REPORT

November 2011

FOLLOWING SITE INVESTIGATION AND MONITORING IN 2009 AND 2010

BLACKDOG INTERPRETATIVE REPORT

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Study Limitations

IMPORTANT: This section should be read before reliance is placed on any of the opinions, advice, recommendations or conclusions set out in this report.

This report has been prepared for WRG (Northern) Ltd (and WRG Waste Services Ltd, Shanks Group plc and RSA Insurance) (the Clients) for the purpose of undertaking the interpretation of intrusive works pursuant to its appointment of Golder Associates (UK) Ltd (Golder) to act as Consultant. Save for the Clients, no duty is undertaken or warranty or representation made to any party in respect of the opinions, advice, recommendations or conclusions herein set out. Regard should be had to the agreement between Golder and the Client dated 17 February 2010, when considering this report and reliance to be placed on it.

All work carried out in preparing this report has used, and is based upon, Golder's professional knowledge and understanding of current (December 2010) relevant UK and European Community legislation, standards, and guidance. Changes in the legislation, standards, and guidance may cause the opinion, advice, recommendations or conclusions set out in this report to become inappropriate or incorrect. However, in giving its opinions, advice, recommendations and conclusions, Golder has considered pending changes to environmental legislation and regulations of which it is currently aware. Following delivery of this report, Golder will have no obligation to advise the Client of any such changes, or of their repercussions.

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The content of this report represents the professional opinion of experienced environmental consultants. Golder does not provide specialist legal advice and the advice of lawyers will be required.

If the scope of the work includes borings, test pits, or engineering interpretation of such information, attention is drawn to the fact that special risks occur whenever engineering and related disciplines are applied to identify subsurface conditions. Even a comprehensive sampling and testing programme implemented in accordance with a professional Standard of Care may fail to detect certain conditions.

The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between sampling points may differ from those that actually exist. Passage of time, natural occurrences, and activities near the Site may substantially alter discovered conditions.

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1.0 INTRODUCTION

Golder Associates UK Ltd (Golder) was commissioned by Smallbrook Environmental Ltd (Smallbrook) on behalf of WRG Northern Limited to prepare an Interpretive Report based on Site Investigation (SI) and monitoring works conducted at the Blackdog Landfill Site and surrounding area ('the Site') by Smallbrook between June 2009 and June 2010.

This report provides an interpretation of the factual information collected by Smallbrook as well as additional historic Site Investigation and monitoring information where this is relevant. With regards to this report, your attention is drawn to the Study Limitations at the beginning of the report. The objective of this interpretive report is to inform subsequent stages of discussion regarding the Site such as subsequent options appraisals.

The report is set out as follows:

Section 2 provides details of the Site history and summarises previous works conducted at the Site. Section 3 provides a summary of the 2009 and 2010 Site Investigation and monitoring works. Section 4 provides interpretation relating to each pollutant linkage and summarises the updated conceptual Site model. Section 5 details conclusions and recommendations.

1.1 Background

Blackdog Landfill Site is a closed landfill that was operated by Shanks and McEwan (Contractors) Ltd and Shanks and McEwan (Northern) Ltd under the terms of a planning permission and waste disposal licence until 1993, when the waste disposal licence was surrendered. The Site accepted a variety of domestic, commercial and industrial wastes including liquid wastes. The Site was developed as a dilute and disperse Site, as were many similar Sites at the time in the area. The Site is located approximately 8 km north of Aberdeen city centre, close to the coast and separated from the sea by sand dunes. A Site location plan is included as Drawing 1.

On 5 July 2004, the Site was issued with 2 determination notices under Part IIA of the Environmental Protection Act 1990 relating to Contaminated Land (under the Contaminated Land (Scotland) Regulations 2000). Aberdeenshire Council issued these notices, one of which related to the area of the landfill and the other to the adjacent impacted beach deposits east of the landfill. Under the notices, Shanks Waste Services Ltd (now WRG Waste Services Ltd "WRG") and a number of its subsidiaries are identified as Appropriate Persons (Class A Groups) under the Act. A summary of the pollutant linkages is provided in Table 1.

Table 1: Summary of Pollutant Linkages

Linkage	Source	Pathway	Receptor
A	Hydrocarbons within the waste.	Leaching from the waste	Groundwater
B	Hydrocarbons within the waste.	Migration of free phase LNAPL	Groundwater
C	Desorption and solution of hydrocarbon from impacted beach sediments and solution of localised free phase hydrocarbon.	Lateral migration of groundwater within the aquifer.	Groundwater
D	Desorption and solution of hydrocarbons from impacted beach deposits and solution of localised free phase hydrocarbon.	Solution in to coastal waters within the inter-tidal sands.	Coastal Waters
E	Episodic erosion of sand dunes by Blackdog Burn causing impacted sands to enter surface water.	Hydrocarbons and PAHs are released to surface waters as a thin surface film.	Surface Water
F	Episodic desorption of hydrocarbons from beach sediment and mobilisation of free phase hydrocarbon by wave action	Hydrocarbons and PAHs are released to coastal waters as a film.	Coastal Waters

Linkage	Source	Pathway	Receptor
	following erosion of clean cover from the contaminated beach deposits.		
G	Lateral surface flow and migration through the unsaturated zone of hydrocarbons and PAHs present on the surface of Blackdog Burn to impact groundwater within the intertidal sands.	Lateral flow across the beach to re-enter the saturated deposits on the beach.	Groundwater within the intertidal deposits
H	Lateral surface flow and migration through the unsaturated zone of hydrocarbons and PAHs present on the surface of Blackdog Burn to impact coastal waters within and on the surface of the intertidal zone.	Lateral flow across the beach to re-enter the saturated deposits on the beach.	Coastal Waters

In addressing the determinations made by Aberdeenshire Council, the Site has been previously subject to a number of Site Investigations, undertaken on behalf of Aberdeenshire Council and also WRG. The previous work that is of relevance to this report is summarised in Section 2 below.

1.2 OBJECTIVES

The key overall objectives of this interpretive report are as follows:

- To review the results of the Site Investigation and monitoring work performed in 2009 and 2010; and
- To assess the status of each pollutant linkage in light of the additional information gathered during 2009 and 2010.

1.3 SCOPE OF WORKS

The detailed Scope of Work for the interpretive report includes the following:

- Develop a brief overview of all the Site Investigation and monitoring information collected by Golder previously and by Smallbrook during the recent (2009-10) Site Investigation and subsequent monitoring campaign; and
- Undertake an updated assessment of the extent (where relevant and where information allows) of each pollutant linkage. The pollutant linkages are described briefly below.

Pollutant linkage A relates to the leaching of dissolved phase hydrocarbons from within the waste to groundwater. The interpretive report will review concentrations of the dissolved phase both within the landfill and leaving the landfill. Detected concentrations will be compared to Tier 1 screening criteria. A review of the variation of dissolved phase concentration with time will also be conducted.

Pollutant linkage B relates to the migration of free phase hydrocarbons as light non-aqueous phase liquid (LNAPL) from within the waste to groundwater. The interpretive report will review the LNAPL occurrences and thicknesses over time on either side of the landfill boundary to determine whether the conceptual model of LNAPL movement across the landfill boundary held by Aberdeenshire Council is appropriate or not. LNAPL movement from the landfill will be modelled using guidance from the American Petroleum Institute (API) and commentary provided on LNAPL migration beyond the immediate landfill boundary.

Pollutant linkage C relates to the desorption and solution of hydrocarbons from impacted beach sediments and also the solution of localised free phase hydrocarbon with lateral migration of groundwater within the aquifer. The interpretive report will determine the current extent of contamination within the beach area using information from the 2009 - 2010 beach surveys and accompanying analysis. This will be done by assessing the lateral extent (and where information allows depth). We will also identify, from other monitoring results obtained during 2009 - 2010 (where available and appropriate), whether the extent and concentration of contaminants identified from the beach is increasing.

Pollutant linkage D (the desorption and solution of hydrocarbon impacted beach sediments and solution of localised free phase hydrocarbon with solution into coastal waters) and linkage F (episodic desorption of hydrocarbons from beach sediment and mobilisation of free phase hydrocarbon by wave action following erosion of clean cover from the beach and release into coastal waters as a film) will be treated in a similar manner to pollutant linkage C. The assessment of these pollutant linkages is more difficult to assess as the frequency of events and the mechanics of such events are less well understood. The report therefore assesses the beach level relative to the depth of contamination (from the measurements made) and determines the frequency of events where a release was possible.

For pollutant linkage E, the Blackdog Burn has historically been migrating along the beach causing erosion of contaminated sands within the dunes and the beach as it traverses northwards. Hence, hydrocarbon contaminated sand has been disturbed resulting in contamination of the Burn and thus completing the pollutant linkage. It has also been observed that the action of the Burn has led to release of hydrocarbons and polycyclic aromatic hydrocarbons (PAH) which may, through lateral flow, enter groundwater or coastal waters (pollutant linkages G and H). The interpretive report will review the Burn Diversion monitoring and beach monitoring results following the installation of the Burn Diversion. This information will identify the effectiveness of the Burn Diversion following its installation and therefore identify the status of these pollutant linkages.

1.4 Site Setting

The closed Blackdog Landfill is located 8 km north of Aberdeen City Centre to the east of the A90(T) and adjacent to the sea. The centre of the Site is located at NGR NJ 963 143 (Post Code AB23 8BE) and is separated from the sea, to the east, by approximately 70 m of sand dunes. The Site is accessed via a short road that runs from the A90(T), through the small hamlet of Blackdog.

Blackdog Landfill comprises a total area of approximately 13.3 hectares, with average side lengths of around 400 m (north to south) by 300 m (west to east). The operational area of the Site was in the order of 8 ha. It was formerly a sand pit, with landfill filling the void remaining from mineral extraction.

The Site's internal configuration currently forms two separate areas. The western half of the Site forms a ridge above the level of the surrounding ground at a height of around 25 m AOD. The eastern part of the Site slopes down towards the rear of a line of sand dunes and forms a smaller flat area at the base of the slope at an elevation of around 10 - 12 m AOD. The dunes rise to a level of around 13 - 18 m AOD.

To the north of the Site there is an MOD firing range, to the south there is a smallholding and residential property. To the west the land is predominantly pasture, with Blackdog hamlet being some 500 m from the Site entrance.

There is a shed and open storage areas to the west of the Blackdog Burn that are understood to be owned and used by Mr Fraser, for the storage of fishing nets and equipment. These are used in conjunction with a fishing business that operates from the adjacent beach.

The Site is located in the Aberdeen Green Belt. There are no statutory landscape or nature conservation designations in the vicinity of the Site. However, there are two relevant local environmental designation Sites. These are 'Sites of Environmentally Sensitive Areas' (SESA)/'Sites of Interest to Natural Science' (SINS) covering the coastal dunes from Bridge of Don to Blackdog (Balgownie Links). These are noted for their entomological interest (Sand Dart Moth (*Agrostis ripae*)) and ornithological interest (ducks including moulting flocks of Common Scoter (*Melanitta nigra*) and Eider (*Somateria mollissima*).

Within the area surrounding Blackdog landfill (more properly referred to as Blackdog Farm North), there are a number of closed and active landfills. Some of these were engineered as dilute and disperse sites in a similar design to Blackdog. The following dilute and disperse Sites were operated within 3 km of the Site:

- Blackdog Farm (south) operated by Aberdeen District Council during the 1970's which accepted household and commercial wastes (and possibly drilling muds);
- Tarbothill Farm operated by Aberdeen District Council during the 70's and early 80's. This Site accepted household and commercial wastes but it is not known whether it accepted drilling muds;
- Hill of Traumaud operated by Aberdeen District Council during the early to mid 80's to February 2000. The Site accepted household and commercial wastes, some industrial solid wastes and considerable quantities of drilling muds (some of which was disposed of directly to trenches excavated in to the underlying sands rather than into the waste mass); and
- Easter Hatton operated by JJ Spence but limited to industrial wastes (especially from a paper mill).

2.0 SUMMARY OF PREVIOUS SITE CHARACTERISATION FINDINGS

The following section provides a synthesis of the findings of previous Site Investigations, monitoring information and other environmental works reported to date.

Whilst the results of these previous works have been summarised below, it is recognised that the level of detail within this summary section does not substitute for the complete details provided within the original reports.

2.1 Site History

Blackdog Landfill has had a number of operators, a complex planning history and a number of waste management licences. It is understood (from an undated planning committee report reference 01/90/1310) that landfilling commenced prior to 1982 when unauthorised landfilling was conducted within sand and gravel workings which were also not consented. A temporary planning permission (G/84/P/845), which has not been reviewed by Golder, was issued that allowed landfilling until November 1989. Following the landfilling that was undertaken during this period, it is reported that the eastern portion of the Site (presumably that adjacent to the dunes) was substantially complete but that no restoration was undertaken. On 2 August 1990 a planning enforcement notice was issued requiring landfilling and sand extraction to stop, as planning consent was no longer in existence.

Planning permission for continued operation and restoration of the Site was granted on 29 January 1991 (reference number 01/90/1310) by Gordon District Council along with the construction of an access track from Blackdog Industrial Estate. Time constraints were placed on the completion and restoration of the Site in the four phases of the landfill.

A number of Waste Management Licences have been issued for the Site and it would appear that the last was issued on 30 April 1991. The Site was licensed to accept domestic, commercial, industrial, hazardous and liquid wastes. The amount of liquid wastes that the Site could accept was limited to 25% of the total solid waste accepted. A large proportion of the liquid wastes accepted were drilling muds from oil exploration and production in the North Sea. At the time these wastes were accepted (from 1982 through to 1993 when the Site closed), most of the drilling muds were oil based muds (OBM). Drilling muds contain a variety of materials formulated to stabilise and lubricate deep well drilling and as such have a high density (achieved by adding barite to the muds) and 10 - 20% oil content. Originally diesel was used as the oil additive although during the period of the landfill operations it is understood that less toxic oils were introduced into general usage within the North Sea; initially detoxified diesel then vegetable oils.

2.2 Summary of Environmental Work Preceding the 2009 Site Investigation

A number of Site Investigations have previously been undertaken at Blackdog to characterise the nature and extent of contamination in both Blackdog Landfill and the adjacent sand dunes and beach area. A summary of each investigation is provided below.

2.2.1 MJ Carter Report of 1988

MJ Carter Associates (MJCA) undertook a hydrogeological study of the Site in 1988. Three boreholes were constructed to depths of between 5 and 8 m. Borehole 7, located furthest inland, encountered clay at 3.9 m and this was proved to a thickness of 1.1 m. Above the clay was a deposit of coarse to medium grained sand. Boreholes 8 and 9, located along the eastern boundary of the Site adjacent to the dunes, encountered only medium to coarse sand, noted to be grey at depth. The grain size analyses contained in the MJCA report show the sand to be predominantly medium grained (with little coarse sand). Golder interprets that the dune sands (due to their depositional nature) would be fine sands and hence were unlikely reported to have been encountered in these wells.

Hydraulic conductivity data for the sand deposits has been reported in the MJCA report as in the order of 20 m/d (2.3×10^{-4} m/s) based on both *in situ* hydraulic testing in the wells and calculations based on grain size analyses. The value reported by MJCA is at the upper end of likely hydraulic conductivity values for coarse to medium sand (9×10^{-7} m/s – 6×10^{-3} m/s, Domenico & Schwartz, 1990). Golder interprets from the grading analyses that the fines content of the sand is very low (less than 0.5%). It is possible that some fines are lost if the samples were obtained below the water table using shell and auger drilling (the actual depths of the samples are not reported), but equally, the depositional environment of glacial meltwater would have resulted in well sorted (i.e. very similar grain size material) being deposited.

It is reported in the Preliminary Evaluation of the Blackdog and Tarbothill Sites (MJCA, July 1988) that the original base of the landfill was likely to be between 2 and 6 m AOD. This is only partially confirmed in their cross sections which indicate that the base of the landfill lies between 5 and 6 m AOD. There is no evidence from the sections to suggest basal levels are below 5 m AOD. In the MJCA September 1988 report, they indicate that groundwater elevation at the two downstream monitoring wells varies between 2.22 m and 5.91 m AOD. This suggests that the thickness of the unsaturated zone beneath the Site is small to non-existent.

The report also suggests that groundwater flow is towards the northeast. As such there would be areas of the southeastern part of the Site that may well be below, or at the very least in close proximity, to the water table. However, we consider that there is a strong likelihood that the flow direction indicated by the wells was influenced by the shallow clay encountered in CA7 and by groundwater mounding caused by the liquid waste inputs.

The reported hydraulic gradient within the MJCA report is 0.2. We believe this to be a typographical error as the hydraulic gradient shown on the plan contained within the report indicates a value nearer to 0.02, and the value (back calculated) from the reported groundwater velocity calculated within the MJCA Report is nearer to 0.015. Furthermore, from the documents seen, there appears to be no long-term monitoring records, so fluctuations in groundwater level cannot be assessed.

Within the environmental audit report prepared by MJCA in 1988, there is reference to some of the liquid waste disposal trenches being located in the base of the quarry with the trenches extending down into the sand, albeit that the reference makes it clear that this was not witnessed by the auditor, simply that it was understood to have occurred. Such a practice would not have been likely at the time that Shanks & McEwen acquired the Site as there was up to 5 m of waste in place above the base of the Site in the lower eastern part and 20 m of waste in the western part of the Site. Furthermore, discussions with individuals who have worked at the Site from its start indicated that such a practice was never undertaken. Therefore, it is considered that trenches were only ever excavated into the waste, and not into the underlying sand.

Golder draws a number of intermediate conclusions from the MJCA report:.

- The deposit is highly permeable and has the capability of transmitting large volumes of water;
- The uniform grading will result in a high porosity (probably in the order of 30% close to the maximum theoretical value);
- The absence of fine material (clays and silts) will result in the aquifer having a low attenuation capacity for conventional landfill contaminants but a high retention capacity for hydrocarbons;

- Given the likely shallow unsaturated zone at the Site, it is probable that dilution was the key means by which leachate migration out of the Site would be attenuated; and
- The low calcium carbonate content of the sands (reported in the MJCA report) would provide little buffering capacity of the soils reducing the effectiveness of biodegradation of organic contaminants, although the leachate is likely to be well buffered with a high alkalinity.

2.2.2 Remedios Report of 2001

Remedios carried out a Site Investigation on behalf of Aberdeenshire Council. The Remedios Report provided little conventional assistance in understanding the conceptual model of the Site. Much of their work focused on the sampling of soils from depths, which is likely to have included wastes deposited at the Site, and the finding that these samples have a medium toxicity to certain bacteria. Groundwater wells would appear to have been drilled, but no geological logs, description of completion details or groundwater levels (related to Ordnance Datum) are included in their report. Without such information, little can be concluded from the study. Some limited hydrocarbon analysis has been undertaken and trial pits excavated, but the report does not contain details of the pits, the geological material encountered or any observations made.

2.2.3 Glasgow Caledonian University Report of 2002

Glasgow Caledonian University, on behalf of EB Scotland Ltd, undertook an examination of the cap material, landfill gas and leachate. The Glasgow Caledonian University study had the objective of examining the quality of the cap, investigating the presence of landfill gas within the Site and assessing leachate seepage from the Site. Although 12 (no.) boreholes were drilled across the Site, these were all too shallow to be of benefit to this study. The maximum depth drilled was 2.0 m, with many of the wells being less than 1 m in depth. The presence of water in the wells might have proved useful in determining the level of leachate within the Site, but inconsistencies within the reported levels devalue the results (e.g. borehole 6 was drilled to a depth of 0.8 m bGL but the measured water level was 1.1 m bGL). However, they did measure the rate of leachate seepages emerging from the east-facing scarp slope that runs up the length of the Site. The reported flows were 40 litres/hour. It should be noted that the work was undertaken during August 2002 and as such it is likely that much higher flows occur during the typically wetter parts of the year. The report makes reference to the upper part of the landfill being retained behind a clay bund some 5 m high. Above the bund a number of leachate springs can be observed, one in particular is considerably larger than the others and exhibited the greatest flow rates.

The University also report that a sample of the leachate has been analysed from the seepage area. Unusually, the results are expressed in mg/kg rather than mg/l. While it can be assumed that 1 litre of water would have a mass of 1 kg, there remains some concern that the sample may have been of the semi-solid residue that accompanies the leachate springs. Furthermore, the analyses do not include typical leachate species such as chloride and ammonia, which would assist in determining the nature of the material tested. A hydrocarbon concentration of 3.7 mg/kg was, however, reported. If this had been a liquid sample, it is unlikely that this amount of hydrocarbon could have been dissolved in the water as it exceeds the solubility limit of most hydrocarbons.

2.2.4 Fisheries Research Services Study of 2002 to 2003

Fisheries Research Services investigated the polycyclic aromatic hydrocarbon (PAH) contamination of shell fish for Aberdeenshire Council. The Fisheries Research Services report is a factual account of the monitoring of mussels placed on the beach adjacent to the shoreline east of the landfill. While it appears that storms in November 2002 washed many of the mussels away, some were retained and others replaced. The most northerly sampling station (adjacent to the landfill and north of the fishing station and Blackdog Rock) shows the highest PAH concentration (during the winter months) with lower values at the fishing station and no results reported for Blackdog Rock. The report concludes that the range of PAHs was consistent with a petroleum hydrocarbon source.

2.2.5 Aberdeenshire Council Study of 2003

Aberdeenshire Council undertook a number of studies including Site Investigation of the beach area and groundwater monitoring of a number of wells. The Site Investigation prepared for Aberdeenshire Council by

Environmental Services seems to be a substantive and well executed investigation of the beach. The Site Investigation involved the construction of 9 (no.) boreholes on the beach and (at least) two trial pits. Only one of the wells was completed to allow a groundwater sample to be collected that was unaffected by the drilling process. However, given the nature of the coast it is expected that no monitoring well on the beach would survive or remain functional after even a modest storm or high tide. The investigation has proved the geological sequence (possibly to bedrock in one well), and a number of wells indicated the presence of a clay layer below glacial sands and gravels.

The location of black anoxic and contaminated sand horizons beneath parts of the beach were determined along with levels of hydrocarbon contamination. These horizons were found to up to 2.4 m thick. In all cases the sand above the black horizon was largely uncontaminated and brown in colour. Beneath the black sands, and elsewhere where no black sands were observed, grey and dark grey sands have also been observed.

The report also documents a number of instances especially during the winter months, where hydrocarbon has been seen seeping from the beach. During very high (spring) tides, where sea levels will result in higher than normal groundwater levels on the beach, oil sheens have been seen at the surface. It is also reported that the cover of clean sands over the heavily contaminated sands varies considerably depending upon antecedent storm conditions with up to 1 m of beach sand being removed, and then replaced over quite short periods of time.

Erosion of the coast line was raised as an issue on a number of occasions, the Environmental Health Services report states that erosion of the dunes can occur at rates of up to 10 m per year. However, there is no evidence to suggest that such extreme erosion is occurring on an annual basis, albeit that occasional storms may erode the dune line. No mention is made of further redistribution of sand to the dunes during intervening periods.

The Site Investigation (which was conducted in March 2003) was confined solely to the beach. No drilling was undertaken within the dunes or adjacent to the landfill. A subsequent groundwater sampling round was undertaken around the landfill. Only three wells could be located that actually contained water. Groundwater samples were obtained from R1, R2 and CA9. CA8a, CA8b and R3 were found to be dry. The “CA” series boreholes are presumed to be the MJCA wells, although the notation 8a and 8b is confusing as the MJCA report refers only to Boreholes 7, 8 and 9. None of the reports reviewed have contained logs for the “R” series of wells, but these seem to correspond to the locations shown in the Remedios report. CA9 was reported to be severely silted with only 0.7 m of open well below the water level. While the report states that the water level in each well was measured using a dip meter, only the water level in R2 is actually reported. The water level was 6.29 m bGL. No ordnance datum is reported for this well so it provides limited additional hydrogeological evidence, other than it was reported that the well recovered almost instantly following purging. Furthermore, without the well completion details, it is unclear whether the standing water level in the well is above or below the screened portion of the well. If the groundwater level is above the screened portion of the well then any free product that may be within the aquifer would not be able to enter the well.

In relation to CA9, it was reported that as much as half of the free standing fluid in the well was hydrocarbon LNAPL floating on the water surface. While the report states that this might be hydrocarbon trapped in the well, it is known that this well has a plain screen from the surface to 5.2m depth and then is screened for its lower 2.8 m (MJCA report 1988). A water level was reported and was within the slotted section of the well.

Samples from the two “R” series wells (R1 and R2) showed concentrations of total hydrocarbon concentrations of 0.038 and 0.075 mg/l (Note that subsequent investigation in 2009 showed that these boreholes were installed with just plain casing and were therefore not suitable as monitoring wells).

2.2.6 Golder Desk Study of 2004

Since the issue of the Notices of Identification of Contaminated Land, the following work was completed by Golder.

A desk study of pre-existing data was conducted to assist in developing preliminary conceptual model of the Site. The hydrogeological regime at the Site was considered to be relatively simple, consisting of one aquifer comprising glacial sands and gravels. Groundwater flow beneath the landfill was concluded to be towards the east, discharging to the sea some 70 – 100 m to the east. There was limited monitoring data with which to confirm either the groundwater flow direction or any long term changes in groundwater quality. However, hydrocarbon contamination on the beach appeared to have resulted from free product migration from the Site. This in turn has resulted in dissolved hydrocarbons entering groundwater from the impacted beach deposits. In addition, hydrocarbons within the landfill were also judged likely to be continuing to generate low levels of dissolved hydrocarbons as a result of infiltration into, and subsequent leakage from, the Site. However, there remained some significant uncertainties at the time with respect to specific issues, and these are discussed below.

Firstly, it was considered important to establish whether free product was still leaving the landfill. There was evidence that in the early ’90s free product was migrating to the beach and was visible as such. Retained hydrocarbon was certainly present beneath the beach and almost certainly beneath the dunes. If free product continued to leave the landfill then this migration could be expected to continue. If free product was no longer leaving the landfill, then the mechanism to drive the migration would have been removed, and the retained product would no longer be migrating as a free phase liquid. Rather, it would remain immobile but contributing to ongoing dissolved hydrocarbon in the groundwater. This has implication in judging the significance of the impact on controlled waters and the range of remedial actions (if any) that might be invoked.

Secondly, there was uncertainty relating to the movement of groundwater itself, up-to-date groundwater levels and water quality (up and down hydraulic gradient) still needed to be established. A preliminary conclusion of this report was that it was unlikely that groundwater upstream of the landfill was contaminated with hydrocarbons. This needed to be proved prior to proceeding with further work.

Finally, the report also identified uncertainty with regards to the possible contamination of surface waters from other sources. This was primarily due to the existence of multiple potential sources within close proximity to Blackdog landfill.

2.2.7 Golder Site Investigation April 2005

A Site Investigation was completed in April 2005. The objectives of the investigation were agreed with Aberdeenshire Council prior to the works commencing and included the following:

- Determine the extent of hydrocarbons within the waste;
- Determine the extent of free product within the Aquifer;
- Determine the origin of the oil on the beach;
- Confirm the groundwater regime;
- Establish monitoring infrastructure;
- Obtain data to assist in any remedial design;
- Obtain samples of soil, leachate, groundwater, and surface water for chemical analysis; and
- Further delineate the extent of hydrocarbons in the beach deposits.

A total of 10 pin wells (P1-P10) were installed within the landfill on 12 April 2005 by F.A. Hay Ltd. Pin well locations were decided based on an approximate spacing of 50 m with a 15 m stand off from the eastern boundary of waste placement. Pin well spacing was reduced to approximately 25 m to increase the resolution of data in the following two areas:

- Around the largest leachate spring; and

- Upgradient of exposed sand deposits containing hydrocarbon on the beach where the Blackdog Burn has eroded a new channel.

The pin wells were installed by driving a 5 m long, 150 mm diameter pin into the landfill using the arm of a 360° excavator. On withdrawing the pin, a 90 mm OD, PE pipe with holes drilled at 10 mm intervals was placed in the hole, with the remaining annulus backfilled with gravel to 0.5 m bGL, the pipe was sealed up to ground level with bentonite.

Initially the pin wells were made secure by EF welding caps to the top of the pipe. Lockable steel headworks were subsequently concreted over each pipe.

A total of 5 boreholes (GA1-GA5) were drilled by Ritchies, between 19 and 26 April 2005 using an Edeco Pilcon light cable percussion drilling rig. The boreholes were located to help determine the groundwater flow direction and hydraulic gradient across the Site. The downgradient monitoring boreholes were located adjacent to those areas within the landfill estimated to contain the most hydrocarbon free product and/or the highest leachate level.

A total of 155 auger holes (A1-A155) were drilled in order to identify the visual and olfactory presence of hydrocarbon beneath the beach. Holes were progressed as deep as practical, up to a maximum depth of 1.5 m. Auger hole locations were located along a traverse at the foot of the sand dunes, extending from a location 50 m north of the Site to a point approximately 30 m south of the extent of the Site. Spacing of auger holes was 6 m for the first 9 holes (to the north) and 3 m thereafter towards the south.

Visual presence of hydrocarbon was identified within the bank of Blackdog Burn and an auger hole was not necessary.

Auger holes A87, A90, A94-A97 and A103-A155 were drilled to the east (seaward) side of Blackdog Burn due to the Burn flowing along the foot of the dunes.

The initial desk study carried out by Golder (2004) derived a conceptual model based on a review of the information to that point. In the light of the 2005 Site Investigation the conceptual model for the Site was updated as described below.

Blackdog Landfill Site was developed as a dilute and disperse Site within shallow sand and gravel deposits a short distance from the sea. The Site accepted solid household, commercial and industrial wastes including hazardous wastes (asbestos). It also received a significant quantity of non-hazardous liquid wastes including oil based drilling muds (OBM). The unsaturated zone was likely to have been thin (at best), or absent. The sands into which the leachate and light non-aqueous phase liquid (LNAPL) will have passed into are likely to be of low attenuation capacity for conventional leachate constituents. As such the zone of anaerobic conditions beneath the Site is likely to be extensive resulting from the migration of conventional landfill leachate components. Hydrocarbon compounds such as those used in oil based muds (OBM) degrade poorly (or not at all) under anaerobic conditions. The small molecules will degrade more rapidly under aerobic conditions while the larger molecules will degrade slowly under aerobic conditions.

Groundwater underflow is relatively high even though the catchment area is likely to be small. This is due, primarily, to the highly permeable nature of the glacial melt water deposits and the absence of fines. With little retardation of contaminants within the sands, the travel time to the beach would be relatively fast. It is anticipated that there is a dilution factor of 2 for conventional contaminants. However, oils within the landfill are able to migrate from the landfill as emulsions and as free product. While the sands have a high retention capacity for holding hydrocarbons, the total amount of hydrocarbons disposed of has allowed them to migrate on the top of the groundwater surface, as far as the beach in at least two areas. In the soil auger investigation carried out as part of this Site Investigation, the northernmost plume of hydrocarbon previously outlined by Aberdeenshire Council was proven to be largely accurate but extends further south by a distance of approximately 20 m. The second, southernmost plume of hydrocarbon was not identified in the soil auger investigation. This was thought to lie in the course of the Burn at that time (note that this is north of the current diverted location of the Burn) and may have been washed away. The soil auger investigation had to follow the seaward side of the Burn and no evidence of hydrocarbon was found.

Hydrocarbon impacted soil arisings were identified in all groundwater monitoring boreholes drilled on the downgradient boundary of the landfill. It is thus considered likely that there is a wide plume of retained hydrocarbon within the sands adjacent to the landfill. The small amount of free product in the monitoring wells and the relatively small quantities of hydrocarbon free product located within the landfill indicates that the movement of hydrocarbon out of the landfill had been reduced, but this needed to be confirmed with further sampling. The plumes of hydrocarbon extending on to the beach were anticipated to be along the lines of preferential pathways with migration of LNAPL as a free phase essentially pushed along by the addition of more hydrocarbon. Once the addition of the free product to the aquifer ceases, the retained hydrocarbon within the soil becomes static and stops migrating further, albeit that dissolved hydrocarbons will continue to be released.

The Site still appeared to contain a very small amount of free phase oils. This was identified in the pin well investigation. Pin wells P3, P8 and P9 identified free phase hydrocarbon, however the amount in P3 and P8 was minimal at 0.01 m. A thickness of 0.44 m of product was identified in P9 at the southern end of the Site; this hydrocarbon was identified as fuel oil (similar to diesel given its extended period within a landfill).

Initially, free product was not encountered in the newly installed downgradient wells but subsequent monitoring indicated a small accumulation (0.09 m) in GA04.

The local hydrogeological regime was established and the groundwater flow direction refined from that assumed in earlier reports.

The upgradient wells indicated the existence of perched water levels above the main groundwater elevation. These perched levels were concluded to be supported by an intermediate silty clay horizon. This horizon does not extend across the landfill to the East and its presence has not been noted downgradient of the Site.

2.2.8 Golder Interpretative Report April 2005

Interpretation of the Site Investigation completed in April 2005 was reported in December 2005. Interpretation of the April 2005 Site Investigation results was completed with a focus on the specific pollutant linkages.

With respect to Linkages A and B it was considered likely that only a small fraction (less that 1%) of the original hydrocarbon deposited at the Site remained within the landfill. There was an expectation that there would be (or probably had been) a substantial reduction in the flux of hydrocarbon leaving the landfill (either as LNAPL or dissolved phase). The situation was therefore expected to be an improving system. Monitoring on a regular basis was recommended to determine whether this is measurable. The location of the Site, adjacent to the sea, means that the receiving groundwater is of very limited extent and thought to be of no resource value due to the salinity. As such it was considered that the resulting groundwater contamination was not serious.

Linkages C, D and F relate to a source comprising contaminated beach deposits. Contamination was considered to be migrating from these deposits to controlled waters via groundwater and surface water. The limited extent of the groundwater resource and its juxtaposition to the sea mean that the resource has a very limited value.

It was expected that low level contamination of the beach deposits might continue for a few years. The primary source of the oil (i.e. the landfill) appeared to contain very little hydrocarbon compared to the amount that is understood to have been deposited, and hence the overall situation was considered to be one that was gradually improving.

Linkages E, G and H relate to contaminated dune deposits. Comments made in the preceding paragraph to the reduced flux of fresh oil from the landfill apply. Burn Diversion works to divert the flow of Blackdog Burn away from contaminated dune deposits have also been implemented since this study took place.

2.2.9 Golder Further Site Investigation of November 2006

A further Site Investigation was undertaken in October and November 2006 to supplement information collected during previous investigations regarding the source of the hydrocarbons within the landfill waste mass. One of the key objectives of this investigation was to determine the presence, or otherwise, of free phase hydrocarbon within the landfill.

The investigation strategy involved a two-phased approach to the intrusive Site works. Initially 26 wells were drilled to a maximum depth of 12 m in order to provide an estimate of the quantity of free-phase hydrocarbons remaining within the waste mass, as well as to identify areas impacted from free-phase hydrocarbons. Following this, a second phase of investigation was initiated which involved the installation of a further four targeted in-waste monitoring points, using rotary auger drilling, in order to collect waste samples to determine the concentrations of retained hydrocarbons present within the waste. For the sake of differentiating the initial round of drilling and the second part of this investigation where targeted drilling was undertaken, we have opted to call the installation of the initial 26 wells “pin-wells”.

The investigations focused on evaluating the degree to which the source in the determined pollutant linkages exists at the Site. No assessment was made regarding the other determinations made against the Site.

A total of 26 pin wells (GA06-P01 to GA06-P26) were undertaken between 26 September 2006 and 3 October 2006 by Magpie Environmental Drilling Services Ltd. The pin wells were positioned to provide general coverage of the entire landfill area and were based largely on an approximate spacing of 50 m. (Note that two of the pin wells were not completed as they encountered sand from the surface and their locations were deemed to be outside of the landfilled area).

With the exception of one well (GA06-P13) the remaining pin wells were drilled to a maximum depth of 12 m. Upon completion, each of the pin wells was installed as a leachate monitoring point, consisting of 90 mm slotted well screen with plain well casing above. In all of the installations, slotted pipe was installed across any perceived leachate strike to ensure that any free product floating on the surface of the leachate would not be restricted from entering the installation.

Following installation of pin wells and a rest period of two weeks, all pin well locations were dipped using an oil water interface probe to assess for the presence of free-phase hydrocarbons across the landfill. Based on the results of the monitoring round, a total of four in-waste boreholes (GA06-BH1 to GA06-BH4) were drilled between 1 and 3 November 2006. The boreholes were positioned to allow waste sampling in areas where free-phase hydrocarbon impact was identified and also in areas where no discernable quantities of free product had been recorded.

The boreholes were drilled to a maximum depth of 8 m using 300 mm diameter barrel augers driven by a track-mounted Comacchio MC1500 Drilling Rig. Upon completion, each of the boreholes was installed as a permanent leachate monitoring point.

The investigation identified free product in six of the 23 installations that contained leachate, the apparent thickness of the hydrocarbon ranged from 1 mm to 300 mm. The remaining wells that contained leachate indicated no free phase hydrocarbon present. Using the de Pastrovich (1979) method of determining the thickness of Non Aqueous Phase Liquid (NAPL) in the surrounding waste mass the range in total free-product thicknesses observed was translated as a thickness of between 0.21 mm and 63 mm.

Based on these results an approximate volume of the free-phase hydrocarbon within the landfill was estimated at around 210 tonnes. The retained hydrocarbon content (i.e. that bound to the waste and not present as free or dissolved phase) was estimated as in the order of 10,000 tonnes.

Where free phase hydrocarbon is present, it is not present in large amounts over large areas. The second phase of this investigation targeted wells to areas where hydrocarbon was identified in the first phase. On the upper bench of the landfill, where the well with the thickest accumulation of hydrocarbon was noted (GA06-P21), a further investigation well (GA06-BH4) was placed 5 m to the southeast. This well recorded a fraction of the amount of hydrocarbon noted in the “pin well” (5 mm compared to 300 mm – uncorrected thickness). On the lower bench there was only very small amounts of free product noted in the “pin wells” and while a targeted well was drilled close to a “pin well” containing 10 mm of hydrocarbon, the well did not record the presence of hydrocarbon.

The distribution of hydrocarbon appeared to be randomly distributed and not related to any obvious features of either the landfill or the leachate surface.

2.2.10 Burn Diversion in November 2008

A Burn Diversion was installed in November 2008, details are as follows:

A remediation statement and planning application were provided to Aberdeenshire Council (and their statutory consultees) prior to the construction of the Burn Diversion.

The construction phase of the Burn Diversion works took place between 11 and 18 November 2008 and comprised the delivery of rock for bund construction, construction of the 5 m (small) high bund adjacent to the secondary dune system, construction of the 25 m (large) high bund adjacent to the primary dune system and the excavation of the Burn channel. During the course of the construction phase surface water sampling was undertaken from the Burn at the same location as the previous sampling exercise. Below is a description of the components of the construction phase.

SUAT (Archaeological Consultants and Contractors) were present at all times during excavation work, to ensure structures and objects of archaeological significance were not damaged and were recorded accordingly.

In total approximately 650 tonnes of rock were delivered to complete the Burn Diversion Works.

The small rock bund was constructed on 12 November 2008. Prior to excavating the area for the small bund, the adjacent lagoon area and the downstream component of the Burn was excavated to allow it to drain more readily and reduce water ingress into the small bund excavation. Geofabrics HPS6 geotextile was cut to size ready and placed at the base of the excavation.

The small bund excavation was dug to approximately 3 m bGL, the base of the excavation was approximately 5 m long and 6.5 m wide. During the course of excavating; water seepage did occur, and the excavation did exhibit signs of instability, such as minor sidewall collapse which was minimised by over digging.

Once the excavation was completed, the geotextile was placed in the base of the excavation, and rocks were placed on top of the geotextile in a triangular profile to a height of approximately 3.5 m. The placement of the rocks and the minor sidewall collapse prevented the geotextile completely covering the base of the excavation. Sand removed from the excavation was used to fill areas of the excavation left open following rock placement.

The large rock bund was constructed between 14 and 18 November 2008. The excavation was undertaken in 5 sections, each approximately 5 m long (25 m in total). Prior to excavating the areas for the large bund, the adjacent lagoon area and the downstream component of the Burn was excavated to allow it to drain more readily and reduce water ingress into the excavations. Prior to the excavation of each section, a piece of Geofabrics HPS6 geotextile was cut to approximately double the length required cover the base of each section, to ready to be placed in the base of the excavations.

The large bund excavations were dug to approximately 2.5 m bGL, the base of each excavation was approximately 5 m long and 6.5 m wide. During the course of the excavating; water seepage did occur, and the excavation did exhibit signs of instability, such as minor sidewall collapse which was minimised by over digging.

Once the excavations were completed, the geotextile was placed in the base of the excavation and held in place to allow rocks to be placed on top of the geotextile in a triangular profile to a height of approximately 3.5 m. Sand removed from the excavation was used to fill areas of the excavation left open following rock placement.

The five sections of the large bund were completed in sequence starting adjacent to the primary sand dune system, with each section backfilled prior to commencing the subsequent section. It was not possible to key the first rock bund section into the primary sand dune system, as this may have caused significant slope failure. However it was possible to push rocks into the toe of the sand dunes with the 360º excavator.

Following completion of the small and large rock bunds the Burn channel was excavated to widen and deepen it and encourage the Burn to follow the desired path.

3.0 SUMMMARY OF SITE INVESTIGATION AND SUBSEQUENT MONITORING WORKS FOR 2009 AND 2010

3.1 Scope of Works

Site Investigation and subsequent monitoring work was completed between July 2009 and September 2010, by Smallbrook Environmental (Smallbrook 2009 and 2010) following an agreement of the scope of works with Aberdeenshire Council. The specific SI activities undertaken by Smallbrook included the following:

- An initial review and assessment of the efficacy of the existing boreholes, wells and pin wells to confirm suitability for use;
- The measurement of water level and NAPL presence and thickness in all existing wells to allow determination and agreement of the location of the proposed new boreholes with Aberdeenshire Council. This work was also to include a camera survey of borehole R2 to allow assessment of whether this borehole could be used for monitoring purposes going forwards. If not then an additional (5^{th}) new borehole would be required;
- A meeting with Aberdeenshire Council to agree the following;
  - The requirement for an additional 5^{th} borehole based on the results of the camera survey and to agree final locations of the 4 proposed new boreholes;
  - Locations of the proposed trial pits on the landfill Site;
  - Locations of the four marker posts on the beach;
  - The method to be employed for beach sediment monitoring, augering; and
  - The scope/area of the topographic survey required.
- The drilling and installation of 5 new boreholes adjacent to the landfill's eastern boundary. These were planned to supplement the existing boreholes allowing a transect of boreholes to be established along the eastern landfill boundary. The boreholes were extended as far as possible in an attempt to comply with Aberdeenshire Council's wishes to prove the depth to the underlying bedrock;
- The installation of 4 permanent marker posts on the beach to allow beach sand level to be easily assessed in terms of the depth overlying the upper surface of the hydrocarbon contamination plume. Locations of these were agreed with Aberdeenshire Council;
- Beach sediment monitoring (via excavations) was undertaken to effectively "map" the hydrocarbon plume and assess the extent of hydrocarbons in the beach. The depth and lateral extent of the hydrocarbon contaminated beach sediments may alter due to changes in the inputs as well as through movement of the beach as it is drawn up and down due to tidal and weather variation. Over time and as part of the ongoing monitoring works, the mapping exercise will demonstrate whether the extent of hydrocarbon contaminated beach sediment is changing significantly (increasing or decreasing) or not;
- The excavation and backfilling of 5 trial pits on the landfill Site to allow for the mass characteristics of the landfill to be assessed and samples of the waste materials and liquids within the excavations taken;

- Undertaking a topographical survey of the area including all new wells and boreholes, marker posts, trial pits and other points of note to allow a clear understanding of the locations, depths and heights of structures and works undertaken at the Site. The survey will also include the surveying in of the recently installed Blackdog Burn Diversion;

- In addition the works agreed included:
  - Undertaking the collection and monitoring of samples taken from the above works to include;
  - 5 beach samples from the beach monitoring exercise (analysed for total petroleum hydrocarbons TPH PAH);
  - The measurement of tidal and weather related influences in 12 boreholes on the Site;
  - The collection and analysis of 10 samples from waste boreholes where LNAPL was present, especially those near the boundary;
  - Variable head (slug test) testing in up to 10 boreholes/wells including the new boreholes;
  - The collection and analysis of up to 12 soils samples for TPH and PAH (speciated) from the five new boreholes (3 per borehole), collected during the drilling work and included visual and olfactory logging of each borehole through the profile;
  - The collection and analysis of 10 groundwater samples for TPH and PAH from the new boreholes;
  - The collection and analysis of 2 samples from each landfill trial pit for free oil; and

- Monitoring of five new boreholes adjacent to the landfill's eastern boundary on a frequent (monthly) basis to allow an understanding of LNAPL flux across the landfill boundary to be developed.

Full details of the work performed are provided in the Site Investigation factual report and the quarterly monitoring reports.

3.2 Summary of Results of the 2009-10 Site Investigation and Monitoring

A brief summary of the factual results of the Site Investigation and subsequent monitoring performed in 2009 and 2010 are provided below. Full details of the results obtained are provided in the Site Investigation factual report and the quarterly monitoring reports (Smallbrook 2009 and 2010).

3.2.1 Installation of 5 Boreholes on Downgradient boundary of the Landfill

Five boreholes (GA6, GA7, GA8, GA8B and GA9) were installed just beyond the downgradient boundary of the landfill Site. The location of these boreholes is shown on Drawing 2.

Based on the geological logs of drilling cuttings from drill holes prior to installation of boreholes, the geological conditions surrounding the Site comprise fine to coarse (mainly medium) sand overlying bedrock of sandstone. The sand was slightly silty and, around the water table, also contained slight gravel content. In some locations the presence of a small layer of clay was observed. Downgradient of the landfill, clay was observed below the water table and usually directly above the sandstone bedrock (1.2 m thickness of clay in GA7, > 5.2 m thickness of clay in GA8, 1.6 m thickness of clay in GA8B and 4.5 m thickness of clay in GA9). This should be compared to previous investigations of upgradient areas of the landfill, where clay was observed at around 5 m in thickness. A bedrock of sandstone was identified in all boreholes except GA8 (although has been incorrectly identified as Basalt in GA6 and GA7). The depth to bedrock dipped from north to south along the eastern boundary of the landfill Site.

Hydrocarbon staining of soils was identified in all new boreholes and was located just above the water table. Volatile organic compounds were measured in the soil headspace using a photo-ionisation detector and the highest values were associated with soils around the water table (maximum readings 80 to 500 ppm).

Analysis of collected soils from the boreholes indicated elevated levels of hydrocarbons coincident with the water table and reducing above and below with the highest soil concentration for total petroleum hydrocarbons (TPH) as follows:

- BH6 8,073 mg/kg TPH (range < 30 mg/kg to 8,073 mg/kg TPH);
- BH7 11,617 mg/kg TPH (range < 30 mg/kg to 8,073 mg/kg TPH);
- BH8 5,790 mg/kg TPH (range < 30 mg/kg to 8,073 mg/kg TPH);
- BH8B 14,208 mg/kg TPH (range < 30 mg/kg to 8,073 mg/kg TPH); and
- BH9 13,162 mg/kg TPH (range < 30 mg/kg to 8,073 mg/kg TPH).

In general, the concentration of aliphatic compounds accounted for three times more of the TPH content compared to the aromatic content. C12 to C16 was the preponderant aliphatic range whilst C12 to C16 and C16 to C21 were the preponderant aromatic ranges.

For PAH, the results are as follows:

- BH6 2.8 mg/kg PAH (range <0.38 mg/kg to 2.8 mg/kg Total PAH);
- BH7 18.4 mg/kg PAH (range 0.42 mg/kg to 18.4 mg/kg Total PAH);
- BH8 8.6 mg/kg PAH (range 0.5 mg/kg to 8.6 mg/kg Total PAH);
- BH8B 15.7 mg/kg PAH (range <0.38 mg/kg to 15.7 mg/kg Total PAH); and
- BH9 20.7 mg/kg PAH (range <0.38 mg/kg to 20.7 mg/kg Total PAH).

Phenanthrene and Fluorene were the most abundant PAHs.

3.2.2 Water and NAPL Levels

Following drilling and installation, water levels in the boreholes were recorded as between 5 and 9 m bGL, equivalent to 2.09 to 2.18 m AOD.

Water and NAPL (where present) levels were also measured in 54 existing boreholes within and outside the landfill Site on a quarterly basis. Water levels did not vary substantially in most wells over the duration of the monitoring period, with all but 7 wells (GA7, GA06-BH3, GA06-BH15, GA06-P20, GA06-P22, P2 and CA9/BH9) showing less than one meter variation. Plots of variation of water levels versus time are shown in the Quarterly Factual Monitoring Report - April to June 2010.

Groundwater flow direction was indicated as being consistently towards the east, based on the data from each monitoring round. This water level data is presented as hydrogeological plots in Drawings 3 to 6.

Tidal fluctuation had no measurable influence on leachate/water levels, this included GA06-P14, CA8-R2, GA06-P26, GA7, GA5, GA06-BH2, GA9, GA5, GA6-BH3, GA06-P02, GA06-P23, GA8B and P6. This indicates the lack of hydrogeological connection between the sea and leachate/groundwater within and immediately outside the landfill.

The presence of LNAPL in boreholes appeared (in the initial monitoring rounds) to be limited to those boreholes where it had been identified historically and in some of the new boreholes installed as part of the 2009 SI.

Over the entire monitoring period the number of monitoring wells where LNAPL has been measured has declined. Table 2 (Section 4.3.2) provides details of the number of wells in which LNAPL has been measured during each monitoring period. In April 2008, LNAPL was measured in 10 monitoring wells (with a mean thickness of 0.07 m). This increased to 11 wells in September and November 2009, where LNAPL was measured, but by August 2010 no measurable LNAPL thickness was identified in any monitoring well and a sheen (<1 mm in thickness) was evident in 5 monitoring wells. This is discussed further in Section 4.3.

Slug tests were conducted in the new boreholes located downgradient of the landfill boundary at GA6, GA7, GA8 and GA8B. Results for the new boreholes are provided in Appendix 13 of the 2009 SI factual report (Smallbrook 2009). Calculated permeability ranged from 1.17×10^{-4} m/s to 2.12×10^{-4} m/s. These values compare well with the estimates derived using Hazen's formula applied to the PSD data, this gave a range of values between 6.4×10^{-5} m/s and 7.3×10^{-4} m/s.

Analysis of slug tests conducted on existing boreholes GA06-BH2, GA06-BH3 and GA06-BH4, yielded calculated permeabilities ranging from 4.6×10^{-5} m/s to 2.7×10^{-4} m/s.

3.2.3 Beach Sediment Monitoring

Beach sediment monitoring was conducted during the preliminary Site Investigation and at four subsequent quarterly monitoring rounds. This comprised the installation of trial pits to "map" the extent of sediment staining and hydrocarbon impact, and included the collection and chemical analysis of 6 beach sediment samples for each sampling round. Sampling on the beach is inherently difficult due to conditions experienced which include problematic access, falling in of trial excavations due to poor ground conditions and problems in obtaining samples taking accurate measurements because of these difficulties. Appendix G presents drawings which show the observations (indications of the presence of hydrocarbons from visual indicators, odour observations and photo ionisation detector (PID) readings made during the quarterly beach sediment monitoring.

There are two areas of the beach (a larger northern area and smaller southern area) at which visual discoloration (of black or green colour) and hydrocarbon odour has been noted at depth in beach trial pits.

Locations of beach trial pits, elevations at which visual discolouration was observed and cross sections based on trial pit observations are illustrated within figures presented in Appendix G, entitled "Cross Section and Plans with Elevation of Green and Black Stained Sand". Associated PID readings and records of hydrocarbon odours are also illustrated in figures presented in Appendix G, entitled "Cross Section and Plans with Hydrocarbon Odours and PID Readings". The trail pits utilised for this assessment are located within the lines of Cross Sections 1, 2 and 3 for the quarterly monitoring rounds in December 2009, March 2010 and June 2010. Information for beach sediment monitoring in June and September 2009 is also provided in Appendix G. However, the information is limited in extent compared to later monitoring periods. Sections1, 2 and 3 used in later monitoring periods are either not present or are not in the same locations for comparison purposes.

Cross Sections 1 and 2 both run west to east across the beach (perpendicular to the landfill boundary) and are located within the larger northern area of visual discolouration. Figures 1 and 2 of Appendix G illustrate the elevation at which evidence of contamination was first noted across the chainage of Cross Sections 1 and 2 respectively, for three monitoring rounds (December 2009, March 2010 and June 2010). Figures 1 and 2 of Appendix G provide contradictory evidence whether the elevation of the visual discolouration is stable or fluctuating. Figure 1 appears to indicate that it is stable as all three monitoring rounds present similar elevations across the chainage (within the range to be expected due to the method uncertainty). Figure 2 appears to demonstrate fluctuating elevations, with the December 2009 round consistently lower across the chainage than that of the March 2010 and June 2010 rounds (which are of similar elevations). It can be concluded that there is contradictory evidence as to whether it is historic or continuing contaminant migration associated with the larger northern area. There are large uncertainties associated with the data, and therefore further investigation is required before a conclusion can be made either way.

Cross Section 3 runs west to east across the beach and perpendicular to the landfill boundary and it is located within the smaller southern area of visual discolouration. There is too little evidence of contamination within this cross section to illustrate changes in elevation, and the fact that there is little evidence of visual discolouration itself points to a historic migration of contamination rather than continuing migration.

A comparison of TPH and PAH concentrations in the soil from trial pits installed during the quarterly monitoring period revealed the following:

PAH chemical analysis results for soils from the beach have generally been below detection limits. Only two samples, both from June 2009, from the thirty collected throughout the monitoring period exceeded the detection limit, returning concentrations of 1.3 and 6.9 mg/kg total PAHs.

The majority of TPH (27 out of 30 samples or 90%) chemical analysis results for soils were below detection limits during this monitoring campaign. The exceptions were two samples from June 2009, returning TPH results of 4,487 mg/kg and 6,198 mg/kg, and one sample from December 2009 TPH at 96 mg/kg.

The black (or green) staining observed on the beach does not show a strong current correlation with elevated hydrocarbons in the beach sediment.

Groundwater was also obtained from trial pits 1, 6 and 8 during the March 2010 beach investigation. Trial pit 1 located closest to the dunes and displaying black staining, produced TPH concentrations (total C5 to C35 aliphatics and aromatics) greater than 270 mg/l which may be considered indicative of LNAPL. PAH concentrations were found to be below the detection limit in samples collected from this trial pit.

Trial pits were extended eastwards during this monitoring event (i.e. in the approximate direction of groundwater flow towards the sea) along a line from trial pit 1. Trial pits 6 and 8 (around 61 m and 80 m east of the sand dunes) encountered sand with green staining rather than black staining. TPH and PAH concentrations in groundwater collected from both trial pits were below detection limits.

Surface water samples from Blackdog Burn were obtained on 18 December 2009. The concentration of TPH and PAH in the upstream sample was higher (TPH (410 µg/l) and PAH (6.1 µg/l)) compared to the downstream sample for TPH (380 µg/l) and PAH (<0.3 µg/l). Consequently, the downstream samples do not indicate additional impact from TPH and PAH substances.

Four marker posts have been installed on the beach to aid assessment of the change in beach level over time. Details of their location and level are provided in the factual and quarterly monitoring reports. For most of the monitoring period, beach levels have been between 2 m AOD and 3 m AOD. The variation of the beach level with time is shown graphically in the quarterly monitoring reports. A relatively low level in the beach height was observed between September to November 2009, at around 1 to 1.5 m AOD (coinciding with a breach of the Burn Diversion) and April 2010, at around 1.5 m AOD.

3.2.4 Installation of 5 Trial Pits within the Landfill

Five trial pits were installed within the landfill during the Site Investigation in July 2009. The trial pit logs indicate a mixture of domestic and commercial waste in all trial pits. Only one of the trial pit logs records the presence of oil (TP5 at 2 m bGL).

Chemical analysis of ten collected samples from the trial pits installed within the landfill show TPH concentrations varying between <30 mg/kg (TP1) to 50,169 mg/kg (TP5). A considerable difference in concentration was observed between the samples collected in trial pits 1 to 4 (<30 mg/kg to 4,362 mg/kg, with an average TPH concentration of 2,336 mg/kg) compared to trial pit 5 (28,281 mg/kg to 50,169 mg/kg). Results for trial pit 5 indicate the presence of free oil (LNAPL) and confirm observations in the trial pit logs.

Total PAH concentrations varied between <0.38 mg/kg (TP4) and 439 mg/kg (TP5).

3.2.5 Burn Diversion Monitoring

The Burn Diversion monitoring comprised continuing assessment of the effectiveness of the Burn over the monitoring period. Monitoring since the installation of the Burn Diversion in November 2008 has shown that the Burn Diversion was breached on 5 occasions (end January 2009, September 2009, October 2009, November 2009 and July 2010) for short periods of time. On each occasion the Burn was re-aligned. Further information concerning the beach monitoring is shown in Section 4.5.

4.0 INTERPRETATION

4.1 Conceptual Site Model

The preliminary conceptual Site model developed in 2005 is described above in Section 2.2.7.

This conceptual Site model has been revised in light of the Site Investigation and monitoring works completed during 2009 and 2010. This revised conceptual Site model is described below and is focused on hydrocarbons and PAHs related to the pollutant linkages determined by Aberdeenshire Council as contaminated land. Figure 7 shows a conceptual model using cross sections through the landfill and indicative flow paths and volumes through and under the landfill Site. Appendix G shows cross sections through the beach and the distribution of hydrocarbon indicators (indications of the presence of hydrocarbons from visual indicators, odour observations and PID readings) made during the quarterly beach sediment monitoring.

4.1.1 Site Summary

The Blackdog Landfill comprises a total area of approximately 13.3 ha. The operational area of the Site was in the order of 8 ha.

No additional information has been added to the Site history during this study. It was formerly a sand pit, with landfill filling the void remaining from mineral extraction. Planning and operational history is provided in Section 2.1.

The surrounding area is as described in Section 2.2.7 and includes open land to the north (firing range), south (small holding) and west. Dunes, beach and the sea are located to the east. The Site is located in the Aberdeen Green Belt. Within the surrounding area, there are a number of closed and active landfills, some of which operated on the basis of dilute and disperse in a similar fashion to Blackdog.

4.1.2 Geological, Hydrogeological, Hydrological and Topographical Setting

4.1.2.1 Topographical and Geological Setting

The Site's internal configuration currently forms two separate areas. The western half of the Site forms a ridge above the level of the surrounding ground at a height of around 25 m AOD. The eastern part of the Site slopes down towards the rear of a line of sand dunes and forms a smaller flat area at the base of the slope at an elevation of around 10-12 m AOD. The dunes rise to a level of around 13-18 m AOD. This area then falls away to beach level and the open sea.

Geological conditions surrounding the Site comprise fine to coarse (mainly medium) sand overlying bedrock of sandstone. The sand was slightly silty with slight gravel content around the water table. In some locations the presence of a small layer of clay was observed. Upgradient this consisted of around a 5 m thickness of clay. Downgradient of the landfill, clay was observed below the water table and usually directly above the sandstone bedrock (1.2 m thickness of clay in GA7, > 5.2 m thickness of clay in GA8, 1.6 m thickness of clay in GA8B and 4.5 m thickness of clay in GA9).

4.1.2.2 Hydrogeology

The measured permeability of the deposits outside of the landfill is consistent with the material observed. Measured (from slug testing) and calculated (from Hazen's formula) permeability's ranged between 6.4×10^{-5} m/s to 7.3×10^{-4} m/s, with a mean permeability estimated at 1.58×10^{-4} m/s. In order to consider an order of magnitude of uncertainty in the hydraulic conductivity of the aquifer, an anticipated range for the purposes of modelling is set at between 1×10^{-5} m/s to 2.7×10^{-4} m/s.

Quarterly hydrogeological plots are provided in Drawings 3 to 6. These plots are based on data from boreholes installed outside the waste mass. As would be expected, the groundwater contours shown on the hydrogeological plots demonstrate that the gradient of the water table and hence groundwater flow direction is predominantly from the landfill towards the Sea. Beneath the landfill the range of groundwater hydraulic gradients recorded from the hydrogeological plots is between 0.028 and 0.049.

The hydraulic gradients presented on Drawings 3 to 6 appears seasonally consistent and do not significantly vary between quarterly monitoring rounds.

4.1.2.3 Site Water balance

Inflows to the Site

There are two mechanisms for recharge to the Site; infiltration from precipitation and groundwater inflow from the perched water to the west of the Site.

The Site was restored with soil in accordance with the requirements and industry protocol at the time. A value of 300 mm per year for infiltration has been derived based on SNIFFER (2003) wherein Section 2.3.4 of this documents states "in Scotland the driest area is the east coast where precipitation is as low as 600 mm/a. This is supported by rainfall data from Aberdeen Airport suggesting an annual average of 668 mm. It has been assumed that 50% of precipitation is available for recharge following surface runoff and evaporation. The recharge rate has been applied uniformly throughout the water balance therefore recharge to the landfill area and the upgradient groundwater catchment has been consistently applied. Hence, any sensitivity in the magnitude if the recharge rate in dilution calculations between leachate and groundwater would be negated.

The operational area of the Site is approximately 8 Ha and it is assumed that the surface area available for infiltration to the closed landfill is also 8 Ha. Surface water run-off from the Site is considered negligible based on the Site topography, which comprises a plateau to the west and a flat lower area to the east separated by a steep clay bund. The restoration profile was not designed to promote surface water run-off. A small amount of run-off might occur from the area adjacent to the larger leachate spring, with ephemeral flows to the dunes primarily during periods of heavy rainfall. The resulting total infiltration to the Site is estimated to be in the region of 24,000 m^3/yr or 66 m^3/d.

A positive head gradient exists between the perched and underlying natural groundwater encountered in Boreholes GA1 and GA2 to the west of the Site and the leachate level within the landfill. As such, there is the potential for groundwater ingress through the base of the Site. During drilling, perched water was encountered at maximum elevations of 19.19 m AOD in GA1 and 21.46 m AOD in GA2. The subsequent monitoring installation was sealed deeper than the perched water to give a true indication of the natural groundwater elevation. The maximum observed groundwater elevation in these monitoring installations during 2010 was 14.11 m AOD and 20.72 m AOD, respectively. Both the perched groundwater and the underlying groundwater are at an elevation that is above both the base of the Site and similar to the elevation of the leachate springs issuing from the clay bunds in the centre of the Site. It is therefore considered that there could be the potential for groundwater flow into the Site from this perched groundwater body and the upgradient groundwater.

A tributary of the Blackdog Burn that flows down from the industrial estate occupies a channel to the west of the Site. Therefore, the recharge to the west of the Burn will be intercepted and not form underflow beneath the Site. In addition, the relief of the channel will mean that some of the recharge to the east of the burn will also flow to the Burn and not recharge the Site or form underflow. Taking this into account, the groundwater catchment has been estimated at around 10 Ha. This estimate is subject to a small amount of uncertainty. It is not thought that perched groundwater flows into the Site across the whole of the western boundary, based on the reduced thickness of the clay horizon in GA2. Therefore, for the purposes of this water balance, it is considered that inflow is occurring from the southern half of the catchment area to the west of the Site (resulting in a catchment area of 5 Ha), and that 90% of the infiltration to this area is prevented from recharging the underlying sand and gravel aquifer, and instead forms perched groundwater that flows into the Site.

Applying a 300 mm/yr infiltration rate to this area, the inflow into the landfill would be 13,500 m^3/yr or 37 m^3/d (i.e. 270 mm/yr over the southern 5 Ha of the catchment area) This assumption infers that the remaining 16,500 m^3/yr or 45 m^3/yr of groundwater from the 10 Ha catchment area will constitute the underflow beneath the Site (i.e. 30 mm/yr from the southern 5 Ha catchment and 300 mm/yr from the northern 5 Ha catchment). These water balance fluxes are shown on Drawing 7.

Outflows from the Site

There are two routes of leachate leakage from the Site. The primary mechanism is leakage via the base and sides of the Site. Additionally, leachate is breaking out through the clay bund that forms the break of slope through the centre of the Site, and creates the potential for this leakage to form run-off. It is likely, however, that virtually all of the leachate from these springs infiltrates back into the landfill over the flatter eastern part of the Site through the thin restoration soils. Therefore, this report will not consider the flow of these leachate springs further in the context of the mass balance for the landfill.

It is assumed that basal leakage accounts for all of the outflows from the Site. As landfilling ceased in 1993, it is considered that the effects of the liquid waste inputs on the water balance no longer have any influence on the hydrogeological regime. Therefore, the Site is in annual equilibrium, with basal leakage of leachate matching the inputs of infiltration and perched groundwater being driven by the head of leachate on the base of the Site.

It follows that the total inflow to the landfill from infiltrating rainfall is in the order of 66 m^3/d and the input from the perched groundwater to the east is estimated to be 37 m^3/d. This results in a total daily flux through the Site of 103 m^3/d.

Calculation of Basal Leakage

It is noted that steady state leakage rates from the base of the landfill will be equal to the input of perched groundwater and infiltration to the landfill. A probabilistic calculation has been conducted that considers the leakage rate through the base of the site based on assumed hydraulic properties for comparison to the water balance. This calculation considers the operational plan area of the site, the range of heads of leachate in the waste and a range for the potential hydraulic conductivity of the waste at the base of the site for a compacted waste comprising co-disposed domestic waste with drilling mud which is typically described in drilling logs as “WASTE comprising plastics, wood, metals, cables, wires and paper in a sandy clay matrix”.

The inputs to this calculation are identified in Table 2 below and the calculation spreadsheets in Appendix A:

Table 2: Basal Leakage Calculation

Parameter	Min	Max	Distribution	Justification
Area of Site (m^2)	80,000		Single Value	Operational area of Site
Leachate head (m)	5	10	Uniform	Estimated range of leachate heads across Site footprint
Permeability of waste (m/s)	$1.00x10^{-9}$	$1.00x10^{-8}$	Log Uniform	Anticipated hydraulic conductivity of compacted waste comprising domestic wastes in a matrix of sandy Clay drilling mud at base of Site
Depth of waste at base of site that the leachate head acts over (m)	2		Single Value	Golder Judgment

The estimated basal leakage based on the parameters listed in Table 2 above at the 5 (lowest), 50 (most likely) and 95 (maximum) percentiles are 27, 81 and 246 m^3/d respectively. It is therefore noted that the calculated basal leakage rate at the most likely, 50 percentile at 81 m^3/d is broadly comparable with the water balance calculation for basal leakage of 103 m^3/d.

Validation of Total Underflow

In order to validate the total underflow inclusive of basal leakage which was estimated by water balance to be 148 m^3/d, a probabilistic calculation of the flow rate beneath the Site has been considered. This calculation considers the hydraulic gradient between the up and downgradient boreholes on the western and eastern boundaries respectively, the range of saturated thickness of the aquifer as identified by drilling records (thickness of saturated sand and gravel excluding low permeability deposits or rockhead) and a range of hydraulic conductivities of the aquifer that includes all reported values to date.

Table 3: Parameters: Underflow Calculation

Parameter	Min	Max	Distribution	Justification
Hydraulic Gradient	0.028	0.049	Uniform	Measured hydraulic gradient across Site footprint
Hydraulic conductivity of aquifer (m/s)	$1.0x10^{-5}$	$2.7x10^{-4}$	Log Uniform	Anticipated hydraulic conductivity of aquifer including Site observations listed in Golder, 2010.
Saturated aquifer thickness (m)	1.6	4.2	Uniform	Interpreted from borehole logs
Site width normal to groundwater flow (m)	420		Single Value	

The underflow based on the parameters listed in Table Y above at the 5 (lowest), 50 (most likely) and 95 (maximum) percentiles are 49, 197 and 1046 m^3/day respectively. It is therefore noted that the calculated underflow rate at the most likely, 50 percentile at 197 m^3/day is broadly comparable with the water balance calculation for underflow of 148 m^3/day.

Validation of Water Balance with 2010 Data

The volume of leachate generated within the Site and the estimated groundwater underflow beneath the landfill, into which the leachate is assumed to be infiltrating, have been discussed above. These volumes can be combined with the concentrations of the conservative contaminant chloride, recorded during monitoring undertaken at the Site, to assess and validate the landfill hydraulic balance presented above.

The concentration of chloride in the leachate in 2010 ranged between 77.7 mg/l (GA06-P23) and 2356.8 mg/l (GA06-P06). The average chloride concentration in May and June 2010 (from GA06-P03, GA06-P06, GA06-P15, GA06-P17, and GA06-P23) was 959.6 mg/l and 1242.5 mg/l. The concentration of chloride in the upgradient groundwater monitoring wells (GA1 and GA2) was between 46.2 and 91.3 mg/l. The downgradient groundwater chloride concentrations recorded in GA5, GA6, GA7, GA8, GA8b and GA9 were in the range 49.1 mg/l to 1168.6 mg/l.

The chloride concentrations and the water volumes can be combined to estimate chloride concentrations in groundwater beneath the Site using the following mass balance calculation:

$$Cl_3 = \frac{(Cl_1 \ X \ LL) + (Cl_2 \ X \ GW)}{LL + GW}$$

where:

Cl_1 is the concentration of chloride in the leachate;

Cl_2 is the concentration of chloride in the groundwater upgradient of the Site;

Cl_3 is the concentration of chloride in the groundwater downgradient of the Site;

LL is the volume of leachate leakage; and

GW is the volume of groundwater underflow beneath the Site.

Assuming that the daily generation of leachate, hence leakage is approximately 103 m^3/d and the underflow is 45 m^3/d, the predicted concentration of chloride from the mass balance equation is approximated to be 880 mg/l. The actual mean chloride concentration during the 2009/2010 monitoring events for downgradient monitoring wells was 356 mg/l. This concentration is around half of that predicted by the calculation indicating that total flows (leakage plus groundwater underflow) could be double that predicted and suggesting that the hydraulic balance of the Site as presented above remains moderately accurate although indicates the level of compound uncertainty of flow rate, leakage rate and chloride concentration attribute to variations in the calculated dilution rate.

4.1.3 Hydrocarbon Source

The key components of the contamination source at Blackdog Landfill (relative to the contaminated land notices) relate to hydrocarbons (TPH and PAH) originating from oil based drilling muds disposed of in the landfill.

4.1.3.1 Hydrocarbon Mass

It was agreed with Aberdeenshire Council that five trial pits were to be installed within the landfill to help assess the hydrocarbon mass remaining within the landfill. Five trial pits were therefore installed within the landfill during the 2009 Site Investigation. Based on the trial pit logs, free phase hydrocarbon was observed in only one of the five trial pit logs. Chemical analysis confirmed a high concentration of TPH in this trial pit (TP5) (28,000 – 50,170 mg/kg total aliphatic and aromatic hydrocarbons). In the other four trial pits concentrations of hydrocarbons were detected at lower concentrations (226 - 4,361 mg/kg total aliphatic and aromatic hydrocarbons).

Hydrocarbon saturation estimates for samples obtained from these trial pits have been conducted. The percent saturation of hydrocarbon is calculated by dividing the observed concentration of a particular carbon band of hydrocarbon by its relative maximum solubility and multiplying by 100.

Exhibited a mean hydrocarbon saturation of around 2.9% and a 95%ile hydrocarbon saturation of around 11% (the latter taking account of the higher concentrations observed in TP5). The saturation estimates have been calculated by assuming the hydrocarbon concentration (as a percentage), as a percentage of an estimated total waste saturation. The LNAPL thicknesses identified within boreholes in the landfill have not been used to estimate a hydrocarbon mass and instead it has been assumed that the LNAPL volumes would be included in the residual hydrocarbon estimates using information from the five trial pits.

LNAPL measurements have been monitored within and outside the landfill. Out of 54 boreholes monitored throughout the monitoring period, LNAPL was detected in a maximum of 12 boreholes during any monitoring event. Over the duration of the monitoring period the incidences of identification of LNAPL reduced. Initially this resulted in a general reduction in the thickness of LNAPL and then during the last 3 monitoring events LNAPL was only detected at measurable levels (i.e. > 1 mm) in GA04 (0.18 m in April and 0.06 m in May) and P9 (0.01 m in April). The final monitoring round, June 2011, did not detect LNAPL at measurable levels (i.e. > 1 mm) in any wells either within or outside the landfill.

As assessment of the degree of influence of water levels (groundwater and leachate) has been undertaken by comparing these with the thickness of LNAPL monitored. A series of graphs plotting water elevation against LNAPL thickness have been produced for the seven boreholes where thicknesses of LNAPL have been observed more frequently (GA06-BH3, GA06-BH4, GA06-BH8, GA4, GA7, GA9 and CA9/BH9) and are included in Appendix B. The graphs suggest that there is no clear relationship between variation in water level and LNAPL thickness in almost all boreholes. Slight correlations were observed in GA06-BH8 (decreased water level with increased NAPL thickness), GA04 (increased water level with increased NAPL thickness) and GA06 – BH3 (decreased water level with increased NAPL thickness).

LNAPLs recovered from within the landfill, at the start of the monitoring programme in July 2009 comprised <0.01% PAH content. Samples of waste from trial pits excavated from the landfill comprised Total PAH (16 species) concentrations ranging between <0.38 mg/kg and 439 mg/kg (mean 70 mg/kg).

Within the Golder 2006 interpretive report an assessment of the amount of hydrocarbons remaining within the landfill was made. This included the free product, dissolved hydrocarbon and retained hydrocarbons. These estimates have been updated below using information gained during the 2009/10 Site Investigation and monitoring works.

In order to estimate the quantity of retained product within the landfill, a limited number of trial pits were installed as indicated above. Five trial pits (TP1 to TP5) were installed within the landfill in 2009 and chemical analysis results for samples collected have been used to calculate the volume of retained product.

The result for total aliphatics and aromatics (C5-C35) ranged between <30 mg/kg (TP1 at 0.6 m bGL) and 50,169 mg/kg (TP5 at 3.8 m bGL). The average of the ten values returned is 9,482 mg/kg. If the same calculation is applied whereby this average value is assumed to represent the entire waste mass of 1.2 Mm^3, then again assuming a waste density of 1 ton/m^3 the remaining mass of hydrocarbon retained in the waste is approximately 11,400 tonnes. However, there are a number of uncertainties associated with this estimate which is explored further below.

This estimated residual mass is similar to the value of 10,600 tonnes calculated in the Golder factual report (2006). However, the 2009 trial pits were more targeted at areas expected to contain higher concentrations of hydrocarbons in light of the information collected at the time of the investigation (in close proximity to boreholes where LNAPL had been observed); therefore, it is difficult to ascertain the true evolution of the mass of retained hydrocarbon within the waste mass as it is understood to be so spatially variable. Consequently, a comparison of the results of the in-waste sampling results from 2006 and 2009 has been undertaken by comparing data from sampling locations in similar positions within the waste mass. With regards to the elevations of the sampling locations, the ground levels for each pair of compared locations do not vary by more than 1 m. It should be noted that slightly different analysis was undertaken on the two sets of samples: TPHCWG (C5-C35) in 2009 and EPH (C10-C40) in 2006. However, the hydrocarbon composition within the landfill means that both sets of results are considered representative of the residual mass within the waste and are suitable for this qualitative comparison. The results of the comparison exercise are summarised in Table 3 below.

Table 4: Comparison of 2006 and 2009 In-Waste Hydrocarbon Analysis Results

2009 Investigation Data			2006 Investigation Data			Distance Between Locations (m)
2009 Location ID	2009 Sample Depth (m bGL)	TPH (C5-C35) (mg/kg)	2006 Location ID	2006 Sample Depth (m bGL)	EPH (C10-C40) (mg/kg)	
TP1	0.6	<30	GA06-BH4	2	2282	26.7
	3.6	2481		4	14344	
	4	3344		6.5	5690	
TP2	2.5	1946	GA06-BH3	2	10697	12.5
	2.9	3468		3	432	
TP3	1.4	266	GA06-BH2	1	930	10.1
				2	11490	
TP5	2	28281	GA06-BH1	2	8588	34.7
	3.8	50169		3	25596	
				4	3086	

The comparison exercise indicates that in general the hydrocarbon content of the waste seems to have reduced between 2006 and 2009. The exception to this is in the vicinity of TP5. However, these conclusions are based on very limited data.

In summary, the 2009 trial pit exercise within the waste has indicated a residual mass of hydrocarbons within the waste that is similar to the estimate in 2006. Both estimates carry a degree of uncertainty.

4.1.3.2 LNAPL Thickness

LNAPL has been measured in a limited number of boreholes within the landfill and outside the eastern boundary of the landfill from 2005 to 2010 (end of the monitoring period for this report). The boreholes where LNAPL was identified have remained the same during this monitoring period with no new boreholes (except those drilled in 2009) showing LNAPL. This infers that the LNAPL extent is not expanding. The LNAPL thickness has generally reduced over the monitoring period with clear indications of a reducing thickness of LNAPL observed during the last monitoring rounds of 2010. The latest monitoring results available for this report (June 2010) indicate that LNAPL thicknesses were thinner than the detection range (0.1 mm) of the interface probe in all monitoring boreholes within the landfill. It is also recognised that the thickness of free product measured in a monitoring well will be greater than the thickness of LNAPL in the surrounding waste mass. Analysis of the LNAPL measurements presented above suggests there is no seasonal related influence on LNAPL thickness and limited water level influence on LNAPL fluctuation. Residual LNAPL has been calculated above in Section 4.1.3.1 using information gained from trial pits installed within the landfill during the 2009 site investigation.

4.1.3.3 Dissolved Phase Hydrocarbon

Leachate monitoring results (using boreholes not containing LNAPL from within the landfill) can be used to estimate dissolved phase hydrocarbons within the landfill. During the 2009/10 Site Investigation and monitoring exercise, groundwater and leachate samples were collected for chemical analysis from GA06-P03, GA06-P06, GA06-P15, GA06-P17 and GA06-P23. The mean TPH concentration for these monitoring wells during June 2010 was 2,266 µg/l. The average leachate thickness based on June 2010 monitoring results was 2.73 m.

The mass of dissolved phase hydrocarbons remaining in the landfill in kg (M) was calculated using the approach outlined below;

This provides an estimate of around 200 kg (0.20 tonnes) of dissolved hydrocarbons within the landfill compared to an estimate of 0.24 tonnes in 2006 (Golder, 2006). The figure of 0.24 tonnes was calculated using a leachate depth of 2.5 m, a mean TPH of 3,010 µg/l and the same site dimensions and assumed waste porosity of 40%. The above results are similar within the uncertainties associated with these estimates. However, the above estimates are also considered conservative if we take account of the solubility limit of the main hydrocarbon bands detected.

Note that only the June 2010 monitoring round results are presented above. Results for the same boreholes during other monitoring periods were below (December 2009 - mean TPH of 1,572 µg/l, March 2010 - mean TPH of 644 µg/l) TPH concentration estimated for June 2010.

It is acknowledged that the concentrations returned from the laboratory analysis of the leachate samples are high relative to solubility. A comparison table of the TPH bands found at the highest concentrations and their corresponding solubility's is provided in Table 5 below.

Table 5: Comparison of Laboratory Analysis Results and Solubility

TPHCWG - Aliphatics	Solubility from TPHCWG by Correlation ug/l	Results GA06-P17 from 23/06-10 (ug/l)	Above Solubility
>C5-C6 #	36000	49	N
>C6-C8 #	5400	204	N
>C8-C10 #	430	757	Y
>C10-C12	34	130	Y
>C12-C16	0.76	675	Y
>C16-C21	0.0025	259	Y
>C21-C35		1143	
Total aliphatics C5-35		3217	

TPHCWG - Aliphatics	Solubility from TPHCWG by Correlation ug/l	Results GA06-P17 from 23/06-10 (ug/l)	Above Solubility
TPHCWG - Aromatics			
>C5-EC7 #	220000	7	N
>EC7-EC8 #	130000	19	N
>EC8-EC10 #	65000	661	N
>EC10-EC12	25000	264	N
>EC12-EC16	5800	34	N
>EC16-EC21	650	35	N
>EC21-EC35	6.6	<10	N
Total aromatics C5-35		1020	
Total aliphatics and aromatics(C5-35)		4237	

It is apparent from Table 5 that there are several aliphatic bands (>C8) that exceed their approximate solubility's but none of the aromatic's exceed their approximate solubility limit. We note that theoretical hydrocarbon solubility limits are usually related to individual compounds in fresh water. The presence of other hydrocarbons within a leachate will reduce the relative solubility of each hydrocarbon. Therefore, the use of these results to calculate dissolved phase hydrocarbon within the site is considered conservative.

Concentrations of hydrocarbons greater than their solubility limit may be found in groundwater/leachate samples where small quantities of LNAPL are also obtained during the sampling stage. There is a difficulty with sampling groundwater/leachate in the presence of even small quantities of LNAPL with the potential for traces of LNAPL to be entrained in some samples. It is unlikely that hydrocarbon concentrations in excess of the solubility limit outside of the landfill indicate colloidal or emulsion migration and no visual indications of emulsion or colloidal hydrocarbons have been identified in groundwater samples collected from the eastern boundary boreholes during the 2009 - 2010 monitoring period.

The above results reflect (conservatively) dissolved hydrocarbon within the landfill leachate. As groundwater migrates from the landfill, the groundwater may also gain hydrocarbons due to dissolution of LNAPL which may increase the dissolved phase hydrocarbons further.

4.1.4 Pathways

Contaminant migration pathways identified in Aberdeenshire's contaminated land notices all remain in place with the exception of those relating to Blackdog Burn.

Blackdog Burn has been diverted since the contaminated land notices were issued. The diverted route of Blackdog Burn ensures that the flow of the Burn does not coincide with the beach directly east of the landfill. Details of the effectiveness of the Burn Diversion are discussed below and whilst there have been five breaches of the Burn Diversion since its installation in November 2008 these have been for a short period of time. It was also recognised that the revised construction of the Burn which represented a "soft" engineering option compared to that put forward in the original planning application and would be subject to maintenance requirements.

4.1.5 Receptors

Receptors identified in Aberdeenshire's contaminated land notices all remain in place and include groundwater, the Burn and coastal waters. Groundwater has previously been identified as being of limited potential as a resource (Golder, 2005) due to its limited extent and saline nature of groundwater on the beach.

The diverted Burn is no longer considered a receptor since it was diverted in November 2008 and subsequent monitoring has confirmed the successful nature of the diversion. This remains the case whilst the Burn remains within its remediation envelope. However, the reduced presence of LNAPL in sediments within the beach would indicate that should the Burn flow outside its remediation envelope, the potential for release of hydrocarbons by the action of the Burn is reduced.

Coastal waters (defined by Aberdeenshire during meeting in September 2005) are surface waters on the beach and as well as saline impacted beach deposits in the intertidal zone.

The extent of each pollutant linkage is described below in Sections 4.2 to 4.5.

4.2 Pollutant Linkage A

Pollutant linkage A relates to the leaching of dissolved phase hydrocarbons from within the waste to groundwater. Hydrocarbons of interest with respect to the determination of contaminated land include Total Petroleum Hydrocarbons (TPH) and Polycyclic Aromatic Hydrocarbons (PAHs).

This section reviews concentrations of the dissolved phase hydrocarbons within the landfill (in the upper section to the west and lower section to the east) and leaving the landfill at the eastern boundary.

4.2.1 Dissolved Phase Hydrocarbon Concentrations

Groundwater samples were taken from selected monitoring wells during the 2009/2010 work. Issues associated with dissolved phase hydrocarbon analysis exceeding solubility limits have been discussed above in Section 4.1.3.3. Time series charts presenting the concentration in groundwater of TPH (Aliphatics & Aromatics >C5-35), PAH and chloride are provided in Appendix D. The time series charts are provided for monitoring wells located within the landfill (upper lower and lower sections) and at the eastern boundary of the landfill.

During the 2009/2010 monitoring work, elevated TPH (Aliphatics & Aromatics >C5-35) concentrations in leachate ranged from 125 µg/l to 4,237 µg/l (mean of 1,627 µg/l) in the upper section of the landfill, 396 µg/l to 2,483 µg/l (mean of 1,295 µg/l) in the lower section of the landfill. TPH concentrations ranged from 24 µg/l to 35,062 µg/l (mean of 5,585 µg/l) in groundwater at the eastern boundary of the landfill. (Data from monitoring wells GA06-BH3, GA06-P08, GA4, GA7 and GA9 is not reported because LNAPL was identified in these boreholes during the 2009/2010 monitoring work, which will have influenced dissolved phase analysis results). The highest TPH concentrations detected are above the solubility limit and this has been demonstrated in Table 5 above for a within landfill borehole (GA06-P17). It is considered that the reasons that solubility limits are exceeded for some hydrocarbon species is due to problems during sampling when small amounts of LNAPL may be entrained within the sampled groundwater. The concentrations of dissolved hydrocarbon identified here can therefore be regarded as conservative.

During the 2009/2010 monitoring work, elevated PAH concentrations in leachate ranged from 5.1 µg/l to 17.55 µg/l (mean of 10.8 µg/l) in the upper section of the landfill, 11.9 µg/l to 106.5 µg/l (mean of 46.4 µg/l) in the lower section of the landfill. PAH concentrations ranged from 1.8 µg/l to 77.6 µg/l (mean of 15.4 µg/l) in groundwater at the eastern boundary of the landfill (data from monitoring wells GA06-BH3, GA06-P08, GA4, GA7 and GA9 is not reported because LNAPL was identified in these boreholes during the 2009/2010 monitoring work, which will have influenced dissolved phase analysis results).

The Golder Interpretive Report of 2005 (Golder, 2005) reported an average dissolved hydrocarbon concentration of 2.18 mg/l (2,180 µg/l) within the landfill. Samples of groundwater from boreholes installed adjacent to the Site (at the eastern boundary) by Golder (2005) GA3, GA4, and GA5 contained dissolved petroleum hydrocarbon concentrations between 0.93 mg/l and 4.75 mg/l (930 µg/l and 4750 µg/l).

No consistent or observable trends in groundwater concentrations of TPH or PAH have been identified from the time series charts (Appendix D). However, groundwater hydrocarbon concentrations do appear to have decreased within the landfill and increased at the eastern boundary of the landfill compared to data reported in the 2005 report.

4.2.2 Chloride

Elevated chloride concentrations in leachate and groundwater wells can be an indicator of the presence of landfill leachate. Concentrations of chloride are presented on the time series charts in Appendix D along with TPH and PAH. As would be expected, the monitoring wells within the landfill demonstrate chloride concentrations greater than at the landfill eastern boundary.

Based on the March 2010 monitoring (note June monitoring round did not include BH9) round the following mean concentrations were observed from the boreholes monitored:

- Within landfill 960 mg/l chloride; and
- Eastern boundary 467 mg/l chloride.

These results therefore indicate that leachate is detected in the groundwater at the eastern boundary following a twofold dilution (assuming that the background concentration of chloride is not also elevated).

4.2.3 Tier 1 Groundwater Risk Assessment

An assessment of groundwater chemical analysis results was conducted by comparing results to recognised criteria in a groundwater (note that coastal waters are not included within this groundwater risk assessment). Assessment criteria were used in the following hierarchy:

- Annual Average Environmental Quality Standards Freshwater (EQS FW);
- Annual Average Environmental Quality Standards Saltwater (EQS SW);
- European Union Drinking Water Standards (EUDWS);
- UK Drinking Water Standards (UKDWS);
- World Health Organisation (WHO); and
- US Environmental Protection Agency Regional Screening Levels (USEPA RSL) (tap water standard).

The results of the Tier 1 groundwater risk assessment demonstrate that the concentration of TPH and PAH in groundwater exceeds the screening criteria within the landfill and at the eastern boundary of the landfill. A table presenting the results of the Tier 1 Groundwater Risk Assessment and the relevant screening criteria is presented in Appendix E.

The criteria used for the Tier 1 groundwater risk assessment should be viewed as conservative with respect to groundwater, given the limited use of the groundwater due the close proximity to costal sea water.

4.2.4 Determination of Hydrocarbon Mass leaving the Site in Dissolved Phase

By using the water balance data derived as part of the conceptual model with an interpretation of the concentration of hydrocarbon substances in groundwater on the down-gradient site boundary, the flux of hydrocarbon substances from the Site may be calculated. The values derived for aquifer underflow and leachate leakage within the water balance have been validated using data gained during the 2009/2010 monitoring period. Groundwater contour plots have been developed for the 2009/2010 monitoring period, and exclude measurements of leachate elevation within the landfill. A range of hydraulic conductivities have subsequently been considered to generate a stochastic assessment of groundwater flow volumes, which also includes a representative range of likely hydraulic conductivities for the underlying sediments. The calculations were conducted using the Microsoft excel based Monte-Carlo simulation package: Crystal Ball. The stochastic assessment is presented below and the calculation spreadsheets presented in Appendix F.

Probabilistic Calculation of Hydrocarbon Mass Migration

A consideration of the range of values that parameters considered in the calculation of the mass flux of total dissolved hydrocarbon and the ultimate concentration of dissolved hydrocarbon in the sea has been considered. The calculations were again conducted using Crystal Ball, as an extension of the flow volume calculations. This approach allows the computer simulation of the dissolved hydrocarbon mass flux and the concentration in sea water to be modelled on the basis of key parameters.

Few of the input parameters are known exactly. However, each parameter can be described by a range of possible/probable values incorporating the available information. During each simulation the parameters are assigned a value from within the defined ranges. After, say, 201 iterations, a range of possible predicted leakage or outcome values are obtained and it becomes possible to quantify the likelihood of a certain outcome.

This approach uses statistical distributions or probability density functions (PDFs) to characterise some of the input parameters. Each time a calculation is carried out, one value from the defined input distributions is chosen by the computer code and, for example, a concentration in seawater is calculated. Each result is stored such that after repeating the same calculation many times, an output distribution for concentration is obtained. The distribution output is given in terms of percentiles (%iles). These %iles specify the probability with which a certain value will not be exceeded. For instance, if the 95%ile of a concentration distribution is given as 10 µg/l there is a 95% chance that the concentration will be below or equal to 10 ug/l. It follows that there is also a 5% chance that the actual concentration will be greater than 10 µg/l. The 95%ile is generally considered to be a reflection of worst case, whereas the 50% is a reflection of the most likely outcome.

The calculation of mass flux of dissolved hydrocarbon in groundwater has been calculated with the spreadsheet provided in Appendix F. This calculation uses the total volume of groundwater underflow to the site and the hydrocarbon concentration measured in the down-gradient boreholes.

To calculate a normalised loading of dissolved hydrocarbon at the down-gradient Site boundary for each particular monitoring round considered, the concentration along the boundary for each monitoring round was averaged to get an even influence of the total flux of hydrocarbon. The data are used as a triangular distribution with min, median and max. The most likely or mode of the triangular distribution was taken as the median because it was not possible to create a histogram of the data pool to identify a most likely bin range. Consequently, the median of the data was chosen is because the maximum value, whilst being a valid data point is an outlier to the dataset and hence would skew the distribution if a mean was used.

A mass flux of dissolved hydrocarbon at the 50%ile and the 95%ile was calculated at rates of 0.19 and 0.89 kg/day respectively.

Probabilistic Calculation of Hydrocarbon Dilution into Seawater

The calculation of the potential concentration of dissolved hydrocarbon in seawater is based on dilution of groundwater in the amount of seawater available from daily tidal fluctuation. The volume of groundwater and the concentration of dissolved hydrocarbons considered are taken from the hydrocarbon migration calculations above. The volume of sea water available per day is calculated by considering the width of the Site adjacent to the sea, the distance between the low and high tide and the typical tidal range. The product of these factors is divided by a factor of 2 to take account of the geometry of the shore and multiplied by a factor of 2 to take account of the number of tides per day. The calculation does not consider the effects of attenuation of the dissolved hydrocarbon in the aquifer pathway or beach sediments. The predicted concentration of dissolved TPH in seawater at the 50%ile and the 95%ile was calculated to be 1.7 µg/l and 8.2 µg/l respectively.

It is noted that these predicted concentrations are below the taste-odour threshold. However, only dilution in the inter-tidal zone is considered and there is further potential for the attenuation of contaminants within the environment that is not considered within this conservative assessment. In addition, the total concentration predicted is below the EQS saltwater values for individual benzene, toluene and xylene species (assuming that all the hydrocarbons were one of these individual species), although are above specific PAH species.

4.2.5 Pollutant Linkage A Summary

There are no consistent observable trends in groundwater concentrations of TPH or PAH identified from the time series charts (Appendix D). However, groundwater concentrations do appear to have decreased within the landfill and increased at the eastern boundary of the landfill compared to data reported in the 2005 report (Golder, 2005).

The results of a Tier 1 groundwater risk assessment demonstrate that TPH and PAH groundwater concentration exceed screening criteria within the landfill and at the eastern boundary of the landfill. Though it should be noted that some of the criteria used for the Tier 1 risk assessment should be viewed as conservative given limited use of the groundwater due the close proximity of the landfill to coastal sea water.

We have calculated a mass of between 0.19 and 0.89 kg of TPH leaving the eastern boundary of the landfill per day which will undergo significant dilution on reaching the sea.

Section 4.4.1 presents information about the findings of the beach monitoring work. The results indicate that the presence of hydrocarbon on the beach (as indicated by staining, sheens, odour and PID results) is replenished in some locations. Further details are provided in section 4.4.1.

It is considered that at present there is insufficient data to allow an assessment of the evolving migration hydrocarbon as defined by Pollutant Linkage A. At present there is clearly a risk of potential impact but more data is required before an attempt to predict future impacts is made.

4.3 Pollutant Linkage B

4.3.1 Background

Pollutant linkage B relates to the migration of free phase hydrocarbons as Light Non Aqueous Phase Liquid (LNAPL) from within the Blackdog Landfill Site waste to groundwater. We have provided below an overview of an LNAPL risk management framework that was developed on behalf of British Colombia (Golder Associates, 2008). This framework has been described to place LNAPL at the Blackdog Site in context. This section also details the latest findings of the 2009/2010 Site characterisation and monitoring works with respect to LNAPL and considers lines of evidence relative to the LNAPL management framework referenced above. We have also performed LNAPL modelling using the American Petroleum Institute (API) model in order to determine if LNAPL is liable to migrate (rather than be stable) and to estimate the rate of LNAPL migration.

4.3.2 Background

LNAPL is a group of organic substances that are relatively insoluble in water and are less dense than water (i.e. a specific density of less than 1.0). LNAPLs tend to spread across the surface of the water table and form a layer at the top of the water table. LNAPL is considered present when free organic phase liquid is identified in monitoring wells screened across the water table.

Liquid wastes accepted at Blackdog Landfill Site (from 1982 through to 1993 when the Site closed) were predominantly drilling muds from oil exploration and production in the North Sea. Originally diesel would have been used although during the period of the landfill operations it is understood that less toxic oils were introduced into general usage within the North Sea, initially detoxified diesel then vegetable oils. Such liquid wastes are likely to result in LNAPL being present.

LNAPL levels have been monitored monthly at the Blackdog Landfill Site for depth and thickness (measured as thickness within monitoring wells using an interface probe). Eleven monitoring wells have been recorded with LNAPL during the 2009/10 work. The monitoring wells where LNAPL has been observed are the same locations (with the exception of newly installed wells) as where LNAPL was identified in 2005. There has been no expansion of the area in which LNAPL has been observed. The apparent LNAPL thicknesses ranged from 0.00 (a sheen on the interface probe) to 0.83 m. The previously measured thickness ranged from 0.00 (a sheen on the interface probe) to 0.66 m. Although, the overall trend is reducing thickness during the 2009-2010 monitoring (discussed in further detail in Section 4.3.4 below).

Understanding the potential for LNAPL movement is critical in the characterisation of LNAPL impacted sites. Within the subsurface, LNAPL may occur as either residual LNAPL or as mobile LNAPL. LNAPL that is retained by soil capillary forces or is trapped within pore spaces is relatively immobile and termed residual LNAPL. Mobile LNAPL occurs when the LNAPL saturation exceeds the residual saturation and a continuous LNAPL phase exists between pores in the soil matrix. This mobile LNAPL volume may move vertically or horizontally. Mobility of LNAPL is assessed based on lines of evidence including:

- Temporal sampling indicates an increasing thickness of LNAPL in monitoring wells;
- Temporal sampling indicates advancement of LNAPL across a monitoring well network; and
- LNAPL is measured in monitoring wells at thicknesses exceeding theoretical estimates of LNAPL mobility (LNAPL modelling).

The assessment of LNAPL mobility based on measurement (observational) data and model predictions is provided in this report. The management framework for assessment of LNAPL mobility is illustrated in the Flow Chart overleaf:

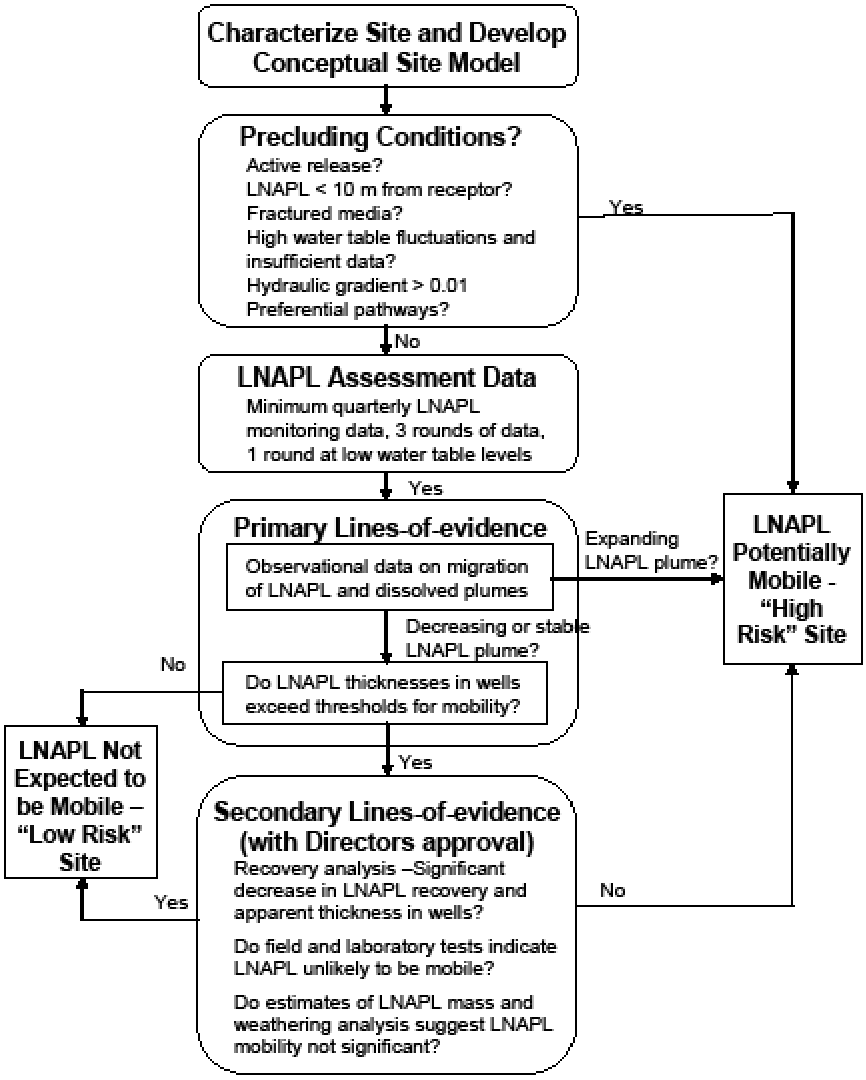

Figure 1: LNAPL Framework Assessment Flow Chart (Golder, 2008).

4.3.3 Precluding Conditions

Under the LNAPL management framework, if precluding conditions are present at a site, then LNAPL may be considered mobile without further assessment (Golder, 2008), and the site is considered to be a high risk site with respect to LNAPL in terms of the LNAPL management framework. This section addresses precluding conditions with respect to the LNAPL management framework (it is noted that this does not relate to the LNAPL modelling work which estimates LNAPL mobility).

- **An Active Release**

The Blackdog Landfill Site is a closed landfill which operated up to 1993. There is no active or ongoing release of liquid waste into the landfill. Therefore, the precluding condition of an active release is not applicable at this Site;

- **LNAPL in Close Proximity to a Receptor**

Monitoring wells at the eastern edge of the Landfill have recorded LNAPL (monitoring wells CA9/BH9, GA4, GA7 and GA9); however, the thickness of LNAPL in these monitoring wells has reduced with time (see the time series charts provided in Appendix C and the LNAPL monitoring summary presented in Table 7. The last two monitoring rounds (2010) have not recorded any measurable thickness of LNAPL other than a sheen on the interface probe. However, further monitoring would be required to determine if this is a transient or final situation. LNAPL has been identified on the beach and within the burn and coastal waters historically. The landfill boundary is around 50 m distant from the beach;

Fractured Media

Based on the stratum description of the borehole logs for the five new boreholes adjacent to the landfill's eastern boundary (Smallbrook, 2009) the media is predominantly granular sand and is not a fractured media. Therefore, the precluding condition of fractured media is not applicable at this Site;

- **High Water Table Fluctuations**

A summary of groundwater levels recorded in monitoring wells at the Site is provided in the quarterly monitoring reports (Smallbrook 2009 and 2010). The data demonstrates that the mean water table fluctuation (the difference between the mean maximum and minimum groundwater levels recorded in monitoring wells) across the Site is 0.61 m which is not considered a high water table fluctuation. Therefore, the precluding condition of high water table fluctuations is not applicable at this Site;

- **Hydraulic Gradient Greater Than 0.01**

Quarterly hydrogeological plots are provided in Drawings 3 to 6. The hydraulic gradient at the Site appears consistent and does not significantly vary between quarterly hydrogeological plots. The hydraulic gradient across the entire Site (excluding boreholes inside the landfill) ranges between 0.028 and 0.049.

As the boreholes along the eastern boundary are arranged linearly, broadly parallel to the coast, it is not possible to accurately define the hydraulic gradient in this area. However, it is indicated on the hydrogeological plots that despite the apparent easing of the gradient towards the coast that the hydraulic gradient is greater than the precluding condition of 0.01;

- **Preferential Pathways**

A gas trench is present in the southern area of the Blackdog Landfill Site which is known to be 1 to 2 m in depth. At this depth the gas trench is too shallow to have any bearing on LNAPL mobility, which has been recorded much deeper within the landfill (the water table has been recorded between 3.38 and 4.5 m bGL in local monitoring wells GA06-P02 and P9) and will not provide a preferential pathway. There are no other known features at the Site which could potentially create a preferential pathway for LNAPL mobility. Therefore, the precluding condition of preferential pathways is not applicable at this Site; and

- **Summary**

There are a number of precluding conditions (LNAPL close to receptor and hydraulic gradient greater than 0.01) which would infer that the Site is relatively high risk with respect to LNAPL relative to the LNAPL management framework and that LNAPL is potentially mobile. Further assessment in the following sections has been undertaken to evaluate any trends and to consider how mobile LNAPL might be.

4.3.4 LNAPL Assessment Data

Time series charts illustrating the results of the LNAPL monitoring are presented in Appendix C.

Table 6 below contains a summary of the LNAPL monitoring results. Please note that the mean apparent thickness calculations used a value of 1 mm where a sheen was noted on the interface probe but a thickness was not recordable.

The 2009/2010 monthly monitoring frequency is within the recommended minimum for LNAPL monitoring of quarterly data. This is because at least one round was conducted at low water table levels and the monthly monitoring frequency is suitable for costal Sites (Golder, 2008).

Table 6: Summary of LNAPL Monitoring

Monitoring Date	04-Apr-08	25-Jun-08	13-Jul-09	19-Aug-09	21-Sep-09	20-Oct-09	03-Nov-09	08-Dec-09	28-Jan-10	15-Feb-10	09-Mar-10	19-Apr-10	19-May-10	22-Jun-10	26-Aug-10
Number of wells containing LNAPL within the upper landfill section to the west*	4	4	4	4	4	4	4	4	3	4	2	0	0	3	2
Mean thickness	0.14	0.21	0.23	0.20	0.13	0.14	0.01	0.02	0.04	0.03	0.02	none	none	0.00	0.00
Number of wells containing LNAPL within the lower landfill section to the east**	4	2	4	1	3	3	3	1	1	1	2	3	3	3	2
Mean thickness	0.03	0.08	0.04	0.07	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Number of monitoring wells containing LNAPL at the landfill eastern edge***	2	2	1	3	4	2	4	4	4	4	3	2	3	2	1
Mean thickness	0.02	0.07	0.02	0.03	0.15	0.13	0.27	0.11	0.13	0.13	0.14	0.09	0.02	0.00	0.00
Total number of wells containing LNAPL	10	8	9	8	11	9	11	9	8	9	7	5	6	8	5
Mean thickness	0.07	0.14	0.12	0.12	0.11	0.10	0.10	0.06	0.08	0.07	0.06	0.04	0.01	0.00	0.00

* *Monitoring wells located within the upper landfill are: GA1, GA06-BH3, GA06-BH4, GA06-P14, GA06-P15, GA06-P16¸ GA06-P17, GA06-P18, GA06-P19, GA06-P20, GA06-P21, GA06-P22, GA06-P23, GA06-P24, GA06-P25 and GA06-P26 (16 monitoring wells).*

** *Monitoring wells located within the lower landfill are: GA06-BH1, GA06-BH2, GA06-P01, GA06-P02, GA06-P03, GA06-P04, GA06-P05, GA06-P06, GA06-P07, GA06-P08, P1, P2, P3, P4, P5, P6, P7, P8, P9, P10 and R1 (21 monitoring wells)*

*** *Monitoring wells located at the landfill eastern edge are: CA8a, CA8b, CA8/R2, CA9/BH9, GA3, GA4, GA5, GA6, GA7, GA8, GA8b, GA9 and R3 (13 monitoring wells)*

4.3.5 Primary Lines of Evidence

LNAPL is considered mobile when:

- Temporal sampling indicates increasing thickness of LNAPL in monitoring wells;
- Temporal sampling indicates advancement of LNAPL across a monitoring well network; and
- LNAPL is measured in monitoring wells at thicknesses exceeding theoretical estimates of LNAPL mobility (LNAPL modelling).

These primary lines of evidence are considered in this section.

4.3.5.1 Thickness of LNAPL in Monitoring Wells

The time series charts (Appendix C) and the summary table above (Table 6) demonstrate that, overall, the thickness of LNAPL in monitoring wells has demonstrably decreased with time. During the last two monitoring rounds of the 2010 monitoring exercise, no measureable thickness (i.e. nothing greater than 0.1 mm) of LNAPL was identified in any monitoring well. Therefore, there is evidence to suggest a stable or decreasing thickness of LNAPL in monitoring wells, indicating at present a lower risk of mobile LNAPL at the Blackdog Landfill Site. However, further monitoring is required to confirm whether this observation is a temporary situation or whether it is a permanent trend. We note that further monitoring in August and September 2011 (not reported here) confirmed these results.

4.3.5.2 Advancement of LNAPL across the Monitoring Well Network

Throughout the LNAPL monitoring (the 2008 and 2009-2010 work) LNAPL has been identified in 11 monitoring wells (a total of 48 monitoring wells were monitored during the 2009/2010 work, not including those that were lost or dry).

Of the 11 monitoring wells in which LNAPL was identified during the monitoring period, 9 are located within the landfill with monitoring installations screened within the landfill waste (4 located within the upper section of the landfill to the west and 5 located within the lower section of the landfill to the east) and 4 are located at the eastern boundary of the landfill with monitoring installations screened within the (predominantly) sand lithology.

LNAPL at the Blackdog Site does not appear to be interconnected as there are LNAPL free monitoring wells across the Site that delineate the LNAPL into discrete pockets of LNAPL, randomly spaced across the landfill.

Of the 11 monitoring wells that LNAPL was identified, the number of monitoring wells in which LNAPL was identified on a particular monitoring round varies, but the overall trend is that the number of monitoring wells that LNAPL is identified is reducing and often the fluctuations can be attributed to a small change in thickness of LNAPL.

The summary table above (Table 6) demonstrates that monitoring wells recorded with LNAPL has reduced from 10 in first monitoring round (April 2008) to 5 in the latest monitoring round (August 2010) and in these 5 wells no measurable thickness of LNAPL was identified (i.e. only a sheen was evident).

Based on the above, there is evidence to suggest a decreasing or stable LNAPL plume, indicating low risk of mobile LNAPL at the Blackdog Landfill Site.

4.3.5.3 LNAPL Modelling

When LNAPL is observed in wells, a common concern is whether the LNAPL is moving. Typically, as long as an LNAPL release continues, LNAPL in the subsurface is moving. Once a release stops, the forces driving migration dissipate and the rate of LNAPL migration slows. With time the driving force becomes insufficient to drive further LNAPL movement. This occurs when the pressure in the LNAPL is not large enough to displace the water at the margin of the released LNAPL body.

Many LNAPL problems can be analyzed using mathematical models. Necessary inputs can be obtained by conducting site specific studies or by using typical values for known conditions. To facilitate use of models API produced *Methods for Determining Inputs to Environmental Petroleum Hydrocarbon Mobility and Recovery Models* (Sale, 2001).

LNAPL modelling has been performed to determine the thickness at which LNAPL might be mobile. It is recognised that the LNAPL management framework (which is not connected to the modelling approach) identified that the Site exhibited some of the precluding conditions indicating a high risk of LNAPL mobility but this does not necessarily rule out the validity of the API modelling. The modelling estimates LNAPL migration rates which help understanding when LNAPL may arrive at the beach if it is mobile. The API LNAPL mobility model was used to relate the measured LNAPL thickness in wells to the potential LNAPL velocity in the LNAPL plume, and the potential for LNAPL to exceed displacement entry pressure and enter water-wet pores at the periphery of the LNAPL plume.

Modelling was undertaken for the upper section of the landfill to the west, the lower section of the landfill to the east and at the eastern boundary of the landfill.

Upper Section of the Landfill to the West

Of the monitoring wells installed within the upper section of the landfill to the west, LNAPL has been identified in 4 monitoring wells. There are 3 discrete pockets of LNAPL, 2 of the monitoring wells appear to be interconnected without any ‘clean’ monitoring wells in between. The spatial areas of the pockets of LNAPL, delineated to the closest ‘clean monitoring wells, are measured as 80 m in length and 100 m in width, for all 3 pockets of LNAPL, due to the spacing of the monitoring wells.

Borehole logs (Golder, 2006) for monitoring wells drilled within the upper section of the landfill to the west, describe the waste as a mixed waste within a sandy clay matrix. Clayey sand was chosen to represent the soil type in the API model.

Liquid wastes accepted at Blackdog Landfill Site typically comprised Diesel. Measured LNAPL parameters from the Blackdog Landfill Site were used in the API model. Samples taken during the 2009/2010 monitoring work give a mean LNAPL kinematic viscosity of 7.0 cp and a mean density at 20 degrees Celsius of 0.8442 (g/cc).

LNAPL was recorded within the landfill waste at a depth ranging from 2.54 to 6.53 m bGL, with the mean of 4.31 m utilised for the API model. Based on this depth a typical landfill waste total porosity of 0.525 and a residual saturation of water of 0.39 (Beaven and Powrie, 1995) was used in the API model.

The range of groundwater hydraulic gradients recorded in the upper section of the landfill is 0.02 to 0.17 and does not significantly vary between seasons. A mean value of 0.10 was used for the API model.

LNAPL ranged in thickness from 0.00 m to 0.83 m with a mean thickness of 0.10 m for the upper section of the landfill to the west. Please note that the mean thickness calculation used a value of 1 mm where a sheen was noted on the interface probe but a thickness was not recordable.

Modelling was undertaken to determine a threshold thickness for mobility and the LNAPL velocity for the mean and worst case thickness. The results of the modelling are provided in the table below and print outs of the modelling executive summaries are provided in Appendix C.

Table 7: Modelling of the Upper Section of the Landfill to the West

Threshold Thickness for Mobility	LNAPL Plume Velocity at the Mean Thickness	LNAPL Plume Velocity at the Worst Case Thickness
0.05 m	0.000005 m/day	0.0000687 m/day

Lower Section of the Landfill to the East

Of the monitoring wells installed within the lower section of the landfill to the east, LNAPL was identified in 5 monitoring wells. There are 4 discrete pockets of LNAPL as only 2 of the monitoring wells appear to be interconnected without any 'clean' monitoring wells in between. The range in area of the pockets of LNAPL, delineated to the closest 'clean monitoring wells, are measured as between 30 m in length and 22.5 m in width to 52.5 m in length and 90 m in width.

Borehole logs (Golder, 2006) for monitoring wells drilled within the lower section of the landfill to the east, describe the waste as a mixed waste within a sandy clay matrix. Clayey sand was chosen to represent the soil type in the API model.

Liquid wastes accepted at Blackdog Landfill Site typically comprised Diesel. Measured LNAPL parameters from the Blackdog Landfill Site were used in the API model. Samples taken during the 2009/10 monitoring work give a mean LNAPL kinematic viscosity of 7.0 cp and a mean density at 20 degrees Celsius of 0.8442 (g/cc).

LNAPL was recorded within the landfill waste at a depth ranging from 1.19 to 5.32 m bGL, with a mean of 3.45 m utilised for the API model. Based on this depth a typical landfill waste total porosity of 0.525 and a residual saturation of water of 0.39 (Beaven and Powrie, 1995) was used in the API model.

The range of groundwater hydraulic gradients recorded in the lower section of the landfill is 0.04 to 0.33 and does not significantly vary between seasons. A mean value of 0.19 was used to assess the Site.

LNAPL ranged in thickness from 0.00 m to 0.12 m with a mean thickness of 0.02 m for the lower section of the landfill to the east. Please note that the mean thickness calculations included an assumed value of 1 mm where a sheen was noted on the interface probe but a thickness was not recordable.

Modelling was undertaken to determine a threshold thickness for mobility (in the largest LNAPL area) and LNAPL plume velocity for the mean thickness (in the largest LNAPL area) and worst case thickness (0.12 m thickness in the corresponding area of 45 m length by 45 m wide). The results of the modelling are provided in the table below and print outs of the modelling executive summaries are provided in Appendix C.

Table 8: Modelling of the Lower Section of the Landfill to the East

Threshold Thickness for Mobility	LNAPL Plume Velocity at the Mean Thickness	LNAPL Plume Velocity at the Worst Case Thickness
0.06 m	n/a (does not exceed the threshold thickness to allow mobility)	0.0000119 m/day

Eastern Boundary of the Landfill

Of the monitoring wells installed within the eastern boundary of the landfill, LNAPL has been identified in 4. There are 2 discrete pockets of LNAPL as 3 of the monitoring wells appear to be interconnected without a 'clean' monitoring well between. The area of the 2 pockets of LNAPL, delineated to the closest 'clean monitoring wells, are measured as 60 m in length and 157.5 m in width and 45 m in length and 105 m in width. The areas are delineated at the beach to the east, as the beach is considered separately in Section 3.4.

Borehole logs and Physical Analysis results (Smallbrook, 2009) for monitoring wells drilled within the eastern boundary of the landfill, describe the strata as predominantly a medium sand.

LNAPL was recorded at a depth of 5.12 to 8.70 m, with a mean of 6.64 m utilised for the API model.

The range of groundwater hydraulic gradients recorded in the underlying aquifer is 0.028 to 0.049, measured across the site footprint with a mean value of 0.039 used to assess the Site. The anticipated hydraulic conductivity of the underlying aquifer is 1.0×10^{-5} to 2.7×10^{-4} m/s with a mean value of 1.4×10^{-4} m/s being used for the modelling.

LNAPL ranged in thickness from 0.00 m to 0.60 m with a mean thickness of 0.11 m for the eastern boundary of the landfill. The most recent recorded LNAPL thickness was 0.06 m in May 2010. Please note that the mean thickness included an assumed thickness value of 1 mm where a sheen was noted on the interface probe but a thickness was not recordable.

Modelling was undertaken to determine a threshold thickness for mobility in the larger LNAPL area and the LNAPL plume velocity for the mean thickness and the worst case thickness in the larger LNAPL area. The last recorded thickness of LNAPL (located in the larger LNAPL area in April 2010) was also modelled. The results of the modelling are provided in the table below and print outs of the modelling executive summaries are provided in Appendix C.

Table 9: Modelling of the Lower Section of the Landfill to the East

Threshold Thickness for Mobility	LNAPL Plume Velocity at the Mean Thickness	LNAPL Plume Velocity at the Worst Case Thickness	LNAPL Plume Velocity at the Most Recent Thickness
0.03 m	0.00378 m/day	0.0224 m/day	0.00199 m/day

4.3.6 Pollutant Linkage B Summary

Based on the findings of the LNAPL assessment for the Blackdog Landfill Site, it can be concluded that there are a number of precluding conditions regarding the site setting (proximity to a receptor and hydraulic gradient greater than 0.01). As a consequence, if LNAPL were present, the Site would be classified as a high risk site in terms of LNAPL mobility using the LNAPL management framework guidance.

However, the evidence, obtained during the 2009/2010 site investigation and monitoring exercise suggests that the risk of LNAPL mobility (from the landfill) is reducing or is low. Evidence for this primarily relates to the reduction in the thickness of LNAPL recorded in monitoring wells, with no recordable thickness (i.e. <0.1 mm) in the most recent monitoring round. However, it is not known whether this is a temporary observation or part of a longer term trend and further monitoring data is required in order to increase confidence in this assessment. API modelling using input parameters for the geology at the landfill boundary and physical hydrocarbon parameters from the Site has identified a threshold hydrocarbon thickness below which LNAPL mobility is unlikely. The last monitoring round where the threshold (0.03m) of mobility at the eastern boundary was exceeded was in May 2010.

There is photographic evidence of hydrocarbon on the beach adjacent to the Site as early as 1993 (Golder, 2004), suggesting therefore, that migration must have occurred reasonably rapidly after the original deposit of the waste.

Modelling of conditions at the Site boundary indicate that LNAPL, if present, would migrate through the dunes (around 50 m width) and onto the beach in around 50 years using the mean modelling results and around 8.6 years using the worst case modelling results.

Due to the LNAPL being located in discrete pockets and the relatively low plume velocity within the landfill, it is likely that LNAPL monitoring (including bail down tests) may have influenced the reduction in LNAPL at the Blackdog Landfill Site (i.e. by removing small pockets of LNAPL that subsequently were not replenished as there was insufficient LNAPL present).

4.4 Pollutant Linkage C, D and F

Pollutant linkage C relates to the desorption and solution from hydrocarbon impacted beach sediments and solution of localised free phase hydrocarbon with lateral migration of groundwater within the aquifer.

Pollutant linkage D (the desorption and solution from hydrocarbon impacted beach sediments and solution of localised free phase hydrocarbon with solution into coastal waters) and F (episodic desorption of hydrocarbons from beach sediment and mobilisation of free phase hydrocarbon by wave action following erosion of clean cover from the beach and release into coastal waters as a film) will be treated in a similar manner to pollutant linkage C.

Historically black staining of the beach sediments has been linked to hydrocarbons (mainly LNAPL) migrating from the landfill. Examination of the black/green (hereafter referred to as black staining) staining during trial excavations on the beach has determined that the black colouration is not necessarily hydrocarbons although indications of hydrocarbons have been observed in some of the stained areas. This has been confirmed by hydrocarbon analysis of the beach sediments which does not show a correlation between the black staining and detectable concentrations of TPH or PAH. However, this may be due in part to the poor sorption ability of sand and gravel, whereby the bulk of any hydrocarbons would reside within the pore water. There is the potential for LNAPL or high concentrations of hydrocarbons within the dissolved phase.

The black staining may be due to the presence of sulphides resulting from the action of sulphate reducing bacteria on hydrocarbons. The staining is therefore an indication of the past presence of hydrocarbons. However, what is not clear is how recent the impact has been.

- Extent of black staining gives past extent of hydrocarbon impact to the beach sediments; and
- Extent of TPH in soil and groundwater gives current extent of hydrocarbon impact to the beach sediments.

These pollutant linkages are all related by the source of hydrocarbons within the beach sediments and include the sorbed component and free phase component. The hydrocarbon source within the beach is therefore first considered below before considering how they might be mobilised.

4.4.1 Extent of Visual Discolouration

Trial pits were excavated to try to determine the northern, eastern and southern extents of the visual discolouration beneath the beach.

Beach sediment monitoring was conducted during the preliminary Site Investigation and at four subsequent quarterly monitoring rounds. This comprised the installation of trial pits to “map” the extent of sediment staining and hydrocarbon impact, and included the collection and chemical analysis of 6 beach sediment samples for each sampling round. Sampling on the beach is inherently difficult due to conditions experienced which include problematic access, falling in of trial excavations due to poor ground conditions and problems in obtaining samples taking accurate measurements because of these difficulties. Appendix G presents drawings which show the observations (indications of the presence of hydrocarbons from visual indicators, odour observations and PID readings) made during the quarterly beach sediment monitoring.

There are two areas of the beach (a larger northern area and smaller southern area) at which visual discoloration (of black or green colour) and hydrocarbon odour has been noted at depth in beach trial pits. The black staining observed on the beach does not show a strong current correlation with measured elevated hydrocarbon concentrations. However, it is recognised that the black (and green) staining may be a result of biodegradation of hydrocarbons and chemical reactions from the past, as leachate migrated from the landfill Site and onto the beach. In addition, other indications of the presence of hydrocarbon have been observed during the beach monitoring exercise. These indications include visual staining, the visual presence of a sheen, odour observations of hydrocarbons and elevated PID results. The hydrocarbon indications are more widespread than the actual measured elevated hydrocarbon in the beach sediments. These results reflect the lack or sorption of hydrocarbons to the beach sediments but show that hydrocarbons are still present within the groundwater on the beach (either as dissolved or LNAPL). However, whilst these indicators of hydrocarbons are more widespread than the measured elevated hydrocarbons sorbed to beach sediments the observed information does help to differentiate between historic and refreshed hydrocarbon on the beach and this is discussed further below.

Locations of beach trial pits, elevations at which visual discolouration was observed, associated PID readings and records of hydrocarbon odours and cross sections based on trial pit observations are illustrated within figures presented in Appendix G. The trail pits utilised for this assessment are located within the lines of Cross Sections 1, 2 and 3 for the quarterly monitoring rounds in December 2009, March 2010 and June 2010. Information for beach sediment monitoring in June and September 2009 is also provided in Appendix G. However, the information is limited in extent compared to later monitoring periods.

Sections 1, 2 and 3 used in later monitoring periods are either not present or are not in the same locations for comparison purposes.

Cross Sections 1 and 2 both run west to east across the beach (perpendicular to the landfill boundary) and are located within the larger northern area of visual discolouration. Figures 1 and 2 of Appendix G illustrate the elevation at which evidence of contamination was first noted across the chainage of Cross Sections 1 and 2 respectively, for three monitoring rounds (December 2009, March 2010 and June 2010). Figures 1 and 2 of Appendix G provide contradictory evidence whether the elevation of the visual discolouration is stable (therefore reflecting a historic presence of hydrocarbons) or fluctuating (representing hydrocarbon that is being refreshed).

Figure 1 (of Appendix G), showing the northernmost section, appears to indicate that is the hydrocarbon indications are stable during all three monitoring rounds with similar elevations across the chainage (within the range to be expected due to the method uncertainty).

Figure 2 (of Appendix G), showing the central section, appears to demonstrate fluctuating elevations, with the December 2009 round consistently lower across the chainage than that of the March 2010 and June 2010 rounds (which are of similar elevations). This would indicate that the hydrocarbon is being refreshed in this location.

Cross Section 3 runs west to east across the beach and perpendicular to the landfill boundary and it is located within the smaller southern area of visual discolouration. There is too little evidence of contamination within this cross section to illustrate changes in elevation, and the fact that there is little evidence of visual discolouration itself points to a historic migration of contamination rather than continuing migration. The southernmost section shows limited indications of hydrocarbon impact from visual indicators, odour observations and PID readings and so has not been considered further.

It can be concluded that there is contradictory evidence as to whether hydrocarbon impact on the beach is historic or continuing with respect to the larger stained northern area of beach. However, there is evidence that there is some degree of refreshment of hydrocarbon impact on the beach in some areas on some occasions, whilst in other areas the observed impact appears to be historic. It is recognised that there are uncertainties associated with the data due to the difficulties of sampling and measuring on the beach.

The locations of the trial pits and the depths at which the visual discolouration, possibly due to hydrocarbon contamination, was encountered, is also shown in Figure 1, in Section 7 of the Quarterly Factual Monitoring Report – January to March 2010 (Smallbrook, 2010) entitled “Locations of Exploratory Holes and Depth to Hydrocarbon Affected Sand”. Drawings from the previous beach excavations in July 2009, September 2009, December 2009 and March 2010 are also provided.

The visual discolouration is noted in two areas of the beach, a larger northern area and smaller southern area. The areal extent of discolouration is estimated below. However, due to the uncertainties associated with measurements on the beach the differences are not considered to be significant.

Table 10: Northern Area of Visual Discolouration

Date Trial Pits Excavated	Jun-09	Sep-09	Dec-09	Mar-10	Jun-10
Length (m)	Not Delineated (> 33)	Not Delineated (> 99)	66	57	54
Width (m)	135	174	210	192	195
Area (m²)	Not Delineated	Not Delineated	13,860	10,944	10,530

Table 11: Southern Area of Discolouration

Date Trial Pits Excavated	Jun-09	Sep-09	Dec-09	Mar-10	Jun-10
Length (m)	Not Delineated (>20 m)	na	Not Delineated (>37.5 m)	Not Delineated (>37.5 m)	na
Width (m)	15	na	16.5	15	na
Area (m²)	Not Delineated	na	Not Delineated	Not Delineated	na

Please note that 'na' is stated where visual discolouration (of black colour) was not observed

Thickness

During the 2009/2010 work, only two trial pits excavated visually identified possible hydrocarbon contamination and possible bedrock. From these two trial pits the interpreted thickness of the potential hydrocarbon contamination was 0.9 m and 0.2 m, giving a mean thickness of 0.55 m potential hydrocarbon contamination at the Blackdog beach.

4.4.2 Hydrocarbon Sources for Pollutant Linkages C, D and F

There are two areas of the beach (a larger northern area and smaller southern area) at which visual discoloration (of black colour) has been noted at depth in trial pits. This section reviews the results of the hydrocarbon analysis from the beach sediment. It is noted that hydrocarbon sorption onto sand (and gravel) is not significant. Section 4.4.1 discusses the importance of other indicators of hydrocarbons in the beach sediment in addition to the chemical analysis results discussed below.

The locations of trial pits and the depths at which visual discolouration was observed are shown in drawing Figure 1, in Section 7 of the Smallbrook report (Smallbrook, April to June 2010) entitled "Locations of Exploratory Holes and Depth to Hydrocarbon Affected Sand". Drawings from the previous beach excavations in July 2009, September 2009, December 2009 and March 2010 are also provided.

Soil samples were taken and analysed from areas of visual discolouration. Of the 14 samples taken within the northern area, elevated concentrations of TPH was identified in 3 (range of 96 to 6,198 mg/kg) and 2 demonstrated elevated Total PAH results (1.34 and 6.89 mg/kg). The 1 sample taken within the southern area demonstrated elevated TPH (16 mg/kg); however, the Total PAH result was below the limit of detection. Therefore, it can be concluded that visual discolouration within the beach does not necessarily correlate to the presence of elevated concentrations of hydrocarbons.

Soil samples were also taken where potential hydrocarbon contamination was identified by odour and green staining. The 4 trial pit samples taken in the northern area and the 3 samples taken in the southern area where potential hydrocarbon contamination was identified by odour and green staining were all below the limit of detection for both TPH and PAH analysis. Therefore, it can be concluded that odour and green staining within the beach does not correlate to elevated concentrations of hydrocarbons.

Trial pit samples taken where no visual or odour identification of hydrocarbons was made, all returned analysis results below the limit of detection for TPH and PAH.

A review of TPH and PAH concentrations in the beach sediments from trial pits installed during the quarterly monitoring period revealed the following variation by monitoring period:

June 2009

Soil samples from trial pits 7 and 20 located on the beach were subjected to TPH and PAH analysis and were below detection limits.

Soil samples from trial pits 8 (TPH 4487 mg/kg, PAH 1.3 mg/kg) and 17 (TPH 6198 mg/kg, PAH 6.9 mg/kg) located on the beach were subjected to TPH and PAH analysis and were above detection limits for both compounds, whilst trial pit 21 had TPH concentrations greater than detection limit (16 mg/kg) but PAH concentrations below detection limit.

September 2009

Soil samples from trial pits 5, 10, 13, 16, 21 and 25 (no staining observed in this trial pit) located on the beach were subjected to TPH and PAH analysis and were all below detection limits.

December 2009

Soil samples from trial pits 1, 11, 17, 24, 35 and 39 (located on the beach) were subjected to TPH and PAH analysis and were all below detection limits. Soil samples from trial pit 6 displayed a concentration of 96 mg/kg TPH, although PAH concentrations were below detection limits.

March 2010

Soil samples from trial pits 1, 6, 11, 17, 35 and 39, located on the beach were subjected to TPH and PAH analysis and were all below detection limits.

June 2010

Soil samples from trial pits 1, 6, 11, 17, 35 and 38 located on the beach were subjected to TPH and PAH analysis and were all below detection limits.

Summary

PAH chemical analysis results for soils from the beach have been below detection limits with the exception of two samples out of thirty (i.e., 93% showing no signs of impact) collected in June 2009, with concentrations of 1.3 and 6.9 mg/kg total PAHs.

The majority of TPH (27 out of 30 samples or 90%) chemical analysis results for soils were below detection limits during this monitoring campaign with the exception of two samples in June 2009 (TPH 4,487 and 6,198 mg/kg) and one sample in December 2009 (TPH 96 mg/kg).

In the 2004 Site Investigation only three samples were collected and analysed and these all displayed detectable hydrocarbon.

The black staining observed on the beach does not show a strong current correlation with elevated hydrocarbon concentration. However, it is recognised that the black (and green) staining may be a result of biodegradation of hydrocarbons and chemical reactions from the past, as leachate migrated from the landfill Site and onto the beach. In addition, other indications of the presence of hydrocarbon have been observed during the beach monitoring exercise. These indications include visual staining, the visual presence of a sheen, odour observations of hydrocarbons and elevated PID results.

It can be concluded that there is contradictory evidence as to whether hydrocarbon impact on the beach is historic or continuing with respect to the larger stained northern area of beach. However, there is evidence that there is some degree of refreshment of hydrocarbon impact on the beach in some areas, whilst in other areas the observed impact appears to be historic. It is recognised that there are large uncertainties associated with the data.

Further analysis was conducted on the black stained beach sediment sample from Trial Pit 1 to identify the nature of the coating on the sand grain surfaces to determine whether the coating is of organic matter or hydrocarbon, or of mineralogical origin (e.g. manganese or iron oxide coating).

The sample was examined under a stereomicroscope followed by exposure to UV light microscopy. Individual sand particles were also analysed using Raman Spectroscopy (Raman).

The sample was described as a medium to coarse beach sand with particles comprising quartz, lithic fragments and biotite. The majority of the quartz grains are clear and have a glassy appearance although some have a thin coating. This coating is, for the most part, oxidised iron staining and has been identified by Raman as haematite and goethite. Occasional grains exhibit a darker coating and this has been identified by Raman as amorphous carbon and manganese oxide. The lithic fragments have a dark appearance and when occurring in high percentages lend a dark colour to the sand. The lithic fragments have partly been identified as comprising several plagioclase feldspars including albite and oligoclase. The dark minerals were not identifiable using Raman but were identified using conventional polarising light microscopy. They comprise biotite (often oxidised), magnetite and chlorite. Muscovite was also identified and this mineral, although light in colour appears as dark in many of the sand particles due to its very fine grain size. Hydrocarbons were not identified by either UV fluorescence or Raman Spectroscopy as a coating on any of the particles in the sample.

It is therefore considered reasonable to conclude that the presence of staining on the beach sediments does not on its own indicate the presence of retained hydrocarbon. The inorganic coatings may well be precipitated oxides of dissolved substances from landfill leachate.

4.4.3 Groundwater Hydrocarbon Concentrations within the Beach

Only three groundwater samples were taken from trial pits located within the beach during the 2009/2010 site investigation and monitoring exercise.

Groundwater was also obtained from trial pits 1, 6 and 8 during the March 2010 beach investigation. Trial Pit 1 located closest to the dunes and was reported to expose black staining of the beach deposits. The analysis of groundwater collected from Trial Pit 1 reported TPH concentrations (total C5 to C35 aliphatics and aromatics) greater than 270 mg/l which is indicative of LNAPL. PAH concentrations were below detection limits in groundwater from this trial pit.

Trial pits were extended eastwards during this monitoring event (i.e. in the approximate direction of groundwater flow) along a line from Trial Pit 1 (around 14 m east of the sand dunes). Trial Pits 6 and 8 (around 61 m and 80 m east of the sand dunes) excavated sand with green staining rather than black staining. TPH and PAH concentrations in groundwater collected from both trial pits were below detection limits.

One groundwater sample returned an elevated TPH concentration (271,472 µg/l) with a PAH concentration below the limit of detection. This sample was taken from a trial pit (TP1, March 2010) located 20 m from the sand dunes in an area identified with visual discolouration. The concentration of TPH in this sample is indicative of the presence of LNAPL.

Hydrocarbon sheens were observed in water observed in trial pits installed on the beach during the beach monitoring exercise as follows:

- June 2009 – No observations;
- September 2009 – Free product observed in one trial pit;
- December 2009 – No observations;
- March 2010 – Slight hydrocarbon sheen was observed in 9 trial pits; and
- June 2010 – Slight hydrocarbon sheen observed in 4 trial pits.

Trial pits where indications of hydrocarbon have been identified are located at distances of up 80m east of the dunes.

The two other groundwater samples were taken from trial pits (TP6 and TP8, March 2010) located 66 m and 83 m from the sand dunes in areas identified as potential hydrocarbon contamination by odour and green staining. These samples did not record elevated TPH or PAH concentrations.

Reported concentrations of TPH were sufficiently high to indicate that LNAPL was present in Trial Pit 1; however the absence of hydrocarbon in the sediment sample indicates that LNAPL is not retained in the sediment.

Trial pits were excavated in the beach deposits to the water strike; excavation to deeper depths in granular sediments without supporting the sides of the excavation is not practical. However it is considered that the trial pits were excavated to sufficient depth to consider the affect of dissolved hydrocarbon in freshwater groundwater as it interacts with more dense saline water on the beach foreshore.

- The analysis of water for sodium and chloride collected from the trial pits identify that the saline interface in the beach deposits is located between Trial Pit 1 and Trial Pit 6 (Between 13 m and 61 m from the sand dunes).

4.4.4 Free Phase Hydrocarbon within the Beach

As stated above; Groundwater TPH concentrations within the beach appear to be indicative of LNAPL within close proximity to the dunes, but at distances greater than 20 m from the dunes, hydrocarbons appear to be below the detection limit based on current and 2004 groundwater analysis results. However, observations of hydrocarbon sheens during the quarterly beach monitoring exercise show that free phase material is present in some locations and at distances up to around 80 m east of the sand dunes.

As stated previously (section 4.3) the LNAPL monitoring in boreholes both within and downgradient of the landfill have shown a reduction of LNAPL presence and thickness over rime. The last two monitoring events during 2010 indicated no measurable thickness (i.e. nothing > 0.1mm). Further monitoring is required to determine if this is temporary or more permanent. If it is more permanent this would lead to a reducing LNAPL source entering the beach.

Further monitoring of the presence of LNAPL on the beach (in soils and groundwater) would provide routine information to determine whether the conceptual model considered here (i.e., the reduction in mobile LNAPL within the landfill and at the landfill boundary and residual migration of LNAPL through the dunes and onto the beach) is confirmed. Once an improving trend or absence of LNAPL on the beach in soils and groundwater is identified proposals will be made for the reduction of monitoring frequency and ultimately the cessation of monitoring.

4.4.5 Pollutant Linkage C

Pollutant linkage C relates to desorption and solution from hydrocarbon impacted beach sediments and solution of localised free phase hydrocarbon with lateral migration of groundwater within the aquifer.

Groundwater at the Site has been shown to flow from the landfill through the dunes and beach and towards the sea. Historically beach sediments will have been impacted by migration of dissolved and free phase hydrocarbons from the landfill. LNAPL will have migrated from the landfill, through the dunes and onto the beach.

Residual hydrocarbons remain within the landfill and have been estimated to hold around 11,500 tonnes. Dissolved phase hydrocarbons continue to migrate from the landfill towards the beach. As stated previously (section 4.3) the LNAPL monitoring in boreholes both within and downgradient of the landfill have shown a reduction of LNAPL presence and thickness over rime. The last two monitoring events during 2010 indicated no measurable thickness (i.e. nothing > 0.1mm). Further LNAPL monitoring is recommended to confirm whether the LNAPL monitoring observed during the latter stages of the 2010 monitoring exercise (i.e. reduced presence of LNAPL within the landfill and at the landfill boundary) are temporary or whether this is indicative of a longer term trend. This information will be used to determine the ongoing risk to receptors from LNAPL migration from the landfill and whether any active remediation of LNAPL within or on the boundary of the landfill is required. The current results (if confirmed by further monitoring) suggest that active remediation including collection of LNAPL at and within the landfill is not warranted. If there is a reduced presence of LNAPL within the landfill and at the landfill boundary this would lead to a reducing LNAPL source entering the beach.

Hydrocarbons sorbed onto the beach sediment are limited in extent with 10% or less of samples showing detectable concentrations of hydrocarbons. In addition, comparison of mean concentrations between 2004 and 2009-10 show a reduction in concentration. However, there may be a discrepancy between the extent of the hydrocarbon plume, as defined by field observations compared to the results of laboratory analyses of beach sediment samples.

Hydrocarbons measured within the groundwater on the beach in March 2010 show a concentration indicative of LNAPL within trial pit 1 located around 13 m east of the dunes. Trial pits 6 and 8 extending further east of this trial pit (and around 61 m and 80 m east of the dunes), in the direction of groundwater flow, show no such detectable concentrations of hydrocarbons. This indicates that the presence of LNAPL on the dissolved phase hydrocarbon concentration within groundwater on the beach is also limited in extent.

These results are similar to those found during the 2004 Site Investigation where hydrocarbon concentrations indicative of LNAPL were observed in close proximity to the dunes, but concentrations reduced and were at or below detection limits greater than 20 m from the dunes.

Table 12: TPH Analysis of Beach Sediments from 2004

Sample	TPH mg/l	Approximate Distance from Dunes/m
BD02	105.3	15
BD03	0.1	20
BD04	<0.1	12.5
BD05	148.8	15
BD06	<0.1	112
BD07	1.8	12.5
BD08	<0.1	55
BD09	<0.1	50

Overall the collected Site Investigation information for this pollutant linkage can be summarised as follows:

- The black staining observed on the beach does not show a strong current correlation with elevated hydrocarbon concentration. However, it is recognised that the black (and green) staining may be a result of biodegradation of hydrocarbons and chemical reactions from the past, as leachate migrated from the landfill Site and onto the beach. In addition, other indications of the presence of hydrocarbon have been observed during the beach monitoring exercise. These indications include visual staining, the visual presence of a sheen, odour observations of hydrocarbons and elevated PID results. These results indicate that hydrocarbon remains in areas of the beach and that in some locations the hydrocarbon is being replenished;

- It can be concluded that there is contradictory evidence as to whether hydrocarbon impact on the beach is historic or continuing with respect to the larger stained northern area of beach. There is evidence that there is some degree of refreshment of hydrocarbon impact on the beach in some areas, whilst in other areas the observed impact appears to be historic. It is recognised that there are some uncertainties associated with the data but not sufficient to refute this data;

- Residual hydrocarbons remain within the landfill and have been estimated to hold around 11,500 tonnes. Dissolved phase hydrocarbons continue to migrate from the landfill towards the beach. As stated previously (section 4.3) the LNAPL monitoring in boreholes both within and downgradient of the landfill have shown a reduction of LNAPL presence and thickness over rime. The last two monitoring events during 2010 indicated no measurable thickness (i.e. nothing > 0.1mm). Further LNAPL monitoring is recommended to confirm whether the LNAPL monitoring observed during the latter stages of the 2010 monitoring exercise (i.e. reduced presence of LNAPL within the landfill and at the landfill boundary) are temporary or whether this is indicative of a longer term trend. This information will be used to determine the ongoing risk to receptors from LNAPL migration from the landfill and whether any active remediation of LNAPL within or on the boundary of the landfill is required. The current results (if confirmed by further monitoring) suggest that active remediation including collection of LNAPL at and within the landfill is not warranted. If there is a reduced presence of LNAPL within the landfill and at the landfill boundary this would lead to a reducing LNAPL source entering the beach;

- Analysis of the beach sediments show only a limited presence of detectable hydrocarbons, with only 10%, or less, of beach sediments indicating TPH and PAH. Hydrocarbon concentrations within beach sediments have also reduced between the 2004 Site Investigation and 2009-10. The reduced presence of hydrocarbons within the beach sediments therefore reduces the possibility of sorbed hydrocarbons being mobilised within groundwater;

- Only limited groundwater data has been collected from the beach. Groundwater TPH concentrations within the beach appear to be indicative of LNAPL within close proximity to the dunes, but at distances greater than 20 m from the dunes, hydrocarbons appear to be below the detection limit based on current and 2004 information. Observations from trial pits during the 2009/2010 quarterly beach monitoring exercise have show a number of indications of the presence of a hydrocarbon sheen with some up to around 80m east of the sand dunes; and
- Current groundwater PAH concentrations within the beach are below detection limits both within close proximity to the dunes, and at distances greater than 20 m from the dunes.

4.4.6 Pollutant Linkage D

Pollutant linkage D is the desorption and solution of hydrocarbon impacted beach sediments and solution of localised free phase hydrocarbon with solution into coastal waters.

Considerations for this pollutant linkage are the same as for pollutant linkage C above and so are not repeated here. Should hydrocarbons be identified within groundwater (pollutant linkage C) then these will ultimately migrate to coastal waters. For the same reasons set out in pollutant linkage C this pollutant linkage is also no longer considered valid.

An additional consideration is relevant to pollutant linkage D in that once groundwater reaches coastal waters, the sea will give rise to significant dilution. Quantification of the effect of dilution of groundwater has been estimated and indicates that hydrocarbons would be below 10 μg/l. This is below the hydrocarbon taste/odour threshold and below relevant EQS saltwater values for key hydrocarbon species that have an EQS.

4.4.7 Pollutant Linkage F

Pollutant linkage F is the episodic desorption of hydrocarbons from beach sediment and mobilisation of free phase hydrocarbon by wave action following erosion of clean cover from the beach and release into coastal waters as a film.

Considerations for part of this pollutant linkage are the same as for pollutant linkage C and D above and so are not repeated here. The validity of this pollutant linkage is first related to the presence of hydrocarbons within the beach sediment.

Monitoring of the beach level has also been undertaken since the installation of the Burn Diversion in November 2008. During the lowest beach levels monitored (September to November 2009 and April 2010), clean sand cover of between 0.5 m to > 2.0 m was observed. A summary of clean sand cover depths is provided in Tables 13 and 14 below. Due to the natural dip of the beach level, clean sand cover increases on the west side of the beach (> 2.0 m) where hydrocarbon concentrations are highest and reduces eastwards, towards the sea. The greatest protection of sand cover is therefore afforded in areas where highest TPH concentrations are observed. During the monitoring period 2008-2010 (i.e. from installation of Burn Diversion), evidence for this pollutant linkage has not been observed.

This pollutant linkage also relates to episodic events that are likely to be rare storm events outside the normal storm and tidal events encountered during recent monitoring (2008-2010). Storm events will be most effective in impacting the beach on the eastern margins. On the western end of the beach, the impact will be attenuated by the higher beach levels.

Table 13: Northern Area Thickness of Clean Sand Cover

Date Trial Pits Excavated	Jun-09	Sep-09	Dec-09	Mar-10	Jun-10
Minimum Depth to Visual Discolouration (m)	1.33	0.80	0.90	0.50	1.20
Mean Depth to Visual Discolouration (m)	1.74	1.69	1.50	1.10	1.50
Maximum Depth to Visual Discolouration (m)	2.30	2.38	2.30	2.30	1.80

Table 14: Northern Area Thickness of Clean Sand Cover

Date Trial Pits Excavated	Jun-09	Sep-09	Dec-09	Mar-10	Jun-10
Minimum Depth to Visual Discolouration (m)	1.39	na	1.40	2.20	na
Mean Depth to Visual Discolouration (m)	1.39	na	2	2.2	na
Maximum Depth to Visual Discolouration (m)	1.39	na	2.6	2.2	na

Please note that 'na' is stated where visual discolouration was not observed.

4.5 Pollutant Linkage E, G and H related to Blackdog Burn

4.5.1 Pollutant Linkages

For pollutant linkage E, the Blackdog Burn has historically been migrating along the beach causing erosion of contaminated sands within the dunes and the beach as it traverses northwards. Hence, hydrocarbon contaminated sand has been disturbed resulting in contamination of the Burn and thus completing the pollutant linkage. It has also been observed that the action of the Burn has led to release of hydrocarbons and PAHs, which may through lateral flow enter groundwater or coastal waters (pollutant linkages G and H). Burn Diversion monitoring and beach monitoring results following the installation of the Burn Diversion have been reviewed to identify the effectiveness of the Burn Diversion following its installation and therefore identify the status of these pollutant linkages.

4.5.2 Blackdog Burn Diversion

The Blackdog Burn Diversion accepted by the planning authority and constructed on Site was considered to be a "soft" engineering option. This design followed comment during the original planning process, when an engineered option (comprising a longer gabion wall) was initially submitted. Specific comment from SNH and SEPA indicated that they required a "softer" engineering option. It was recognised that this option would require more frequent maintenance than the original engineered option. This was not considered ideal by WRG but was accepted in order to halt this pollutant linkage.

The construction phase of the Burn Diversion works took place between 11 and 18 November 2008 and comprised the construction of the 5 m high (small) bund adjacent to the secondary dune system, construction of the 25 m high (large) bund adjacent to the primary dune system and the excavation of the Burn channel.

Construction details are provided in Section 2.2.

The effectiveness of the Burn Diversion has been visually monitored since its construction.

Monitoring comprised visual inspection of the Burn and surrounding area on a monthly basis and measurement of the beach levels at four locations (using the four installed and surveyed metal posts) within the beach. A summary of the results of the monitoring exercise is provided in Table 15 below.

Table 15: Burn Status since installation of Burn Diversion

Date	Burn Status	Notes
Nov-08	Installed on 18 November 2008	
Dec-08	Within Burn Diversion and within remediation envelope.	
Jan-09	Burn outside diversion for some days	Visit on 29 January 2009 showed Burn had overrun diversion.
Feb-09	Within Burn Diversion and within envelope after re-alignment on 4 February.	Re-excavated on 4 February 2009.
Mar-09	Within Burn Diversion and within remediation envelope.	
Apr-09	Within Burn Diversion and within remediation envelope.	
May-09	Within Burn Diversion and within remediation envelope.	
Jun-09	Within Burn Diversion and within remediation envelope.	
Jul-09	Within Burn Diversion and within remediation envelope.	
Aug-09	Within Burn Diversion and within remediation envelope.	
Sep-09	Burn outside diversion and outside the remediation envelope.	Re-aligned again on 21 September 2009.
Oct-09	Burn outside diversion and outside the remediation envelope.	Re-aligned again on 13 October 2009.
Nov-09	Burn outside diversion and outside the remediation envelope.	Re-aligned again on 24 to 25 November 2009.
Dec-09	Burn outside diversion and outside the remediation envelope.	Re-aligned again in December 2009.
Jan-10	Within Burn Diversion and within remediation envelope.	
Feb-10	Within Burn Diversion and within remediation envelope.	
Mar-10	Within Burn Diversion and within remediation envelope.	
Apr-10	Within Burn Diversion and within remediation envelope.	
May-10	Within Burn Diversion and within remediation envelope.	
Jun-10	Within Burn Diversion and within remediation envelope.	
Jul-10	Burn outside diversion and outside remediation envelope at start of month and again on 15 July.	Re-aligned on 2 July and again later in July.
Aug-10	Within Burn Diversion and within remediation envelope.	

Comparison of the visual monitoring of the Burn Diversion with the beach levels (where data is available) indicates the following:

- Beach level monitoring data is not available for January 2009 where the Burn bypasses the diversion;
- The beach level is significantly reduced during the September to November 2009 period where the Burn bypasses the diversion on three separate occasions; and
- The beach level does not indicate significant reduction during June and July 2010 when the Burn bypasses the diversion.

A review of TPH and PAH concentrations in the beach sediments from trial pits installed during the quarterly monitoring period revealed the following:

June 2009

Soil samples from trial pits 7 and 20 located on the beach were subjected to TPH and PAH analysis and were below detection limits.

Soil samples from trial pits 8 (TPH 4487 mg/kg, PAH 1.3 mg/kg) and 17 (TPH 6198 mg/kg, PAH 6.9 mg/kg) located on the beach were subjected to TPH and PAH analysis and were above detection limits for both compounds, whilst trial pit 21 had TPH concentrations greater than detection limit (16 mg/kg) but PAH concentrations below detection limit.

September 2009

Soil samples from trial pits 5, 10, 13, 16, 21 and 25 (no staining observed in this trial pit) located on the beach were subjected to TPH and PAH analysis and were all below detection limits.

December 2009

Soil samples from trial pits 1, 11, 17, 24, 35 and 39 (located on the beach) were subjected to TPH and PAH analysis and were all below detection limits. Soil samples from trial pit 6 displayed a concentration of 96 mg/kg TPH, although PAH concentrations were below detection limits.

March 2010

Soil samples from trial pits 1, 6, 11, 17, 35 and 39, located on the beach were subjected to TPH and PAH analysis and were all below detection limits.

June 2010

Soil samples from trial pits 1, 6, 11, 17, 35 and 38 located on the beach were subjected to TPH and PAH analysis and were all below detection limits.

Summary

Residual hydrocarbons remain within the landfill and have been estimated to hold around 11,500 tonnes. Dissolved phase hydrocarbons continue to migrate from the landfill towards the beach. As stated previously (section 4.3) the LNAPL monitoring in boreholes both within and downgradient of the landfill have shown a reduction of LNAPL presence and thickness over rime. The last two monitoring events during 2010 indicated no measurable thickness (i.e. nothing > 0.1mm). Further LNAPL monitoring is recommended to confirm whether the LNAPL monitoring observed during the latter stages of the 2010 monitoring exercise (i.e. reduced presence of LNAPL within the landfill and at the landfill boundary) are temporary or whether this is indicative of a longer term trend. This information will be used to determine the ongoing risk to receptors from LNAPL migration from the landfill and whether any active remediation of LNAPL within or on the boundary of the landfill is required. The current results (if confirmed by further monitoring) suggest that active remediation including collection of LNAPL at and within the landfill is not warranted. If there is a reduced presence of LNAPL within the landfill and at the landfill boundary this would lead to a reducing LNAPL source entering the beach. These sources have the potential to feed into the beach sediments. This information will be used to determine the ongoing risk to receptors from LNAPL migration from the landfill and whether any active remediation of LNAPL within or on the boundary of the landfill is required. The current results (if confirmed by further monitoring) suggest that active remediation including collection of LNAPL at and within the landfill is not warranted.

PAH chemical analysis results for soils from the beach have been below detection limits with the exception of two samples out of thirty collected in June 2009, with concentrations of 1.3 and 6.9 mg/kg total PAHs.

The majority of TPH (27 out of 30 samples or 90%) chemical analysis results for soils were below detection limits during this monitoring campaign with the exception of two samples in June 2009 (TPH 4,487 mg/kg and 6,198 mg/kg) and one sample in December 2009 (TPH 96 mg/kg).

The black staining observed on the beach does not show a strong current correlation with elevated hydrocarbon concentration. However, it is recognised that the black (and green) staining may be a result of biodegradation of hydrocarbons and chemical reactions from the past, as leachate migrated from the landfill Site and onto the beach. In addition, other indications of the presence of hydrocarbon have been observed during the beach monitoring exercise. These indications include visual staining, the visual presence of a sheen, odour observations of hydrocarbons and elevated PID results. These results indicate that hydrocarbon remains in areas of the beach.

It can also be concluded that there is contradictory evidence as to whether hydrocarbon impact on the beach is historic or continuing with respect to the larger stained northern area of beach. There is evidence that there is some degree of refreshment of hydrocarbon impact on the beach in some areas, whilst in other areas the observed impact appears to be historic. It is recognised that there are large uncertainties relating to the presence and source (i.e. historically or recently deposited) of retained hydrocarbon in the beach sediments.

The lack of widespread soil TPH and PAH concentrations in the beach sediments would remove the potential for hydrocarbons to be released should the Burn cut through this area in the future. However, whilst hydrocarbons were detected in only a small number of samples, the concentrations detected in June 2009 specifically remains high, although lower than the highest detected concentrations historically (previously up to 21,012 mg/kg from BDB1 collected by Aberdeenshire).

Groundwater was also obtained from trial pits 1, 6 and 8 during the March 2010 beach investigation. Sand excavated from trial pit 1, closest to the dunes was stained black. The concentrations of TPH in groundwater from this trial pit were greater than 270 mg/l (TPH total C5 to C35 aliphatics and aromatics) which is indicative of LNAPL. PAH concentrations were below detection limits in groundwater from this trial pit.

Trial pits were extended eastwards during this monitoring event (i.e. in the approximate direction of groundwater flow) along a line from to trial pit 1. Trial pits 6 and 8 where located outside of the black staining and instead both contained sands with green staining. TPH and PAH concentrations in groundwater collected from both trial pits were below detection limits.

Surface water measurements for Blackdog Burn were obtained on 18 December 2009. The concentration of TPH and PAH in the upstream sample was higher (TPH (410 µg/l) and PAH (6.1 µg/l)) compared to the downstream sample for TPH (380 µg/l) and PAH (<0.3 µg/l). Consequently, the downstream samples do not indicate additional impact from TPH and PAH substances. Sample locations are shown on Drawing 2.

4.5.3 Summary of Pollutant Linkage E, G and H

Pollutant linkages E, G and H are related as the pathway for these pollutant linkages is created by Blackdog Burn. The Blackdog Burn has been successfully diverted removing this pathway.

In addition, results from the beach monitoring indicate that the sorbed hydrocarbon within the beach sediments may be limited in extent although other indicators form the quarterly beach monitoring show hydrocarbon is still present in some areas of the beach but may be more associated with the groundwater.

For pollutant linkage E, the Blackdog Burn historically migrated northwards along the beach causing erosion of contaminated sands within the dunes and the beach. This resulted in hydrocarbon contaminated sand being disturbed resulting in contamination of the Burn and thus completing the pollutant linkage. As detailed in Section 4.5.2 above, the installation of the Burn Diversion has effectively removed the pathway for this pollutant linkage.

For pollutant linkage G, the Blackdog Burn has historically been migrating along the beach causing erosion of contaminated sands within the dunes and the beach as it traverses northwards. Hence, hydrocarbon contaminated sand has been disturbed and has led to release of hydrocarbons and PAHs, which may through lateral flow enter groundwater (pollutant linkage G). As detailed in Section 4.5.2 above, the installation of the Burn Diversion has also effectively removed the pathway for this pollutant linkage.

For pollutant linkage H, the Blackdog Burn has historically been migrating along the beach causing erosion of contaminated sands within the dunes and the beach as it traverses northwards. Hence, hydrocarbon contaminated sand has been disturbed and has led to release of hydrocarbons and PAHs, which may through lateral flow enter coastal waters (pollutant linkages H). As detailed in Section 4.5.2 above, the installation of the Burn Diversion has also effectively removed the pathway for this pollutant linkage.

Based on historic and recent Site Investigation, monitoring and remedial action pollutant linkages E, G and H are no longer considered active for the reasons summarised below:

- The action of the Burn has been managed effectively by the Burn Diversion since its installation was completed on 18 November 2008. There have been a small number of events that have resulted in the Burn Diversion being bypassed due to a combination of tidal conditions, storm events and weather conditions. These have been limited in number and duration. These events were also recognised as likely to occur during the planning process when the “softer” engineering option was requested for the Burn Diversion. The Burn Diversion can therefore be considered to have effectively cut off the pathway for these pollutant linkages as designed, but does require ongoing maintenance to ensure the pollutant linkage remains cut off;

- Chemical analysis of the beach sediments has shown only limited detection of TPH and PAH species, with three out of thirty samples (10%) of those collected identifying TPH above detection limits, and only two out of thirty samples (7%) indicating PAH above detection limits. The lack of a widespread presence of hydrocarbons does further limit the potential for release of hydrocarbons should the Burn bypass the Burn Diversion in the future. The case for requiring the Burn Diversion to remain in place reduces as hydrocarbons in the beach sediment reduce their extent. Hydrocarbons in groundwater have been found to be at concentrations indicative of LNAPL within 20 m of the dunes but reduce to concentrations at or below the detection limit further eastwards;

- As stated previously (section 4.3) the LNAPL monitoring in boreholes both within and downgradient of the landfill have shown a reduction of LNAPL presence and thickness over rime. The last two monitoring events during 2010 indicated no measurable thickness (i.e. nothing > 0.1 mm). Further monitoring is required to determine if this is temporary or more permanent. If it is more permanent this would lead to a reducing LNAPL source entering the beach. If present, this sources has the potential to feed into the beach sediments;

- Surface water samples collected from upstream and downstream of the Burn do not indicate additional impact in the downstream samples;

- Groundwater TPH concentrations within the beach appear to be indicative of LNAPL within close proximity to the dunes, but at distances greater than 20 m from the dunes, hydrocarbons appear to be below the detection limit based on current and 2004 information. The lack of hydrocarbon detection within groundwater beyond 20 m of the beach indicates that groundwater is not being transported laterally with groundwater flow;

- Current groundwater PAH concentrations within the beach are below detection limits both within close proximity to the dunes, and at distances greater than 20 m from the dunes; and

- It is recognised that indication of LNAPL is still observed in groundwater as seen by hydrocarbon concentrations in trial pit 1 (March 2010) and observations of sheens within groundwater from trial pits on the beach.

5.0 CONCLUSIONS

5.1 Summary

Estimates of residual hydrocarbon have been calculated and are estimated at around 11,500 tonnes.

A review of site conditions against the LNAPL risk management frameworks indicates that the landfill Site is high risk with respect to LNAPL mobility due to the steep gradient and proximity of receptors.

Monitoring information presents a contrary view as LNAPL thicknesses in measured boreholes have reduced significantly over the latter stages of the monitoring since 2005, with June 2010 monitoring results showing limited presence and thicknesses less than 0.1 mm (note that monitoring should continue to determine whether this observation is temporary or if it reflects ongoing future conditions).

LNAPL migration from the landfill boundary to the beach has been estimated to take between 50 years (mean case) and 8.6 years (worst case).

Chemical analysis of beach sediments has shown relatively low levels of sorbed hydrocarbon and most related to locations within 20 m of the sand dunes. Observations during the quarterly beach monitoring trial pit exercise exhibited other indicators of hydrocarbons including visual indicators of sediment staining, hydrocarbon sheens, hydrocarbons odours and elevated PID results. These results indicate a more widespread presence of hydrocarbon on the beach. The hydrocarbons appear related to the water phase. Whilst the recent monitoring immediately downgradient of the landfill indicates limited LNAPL presence (and this needs to be confirmed for the future) it is possible that historic LNAPL migration is still responsible for the indications of LNAPL currently observed on the beach due to the migration time from the landfill boundary to the beach.

Dissolved phase hydrocarbons continue to migrate beyond the eastern boundary of the landfill and are above relevant EQS limits where these are applicable.

Discharge of hydrocarbons into the sea from the dissolved phase has been modelled and it has been estimated that on dilution concentrations will be below EQS limits where these are relevant.

5.2 Statement of Mass of Hydrocarbon Remaining in the Landfill

Within the report, estimations have been made as to the likely mass of hydrocarbon remaining within the Site, see Section 4.1.3.

There are obviously many sources of uncertainty in such calculations but the mass of hydrocarbon present within the landfill is estimated at around 11,500 tonnes based on results from the 2009 trial pit installation in the landfill. A brief discussion of the validity of this figure is provided above, following its calculation. This figure will include LNAPL residing in the landfill and observed in a small number of discrete boreholes within the landfill.

The mass of “dissolved phase” hydrocarbon was calculated based on 2010 data, returning a value of 0.18 tonnes. This is similar to, though slightly lower than, the 0.24 tonnes calculated in 2006. The latest estimate includes a conservative assumption of the hydrocarbon concentration in groundwater, which includes some aliphatic bands which exceed their solubility limit. This exceedance of solubility limit is considered due to sampling limitations whereby small quantities of LNAPL may be entrained during the leachate sampling exercise. The continuing partitioning of hydrocarbon into water that infiltrates into the Site, and ongoing basal leakage, means that that significant change in this mass would not be expected to occur over such relatively short time scales. This relatively stable dissolved phase mass may also indicate a relatively steady state.

A conceptual site model has been developed and in part quantified showing the inflows and outflows through and under the landfill. This is presented schematically in Figure 7. Quarterly beach monitoring results showing indicators of the presence of hydrocarbons also show the conceptual site model related to the beach in a diagrammatic form. These drawings are shown in Appendix G.

5.3 Current Status of Pollutant Linkages

The following pollutant linkages have been assessed:

Pollutant linkage A relates to the leaching of dissolved phase hydrocarbons from within the waste to groundwater.

No consistent or observable trends in groundwater concentrations of TPH or PAH have been identified from the time series charts (Appendix D). However, groundwater concentrations do appear to have decreased within the landfill (i.e. dissolved phase within leachate) and increased at the eastern boundary of the landfill compared to data reported in the 2005 report.

The results of the Tier 1 groundwater risk assessment demonstrate that the concentration of TPH and PAH in groundwater exceeds the screening criteria within the landfill and at the eastern boundary of the landfill. A table presenting the results of the Tier 1 Groundwater Risk Assessment and the relevant screening criteria is presented in Appendix E. The criteria used for the Tier 1 risk assessment should be viewed as conservative given the limited use of the groundwater due the close proximity of the landfill to costal sea water. Also, some groundwater concentrations exceed their solubility limit. This is likely due to small quantities of LNAPL being entrained within the collected groundwater samples. The groundwater TPH concentrations observed are therefore likely to represent a conservative concentration.

Residual LNAPL estimates within the landfill appear to be similar to those previously estimated in 2005. Relatively low residual LNAPL will result in relatively high levels of dissolved phase hydrocarbons being released from the landfill for a number of years through solubilisation.

Concentrations of dissolved phase hydrocarbons do not appear to show a reduction over time at the landfill boundary. Less than 1 kg/day of TPH has been estimated (subject to a degree of uncertainty, 0.19 kg at the 50th percentile) to be released from the landfill in the dissolved phase each day. This TPH mass would undergo dilution on reaching sea water.

The widespread presence of hydrocarbons within the landfill is expected to result in the long term slow release of dissolved phase hydrocarbons over time. It is suggested that a remediation declaration is considered for this pollutant linkage on the basis that the presence of the hydrocarbon mass cannot be easily removed from the landfill and that the impact is relatively low compared to the impact from free phase material that continues to migrate from the area between the landfill and the dunes onto the beach. It is noted that recent monitoring between 2009 through to 2011 has shown that LNAPL leaving the landfill has reduced and is currently not measured at an appreciable thickness (i.e., < 0.1 mm) in any borehole. The LNAPL travel time between the landfill boundary and the beach has been estimated at between 8.6 and 50 years (see section 4.3 above). The case for a remediation declaration will have to be presented to Aberdeenshire Council for their consideration.

Pollutant linkage B relates to the migration of free phase hydrocarbons as LNAPL from within the waste to groundwater.

Based on the findings of the LNAPL assessment for the Blackdog Landfill Site, it can be concluded that there are a number of precluding conditions regarding the site setting (proximity to a receptor and hydraulic gradient greater than 0.01). As a consequence, if LNAPL were present within the landfill or at its boundary, the Site would be classified as a high risk site in terms of LNAPL mobility using the LNAPL management framework guidance.

However, evidence, obtained during the 2009/2010 site investigation and monitoring exercise suggests that the risk of LNAPL mobility (from the landfill) is reducing or is low due to its reduced presence. Evidence for this primarily relates to the reduction in the thickness of LNAPL recorded in monitoring wells, with no recordable thickness (i.e. <0.1 mm) in the most recent monitoring rounds. However, it is not known whether this is a temporary observation or part of a longer term trend and further monitoring data is required in order to increase confidence in this assessment. API modelling using geological/hydrogeological input parameters for the landfill boundary and physical hydrocarbon parameters from the Site has identified a threshold hydrocarbon thickness (0.03 m) below which LNAPL mobility is unlikely.

There is photographic evidence of hydrocarbon on the beach adjacent to the Site as early as 1993 (Golder, 2004), suggesting therefore, that migration must have occurred reasonably rapidly after the original deposit of the waste.

Modelling of conditions at the Site boundary indicate that LNAPL, if present, would migrate through the dunes (around 70 m width) and onto the beach in around 50 years using the mean modelling results and around 8.6 year using the worst case modelling results.

Due to the LNAPL being located in discrete pockets and the relatively low plume velocity within the landfill, it is likely that LNAPL monitoring (including bail down tests) may have influenced the reduction in LNAPL at the Blackdog Landfill Site (i.e. by removing small pockets of LNAPL that subsequently were not replenished as there was insufficient LNAPL present).

Evidence for the above conclusions exists as follows:

- LNAPL at the Blackdog Site during historic monitoring did not appear to be interconnected as there were LNAPL free monitoring wells across the Site that delineated the LNAPL into limited discrete pockets of LNAPL, randomly spaced across the landfill;
- The time series charts and the summary table (Table 7) demonstrate that, overall, the thickness of LNAPL in monitoring wells has demonstrably decreased with time, particularly in the 2010 monitoring rounds. Further monitoring will be required to confirm whether this is a continuing trend or not;
- The last two quarterly LNAPL monitoring rounds have not demonstrated any measureable thickness of LNAPL in any monitoring well. Further monitoring will be required to confirm whether this is a continuing trend or not;
- Throughout the LNAPL monitoring (the 2008 and 2009-2010 work) LNAPL was identified in a maximum of 11 monitoring wells (out of a total of 48 wells monitored) during any one monitoring period. This reduced to 5 during the last two monitoring round and within those wells no measurable LNAPL thickness was identified (i.e. only a sheen observed). This is a primary line of evidence according to LNAPL risk management framework and the reduction in observation of LNAPL strongly supports the concept that LNAPL is no longer widespread and that there is no ongoing LNAPL flux leaving the landfill; and
- The API LNAPL mobility model was also used to determine the threshold LNAPL thickness that would give rise to LNAPL mobility. LNAPL thicknesses have not exceeded the calculated threshold thicknesses (0.03m) since May 2010, within the landfill and at the boundary of the landfill.

Further LNAPL monitoring is recommended to confirm whether the LNAPL monitoring observed during the latter stages of the 2010 monitoring exercise (i.e. reduced presence of LNAPL within the landfill and at the landfill boundary) are temporary or whether this is indicative of a longer term trend. This information will be used to determine the ongoing risk to receptors from LNAPL migration from the landfill and whether any active remediation of LNAPL within or on the boundary of the landfill is required. The current results (if confirmed by further monitoring) suggest that active remediation including collection of LNAPL at and within the landfill is not warranted.

Further monitoring of the presence of LNAPL on the beach (in soils and groundwater) is required to provide routine information to determine whether the conceptual model considered here (i.e., the reduction in mobile LNAPL within the landfill and at the landfill boundary and residual migration of LNAPL through the dunes and onto the beach) is confirmed. Once an improving trend or absence of LNAPL on the beach in soils and groundwater is identified proposals will be made for the reduction of monitoring frequency and ultimately the cessation of monitoring.

The exact terms of the monitoring should be agreed between WRG and the local authority.

Pollutant linkage C relates to the desorption and solution from hydrocarbon impacted beach sediments and solution of localised free phase hydrocarbon with lateral migration of groundwater

within the aquifer. Pollutant linkage D relates to the desorption and solution of hydrocarbon impacted beach sediments and solution of localised free phase hydrocarbon with solution into coastal waters. These pollutant linkages are linked.

Overall the collected SI information suggests that these pollutant linkages do not appear significant for PAH and TPH across the entire beach due to the following reasons:

- Groundwater on the beach is considered to be of limited use in terms of a resource;
- The current lack of LNAPL measured at an appreciable thickness (in the latest monitoring rounds from this exercise) both within the landfill and in downgradient boundary monitoring wells infers that there is no continued flux of LNAPL leaving the landfill. However, this is based on the most recent LNAPL monitoring results and it is not known if this is temporary or a continuing trend. Further monitoring is required to confirm the status. The potential for replenishment of hydrocarbons in the beach sediments (either as impacted beach sediments or as free phase material) in the future (i.e., taking account of the estimated travel time of between 8 and 50 years for historically identified LNAPL) depends on LNAPL flux leaving the landfill;
- Assessment of indicators of hydrocarbons within the beach (visual, odour, PID measurements) has shown a mixed picture whereby the southernmost section exhibits limited indications of hydrocarbon impact. The central section shows indications of ongoing replenishment of hydrocarbons from the landfill as displayed by changes in the level of indicators of hydrocarbon impact during the monitoring period (2009-2010). Variations of up to around 1 m AOD difference were observed between quarterly monitoring periods. The northernmost section shows less indication of recent impact with very similar levels (m AOD) observed between quarterly monitoring periods indicating historic contamination that is not being refreshed;
- Chemical analysis of the beach sediments show only a limited presence of detectable hydrocarbons, with only 10%, or less, of beach sediments (analysed) indicating detectable concentrations of TPH and PAH. This is likely due to the limited hydrocarbon sorption ability of sand and gravel;
- Only a small number of groundwater samples were collected from the beach for TPH analysis during the monitoring period. Groundwater TPH concentrations within the beach appear to be indicative of LNAPL within close proximity to the dunes (i.e. within 20 m). Further downgradient at distances greater than 20 m east of the dunes (and therefore closer to the sea), hydrocarbons appear to be below the detection limit based on current and 2004 results. Observations within trial pits installed during the quarterly beach monitoring exercise indicate that LANPL indicators (hydrocarbon sheen in incoming water) were present in trial pits up to 80 m east of the sand dunes;
- Current groundwater PAH concentrations within the beach are below detection limits both within close proximity to the dunes, and at distances greater than 20 m from the dunes. Consideration should be given to removing PAH's as part of the pollutant linkage; and,
- Coastal waters include saline groundwater in the beach and the sea, are further downgradient of the landfill which would afford additional attenuation and dilution.

TPH in the groundwater on the beach and in the beach sediments should be monitored annually (as part of a monitoring programme which should be agreed between WRG and the local authority) to determine whether there is a reduction in TPH concentration over time. Desorption does not appear to be an active mechanism as there is little hydrocarbon sorbed to sediment. The monitoring information should be used to consider whether this pollutant linkage is still active.

Pollutant linkage F (episodic desorption of hydrocarbons from beach sediment and mobilisation of free phase hydrocarbon by wave action following erosion of clean cover from the beach and release into coastal waters as a film) will be treated in a similar manner to pollutant linkage C.

Pollutant linkage F follows the same considerations as those identified for pollutant linkage C and are not repeated here. The difference being for pollutant linkage F is the mode of mobilisation from the beach sediments (from the sorbed or free phase) which is due to the physical action of the waves.

As indicated above there is some evidence of hydrocarbon remaining within the beach sediments although this is unlikely to be in the sorbed state. Whilst there is residual hydrocarbon in the landfill, the LNAPL levels as measured in boreholes appear to be decreasing in terms of presence and thickness. However, the status of this needs to be confirmed by further monitoring. These hydrocarbons feed the hydrocarbon presence on the beach and if diminishing would limit the impact on the beach in the future.

TPH in the beach sediments (as LNAPL) should be monitored annually for a time period to be agreed, to determine if the hydrocarbon concentration reduces over time.

For pollutant linkage E, the Blackdog Burn has historically been migrating along the beach causing erosion of contaminated sands within the dunes and the beach as it traverses northwards. Hence, hydrocarbon contaminated sand has been disturbed resulting in contamination of the burn and thus completing the pollutant linkage. It has also been observed that the action of the burn has led to release of hydrocarbons and PAHs, which may, through lateral flow, enter groundwater or coastal waters (pollutant linkages G and H).

The diversion of the Burn has proved successful and appears to function as effectively as envisaged during the planning process. The burn diversion has halted pollutant linkages E, G and H from being active since its installation in November 2008.

The constructed Burn Diversion was a “soft” engineering option compared to the original design and ongoing maintenance was anticipated and accepted by all parties. This maintenance has been performed on the small number of occasions required, following short-lived excursions of the Burn beyond the remediation envelope. Reaction to these events has always been rapid and the route of the Burn was soon corrected to ensure it remained within the remediation envelope. This re-enforces the efficacy of the burn diversion as an effective remediation solution. The continuation of the Burn Diversion (coupled with effective maintenance when required) removes these pollutant linkages by removing the pathway. Once there is no perceived risk of mobilising hydrocarbon retained in the beach sediments or groundwater a cessation of maintenance of the Burn Diversion is proposed.

Assessment of indicators of hydrocarbons within the beach (visual, odour, PID measurements) has shown a mixed picture whereby the southernmost section exhibits limited indications of hydrocarbon impact. The central section shows indications of replenishment of hydrocarbons from the landfill as displayed by changes in the level of indicators of hydrocarbon impact. Variations of up to around 1m AOD difference were observed between quarterly monitoring periods. The northernmost section shows less indication of recent impact with very similar levels (m AOD) observed between quarterly monitoring periods indicating historic contamination.

Chemical analysis of the beach sediments show only a limited presence of detectable hydrocarbons, with only 10%, or less, of beach sediments (analysed) indicating detectable concentrations of TPH and PAH. This may be partially due to the limited hydrocarbon sorption ability of sand and gravel.

The current lack of LNAPL measured at an appreciable thickness (in the latest monitoring rounds from this exercise) both within the landfill and in downgradient boundary monitoring wells infers that there is no continued flux of LNAPL leaving the landfill. However, this is based on the most recent LNAPL monitoring results and it is not known if this is temporary or a continuing trend. Further monitoring is required to confirm the status. The potential for replenishment of hydrocarbons in the beach sediments (either as impacted beach sediments or as free phase material) in the future (i.e., taking account of the estimated travel time of between 8 and 50 years for historically identified LNAPL) depends on LNAPL flux leaving the landfill.

It is considered that there will be a point in the future where the need to maintain the Burn Diversion is no longer required. In order to reach this position TPH in the beach sediments (within 20 m of the dune) should be monitored annually over the next five years to determine whether the expected reduction in TPH concentration over time is realised. If so, these pollutant linkages can be removed.

6.0 REFERENCES

1) Aberdeenshire Council Environmental Health Department SI 2003;

2) Aberdeenshire Council Water Sampling Report 2003;

3) Annual Average Environmental Quality Standards Freshwater (EQS FW);

4) American Petroleum Institute Guidance;

5) Blackdog Burn Diversion Remediation Statement - Annual Review, November 2009. Smallbrook Environmental;

6) Blackdog Landfill Site Investigation – June/July 2009. Smallbrook Environmental;

7) Blackdog Landfill Site Quarterly Factual Monitoring Report – April to June 2010. Smallbrook Environmental;

8) Blackdog Landfill Site Quarterly Factual Monitoring Report – January to March 2010. Smallbrook Environmental;

9) Blackdog Landfill Site Quarterly Factual Monitoring Report – July to September 2009. Smallbrook Environmental;

10) Blackdog Landfill Site Quarterly Factual Monitoring Report – October to December 2009. Smallbrook Environmental;

11) Diversion of the Blackdog Burn, Blackdog, Aberdeenshire, April 2009. Report No 08514290254.500;

12) Domenico & Schwartz, 1990, Physical and Chemical Hydrogeology, John Wiley & Sons, New York;

13) European Union Drinking Water Standards (EUDWS);

14) Fisheries Research Services – Mussel Monitoring Report May 2002 - September 2003;

15) Flood Studies Report. 1975. NERC;

16) Glasgow Caledonia University Report Site Investigation of the Blackdog former Landfill Site 2002;

17) Golder Associates (UK) Ltd, 2004. Assessment of Blackdog Landfill in Relation to Contaminated Land Determination Notices. Report Number 0429632.500;

18) Golder Associates (UK) Ltd, 2005a. Draft Factual Report Blackdog Landfill Site Investigation. Report Number 0429632.501;

19) Golder Associates (UK) Ltd, 2005b. Interpretation of Pollutant Linkages In Relation To Contaminated Land Determination Notices and Remediation Options Assessment. Report Number 0429632.500;

20) Golder Associates (UK) Ltd, 2006. Draft Factual Report Blackdog Landfill Site Investigation 2006. Report Number 0429632.503;

21) Guidance on Assessment of LNAPL Mobility for Site Classification Purposes in British Columbia, Golder Associates Ltd. October 2008;

22) MJ Carter Hydrogeological Report 1988;

23) MJ Carter Environmental Audit 1990;

24) MJ Carter Preliminary Evaluation of the Blackdog and Tarbothill Sites 1988;

25) Reeds Nautical Almanac, 2007;

26) (Beaven and Powrie, 1995). Hydrogeological and Geotechnical Properties of Refuse Using a Large Scale Compression Cell, Proceedings Sardinia 95, Fifth International Landfill Symposium;

27) Remedios Environmental Assessment of Blackdog Landfill Site and the adjacent Dune Area 2001;

28) Total Petroleum Criteria Working Group Series, Volume 3, Selection of Representative TPH Fractions Based on Fate and Transport Considerations. July 1997.UK Drinking Water Standards (UKDWS);

29) US Environmental Protection Agency Regional Screening Levels (USEPA RSL) (tap water standard); and

30) World Health Organisation (WHO).

Report Signature Page

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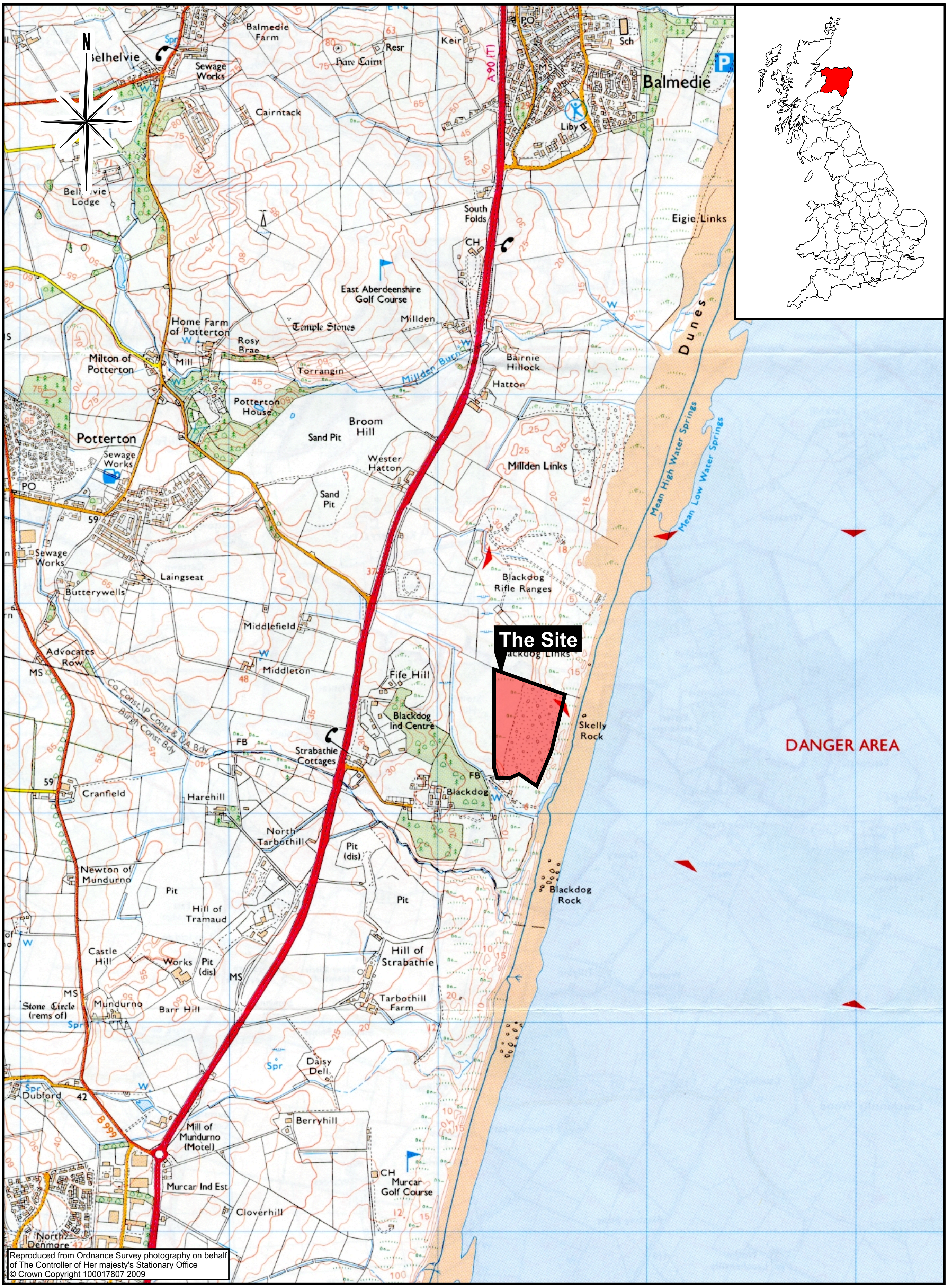
DRAWINGS

Drawing 1 - Site Location Plan
Drawing 2 - Site Layout Plan
Drawing 3 - Hydrogeological Plot September 2009
Drawing 4 - Hydrogeological Plot December 2009
Drawing 5 - Hydrogeological Plot March 2010
Drawing 6 - Hydrogeological Plot June 2010
Drawing 7 – Conceptual Cross Section



Client	WRG (Northern) Limited
Project	Blackdog Landfill Interpretative Report
Title	Site Location Plan

Created by	Requested by	Proj Manager	Reviewer	Date
CB	DOC	DGH	DGH	24/11/11

File No.	Project No.
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Size	Scale	Status
A4	1:50,000	Issue

Drawing No.	Rev
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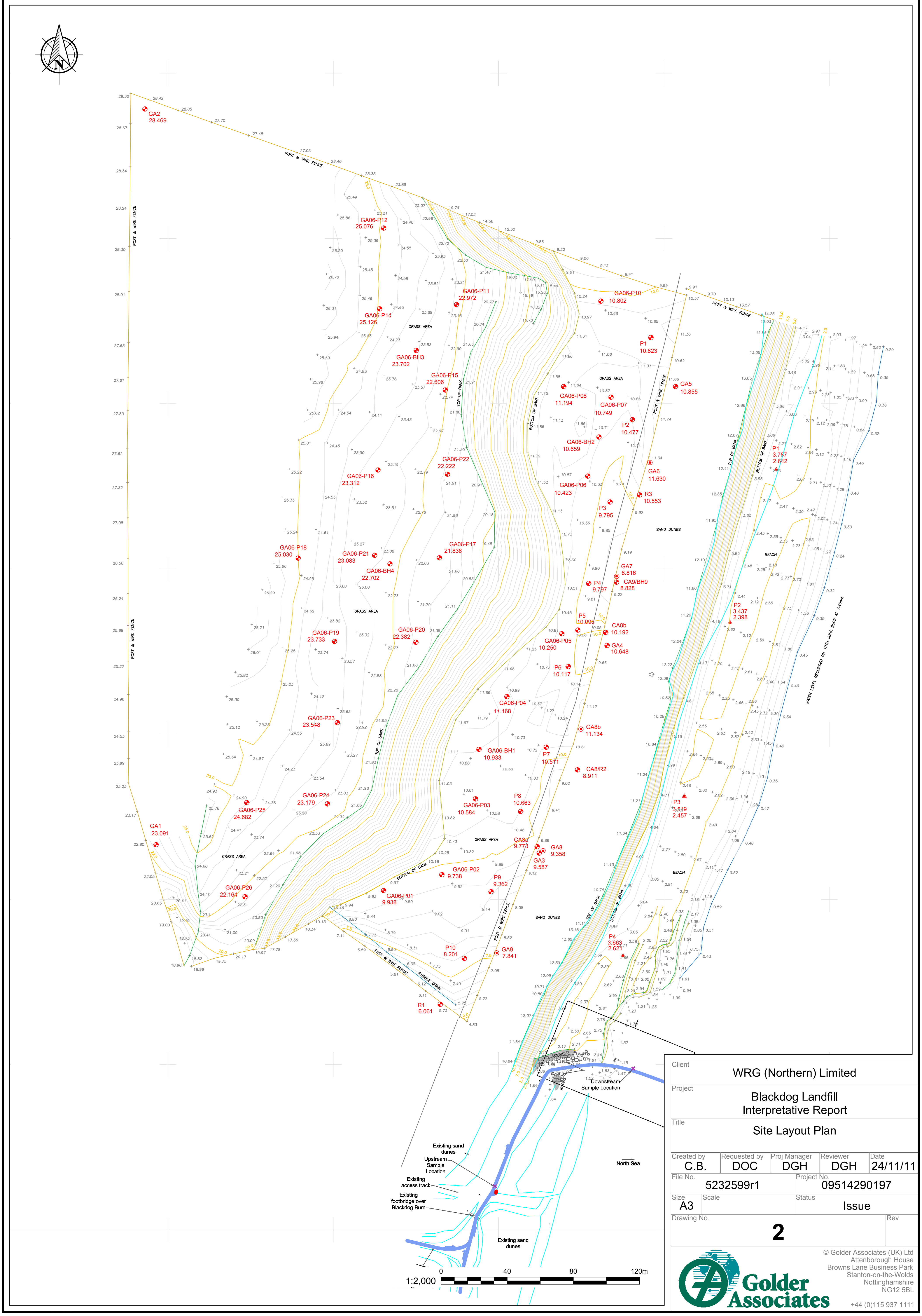

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Project	Blackdog Landfill Interpretative Report
Title	Site Layout Plan

Created by	Requested by	Proj Manager	Reviewer	Date
C.B.	DOC	DGH	DGH	24/11/11

File No.	Project No.
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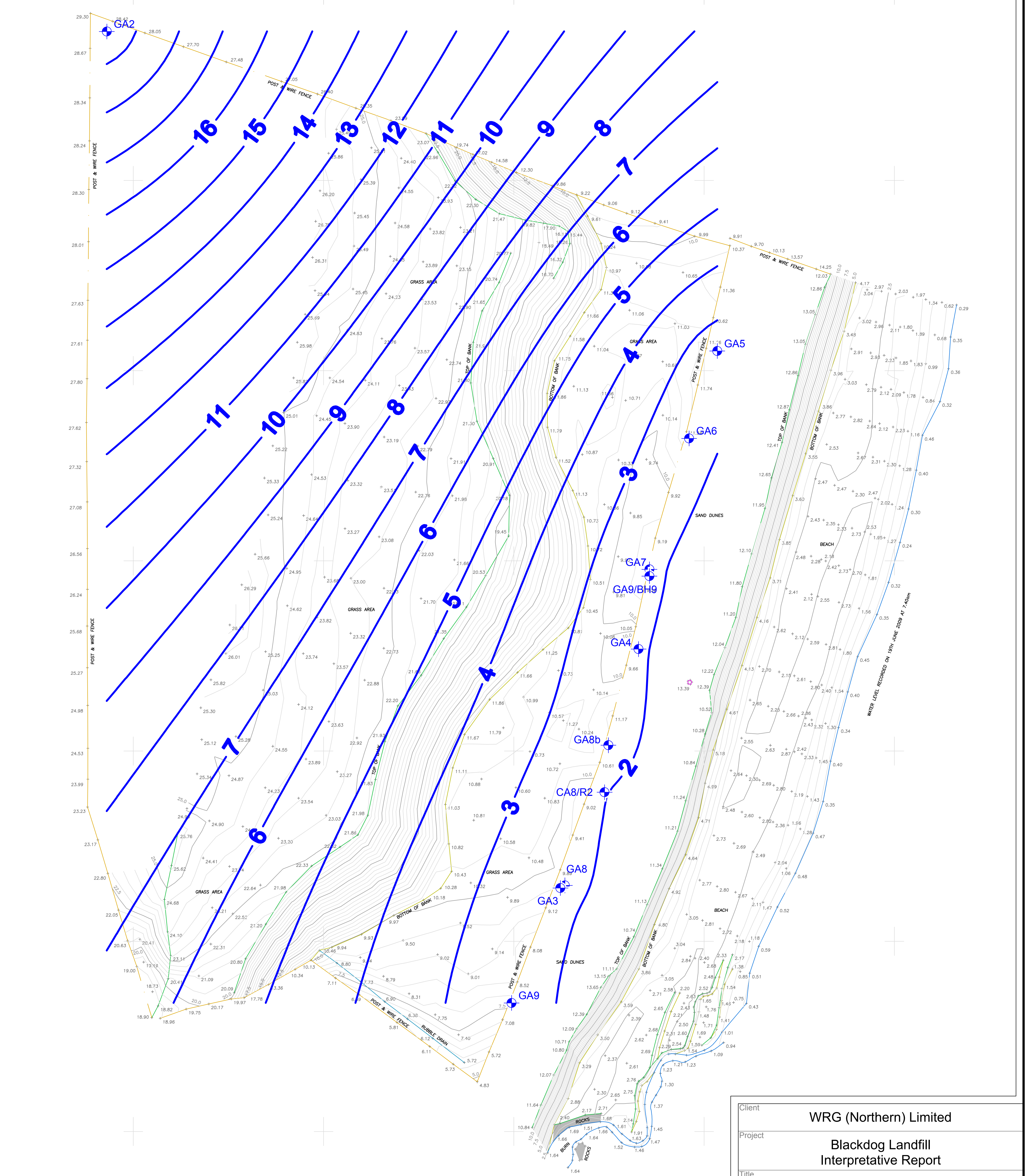
Legend

Interpretation of Groundwater Elevation (m AOD)

Groundwater Monitoring Borehole



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Client	WRG (Northern) Limited
Project	Blackdog Landfill Interpretative Report
Title	Hydrogeological Plot September 2009

Created by	Requested by	Proj Manager	Reviewer	Date
AB	DOC	DGH	DGH	24/11/11

File No.	Project No.
5232601r1	09514290197

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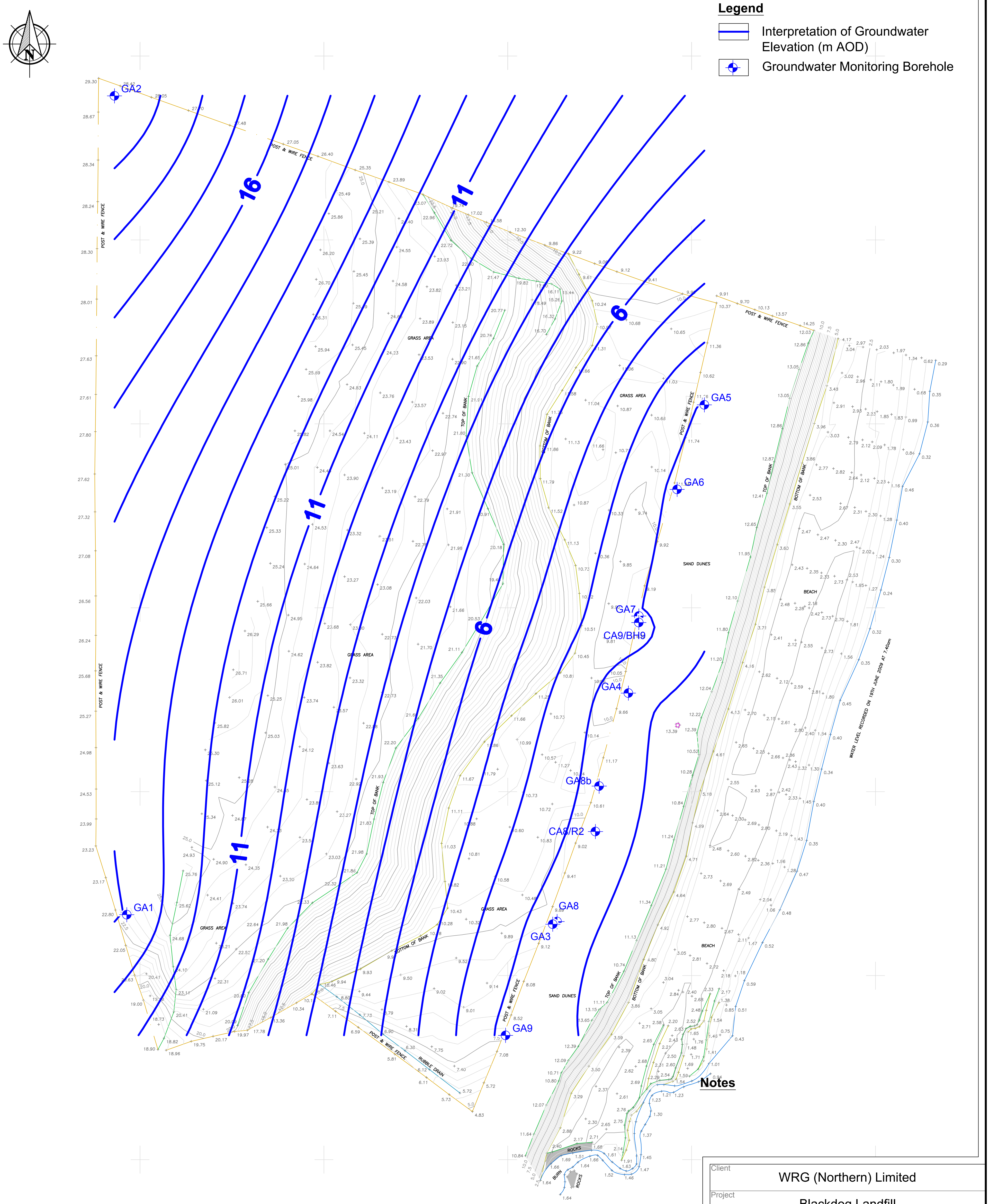

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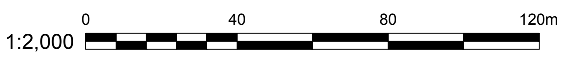
Interpretation of Groundwater Elevation (m AOD)

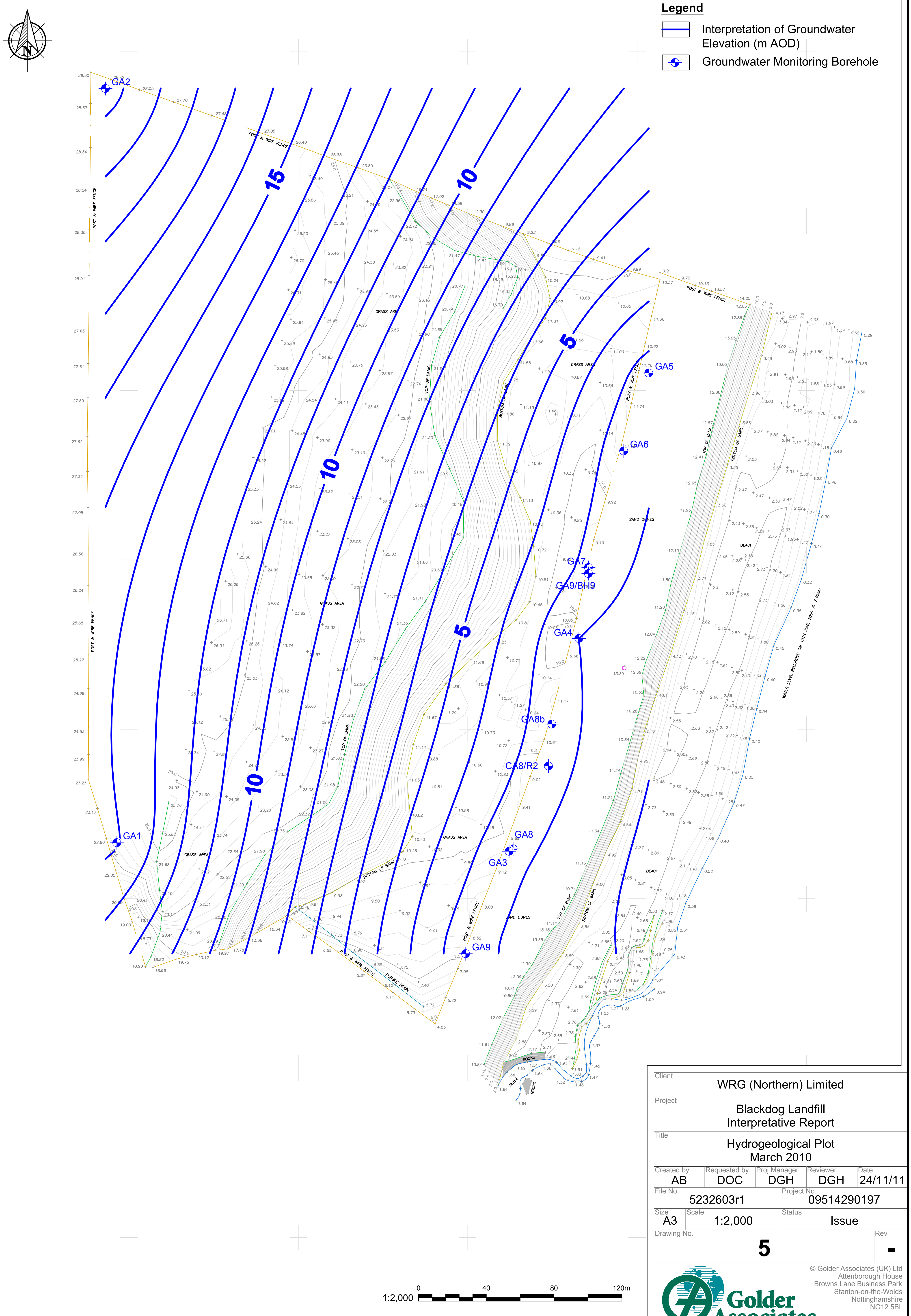
Groundwater Monitoring Borehole

Notes

Client	WRG (Northern) Limited			
Project	Blackdog Landfill Interpretative Report			
Title	Hydrogeological Plot December 2009			
Created by: AB	Requested by: DOC	Proj Manager: DGH	Reviewer: DGH	Date: 24/11/11
File No.: 5232602r1		Project No.: 09514290197		
Size: A3	Scale: 1:2,000	Status: Issue		
Drawing No.: 4				Rev: -

Golder Associates
Attenborough House
Browns Lane Business Park
Stanton-on-the-Wolds
Nottinghamshire
NG12 5BL
+44 (0)115 937 1111





Client
WRG (Northern) Limited

Project
Blackdog Landfill
Interpretative Report

Title
Hydrogeological Plot
March 2010

Created by	Requested by	Proj Manager	Reviewer	Date
AB	DOC	DGH	DGH	24/11/11

File No.	Project No.
5232603r1	09514290197

Size	Scale	Status
A3	1:2,000	Issue

Drawing No.	Rev
5	-

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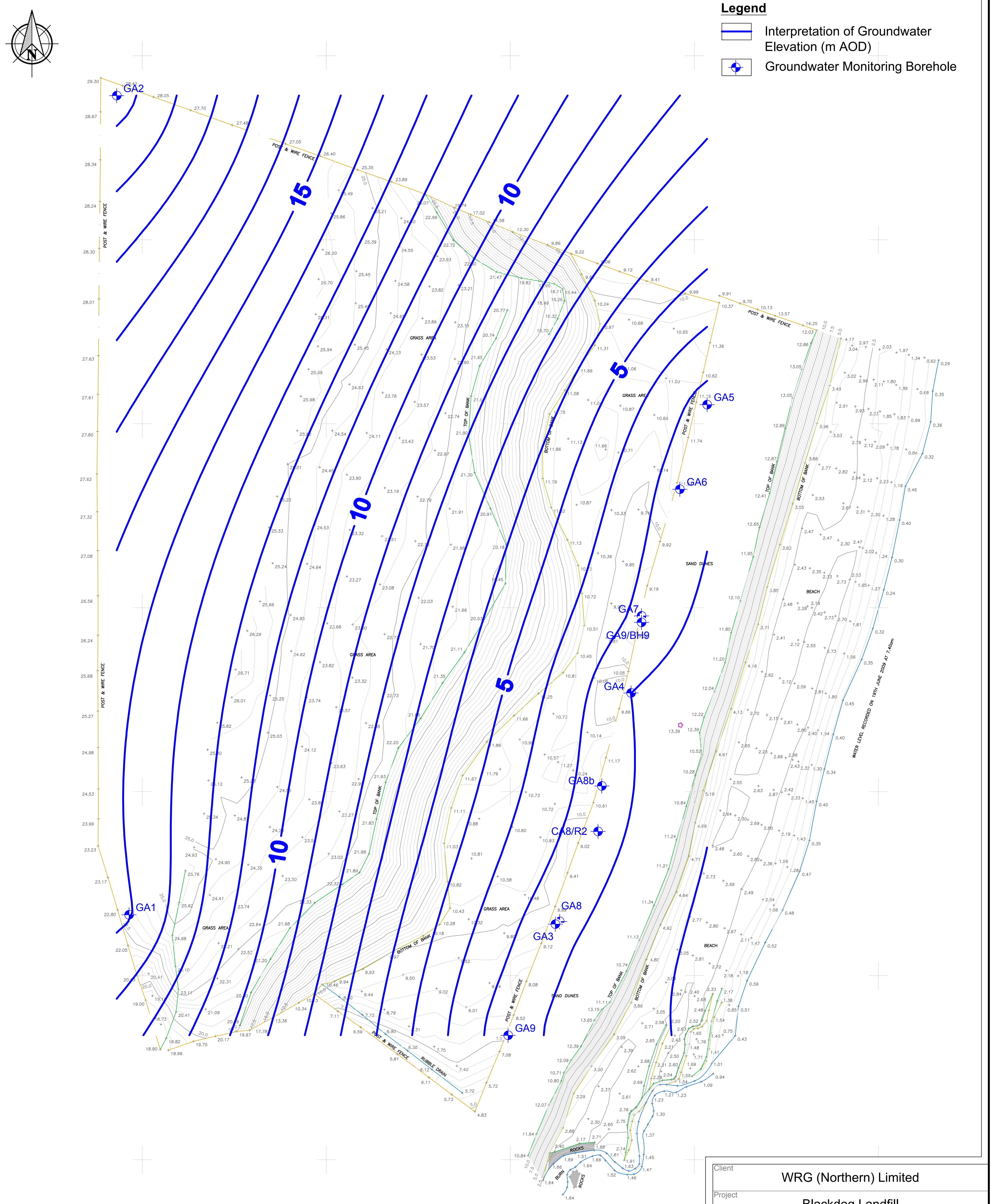

Legend

Interpretation of Groundwater Elevation (m AOD)

Groundwater Monitoring Borehole

Client	WRG (Northern) Limited
Project	Blackdog Landfill Interpretative Report
Title	Hydrogeological Plot June 2010

Created by	Requested by	Proj Manager	Reviewer	Date
AB	DOC	DGH	DGH	24/11/11

File No.	Project No.
5232604r1	09514290197

Size	Scale	Status
A3	1:2,000	Issue

Drawing No.	Rev
6	-

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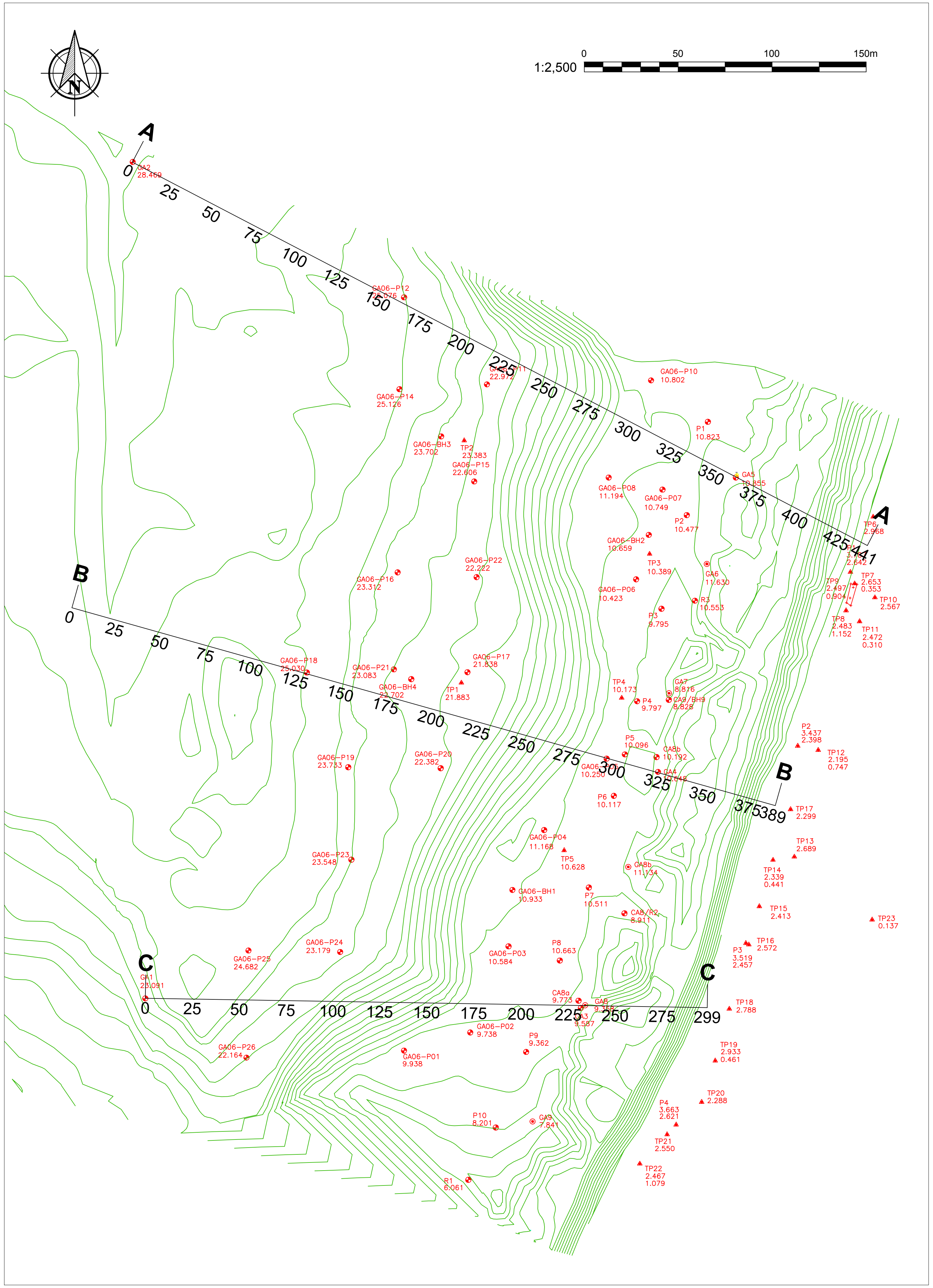
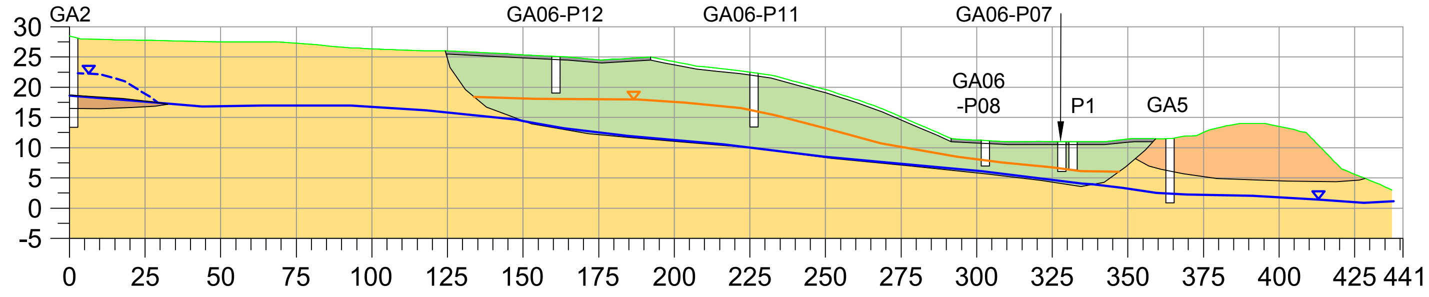
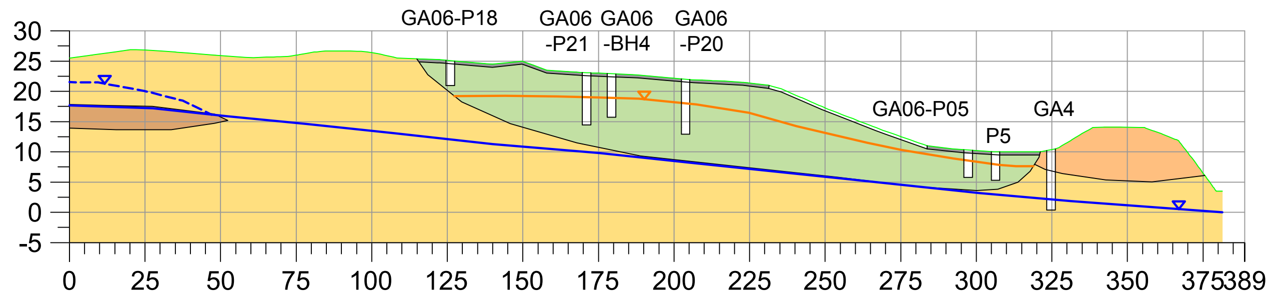


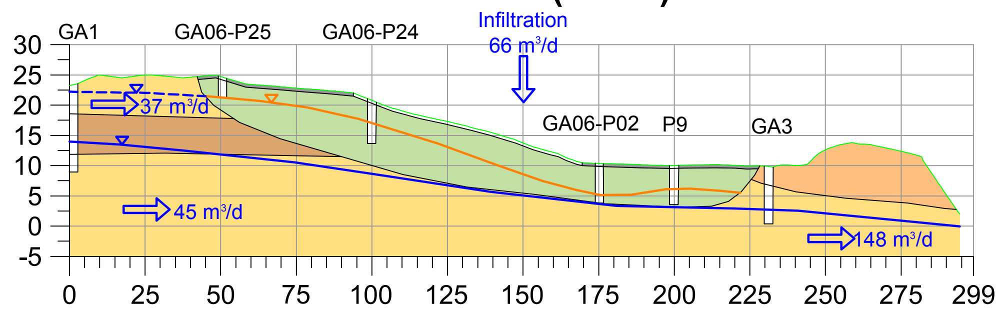
Section A (1h:2v)



Section B (1h:2v)



Section C (1h:2v)



Legend

- Clay
- Blown sands
- Sand and gravel
- Waste
- Water table
- Perched water table
- Leachate
- Water balance flux

Client	Smallbrook
Project	Blackdog Landfill Interpretative Report
Title	Conceptual Cross Section

Created by	Requested by	Proj Manager	Reviewer	Date
AB	RL	DH	DH	24/11/11

File No.	Project No.
5233061	09514290197

Size	Scale	Status
A3	1:2,500	Issue

Drawing No.	Rev
7	-

Golder Associates

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APPENDIX A

Probabilistic Calculations of Basal Leakage

Table 1: Parameters: Basal Leakage Calculation

Parameter	Min	Max	Distribution	Justification
Area of site (m^2)	80,000		Single Value	Operational area of site
Leachate head (m)	5	10	Uniform	Estimated range of leachate heads across site footprint
Permeability of waste (m/s)	$1.00x10^{-9}$	$1.00x10^{-8}$	Log Uniform	Anticipated hydraulic conductivity of compacted waste comprising domestic wastes in a matrix of sandy Clay drilling mud at base of site
Depth of waste at base of site that the leachate head acts over (m)	2		Single Value	Golder Judgment

The estimated basal leakage based on the parameters listed in Table 1 above at the 5 (lowest), 50 (most likely) and 95 (maximum) percentiles are 27, 81 and 246 m^3/day respectively. It is therefore noted that the calculated basal leakage rate at the most likely, 50 percentile at 81 m^3/day is broadly comparable with the water balance calculation for basal leakage of 103 m^3/day.

In order to validate the total underflow inclusive of basal leakage which was estimated by water balance to be 148 m^3/d, a probabilistic calculation of the flow rate beneath the site has been considered. This calculation considers the hydraulic gradient between the up and down gradient boreholes on the western and eastern boundaries respectively, the range of saturated thickness of the aquifer as identified by drilling records (thickness of saturated sand and gravel excluding low permeability deposits or rockhead) and a range of hydraulic conductivities of the aquifer that includes all reported values to date.

Table 2: Parameters: Underflow Calculation

Parameter	Min	Max	Distribution	Justification
Hydraulic Gradient	0.028	0.049	Uniform	Measured hydraulic gradient across site footprint
Hydraulic conductivity of aquifer (m/s)	$1.0x10^{-5}$	$2.7x10^{-4}$	Log Uniform	Anticipated hydraulic conductivity of aquifer including site observations listed in Golder, 2010.
Saturated aquifer thickness (m)	1.6	4.2	Uniform	Interpreted from borehole logs
Site width normal to groundwater flow (m)	420		Single Value	

The underflow based on the parameters listed in Table 2 above at the 5 (lowest), 50 (most likely) and 95 (maximum) percentiles are 49, 197 and 1046 m^3/day respectively. It is therefore noted that the calculated underflow rate at the most likely, 50 percentile at 197 m^3/day is broadly comparable with the water balance calculation for underflow of 148 m^3/day.

Groundwater Underflow

		Min	Max	
Hydraulic Gradient		0.028	0.049	0.03
Hydraulic Conductivity (m/s)		1.00E-05	2.70E-04	1.00E-04
		-1.15E+01	-8.22E+00	-9.21E+00
Saturated thickness (m)		1.6	4.2	2.9
Width normal to groundwater flow (m)		420	420	420
Groundwater underflow (m3/s)		3.65E-03		
Groundwater underflow (m3/d)		315.7		

Interpreted aquifer thickness (+/- 0.1m)	
GA1	>4.0
GA2	>2.6
GA3	1.7
GA4	1.6
GA5	1.6
GA6	4.2
GA7	1.7
GA8	2.5
GA9	3.5

Percentile	**Groundwater underflow (m3/d)**
5.0%	48.7
50.0%	**196.5**
95.0%	1025.9

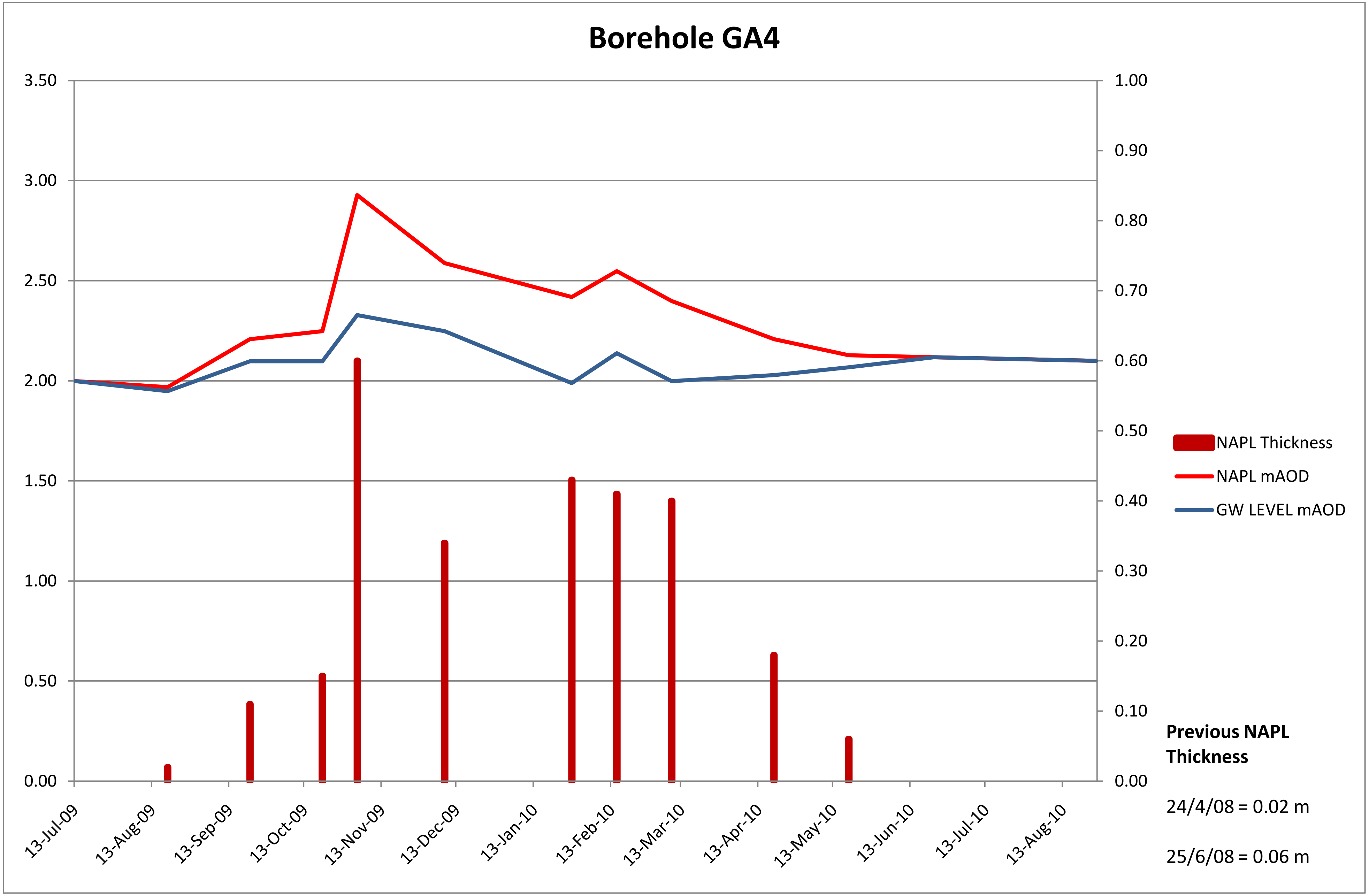
Leakage rate of leachate

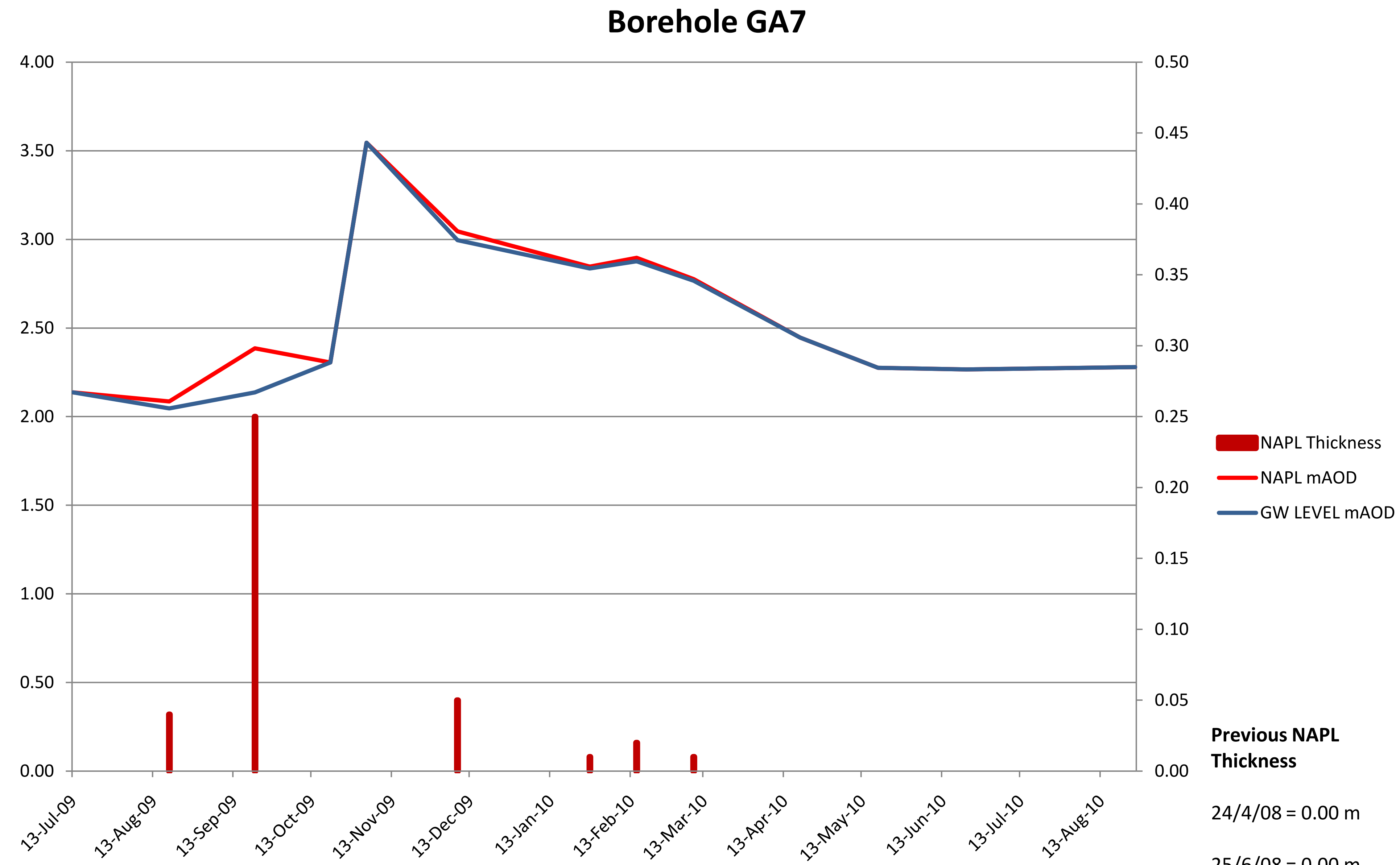
Area of site (m2)	80000		80000	
Leachate head (m)	5	10	7.5	
Permeability of waste	1.00E-09	1.00E-08	3.06E-07	
	-2.07E+01	-1.84E+01	-1.50E+01	
Gradient			3.75	Assuming lower 2 m of waste act as confining layer
Leakage rate (m3/day)			7929	

Percentile	**Leakage rate (m3/day)**
5.0%	27
50.0%	**81**
95.0%	246

APPENDIX B

Graphs of Water Level against LNAPL Thickness

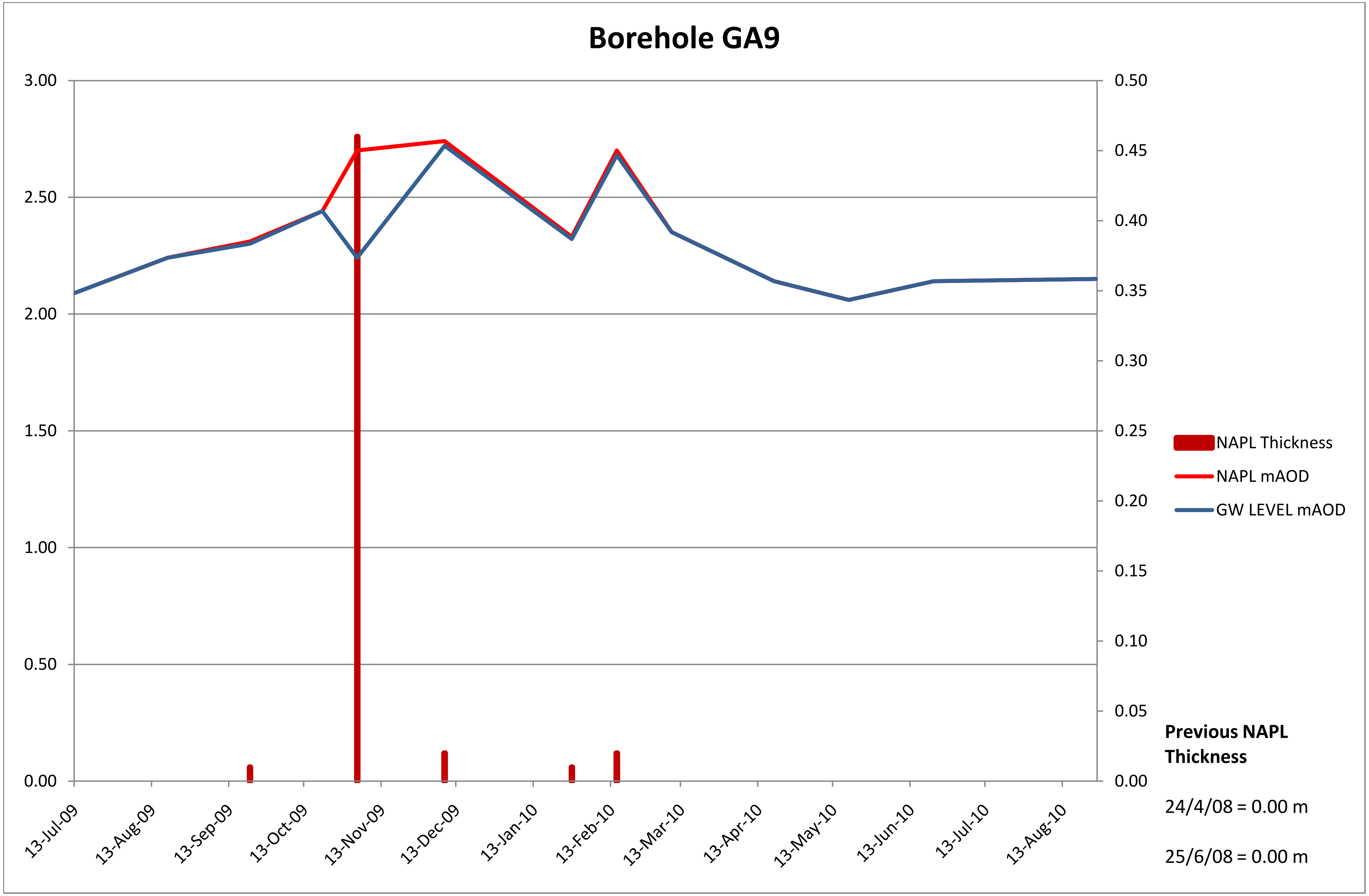

Borehole GA4
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
13-Jul-09
13-Aug-09
13-Sep-09
13-Oct-09
13-Nov-09
13-Dec-09
13-Jan-10
13-Feb-10
13-Mar-10
13-Apr-10
13-May-10
13-Jun-10
13-Jul-10
13-Aug-10
NAPL Thickness
NAPL mAOD
GW LEVEL mAOD
Previous NAPL Thickness
24/4/08 = 0.02 m
25/6/08 = 0.06 m



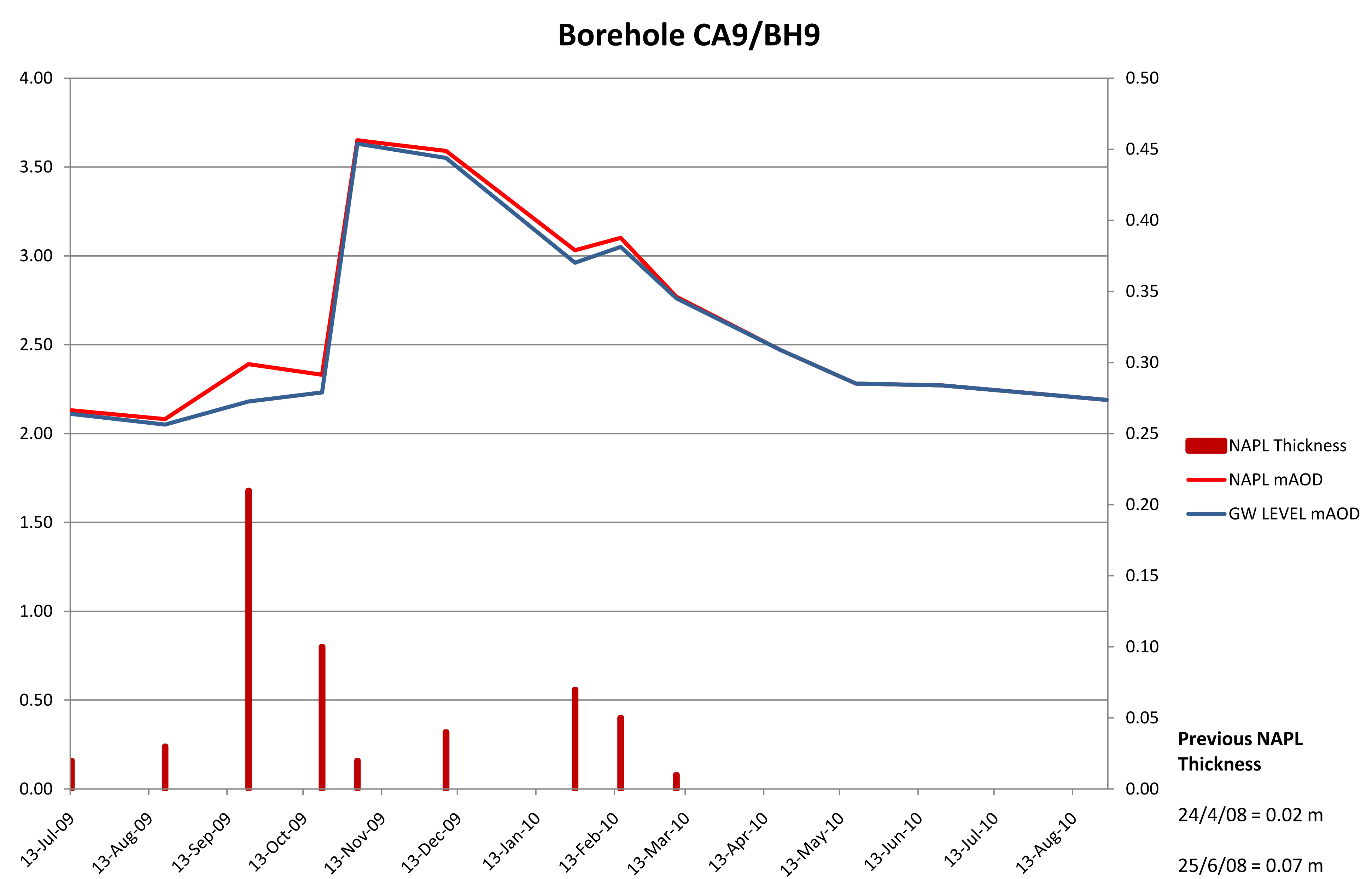
Previous NAPL Thickness

24/4/08 = 0.00 m

25/6/08 = 0.00 m



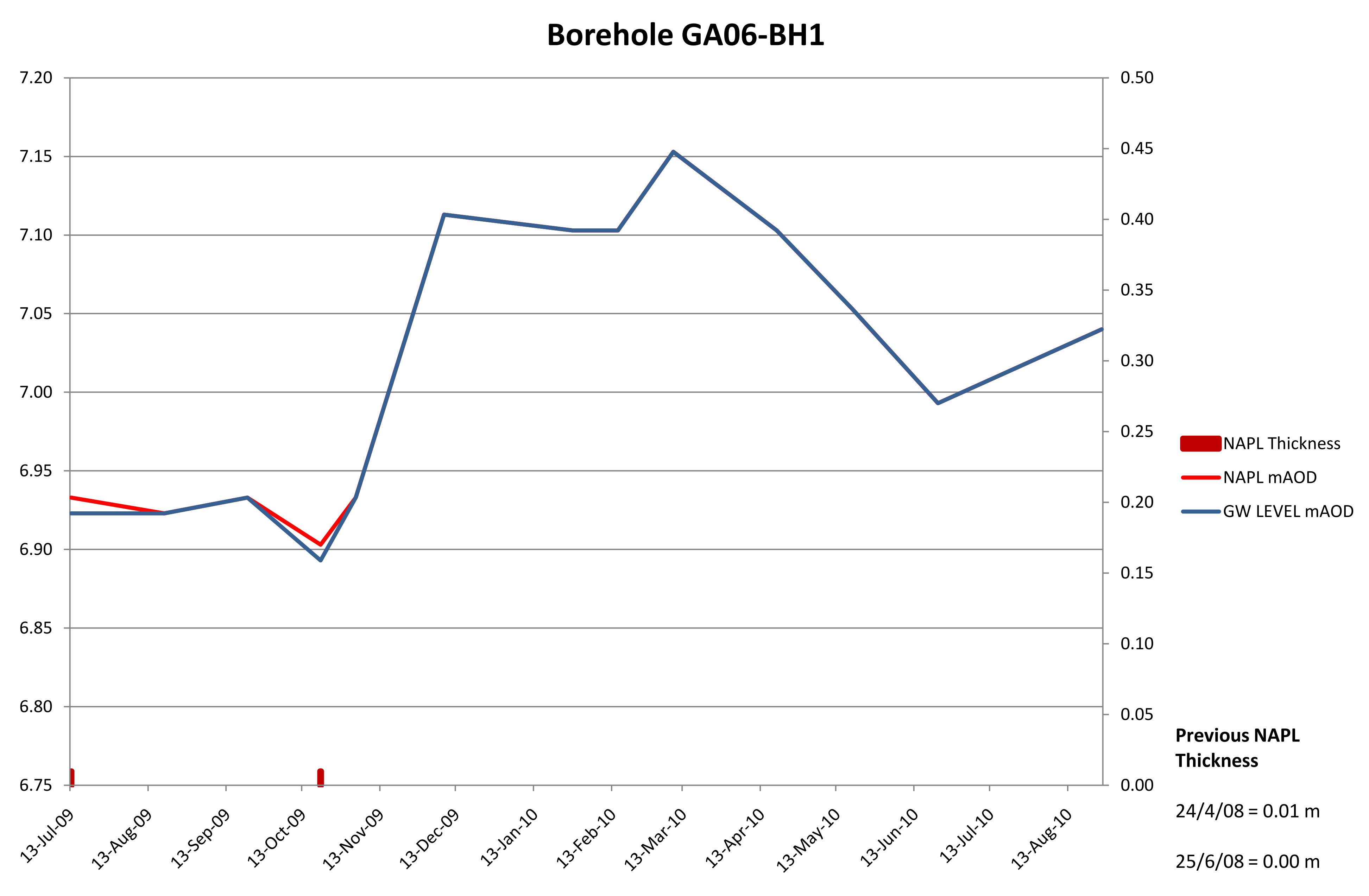
Borehole GA9
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
13-Jul-09
13-Aug-09
13-Sep-09
13-Oct-09
13-Nov-09
13-Dec-09
13-Jan-10
13-Feb-10
13-Mar-10
13-Apr-10
13-May-10
13-Jun-10
13-Jul-10
13-Aug-10
NAPL Thickness
NAPL mAOD
GW LEVEL mAOD
Previous NAPL Thickness
24/4/08 = 0.00 m
25/6/08 = 0.00 m



Previous NAPL Thickness

24/4/08 = 0.02 m

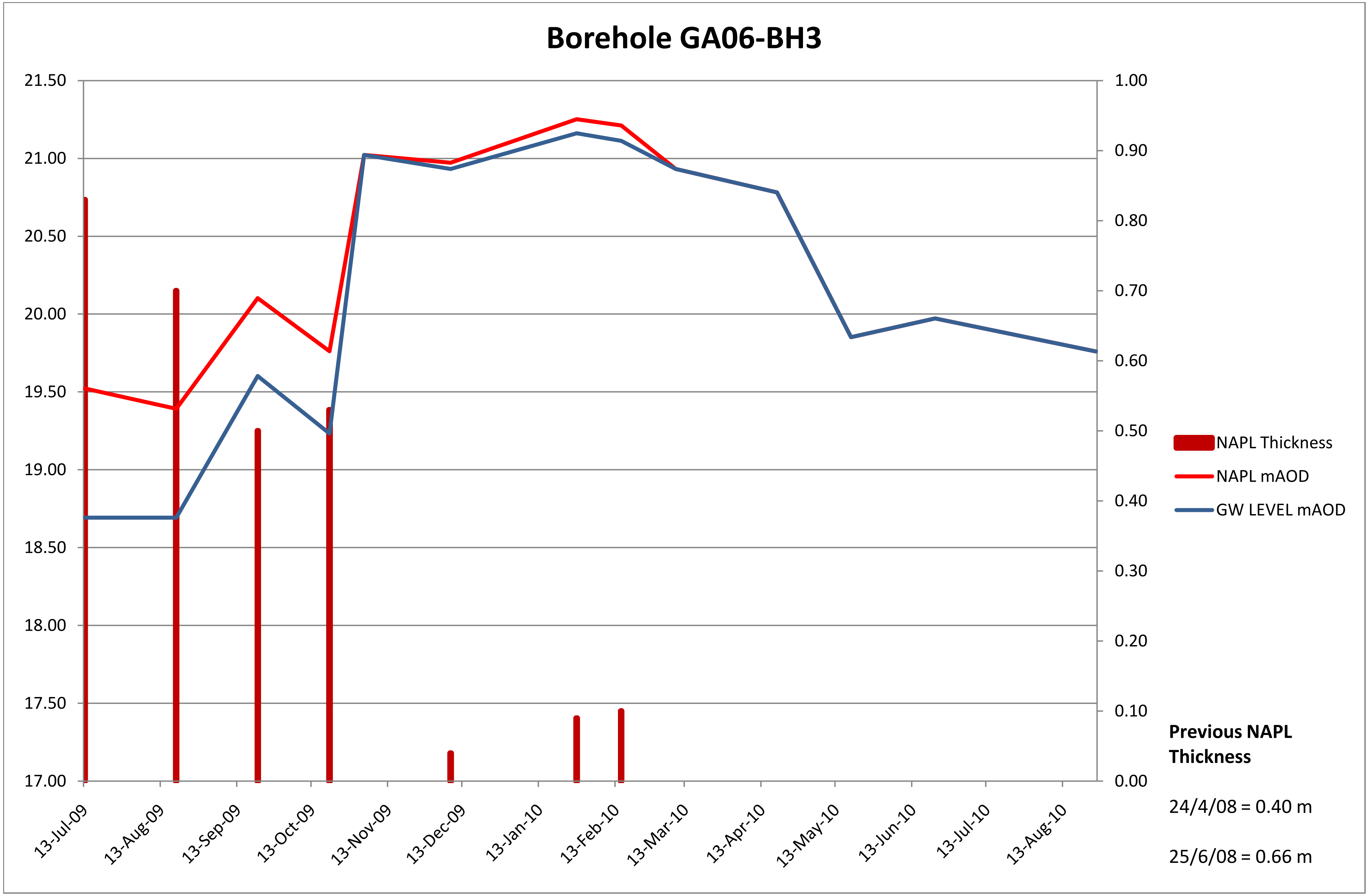
25/6/08 = 0.07 m



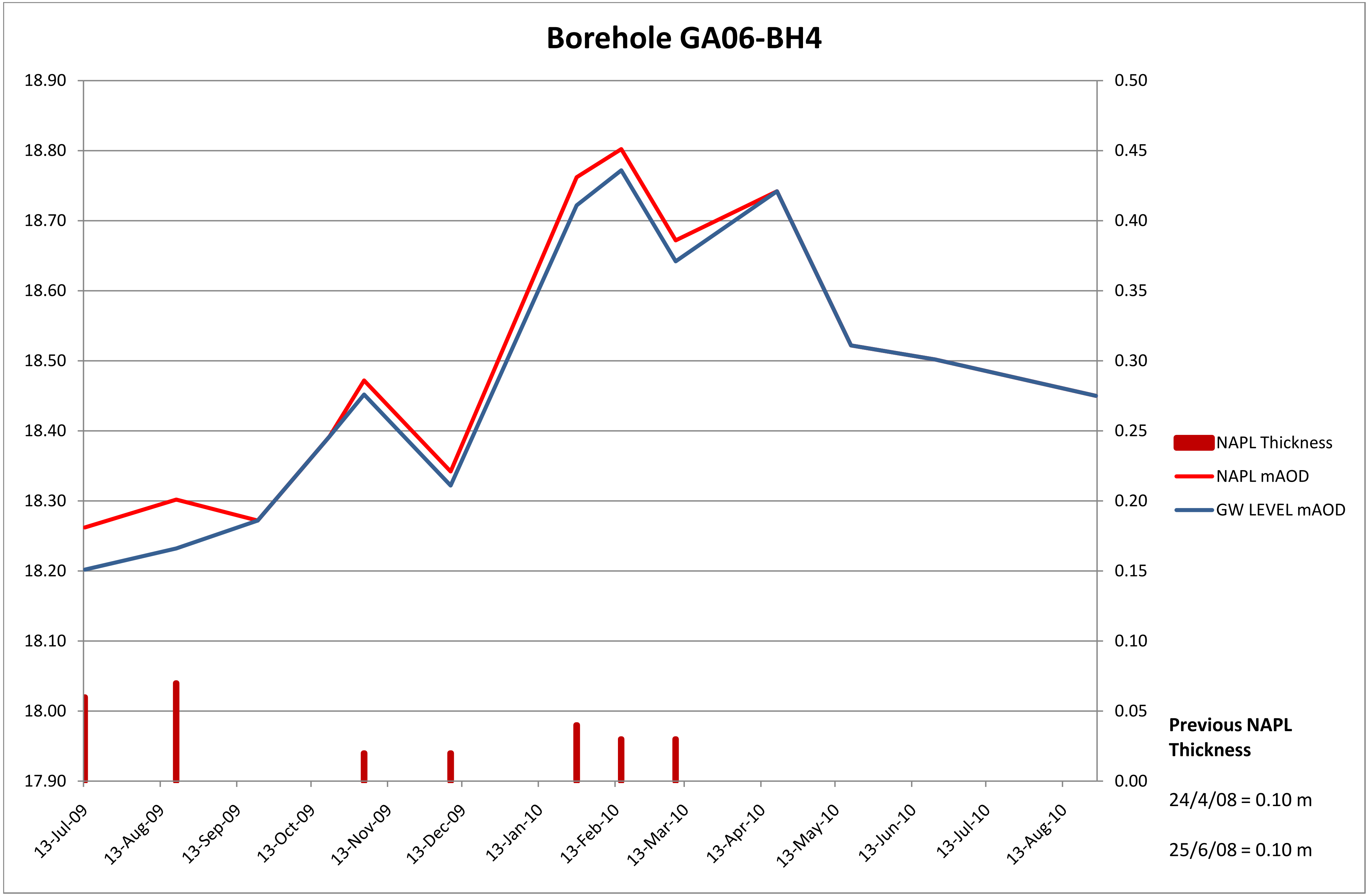
Previous NAPL Thickness

24/4/08 = 0.01 m

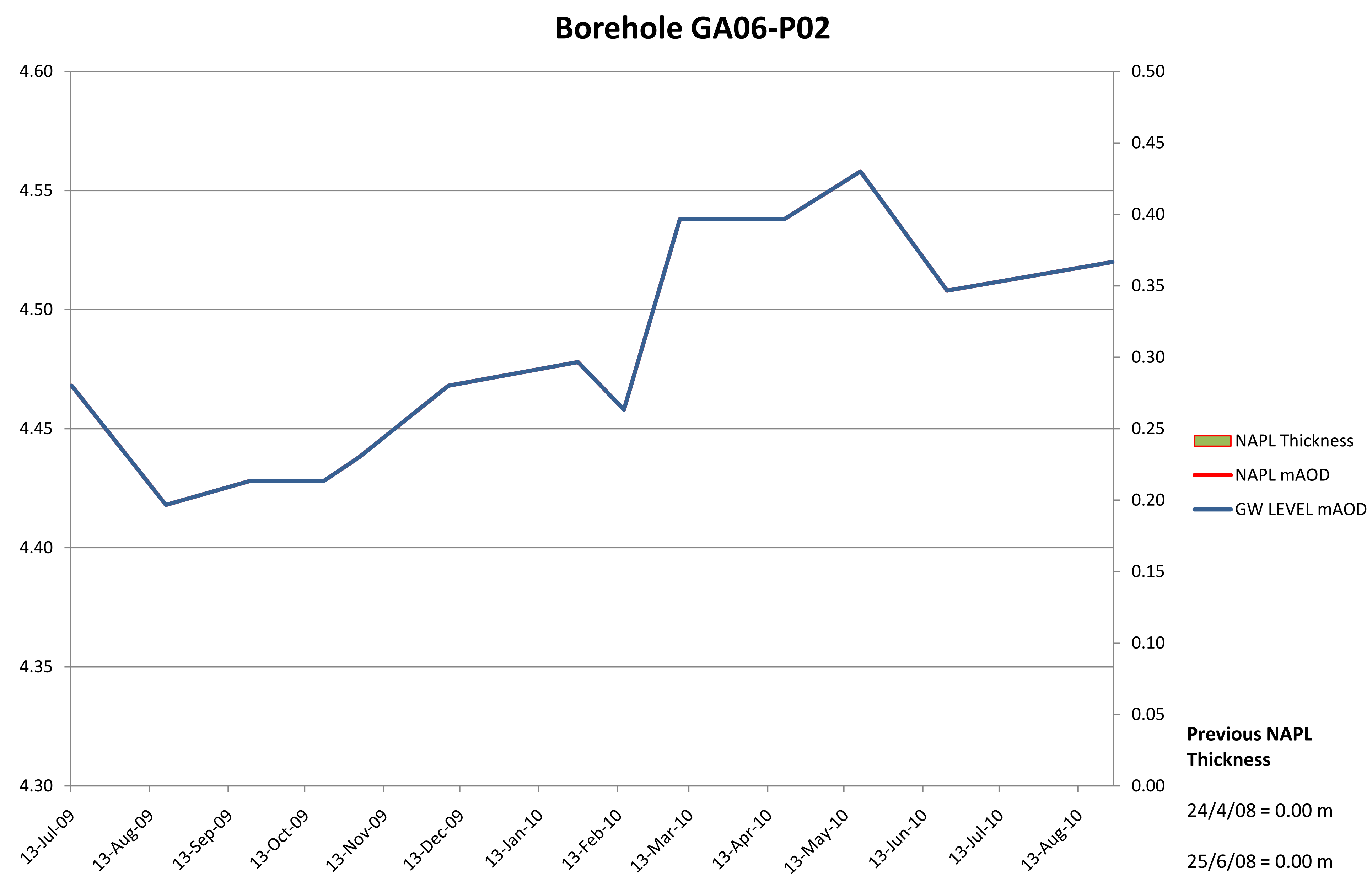
25/6/08 = 0.00 m



Borehole GA06-BH3
21.50
21.00
20.50
20.00
19.50
19.00
18.50
18.00
17.50
17.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
13-Jul-09
13-Aug-09
13-Sep-09
13-Oct-09
13-Nov-09
13-Dec-09
13-Jan-10
13-Feb-10
13-Mar-10
13-Apr-10
13-May-10
13-Jun-10
13-Jul-10
13-Aug-10
NAPL Thickness
NAPL mAOD
GW LEVEL mAOD
Previous NAPL Thickness
24/4/08 = 0.40 m
25/6/08 = 0.66 m



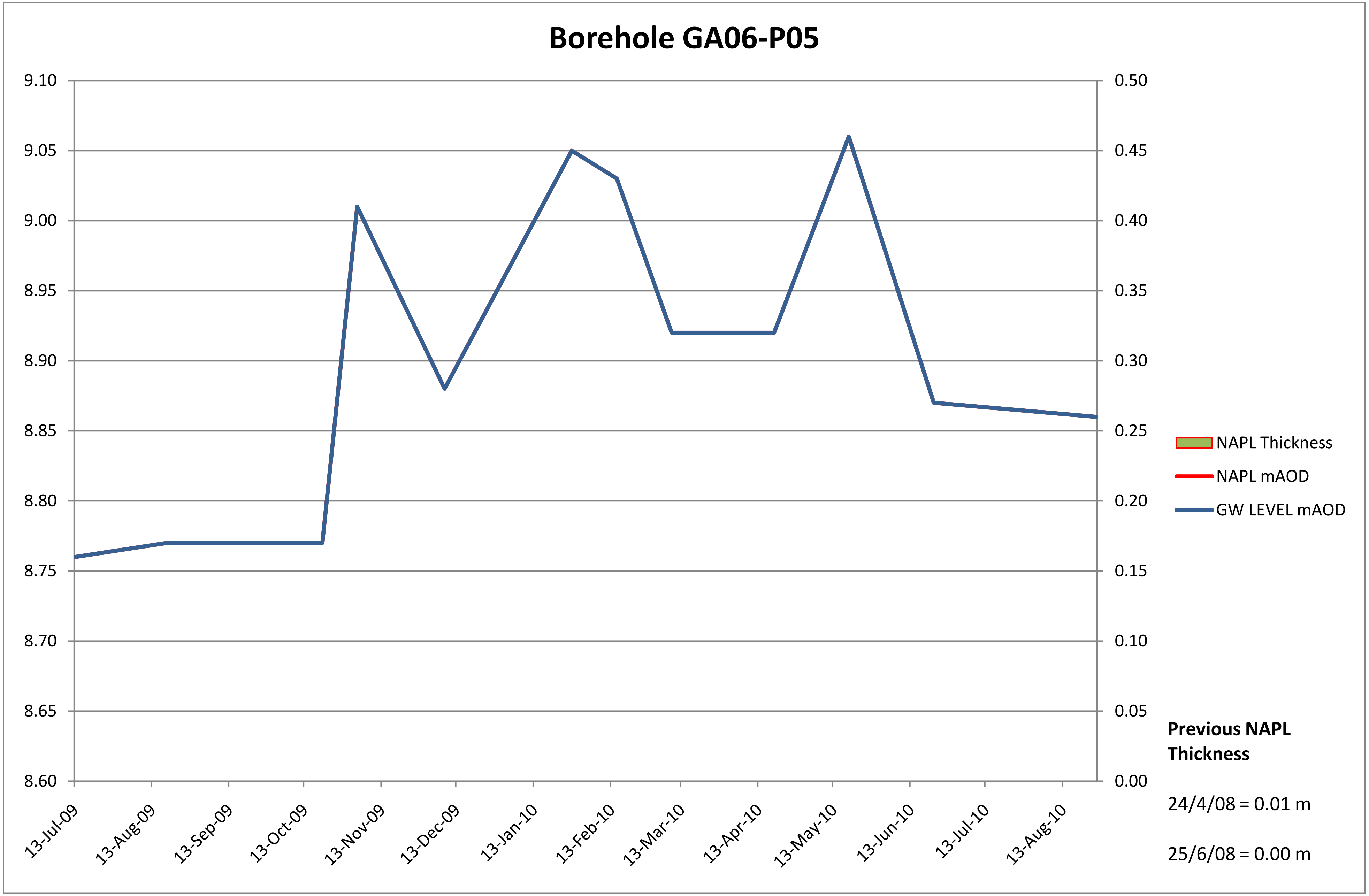
Borehole GA06-BH4
18.90
18.80
18.70
18.60
18.50
18.40
18.30
18.20
18.10
18.00
17.90
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
13-Jul-09
13-Aug-09
13-Sep-09
13-Oct-09
13-Nov-09
13-Dec-09
13-Jan-10
13-Feb-10
13-Mar-10
13-Apr-10
13-May-10
13-Jun-10
13-Jul-10
13-Aug-10
NAPL Thickness
NAPL mAOD
GW LEVEL mAOD
Previous NAPL Thickness
24/4/08 = 0.10 m
25/6/08 = 0.10 m



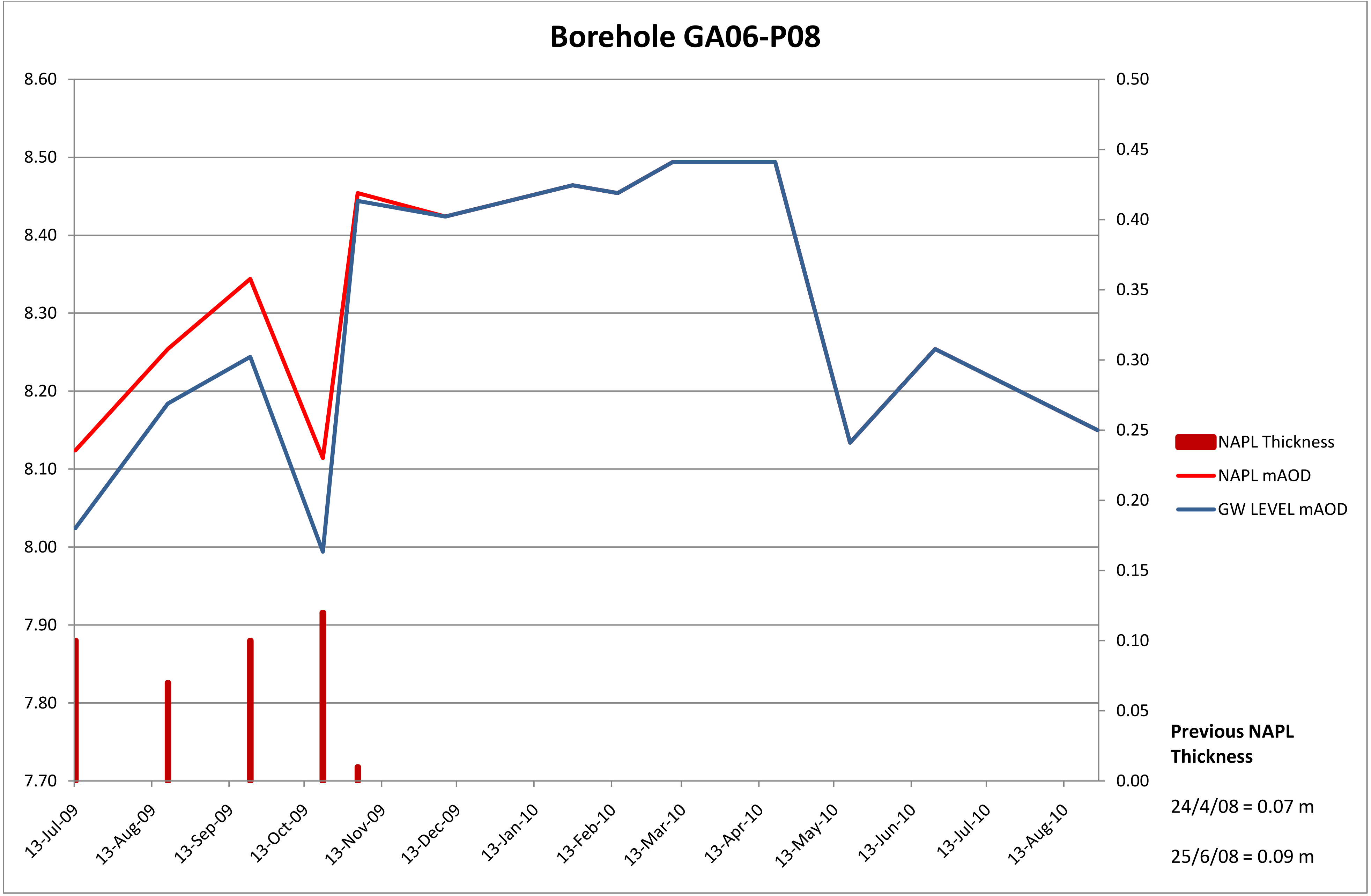
Previous NAPL Thickness

24/4/08 = 0.00 m

25/6/08 = 0.00 m



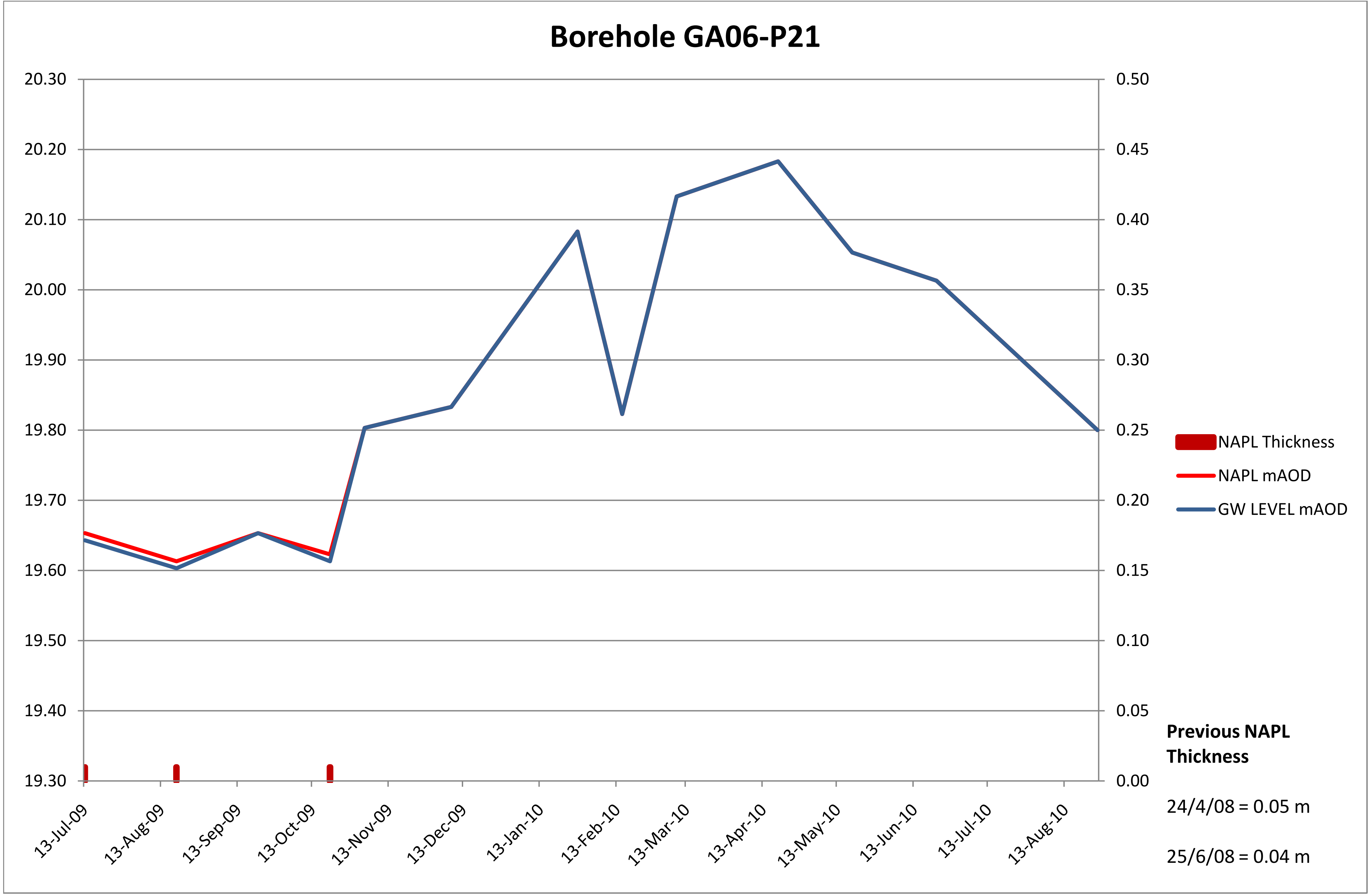
Borehole GA06-P05
9.10
9.05
9.00
8.95
8.90
8.85
8.80
8.75
8.70
8.65
8.60
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
13-Jul-09
13-Aug-09
13-Sep-09
13-Oct-09
13-Nov-09
13-Dec-09
13-Jan-10
13-Feb-10
13-Mar-10
13-Apr-10
13-May-10
13-Jun-10
13-Jul-10
13-Aug-10
NAPL Thickness
NAPL mAOD
GW LEVEL mAOD
Previous NAPL Thickness
24/4/08 = 0.01 m
25/6/08 = 0.00 m



Previous NAPL Thickness

24/4/08 = 0.07 m

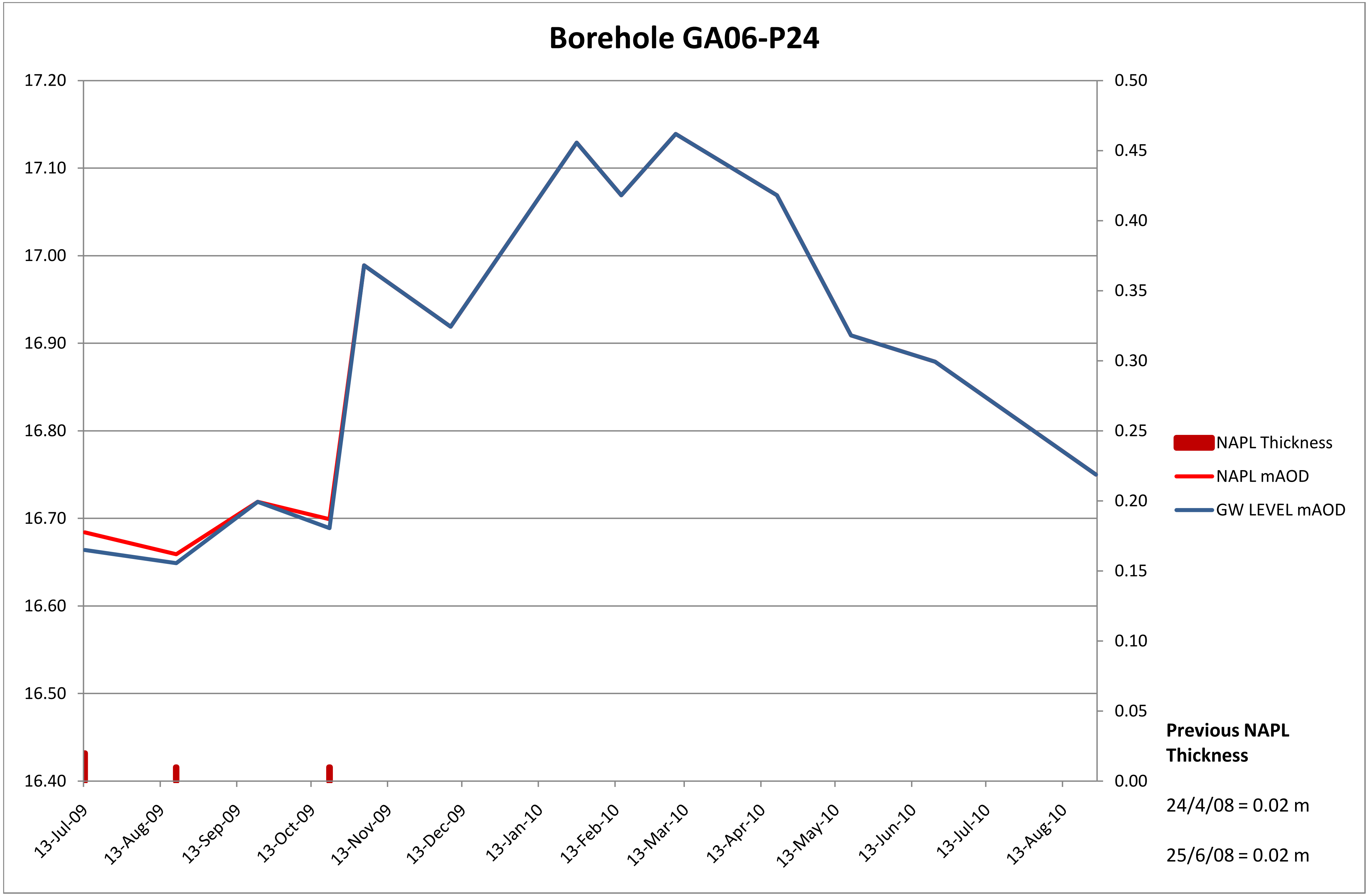
25/6/08 = 0.09 m



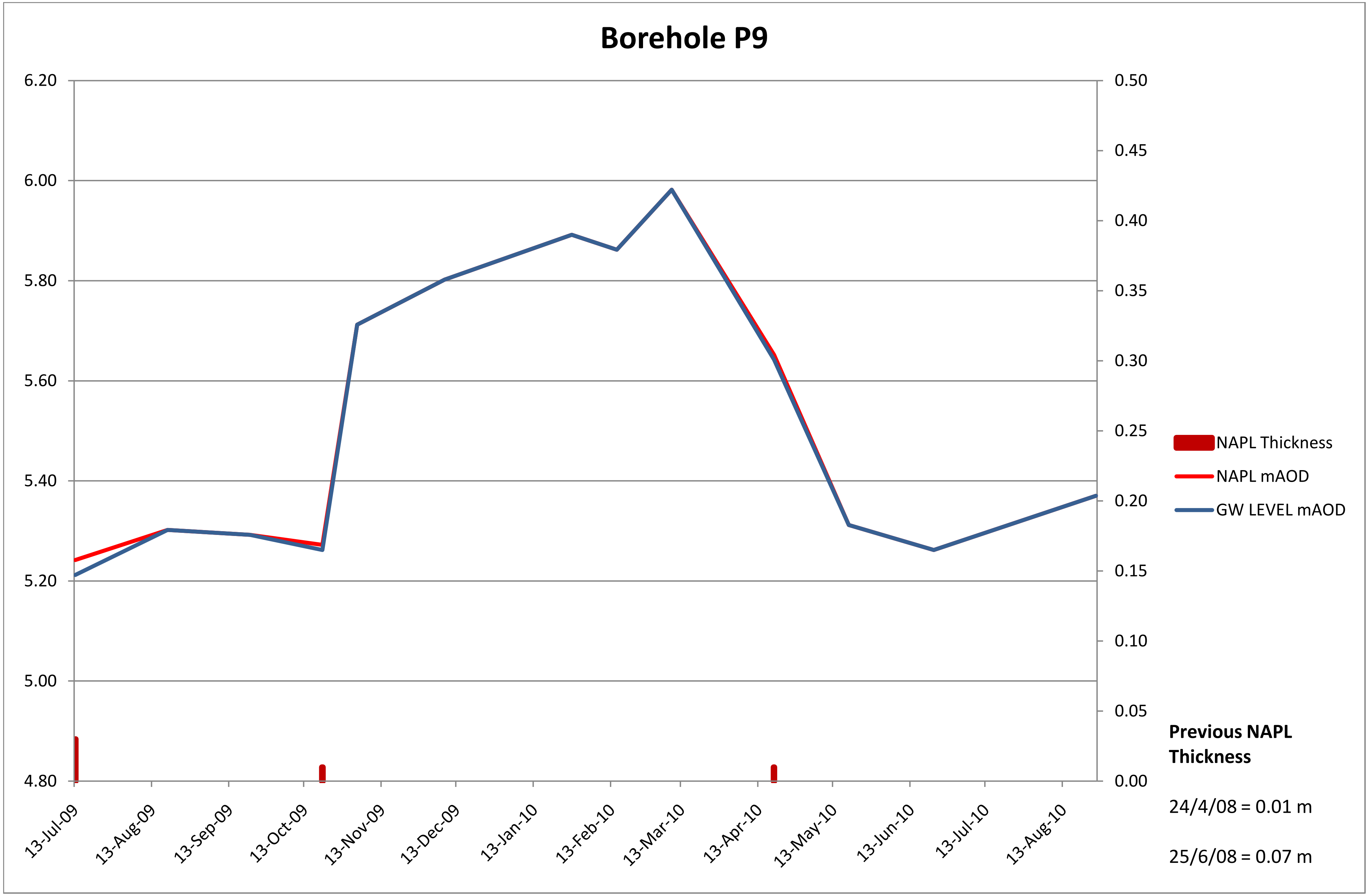
Previous NAPL Thickness

24/4/08 = 0.05 m

25/6/08 = 0.04 m



Borehole GA06-P24
17.20
17.10
17.00
16.90
16.80
16.70
16.60
16.50
16.40
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
13-Jul-09
13-Aug-09
13-Sep-09
13-Oct-09
13-Nov-09
13-Dec-09
13-Jan-10
13-Feb-10
13-Mar-10
13-Apr-10
13-May-10
13-Jun-10
13-Jul-10
13-Aug-10
NAPL Thickness
NAPL mAOD
GW LEVEL mAOD
Previous NAPL Thickness
24/4/08 = 0.02 m
25/6/08 = 0.02 m



Borehole P9
6.20
6.00
5.80
5.60
5.40
5.20
5.00
4.80
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
13-Jul-09
13-Aug-09
13-Sep-09
13-Oct-09
13-Nov-09
13-Dec-09
13-Jan-10
13-Feb-10
13-Mar-10
13-Apr-10
13-May-10
13-Jun-10
13-Jul-10
13-Aug-10
NAPL Thickness
NAPL mAOD
GW LEVEL mAOD
Previous NAPL Thickness
24/4/08 = 0.01 m
25/6/08 = 0.07 m

APPENDIX C

LNAPL Modelling Results

Executive Summary - Mobility

Site Name:

Project Manager:

Date of Analysis: 27/07/2011

Title of Simulations: Blackdog Landfill Site - Eastern Boundary - Most Recent

Initial Conditions

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	Selected S_{ro} (%)
1	1	Medium Sand	1.51	0.15

Simulation Number	LNAPL Type	LNAPL Zone Thickness (m)	Saturation Condition
1	Diesel	0.06	Vertical Equilibrium

Results

Simulation Number	Type Area Volume (cu m)	% Interval Greater than Field S_{ro}	Max S_o	Average S_o	Mobility (m/day)	Plume Velocity (m/day)
1	1.15E-01	0.00E+00	0.00	4.58E-05	5.09E-02	1.99E-03

User Input Parameters

Soil Properties

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	van Genutchen n	Srw	Sro	K (m/d)	Total Porosity
1	1	Medium Sand	1.51	2.04	0.29	0.15	7.30E+00	0.38

Groundwater Condition Input Parameters

Simulation Number	Groundwater Darcy Flux (m/day)	Linear Velocity (m/day)	Groundwater Gradient (m/m)
1	2.85E-01	1.06E+00	3.90E-02

Source Area Input Parameters

Simulation Number	Vertical Formation Thickness (m)	Depth to Top of LNAPL (m)	Length of LNAPL Zone (m)	Width of LNAPL Zone (m)
1	0.06	6.64	60.00	157.50

LNAPL Properties

Simulation Number	Product Type	Oil/Water IFT (dynes/cm)	Oil/Air IFT (dynes/cm)	Oil Density (gm/cc)	Viscosity (cp)
1	Diesel	50.00	25.00	0.8442	7.00

Method Used to Calculate LNAPL Saturation Input Parameters

Simulation Number	Method Used To Calculate LNAPL Saturation	Source Volitilization	Criteria For Minimum Mobility (m/day)
1	Equilibrium LNAPL Distribution	Volatilization Included	1.40E-04

Executive Summary - Mobility

Site Name:

Project Manager:

Date of Analysis: 27/07/2011

Title of Simulations: Blackdog Landfill Site - Eastern Boundary - Mean

Initial Conditions

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	Selected S_{ro} (%)
1	1	Medium Sand	1.51	0.15

Simulation Number	LNAPL Type	LNAPL Zone Thickness (m)	Saturation Condition
1	Diesel	0.11	Vertical Equilibrium

Results

Simulation Number	Type Area Volume (cu m)	% Interval Greater than Field S_{ro}	Max S_o	Average S_o	Mobility (m/day)	Plume Velocity (m/day)
1	7.52E-01	0.00E+00	0.00	1.58E-04	9.69E-02	3.78E-03

User Input Parameters

Soil Properties

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	van Genutchen n	Srw	Sro	K (m/d)	Total Porosity
1	1	Medium Sand	1.51	2.04	0.29	0.15	7.30E+00	0.38

Groundwater Condition Input Parameters

Simulation Number	Groundwater Darcy Flux (m/day)	Linear Velocity (m/day)	Groundwater Gradient (m/m)
1	2.85E-01	1.06E+00	3.90E-02

Source Area Input Parameters

Simulation Number	Vertical Formation Thickness (m)	Depth to Top of LNAPL (m)	Length of LNAPL Zone (m)	Width of LNAPL Zone (m)
1	0.11	6.64	60.00	157.50

LNAPL Properties

Simulation Number	Product Type	Oil/Water IFT (dynes/cm)	Oil/Air IFT (dynes/cm)	Oil Density (gm/cc)	Viscosity (cp)
1	Diesel	50.00	25.00	0.8442	7.00

Method Used to Calculate LNAPL Saturation Input Parameters

Simulation Number	Method Used To Calculate LNAPL Saturation	Source Volitilization	Criteria For Minimum Mobility (m/day)
1	Equilibrium LNAPL Distribution	Volatilization Included	1.40E-04

Executive Summary - Mobility

Site Name:

Project Manager:

Date of Analysis: 27/07/2011

Title of Simulations: Blackdog Landfill Site - Eastern Boundary - Threshold

Initial Conditions

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	Selected S_{ro} (%)
1	1	Medium Sand	1.51	0.15

Simulation Number	LNAPL Type	LNAPL Zone Thickness (m)	Saturation Condition
1	Diesel	0.03	Vertical Equilibrium

Results

Simulation Number	Type Area Volume (cu m)	% Interval Greater than Field S_{ro}	Max S_o	Average S_o	Mobility (m/day)	Plume Velocity (m/day)
1	1.28E-02	0.00E+00	0.00	1.11E-05	2.43E-02	9.49E-04

User Input Parameters

Soil Properties

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	van Genutchen n	Srw	Sro	K (m/d)	Total Porosity
1	1	Medium Sand	1.51	2.04	0.29	0.15	7.30E+00	0.38

Groundwater Condition Input Parameters

Simulation Number	Groundwater Darcy Flux (m/day)	Linear Velocity (m/day)	Groundwater Gradient (m/m)
1	2.85E-01	1.06E+00	3.90E-02

Source Area Input Parameters

Simulation Number	Vertical Formation Thickness (m)	Depth to Top of LNAPL (m)	Length of LNAPL Zone (m)	Width of LNAPL Zone (m)
1	0.03	6.64	60.00	157.50

LNAPL Properties

Simulation Number	Product Type	Oil/Water IFT (dynes/cm)	Oil/Air IFT (dynes/cm)	Oil Density (gm/cc)	Viscosity (cp)
1	Diesel	50.00	25.00	0.8442	7.00

Method Used to Calculate LNAPL Saturation Input Parameters

Simulation Number	Method Used To Calculate LNAPL Saturation	Source Volitilization	Criteria For Minimum Mobility (m/day)
1	Equilibrium LNAPL Distribution	Volatilization Included	1.40E-04

Executive Summary - Mobility

Site Name:

Project Manager:

Date of Analysis: 27/07/2011

Title of Simulations: Blackdog Landfill Site - Eastern Boundary - Worst Case

Initial Conditions

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	Selected S_{ro} (%)
1	1	Medium Sand	1.51	0.15

Simulation Number	LNAPL Type	LNAPL Zone Thickness (m)	Saturation Condition
1	Diesel	0.6	Vertical Equilibrium

Results

Simulation Number	Type Area Volume (cu m)	% Interval Greater than Field S_{ro}	Max S_o	Average S_o	Mobility (m/day)	Plume Velocity (m/day)
1	1.28E+02	0.00E+00	0.01	4.92E-03	5.74E-01	2.24E-02

User Input Parameters

Soil Properties

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	van Genutchen n	Srw	Sro	K (m/d)	Total Porosity
1	1	Medium Sand	1.51	2.04	0.29	0.15	7.30E+00	0.38

Groundwater Condition Input Parameters

Simulation Number	Groundwater Darcy Flux (m/day)	Linear Velocity (m/day)	Groundwater Gradient (m/m)
1	2.85E-01	1.06E+00	3.90E-02

Source Area Input Parameters

Simulation Number	Vertical Formation Thickness (m)	Depth to Top of LNAPL (m)	Length of LNAPL Zone (m)	Width of LNAPL Zone (m)
1	0.60	6.64	60.00	157.50

LNAPL Properties

Simulation Number	Product Type	Oil/Water IFT (dynes/cm)	Oil/Air IFT (dynes/cm)	Oil Density (gm/cc)	Viscosity (cp)
1	Diesel	50.00	25.00	0.8442	7.00

Method Used to Calculate LNAPL Saturation Input Parameters

Simulation Number	Method Used To Calculate LNAPL Saturation	Source Volitilization	Criteria For Minimum Mobility (m/day)
1	Equilibrium LNAPL Distribution	Volatilization Included	1.40E-04

Executive Summary - Mobility

Site Name:

Project Manager:

Date of Analysis: 27/07/2011

Title of Simulations: Blackdog Landfill Site - Upper Section - Mean

Initial Conditions

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	Selected S_{ro} (%)
1	1	Clayey Sand	0.764	0.25

Simulation Number	LNAPL Type	LNAPL Zone Thickness (m)	Saturation Condition
1	Diesel	0.1	Vertical Equilibrium

Results

Simulation Number	Type Area Volume (cu m)	% Interval Greater than Field S_{ro}	Max S_o	Average S_o	Mobility (m/day)	Plume Velocity (m/day)
1	8.93E-02	0.00E+00	0.00	1.75E-05	5.00E-05	5.00E-06

User Input Parameters

Soil Properties

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	van Genutchen n	Srw	Sro	K (m/d)	Total Porosity
1	1	Clayey Sand	0.764	2.16	0.39	0.25	2.23E-02	0.525

Groundwater Condition Input Parameters

Simulation Number	Groundwater Darcy Flux (m/day)	Linear Velocity (m/day)	Groundwater Gradient (m/m)
1	2.23E-03	6.96E-03	1.00E-01

Source Area Input Parameters

Simulation Number	Vertical Formation Thickness (m)	Depth to Top of LNAPL (m)	Length of LNAPL Zone (m)	Width of LNAPL Zone (m)
1	0.10	4.31	80.00	100.00

LNAPL Properties

Simulation Number	Product Type	Oil/Water IFT (dynes/cm)	Oil/Air IFT (dynes/cm)	Oil Density (gm/cc)	Viscosity (cp)
1	Diesel	50.00	25.00	0.8442	7.00

Method Used to Calculate LNAPL Saturation Input Parameters

Simulation Number	Method Used To Calculate LNAPL Saturation	Source Volitilization	Criteria For Minimum Mobility (m/day)
1	Equilibrium LNAPL Distribution	Volatilization Included	8.64E-04

Executive Summary - Mobility

Site Name:

Project Manager:

Date of Analysis: 27/07/2011

Title of Simulations: Blackdog Landfill Site - Upper Section - Threshold

Initial Conditions

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	Selected S_{ro} (%)
1	1	Clayey Sand	0.764	0.25

Simulation Number	LNAPL Type	LNAPL Zone Thickness (m)	Saturation Condition
1	Diesel	0.05	Vertical Equilibrium

Results

Simulation Number	Type Area Volume (cu m)	% Interval Greater than Field S_{ro}	Max S_o	Average S_o	Mobility (m/day)	Plume Velocity (m/day)
1	1.28E-02	0.00E+00	0.00	3.91E-06	2.04E-05	2.04E-06

User Input Parameters

Soil Properties

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	van Genutchen n	Srw	Sro	K (m/d)	Total Porosity
1	1	Clayey Sand	0.764	2.16	0.39	0.25	2.23E-02	0.525

Groundwater Condition Input Parameters

Simulation Number	Groundwater Darcy Flux (m/day)	Linear Velocity (m/day)	Groundwater Gradient (m/m)
1	2.23E-03	6.96E-03	1.00E-01

Source Area Input Parameters

Simulation Number	Vertical Formation Thickness (m)	Depth to Top of LNAPL (m)	Length of LNAPL Zone (m)	Width of LNAPL Zone (m)
1	0.05	4.31	80.00	100.00

LNAPL Properties

Simulation Number	Product Type	Oil/Water IFT (dynes/cm)	Oil/Air IFT (dynes/cm)	Oil Density (gm/cc)	Viscosity (cp)
1	Diesel	50.00	25.00	0.8442	7.00

Method Used to Calculate LNAPL Saturation Input Parameters

Simulation Number	Method Used To Calculate LNAPL Saturation	Source Volitilization	Criteria For Minimum Mobility (m/day)
1	Equilibrium LNAPL Distribution	Volatilization Included	8.64E-04

Executive Summary - Mobility

Site Name:

Project Manager:

Date of Analysis: 27/07/2011

Title of Simulations: Blackdog landfill Site - Upper Section - Worst Case

Initial Conditions

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	Selected S_{ro} (%)
1	1	Clayey Sand	0.764	0.25
2	1	Clayey Sand	0.764	0.25

Simulation Number	LNAPL Type	LNAPL Zone Thickness (m)	Saturation Condition
1	Diesel	0.83	Vertical Equilibrium
2	Diesel	0.83	Vertical Equilibrium

Results

Simulation Number	Type Area Volume (cu m)	% Interval Greater than Field S_{ro}	Max S_o	Average S_o	Mobility (m/day)	Plume Velocity (m/day)
1	7.05E+01	0.00E+00	0.00	1.68E-03	6.87E-04	6.87E-05
2	7.05E+01	0.00E+00	0.00	1.68E-03	6.87E-04	6.87E-05

User Input Parameters

Soil Properties

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	van Genutchen n	Srw	Sro	K (m/d)	Total Porosity
1	1	Clayey Sand	0.764	2.16	0.39	0.25	2.23E-02	0.525
2	1	Clayey Sand	0.764	2.16	0.39	0.25	2.23E-02	0.525

Groundwater Condition Input Parameters

Simulation Number	Groundwater Darcy Flux (m/day)	Linear Velocity (m/day)	Groundwater Gradient (m/m)
1	2.23E-03	6.96E-03	1.00E-01
2	2.23E-03	6.96E-03	1.00E-01

Source Area Input Parameters

Simulation Number	Vertical Formation Thickness (m)	Depth to Top of LNAPL (m)	Length of LNAPL Zone (m)	Width of LNAPL Zone (m)
1	0.83	4.31	80.00	100.00
2	0.83	4.31	80.00	100.00

LNAPL Properties

Simulation Number	Product Type	Oil/Water IFT (dynes/cm)	Oil/Air IFT (dynes/cm)	Oil Density (gm/cc)	Viscosity (cp)
1	Diesel	50.00	25.00	0.8442	7.00
2	Diesel	50.00	25.00	0.8442	7.00

Method Used to Calculate LNAPL Saturation Input Parameters

Simulation Number	Method Used To Calculate LNAPL Saturation	Source Volitilization	Criteria For Minimum Mobility (m/day)
1	Equilibrium LNAPL Distribution	Volatilization Included	8.64E-04
2	Equilibrium LNAPL Distribution	Volatilization Included	8.64E-04

Executive Summary - Mobility

Site Name:

Project Manager:

Date of Analysis: 27/07/2011

Title of Simulations: Blackdog Landfill Site - Lower Section - Threshold

Initial Conditions

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	Selected S_{ro} (%)
1	1	Clayey Sand	0.764	0.25

Simulation Number	LNAPL Type	LNAPL Zone Thickness (m)	Saturation Condition
1	Diesel	0.06	Vertical Equilibrium

Results

Simulation Number	Type Area Volume (cu m)	% Interval Greater than Field S_{ro}	Max S_o	Average S_o	Mobility (m/day)	Plume Velocity (m/day)
1	1.28E-02	0.00E+00	0.00	5.81E-06	2.60E-05	4.95E-06

User Input Parameters

Soil Properties

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	van Genutchen n	Srw	Sro	K (m/d)	Total Porosity
1	1	Clayey Sand	0.764	2.16	0.39	0.25	2.23E-02	0.525

Groundwater Condition Input Parameters

Simulation Number	Groundwater Darcy Flux (m/day)	Linear Velocity (m/day)	Groundwater Gradient (m/m)
1	4.24E-03	1.32E-02	1.90E-01

Source Area Input Parameters

Simulation Number	Vertical Formation Thickness (m)	Depth to Top of LNAPL (m)	Length of LNAPL Zone (m)	Width of LNAPL Zone (m)
1	0.06	3.45	52.50	90.00

LNAPL Properties

Simulation Number	Product Type	Oil/Water IFT (dynes/cm)	Oil/Air IFT (dynes/cm)	Oil Density (gm/cc)	Viscosity (cp)
1	Diesel	50.00	25.00	0.8442	7.00

Method Used to Calculate LNAPL Saturation Input Parameters

Simulation Number	Method Used To Calculate LNAPL Saturation	Source Volitilization	Criteria For Minimum Mobility (m/day)
1	Equilibrium LNAPL Distribution	Volatilization Included	8.64E-04

Executive Summary - Mobility

Site Name:

Project Manager:

Date of Analysis: 27/07/2011

Title of Simulations: Blackdog Landfill Site - Lower Section - Worst Case

Initial Conditions

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	Selected S_{ro} (%)
1	1	Clayey Sand	0.764	0.25

Simulation Number	LNAPL Type	LNAPL Zone Thickness (m)	Saturation Condition
1	Diesel	0.12	Vertical Equilibrium

Results

Simulation Number	Type Area Volume (cu m)	% Interval Greater than Field S_{ro}	Max S_o	Average S_o	Mobility (m/day)	Plume Velocity (m/day)
1	3.83E-02	0.00E+00	0.00	2.59E-05	6.26E-05	1.19E-05

User Input Parameters

Soil Properties

Simulation Number	Layer	Soil Type	van Genutchen Alpha (1/m)	van Genutchen n	Srw	Sro	K (m/d)	Total Porosity
1	1	Clayey Sand	0.764	2.16	0.39	0.25	2.23E-02	0.525

Groundwater Condition Input Parameters

Simulation Number	Groundwater Darcy Flux (m/day)	Linear Velocity (m/day)	Groundwater Gradient (m/m)
1	4.24E-03	1.32E-02	1.90E-01

Source Area Input Parameters

Simulation Number	Vertical Formation Thickness (m)	Depth to Top of LNAPL (m)	Length of LNAPL Zone (m)	Width of LNAPL Zone (m)
1	0.12	3.45	45.00	45.00

LNAPL Properties

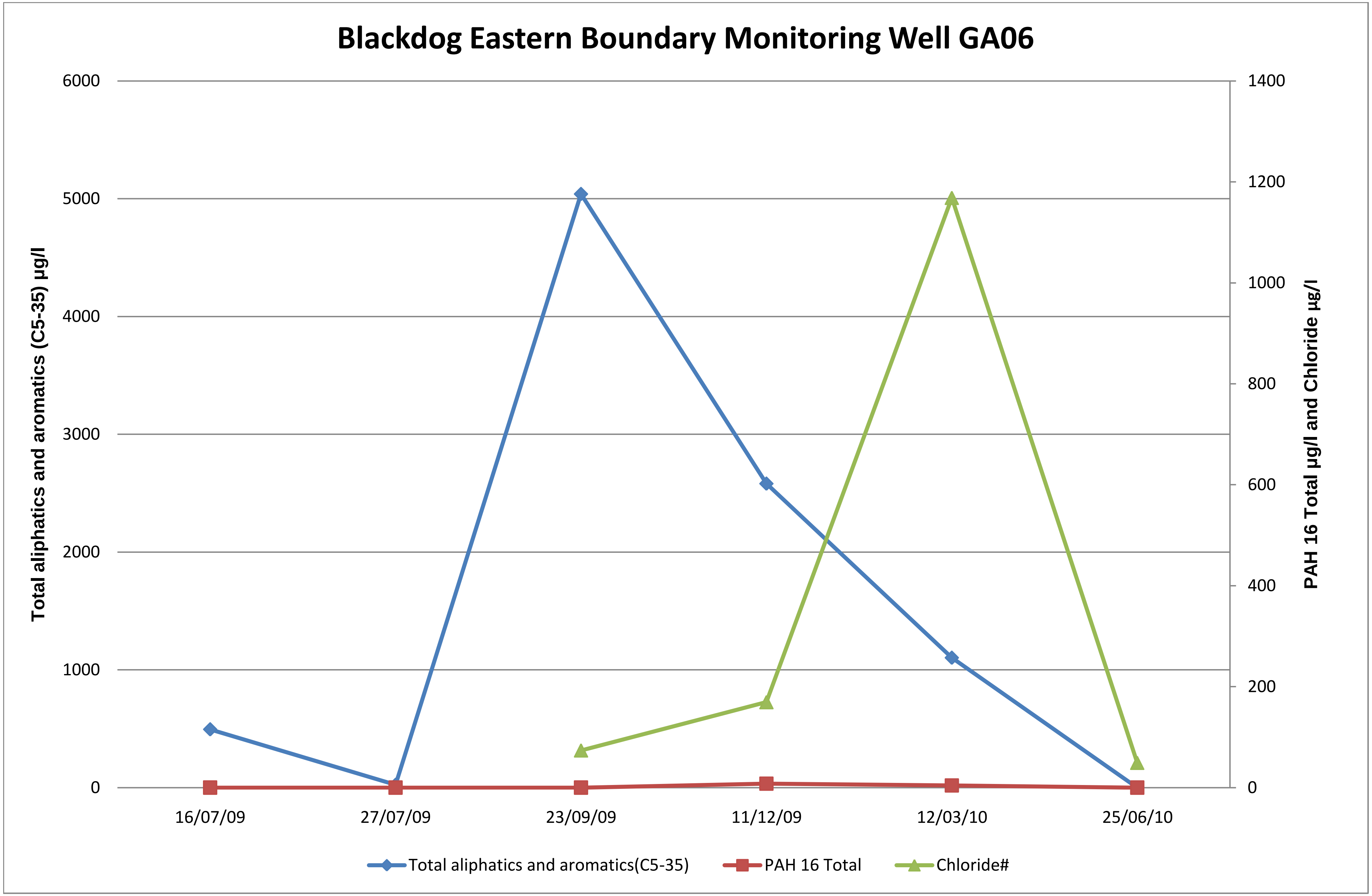
Simulation Number	Product Type	Oil/Water IFT (dynes/cm)	Oil/Air IFT (dynes/cm)	Oil Density (gm/cc)	Viscosity (cp)
1	Diesel	50.00	25.00	0.8442	7.00

Method Used to Calculate LNAPL Saturation Input Parameters

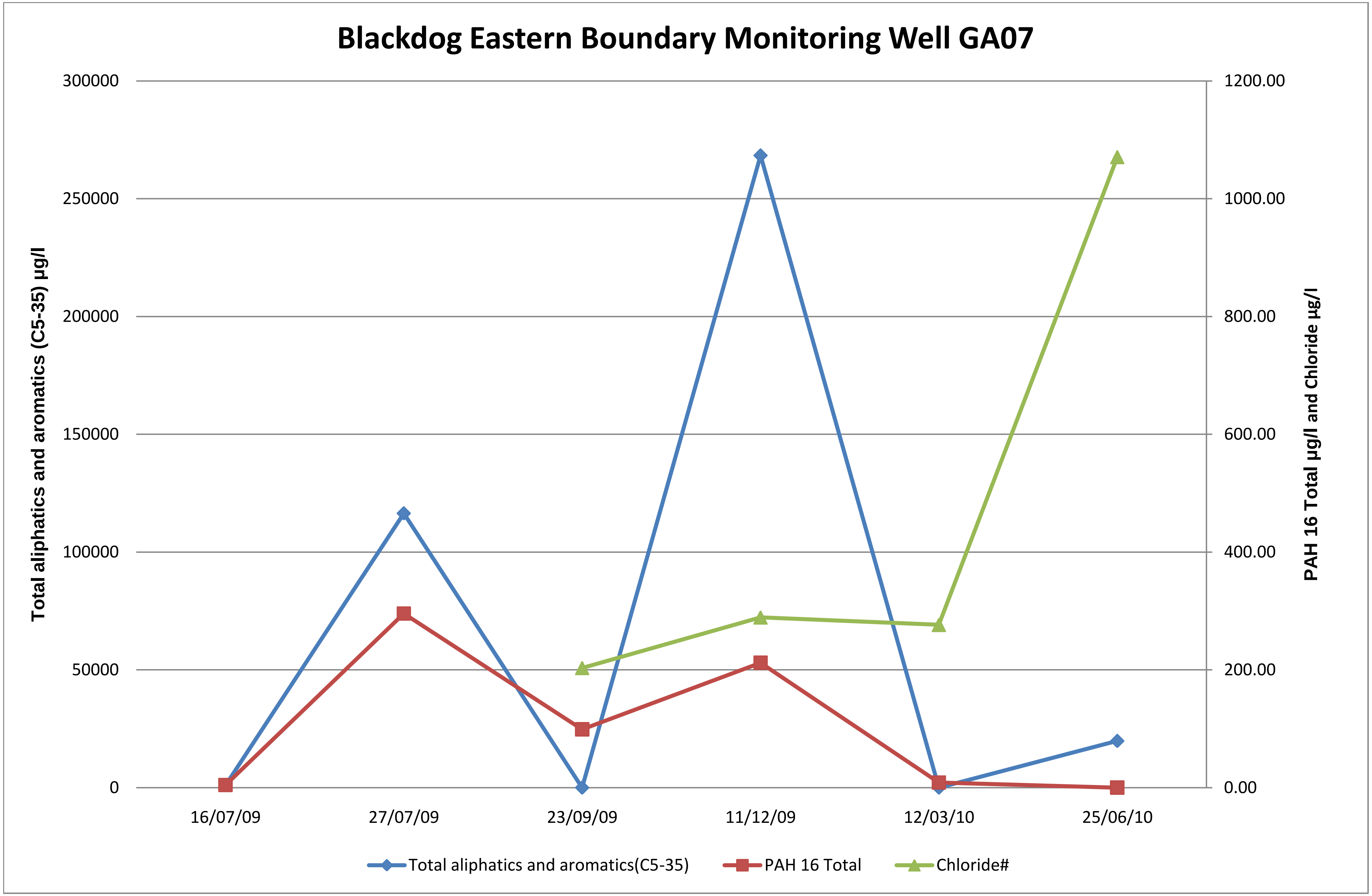
Simulation Number	Method Used To Calculate LNAPL Saturation	Source Volitilization	Criteria For Minimum Mobility (m/day)
1	Equilibrium LNAPL Distribution	Volatilization Included	8.64E-04

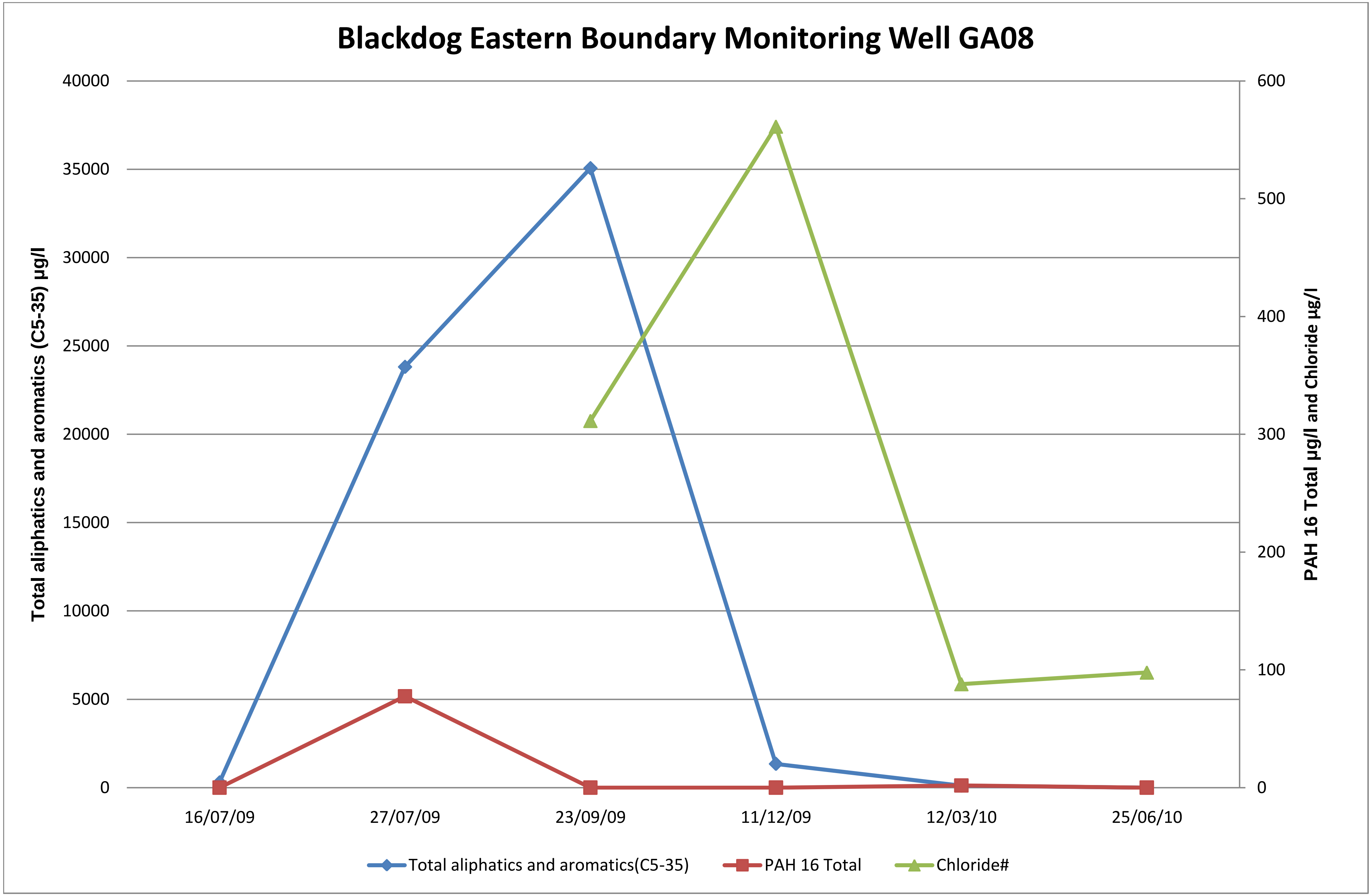
APPENDIX D

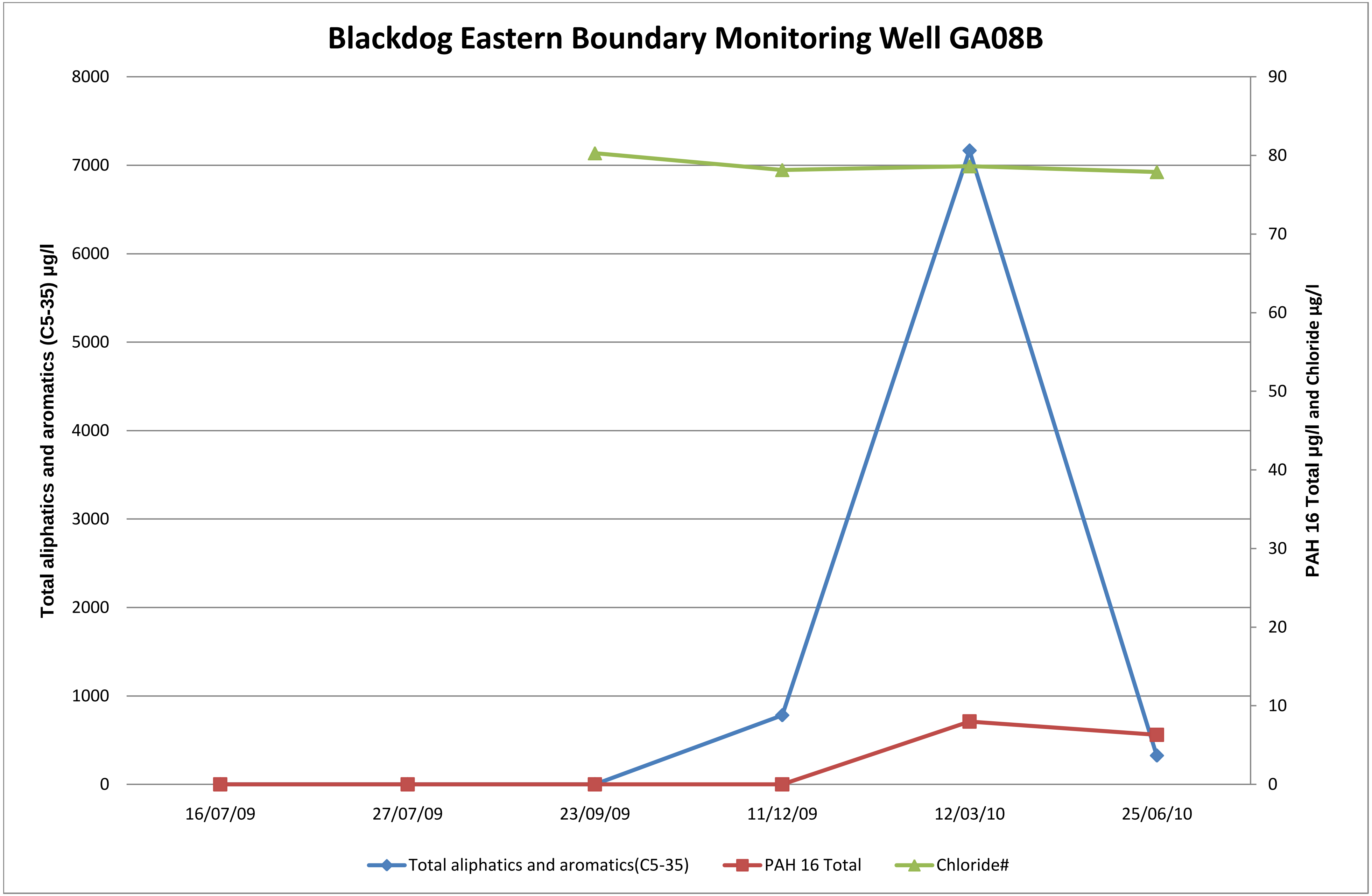
Dissolved Phase Time Series Charts



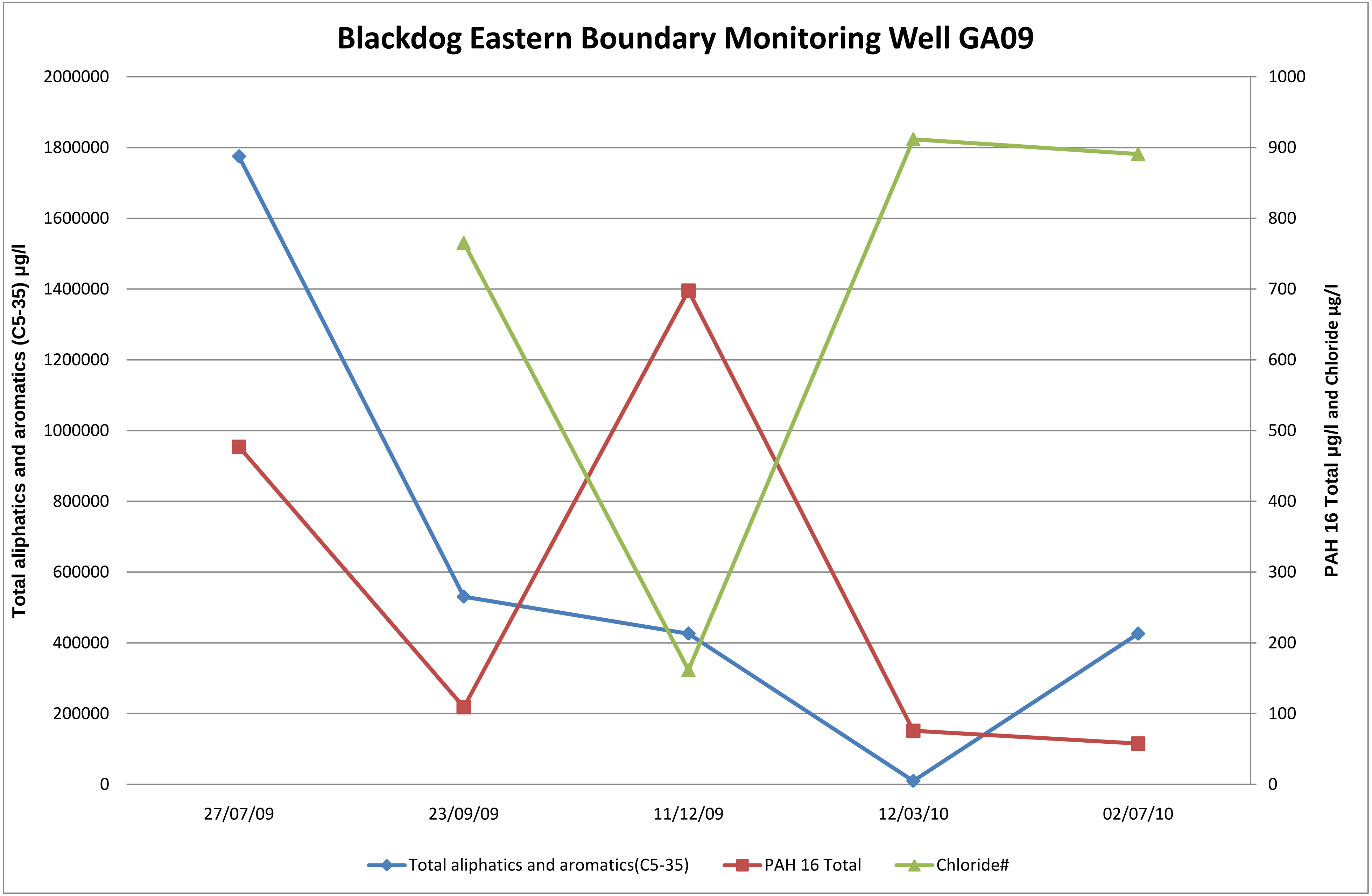
Blackdog Eastern Boundary Monitoring Well GA06
Total aliphatics and aromatics (C5-35) µg/l
PAH 16 Total µg/l and Chloride µg/l
6000
5000
4000
3000
2000
1000
0
1400
1200
1000
800
600
400
200
0
16/07/09
27/07/09
23/09/09
11/12/09
12/03/10
25/06/10
Total aliphatics and aromatics(C5-35)
PAH 16 Total
Chloride#

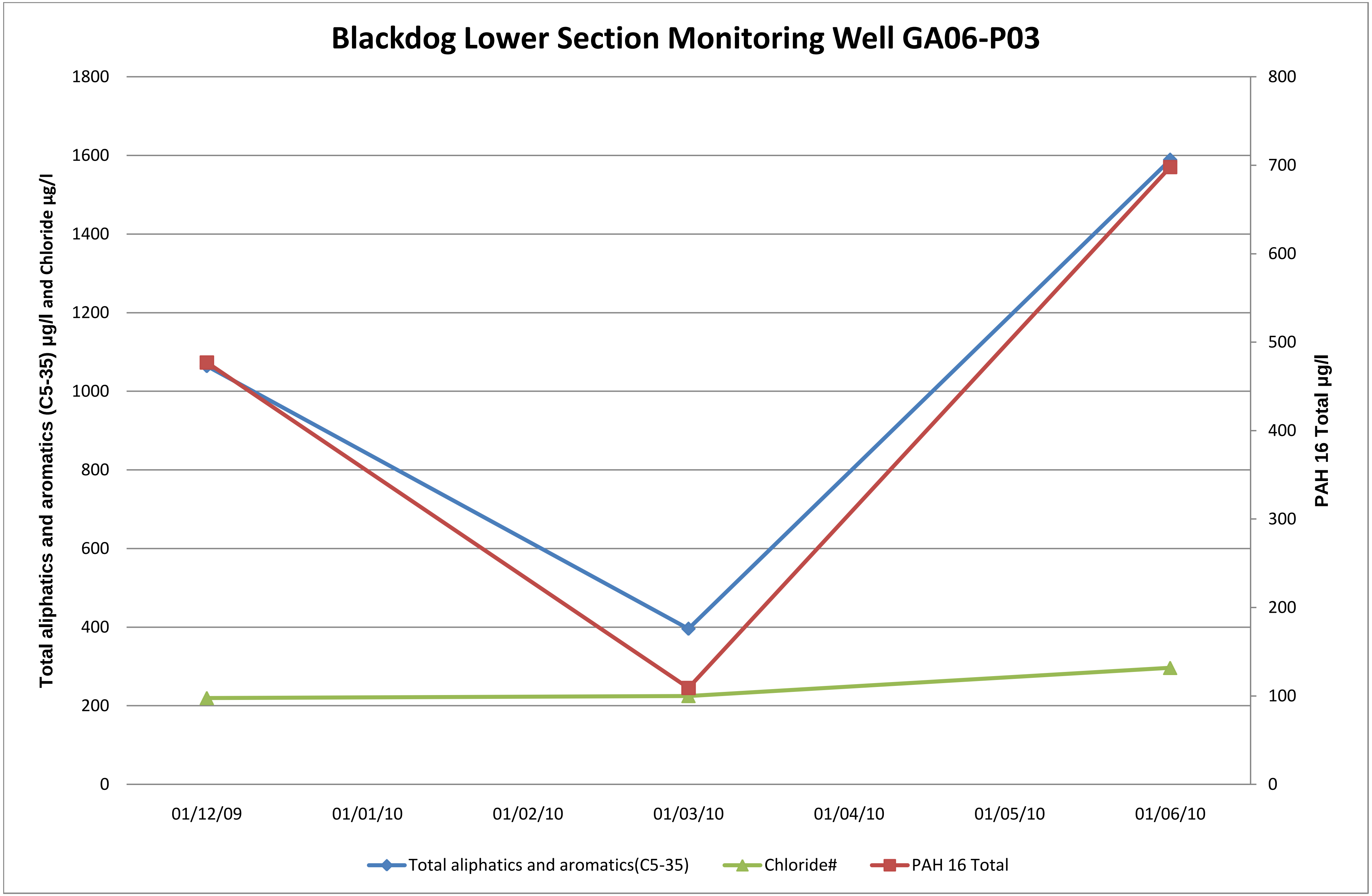

Blackdog Eastern Boundary Monitoring Well GA07
Total aliphatics and aromatics (C5-35) µg/l
PAH 16 Total µg/l and Chloride µg/l
300000
250000
200000
150000
100000
50000
0
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
16/07/09
27/07/09
23/09/09
11/12/09
12/03/10
25/06/10
Total aliphatics and aromatics(C5-35)
PAH 16 Total
Chloride#

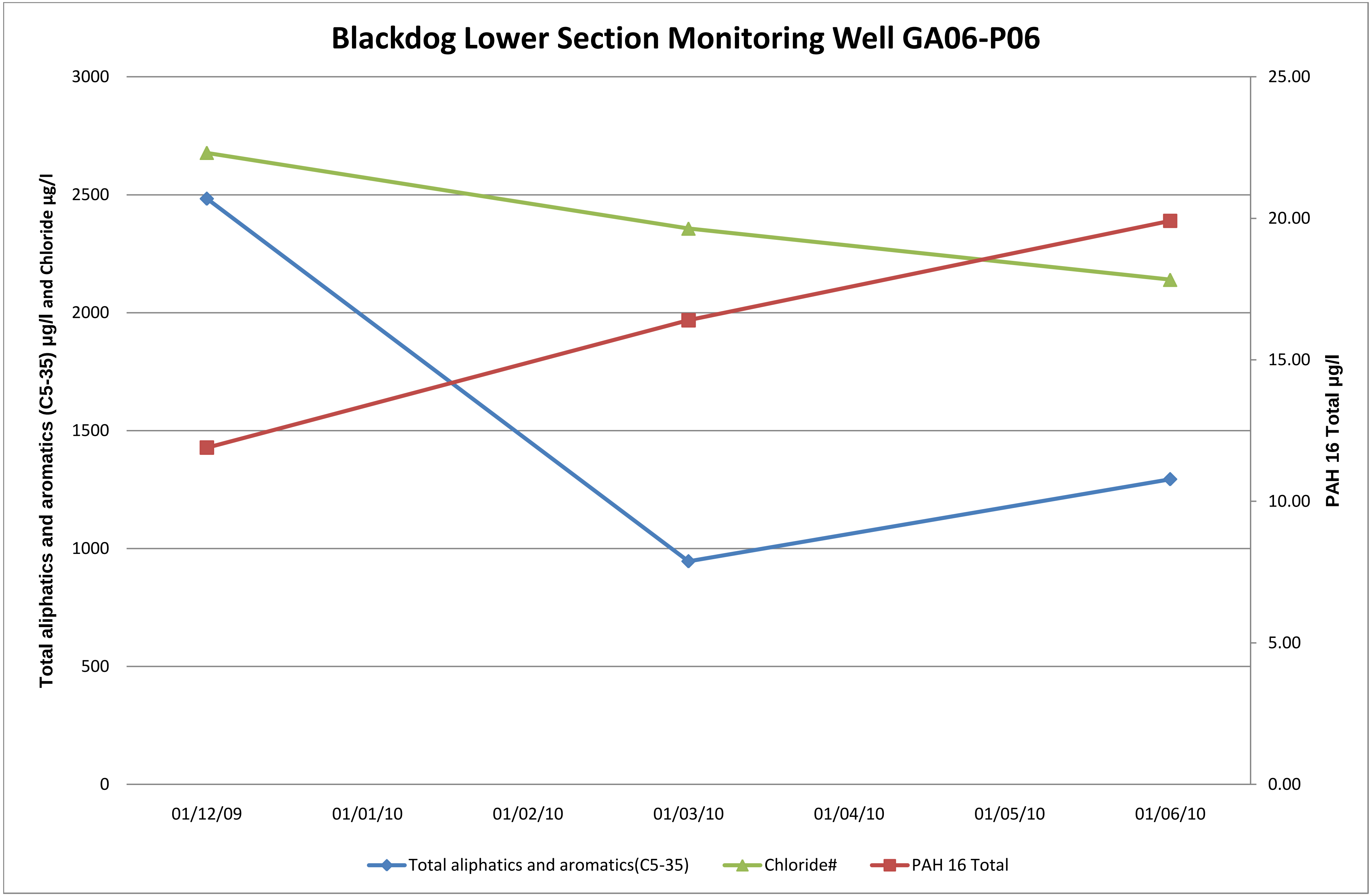

Blackdog Eastern Boundary Monitoring Well GA08
Total aliphatics and aromatics (C5-35) µg/l
PAH 16 Total µg/l and Chloride µg/l
40000
35000
30000
25000
20000
15000
10000
5000
0
600
500
400
300
200
100
0
16/07/09
27/07/09
23/09/09
11/12/09
12/03/10
25/06/10
Total aliphatics and aromatics(C5-35)
PAH 16 Total
Chloride#

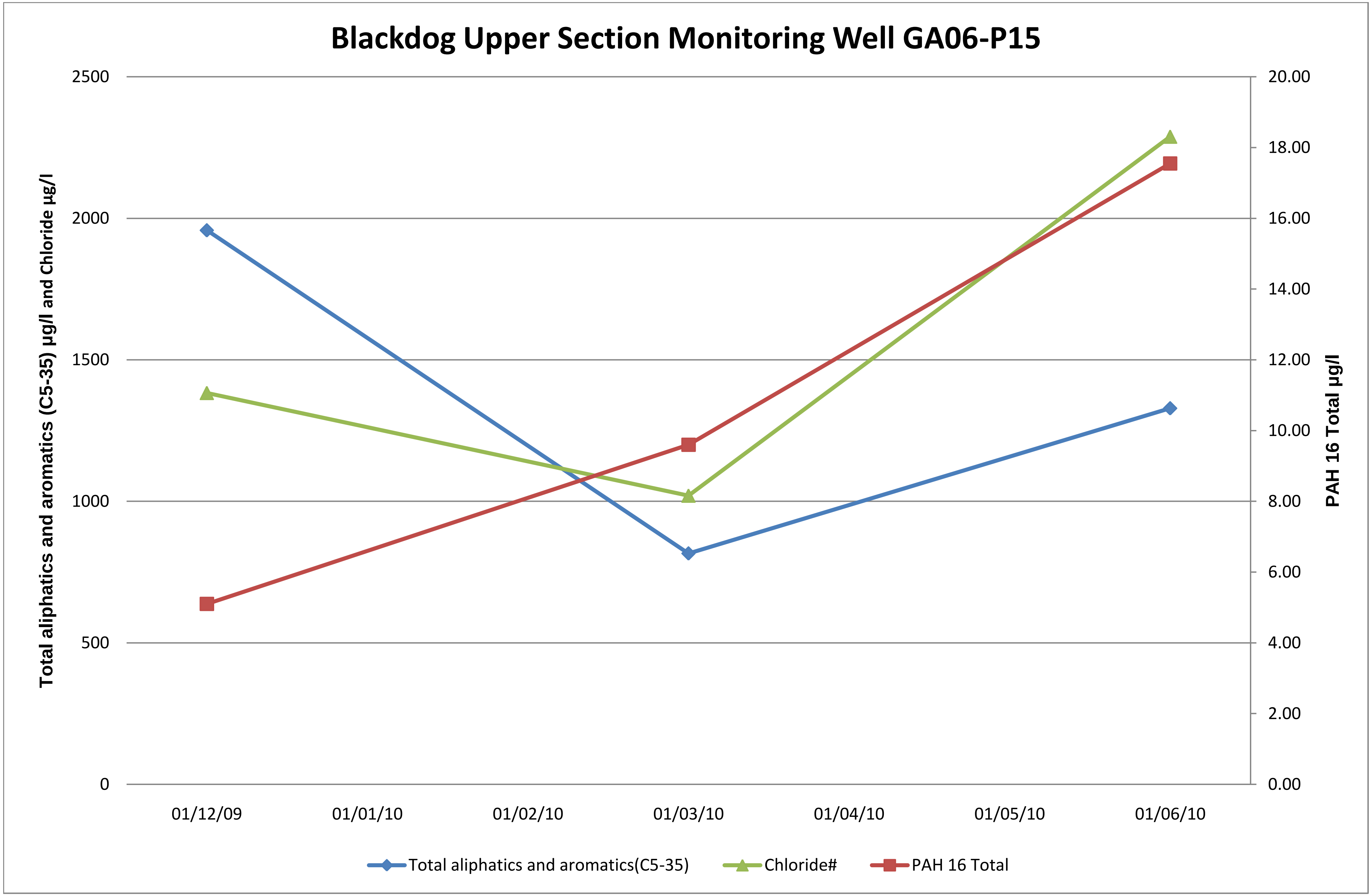


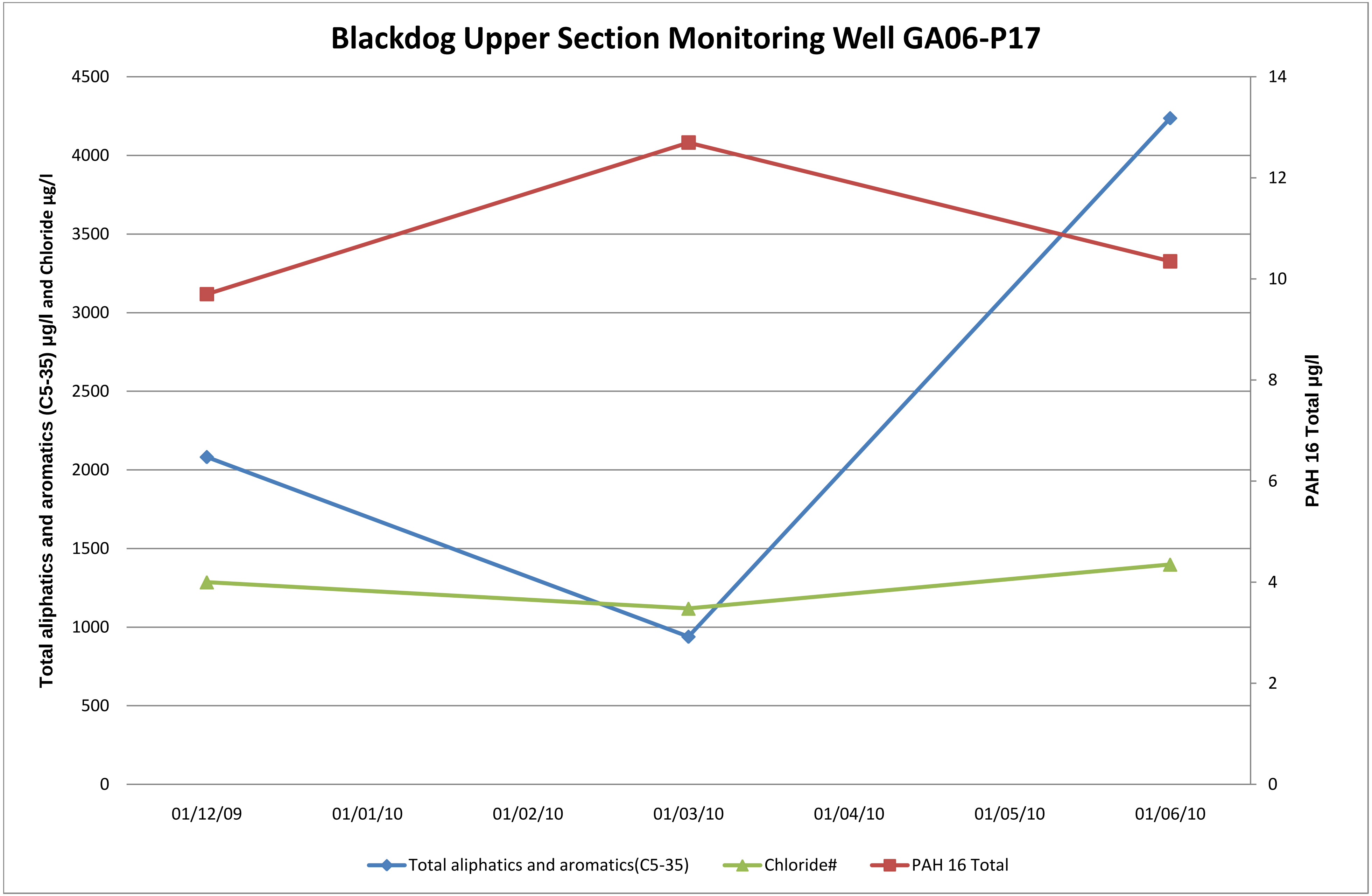
Blackdog Eastern Boundary Monitoring Well GA08B
Total aliphatics and aromatics (C5-35) µg/l
PAH 16 Total µg/l and Chloride µg/l
8000
7000
6000
5000
4000
3000
2000
1000
0
90
80
70
60
50
40
30
20
10
0
16/07/09
27/07/09
23/09/09
11/12/09
12/03/10
25/06/10
Total aliphatics and aromatics(C5-35)
PAH 16 Total
Chloride#

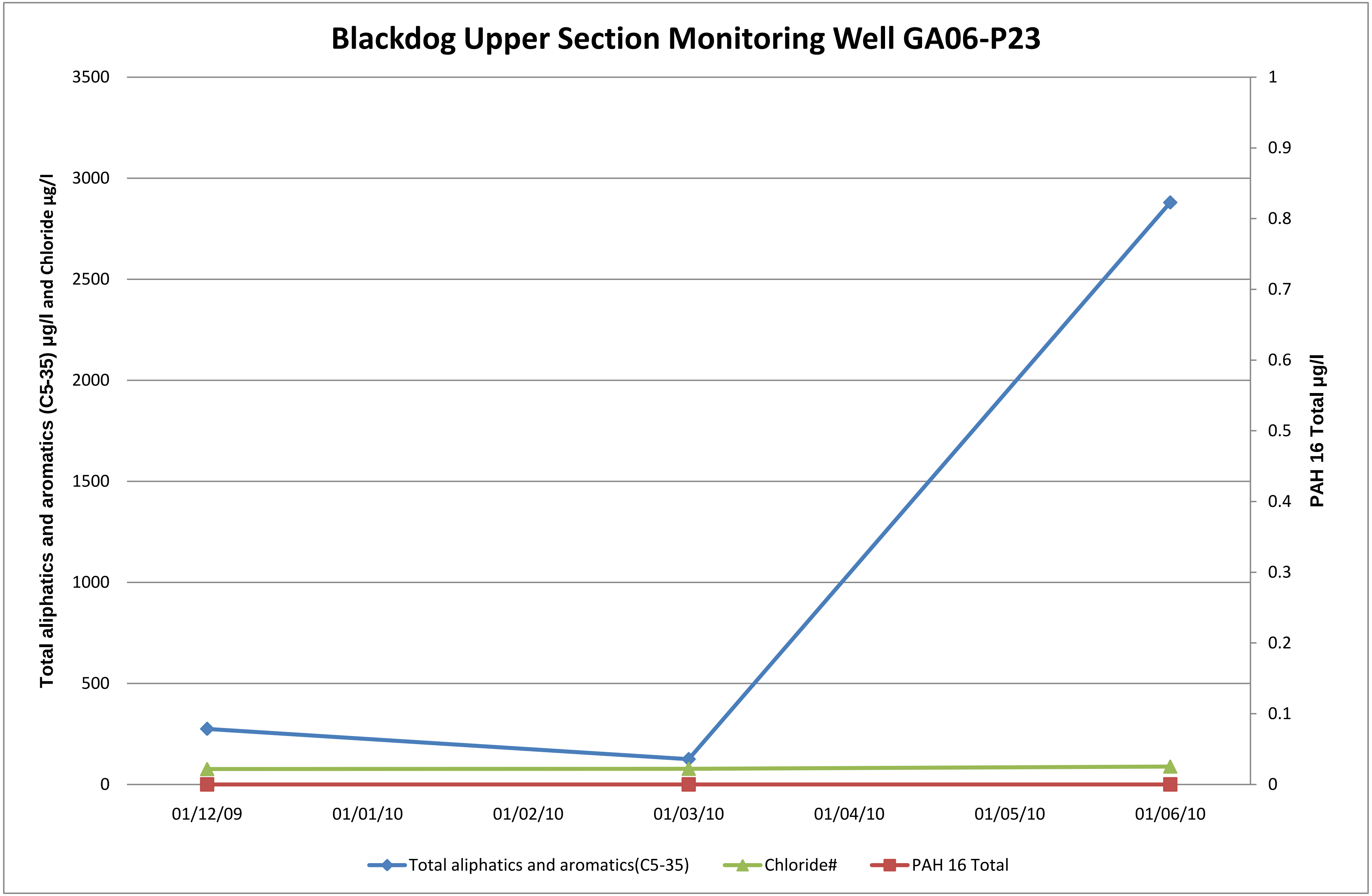

Blackdog Eastern Boundary Monitoring Well GA09
Total aliphatics and aromatics (C5-35) µg/l
PAH 16 Total µg/l and Chloride µg/l
2000000
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
1000
900
800
700
600
500
400
300
200
100
0
27/07/09
23/09/09
11/12/09
12/03/10
02/07/10
Total aliphatics and aromatics(C5-35)
PAH 16 Total
Chloride#


Blackdog Lower Section Monitoring Well GA06-P03
Total aliphatics and aromatics (C5-35) µg/l and Chloride µg/l
PAH 16 Total µg/l
1800
1600
1400
1200
1000
800
600
400
200
0
800
700
600
500
400
300
200
100
0
01/12/09
01/01/10
01/02/10
01/03/10
01/04/10
01/05/10
01/06/10
Total aliphatics and aromatics(C5-35)
Chloride#
PAH 16 Total


Blackdog Lower Section Monitoring Well GA06-P06
Total aliphatics and aromatics (C5-35) µg/l and Chloride µg/l
PAH 16 Total µg/l
3000
2500
2000
1500
1000
500
0
25.00
20.00
15.00
10.00
5.00
0.00
01/12/09
01/01/10
01/02/10
01/03/10
01/04/10
01/05/10
01/06/10
Total aliphatics and aromatics(C5-35)
Chloride#
PAH 16 Total


Blackdog Upper Section Monitoring Well GA06-P15
Total aliphatics and aromatics (C5-35) µg/l and Chloride µg/l
PAH 16 Total µg/l
2500
2000
1500
1000
500
0
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
01/12/09
01/01/10
01/02/10
01/03/10
01/04/10
01/05/10
01/06/10
Total aliphatics and aromatics(C5-35)
Chloride#
PAH 16 Total


Blackdog Upper Section Monitoring Well GA06-P17
Total aliphatics and aromatics (C5-35) µg/l and Chloride µg/l
PAH 16 Total µg/l
4500
4000
3500
3000
2500
2000
1500
1000
500
0
14
12
10
8
6
4
2
0
01/12/09
01/01/10
01/02/10
01/03/10
01/04/10
01/05/10
01/06/10
Total aliphatics and aromatics(C5-35)
Chloride#
PAH 16 Total



Blackdog Upper Section Monitoring Well GA06-P23
Total aliphatics and aromatics (C5-35) µg/l and Chloride µg/l
PAH 16 Total µg/l
3500
3000
2500
2000
1500
1000
500
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
01/12/09
01/01/10
01/02/10
01/03/10
01/04/10
01/05/10
01/06/10
Total aliphatics and aromatics(C5-35)
Chloride#
PAH 16 Total

APPENDIX E

Tier 1 Screening Results

Table 1: Summary of Determinands Identified as a Potential Concern Following a Groundwater GQRA

Determinands Identified as a Concern in Groundwater	Area of Landfill and Borehole Determinand Identified	Concentration Range (µg/l) (Above Criteria)	Tier 1 Assessment Criteria (µg/l)	Tier 1 Assessment Criteria Source
Total Aliphatics >C5-C35	Upper Section		10	Taste/Odour Threshold
	GA06-P15	388 – 691		
	GA06-P17	441 – 3,217		
	GA06-P23	125 – 2,429		
	Lower Section			
	GA06-P03	58 – 641		
	GA06-P06	549 – 954		
	Eastern Boundary			
	GA06	24 – 7,853		
	GA07	698 – 200,294		
	GA08	29 – 22,244		
	GA08B	274 – 5,047		
	GA09	7,330 – 1,410,093		
Total Aromatics C5-C35	Upper Section		10	Taste/Odour Threshold
	GA06-P15	428 – 1,267		
	GA06-P17	498 – 1,124		
	GA06-P23	97 - 451		
	Lower Section			
	GA06-P03	338 – 948		
	GA06-P06	397 – 1,529		
	Eastern Boundary			
	GA05	49		
	GA06	151 - 721		
	GA07	314 – 68,080		
	GA08	80 – 12,818		
	GA08B	51 – 2,121		
	GA09	2,128 – 364,903		
Total Aliphatics & Aromatics >C5-35	Upper Section		10	Taste/Odour Threshold
	GA06-P15	816 – 1,958		
	GA06-P17	939 – 4,237		
	GA06-P23	125 – 2,880		
	Lower Section			
	GA06-P03	396 – 1,589		
	GA06-P06	946 – 2,483		
	Eastern Boundary			
	GA05	49		
	GA06	24 – 5,040		
	GA07	1,012 – 268,374		
	GA08	109 – 35,062		
	GA08B	325 – 7,168		
	GA09	9,458 – 1,774,996		

Determinands Identified as a Concern in Groundwater	Area of Landfill and Borehole Determinand Identified	Concentration Range (µg/l) (Above Criteria)	Tier 1 Assessment Criteria (µg/l)	Tier 1 Assessment Criteria Source
Benzene	Upper Section GA06-P15	13 - 14	10	AA-EQS Inland Surface Waters and Saltwater
	Lower Section GA06-P03 GA06-P06	14 26 – 50		
	Eastern Boundary GA09	14 – 22		
Toluene	Lower Section GA06-P06	149	50 40	EQS FW EQS Saltwater
m & p Xylene	Upper Section GA06-P15 GA06-P17 GA06-P23	70 – 458 76 – 402 29 - 75	30	EQS FW and Saltwater
	Lower Section GA06-P03 GA06-P06	260 – 378 152 – 376		
	Eastern Boundary GA07 GA09	44 52 – 127		
o Xylene	Upper Section GA06-P15 GA06-P17	56 – 110 32 – 126	30	EQS FW and Saltwater
	Lower Section GA06-P06	70 – 139		
	Eastern Boundary GA09	53 – 90		
Naphthalene	Upper Section GA06-BH3 GA06-P15 GA06-P17	40.9 5.1 – 15.11 7.67 – 10.3	2.4	AA-EQS Inland surface waters and Saltwater
	Lower Section GA06-P03 GA06-P06 GA06-P08	37.7 – 99.9 10.8 – 17.89 205		
	Eastern Boundary GA05 GA06 GA07 GA08 GA09	2 2.5 – 5 10 – 126 15 – 44 8 – 277		

Determinands Identified as a Concern in Groundwater	Area of Landfill and Borehole Determinand Identified	Concentration Range (µg/l) (Above Criteria)	Tier 1 Assessment Criteria (µg/l)	Tier 1 Assessment Criteria Source
Anthracene	Upper Section GA06-BH3	4.4	0.1	AA-EQS Inland surface waters and Saltwater
	Lower Section GA06-P08	0.8		
	Eastern Boundary GA04 GA07 GA09	1.8 0.4 – 7.7 1.4		
Fluoranthene	Upper Section GA06-BH3	4.7	0.1	AA-EQS Inland surface waters and Saltwater
	Lower Section GA06-P08	2		
	Eastern Boundary GA04 GA07 GA08B	3 0.6 – 3 0.5		
Benz(a)anthracene	Eastern Boundary GA07 GA08 GA08B GA09	0.4 – 6 1.1 0.4 6	0.029	US EPA RSL
Chrysene	Eastern Boundary GA07 GA09	3 – 11 7 - 8	2.9	US EPA RSL
PAH 16 Total	Upper Section GA06-BH3 GA06-P15 GA06-P17	83 5.1 – 17.55 9.7 – 12.7	0.1	EU DWS
	Lower Section GA06-P03 GA06-P06 GA06-P08	44 – 106.5 11.9 – 19.91 218		
	Eastern Boundary GA04 GA05 GA06 GA07 GA08 GA08B GA09	30 2 4.2 – 7.9 4.5 – 295.6 1.8 – 77.6 6.31 – 8 57.8 – 698		

APPENDIX F

Probabilistic Calculation of Groundwater Flow Volume and Mass of Dissolved Phase Hydrocarbon Migration

Rate of Hydrocarbon Mass Flux	Distribution	Min	Mean/Median	Max	SD	
Concentration of TPH observed in groundwater on down gradient site boundary (µg/l)	Log triangular	85	1643	13369		5495.409
		1.929419	3.215538428	4.126099		3.74
Total volume of groundwater flow (sum of outflows from leakage from site and groundwater underflow) (m^3/day)	Normal		148		14.8	148
Mass of dissolved phase TPH leaving eastern site boundary per day (kg)						0.81332

Mass of dissolved phase TPH leaving S boundary (kg)	Percentiles
0.19	50.0%
0.89	95.0%

Source Term Specification

Total dissolved TPH (Aliphatics & Aromatics >C5-C35) (µg/l)				08/12/09	09/03/10	23/06/10
GA05				49	5	5
	14/07/09	21/07/09	21/09/09	08/12/09	09/03/10	23/06/10
GA06	495	24	5040	2581	1103	5
	14/07/09	21/07/09	21/09/09	08/12/09	09/03/10	23/06/10
GA08	295	23816	35062	1345	109	5
	14/07/09	21/07/09	21/09/09	08/12/09	09/03/10	23/06/10
GA8B	5	5	5	781	7168	325
Average along southern boundary for monitoring round	265	7948	13369	1189	2096	85
	Min	**Median**	**Max**			
	85	1643	13369			

TPH Concentration in Seawater	Distribution	Min	Mean/Median	Max	SD	Predicted from Sheet 1	Value
Concentration of TPH observed in groundwater on down gradient site boundary (µg/l)						5495.408739	
Concentration of TPH observed in groundwater on down gradient site boundary (µg/m^3)						5495408.739	
Total volume of groundwater flow (sum of outflows from leakage from site and groundwater underflow) (m^3/day)							148
Distance between low tide and high tide (m) Ordnance Survey (2009)							120
Width of site (m)			420				420
Typical tidal range (m)		1.5		3			2
Seawater dilution potential per tide (m^3)							50400
Seawater dilution potential per day (m^3)							100800
Seawater dilution per day + groundwater inflow (m^3)							100948
Total dissolved TPH (Aliphatics & Aromatics >C5-C35) (µg/l)							
Concentration in seawater (µg/m^3)							8057
Concentration in seawater (µg/l)							8

Concentration in seawater (µg/l)	Percentile
1.7	50.00%
8.2	95.00%

APPENDIX G

Quarterly Beach Monitoring Results

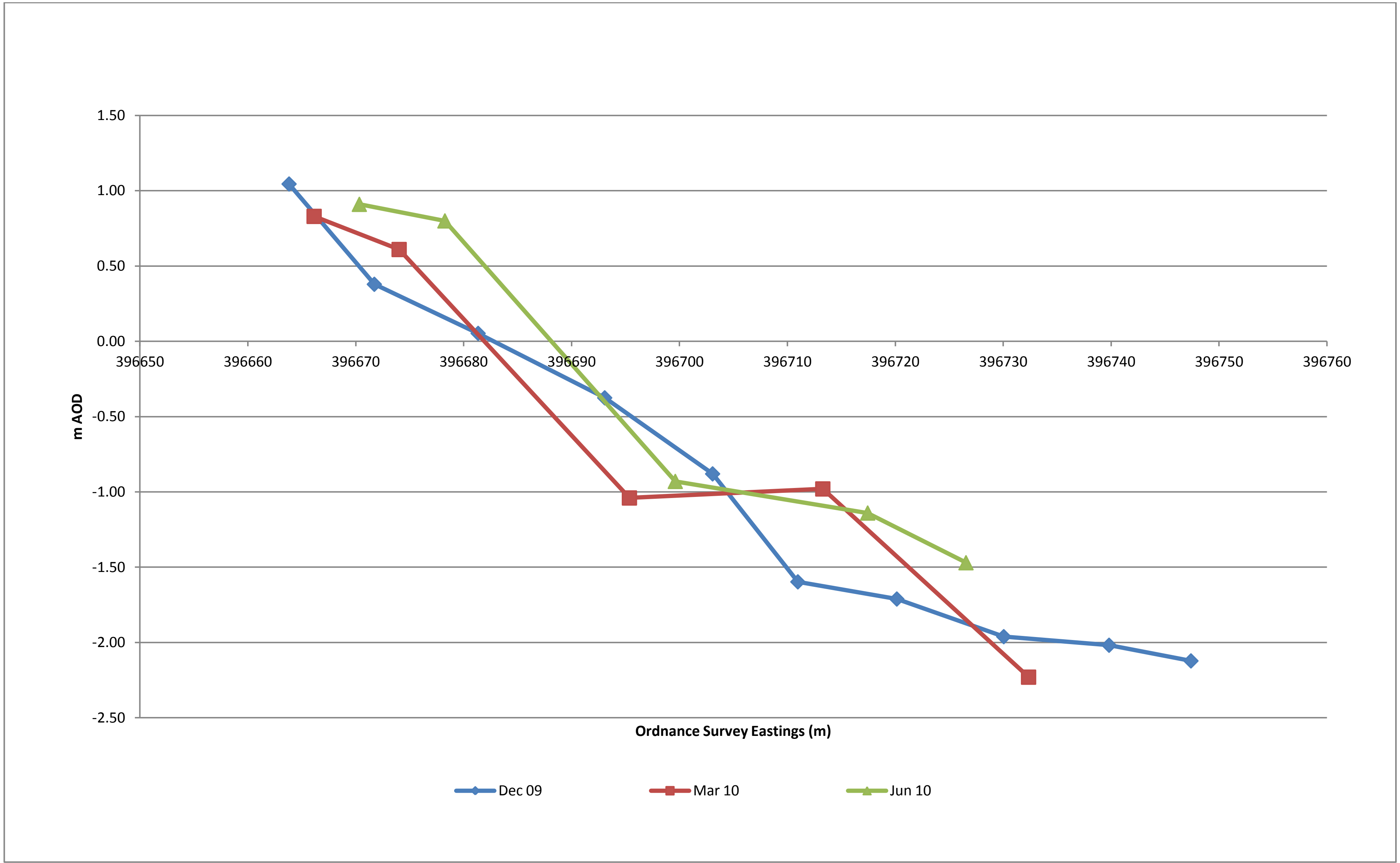


Figure 1: Elevation of the Top of Contamination within Section 1

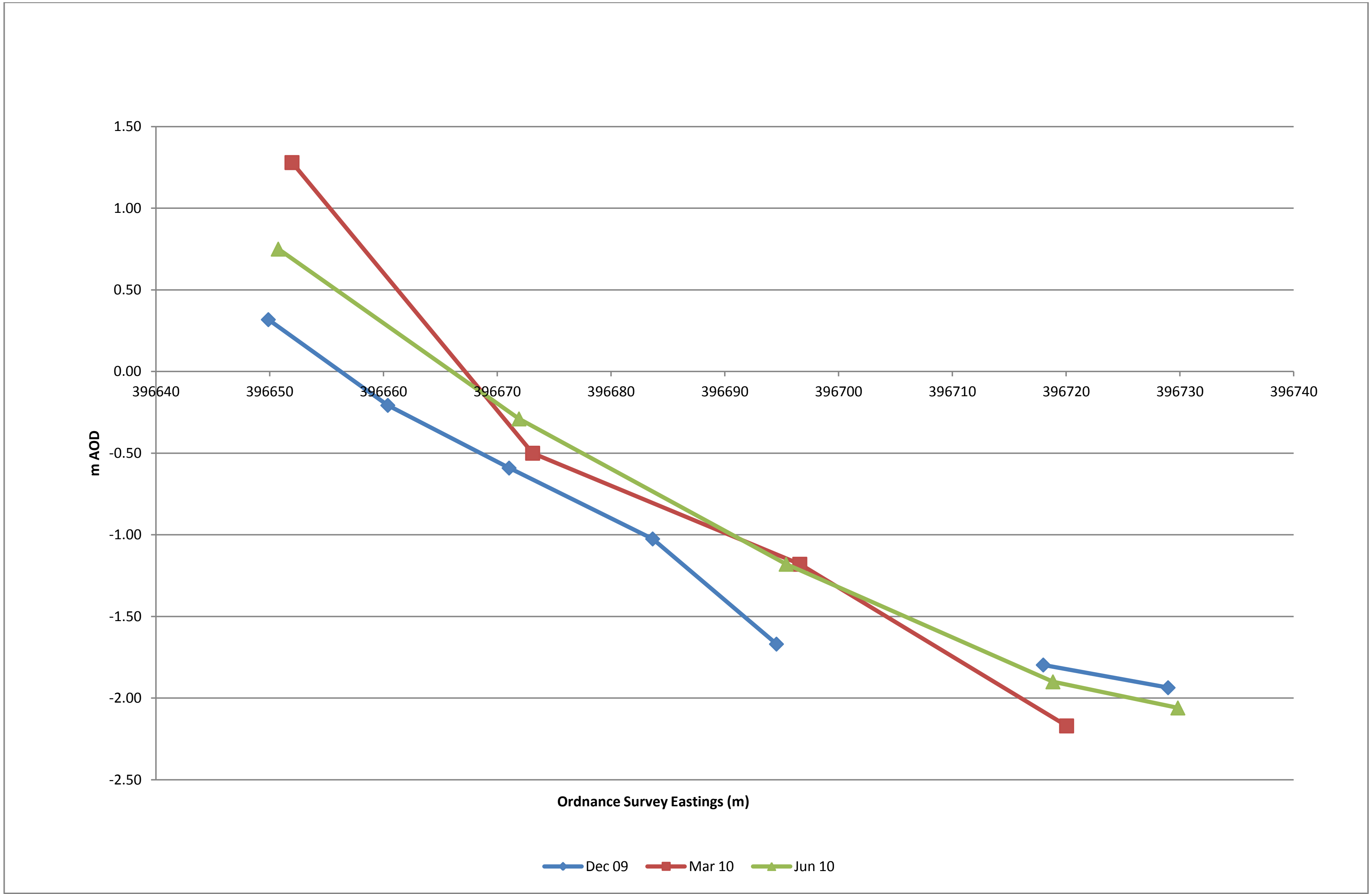
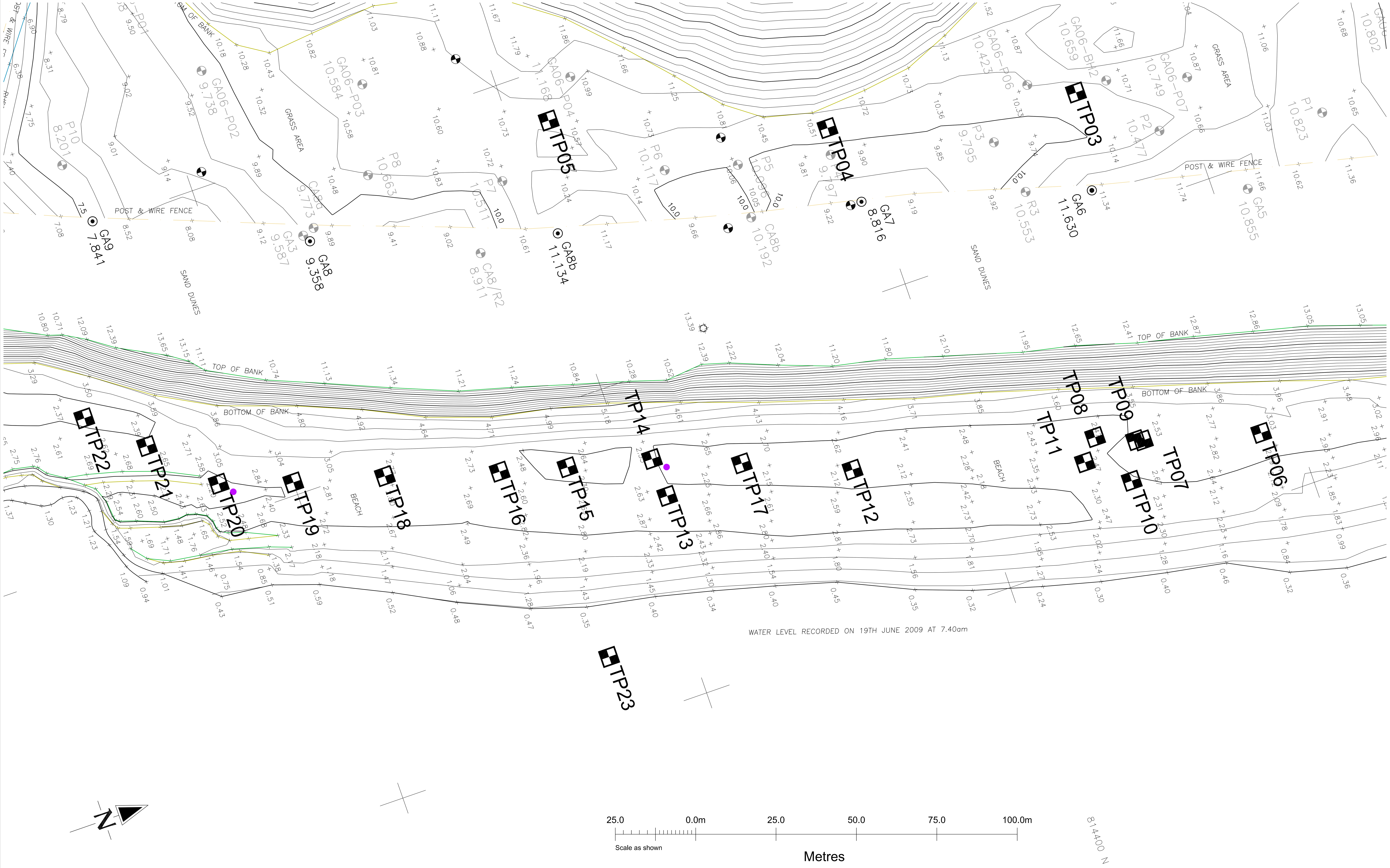


Figure 2: Elevation of the Top of Contamination within Section 2



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Legend:-

Plan

Slight Hydrocarbon Odour | Strong Hydrocarbon Odour

PID Reading (ppm) 4.6 | 0.16 Elevation of PID Reading (mAOD)

Note that no PID measurements were taken during the first round of monitoring.

No.	Date	Revision	By	Chk
0	-	First Issue	-	-

Drawn	R Harrison	Date	July 2011
Checked	L Barlow	Date	July 2011
Approved	R Apted	Date	July 2011

Client / Project

Smallbrook Environmental Ltd.

Blackdog Landfill Site

Title

Figure 1:

Monitoring Period 1: June 2009

Cross Sections and Plans with Hydrocarbon Odours and PID Readings

File Ref : BD-SEC-01a - Odour	Drawing No : Figure 1	
Original Drawing Size: 841x594 - A1	Scale : As shown	Rev : 0

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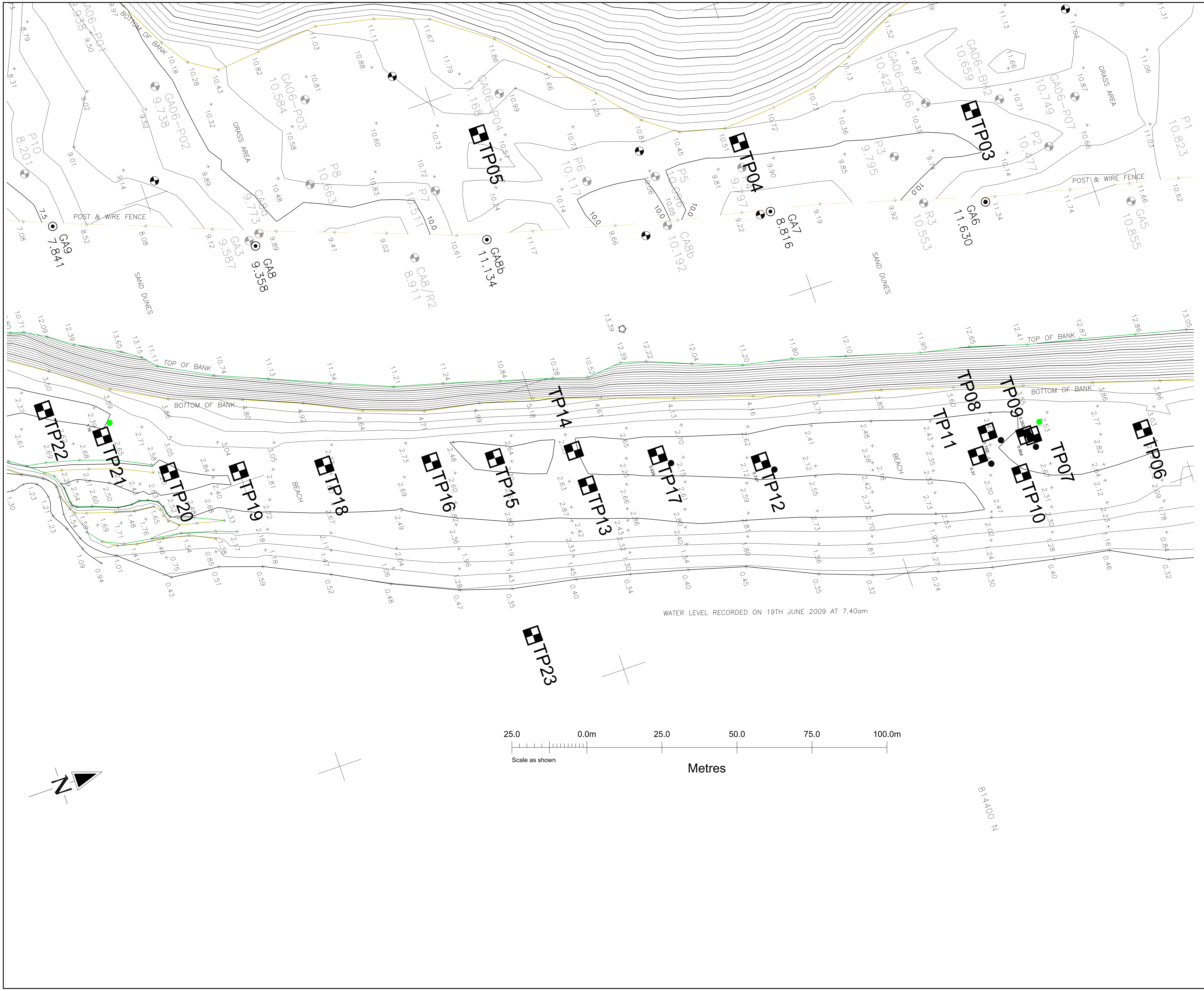

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Legend:-

Plan

Green Stained Sand Encountered

Black Stained Sand Encountered

Elevation of Upper Level of Green Staining (mAOD) 0.1

0.3 Elevation of Upper Level of Black Staining (mAOD)

No.	Date	Revision	By	Chk
0	-	First Issue	-	-

Drawn R Harrison	Date July 2011
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Approved R Apted	Date July 2011

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Title

Figure 2:

Monitoring Period 1: June 2009

Cross Sections and Plans with Elevation of Green and Black Stained Sand

File Ref : BD-SEC-01a - Stain	Drawing No : Figure 2	
Original Drawing Size: 841x594 - A1	Scale : As shown	Rev : 0

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Legend:-

Cross Section

- Clean
- Black Stained Sand
- Green Stained Sand
- Slight Hydrocarbon Odour
- Strong Hydrocarbon Odour
- Water Strike
- PID Reading

Plan

Slight Hydrocarbon Odour
Strong Hydrocarbon Odour
PID Reading (ppm) 4.6
0.16 Elevation of PID Reading (mAOD)

No.	Date	Revision	By	Chk
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Drawn R Harrison	Date July 2011
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Title

Figure 3:

Monitoring Period 2: September 2009

Cross Sections and Plans with Hydrocarbon Odours and PID Readings

File Ref : BD-SEC-02a - Odour	Drawing No : Figure 3	
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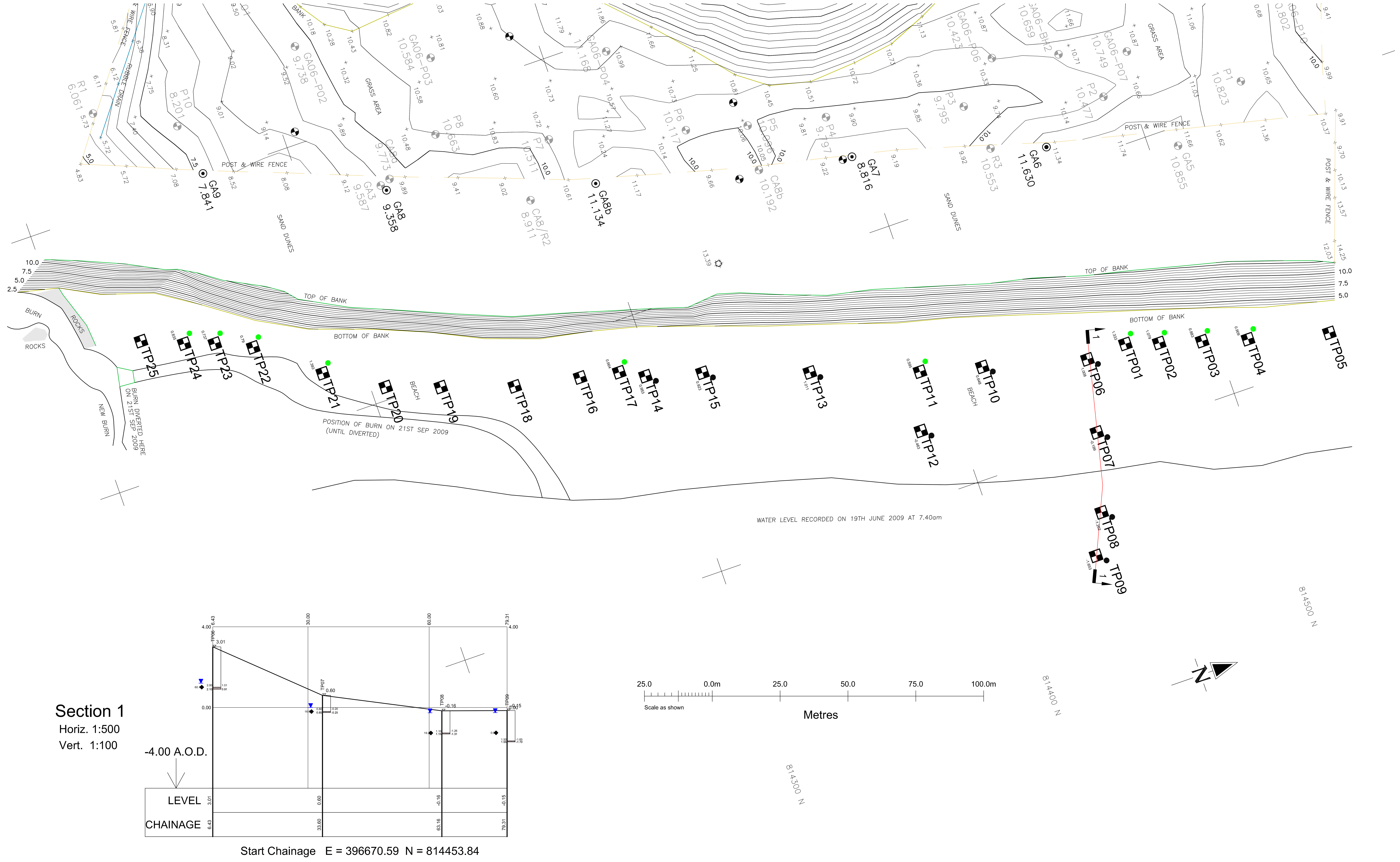

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Legend:-

Cross Section

- Clean
- Black Stained Sand
- Green Stained Sand
- Slight Hydrocarbon Odour
- Strong Hydrocarbon Odour
- Water Strike
- PID Reading

Plan

Green Stained Sand Encountered — Black Stained Sand Encountered

Elevation of Upper Level of Green Staining (mAOD) 0.1 — 0.3 Elevation of Upper Level of Black Staining (mAOD)

No.	Date	Revision	By	Chk
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Title

Figure 4:

Monitoring Period 2: September 2009

Cross Sections and Plans with Elevation of Green and Black Stained Sand

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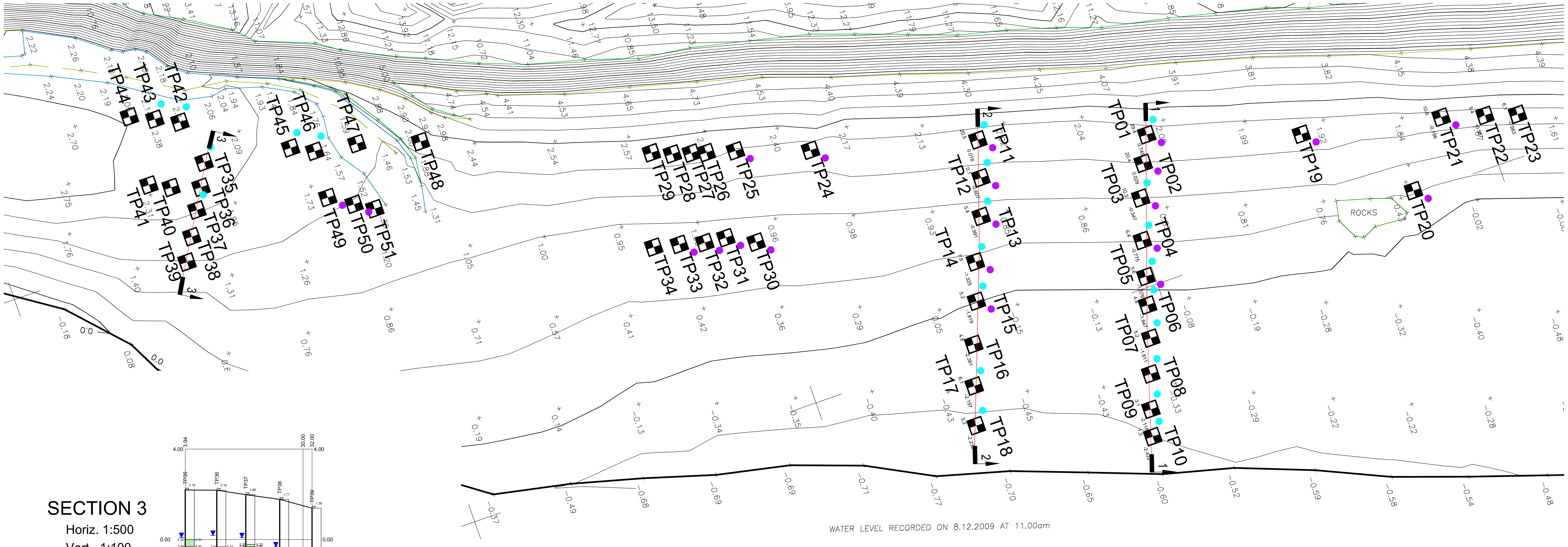
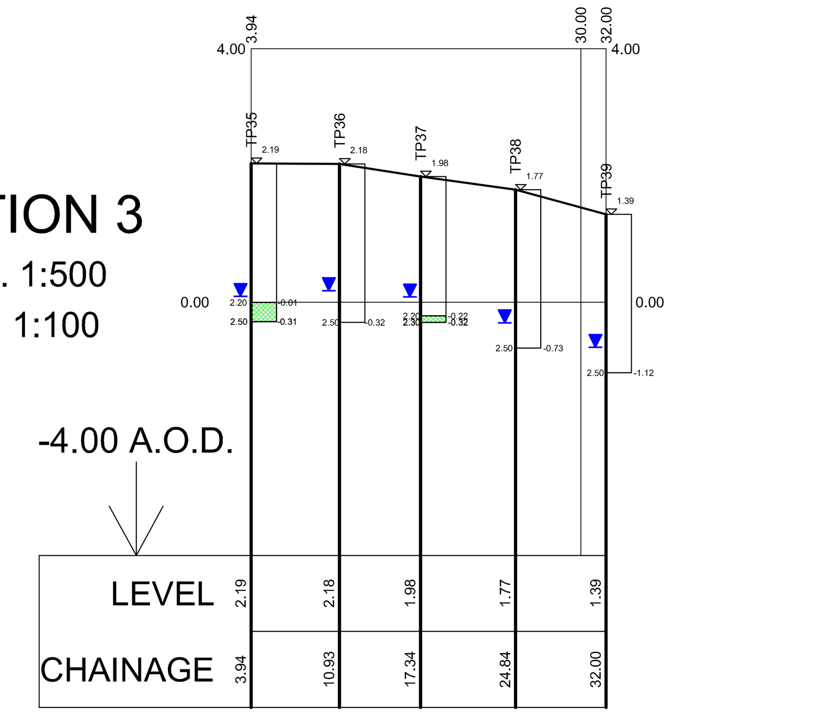


SECTION 3

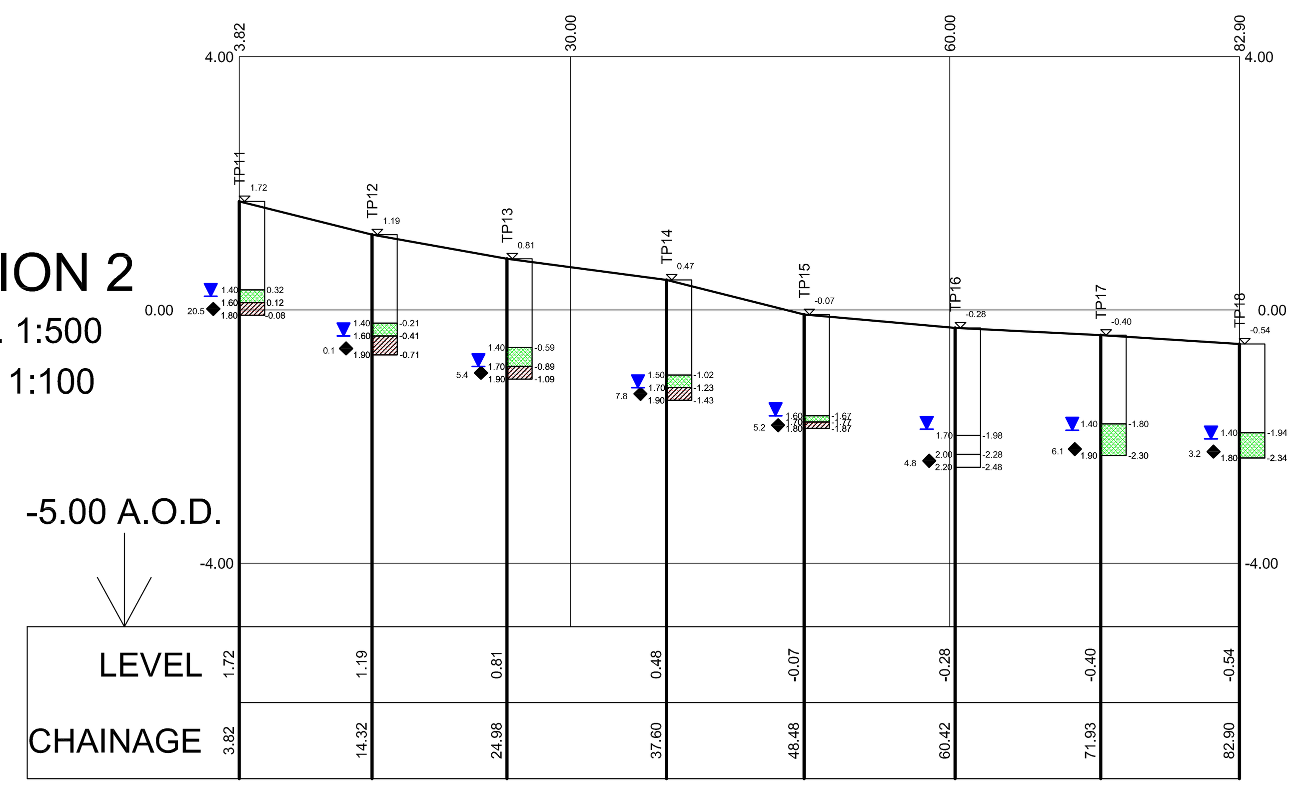
Horiz. 1:500
Vert. 1:100



Start Chainage E = 396581.58 N = 814162.41

SECTION 2

Horiz. 1:500
Vert. 1:100



Start Chainage E = 396646.06 N = 814366.27

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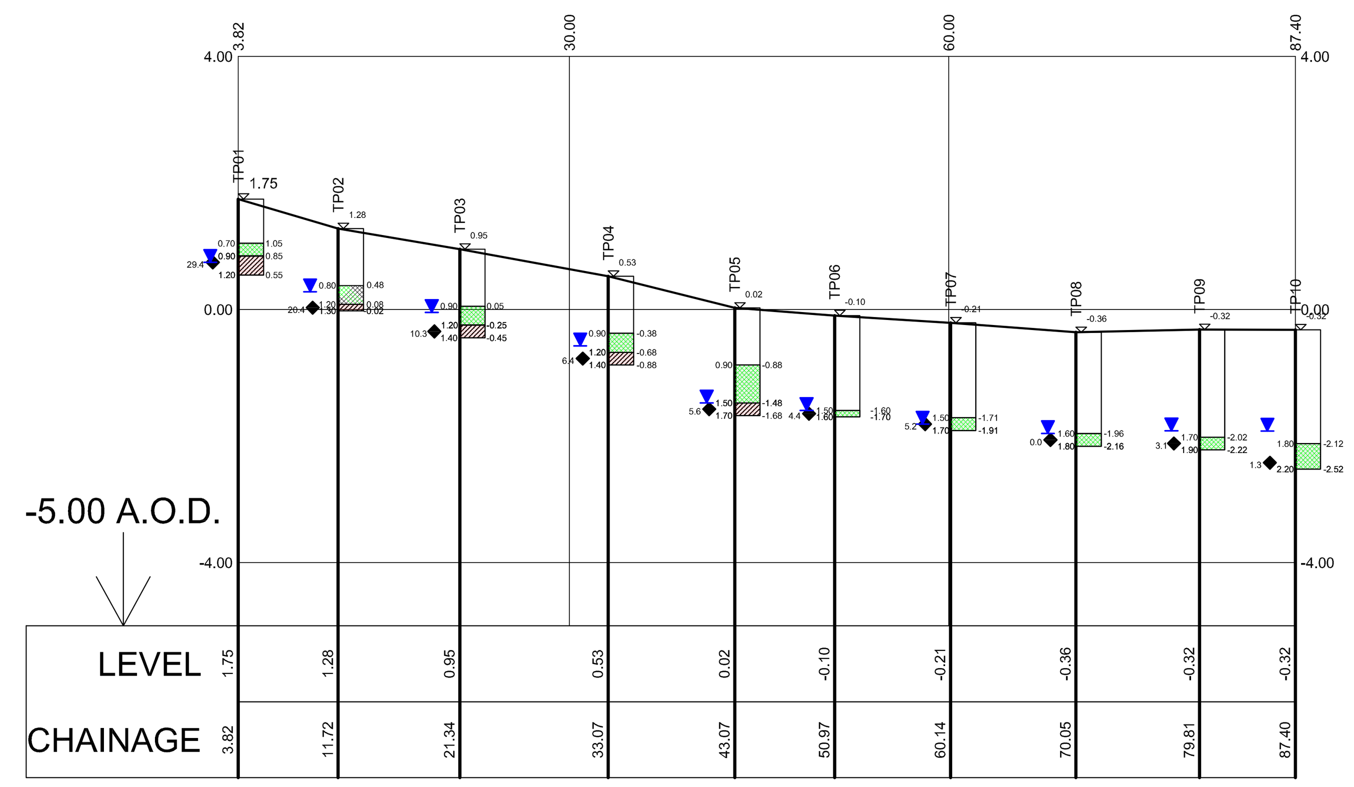
Horiz. 1:500
Vert. 1:100



Start Chainage E = 396660.00 N = 814410.63

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Legend:-

Cross Section

- Clean
- Black Stained Sand
- Green Stained Sand
- Slight Hydrocarbon Odour
- Strong Hydrocarbon Odour
- Water Strike
- PID Reading

Plan

Slight Hydrocarbon Odour
Strong Hydrocarbon Odour
PID Reading (ppm) 4.6
0.16 Elevation of PID Reading (mAOD)

No.	Date	Revision	By	Chk
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Figure 5:

Monitoring Period 3: December 2009

Cross Sections and Plans with Hydrocarbon Odours and PID Readings

File Ref : BD-SEC-03a - Odour
Drawing No : Figure 5
Original Drawing Size: 841x594 - A1
Scale : As shown
Rev : 0

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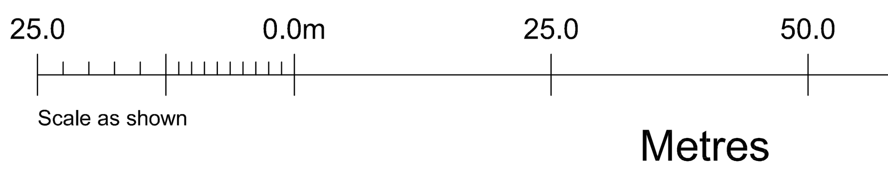
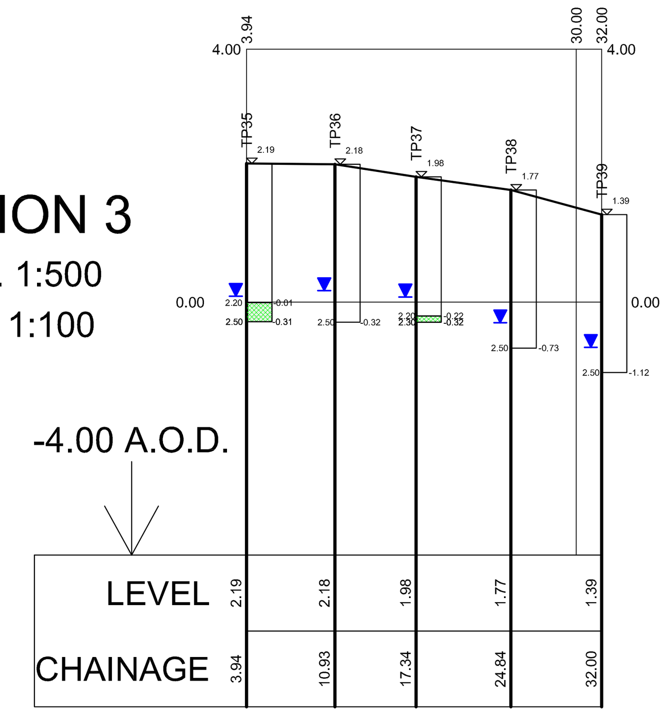


SECTION 3

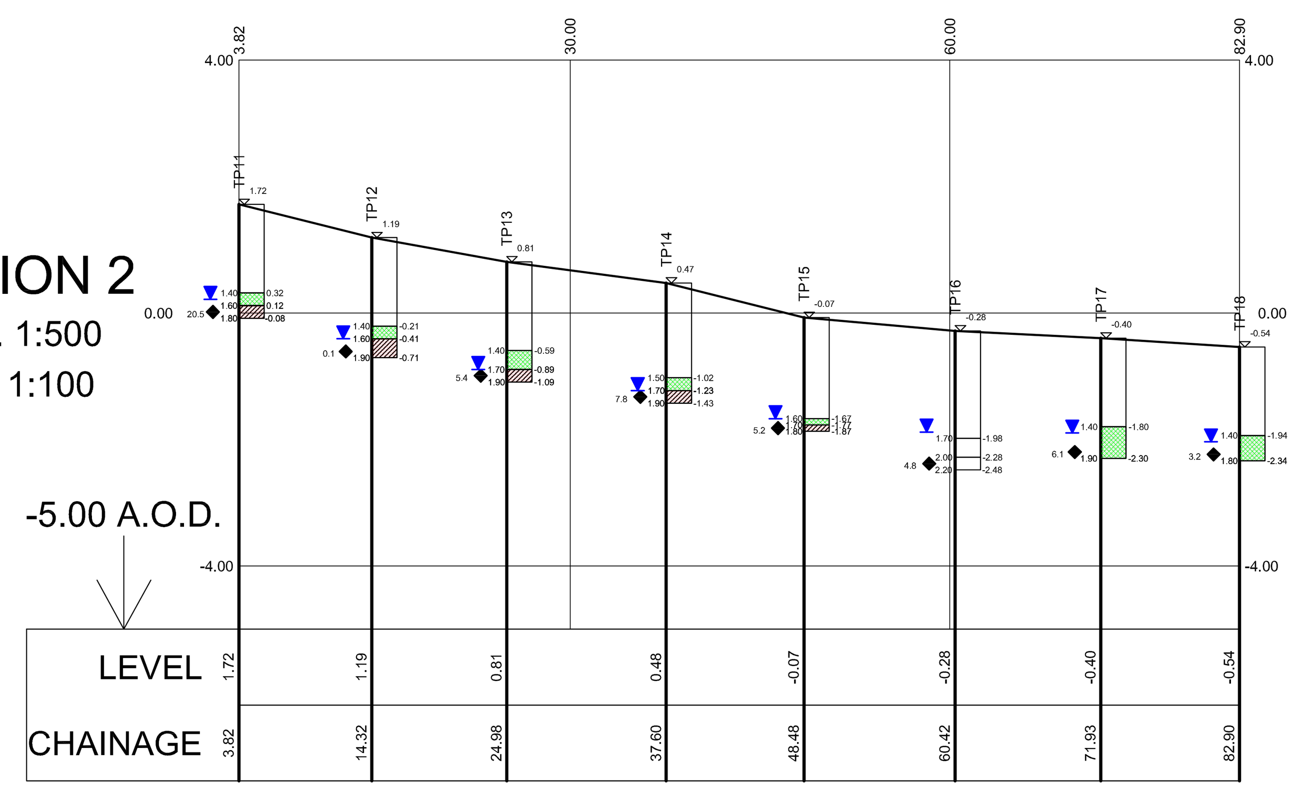
Horiz. 1:500
Vert. 1:100



Start Chainage E = 396581.58 N = 814162.41

SECTION 2

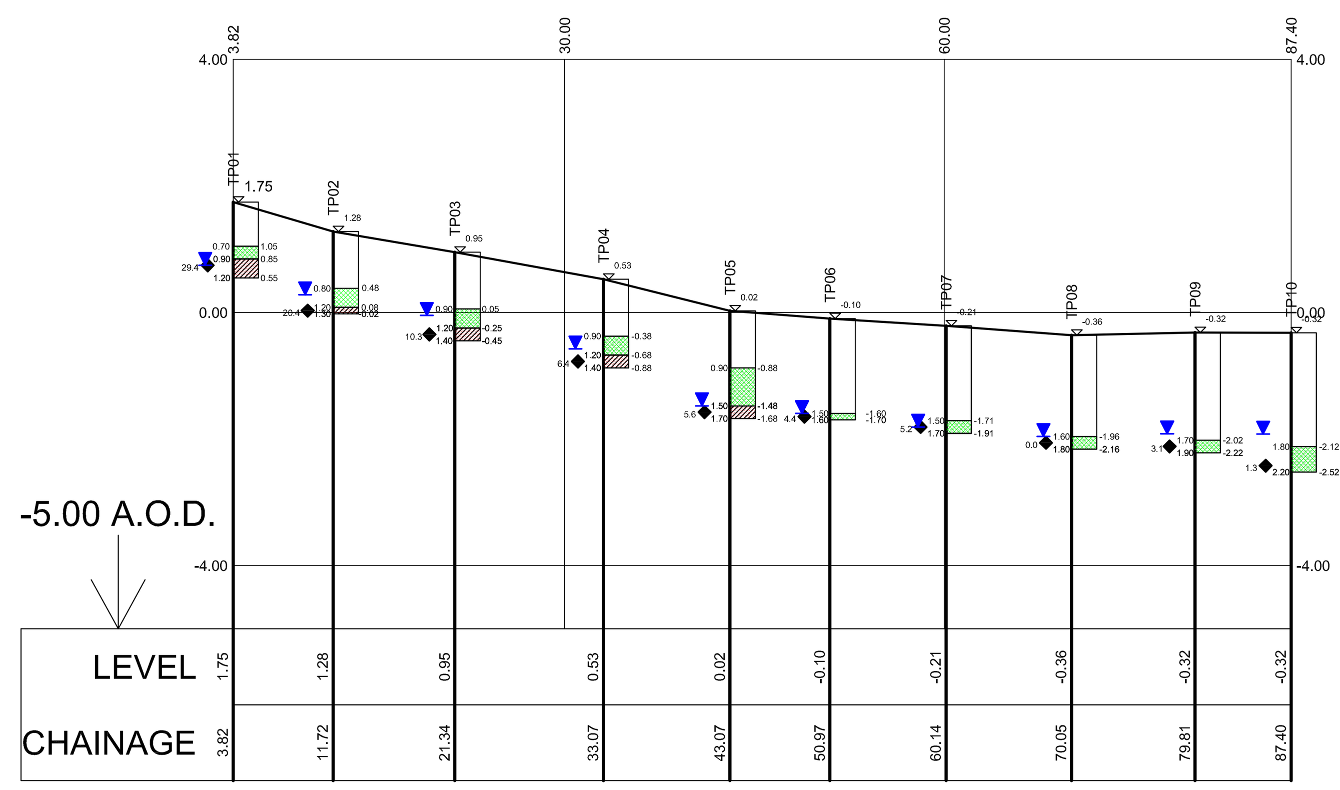
Horiz. 1:500
Vert. 1:100



Start Chainage E = 396646.06 N = 814366.27

SECTION 1

Horiz. 1:500
Vert. 1:100



Start Chainage E = 396660.00 N = 814410.63

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Legend:-

Cross Section

- Clean
- Black Stained Sand
- Green Stained Sand
- Slight Hydrocarbon Odour
- Strong Hydrocarbon Odour
- Water Strike
- PID Reading

Plan

Green Stained Sand Encountered — Black Stained Sand Encountered

0.1 — 0.3

Elevation of Upper Level of Green Staining (mAOD) — Elevation of Upper Level of Black Staining (mAOD)

No.	Date	Revision	By	Chk
0	-	First Issue	-	-

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Client / Project

Smallbrook Environmental Ltd.

Blackdog Landfill Site

Title

Figure 6:

Monitoring Period 3: December 2009

Cross Sections and Plans with Elevation of Green and Black Stained Sand

File Ref : BD-SEC-03a - Stain	Drawing No : Figure 6	
Original Drawing Size: 841x594 - A1	Scale : As shown	Rev : 0

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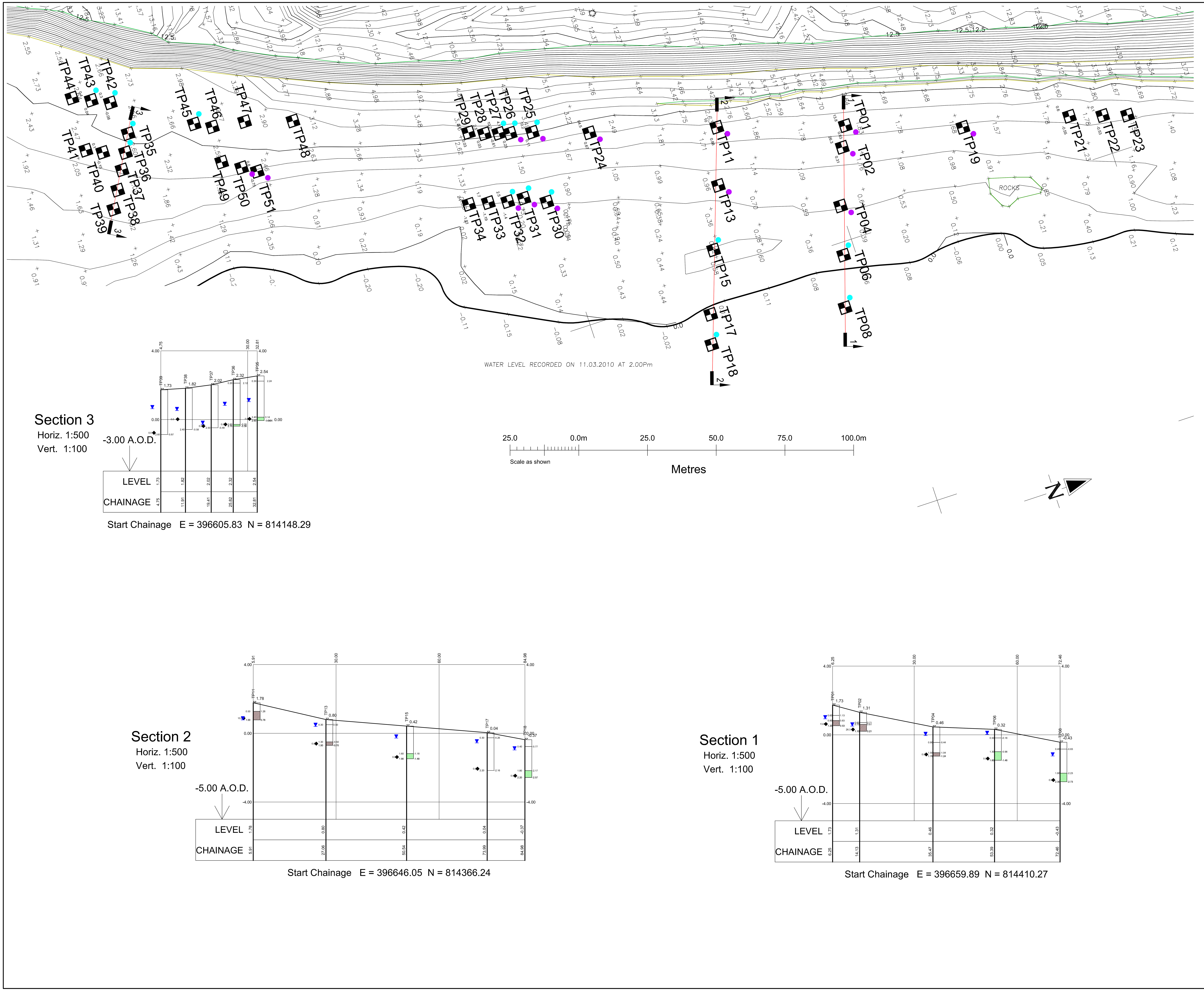

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Legend:-

Cross Section

- Clean
- Black Stained Sand
- Green Stained Sand
- Slight Hydrocarbon Odour
- Strong Hydrocarbon Odour
- Water Strike
- PID Reading

Plan

Slight Hydrocarbon Odour — Strong Hydrocarbon Odour

PID Reading (ppm) 4.6 — 0.16 Elevation of PID Reading (mAOD)

No.	Date	Revision	By	Chk
0	-	First Issue	-	-

Drawn R Harrison	Date July 2011
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Client / Project

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Figure 7:

Monitoring Period 4: March 2010

Cross Sections and Plans with Hydrocarbon Odours and PID Readings

File Ref : BD-SEC-04a - Odour — Drawing No : Figure 7

Original Drawing Size: 841x594 - A1 — Scale : As shown — Rev : 0

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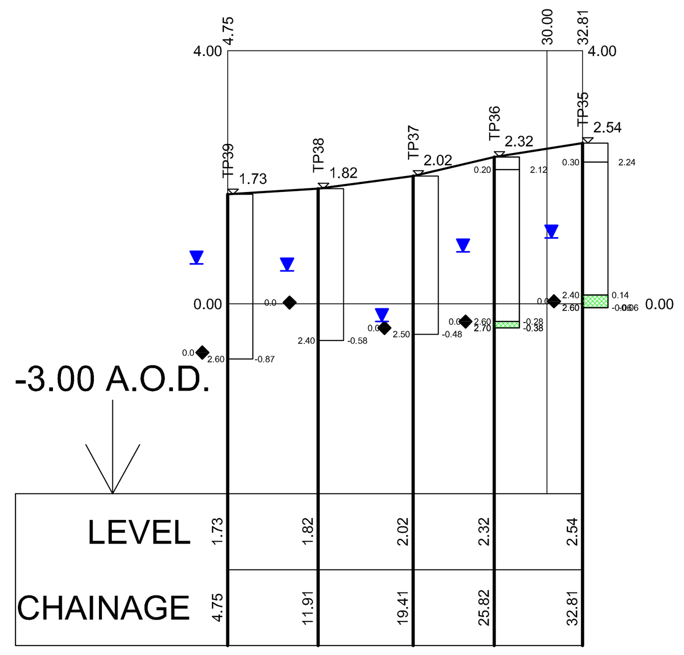
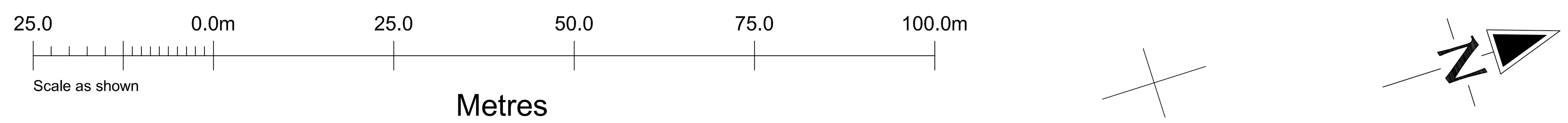
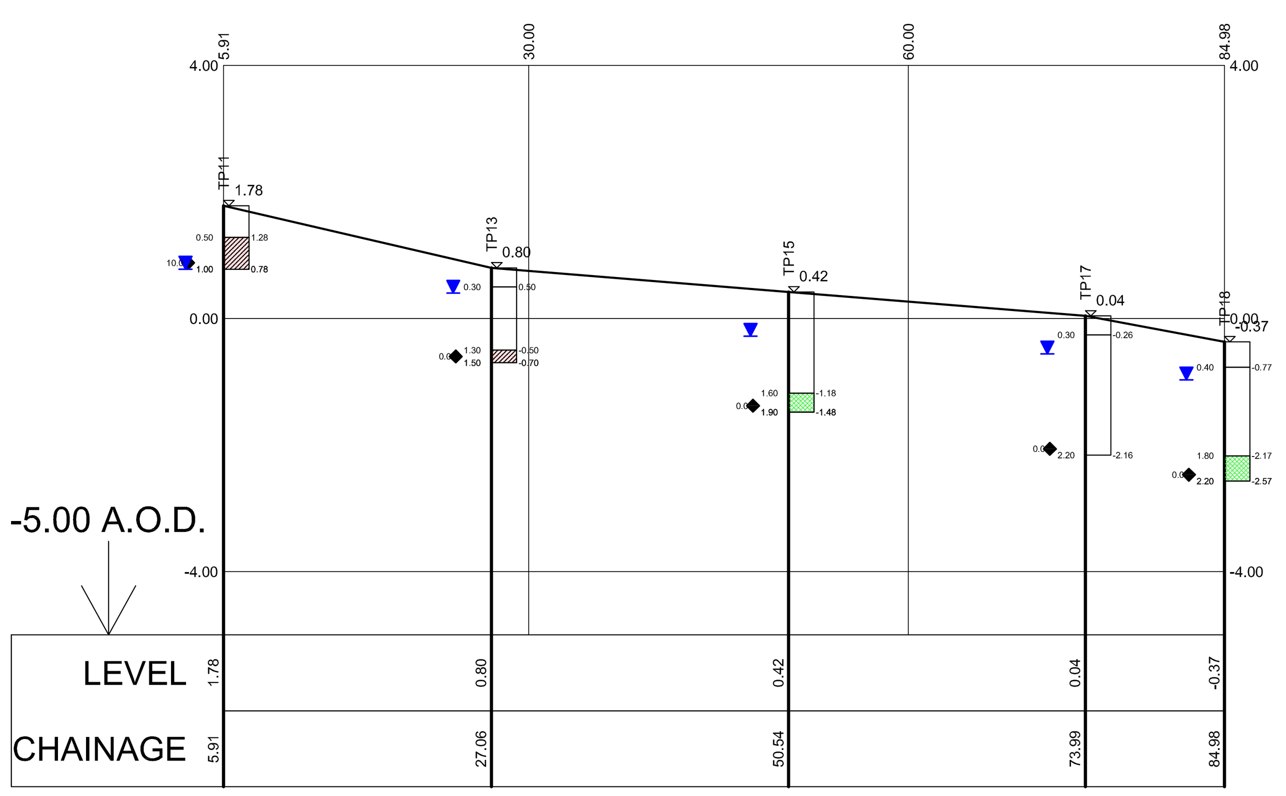
Section 3
Horiz. 1:500
Vert. 1:100



Start Chainage E = 396605.83 N = 814148.29



Section 2
Horiz. 1:500
Vert. 1:100



Start Chainage E = 396646.05 N = 814366.24

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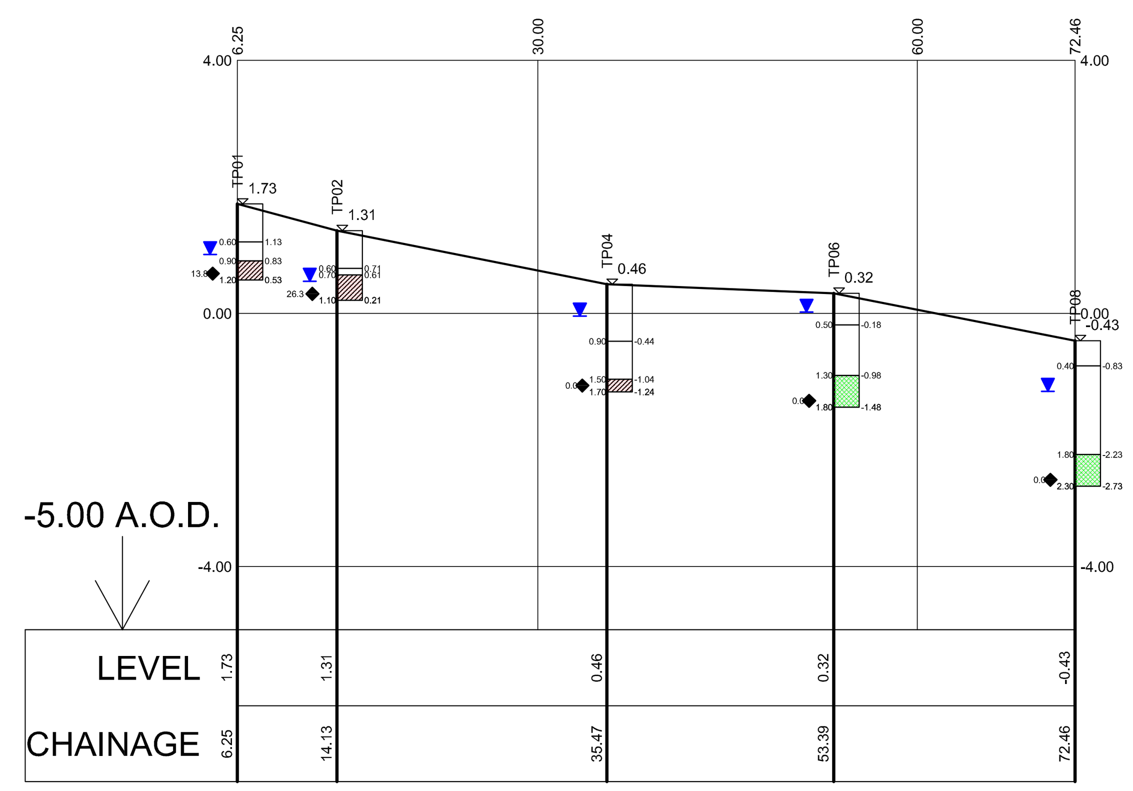
Horiz. 1:500
Vert. 1:100



Start Chainage E = 396659.89 N = 814410.27

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Legend:-

Cross Section
- Clean
- Black Stained Sand
- Green Stained Sand
- Slight Hydrocarbon Odour
- Strong Hydrocarbon Odour
- Water Strike
- PID Reading

Plan

Green Stained Sand Encountered
Black Stained Sand Encountered
0.1 0.3
Elevation of Upper Level of Green Staining (mAOD)
Elevation of Upper Level of Black Staining (mAOD)

No.	Date	Revision	By	Chk
0	-	First Issue	-	-

Drawn R Harrison	Date July 2011
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Title

Figure 8:

Monitoring Period 4: March 2010

Cross Sections and Plans with Elevation of Green and Black Stained Sand

File Ref : BD-SEC-04a - Stain	Drawing No : Figure 8	
Original Drawing Size: 841x594 - A1	Scale : As shown	Rev : 0

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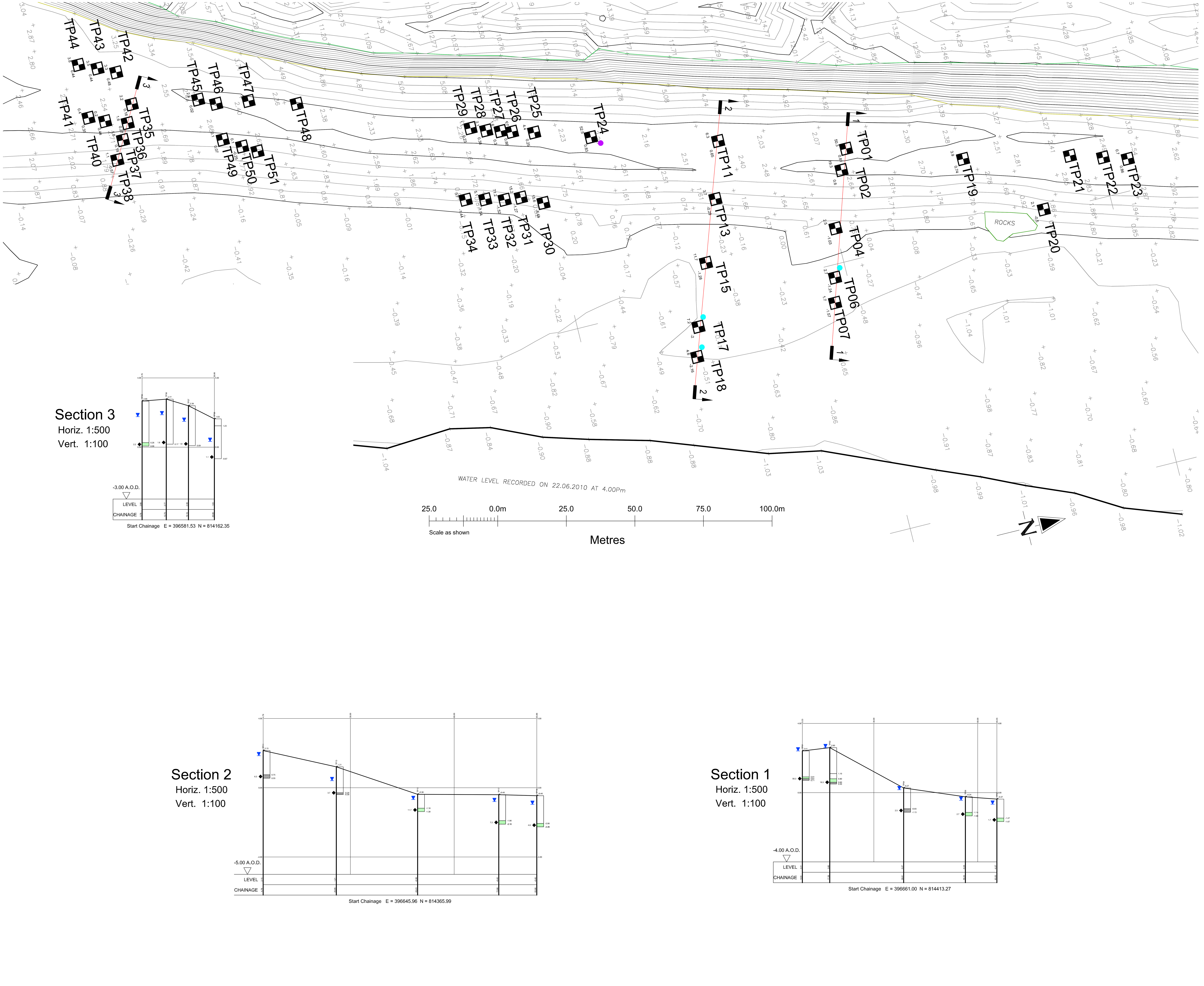

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Legend:-

Cross Section

- Clean
- Black Stained Sand
- Green Stained Sand
- Slight Hydrocarbon Odour
- Strong Hydrocarbon Odour
- Water Strike
- PID Reading

Plan

Slight Hydrocarbon Odour
Strong Hydrocarbon Odour
PID Reading (ppm) 4.6
0.16 Elevation of PID Reading (mAOD)

No.	Date	Revision	By	Chk
0	-	First Issue	-	-

Drawn R Harrison	Date July 2011
Checked L Barlow	Date July 2011
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Client / Project

Smallbrook Environmental Ltd.

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Title

Figure 9:

Monitoring Period 5: June 2010

Cross Sections and Plans with Hydrocarbon Odours and PID Readings

File Ref : BD-SEC-05a - Odour	Drawing No : Figure 9	
Original Drawing Size: 841x594 - A1	Scale : As shown	Rev : 0

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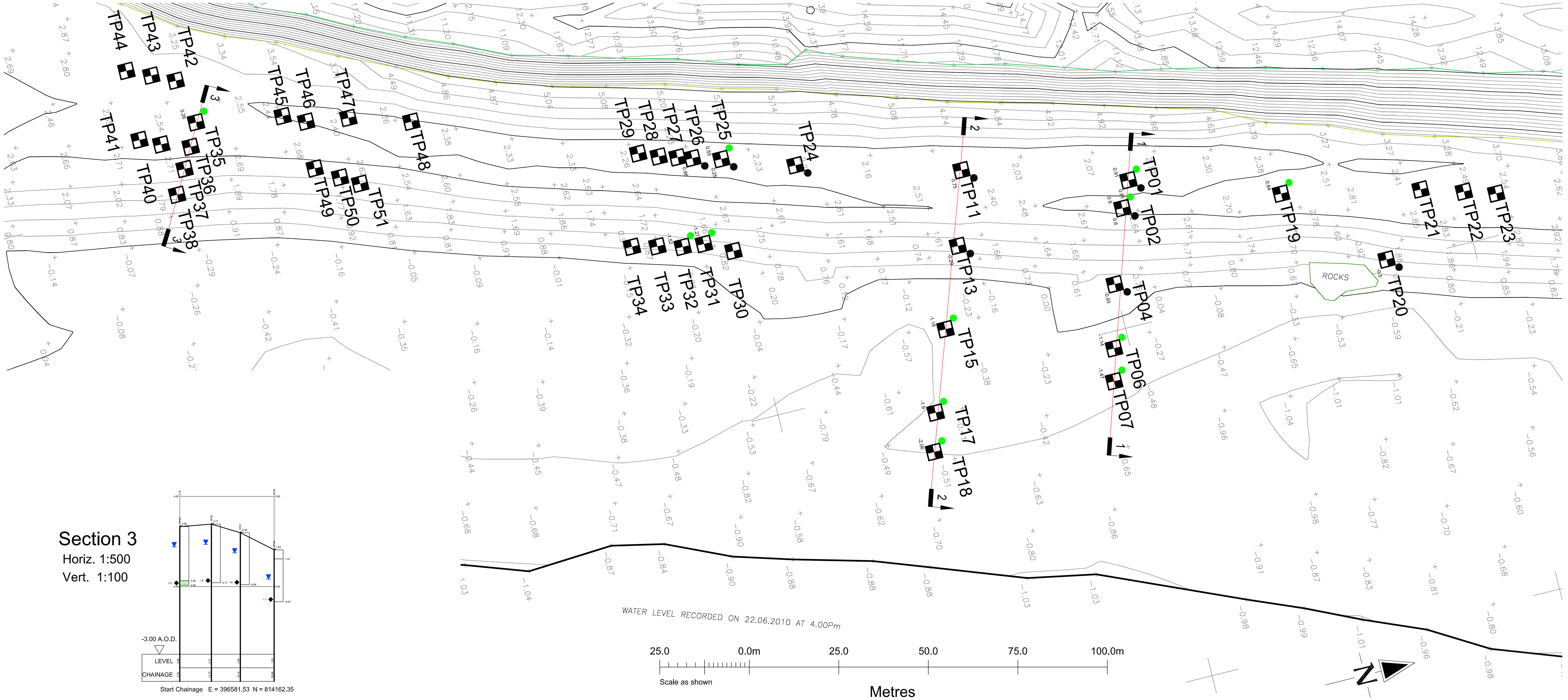
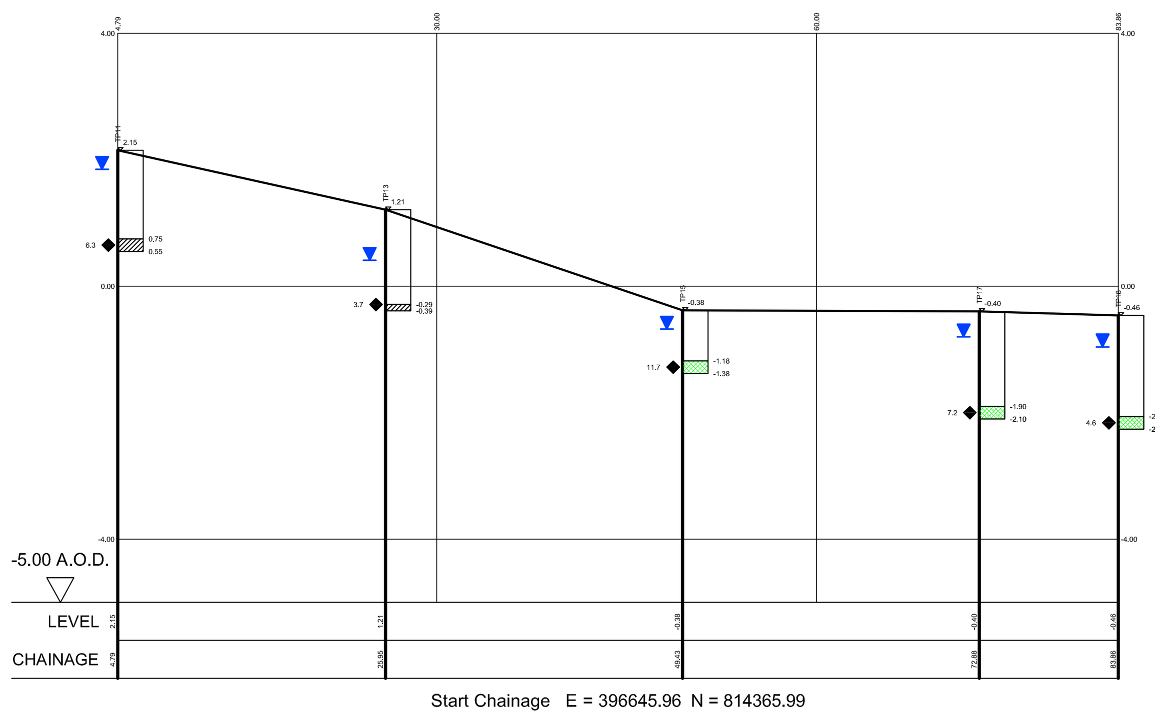


Section 3
Horiz. 1:500
Vert. 1:100

Section 2
Horiz. 1:500
Vert. 1:100



Section 1
Horiz. 1:500
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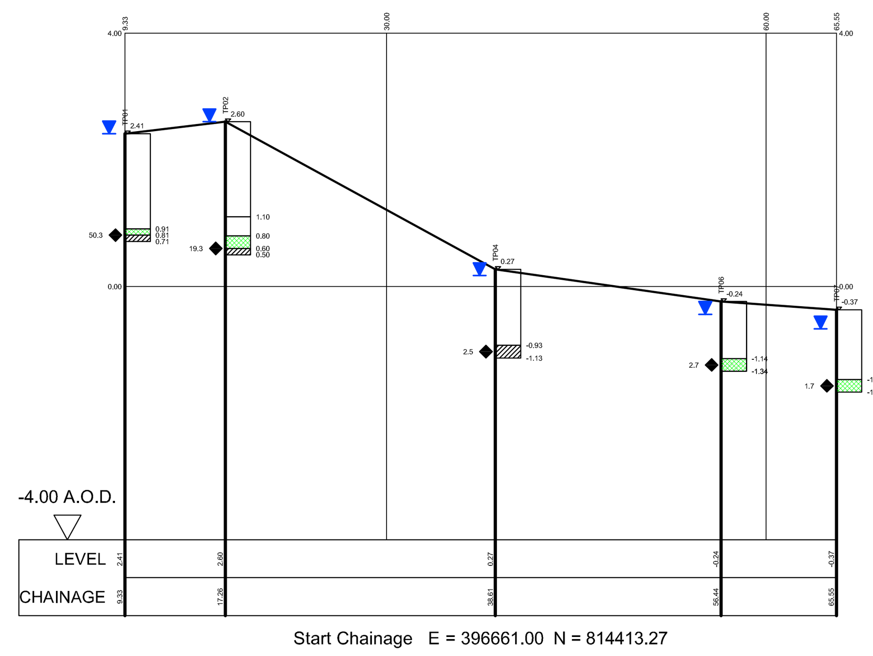

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Legend:-

Cross Section

- Clean
- Black Stained Sand
- Green Stained Sand
- Slight Hydrocarbon Odour
- Strong Hydrocarbon Odour
- Water Strike
- PID Reading

Plan

Green Stained Sand Encountered
Black Stained Sand Encountered
Elevation of Upper Level of Green Staining (mAOD) 0.1
0.3 Elevation of Upper Level of Black Staining (mAOD)

No.	Date	Revision	By	Chk
0	-	First Issue	-	-

Drawn R Harrison Date July 2011
Checked L Barlow Date July 2011
Approved R Apted Date July 2011

Client / Project

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Blackdog Landfill Site

Title

Figure 10:

Monitoring Period 5: June 2010

Cross Sections and Plans with Elevation of Green and Black Stained Sand

File Ref : BD-SEC-05a - Stain | Drawing No : Figure 10
Original Drawing Size: 420x297 - A3 | Scale : As shown | Rev : 0

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