ 11.3 NO3-N g/m3

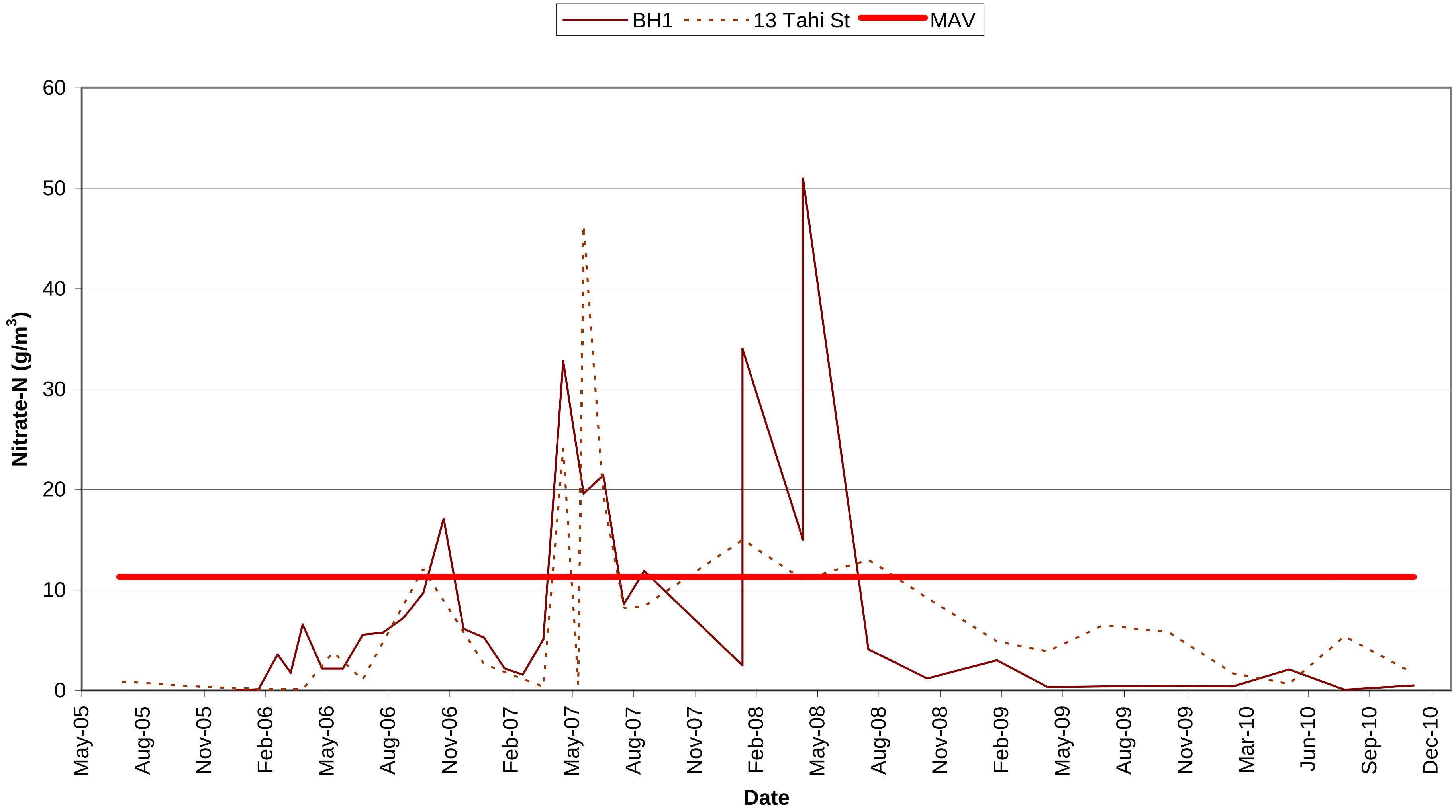


Figure 12a: Nitrate-N
MAV DWSNZ 11.3 NO3-N g/m3

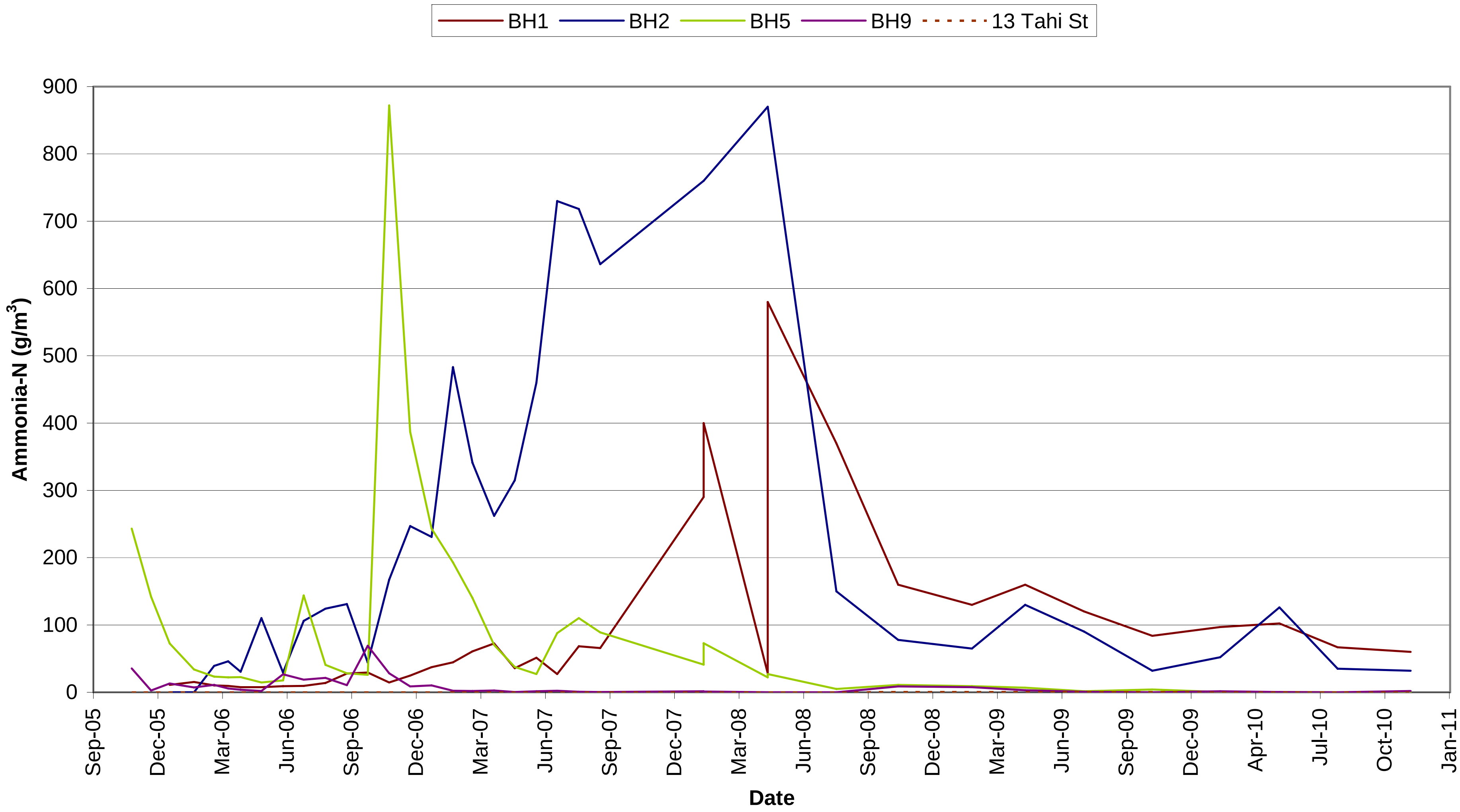


Figure 13: Ammonia-N
GV Aesthetic DWSNZ 0.30 NH3-N g/m3; Aquatic Ecosystem Guideline 0.71g/m3

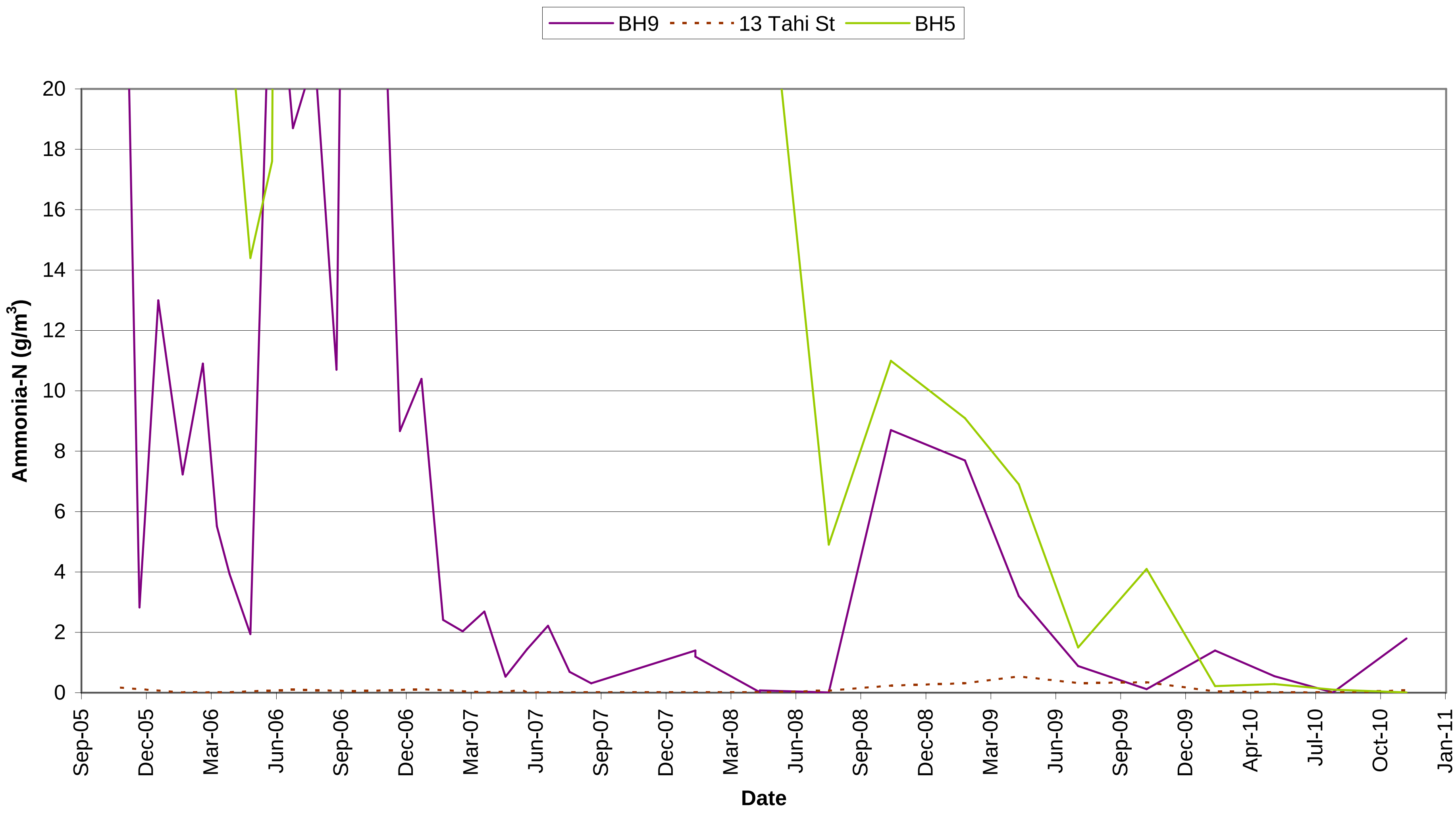


Figure 13a: Ammonia-N
GV Aesthetic DWSNZ 0.30 NH3-N g/m3

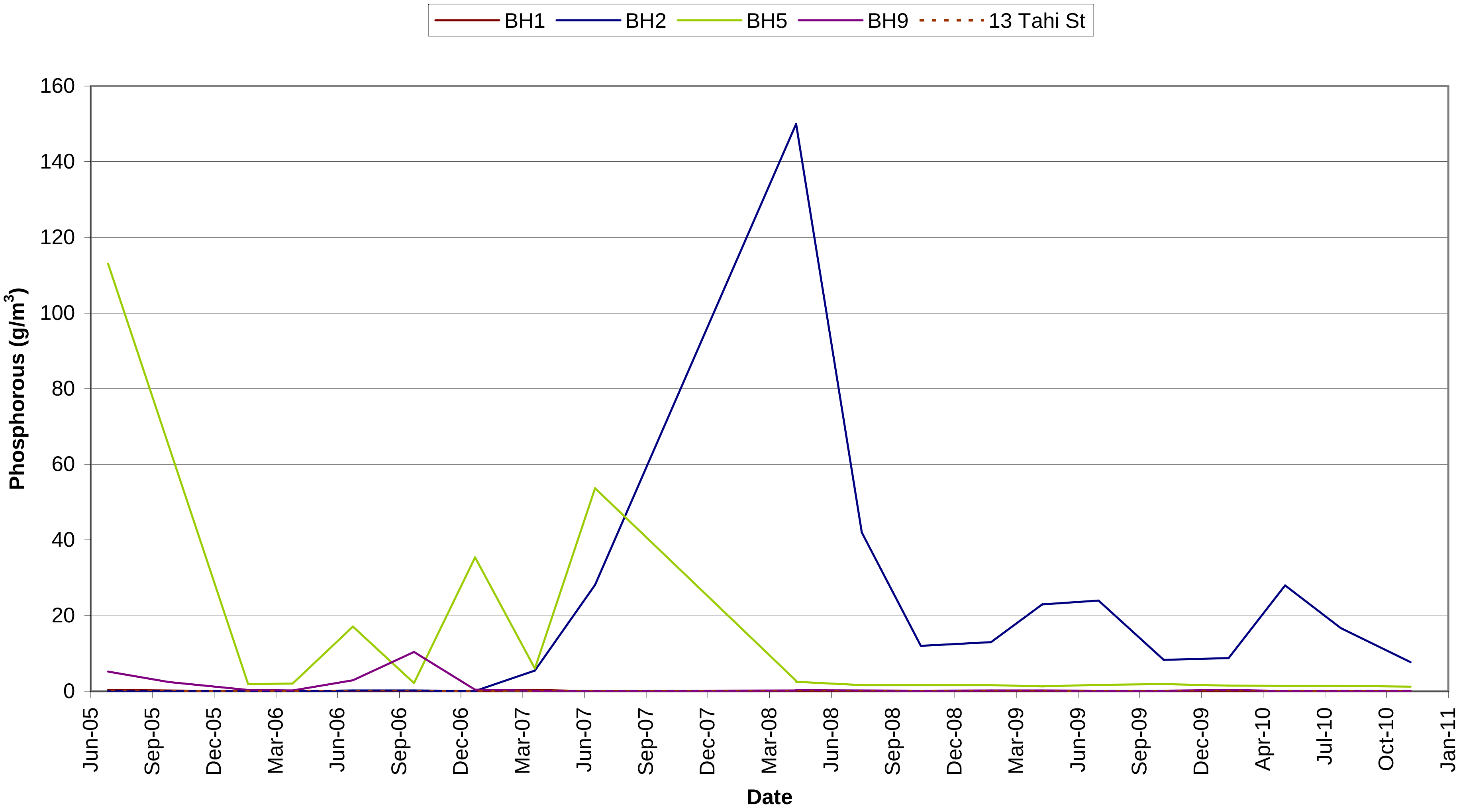


Figure 14: Phosphorous
Aquatic Ecosystem Guideline 0.01g/m3

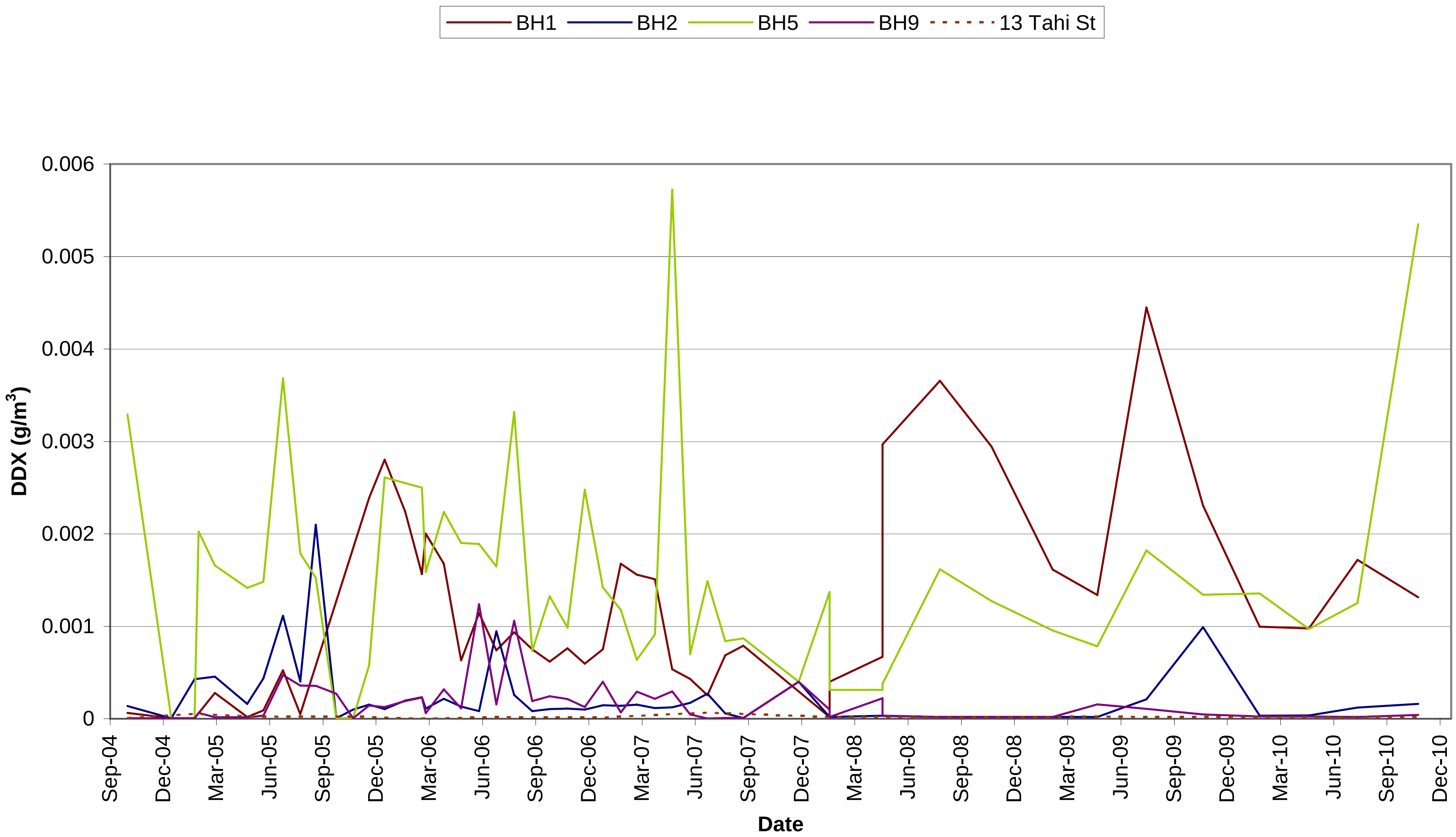


Figure 15: DDX (g/m3)

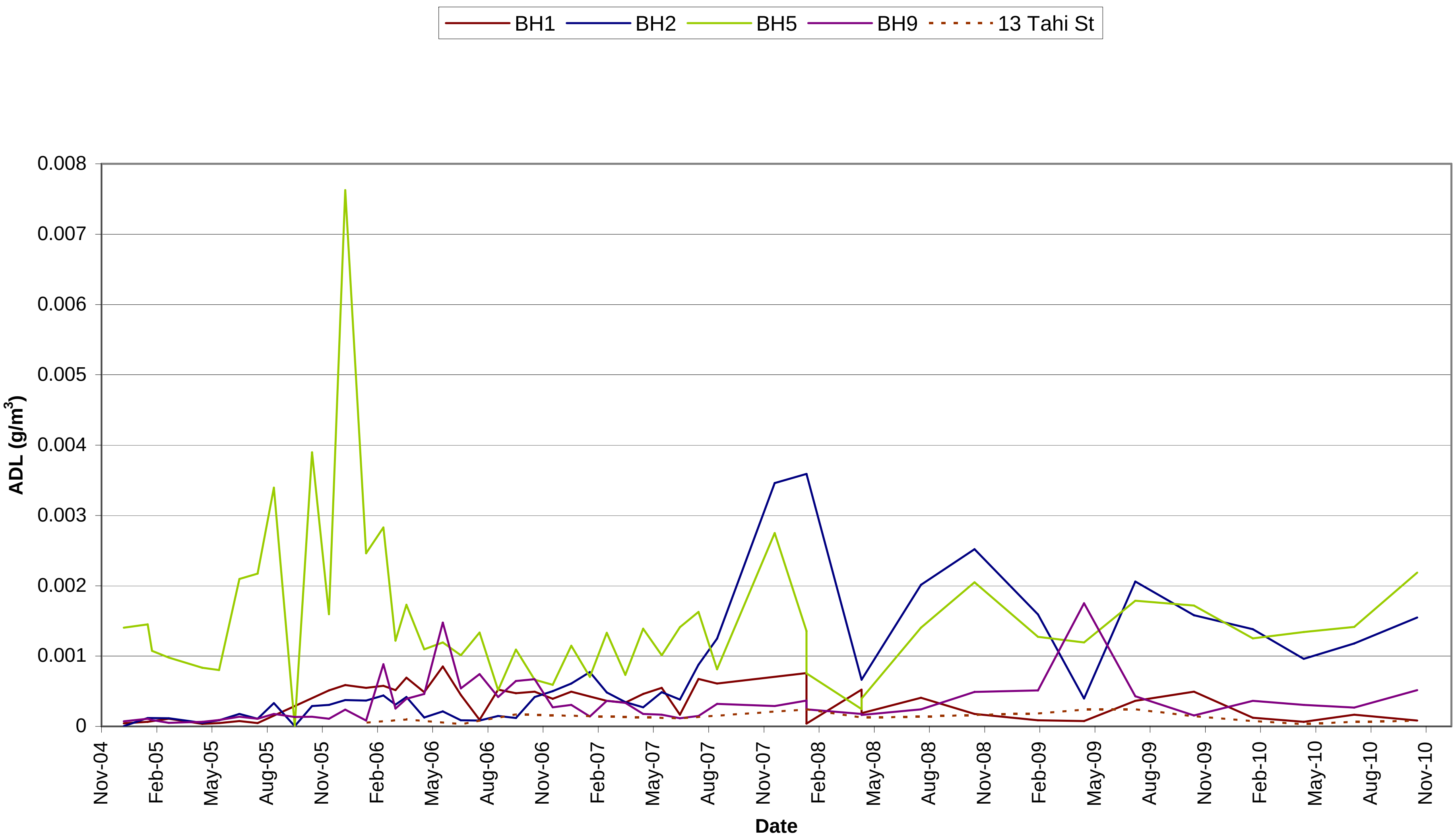


Figure 16: ADL (g/m3)

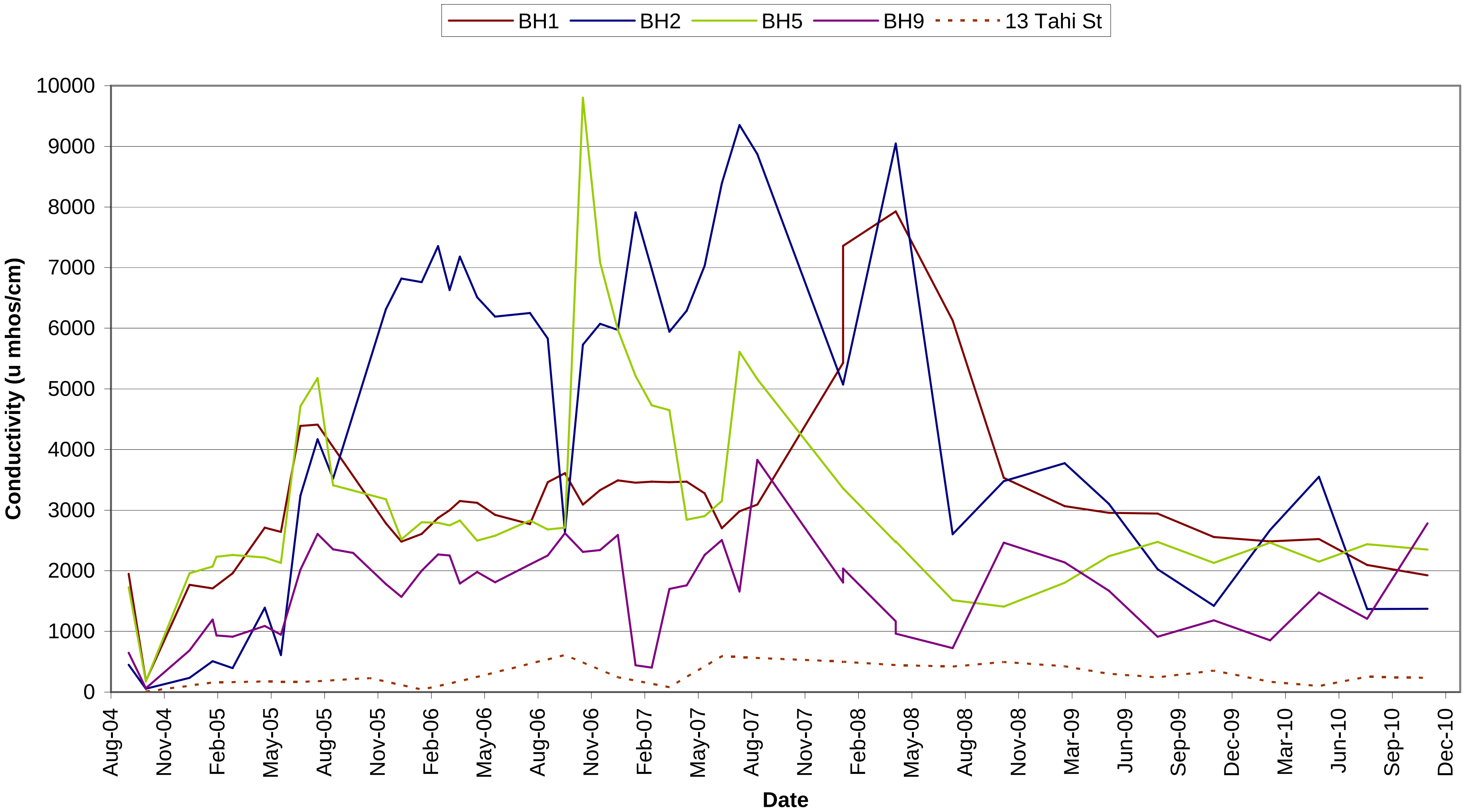


Figure 17: Conductivity (u mhos/cm)

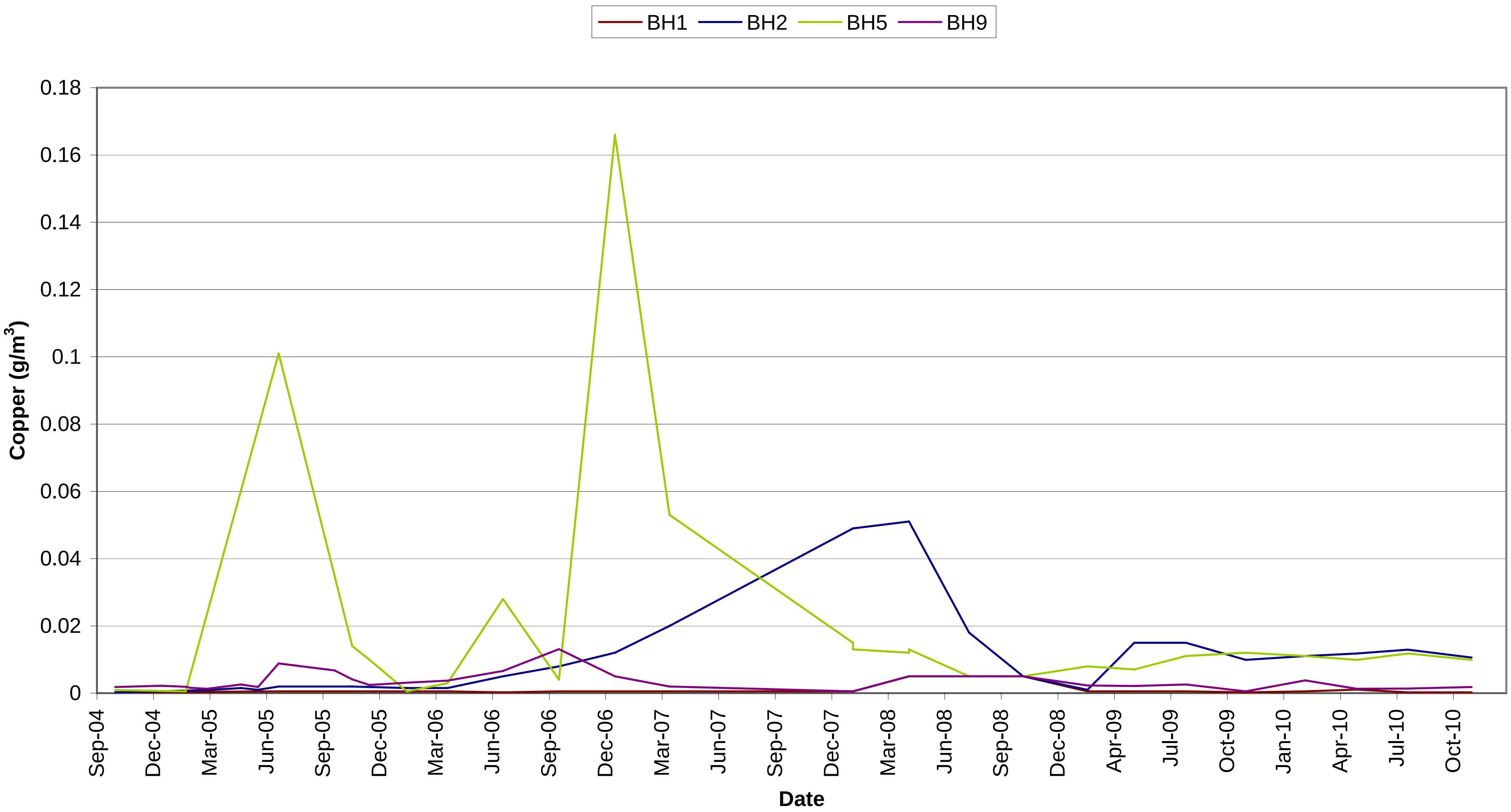


Figure 18: Copper
MAV DWSNZ 2 g/m3, ANZECC Marine Guideline = 0.0013 g/m3

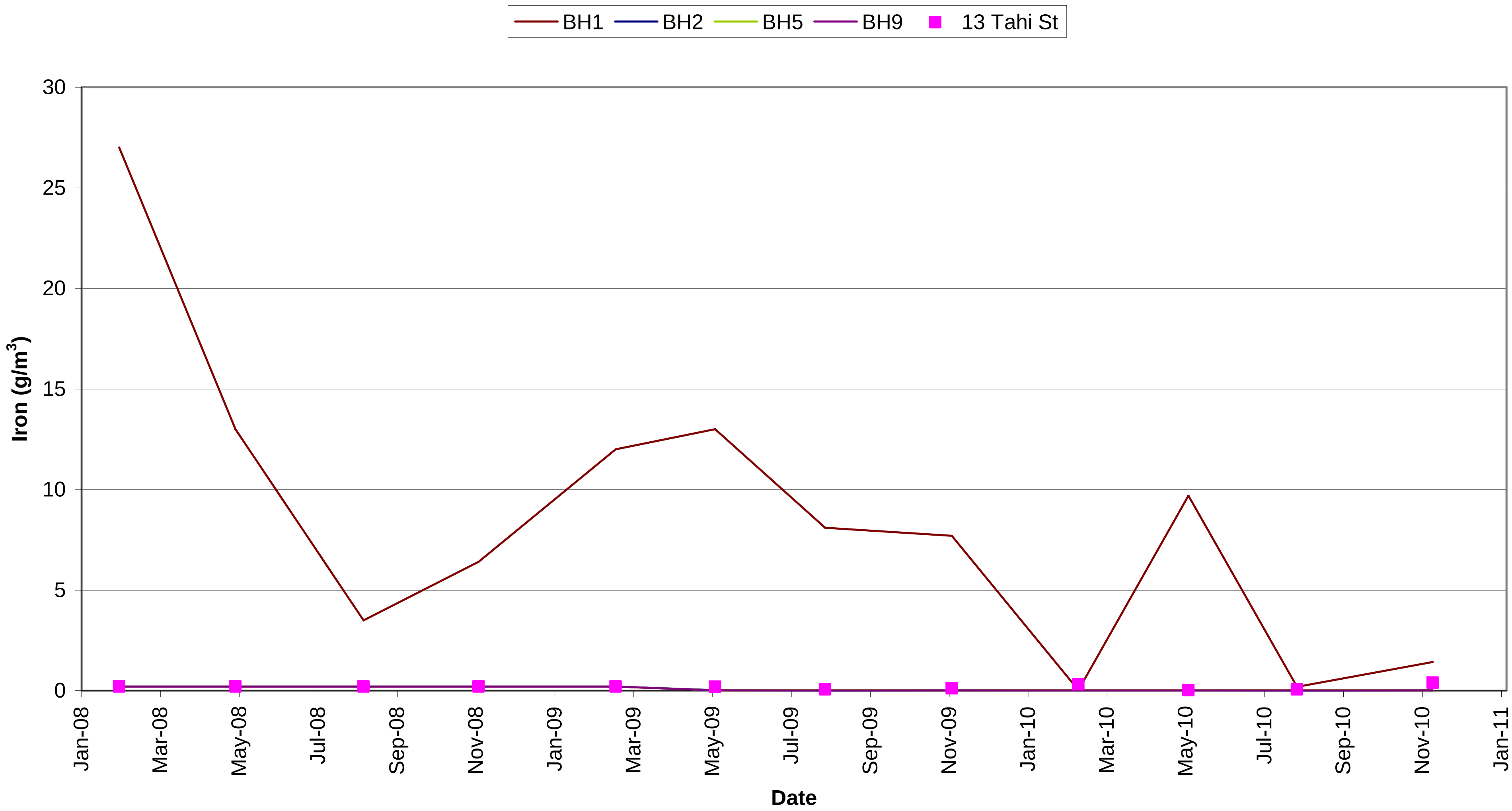


Figure 19: Iron
Aesthetic Guideline Value DWSNZ 0.2 g/m3

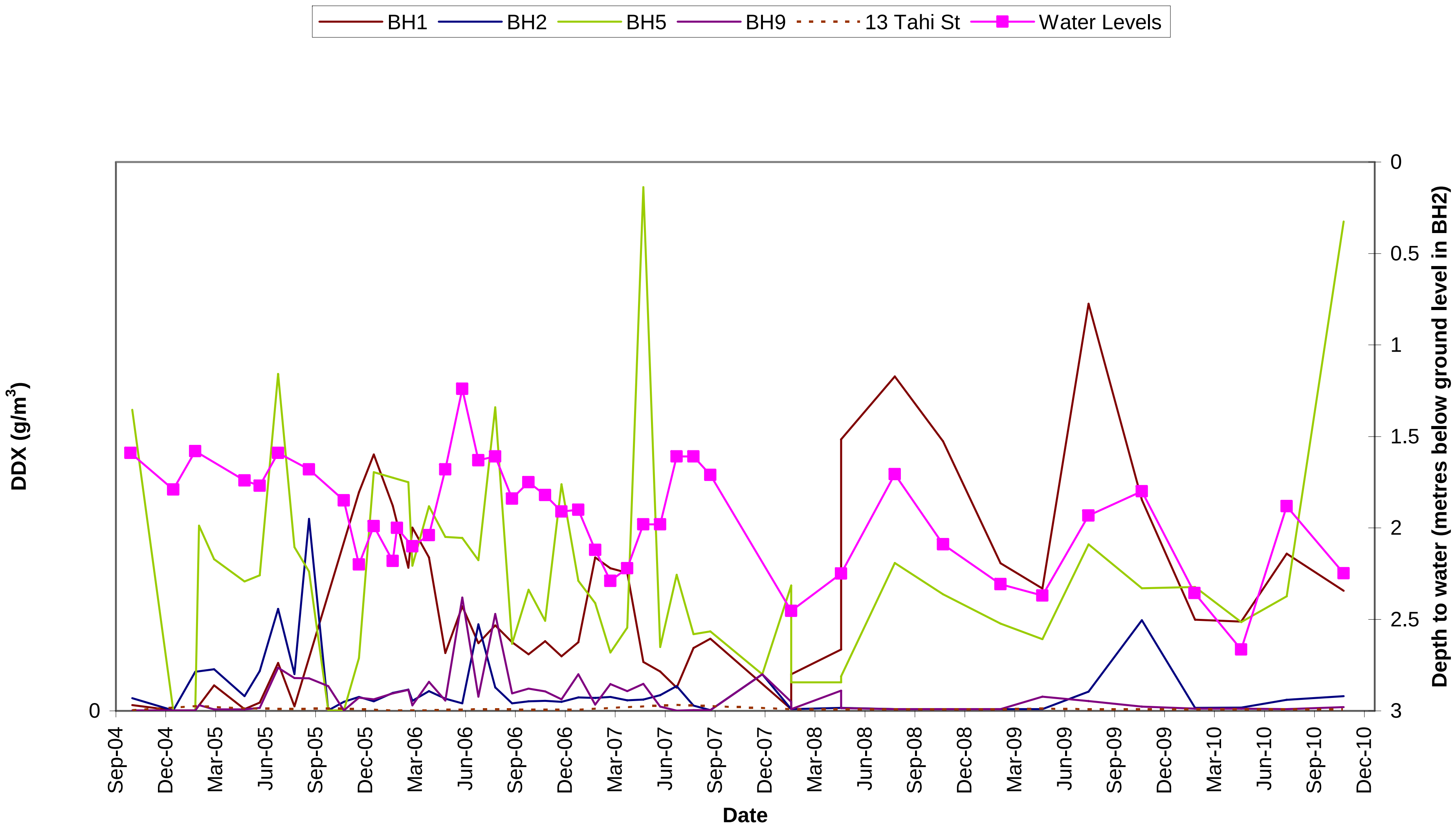


Figure 20: DDX (g/m3)

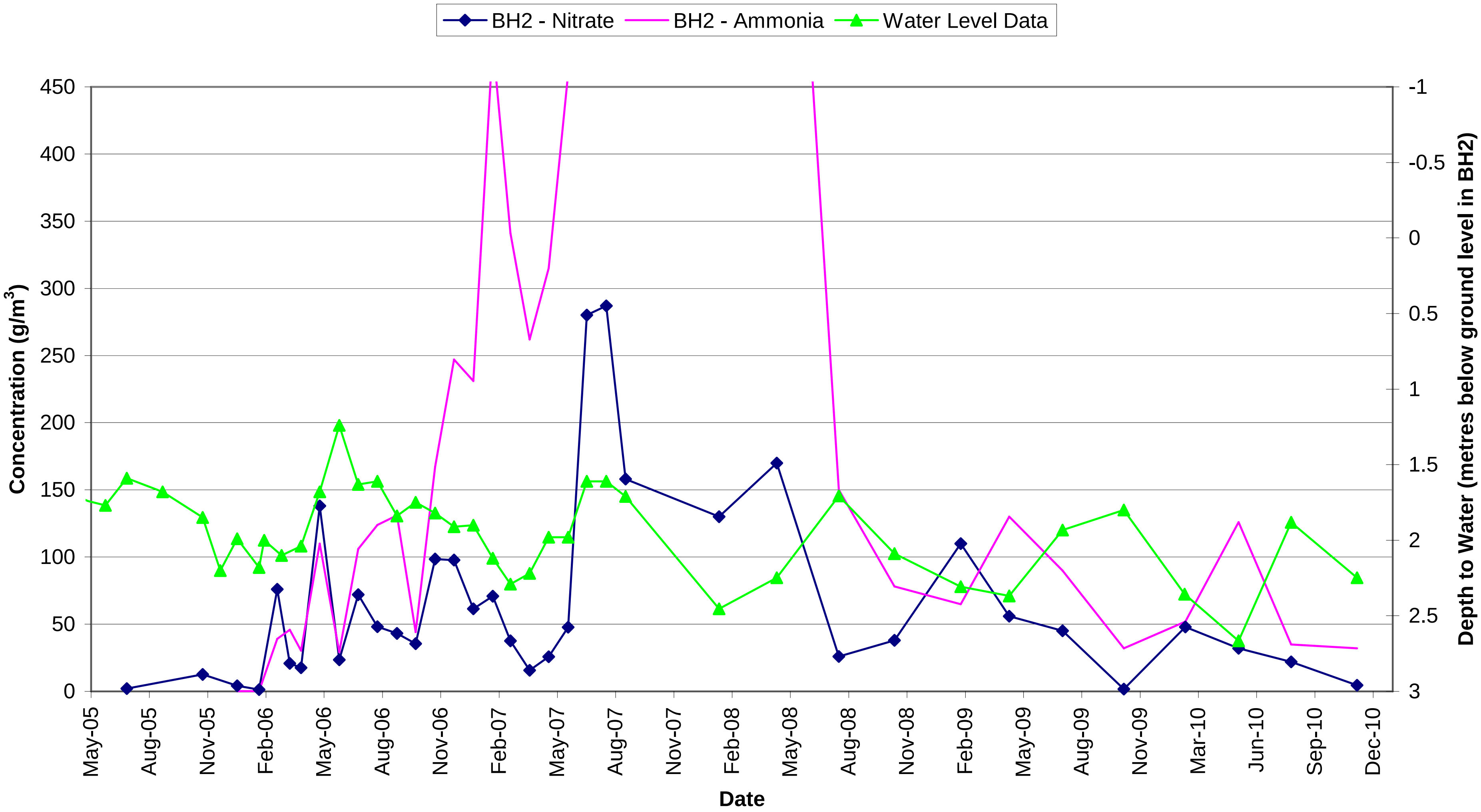


Figure 21: Nitrogen Concentrations in BH2

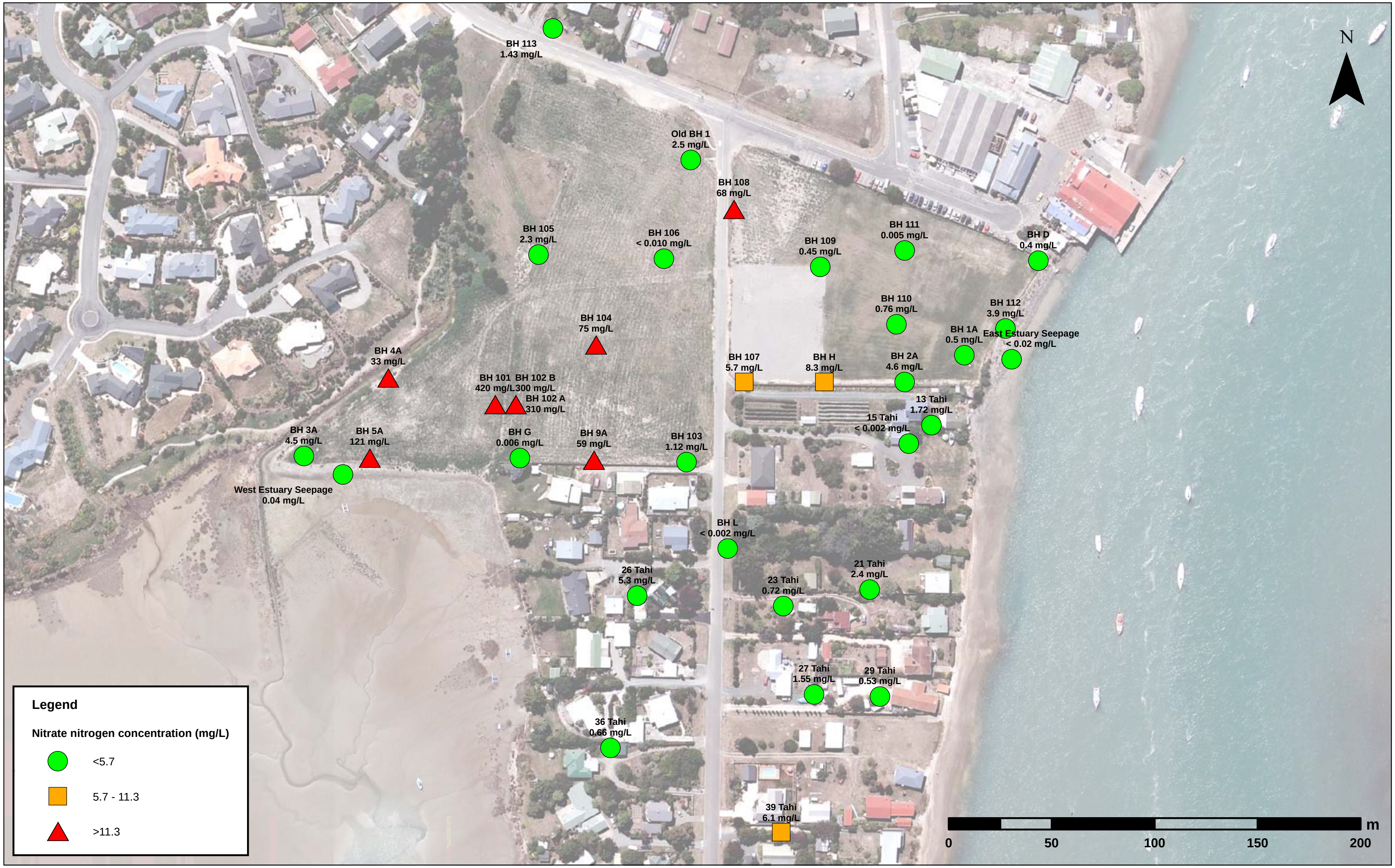


Figure 22 : Nitrate nitrogen concentrations in November 2010

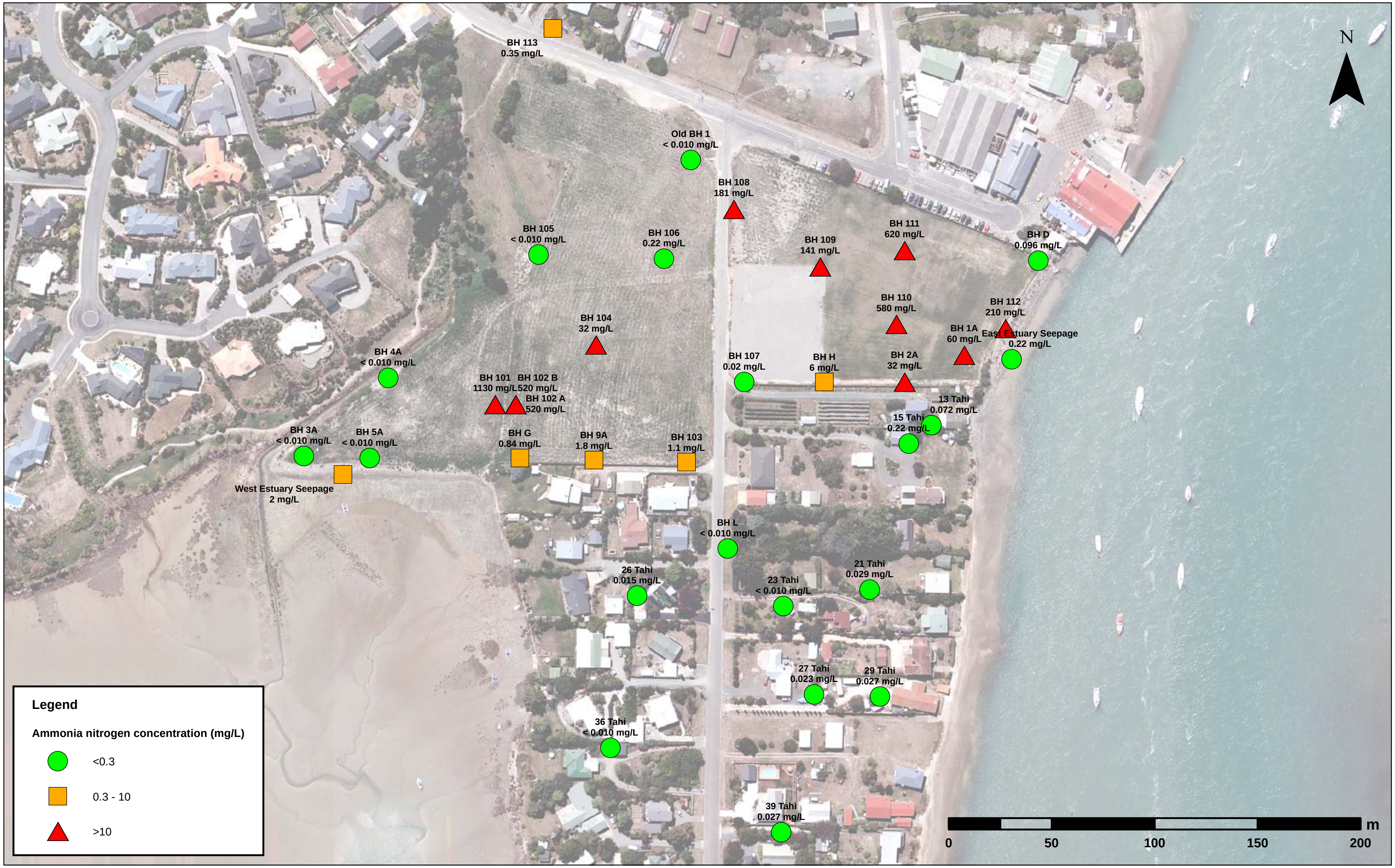


Figure 23 : Ammonia nitrogen concentrations in November 2010

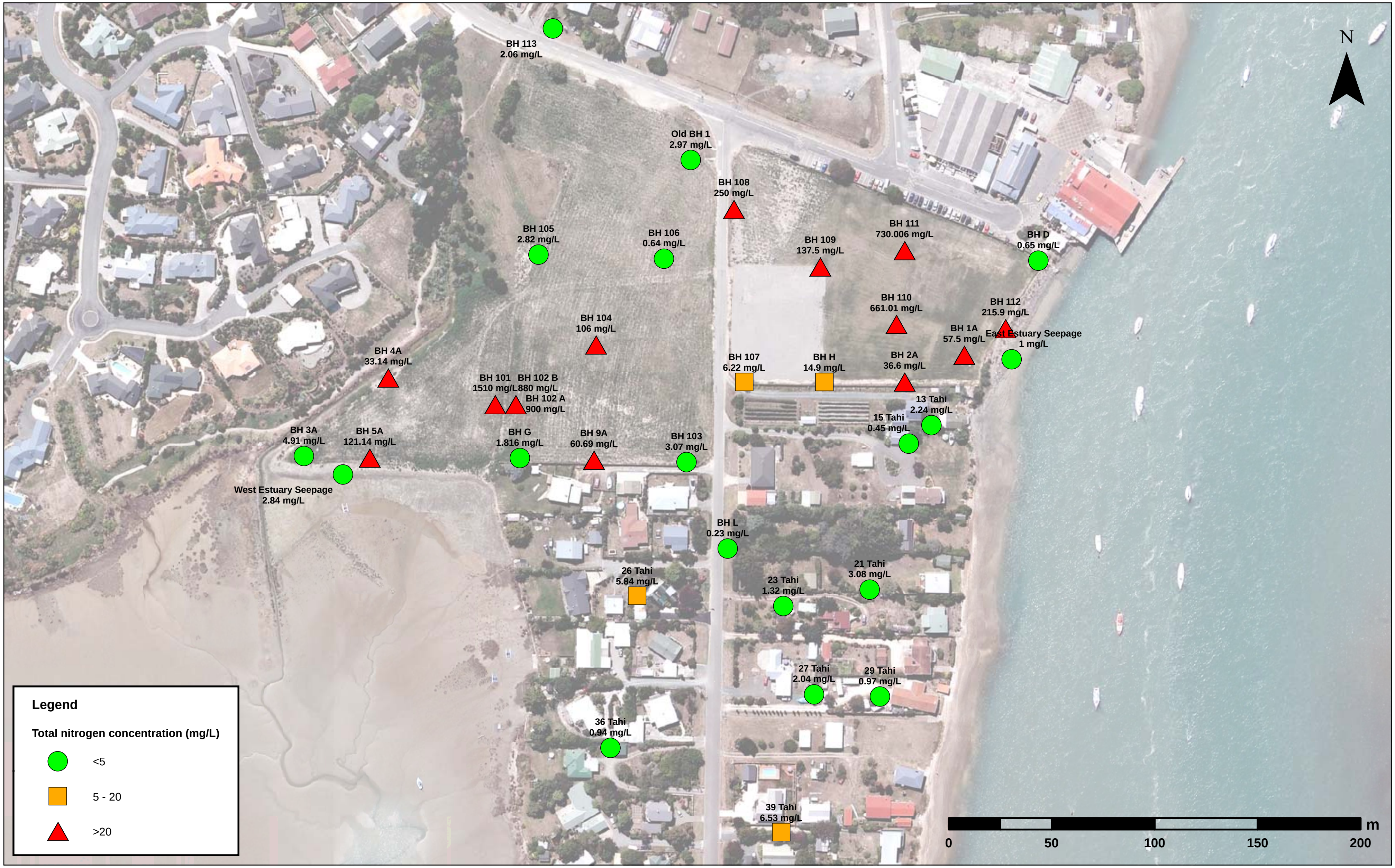


Figure 24 : Total nitrogen concentrations in November 2010

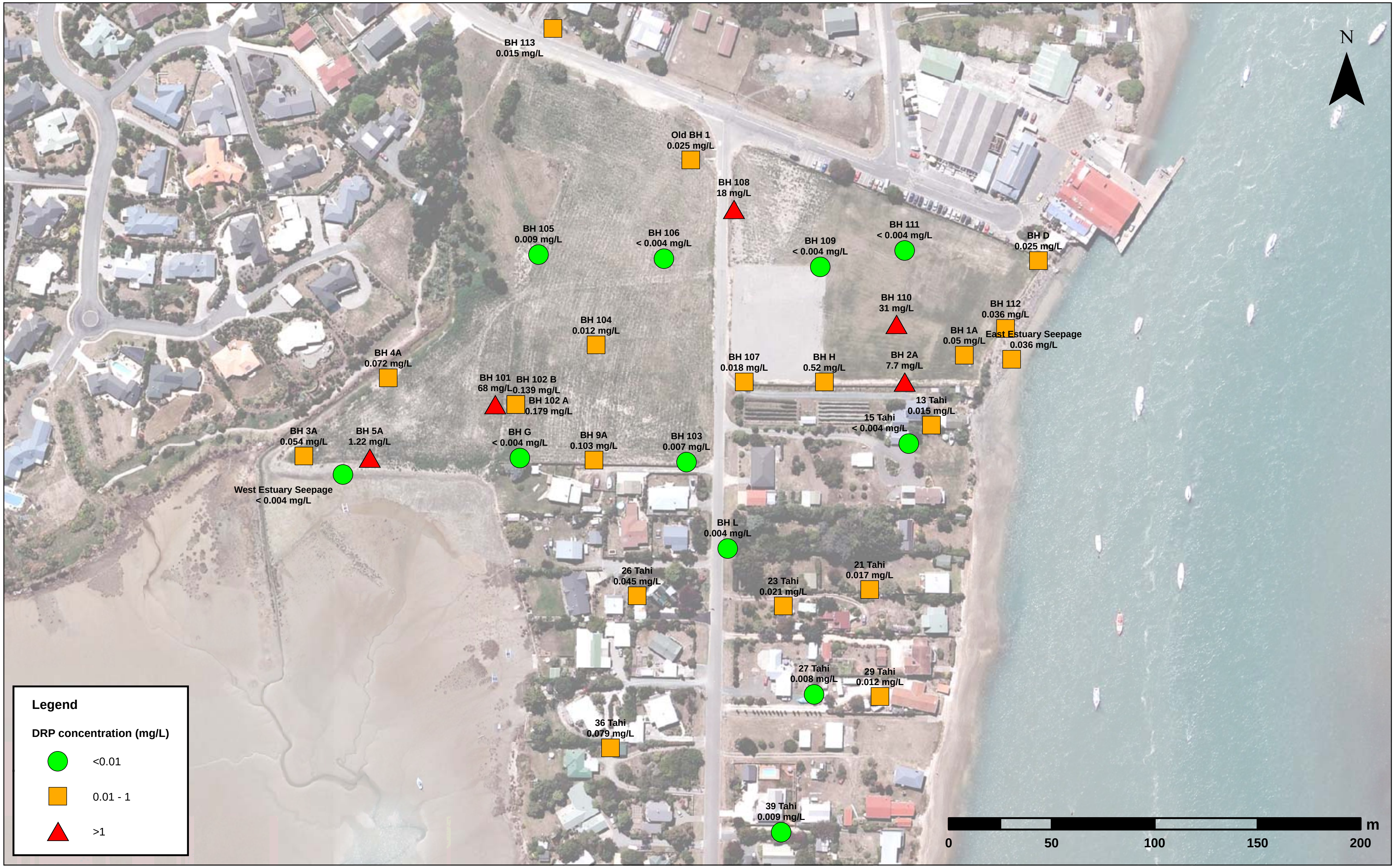
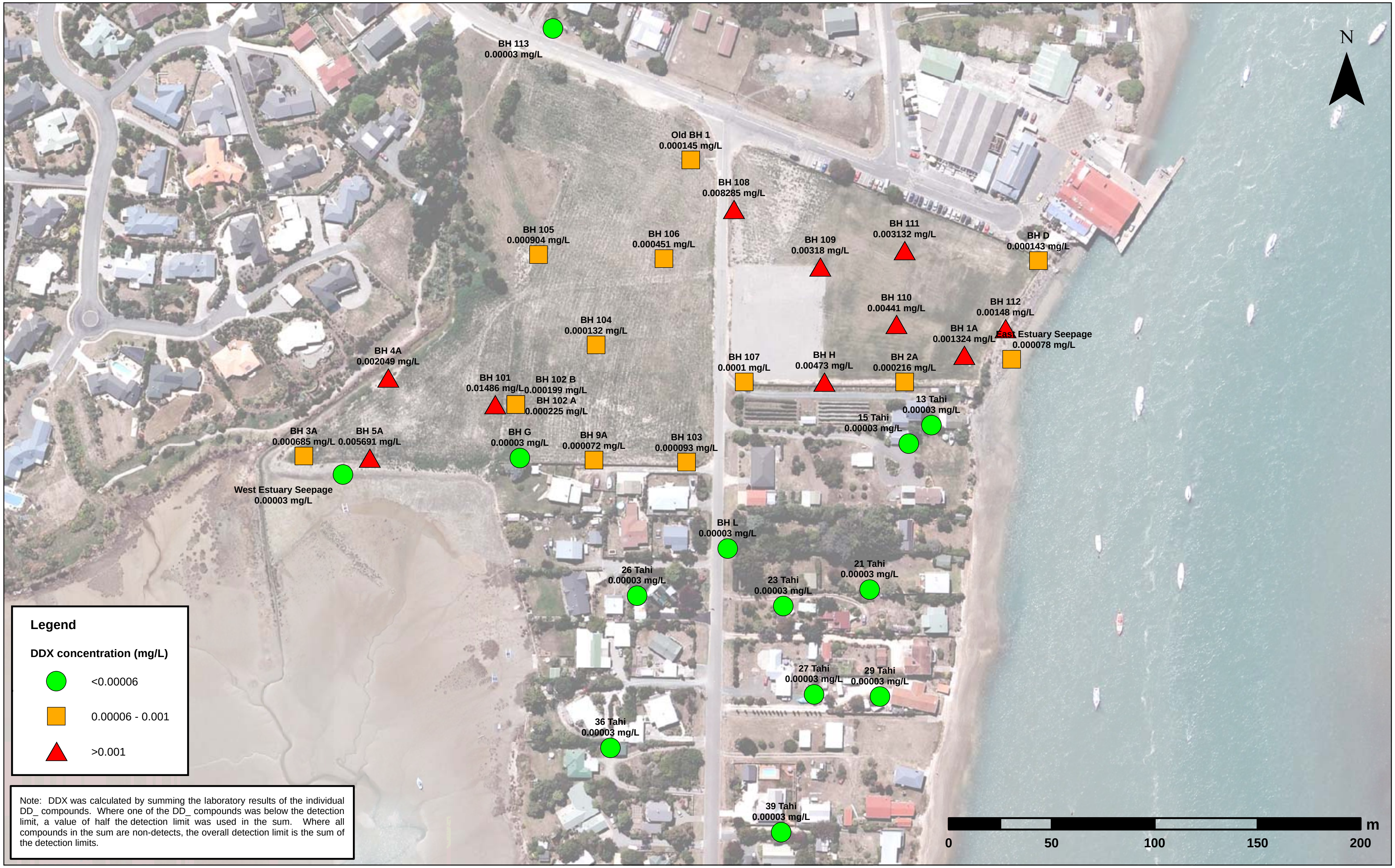


Figure 25 : Dissolved reactive phosphorus concentrations in November 2010

E:\Arcview GIS\Jobs\CJ400-CJ449\CJ41603\Projects\Nov10\CJ41603_Fig22_DRP_Nov10.mxd



Note: DDX was calculated by summing the laboratory results of the individual DD_ compounds. Where one of the DD_ compounds was below the detection limit, a value of half the detection limit was used in the sum. Where all compounds in the sum are non-detects, the overall detection limit is the sum of the detection limits.

Figure 26 : DDX concentrations in November 2010

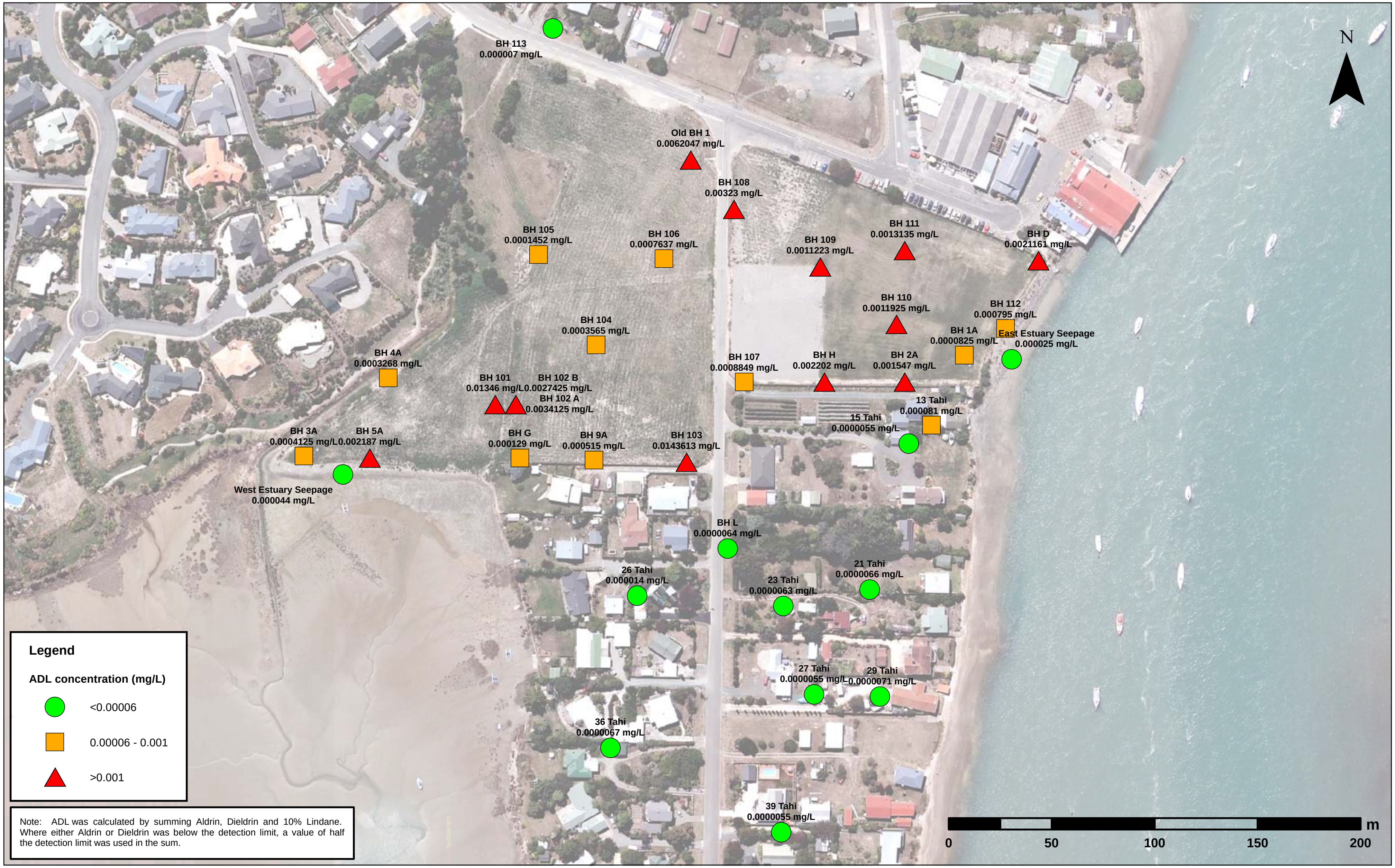


Figure 27 : ADL concentrations in November 2010

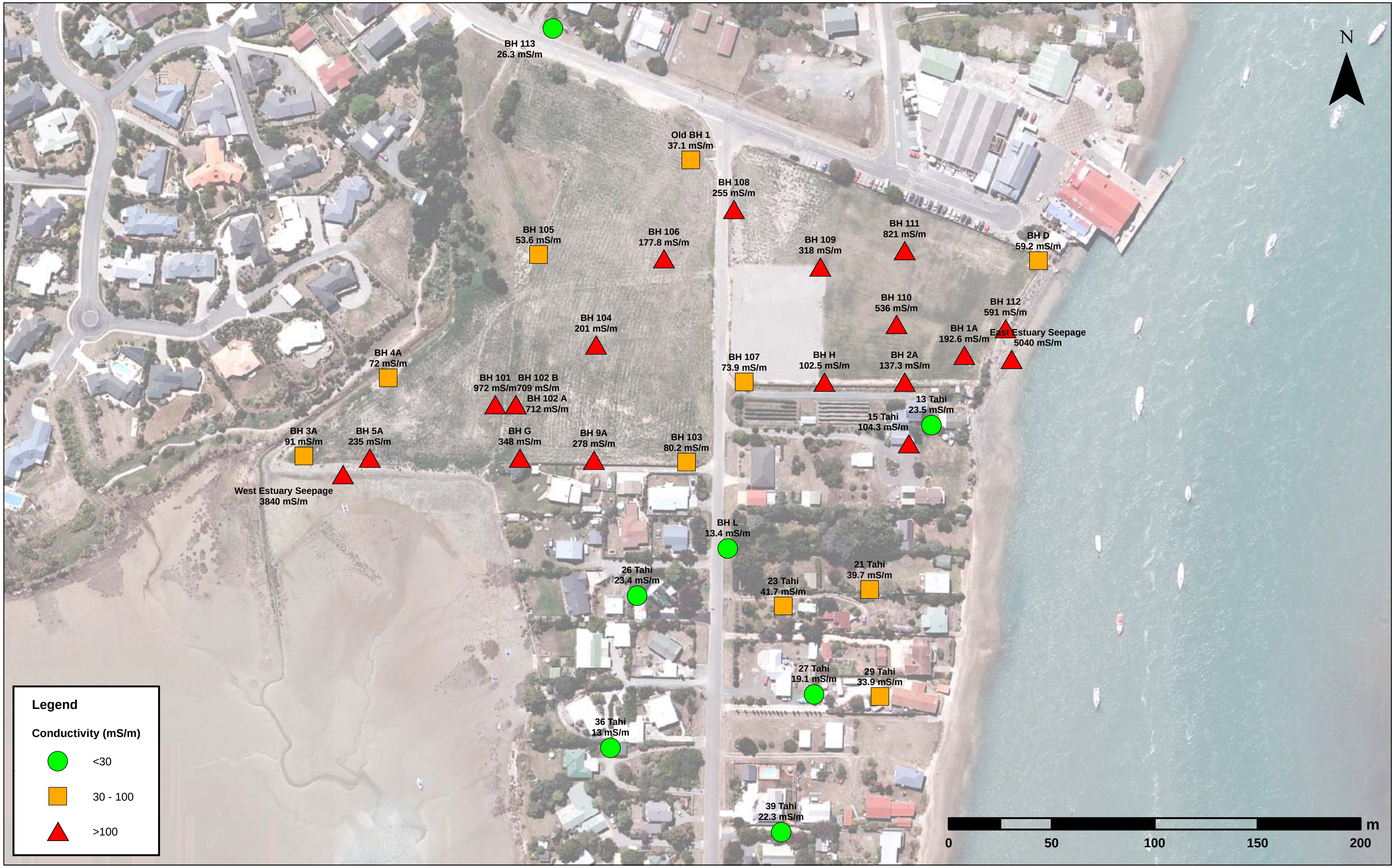


Figure 28 : Conductivity values in November 2010

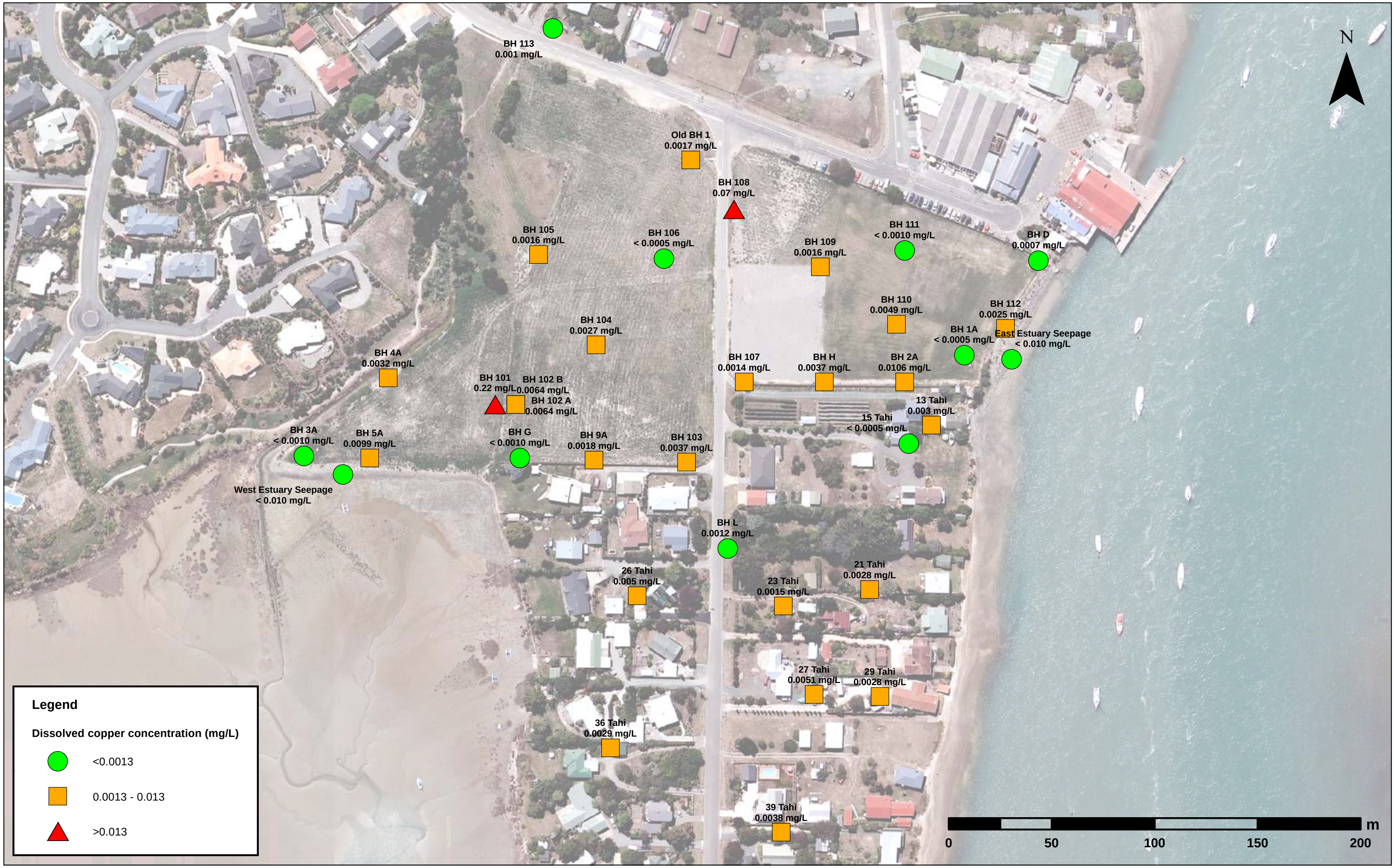


Figure 29 : Dissolved copper concentrations in November 2010

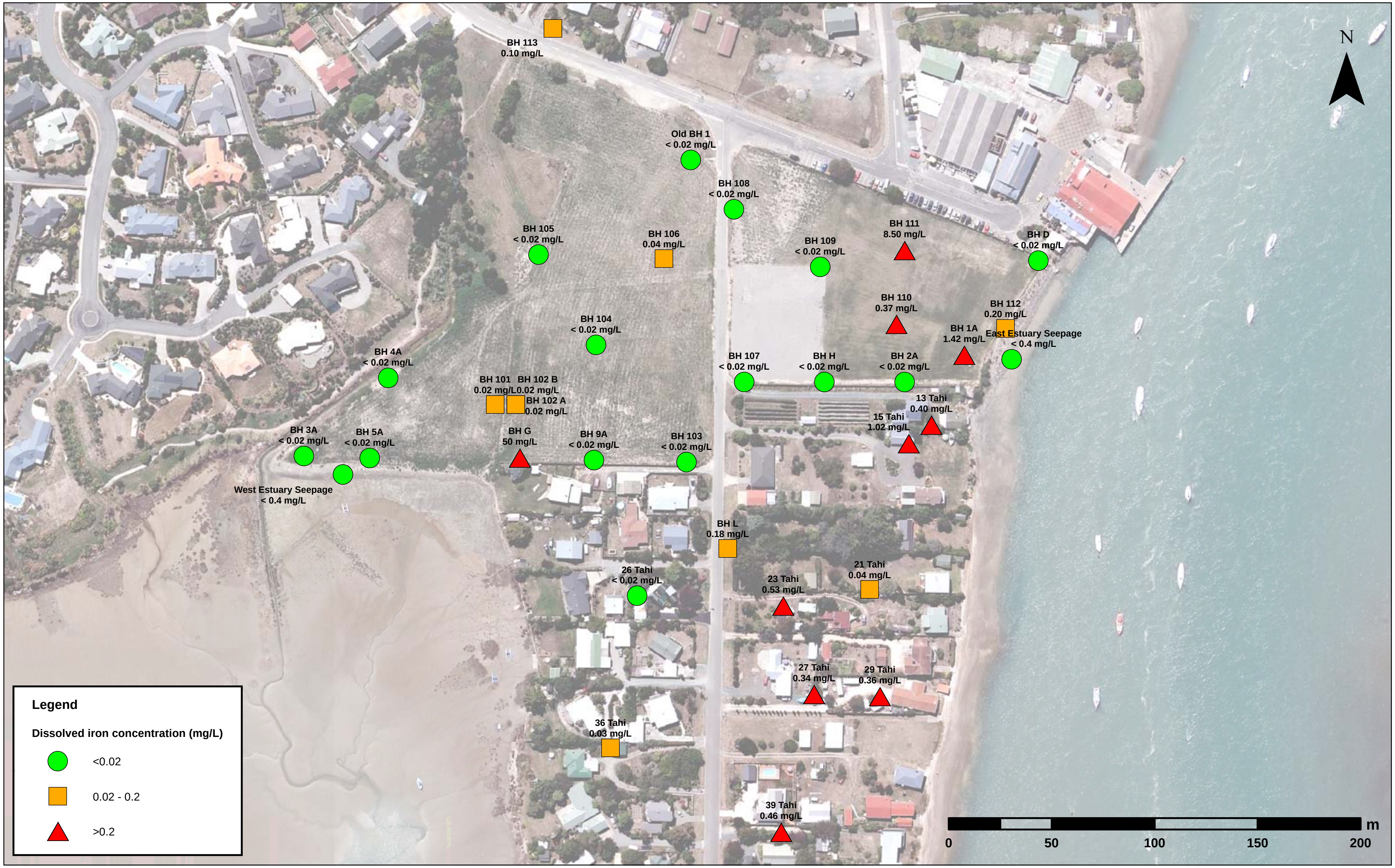


Figure 30 : Dissolved iron concentrations in November 2010

Appendix B

Borehole Details

WWD23593 (BH 101)

Drilled: 8 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518228 N5994369 Ground level: 3.33 m AMSL

0 - 4.9	Not able to be determined - presumably 0.5m clean cover soils over commercial grade processed and backfilled material (i.e. gravels and sands).
at 2.0	Lost circulation water - possibly implying gravels.
4.9 - 6.0	Light brown clay (Moutere Gravel??).
6.0	End of hole.

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 6.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23594 (BH 102)

Drilled: 8 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518238 N5994369 Ground level: 3.34 m AMSL

0.0 - 0.15	Dark brown soil (soil cap).
0.15 - 2.5	Not able to be determined - presumably processed and backfilled residential grade material (i.e. gravels and sands).
2.5 - 5.5	Greenish brown clay with gravels. Wood fragments at 2.5 m.
5.5 - 6.0	Yellow clay with some gravels (Moutere Gravel).
6.0	End of hole.

Bore initially attempted at E2518234 N5994369, however, only clay encountered. Abandoned at 2.0 m and back filled with bentonite.

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 6.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23596 (BH 103)

Drilled: 7 & 8 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518321 N5994341 Ground level: 3.50 m AMSL

0 - 2.7	Not able to be determined - presumably processed and backfilled residential grade material (i.e. gravels and sands).
2.7 - 4.5	Grey fine sand with shell fragments (marine deposits).
4.5 - 6.0	Greenish grey, clayey fine sand with occasional black wood fragments.
6.0	End of hole (Moutere Gravel not encountered).

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 6.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23597 (BH 104)

Drilled: 7 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518277 N5994398 Ground level: 3.78 m AMSL

0.0 - 0.15	Dark brown soil (soil cap).
0.15 - 2.6	Not able to be determined - presumably processed and backfilled residential grade material (i.e. gravels and sands).
2.6 - 3.2	Dark gravels and sands (processed and backfilled material).
3.2 - 4.0	Grey fine sand.
5.5 - 6.0	Grey fine sand with shell fragments and occasional black wood fragments (marine deposits).
6.0	End of hole (Moutere Gravel not encountered).

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 6.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23592 (BH 105)

Drilled: 7 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518249 N5994442 Ground level: 3.96 m AMSL

0.0 - 0.15	Dark brown soil (soil cap).
0.15 - 4.0	Not able to be determined - presumably processed and backfilled residential grade material (i.e. gravels and sands).
4.0 - 6.0	Yellow clay and gravels (Moutere Gravel).
6.0	End of hole.

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 6.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23591 (BH 106)

Drilled: 7 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518310 N5994440 Ground level: 4.35 m AMSL

0.0 - 0.15	Dark brown soil (soil cap).
0.15 - 2.5	Not able to be determined - presumably processed and backfilled residential grade material (i.e. gravels and sands).
2.5 - 3.0	Dark gravels and sands (processed and backfilled material).
3.0 - 5.5	Grey fine sand with shell fragments and occasional black wood fragments (marine deposits).
5.5 - 6.0	Yellow clay with some gravels (Moutere Gravel).
6.0	End of hole.

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 6.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23587 (BH 107)

Drilled: 10 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518349 N5994380 Ground level: 4.20 m AMSL

0.0 – 1.8	Not able to be determined.
1.8 – 2.5	Grey gravels. Loss of drilling water at 1.8 m.
2.5 – 5.0	No cuttings being washed up (inferred as sand from drilling rate)
5.0 - 6.0	Yellow clay with gravels (Moutere Gravel).
6.0	End of hole.

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 6.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23588 (BH 108)

Drilled: 10 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518344 N5994464 Ground level: 4.56 m AMSL

0.0 - 0.5	Soil .
0.5 - 1.0	Course gravel (and sand?).
1.0 – 2.5	Brown clay and gravel.
2.5 - 4.0	Course gravel with brown clay. Wood fragments at 2.7 m.
4.0 – 4.6	Grey fine sand with shell fragments (marine deposits).
4.6 - 6.0	Yellow clay with gravels (Moutere Gravel).
6.0	End of hole.

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 6.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23598 (BH 109)

Drilled: 10 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518386 N5994436 Ground level: 4.79 m AMSL

0.0 - 0.2	Gravel (car parking area).
0.2 - 1.5	Clay and gravel.
1.5 - 2.3	Course gravel with brown clay.
2.3 - 3.0	Course gravel and yellow clay (not Moutere Gravel).
3.0 - 3.8	Grey fine sand (marine deposits).
3.8 - 5.5	Grey fine sand and shell fragments (marine deposits).
5.5 - 6.0	Yellow clay with gravels (Moutere Gravel).
6.0	End of hole.

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 6.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23589 (BH 110)

Drilled: 9 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518423 N5994408 Ground level: 4.26 m AMSL

0.0 - 0.5	Dark brown soil (soil cap).
0.5 - 2.3	Coarse gravels (and sand?).
2.3 - 3.3	Greyish clayey gravel.
3.3 - 3.7	Grey silt. Wood fragments at 3.7 m.
3.7 - 5.8	Grey fine sand.
5.8 - 6.0	Yellow clay (Moutere Gravel).
6.0	End of hole.

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 6.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23590 (BH 111)

Drilled: 9 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518427 N5994444 Ground level: 4.91 m AMSL

0.0 - 0.5	Dark brown soil (soil cap).
0.5 - 3.4	Gravels (and sand?).
3.4 - 4.5	Gravel with grey silt/clay.
4.5 - 6.4	Grey fine sand with wood fragments.
6.4 - 7.0	Yellow clay (with some gravels at 7.0 m) (Moutere Gravel).
7.0	End of hole.

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 7.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23599 (BH 112)

Drilled: 10 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

Location: E2518476 N5994406 Ground level: 3.41 m AMSL

0.0 - 0.1	Gravel and sand (foot path)
0.1 - 2.1	Yellow clay.
2.1 - 3.0	Grey gravels with sand.
3.0 - 5.0	Grey fine sand (marine deposits). Shell fragments at 3.4 m.
5.0	End of hole.

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 2.3 m to 5.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a bentonite seal placed from 2.1 m to surface above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

WWD23595 (BH 113)

Drilled: 9 September 2009 by Waimea Drilling Co Ltd using a tri-cone wash rotary drilling rig. All depths are metres below ground level.

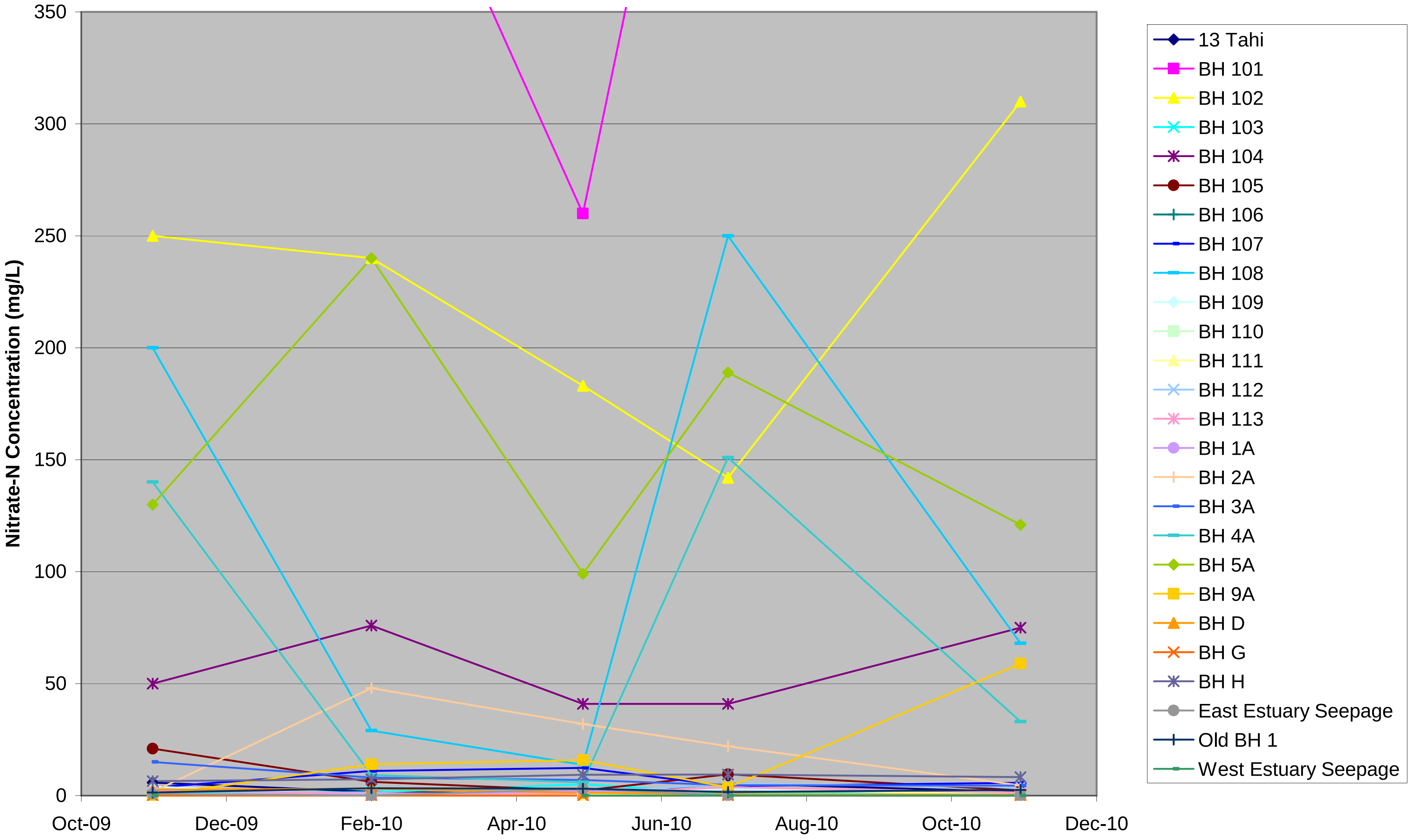
Location: E2518256 N5994552 Ground level: 4.15 m AMSL

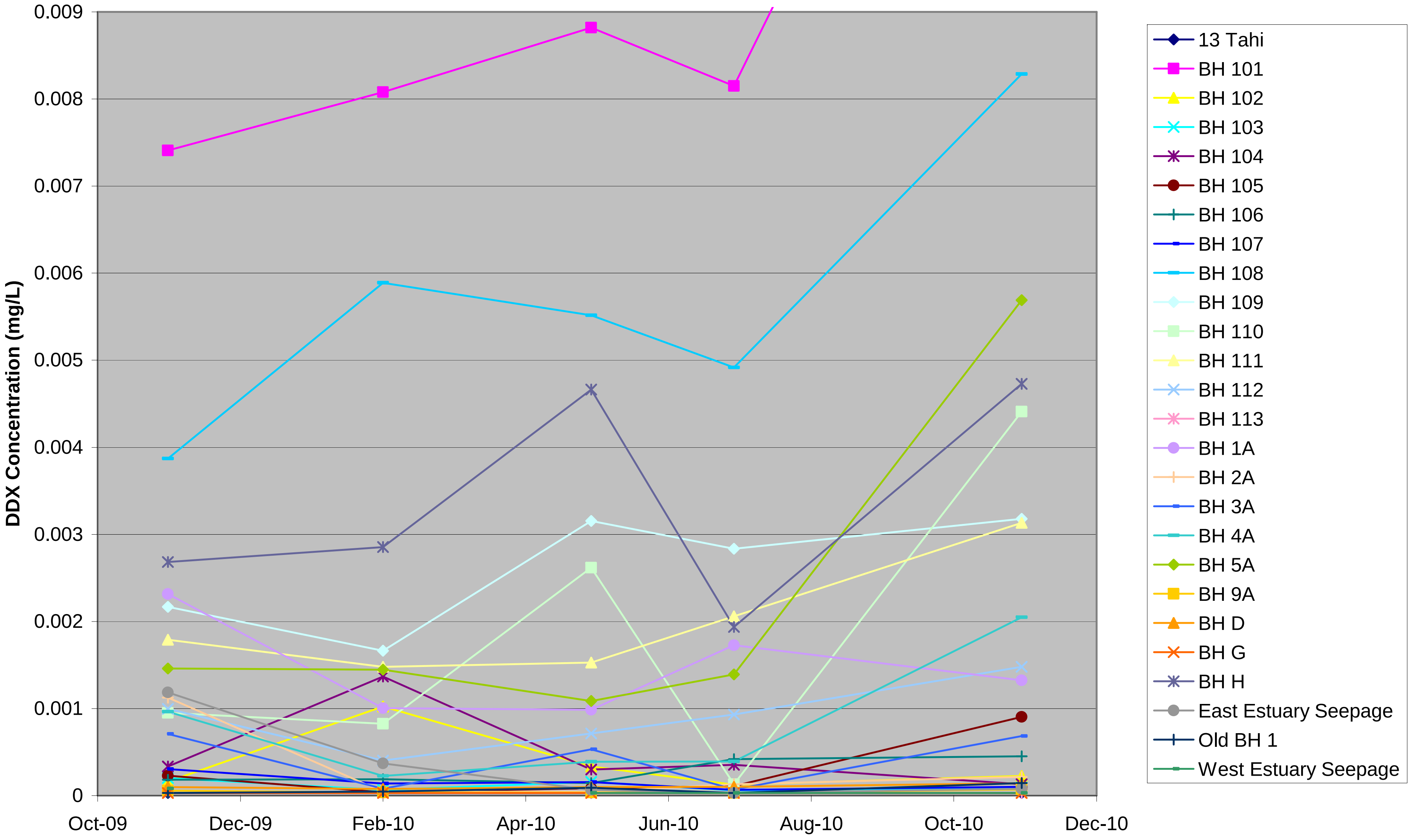
0.0 - 0.8	Brown soil.
0.8 - 4.0	Gravels and sands. Loss of circulation water at 2.5 m.
4.0 - 5.0	Grey fine sand with shell fragments (marine deposits).
5.0 - 6.0	Yellow clay with some gravels (Moutere Gravel).
6.0	End of hole.

The borehole is finished with a 50mm diameter Class D uPVC standpipe. A 1mm machine slotted screened section extends from 1.0 m to 6.0 m and is covered with a filter sock. All joins utilise stainless steel grub screws (no solvents). Around the screened section is back filled with Walton Park Peas with a 0.5 m bentonite seal placed above the screened section. At the surface, the monitoring bore is finished with a lockable toby box set in concrete such that stormwater is excluded.

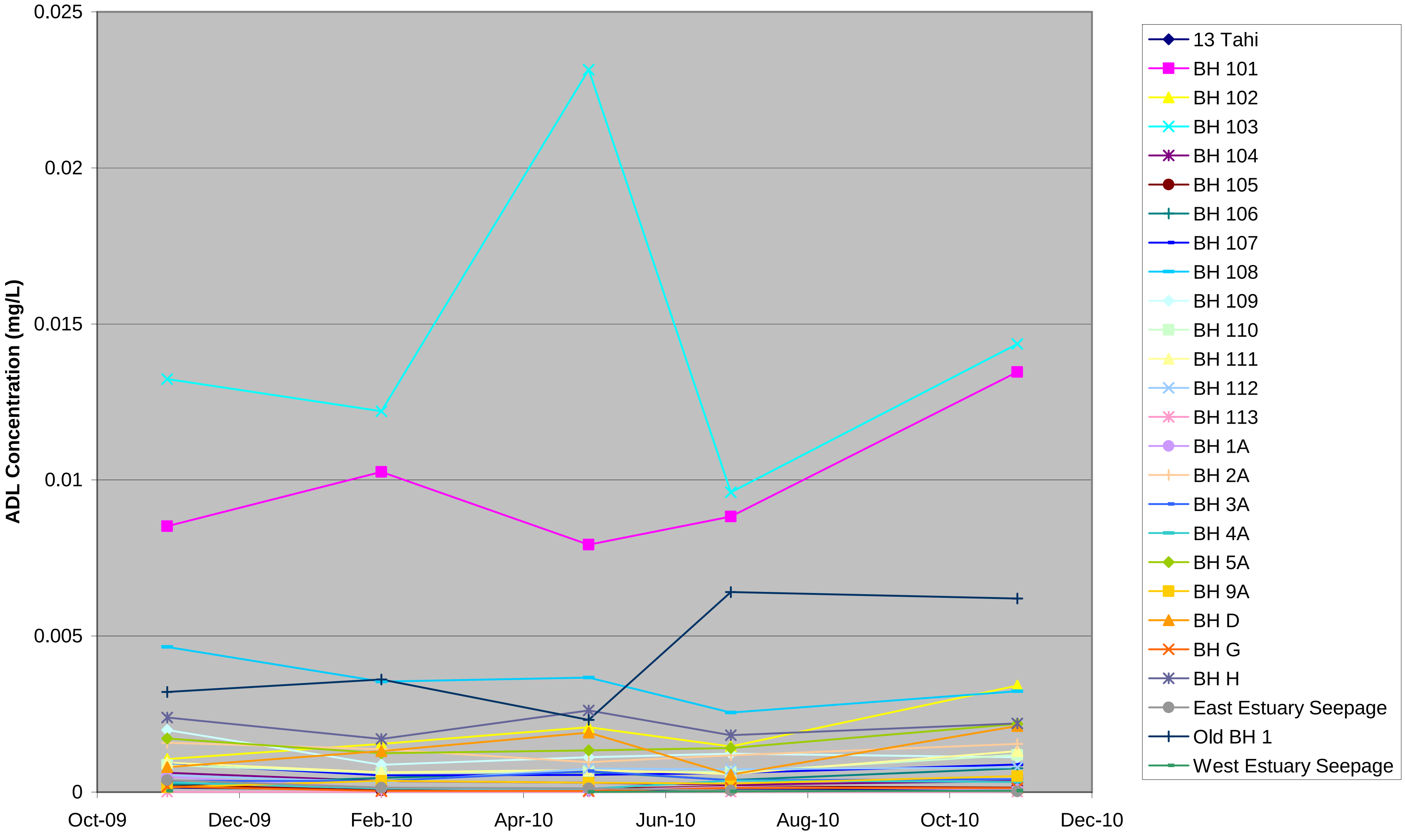
Appendix C

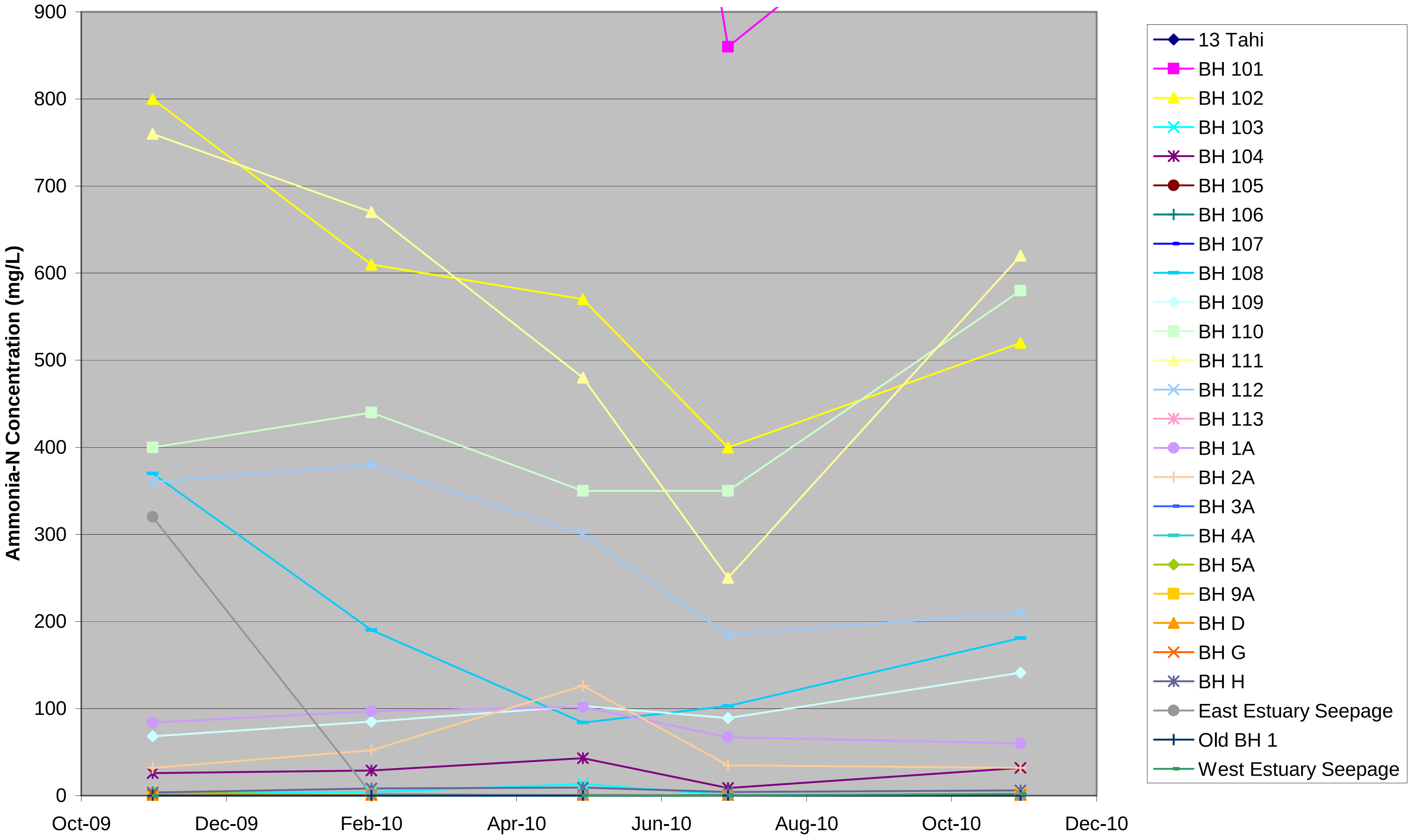
Time Series Plots of Last Five Monitoring Rounds

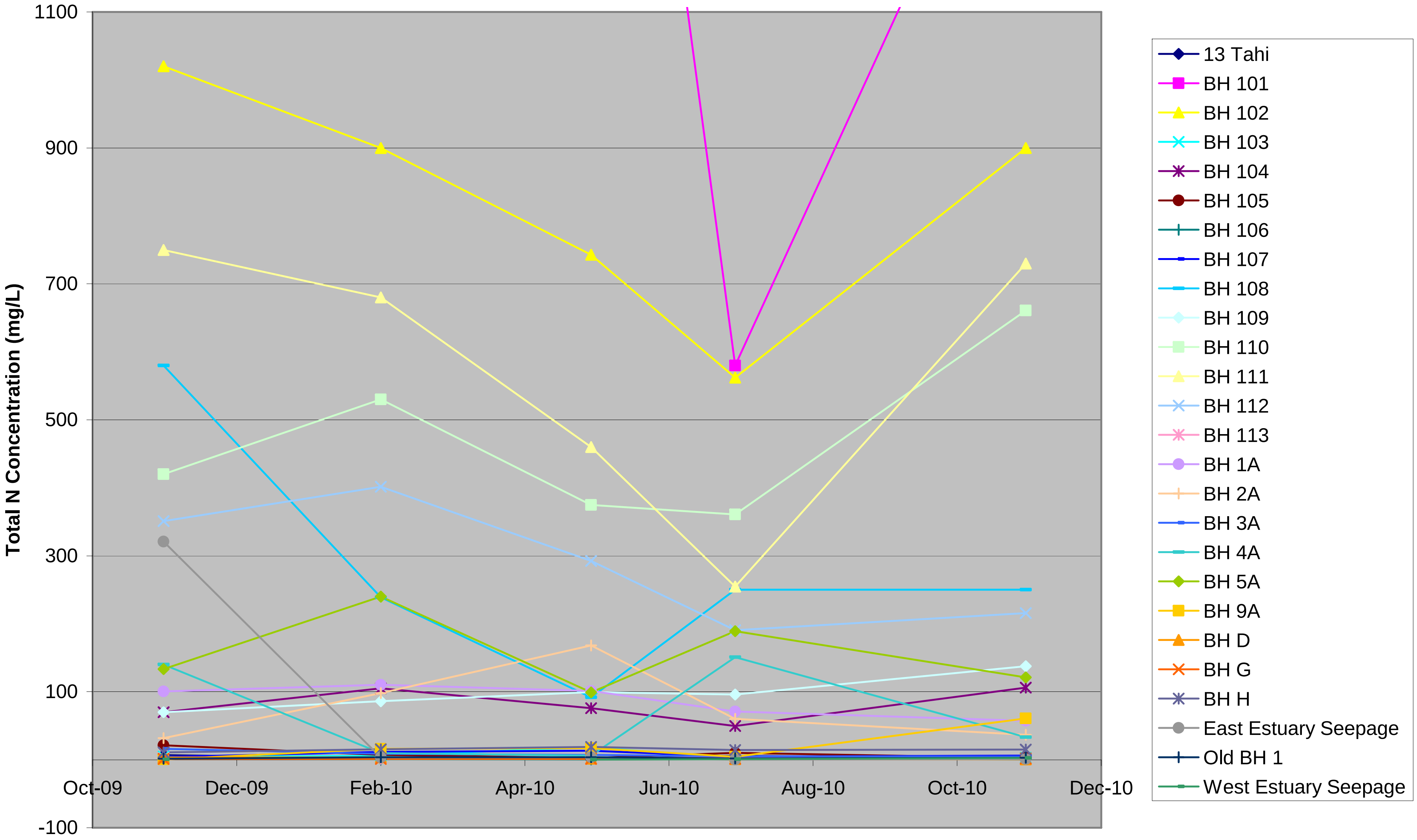

350
300
250
200
150
100
50
0
Nitrate-N Concentration (mg/L)
Oct-09
Dec-09
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
13 Tahi
BH 101
BH 102
BH 103
BH 104
BH 105
BH 106
BH 107
BH 108
BH 109
BH 110
BH 111
BH 112
BH 113
BH 1A
BH 2A
BH 3A
BH 4A
BH 5A
BH 9A
BH D
BH G
BH H
East Estuary Seepage
Old BH 1
West Estuary Seepage

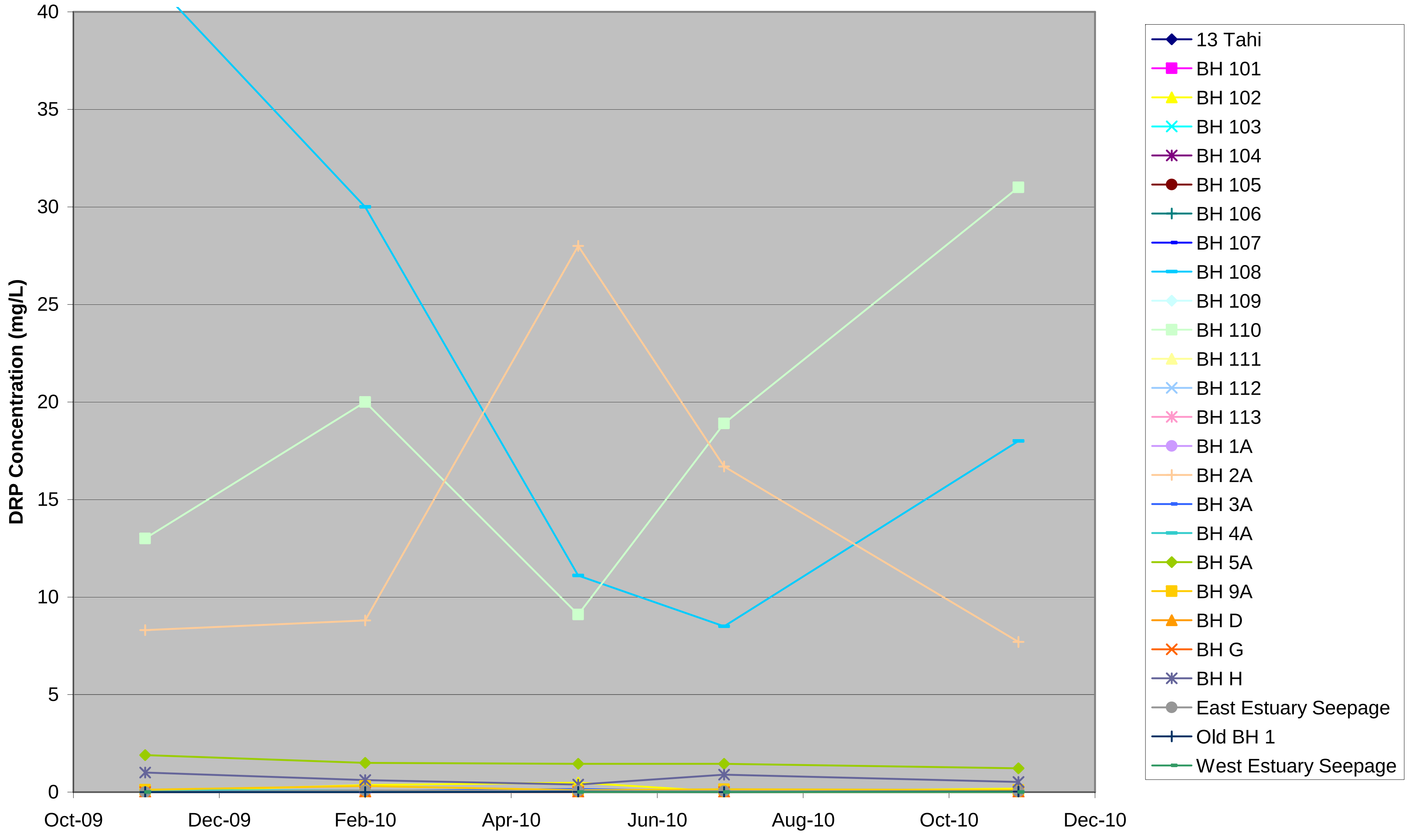


DDX Concentration (mg/L)
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Oct-09
Dec-09
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
13 Tahi
BH 101
BH 102
BH 103
BH 104
BH 105
BH 106
BH 107
BH 108
BH 109
BH 110
BH 111
BH 112
BH 113
BH 1A
BH 2A
BH 3A
BH 4A
BH 5A
BH 9A
BH D
BH G
BH H
East Estuary Seepage
Old BH 1
West Estuary Seepage

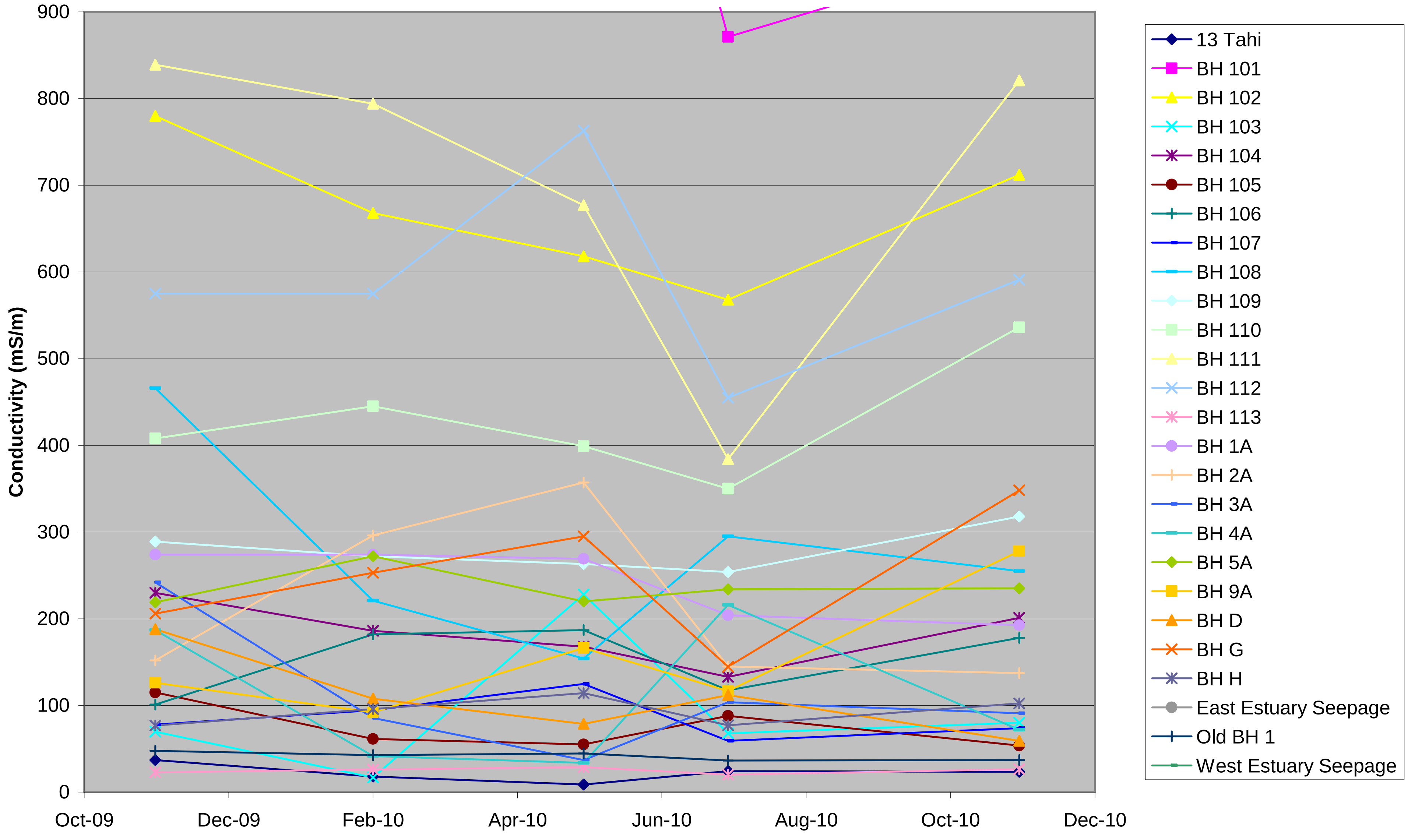

ADL Concentration (mg/L)
0.025
0.02
0.015
0.01
0.005
0
Oct-09
Dec-09
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
13 Tahi
BH 101
BH 102
BH 103
BH 104
BH 105
BH 106
BH 107
BH 108
BH 109
BH 110
BH 111
BH 112
BH 113
BH 1A
BH 2A
BH 3A
BH 4A
BH 5A
BH 9A
BH D
BH G
BH H
East Estuary Seepage
Old BH 1
West Estuary Seepage

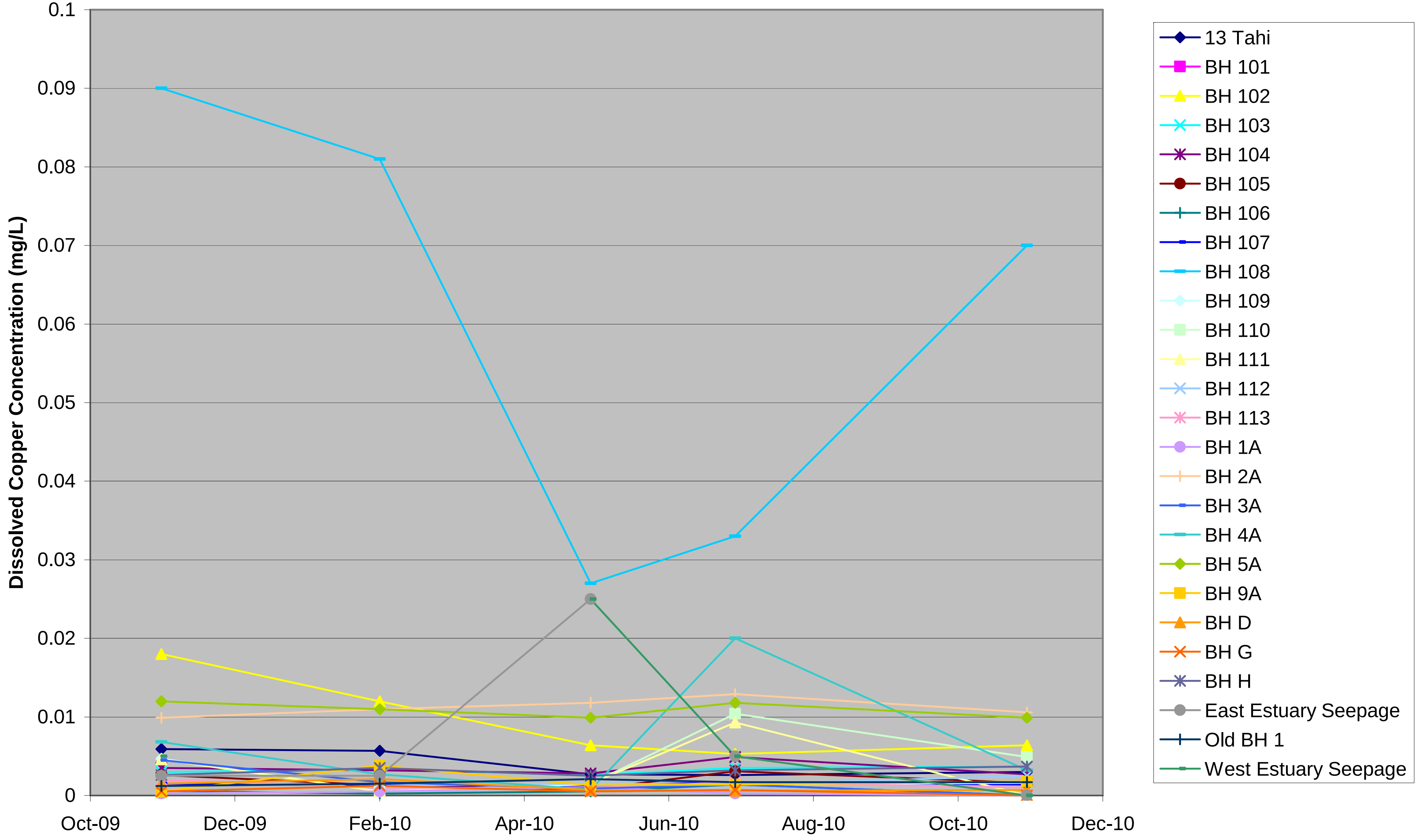

Ammonia-N Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Oct-09
Dec-09
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
13 Tahi
BH 101
BH 102
BH 103
BH 104
BH 105
BH 106
BH 107
BH 108
BH 109
BH 110
BH 111
BH 112
BH 113
BH 1A
BH 2A
BH 3A
BH 4A
BH 5A
BH 9A
BH D
BH G
BH H
East Estuary Seepage
Old BH 1
West Estuary Seepage

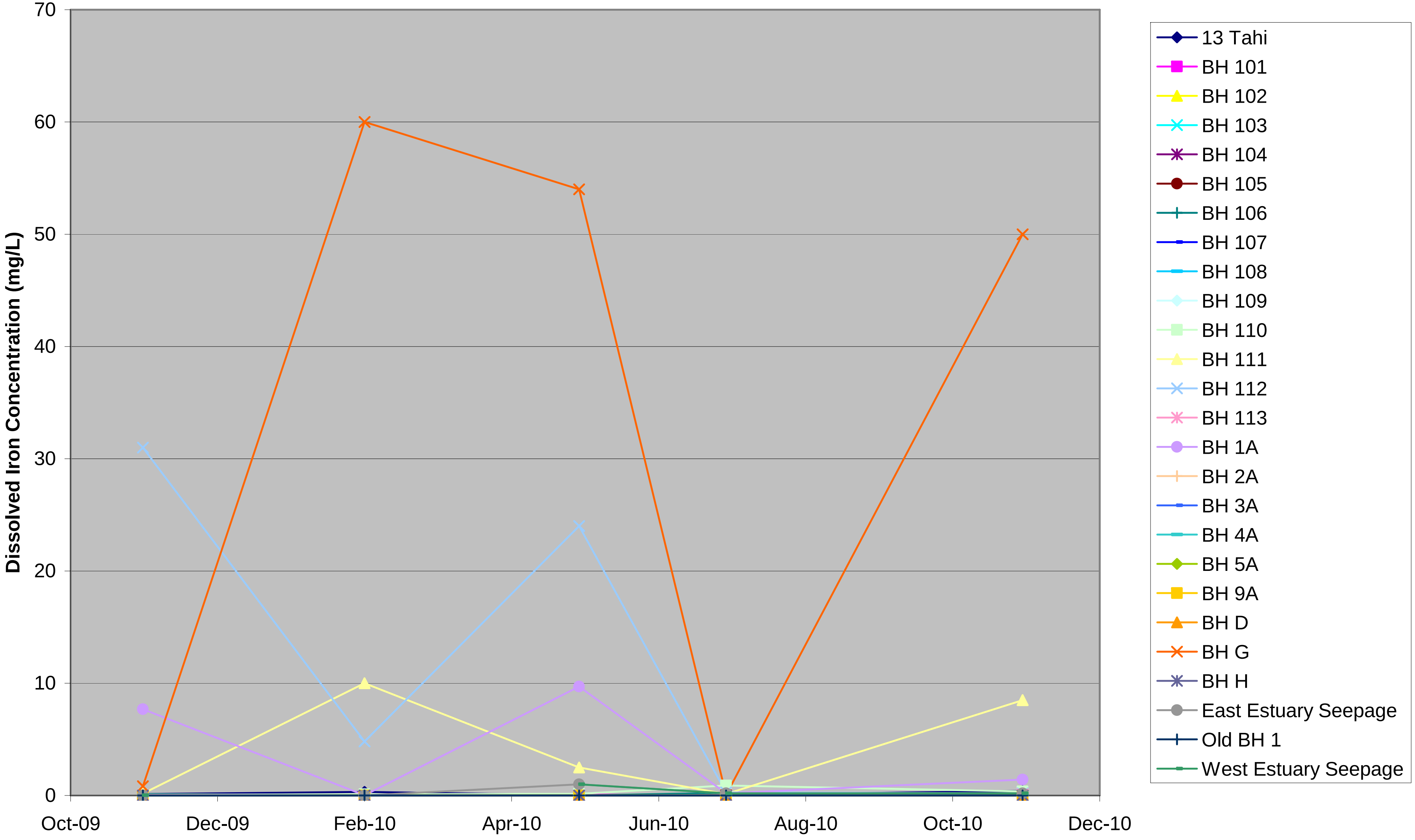

Total N Concentration (mg/L)
1100
900
700
500
300
100
-100
Oct-09
Dec-09
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
13 Tahi
BH 101
BH 102
BH 103
BH 104
BH 105
BH 106
BH 107
BH 108
BH 109
BH 110
BH 111
BH 112
BH 113
BH 1A
BH 2A
BH 3A
BH 4A
BH 5A
BH 9A
BH D
BH G
BH H
East Estuary Seepage
Old BH 1
West Estuary Seepage



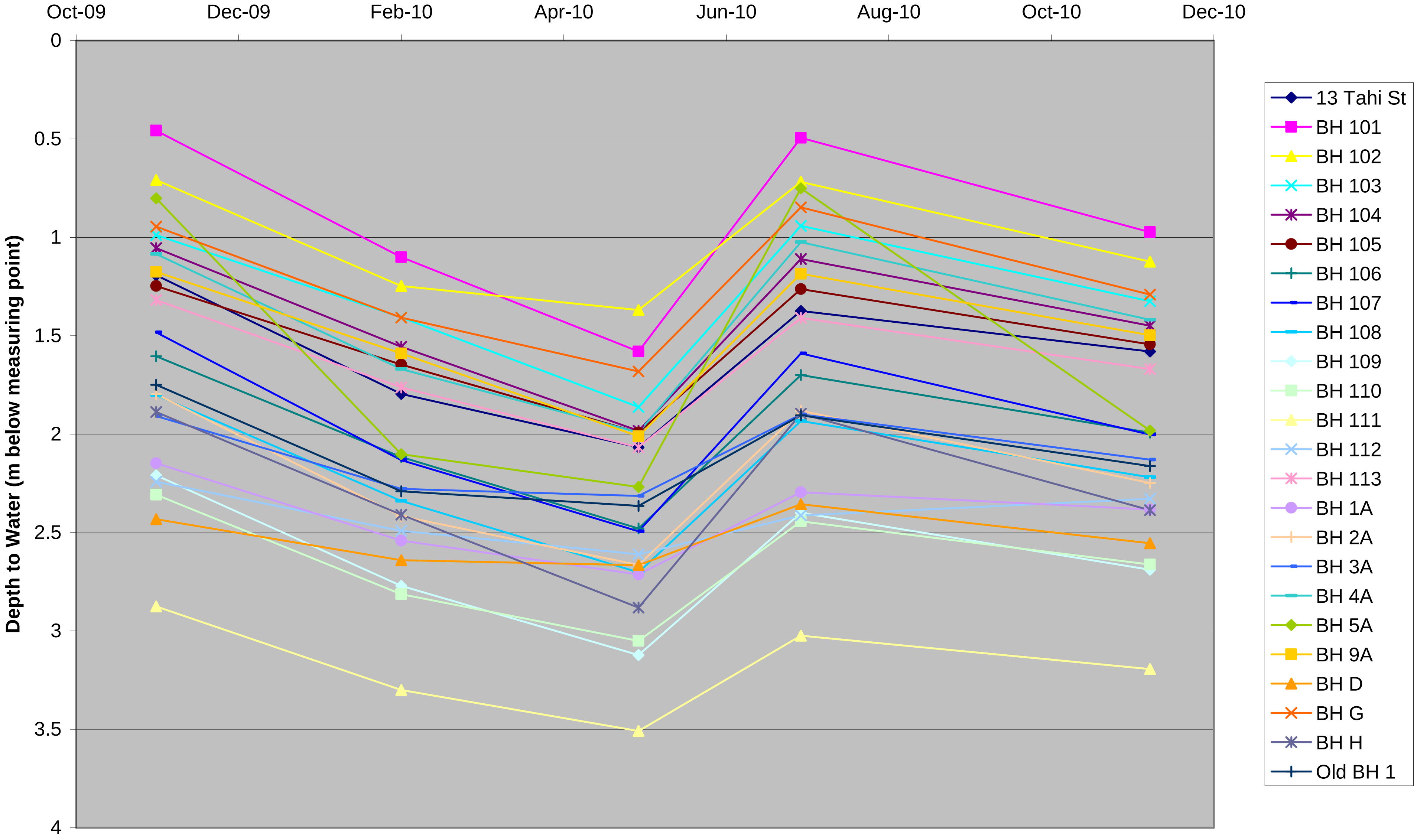
DRP Concentration (mg/L)
40
35
30
25
20
15
10
5
0
Oct-09
Dec-09
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
13 Tahi
BH 101
BH 102
BH 103
BH 104
BH 105
BH 106
BH 107
BH 108
BH 109
BH 110
BH 111
BH 112
BH 113
BH 1A
BH 2A
BH 3A
BH 4A
BH 5A
BH 9A
BH D
BH G
BH H
East Estuary Seepage
Old BH 1
West Estuary Seepage


Conductivity (mS/m)
900
800
700
600
500
400
300
200
100
0
Oct-09
Dec-09
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
13 Tahi
BH 101
BH 102
BH 103
BH 104
BH 105
BH 106
BH 107
BH 108
BH 109
BH 110
BH 111
BH 112
BH 113
BH 1A
BH 2A
BH 3A
BH 4A
BH 5A
BH 9A
BH D
BH G
BH H
East Estuary Seepage
Old BH 1
West Estuary Seepage


Dissolved Copper Concentration (mg/L)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Oct-09
Dec-09
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
13 Tahi
BH 101
BH 102
BH 103
BH 104
BH 105
BH 106
BH 107
BH 108
BH 109
BH 110
BH 111
BH 112
BH 113
BH 1A
BH 2A
BH 3A
BH 4A
BH 5A
BH 9A
BH D
BH G
BH H
East Estuary Seepage
Old BH 1
West Estuary Seepage



Dissolved Iron Concentration (mg/L)
70
60
50
40
30
20
10
0
Oct-09
Dec-09
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
13 Tahi
BH 101
BH 102
BH 103
BH 104
BH 105
BH 106
BH 107
BH 108
BH 109
BH 110
BH 111
BH 112
BH 113
BH 1A
BH 2A
BH 3A
BH 4A
BH 5A
BH 9A
BH D
BH G
BH H
East Estuary Seepage
Old BH 1
West Estuary Seepage



Oct-09
Dec-09
Feb-10
Apr-10
Jun-10
Aug-10
Oct-10
Dec-10
0
0.5
1
1.5
2
2.5
3
3.5
4
Depth to Water (m below measuring point)
13 Tahi St
BH 101
BH 102
BH 103
BH 104
BH 105
BH 106
BH 107
BH 108
BH 109
BH 110
BH 111
BH 112
BH 113
BH 1A
BH 2A
BH 3A
BH 4A
BH 5A
BH 9A
BH D
BH G
BH H
Old BH 1

Appendix D

Analysis to Determine Aquifer Parameters

Appendix D
Analysis to Determine Aquifer Parameters

D2: Analysis of Tidal Fluctuations

The hydraulic diffusivity for the strata can be defined as:

$$a = \frac{T}{S} = \frac{\chi^2}{4\lambda^2 t}$$

Where a = Diffusivity coefficient

T = Transmissivity

S = Storativity

λ = Parameter calculated from the complementary error function as described below

t = Duration of the tidal fluctuation

x = Distance between bore and beach (at mid tide)

λ can be calculated from the complementary error function:

$$erfc(\lambda) = \frac{\Delta H}{\Delta H_0}$$

Where erfc = Complementary error function (can be looked up in tables or calculated in excel)

ΔH = Groundwater fluctuation

ΔH_0 = Tidal fluctuation at coast

The analysis on the data from bores BH D, BH 1A and BH 110 result in the following estimates for diffusivity. Values for transmissivity (assuming S = 0.1) and hydraulic conductivity (for a 5 m thick aquifer) are also shown.

Table 2: Estimated Aquifer Parameters From Groundwater Level Data in Bores BH D, BH 1A and BH110

Bore	**Diffusivity (m^2/day)**	**Transmissivity (m^2/day)**	**Hydraulic Conductivity (m/day)**
BH D	373	37	7.5
BH 1A	707	71	14.1
BH 110	4,234	423	84.7