MEHL

MEHL Integrated Waste Management Facility

EPA Waste Licence Application W0129-03. Response to EPA Article 16: Groundwater

Issue 1 | 16 October 2013

Job number 326877.30

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Document Verification

ARUP

Job title	MEHL Integrated Waste Management Facility			**Job number** 326877.30
Document title	EPA Waste Licence Application W0129-03. Response to EPA Article 16: Groundwater			**File reference**
Document ref				

Revision	**Date**	**Filename**	EPA response DRAFT1.docx		
Draft 1	20 Sep 2013	**Description**	First draft		
			Prepared by	Checked by	Approved by
		Name	Catherine Buckley	Jenny Lightfoot	Ria Lyden
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Draft 2		**Filename**	EPA response DRAFT2.docx		
		Description			
			Prepared by	Checked by	Approved by
		Name	Catherine Buckley	Jenny Lightfoot	Ria Lyden
		Signature			
Issue 1	16 Oct 2013	**Filename**	EPA response_Issue 1.docx		
		Description	Issue 1		
			Prepared by	Checked by	Approved by
		Name	Catherine Buckley	Jenny Lightfoot	Ria Lyden
		Signature	Catherine Buckley	Jenny Lightfoot	Ria Lyden
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			

Issue Document Verification with Document ✓

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1 Introduction

MEHL has planning permission (An Bord Pleanála Ref. 06F.PA0018) to develop an integrated waste management facility which will accept non-biodegradable, solid hazardous and non-hazardous waste streams at their site in Hollywood Great, North County Dublin. The development also requires a waste licence from the Environmental Protection Agency (EPA).

MEHL submitted a Waste Licence Application (W0129-03) to the Environmental Protection Agency (EPA) on 17th December 2010. The EPA responded with a notice in accordance with Article 16(1) of the Waste Management (Licencing) Regulations on the 23rd March 2012. The EPA issued a clarification on the 3rd of May 2012 and further notification on the 11th of July 2012.

This report provides responses to Items 5 – 8 in the Article 16 letter (23rd March 2012) and Items 1 and 3 in the Article 16 notification (11th July 2012).

A separate response for Item 7.2 (a – d) and Item 8.7 was submitted to the EPA on the 18th February 2013: Arup (February 2013) '*Assessment of Hydrogeological Isolation (Bog of the Ring and MEHL Site)'*. Responses to other 'Article 16' requirements were previously submitted by MEHL under separate cover

Other information related to hydrogeology has been submitted to the EPA including:

- An Bord Pleanála Decision and Inspector's Report relating to the proposed facility – submitted by MEHL to EPA on 28th May 2012
- Information provided by the geology/hydrogeology EIS team to An Bord Pleanála Oral Hearing (Ref. 06F.PA0018), March 2011 – submitted by MEHL to EPA on 7th June 2012

This report does not directly respond to the individual items raised in Article 16 clarification from the 3rd of May 2012 as this clarification related to proposed additional ground investigation. The additional ground investigation undertaken is discussed in detail in Chapter 3 and the items raised are addressed within that section as a whole.

2 EPA Questions And Responses

This chapter provides direct responses to the questions raised by the EPA in the notices (issued in accordance with Article 16(1) of the Waste Management (Licencing) Regulations) of the 23rd March 2012 and 11th July 2012. Cross references to other chapters or appendices are provided where required.

The text provided in italics is a direct quote from the EPA notices. Individual responses are provided below.

2.1 Article 16: 23rd March 2012

5. LandSim model

5.1. The Hydrogeological Quantitative Risk Assessment refers to a number of appendices (including Al.1, Al.2, Al.3, A3.l, A3.2, A3.3, A3.4, A4.l, A4.2, A4.3 and A4.4) that do not appear to be included in the application. Please indicate their location in the documentation already submitted or provide a copy of the documents. (It may be appropriate to provide these documents in electronic format).

The appendices A1.1, A1.2, A1.3, A1.4, A1.5, A2.1, A2.2, A2.3, A3.1, A3.2, A3.3, A3.4, A3.5, A4.1, A4.2, A4.3, A4.4 and A4.5 were inadvertently excluded from the original Waste Licence Application (Ref. W0129-03). These appendices are included in **Appendix A** of this report.

These appendices relate to the original Quantitative Risk Assessment (QRA) presented in the Waste Licence Application (WLA). The QRA model has been updated to address the comments received from the EPA in the Article 16 notice of the 23rd March 2012 and as a result of changes to the site conceptual model (CSM). The appendices referred to in the Article 16 notice have been superseded.

The updated QRA is presented in Chapter 5 of this report and the associated appendices for the new models are presented in **Appendix A**.

5.2. Justify whether Landsim is appropriate to use for a site having exposed bedrock, a high water table and a fractured aquifer system directly beneath the proposed landfill development. Although Landsim is considered necessary for evaluating a landfill site generally, the results of the LandSim model should be combined with a more sophisticated numerical groundwater (contaminant transport) model, to consider the regional context and risk or justify why this is not appropriate.

LandSim is the UK Environment Agency approved model for determining potential impacts to groundwater from landfills. It is used extensively in the UK for landfill developments directly overlying fractured chalk and sandstone aquifers and has been deemed to be applicable in those situations. The same applies to the fractured Namurian strata on the MEHL site.

The use of a numerical groundwater (contaminant transport) model was not deemed to be appropriate for the following reasons:

- A wealth of geological and hydrogeological data is available for the MEHL site, however constructing a site specific groundwater (contaminant transport) model would not provide realistic results as the model boundaries would be too close to the site and these would skew any results generated.
- In order to construct and calibrate a groundwater model which provides realistic results a large body of groundwater information in the wider area around the site would be required. Without this information the results would be meaningless as all boundary conditions etc would have to be inferred.
- There are many unmapped faults in the wider region and these are likely to influence groundwater levels and flow patterns on a local scale. Any information that was available in the wider area would have to be treated with caution as local faults may skew the results and this would influence the model results.

5.3. It is stated that a period of 35 years for a management control period is conservative. In section 8.3.4.4 of the Hydrogeological Quantitative Risk Assessment it is stated: "The model assumes that after this period there is no leachate management and leachate head can rise within the cells resulting in greatly increased leakage".

a) Explain how it follows in relation to the claims made for the DAC liner that increased head of leachate will result in increased leakage.

The management control period in LandSim represents the length of time over which a landfill will be maintained by the operator. It assumes that once the management control period is over, the landfill will be 'abandoned' and will have no further maintenance undertaken on it (although this is very unrealistic and contrary to EPA aftercare requirements). This has significant implications for the risk assessment model as beyond the specified management period the leachate head level is no longer controlled and is allowed to rise in the model (see answer 5.4 for further information).

The DAC has been simulated in LandSim as a single clay liner (see response to question 5.9 for the justification for this). The engineered properties of the DAC, i.e. total containment of the leachate, cannot be represented in LandSim.

Once the management period ends in LandSim, the leachate level is no longer controlled. As a result of this, it is a default in LandSim that leakage through the 'clay' liner will increase as the head level rises. This has no reflection on the DAC, its characteristics or behaviour.

b) Describe the predicted/modelled effect of increasing the maximum leachate head in table 8.5 of the Hydrogeological Quantitative Risk Assessment for non-hazardous and hazardous cells to 2m and 5m.

As outlined in the response to question 5.3 above, the management control period in LandSim represents the length of time over which a landfill will be maintained by the operator. It assumes that once the management control period is over, the landfill will be 'abandoned' and that the leachate head level will be allowed to rise.

The primary model presented in the QRA used a management control period of 35 years which assumes that after 35 years the site will have no further maintenance (this is an unrealistic scenario and contrary to EPA requirements, however it has been modelled as a highly conservative scenario). Once the management control period in the LandSim model finishes, the leachate head level rises until surface breakout occurs (i.e. at the minimum thickness of the waste).

The results of the primary model submitted with the WLA indicated that within 100 years of the landfill starting (and within 65 years of the management control period ending) the leachate levels rose to the surface breakout levels. i.e. beyond the management control period the leachate heads applied in the model ranged from 10.5 – 15.5 m, depending on the specific waste cell).

This means that the results presented in the primary model represent a scenario where a 2 m and 5 m head of leachate are included.

The effects of increasing the maximum head of leachate in the hazardous and non-hazardous cells to 2m and 5m during the 'managed' period of the landfill have been modelled in the updated QRA. It should be noted again that this is an unrealistic scenario and is unlikely to occur as leachate levels will be managed at all times in accordance with closure/aftercare procedures. The drainage system has been specifically designed to maintain a maximum head of 1 m in the landfill cells.

The results are discussed in Chapter 5, presented in **Appendix A** and are summarised as follows:

- Hazardous model: The results from the hazardous cells model and the test versions with a leachate level of 2 m and 5 m are very similar. The main difference is that the leakage levels are higher in the first 35 years (i.e. during the management control period) in the model with the higher leachate head levels than in the model with the lower leachate head levels. Once the management control period finishes the results are the same. This is as expected
- Non-hazardous model: The non-hazardous models which included a higher leachate head level of 5 m and those with the shorter management control period became unstable. The results of these are presented in **Appendix A** but were excluded from the discussion. The models with the longer management control period and leachate heads of up to 2m were stable and their results are discussed below.

5.4. *Rainfall and infiltration*

a) Demonstrate that the data for Dublin Airport is adequately representative of the site given the different topography and elevation and taking into account the risk of underestimating site specific infiltration rates used in the LandSim model.

b) Justify not applying a further conservative factor to rainfall given these factors.

Data from Dublin Airport was used on the basis that it is the most extensive data set available for the area. While there may be some local variation in the rainfall level due to the elevation, it is unlikely to be far outside the range of values used in the model.

A conservative factor has been built into the infiltration numbers used as no rainfall runoff to the drainage system when the waste cell is open has been included.

A sensitivity analysis was undertaken in the updated QRA model to establish how sensitive the model results are to infiltration. This assessment determined that the models are not sensitive to the infiltration rates.

5.5. On page 59 of the Hydro geological Quantitative Risk Assessment, it is stated that "of those contaminants potentially present in leachate at the site, only cadmium and mercury are classed as hazardous substances." State the source of this finding and explain the apparent rationale behind' the thinking 'that no other hazardous substances will be present in the leachate.

5.6. Provide further information on the assumptions and justification behind selection of the model leachate inventory and initial leachate concentrations. There appears to be no justification/discussion on which potential contaminants have/have not been progressed to risk assessment, only that they are "likely contaminants which may arise in leachate from the hazardous cell". More proposed-waste-streams-specific data should be obtained if possible (from say other similar sites or proposed source sites) to ensure the modelled suite of potential contaminants is comprehensive enough. Bench-scale testing of some of the more significant waste streams proposed may be appropriate to demonstrate that unacceptably high leaching is not going to happen.

5.7 See next box

5.8. Provide greater justification for the use of marker chemicals for certain potential contaminants present within the leachate inventory but excluded from the model simply because of an absence of WAC data. Provide detailed information on the mobility and toxicity similarities between markers and the excluded contaminants they are supposed to represent, under the expected geochemical conditions within the landfill.

We clarify that the statement referred to under question 5.5 should read "of those *modelled* contaminants potentially present in the leachate at the site, only cadmium and mercury are classed as hazardous substances".

The model leachate inventory is based on those parameters which have EU landfill Waste Acceptance Criteria (WAC) associated with them. The WAC were established pursuant to Article 16 and Annex 2 of the Landfill Directive 1999/31/EC. The purpose of Landfill Directive is to control the operations of landfills "in order to protect, preserve and improve the quality of the environment in the Community". The WAC were specifically chose to protect the environment having regard to the ecotoxicological properties of the waste and the resulting leachate.

The WAC set:

- limitations on the amount of specified, potentially harmful/hazardous components (in relation to the abovementioned protection criteria),
- limitations on the potential and expected leachability of specified, potentially harmful/hazardous components (in relation to the abovementioned protection criteria).

Other contaminants may be present in the leachate. Modelling these was not undertaken on the basis that the modelled contaminants have a higher mobility and/or toxicity than those not modelled. Consequently, if there is no impact to groundwater from the more toxic and/or mobile contaminants, there will be no impact from those not included in the modelling. Waste-stream specific data for the proposed waste to be accepted has been provided by Patel Tonra and is included in **Appendix B**.

None of these expected contaminants are List I or 'hazardous' substances under the Water Framework Directive. Cadmium and mercury are 'hazardous' substances under the Water Framework Directive indicating they are more toxic than the substances listed above.

The expected concentrations of the contaminants excluded from the modelling are proportionally lower than the modelled concentrations of cadmium and mercury. This indicates that the modelled concentrations of cadmium and mercury are likely to represent a worst case scenario for toxic compounds.

The maximum concentrations were set in the LandSim hazardous models as 3 times the waste acceptance criteria for hazardous waste (set in EU Council Decision 2003/33/EC) as a single value. These concentrations are the maximum amount of any particular contaminant which will be accepted into the landfill (subject to EPA agreement).

They were inputted as a single value (rather than a probability density function) meaning that the model presumes that all waste accepted will be at the maximum concentration which is a very conservative scenario. However, by inputting these maximum values the highest potential risk to groundwater can be assessed.

A comparison of the mobility of the contaminants excluded compared with the most mobile modelled contaminants (chloride and sulphate) is provided in **Table 2.1** below. The partition coefficient (Kd) for chloride and sulphate was set as zero in the model which means these contaminants will not be retarded and are freely mobile.

Table 2.1: Comparison of mobility of contaminants

Contaminant	Kd	Modelled concentration (hazardous waste) mg/l	Comments
Modelled contaminants			
Chloride	0	45000	Very high concentration and freely mobile parameter
Sulphate	0	51000	Very high concentration and freely mobile parameter
Excluded contaminants			
Thallium	1.64 (l/kg)		Mobile parameter but concentrations will not reach those for chloride or sulphate
Vanadium	141 (source 34) ml/g		Low mobility parameter
Cobalt	55.7 (source 32) ml/g		Slightly mobile parameter but concentrations will not reach those for chloride or sulphate
Manganese	50 (source 31) ml/g		Slightly mobile parameter but concentrations will not reach those for chloride or sulphate
Tin	2.1 (l/kg)		Mobile parameter but concentrations will not reach those for chloride or sulphate
Free cyanide	0.996 (l/kg)		Mobile parameter but concentrations will not reach those for chloride or sulphate
Nitrite	0		Freely mobile contaminant but concentrations will not reach those for chloride or sulphate

Chloride and sulphate are the most mobile contaminants modelled and also have the highest leachate concentrations of all the contaminants modelled. Based on the information listed in **Table 2.1** none of the contaminants excluded from the modelling will be as mobile or have concentrations at as high concentrations as chloride and sulphate.

Based on the comparison of mobility, toxicity and potential concentrations, it is considered that based on the waste-stream specific data, that the modelled leachate inventory presents the worst case scenario in terms of risk to groundwater.

5.7. Much of the hazardous waste deposited is not expected to degrade with time and therefore may be expected to act as a constant source of potential leaching in the long term. A declining source term has been used in the model. Provide further information on the rationale behind such a selection and the form of the declining source term used. This includes what kappa values have been used (linked to the rate of predicted contaminant release from the waste).

In order to alleviate the concerns outlined in question 5.7 regarding the use of a declining source for the hazardous waste, a constant source was used instead in the updated QRA modelling. The detailed results of this are presented in Chapter 5 and can be summarised as follows:

- The concentrations of contaminants at the base of the unsaturated zone were observed to slightly increase
- No change was observed in the concentrations detected in groundwater, either at the monitoring well adjacent to the cells or at the phantom monitoring well on the site ownership boundary.

As a constant source is used in the updated QRA modelling, the remainder of the query is not relevant.

5.9. Provide greater justification for the use of a single clay mineral layer to represent the proposed DAC liner system, in particular whether attenuation (adsorption) capacities are appropriate for the DAC system that is designed to act as a structural barrier.

The DAC liner was modelled in LandSim in accordance with the LandSim guidelines which states that DAC can be modelled "by setting thickness and hydraulic conductivity values appropriately".

The DAC liner has been modelled as a single clay barrier the thickness of the DAC sealing layer (0.08m). The use of a double clay barrier in the model was also explored, however it was deemed more conservative to exclude the lower liner from the model.

The DAC liner is composed of two low permeability elements: the 0.08 m thick DAC and a 0.5 m thick secondary clay liner below that. The secondary clay liner (0.5m thick) has not been included in the model. Therefore there is significantly greater sorption/attenuation potential in the liner system than has been modelled.

This balances out the fact that contaminants within the liner will have increased sorption within a clay than within a DAC liner. However, it should be noted, that the DAC liner will be constructed to have such a low permeability as to be effectively impermeable – and therefore the sorption potential is irrelevant.

A version of the model was created with the liner modelled as a double layer system. This modelled two clay liners with a drainage layer in between them as part of the lining system. However, LandSim v 2.5 will not allow the two clay barriers in the liner to have different hydraulic conductivities.

Because of this an adjustment of the hydraulic conductivity and thickness of one of the lining systems was made. As the DAC liner is the dominant liner in the system, it was deemed appropriate to adjust the lower clay liner.

If an adjustment is made to the properties of the lower clay liner in the model, the leakage rates will have to remain the same to ensure that the approach is valid. As the permeability of the lower liner is to be reduced then the thickness will need to be reduced too to maintain the same leakage rate.

LandSim requires that both barriers be assigned the same permeability in the model. In reality, the upper DAC layer will be thinner and have a lower permeability than the clay barrier beneath it. The two liners can be given the same permeability in the model by adjusting the thickness of one to allow the same volume of leakage through.

The leakage through the lower liner within the DAC system can be calculated by following formulas:

$$i = ((h+L)/L \qquad \text{(Equation 1)}$$

$$q = ki \qquad \text{(Equation 2)}$$

where, i = hydraulic gradient

h = leachate head

L = thickness of mineral liner

q = velocity / rate of leakage per unit area

The lower liner within the DAC system has a thickness of 0.5 m (L) and a hydraulic conductivity (k) of 1 x 10-9 m/s. The maximum head of leachate (h) in the hazardous cell will be 1 m. This indicates that the leakage rate will be 3 x 10-9 m/s in line with the calculations below.

$$i = ((1+0.5 \text{ m})/0.5 \text{ m}) = 3$$

$$q = ki = (1 \text{ x } 10\text{-}9 \text{ m/s}) (3) = 3 \text{ x } 10\text{-}9 \text{ m/s}$$

This indicates that the thickness will have to be altered to allow the same leakage rate to be maintained if the hydraulic conductivity is reduced to 1 x 10-12 m/s. The formulae used above can be manipulated to allow the thickness to be calculated as shown in Equation 3.

$$L = (kH) / (q – k) \qquad \text{(Equation 3)}$$

The maximum hydraulic conductivity which the DAC will have is 1 x 10-12 m/s based on Attachment D.3 in the Waste Licence Application submitted in December 2010. This value was used to calculate the thickness of the lower liner. If the lower value of 1 x 10-15 m/s was used for this calculation a thicker liner would be achieved which would be less conservative.

Based on Equation 3, the thickness of the lower mineral bed in the DAC when using a hydraulic conductivity value of 1 x 10-12 m/s is 0.000333 m.

$$L = [(1 \text{ x } 1012)(1)] / (3 \text{ x } 10\text{-}9 – 1 \text{ x } 1012) = 0.000333 \text{ m}$$

The results of the LandSim model indicate that there is no risk to groundwater from the proposed development. However, it is believed that modelling the DAC as a single liner is a worst case scenario as it excludes the additional protection offered by the 0.5 m of clay.

This model is not discussed in Chapter 5, however the model print out and results are presented in **Appendix A**.

5.10. Confirm whether the same vertical saturated pathway was used for all waste phases and cell types modelled relative to the varying pathway properties across the site as a whole, in both south to north, and east to west. Justify not using multiple models to provide a cell specific assessment.

An updated QRA has been prepared and is presented in Chapter 5 of this report. Multiple models have been prepared as part of this updated QRA to account for the varying presence of a vertical saturated pathway across the site. The new models presented in Chapter 5, relative to the vertical pathway are summarised below:

- Hazardous model: cells are located in the north of the site only, a vertical pathway has been included
- Non-hazardous model: located in the south of the site only so no vertical pathway has been included

5.11. Specifically, provide information on the vertical saturated pathway hydraulic conductivity values used within the model

No hydraulic conductivities are inputted in LandSim for the vertical saturated pathway. The only input values required in LandSim for the vertical saturated pathway are: pathway length, the porosity and the dispersivity. This is because the inclusion of a vertical saturated pathway assumes a downward flow through saturated material from the unsaturated zone towards the aquifer.

LandSim calculates the flow rate in the vertical pathway by giving it the same flow rate as the unsaturated zone above it.

A vertical hydraulic conductivity value was inputted for the unsaturated zone and is summarised in Table 2.2.

Table 2.2: Hydraulic conductivity of unsaturated zone

Parameter	Value				Comment
	Distribution	Max	Likely	Min	
Hydraulic conductivity (m/s)	Log triangular	2.82E-08	1.53E-07	4.54E-07	Infiltration testing

These hydraulic conductivities were calculated by undertaken infiltration testing on the site as detailed in **Appendix 14.5** of the EIS.

5.12. Refine the overall modelling exercise on foot of the items above and following any additional site investigations and improvement to the conceptual site model – see ·the following sections of this letter.

As outlined in section 5.1 the modelling has been updated in line with comments received from the EPA (Items 5 - 8) and as a result of changes to the Conceptual Site Model (CSM). The updated QRA report is presented in **Chapter** 5 of this report and the model print outs and results are presented in **Appendix A**.

6. Conceptual Site Model

6.1. Develop further the conceptual site model to encompass the requirements of this notice as a whole. As well as explanatory text, this might result in a series of diagrams including:

a) A plan showing all site investigation to date (including additional investigations conducted as a result of this notice), and topographic detail extending beyond the licence boundary to the limits of the monitoring points;

The Conceptual Site Model (CSM) has been revised based on the additional site investigations. This updated CSM is presented in Chapter 4. The additional diagrams are presented in the figures listed below.

Topographic detail is presented from within the site and beyond the licence boundary in Figures 1 and 2 respectfully. The latter is reproduced from the Ordnance Survey Discovery Series.

- **Figure 1**. All site investigation locations undertaken to date
- **Figure 2**. All site investigation locations undertaken to date on regional topographic map

Details and logs for all historic monitoring wells drilled on the MEHL site are presented in **Appendix C**.

b) A plan showing regional groundwater flow, based on measured water levels and including a more accurate depiction of the groundwater divide between the site and the Bog of the Ring;

The GSI have defined a groundwater divide to the north of the MEHL site. A groundwater divide is a topographical divide in the water table which causes groundwater to flow away from the topographically high area.

The presence of the groundwater divide between the MEHL site and the Bog of the Ring report has been dealt with extensively in the report 'Hydrogeological Isolation: Bog of the Ring and the MEHL site' submitted to the EPA on 18th February 2013.

A figure showing the regional groundwater flow, based on measured groundwater levels is presented in **Figure 3**. The regional groundwater level information for this figure was compiled using data gathered for the Fingal landfill project which was collected on the 24th of June 2005.

Figure 4 presents the recorded groundwater levels in the Loughshinny Formation from all the active wells on site.

Groundwater level data was not available for the MEHL site for the 24th of June 2005 which is the date of the data used to create the regional information for **Figure 3**. For this reason only the general groundwater flow contours and flow direction (without quoting specific groundwater levels) from the aquifer beneath the MEHL site, as indicated in **Figure 4,** have been presented on **Figure 3**.

The local groundwater flow pattern observed at the MEHL site shown in **Figure 4** clearly coincides with the regional groundwater level pattern shown in **Figure 3**.

The groundwater divide between the MEHL site and the Bog of the Ring can also clearly be seen in the groundwater flow contours on **Figure 3**.

c) Two separate plans, one showing local groundwater piezometry in the Namurian Formation and one showing it in the Loughshinny Formation;

Groundwater levels collected on 8th July 2013 in all the active wells on the site are presented on the following figures:

- **Figure 4**: Groundwater levels measured in the Loughshinny Formation
- **Figure 5**: Groundwater levels measured in the Namurian strata.
- **Figure 6**: Groundwater contours for both the Visean and Namurian strata

These figures illustrate that:

- Groundwater flow in the Loughshinny Formation is to the southeast in line with the regional groundwater flow pattern
- Groundwater flow within the Namurian formations is mainly driven by topography with some localised variations due to the heterogeneous nature of the Namurian strata.
- Under unstressed conditions, the groundwater within the Namurian deposits and Loughshinny Formation are hydraulically separate

d) A series of cross-sections (e.g. one N-S through the proposed waste cells, and two E-W through the proposed waste cells) that accurately show the geology derived from borehole logs and head gradients derived from monitored water levels in boreholes screened in different strata;

Cross-sections are presented in **Figure 7**. These cross sections were constructed based on information from the borehole logs, down-hole geophysics, palynology, micropaleontology and the pumping tests. In some cases the borehole logs indicate uncertainty regarding which lithology was encountered, palynology, micropaleontology and the down-hole geophysics were used to aid the interpretation.

e) A conceptual site model diagram showing the proposed development superimposed on one or more of the above cross-sections.

A conceptual site model presenting the proposed development, superimposed on the above cross-sections, is shown in **Figure 8**. Please note the design details of the landfill construction have been generalised on the diagram to illustrate their overall geometry e.g. the individual hazardous cells have not been represented, they have been presented as a single hazardous cell.

6.*2. More detailed analysis of existing data and information, where available, is required to improve the overall conceptual model for the site. For example:*

a) Detailed geological log for Dunne Drilling borehole "5668" drilled in November 2008. From Table 14.3 (p.221) of the EIS it seems this borehole may be BH4A, which is available, and if so, confirm that the "black rock" described by Dunnes is in fact the Loughshinny Formation.

The conceptual model has been updated and is presented in Chapter 4 of this report.

The "black rock" logged in BH4a is the Loughshinny Formation. The log for BH4a is a drillers log. An interpretative log is available for BH4 which was drilled approximately 170 m south west of BH4A (**Appendix C**). The log for BH4 shows 3 m of till overlying limestone bedrock (i.e. the Loughshinny Formation). The proximity of these wells confirms that the "black rock" in BH4a is the Loughshinny formation.

Furthermore, BH4A and BH14 are consistent with the pattern of groundwater levels observed on the site e.g. they are both down gradient of the 100 mOD contour line.

b) Boreholes BH1, BH2 and BH3 were presumably drilled on-site in the past and details about these (location, depth, borehole logs etc.) should be presented.

The logs for for BH4, BH10 and BH11 are presented in **Appendix C**.

c) Appendix A14.4 states that borehole logs are not available for BH4, BH10 and BH11; however the 1999 EIS has a log for BHl0. Review the overall findings of the application with this new information.

Details for BH4, BH10 and BH11 are presented in **Appendix C**. The available logs for all historic boreholes drilled on site are also included in this appendix and their locations have been added to **Figure 1** which presents all explorative holes on site.

These logs confirm the overall findings for the application.

- BH4: located 170 m to the west of BH4A has limestone (Loughshinny Formation) at 3 mbgl, as expected
- BH10: located to the east of BH10A. Limestone (Loughshinny Formation) was encountered at 4 mbgl (131 mOD) indicating limestone is shallower here than in BH10A, where limestone was encountered at 21 mbgl (116 mOD). Across the site the limestone levels vary due to the presence of faulting and the erosional period that occurred during the depositional period between the Visean (Loughshinny) and Namurian deposits.
- BH11 is located underneath the proposed hazardous cell, north east of BH16. The log shows shale to end of hole (50 mbgl) which is consistent with BH16.

d) Figures 14.2, 14.5 and 14.12 show most (not all) of the boreholes and trial pits that have been drilled or excavated on-site: Please provide this information all on one figure. The figure should include topographical detail for the area as a whole (including national grid coordinates), including the area beyond the licence boundary (where off-site monitoring wells and water courses are located).

Figures 1 and 2 show all exploratory holes for the site on site specific topographic and OS mapping. **Figure 2** also presents the watercourses in the wider area.

6.3. Provide separate figures showing the shallow (Namurian) and deeper (Loughshinny) groundwater flow regimes. Also present groundwater flow in a regional context on a detailed figure including site and off-site data, householder/farm wells and the Bog of the Ring water supply wells and trial wells (Figure 12 of the Hydrogeological Quantitative Risk Assessment only shows the local site groundwater flow regime).

The flow regimes are depicted on the following figures:

- **Figure 3:** Regional groundwater flow regime
- **Figure 4**: Groundwater levels measured in the Visean strata (Loughshinny Formation)
- **Figure 5**: Groundwater levels measured in the Namurian strata.
- **Figure 6**: Groundwater flow in both Namurian and Loughshinny formations

The regional groundwater flow has been discussed in detail in the report 'Hydrogeological Isolation: Bog of the Ring and the MEHL site' which was submitted to the EPA on the 18th Febuary 2013. The requested figures described in 6.3 are presented in that report in Figures 1, 3, 13, 14 and 17.

7. Geology, hydrology and hydrogeology

7.1. Any further analysis of the impact on groundwater should utilise vulnerability and aquifer classifications using GSI guidelines. This refers specifically to the claim that the Namurian bedrock at the site can be interpreted as low permeability subsoil for the purpose of groundwater vulnerability mapping. Bedrock is not subsoil and cannot necessarily be used in this way. Also, it is not clear that the Namurian bedrock has low permeability in the first place. If it is believed that site specific circumstances allow the aquifer to be considered differently, there is need for much more site specific information on the bedrock units beneath the site, as set out in detail in this notice.

The critical issue relating to the vulnerability and aquifer classifications for the site is the protection of groundwater.

The GSI Guidelines are directed at the protection of shallow groundwater as represented by the water table. The GSI Guidelines do not describe the vulnerability conditions relating to confined groundwaters. For example, where a bedrock aquifer is overlain by a bedrock aquitard which in turn is over lain by a thin layer of overburden then the GSI Guidelines would correctly describe the groundwater (as represented by the water table) in the aquitard as being vulnerable to contamination. However, the same description could not be extended to the groundwater within the confined aquifer simply on the basis of the thin overburden cover.

The GSI document "Groundwater Protection Response for Landfills" states that for an R3[2] site landfills are not generally acceptable unless "*There is a minimum consistent thickness of 3 metres of low permeability subsoil*".

The Landfill Directive (1999/31/EC), however, is the current legal basis for the provision of environmental protection from landfills and the GSI document predates this. Therefore, the requirements of the Landfill Directive supersede those of the GSI document.

Annex 1 of the Landfill Directive states that the location of a landfill must take into consideration requirements relating to *inter alia*:

"(b) the existence of groundwater, coastal water or nature protection zones in the area

(c) the geological and hydrogeological conditions in the area"

Section 3 of Annex 1 of the Landfill Directive deals with the protection of soil and water. Section 3.2 states that:

"*The geological barrier is determined by geological and hydrogeological conditions below and in the vicinity of a landfill site providing sufficient attenuation capacity to prevent a potential risk soil and groundwater*"

Minimum thickness and permeability values are provided for the mineral layer to protect soil, groundwater and surface water for the different waste types.

Critically, the Landfill Directive also states:

"*Where the geological barrier does not naturally meet the above conditions it can be completed artificially and reinforced by other means giving equivalent protection. An artificially established geological barrier should be no less than 0.5 m thick*"

The Landfill Directive does not provide minimum requirements for the natural geological and hydrogeological conditions. Rather it states that engineered solutions are acceptable to protect groundwater and soil.

The GSI vulnerability map describes the site as extremely vulnerable as the site is a former quarry. This vulnerability rating relates to groundwater within the shallow bedrock aquiclude formations and reflects the present absence of overburden deposits overlying the aquitard.

The vulnerability of the groundwater within the confined Loughshinny Formation can be assessed by reference to the protection afforded by the overlying aquitard and which, based on site specific data, can be described as Moderate.

There is a minimum of 10 m of, and up to at least 60 m of, moderate to low permeability material present across the northern part of the site. This material is described as "shale". However in many locations it has weathered to a clay. **Plate 1** shows an imprint clearly embedded in the clay material from BH16.

Plate 1. Thumb print in shale (clay) material from BH16

This clay is typical of the "shale" beneath the site and clearly offers protection to the groundwater in the aquifer. In line with GSI guidelines, this can allow the vulnerability to be redefined to Moderate.

Critically, the clay material described as shale would offer protection to groundwater, which is additional to the protection afforded by the engineered landfill liners required under the Landfill Directive.

7.2. Since the bases of the proposed landfill cells are expected to be only 2m above the current water table in places, more consideration of past, current and potential future water levels and abstraction scenarios linked to the Bog of the Ring water supply scheme is required. Illustrate the effect of the abstraction on groundwater piezometry and potential for change in the (yet to be fully characterised) groundwater divide between the site and the Bog of the Ring.

a) For example, this requires analysis of groundwater level data for the MEHL site area prior to commencement of pumping at the Bog of the Ring (water level data is available in the 1999 EIS) as well as in the more recent past.

b) It also requires consideration of the impact of (a) increased abstraction and (b) reduced abstraction (there being evidence of reduced yields) from the active water supply wells possibly leading to groundwater rebound beneath the proposed landfill cells. ·

c) In addition, more regional groundwater level data is required (for example, this might include local domestic well water levels, Bog of the Ring pumping/monitoring/trial well water levels, water level data from the Fingal County Council EIS, or the installation of additional wells to the north of the MEHL site).

d) If insufficient off-site wells are found to exist to define the groundwater divide location, particularly if fault controlled preferential groundwater movement to the north is an important factor, then this should be addressed

The MEHL site falls outside the catchment of, and any hydrogeological influence from, the existing Bog of the Ring abstraction as detailed in the report 'Hydrogeological Isolation: Bog of the Ring and the MEHL site' submitted to the EPA on 18th February 2013.

Consequently, groundwater levels at the MEHL could not have been influenced by the Bog of the Ring abstraction in the past and will not be affected by any future reduction in the output from the Bog of the Ring abstraction as presently configured.

The future of the Bog of the Ring abstraction was discussed at the Tooman - Nevitt landfill oral hearing. Fingal County Council, which manages the abstraction, stated its intention to supply the north of the County from surface water supplies. This abstraction or the aquifer in the area would not be developed further.

The development of the major abstraction from the River Shannon at Lough Derg to serve the Greater Dublin Area is a key element of national water policy. This scheme has recently been confirmed and should, when complete, provide sufficient water to supply the north of Fingal well into the future

In the event that the Bog of the Ring abstraction was extended through the development of additional production wells to the south of the existing well field then it is possible that the MEHL site could then fall within the influence of an extended Bog of the Ring abstraction.

Based on the updated site conceptual model discussed in Chapter 4, during stressed or pumping conditions, groundwater in the Namurian may enter the underlying aquifer via faults. If the site was to fall within the catchment and cone of depression of an abstraction and the landfill liner leaked, contaminants may, having also passed through the clay liner, enter the catchment of the abstraction. For this reason, the faults beneath the site will be grouted prior to development and the design of this will be confirmed during the detailed design stage, prior to commencement of construction.

7.3. Provide data that proves the upward head gradient currently depicted between the Loughshinny Formation and overlying Namurian Formation in Figure 13 ("Schematic Conceptual Model") of the Hydrogeological Quantitative Risk Assessment. The groundwater level data presented in the EIS suggests there may be an upward head gradient in the north-east of the site, but there appears to be a downward head gradient for the majority of the rest of the site, including where the proposed landfill cells are located. The installation and monitoring of well pairs (each one of a pair screened either in Namurian or Loughshinny Formations) in the areas where landfill cells are proposed appears to be the only way to accurately prove the issue of head gradients (see item 8 below).

New monitoring wells were installed on the site in July 2013. The drilling conditions on the site, meant that well pairs could not be constructed in all areas of the site as suggested above. The site investigation is discussed in **Chapter 3** and **Appendices D-H**.

7.4. Illustrate on an appropriate map or drawing the location and course of the stream referred to as being 1.5km to the east of the site and hydraulically connected to the site via groundwater.

Figure 2 presents the surface water features in the region.

The stream referred to is located 1.5 km east of the site and runs north- south, parallel to the site boundary and is presented on **Figure 2**. This stream is hydraulically connected to groundwater in the aquifer and it is likely that groundwater in the Loughshinny Formation discharges at this point.

8. Additional site investigations

In order to improve the landfill site element of the CSM, additional site investigation is expected to be· carried out. It is expected that there should be groundwater monitoring wells within the footprint of each of the proposed landfill cells. Specifically:

8.1. Where both Namurian and Loughshinny bedrock exist, well pairs are needed (comprising one well screened in Namurian and one in the Loughshinny Formations). Where one suitable well already exists the second can be installed close to it (within 5m).

8.2. Such well pairs are expected to be needed within each of four fault blocks created by the N-S fault and E-W fault that transect the site, allowing better assessment of groundwater flow across fault structures and between the Namurian and Loughshinny, and consideration of potential flow along fault zones during pump testing. As the proposed hazardous waste cell is located across all fault blocks and in an area where both formations exist (Narnurian over Loughshinny), this will be the likely main area of focus.

8.3. There is also a need for good well data for the proposed non-hazardous waste cells and new inert cell. In some of the southern area (southwest quadrant) there appears to be insufficient well points, although, as only the Loughshinny is present only single well points are needed. Where it cannot be demonstrated to the EPA's satisfaction that suitable monitoring wells already exist then additional ones are needed.

8.4. Because pump test data may suggest flow along the fault zone (from our review) there is a need to have a well pair at the north end of the proposed hazardous waste cell on the line of the main N-S fault zone.

8.5. As part of preparation for the additional investigation programme consideration should be given to the benefit of undertaking coring of certain boreholes and downhole geophysical logging to maximise understanding of lithology, fracture distribution and orientation, etc.

8.6. A 7-day pump test and associated step test and recovery test should be carried out. (For such a complex site a 2-day test is too short). It is also suggested that the suitability of BH17 as a pump test well should be reconsidered, and a new well (or a packer in BHl7) potentially installed so that the pump test only draws water from the Loughshinny Formation. This will allow better interpretation of the main aquifer zone and the hydraulic connectivity to the overlying Namurian.

Additional site investigation has been undertaken to address points 8.1 – 8.6. This site investigation is discussed in Chapter 3 and details of this are included in **Appendix D-H)**.

8.7. If the further assessment of off-site (down gradient) groundwater levels do not provide conclusive evidence of the location of the groundwater divide between the site and the Bog of the Ring abstraction scheme, then some off-site drilling may be required to address this data gap in the CSM.

The MEHL site falls outside the catchment of, and any hydrogeological influence from, the Bog of the Ring abstraction as detailed in the report 'Hydrogeological Isolation: Bog of the Ring and the MEHL site' submitted to the EPA on 18th February 2013. No off-site drilling is required.

2.2 Article 16 Notification: 11th July 2012

1. Formation levels

Condition 3.5.5 of the existing licence (W0129-02) authorises development of landfill cells only above 104.5 mOD. Explain on the rationale for now proposing development above 102.5 mOD with sumps to be placed at 102 mOD. State what circumstances have changed to allow for this new proposal. This question should be addressed in the context of our earlier correspondence dated 23 March 2012 (and in particular item 7.2 therein)

Groundwater levels have risen since the original application in December 2010. This is discussed further in section 3.2. For this reason the formation level has been raised to the level of 104.5 mOD licenced in W0129-02.

Conclusive evidence of the location of a groundwater divide between the site and the Bog of the Ring have been addressed in the report 'Hydrogeological Isolation: Bog of the Ring and the MEHL site' submitted to the EPA on the 18th of February 2013. As such no further discussion of this question in the context of item 7.2 (from the 23rd March 2012) is required.

3. Groundwater trigger levels

3.1 Annex III, section (4)(C), of the Landfill Directive requires that trigger levels be laid down in a licence whenever possible,

- *State what trigger levels are proposed*
- *State what contingency plan will be followed in the event of a trigger level being reached*

3.2 In accordance with the requirements of the European Communities Environmental Objectives (Groundwater) Regulations 2010 and having regard to Guidance on the Authorisation of Discharges to Groundwater, published by the Environmental Protection Agency, provide a technical assessment in relation to the setting of groundwater compliance points and values. Propose the compliance points to be utilised, the corresponding compliance values and the compliance monitoring to be employed.

Questions 3.1 and 3.2 have been answered together as the trigger levels, compliance points and contingency plans are all interrelated.

The proposed compliance monitoring network is shown on **Figure 9**. In accordance with the EPA publication *Guidance on the Authorisation of Discharges to Groundwater* the monitoring network points have been based on the conceptual model for the site:

- The monitoring points have been placed in an outer and inner ring to allow any breaches of trigger levels to be detected before they reach the site boundary. The compliance points are those marked on **Figure 9**.
- All wells will have response zones in both the Namurian strata and the Loughshinny.
- Existing wells on site will be incorporated into the monitoring network, particularly for the up-gradient wells. New down-gradient wells will be installed in the direction of flow (south east) and also the north and east.
- Monitoring wells will be located in known fault zones to ensure that any potential movement of contamination is detected

The locations shown on **Figure 9** are indicative only and the exact locations will be agreed in consultation with the Agency, and with due regard for site conditions, the location of site infrastructure, access to monitoring locations etc. However, any monitoring point that is moved will comply with the requirements listed above.

The trigger levels proposed to be used for this licence are based on the Threshold Values listed in S.I. No. 9 of 2010 European Communities Environmental Objectives (Groundwater) Regulations, 2010. The compliance levels proposed are from S.I. 278 of 2007 European Communities (Drinking Water) (No.2) Regulations 2007. Table 2.3 lists the compliance points and trigger levels proposed for the site.

Table 2.3 Proposed compliance points and trigger levels

Parameter	Trigger level (mg/l)	Compliance value (mg/l)
Barium	*0.525	0.7[2]
Cadmium	0.00375	0.005[1]
Total chromium	0.0375	0.05[1]
Copper	1.5	2[1]
Mercury	0.00075	0.001[1]
Molybdenum	*0.0525	0.07[2]
Nickel	0.015	0.02[1]
Lead	0.01875	0.025[1]
Antimony	*0.00375	0.005[1]
Selenium	*0.0075	0.01[1]
Zinc	*3.75	5[3]
Chloride	187.5	250[1]
Fluoride	*0.75	1[1]
Sulphate	187.5	250[1]

[1] S.I. 278/2007 European Communities (Drinking Water) (No.2) Regulations 2007
[2] WHO Health
[3] UK Drinking Water Standard

*No trigger level is available, so a value of ¾ the compliance value was used

Arsenic and manganese will not be included in the monitoring, as they are naturally elevated in the groundwater of the area.

The contingency plan in the event of a trigger level being reached is laid out below. The following infrastructure will be put in place to allow the contingency plan to be operated effectively:

- A leak detection system will be installed between the DAC and the low permeability clay liner. The presence of the low permeability liner below the leak detection system will ensure that if a leak through the DAC does occur, the contamination cannot enter groundwater immediately.
- Monitoring wells will be installed in an ‘inner’ and ‘outer’ perimeter to allow two levels of protection to be put in place.

The contingency plan has been developed in "layers" to allow any elevated contamination instances to be detected before groundwater is unacceptably impacted:

1. Leak detection system is the first element of the contingency plan. Leachate flow in the leak detection system will be monitored and if higher than normal flows and concentrations are observed the cause will be investigated.
2. The first trigger levels will be set at the 'inner' circle of monitoring wells. The use of the threshold values from the Groundwater Regulations as the trigger levels is conservative, as these are three quarters of the corresponding compliance point. This ensures that any potential sustained upward trend in groundwater concentrations will be identified before the compliance values are exceeded.
3. If a breach of the trigger level is detected at the trigger locations, the monitoring frequency will be increased.
4. If the trigger levels are also reached at the compliance points a study will be undertaken to establish if an upward trend, which is not attributed to background contamination can be identified.
5. If a sustained upward trend, which is not attributed to background contamination is identified in both the trigger and compliance wells, an investigation will be undertaken into the competence of the landfill liners
6. While the landfill liners are being investigated, the waste will be covered 24 hours a day. This will prevent further leachate generation during the investigation.
7. In the highly unlikely event of a leak being detected in a cell, no waste will be placed in that cell until the risks have been adequately mitigated.
8. The trigger points will be designed to allow them to be used for pumping of contamination if necessary. If breaches of compliance values are observed and a leak has been identified, a programme of pumping will be undertaken until concentrations reduce to background levels.

3 Additional Site Investigation

3.1 Additional works

A programme of additional site investigation was undertaken on the MEHL site to supplement the information available. These investigations and the reasons they were undertaken are summarised in **Table 3.1**.

Table 3.1 Summary of additional site investigation

Timescale	Work summary	Purpose of work
March 2013	Downhole geophysics on existing wells	Aid the interpretation of the lithologies encountered on site
June 2013	Drilling 7no. new groundwater monitoring wells	Provide additional information on the geology and hydrogeology of the site
	Collection of samples for palynology and micropalaeontology analysis	Aid the interpretation of the lithologies encountered on site
	Downhole geophysics on newly drilled wells	Aid the interpretation of the lithologies encountered on site
July 2013	Groundwater monitoring	Establish current groundwater levels
	7 day pumping test	Provide additional information on the hydrogeological conditions beneath the site

New groundwater monitoring wells were drilled across the site. Details of these are included in **Appendix D**. The groundwater levels recorded across the site are discussed in section 3.2 and data is presented in **Appendix E**.

Two phases of down-hole geophysics were undertaken in December 2012 and July 2013. The factual report for this work is presented in **Appendix F** and the interpretation of the geophysics is presented in section 3.1.1.

Samples were collected from BH24 and BH30 for palynology and micropaleontology analysis to aid in the interpretation of the lithologies encountered. The factual report for this work is saved in **Appendix G** and the interpretation is summarised in section 0.

The pumping test data and interpretation is presented in **Appendix H**.

3.1.1 Downhole Geophysics

The data from the downhole geophysics is presented in **Appendix F** and the results have been summarised in **Table 3.2**.

Table 3.2: Downhole geophysics summary

Location	Monitoring Well and amomaly reference	Approximate depth of anomaly – on the geophysics logs (m bgl)	Comments
BH4a	BH4a-01	1 – end of log	The borehole is located outside of the site boundary by ~250m to the east. There is no detailed interpretation of the geology in this area however both the induction and natural gamma reading suggest there is little variation in the top 8m of the strata logged.
BH11a	BH11a-01	10.5 – 12	Relatively large increase in the natural gamma reading which may be indicative of the 'fractured shale' recorded on the borehole log, especially if the fractures are filled with clay.
	BH11a-02	19 – 23	Reduction in the natural gamma reading which is indicative of an increase in particle size. The borehole log records 'heavily weathered shale from 18m bgl going into to 'sandy shale' at 21m bgl. It is likely that the reduction in the natural gamma output is associated with the sandy shale on the borehole log.
BH15a	BH15a-01	5	The rise in temperature may be indicative of the top of groundwater level.
	BH15a-02	12.5 – 15	Relatively large increase in the natural gamma reading which may be indicative of an increase in clay content.
	BH15a-03	20	The DELC log (assumed change in conductivity) shows a relative increase which may be indicative the boundary between the Balrickard and Donore Formations shown on the borehole logs at 17m bgl.
	BH15a-04	2 – 13	The top portion of the conductivity log is relatively low (typically <75mS/m), whereas the low part of the log records relatively high. This may be indicative of the change between the Balrickard and Donore Formations.
	BH15a-05	15 – 23	
BH17	BH17-01	3	The rise in temperature may be indicative of the top of groundwater level.
	BH17-02	7.5	The DELC log (assumed change in conductivity) shows a relative increase
	BH17-03	15 – 22 and 43 – 51	At these two depth horizons a subtle in conductivity is recorded. Neither of them have a reasonable correlation with the information on the borehole log.
BH18	BH18-01	8	The rise in temperature may be indicative of the top of groundwater level.

Location	Monitoring Well and amomaly reference	Approximate depth of anomaly – on the geophysics logs (m bgl)	Comments
	BH18-02	4 – 10	The natural gamma reading fluctuations observed correlate with the 'interbedded sandstone and mudstone' description provided on the borehole log. The spikes and troughs may be representative of the mudstone and sandstone respectively.
BH19	BH19-01	11 – end of log	BH19 was drilled close to two fault zones. The increase in natural gamma response maybe indicative of material fractured by faulting as observed in the correlation discussed in anomaly BH11a-01.
BH20	BH20-01	10	The DELC log (assumed change in conductivity) shows a relative increase
BH24	BH24-01	11.5 – 13.5	On the natural gamma log, an increase from approximately 80 API units (American Petroleum Institute) to approximately 150 API occurs at the base of the superficial deposits. There is also a notable change in the hydraulic conductivity of the water at this depth.
	BH24-02	31 and 33	Two relatively large readings in the natural gamma log suggesting an increase in the shale / clay content at these depths.
	BH24-03	34 – end of log	The large increase in induced conductivity from ~50mS/m to ~140mS/m, may be indicative of the very soft weathered layer or the iron content causing the iron staining detailed on the logs.
	BH24-04	37 – end of log	The natural gamma log drops to ~80API, there are no other locations on site where this anomaly has been observed however a drop in gamma may indicate the presence of open fractures.
BH25	BH25-01	13.8	Generally over the depth of the borehole there is a steady fluctuation in the natural gamma log which may be indicative of the shale content of the rock. This is discussed in more detail below.
BH26	BH26-01	18.2 – end of log	A relatively large reading in the natural gamma log suggesting an increase in the shale / clay content at these depths. This may be related to the clay filled fractures observed in the borehole logs.
BH27	BH27-01	7 – 8.5	A relatively large reading in the natural gamma log suggesting an increase in the shale / clay content at these depths. This may be related to the heavily weathered rock with large amounts of clay infill observed in the borehole logs.

Location	Monitoring Well and amomaly reference	Approximate depth of anomaly – on the geophysics logs (m bgl)	Comments
	BH27-02	8 – end of log	The induced conductivity increases from ~60mS/m to ~90mS/m. This anomaly may be representative of the increased weathering of the rock and increased amount of infill observed on the borehole logs.
BH28	BH28-01	14.5	The induced conductivity log shows a gradual increase in conductivity (from 50mS/m to 125mS/m) and the profile is less smooth from this depth. This may be indicative of the boundary between the superficial deposits and the underlying rock.
	BH28-02	31 – end of log	The induced conductivity log shows a gradual increase in conductivity (from 50mS/m to 75mS/m) and the profile is less smooth from this depth. This anomaly may be representative of the increased weathering of the rock observed on the borehole logs.
BH29	BH29-01	25 – end of log	The induced conductivity log shows a gradual increase in conductivity (from 25mS/m to 60mS/m) and the profile is less smooth from this depth. This may be indicative of the boundary between the superficial deposits and the underlying rock. The high values may also be representative of the iron staining and increased amount of infill observed on the borehole logs.
BH30	BH30-01	24.5	The induced conductivity log shows a gradual increase in conductivity (from 25mS/m to 50mS/m) and the profile is less smooth from this depth. This may be indicative of the boundary between the superficial deposits and the underlying rock.
	BH30-02	32, 36.3 and 38.7	Three relatively large readings in the natural gamma log suggesting an increase in the shale / clay content at these depths.
	BH30-03	54	The induced conductivity log shows a gradual increase in conductivity (from 50mS/m to 100mS/m). This may be indicative a change in lithology

3.1.2 Paleontological Analysis

The full paleontological analysis is presented in **Appendix G**. Samples were collected from BH30 and BH24 and the results are summarised below:

- BH30: Micropalæontology results from MEHL 30 are late Asbian – Brigantian, consistent with the Loughshinny Formation. The palynology results are in line with these findings, confirming the marine setting for the shales interbedded with limestones. This confirmed that BH30 finished in the Loughshinny Formation
- BH24: There are inherent problems with being definitive with the lithology. The palynology gives broad ranging Visean or younger results, and indicate a strong terrestrial influence. This is in keeping with the younger lithologies of the Donore, Balrickard or Walshestown Formations. Based on the site geology it is likely that this borehole finished in the Walshestown Formation.

3.2 Discussion Of Results

3.2.1 Groundwater Monitoring

As outlined in Chapter 3 groundwater level monitoring was undertaken in all the active wells on the site on the 8th July 2013. This data is presented in **Appendix E**. This data demonstrates that:

- The groundwater levels for the site have been observed to increase since the original application in 2010. The groundwater levels are expected to increase to pre-pumping levels.
- It should be noted that the levels measured in September 2013 were up to 1 m lower than those measured in July 2013. As a worst case scenario, the higher levels recorded have been used as the basis for this discussion.
- The regional groundwater flow direction is to the southeast as shown on **Figure 3**. Groundwater flow contours for the site are presented in **Figures 4 – 6.**
- Over the majority of the site, the Loughshinny Fm and Namurian strata have different flow regimes (e.g. BH29 and BH30), although they appear to be hydraulically connected at some locations (e.g. BH27 and BH18). The vertical gradients and connection between the lithologies are discussed further later in this section.
- The groundwater flow direction in the Loughshinny is clearly to the south east and is in line with the regional groundwater contours (**Figures 4** and **6**).
- The groundwater flow direction in the Namurian is dominated by the topography with local variations due to the inhomogenous nature of the material (**Figures 5** and **6**).

- The site can be divided into 4 quadrants based on the faulting on the site, similarities in the groundwater levels can be observed in each quadrant, in the centre of this site. This may indicate that the faulting is effectively partitioning the groundwater in different areas. However, it may be that the similarities observed are more a function of the lithologies and the distributions of the wells e.g. in the north west of the site, the majority of the wells are screened in the Namurian, while in the southwest of the site, they are primarily in the Loughshinny Fm.
- A vertical upward gradient exists in some areas of the site e.g. the groundwater level recorded in BH30 (Loughshinny Fm) is 1m above that in BH29 (Namurian deposits).
- The ground level recorded in BH12 is consistent with the Loughshinny readings across the rest of the site. However, the groundwater levels in BH13 (122.57 mOD) and BH8 (133.2 mOD) are perched relative to the base of the quarry and the Loughshinny Fm. This is not thought to be indicative of a downward vertical gradient but is more likely a function of the Namurian response zone being located in an isolated fracture or impermeable zone. The 11m head difference between BH13 and BH8 over a relatively short distance (150 m) further corroborates this.
- BH27 (Namurian strata) and BH18 (Loughshinny Fm) would also be expected to show a vertical upward gradient due to their proximity. Groundwater levels recorded in these wells are very similar indicating that they are likely to be hydraulically connected. This may be due to their position close to the east west fault as weathered zones related to this fault may be allowing the connection.
- A vertical downward gradient can also be observed on the site. BH20 and BH26 may be considered a well pair as BH20 is screened across the Namurian strata and the Loughshinny Fm while BH26 is only screened in the Namurian. The groundwater level recorded in BH20 is 0.46 m below the level recorded in BH26 indicating a downward gradient may be present here. It does, however, also illustrate that the Loughshinny and Namurian are hydraulically separate over the majority of the site.

In summary, the groundwater level information indicates that under static conditions the groundwater in the Namurian strata and Loughshinny Formation are hydraulically operate independently of each other.

3.2.2 Faulting

The original conceptual model suggested the site be divided into four quadrants based on the faulting across the site. The recent investigations confirmed the appropriateness of this.

- The geological map of the site shows the main N-S fault and two E-W faults. This was prepared on the basis of geological field mapping and geophysics (original EIS site specific geological map presented in **Figure 10**).
- The E-W fault to the east of the N-S fault was detected by the geophysics which indicated it may have a downthrow of up to 80 m to the north. The geological logs for BH 25, BH18, BH27, BH11 and BH16 show the Loughshinny Formation getting progressively deeper towards the north of the site (shown on **Figure 7**).

- The North-South fault was detected by the geophysics and geological mapping. The movement along this fault is complex as to the south of the east west fault, the eastern block appears to be downthrown however to the north of the E-W fault, the western block appears to be downthrown. This may indicate that the north-south fault is the older faulting while the east-west faulting occurred later.
- **Figure 7** presents cross sections taken across the faults running N-S and E-W. These figures illustrate the influence of faulting on the site geology.

3.2.3 Pumping

A pumping test was conducted in BH17 (the pumping well) at the MEHL site as part of the hydrogeological site investigation in July 2013. The pumping test was split into the following phases:

1. **Constant Rate Test 1** - An abandoned 6-hour constant rate discharge test on Tues, July 9, 2013;
2. A 16.5 hour recovery period between Tues and Wed, July 9 and 10, 2013;
3. **Constant Rate Test 2** - A 7-day constant rate discharge test commenced on Wed, July 10, 2013;
4. **Recovery Test** - A 24-hour recovery test on Wed, July 17, 2013.

Full details of the pumping test and its interpretation are presented in **Appendix H**.

Based on the results of the pumping test it can be determined that under stressed conditions groundwater can move from the Namurian strata into the aquifer along the faults.

4 Updated Conceptual Site Model (CSM)

4.1 Summary Site Conceptual Model

A summary of the hydrogeology of the MEHL site is presented here in the form of a site conceptual model (CSM). This draft updates the previous CSM presented in the EIS and incorporates additional site investigation information gathered in June and July 2013.

The conceptual model for the site has evolved through the various stages of the project from initial desk study through the interpretation of site specific data. Cross sections illustrating the conceptual site model are presented in **Figures 7** and **8** and the model can be summarised as follows:

- From the GSI map of the area (Sheet 13), the Carboniferous rock units (Walshestown, Balrickard, Loughshinny and Naul formations) are folded into a gentle syncline (bowl-shaped fold), whose axis runs roughly WNW-ESE. The Walshestown Formation occupies the centre of the fold, surrounded in sequence by the Balrickard formation, Loughshinny formation and the Naul formation to the south. The site is located on the south west limb of this syncline.
- The effect of this synclinal structure is to bury the Loughshinny Formation even deeper than would be expected had the rocks in the area not been folded. The Loughshinny Formation is dipping in towards the centre of the syncline, resulting in it becoming deeper as its traced northwards.
- Bedrock beneath this former quarry site can be divided into an aquifer unit, the Loughshinny and Donore Formations and an aquitard unit which consists of the overlying Balrickard and Walshestown Formations. The aquifer unit is classified by the GSI as a Locally Important Aquifer and the aquitard as a Poor Aquifer
- The majority of the site is underlain by the aquitard. The limestones of the Loughshinny Formation crop out in the southern part of the MEHL site and dip to the to the north, where they are covered by up to 60 m of aquitard strata in the northern parts of the site.
- The faulting within the site is shown on the site specific geological map presented with the EIS (Figure 10). The understanding of the behaviour of the faulting has been refined with information from site investigation information gathered in 2013 and this is discussed further in this section. The faulting passes through all the rock units found on the MEHL site.
- Permeability in the strata beneath the site is predominantly secondary in the form of joints, fractures, weathered/broken zones and faults. Permeability in the aquifer unit is of the order of 10-4/10-5m/s. In the permeable horizons of the aquitard, permeability is of the order of 10-6m/s and in the remainder of the strata it is of the order of 10-7/10-8m/s. Storage in all of these strata is low.
- The aquitard strata on-site act as a low permeability layer and confine/isolate groundwaters within the aquifer from the surface in some areas of the site. The increasing thickness of these strata reduces the vulnerability to the north.

- The groundwater levels in the aquifer unit are relatively consistent across the site and lie below the floor of the quarry aside from the large pond in the extreme southern part of the site. Groundwater levels in the overlying aquitard strata are more variable and are elevated in relation to those in the underlying aquifer. More permeable fissures are present within the aquitard and these are under artesian pressure.
- Groundwater levels in recent monitoring rounds have been observed to be increasing, indicating that levels may be rebounding following the cessation of dewatering at the quarry. The current design level of the base of the landfill is 102.5 OD while the highest groundwater levels recorded in the base of the landfill are 103.37 mOD. The design base of the landfill has been raised to the original formation level of 104.5 mOD to account for this.
- Groundwater flows in a generally south easterly direction from the site at a gradient of 0.02-0.05 and a velocity of approximately 1.48 x 10-5 m/s.
- The site is located in the upper part of a groundwater catchment. This location, the general absence of large springs in the aquifer, the confined nature of much of the aquifer in the site area and the moderate gradient and velocity indicate that the natural groundwater throughput in the aquifer is relatively low.
- The pumping test indicated that under stressed (pumping) conditions, that groundwater from the Namurian strata can enter the aquifer through the faults on the site. If the site was to fall within the catchment and cone of depression of an abstraction and the landfill liner leaked, contaminants may, having also passed through the clay liner, enter the catchment of the abstraction. Figure 11 presents the conceptual model of this.
- In order to mitigate this risk, the faults beneath the site will be grouted up prior to the development. The design of this will be developed and tested during the detailed design phase of the proposed development.

5 Updated Quantitative Risk Assessment (QRA)

The QRA has been updated in line with additional site investigation information, changes to the conceptual model and questions from the EPA.

5.1 Model Scenarios

Three QRA models were presented in the original WLA. These are outlined below:

- Primary model: This model was constructed based on site specific information for both the landfill design and the hydraulic characteristics of the ground in order to make it as representative of site conditions as possible. All the landfill cells were modelled in the same model.
- Supplementary model 1: Represented the proposed development with a major defect in the liner of one of the hazardous cells.
- Supplementary model 2: Represented the proposed development with no engineered barriers in place.

This report presents a series of updated models and a summary of the changes is listed below:

- The formation level of the landfill cells has been raised to 104.5 mOD. This has also led to a change in the area of the base of the landfill.
- Separate cells have been produced based on the presence or lack of a vertical pathway.
- The unsaturated zone thickness has been reduced to 2 m across the site.
- Representation of the hazardous waste as a constant source rather than a declining source

The EPA requested that the effects of other changes be considered. These include:

- Increasing the leachate head in hazardous and non-hazardous cells to 2 m and 5 m

The management control period has a large influence on the stability of the non-hazardous and inert models as it determines the leachate head on the engineered barrier. For this reason, for the non-hazardous cells, models were constructed with both 35 year and 20,000 year management periods to allow the results of both scenarios to be discussed and compared. It should be noted that the 20,000 year scenario in LandSim represents infinity.

The modelling was not completed for the inert cells as the risk they pose is less than that from the hazardous and non-hazardous cells.

The nomenclature used to discuss the individual models is summarised in **Table 5.1**. All the LandSim inputs (direct model print outs) and outputs (statistical and graphical) are saved in **Appendix A**. The table below lists which sub-appendix the individual models and results are presented in.

Table 5.1: QRA model nomenclature

Model name	Changes incorporated (as compared to original Primary model)	Appendix Reference	
		Model print out	Model results
Non-hazardous model V1	• Removes the vertical pathway as the non-hazardous cells will be placed in the south of the site	A1.1	A1.2
Non-hazardous model V2	• Same as V1 model but with a management control period of 20,000 years (infinity)	A2.1	A2.2
Hazardous model	• Includes the vertical pathway on site as the hazardous cells will be placed in the north of the site where the Namurian strata are present • Increase formation level to 104.5 mOD • Represent waste as a constant source	A3.1	A3.2
Supplementary Hazardous model 1	• Increase the leachate head in the hazardous cells to 2m	A4.1	A4.2
Supplementary Hazardous model 2	• Increase the leachate head in the hazardous cells to 5m	A5.1	A5.2
Supplementary Hazardous model 3	• Represent DAC as a double liner (not discussed in this report as the results did not indicate an impact on groundwater)	A6.1	A6.2
Supplementary non-hazardous model V1	• Non hazardous model v1 (management control period of 35 years) • Leachate head of 2m	A7.1	A7.2
Supplementary non-hazardous model V2	• Non hazardous model v1 (management control period of 35 years) • Leachate head of 5m	A8.1	A8.2
Supplementary non-hazardous model V3	• Non hazardous model v2 (management control period of 20,000 years) • Leachate head of 2m	A9.1	A9.2
Supplementary non-hazardous model V4	• Non hazardous model v2 (management control period of 20,000 years) • Leachate head of 5m	A10.1	A10.2
Appendices from original WLA, December 2010		A10	

5.2 Models Construction

The majority of the construction parameters for the models remain the same as the Primary models submitted with the original WLA. For this reason, much of the information provided in that report has not been repeated.

The model input parameters are presented in **Appendix A** as print-outs directly from LandSim.

The non-hazardous models V1 and V2 have all the same input parameters except for the management control period.

5.2.1 Source Term Input Parameters

The source term input parameters include the physical and chemical characteristics of the waste itself, the cell geometry and phasing details and the infiltration rates. These input parameters are discussed in detail in sections 5.2.1.1 to 5.2.1.4. The model print out from LandSim which summarises the input parameters for the primary model are presented in **Appendix A**.

5.2.1.1 Cell Geometry

As outlined above separate models have been constructed for the hazardous, non-hazardous and inert waste streams. The models and the number of cells in each is summarised below:

- Non-hazardous model: 3 cells (NH1a, NH1b and NH2)
- Hazardous model: 6 cells (H1a, H1b, H2a, H2b, H3a and H3b)

Important points to note include:

- For each waste type multiple cells will be constructed to reduce the amount of time that waste remains open to infiltration and to minimise leachate generation. In order to construct a representative model, each of these cells was modelled as an individual cell within the LandSim model.
- On the proposed development many of the cells have been divided in two in order to minimise leachate generation e.g. H1 has been divided into H1a and H1b.
- Each of the proposed cells will have its own sump so they have all been constructed separately in LandSim
- The proposed design for the cells shows them as irregular shapes as shown on Figure 14. In the LandSim model these cells were constructed as squares or rectangles with the area of the top and base maintained at the same size as the irregular shape.
- Where a cell has been divided in two to minimise leachate generation (e.g. H1 into H1a and H1b) the full design details of each individual cell are not available. For this reason it has presumed that the two cells will be identical with the volume of waste expected in cell H1 divided equally between cell H1a and cell H1b.
- The thickness of the waste varies across the site. To account for this variation, the thickness of each cell was entered as a Probabilistic Density Function.
- The thickness of the waste was reduced by 2 m when compared to the original Primary model as the formation level has been raised by 2 m. This has also led to a change in the area of the base of the landfill cell.

The details of the parameters used for the cell geometry are contained within Table 5.2.

Table 5.2: Cell Geometry Input Parameters

Cell number	Base area (ha)	Top area (ha)	Waste thickness			Comments
			Distribution	Min	Max	
Non-hazardous model (both V1 and V2)						
NH1a	0.86	2.24	Uniform	23.5	37.5	Dimensions from site plans and cross sections
NH1b	0.86	2.24	Uniform	23.5	37.5	Dimensions from site plans and cross sections
NH2	0.127	1.1	Uniform	7	16	Dimensions from site plans and cross sections
Hazardous model						
H1a	1.01	1.71	Uniform	8.5	17.5	Amended based on increase in formation level
H1b	1.01	1.71	Uniform	8.5	17.5	Amended based on increase in formation level
H2a	1.4	2.2	Uniform	9.5	24.5	Amended based on increase in formation level
H2b	1.4	2.2	Uniform	9.5	24.5	Amended based on increase in formation level
H3a	1.29	2.55	Uniform	13.5	32.5	Amended based on increase in formation level
H3b	1.29	2.55	Uniform	13.5	32.5	Amended based on increase in formation level

5.2.1.2 Phasing, Management Control Period And Infiltration

The phasing and infiltration values have not been amended for the updated modelling.

The management control period has a large influence on the stability of the models, particularly for the non-hazardous and inert cells due to its influence on the leachate head levels in the cells. It assumes that once the management control period is complete the landfill will be ‘abandoned’ and will have no further maintenance undertaken on it (although this is very unrealistic and contrary to EPA aftercare requirements). This has significant implications for the risk assessment model as beyond the specified management period the leachate level is no longer controlled. The leachate level and, as a result, leakage through the liner will increase.

The management control period for the hazardous cells has been set at 35 years, for the purpose of the model. Due to the instability of the non-hazardous models with a short management control period, two versions of the non-hazardous model have been created. The first has a management control period of 35 years and the second has a management control period of 20,000 years. A comparison of the concentrations of contaminants in groundwater for both models was undertaken to establish the difference between them and assess how much of an influence the instability of the model with the 35 year management period is having on the results.

5.2.1.3 Leachate And Waste Characteristics

The physical characteristics of the waste influence how much leachate may be generated while the chemical characteristics influence the contaminants which may arise. The head at which leachate head is maintained within the system determines how much leachate is allowed to build up within the cell before appropriate removal and disposal.

The head of leachate within the LandSim model was fixed in line with details from the Engineering Planning Report. Within the hazardous and non-hazardous cells the leachate will be allowed to reach a maximum of 1 m above the base of the cell.

As discussed in section 5.2.1.2 the management control period has a large influence on the leachate head levels. The leachate head assigned in the model only applies for the duration of the management control period, once this period ends, the leachate heads are allowed to rise within the model. Leachate head increases to the level where surface breakout occurs, defined by LandSim as the location where waste is thinnest.

The EPA has requested that model scenarios with leachate heads of 2 m and 5 m also be created for the hazardous and non-hazardous cells.

A summary of the models with the varying leachate heads is listed in **Table 5.3**. The management control period has also been listed in the table below due to its relevance to the leachate head.

The maximum head of leachate at which surface breakout occurs is also relevant and is included in **Table 5.3**. This parameter is the minimum thickness of waste in each cells. Once the management control period ends, the leachate head rises to this level and is set at this level for the rest of the simulation period. This indicates that very high leachate heads are present on the lining system once the management control period ends.

Table 5.3: Leachate Head Details Inputted To LandSim

Model name	Leachate head (m)				Control period (years)	Maximum head of leachate when surface breakout occurs (m)	Comment
	Distribution	Min	Likely	Max			
Non-hazardous model V1	Uniform	0.5		1	35	23.5 (NH1a, NH1b) 7 (NH2)	Management control period of 35 years A minimum value of 0.5m was chosen as it is unlikely a head of less than 0.5 m could be maintained. The maximum head value has been set as the maximum head stated in the Engineering Report for Planning (WYG, 2010)
Non-hazardous model V2	Uniform	0.5		1	20,000	23.5 (NH1a, NH1b) 7 (NH2)	Management control period of 20,000 years A minimum value of 0.5m was chosen as it is unlikely a head of less than 0.5 m could be maintained. The maximum head value has been set as the maximum head stated in the Engineering Report for Planning (WYG, 2010)
Supplementary non-hazardous model V1	Single		2 m		35	23.5 (NH1a, NH1b) 7 (NH2)	Management control period of 35 years A minimum value of 0.5m was chosen as it is unlikely a head of less than 0.5 m could be maintained. The maximum head value has been set as the maximum head stated in the Engineering Report for Planning (WYG, 2010)
Supplementary non-hazardous model V2	Single		5 m		35	23.5 (NH1a, NH1b) 7 (NH2)	Management control period of 35 years A minimum value of 0.5m was chosen as it is unlikely a head of less than 0.5 m could be maintained. The maximum head value has been set as the maximum head stated in the Engineering Report for Planning (WYG, 2010)

Model name	Leachate head (m)				Control period (years)	Maximum head of leachate when surface breakout occurs (m)	Comment
	Distribution	Min	Likely	Max			
Supplementary non-hazardous model V3	Single		2 m		20,000	23.5 (NH1a, NH1b) 7 (NH2)	Management control period of 20,000 years A minimum value of 0.5m was chosen as it is unlikely a head of less than 0.5 m could be maintained. The maximum head value has been set as the maximum head stated in the Engineering Report for Planning (WYG, 2010)
Supplementary non-hazardous model V4	Single		5 m		20,000	23.5 (NH1a, NH1b) 7 (NH2)	Management control period of 20,000 years A minimum value of 0.5m was chosen as it is unlikely a head of less than 0.5 m could be maintained. The maximum head value has been set as the maximum head stated in the Engineering Report for Planning (WYG, 2010)
Hazardous model	Uniform	0.5		1	35	8.5 (H1a, H1b) 9.5 (H2a, H2b) 13.5 (H3a, H3b)	A minimum value of 0.5m was chosen as it is unlikely a head of less than 0.5 m could be maintained. The maximum head value has been set as the maximum head stated in the Engineering Report for Planning (WYG, 2010)
Supplementary Hazardous model 1	Single		2 m		35	8.5 (H1a, H1b) 9.5 (H2a, H2b) 13.5 (H3a, H3b)	EPA request
Supplementary Hazardous model 2	Single		5 m		35	8.5 (H1a, H1b) 9.5 (H2a, H2b) 13.5 (H3a, H3b)	EPA request

The waste porosity, dry density and field capacity influence the amount of leachate which can be produced from the waste. The parameters used in this model are the same as those used in the previous version.

5.2.1.4 Leachate

As discussed in the response to questions 5.5, 5.6 and 5.8 the leachate inventory is composed of the most likely contaminants to arise from the waste. Waste-stream specific data is provided in **Appendix B** and some of the contaminants listed here have been excluded from the LandSim modelling e.g. thallium, vanadium, cobalt, manganese, tin, free cyanide and nitrite on the basis that they do not have waste acceptance criteria associated with them.

However, as discussed in the responses to questions 5.5, 5.6 and 5.8, the modelled contaminants have a higher mobility and toxicity than those not modelled. Therefore, if there is no impact to groundwater from the more toxic and mobile contaminants, there will be no impact from those not modelled.

Table 8.7: LandSim Leachate Inventory

Contaminant	Concentrations entered into LandSim (mg/l)		
	Inert waste: WAC	Non-hazardous waste: WAC	Hazardous waste: 3 x WAC
Arsenic	0.06	0.3	9
Barium	4	20	180
Cadmium	0.02	0.3	5.1
Total chromium	0.1	2.5	45
Copper	0.6	30	180
Mercury	0.002	0.03	5
Molybdenum	0.2	3.5	30
Nickel	0.12	3	36
Lead	0.15	3	45
Antimony	0.1	0.15	3
Selenium	0.04	0.2	9
Zinc	1.2	15	180
Chloride	460	8500	45000
Fluoride	2.5	40	360
Sulphate	1500	7000	51000

The maximum concentrations were set in the LandSim model as 3 times the Waste Acceptance Criteria (set in EU Council Decision 2003/33/EC) for the relevant waste type as a single value. These concentrations are the maximum amount of any particular contaminant which will be accepted into the landfill.

By inputting the concentration as a single value (rather than a probability density function) it presumes that all waste accepted will be at the maximum concentration which is a very conservative scenario. However, by inputting these maximum values the highest potential risk to groundwater can be assessed.

In the previous model submitted with the WLA, the hazardous waste was modelled as a declining source. In this version, the hazardous waste has been modelled as a constant source. The source of leachate for the non-hazardous and inert models has been set as a 'Declining Source Term' in LandSim which allows the source term concentrations to decrease over time.

The half-lives of each of the contaminants, in the different stages that they move through, has been set at the highest level to effectively simulate zero degradation. The half-lives used for all contaminants at all phases (e.g. within the liner, unsaturated zone, vertical pathway and aquifer) has been set at 1,000,000,000 years. This is a conservative assumption as it does not allow the contaminants to degrade over time.

5.2.2 Pathway Input Parameters

The pathway input parameters are those which define the material which the leachate generated at the source has to move through in order to reach the receptors. The pathways in the proposed development include the drainage system, the engineered barriers and the unsaturated zone.

5.2.2.1 Engineered Barrier

The inputs for the engineered barriers for each of the cells are the same as those provided in the original WLA.

As outlined in the response to question 5.9, the DAC has been modelled as a single clay barrier. This is deemed to be more conservative as it excludes the 0.5 m thick clay barrier which will underlie the DAC layer.

A version of the hazardous model (supplementary hazardous model 3), which models the DAC as a double liner system, has been created. This model and its results are presented in **Appendices A6.1** and **A6.2**.

5.2.2.2 Unsaturated Zone

The unsaturated zone is the ground beneath the site which is above the water table. By inputting this horizon into LandSim V.2.5 it allows the natural protection, which the site offers for the protection of groundwater, to be assessed.

The conceptual model has been updated to reflect the following changes:

- Non-hazardous cells: No saturated vertical pathway will be present between the aquifer and the unsaturated zone. An artificial mineral layer of 1 m thick with a permeability of 6.6 x 10^{-10} m/s will be placed below the cell liner to provide additional protection. This will be used to simulate the unsaturated zone in LandSim and the actual natural protection will not be used. The exclusion of the actual unsaturated zone present will provide additional protection for groundwater.

- Hazardous cells: under conditions observed during the pumping test the aquifer and aquitard are hydraulically connected via the faults. The unsaturated zone thickness has been reduced to 2 m to reflect this.

Based on the conceptual model, changes were made to the unsaturated zone details to ensure that the most conservative scenario is modelled. These changes are summarised below:

- Non-hazardous model: the unsaturated zone was represented using the 1 m thick artificial low permeability (6.6×10^{-10} m/s) layer which will be placed below the liner of the cells to simulate the natural protection. The actual unsaturated zone was excluded from the model indicating there will be additional protection for groundwater than is modelled.
- Hazardous Model: the unsaturated zone thickness was reduced to 2 m and the dispersivity was reduced to 0.02 m. The moisture content was changed to a Uniform distribution of 0.1-0.3 due to the uncertainty associated with that parameter. The hydraulic conductivity remained the same as was previously used.
- Vertical Pathway

A ‘vertical pathway’ zone can be inputted into LandSim V2.5. This is appropriate for use in a situation where a saturated low permeability aquitard overlies the aquifer as is the case beneath the MEHL site.

The separate models account for the fact that the vertical pathway is not present in the south of the site where the aquifer outcrops at the surface.

The presence of the vertical zone in the models can be summarised as follows:

- Non-hazardous model: vertical zone not present;
- Hazardous model: vertical zone present.

5.2.2.3 Aquifer

The aquifer parameters have not changed based on the additional work undertaken. The measured background concentrations of each parameter have been included in the aquifer.

5.2.3 Receptors

Concentrations of hazardous substances at the base of the unsaturated zone are assessed in the model.

Concentrations of non-hazardous pollutants are assessed in groundwater at the land ownership boundary, by modelling a phantom monitoring well placed directly down gradient on the land-ownership boundary. The modelled concentrations in groundwater at the land ownership boundary are compared to appropriate drinking water standards.

The distance to the phantom receptor well changes in each model based on the location of the cells in the model relative to the land ownership boundary (except for the hazardous cells where the phantom well is located closer than the land ownership boundary as described above). These distances are summarised below:

- Non-hazardous Model: 110 m;
- Hazardous Model: 270 m.

5.3 Model Results

The results for the main models (Non-Hazardous Model and Hazardous Model) are presented in the following sections including information on the sensitivity analysis for each.

The Supplementary models for the hazardous and non-hazardous cells are also presented in the relevant sections below to allow a comparison of the results.

The models were each run for 1000 iterations. This means that the model re-ran the Monte Carlo simulation 1000 times, each time randomly selecting parameters from those defined. This ensures that the results from the model are not a single selection of results but are results from multiple runs.

Five fixed time slices were chosen for the model runs and these were concentrations after 30 years, 100 years, 300 years, 1000 years and 20,000 years (i.e. infinity).

5.3.1 Hazardous Model And Supplementary Hazardous Models

5.3.1.1 Statistical And Graphical Results

The statistical results from the LandSim models are presented in the following appendices:

- Hazardous Model: A3
- Supplementary Hazardous Model 1: A4
- Supplementary Hazardous Model 2: A5
- Supplementary Hazardous Model 3: A6

LandSim V 2.5 calculates concentrations of each parameter at the set time slices. The 20,000 year time slice represents infinity.

It is accepted best practice to consider the concentrations at the 95th percentile.

The only hazardous substances (as defined by the Water Framework Directive and Groundwater Daughter Directive) with the potential to be present are Cadmium and Mercury and their concentrations at the base of the vertical pathway are summarised in **Table 5.4** for each model.

Table 5.4 Summary 95th percentile concentration of 'hazardous substances' at the base of the unsaturated zone and vertical pathway from the hazardous

Parameter	Drinking Water Standard (mg/l)	Cell number	Concentration at the base of the unsaturated zone		Concentration at the base of the vertical pathway	
			95th percentile conc. (mg/l)	Time period after which the concentration is detected (years)	95th percentile conc. (mg/l)	Time period after which the concentration is detected (years)
Hazardous Model						
Cadmium	0.005[1]	H1a	0	NA	0	NA
		H1b	0	NA	0	NA
		H2a	0	NA	0	NA
		H2a	0	NA	0	NA
		H3a	0	NA	0	NA
		H3b	0	NA	0	NA
Mercury	0.001[1]	H1a	0	NA	0	NA
		H1b	0	NA	0	NA
		H2a	0	NA	0	NA
		H2a	0	NA	0	NA
		H3a	0	NA	0	NA
		H3b	0	NA	0	NA
Supplementary Hazardous Model 1						
Cadmium	0.005[1]	H1a	0	NA	0	NA
		H1b	0	NA	0	NA
		H2a	0	NA	0	NA
		H2a	0	NA	0	NA
		H3a	0	NA	0	NA
		H3b	0	NA	0	NA
Mercury	0.001[1]	H1a	0	NA	0	NA
		H1b	0	NA	0	NA
		H2a	0	NA	0	NA
		H2a	0	NA	0	NA
		H3a	0	NA	0	NA
		H3b	0	NA	0	NA

Parameter	Drinking Water Standard (mg/l)	Cell number	Concentration at the base of the unsaturated zone		Concentration at the base of the vertical pathway	
			95th percentile conc. (mg/l)	Time period after which the concentration is detected (years)	95th percentile conc. (mg/l)	Time period after which the concentration is detected (years)
Supplementary Hazardous Model 2						
Cadmium	0.005[1]	H1a	0	NA	0	NA
		H1b	0	NA	0	NA
		H2a	0	NA	0	NA
		H2a	0	NA	0	NA
		H3a	0	NA	0	NA
		H3b	0	NA	0	NA
Mercury	0.001[1]	H1a	0	NA	0	NA
		H1b	0	NA	0	NA
		H2a	0	NA	0	NA
		H2a	0	NA	0	NA
		H3a	0	NA	0	NA
		H3b	0	NA	0	NA

[1] S.I. 278/2007 European Communities (Drinking Water) (No.2) Regulations 2007

These results show that after 20,000 years, concentrations of the 'hazardous substances' do not exceed Drinking Water Standards for all the models. These results illustrate that groundwater is not at risk from 'hazardous substances' from the proposed development.

The modelling included the background concentrations of each parameter measured in groundwater. In the original WLA a separate model was created to illustrate the influence that the background concentrations have on the model results. This illustrated that the background concentrations are the dominant concentrations detected at the phantom receptor well.

Separate models have not been created to determine the influence of the background concentrations for this report. The background concentrations are instead listed in **Table 5.5** to allow their comparison with the results generated. They highlight the extent to which the predicted concentrations are due to background concentrations rather than due to the proposed development.

Table 5.5: Summary 95th percentile concentration of all parameters at the receptor.

Contaminant	Drinking Water Standard (mg/l)	Background concentration (mg/l)			Hazardous Model		Supplementary Hazardous Model 1		Supplementary Hazardous Model 2	
		Min	Likely	Max	95th percentile conc. (mg/l)	Time period after which the concentration is detected (years)	95th percentile conc. (mg/l)	Time period after which the concentration is detected (years)	95th percentile conc. (mg/l)	Time period after which the concentration is detected (years)
Arsenic	0.01[1]	0.00026	0.00503065	0.025	**0.013**	All	**0.014**	All	**0.013**	All
Barium	0.7[2]	0.006	0.02655294	0.06	0.045	All	0.043	All	0.044	All
Cadmium	0.005[1]	0.00003	0.0011075	0.0039	0.0024	All	0.0023	All	0.0024	All
Total chromium	0.05[1]	0.0009	0.0068	0.0237	0.014	All	0.015	All	0.015	All
Copper	2[1]	0.001	0.0027	0.005	0.0044	All	0.0043	All	0.0043	All
Mercury	0.001[1]		0.0005		0.0005	All	0.0005	All	0.0005	All
Molybdenum	0.07[2]	0.0002	0.01048	0.043	0.022	All	0.022	All	0.023	All
Nickel	0.02[1]		0		0	All	0	All	0	All
Lead	0.025[1]	0.001	0.00288889	0.006	0.0051	All	0.0051	All	0.0052	All
Antimony	0.005[1]	0.003	0.0034	0.004	0.0038	All	0.0038	All	0.0038	All
Selenium	0.01[1]	0.0012	0.00248	0.005	0.0042	All	0.0042	All	0.0043	All
Zinc	5[3]	0.002	0.0196875	0.169	0.086	All	0.083	All	0.087	All

Contaminant	Drinking Water Standard (mg/l)	Background concentration (mg/l)			Hazardous Model		Supplementary Hazardous Model 1		Supplementary Hazardous Model 2	
		Min	Likely	Max	95^{th} percentile conc. (mg/l)	Time period after which the concentration is detected (years)	95^{th} percentile conc. (mg/l)	Time period after which the concentration is detected (years)	95^{th} percentile conc. (mg/l)	Time period after which the concentration is detected (years)
Chloride	250[1]	18	32.64	57	50.6 51.5	30,100, 300, 1000 20,000	50.42 51.22	30,100, 300, 1000 20,000	50.15 50.66	30,100, 300, 1000 20,000
Fluoride	1[1]	0.1	0.257	0.4	0.35	30, 100, 300, 1000	0.35	30, 100, 300, 1000	0.35	30, 100, 300, 1000
					0.36	20,000	0.36	20,000	0.36	20,000
Sulphate	250[1]	5.08	49.08	244.77	136 137	30,100, 300, 1000 20,000	153 154	30,100, 300, 1000 20,000	129	30,100,300, 1000 20,000

[1] S.I. 278/2007 European Communities (Drinking Water) (No.2) Regulations 2007
[2] WHO Health
[3] UK Drinking Water Standard

The results presented in **Table 5.5** illustrate that arsenic is the only contaminant to exceed the Drinking Water Standard at the receptor for all of the hazardous models created. This is due to the naturally occurring background concentration of arsenic included in the models. The maximum concentration of arsenic modelled was 0.014 mg/l which is 0.004 mg/l above the drinking water standard.

As outlined in previous sections, a large element of conservatism has been built into the models as they do not account for the second low permeability layer and leak detection layer within the hazardous liner etc.

Furthermore the partition coefficient of arsenic used is relatively low compared to values obtained in a wider literature search. If a higher value for retardation was used the model would not exceed the drinking water standard for arsenic.

These results demonstrate that arsenic concentrations, elevated above background levels will not be present down-gradient.

The models which had higher heads of 2 m and 5 m during the management control period exhibited very similar results to the original model. This is indicative of the low permeability nature of the DAC liner.

5.3.1.2 Sensitivity Analysis

A sensitivity analysis was undertaken to assess the impact that changing certain parameters would have on the model. The model was shown to be sensitive to changes in the parameters outlined below:

- **Management control period:** In LandSim the management control period represents the period leachate heads are controlled. In the model the management control period was set to the length of time which the cells are operational (active filling), i.e. 35 years (from 2003). Beyond this the model assumes the landfill would not be maintained (i.e. leachate removal would cease and leachate levels would rise etc). As expected the results of the model are sensitive to the length of the management control period. A highly conservative approach was undertaken with assigning this parameter and as such the model output is conservative. The management control period of 35 years could reasonably be increased.

- **Aquifer parameters:** The model is sensitive to the aquifer parameters such as the aquifer thickness, porosity, gradient and permeability values. These values influence the amount of dilution which takes place in the aquifer. The values assigned were based on extensive experience in working in the Irish context and as such are reasonable.

- **DAC liner parameters:** the permeability of the DAC liner has a large influence on the results of the model. If the permeability of the liner is increased then the concentrations observed would also increase. However, the second clay liner and leak detection system which is part of the DAC system has not been incorporated into the model indicating that there is a conservative element built in.

- **Retardation:** Contaminants were allowed to be retarded as they moved through each pathway. Conservative contaminant-specific retardation parameters were chosen (the lowest of quoted ranges).

The model was also slightly sensitive to changes in other parameters such as the moisture content of the unsaturated zone. However, the changes did not have a significant influence on the results of the model.

Some parameters were highlighted as uncertain during model parameterisation (e.g. the size of the sump for the internal drainage layer in the DAC, dry density of inert waste). The sensitivity analysis illustrated that the model output was not significantly influenced by these parameters.

The sensitivity analysis indicated that the parameters chosen for the model are the most appropriate and in some cases are highly conservative.

5.3.1.3 Discussion

The results of the modelling indicate that with all the mitigation measures in place, no significant impact will be observed at the receptor.

No ‘hazardous substances’ are observed to enter groundwater beneath the hazardous cells (base of the unsaturated zone).

With respect to ‘hazardous substances’ the concentrations modelled are below Drinking Water Standard and are influenced by background levels.

The leachate head levels during the management control period do not have a significant impact on the results of the modelling for the hazardous cells.

It should be noted that the model can be considered highly conservative for the following reasons:

- The modelling of the hazardous cell liner is conservative as it does not incorporate the second low permeability clay liner and leak detection system built into the DAC system.
- The management control period has been modelled as 35 years, the period of active filling of the cells. The model assumes that after this period there is no leachate management and the leachate head can rise within the cells resulting in greatly increased leakage.
- It will be a requirement of the waste licence that the closure, restoration and aftercare management plan be implemented. Surrender of the licence will only be accepted by the EPA when it has been demonstrated that there will be no risk of significant pollution from the site.
- Conservative input parameters have been used throughout the model and the 95th percentile results have been assessed.

5.3.2 Non-Hazardous Models 1 And 2 And Supplementary Non-Hazardous Models

As outlined in section 5.2.1.2, the management control period has a large influence over the model results as it determines the leachate heads.

The models run with a short management control period generated errors indicating that the leachate head was too high for the underlying barrier to sustain. In order to test the influence that this was having on the resultant concentrations models were constructed using a short (Non-Hazardous Model 1) and long management control period (Non-hazardous Model 2).

The supplementary models assessed the influence of fixing the leachate heads during the management control period.

5.3.2.1 Statistical And Graphical Results

The statistical results from the LandSim models are presented in the following appendices:

- Non-Hazardous Model 1 (35 year management period): A1
- Non-Hazardous Model 2 (20,000 year management period): A2
- Supplementary Non-Hazardous Model 1 (35 year management period, 2 m head of leachate): A7
- Supplementary Non-Hazardous Model 2 (35 year management period, 5 m head of leachate): A8
- Supplementary Non-Hazardous Model 3 (20,000 year management period, 2 m head of leachate): A9
- Supplementary Non-Hazardous Model 4 (20,000 year management period, 5 m head of leachate): A10

The models with higher leachate heads were observed to become unstable (leakage rates from the cells were observed to increase and then decrease). Because of this the results were deemed to be unreliable and have not been discussed below.

It should be noted that these high leachate heads are an unrealistic scenario that will not be allowed to occur.

The stable models are: Non-hazardous model 2 and Supplementary non-hazardous model 3.

LandSim V 2.5 calculates concentrations of each parameter at the set time slices. The 20,000 year time slice represents infinity.

It is accepted best practice to consider the concentrations at the 95th percentile.

The only hazardous substances (as defined by the Water Framework Directive and Groundwater Daughter Directive) with the potential to be present are Cadmium and mercury and their concentrations at the base of the unsaturated zone are summarised in **Table 5.6** for each model.

Table 5.6: Summary 95th percentile concentration of 'hazardous substances' at the base of the unsaturated zone from the non-hazardous cells

Parameter	Drinking Water Standard (mg/l)	Cell number	Concentration at the base of the unsaturated zone	
			95th percentile conc. (mg/l)	Time slice in which the concentration is detected (years)
Non-Hazardous Model 2				
Cadmium	0.005[1]	NH1a	0.00414	20,000
		NH1b	0.0045	20,000
		NH2	0.00058	20,000
Mercury	0.001[1]	NH1a	0	NA
		NH1b	0	NA
		NH2	0	NA
Supplementary Hazardous Model 3				
Cadmium	0.005[1]	NH1a	0.0028	20,000
		NH1b	0.0029	20,000
		NH2	0.001	20,000
Mercury	0.001[1]	NH1a	3.0×10^{-13}	20,000
		NH1b	3.7×10^{-12}	20,000
		NH2	2.4×10^{-11}	20,000

[1] S.I. 278/2007 European Communities (Drinking Water) (No.2) Regulations 2007

These results show that after 20,000 years (infinity) concentrations of the 'hazardous substances' do not exceed Drinking Water Standards for the models.

Exceedences of the drinking water standard for cadmium were observed after 20,000 year (effectively infinite) period of time for the stable models. The exceedences observed were minimal and it should be noted that the results are conservative as they do not include the 'real' unsaturated zone where additional attenuation would occur.

Table 5.7 presents the concentrations of all modelled contaminants at the phantom receptor wells. As outlined in section 5.3.1 separate models were not created to exclude the background concentrations and the results below include the background levels.

Table 5.7: Summary 95th percentile concentration of all parameters at the receptor.

Contaminant	Drinking Water Standard (mg/l)	Background concentration (mg/l)			Non-Hazardous Model 2		Supplementary Non-Hazardous Model 3	
		Min	Likely	Max	95th percentile conc. (mg/l)	Time period after which the concentration is detected (years)	95th percentile conc. (mg/l)	Time period after which the concentration is detected (years)
Arsenic	0.01[1]	0.00026	0.005	0.025	**0.0136**	All	0.013	All
Barium	0.7[2]	0.006	0.027	0.06	0.045 0.046	30, 100, 300, 20,000 1000	0.044 0.049	30, 100, 300,20,000 1000
Cadmium	0.005[1]	0.00003	0.001	0.0039	0.0024	All	0.0023	All
Total chromium	0.05[1]	0.0009	0.007	0.0237	0.0145	All	0.015	All
Copper	2[1]	0.001	0.003	0.005	0.0043 0.0046	30,100,300,1000 20,000	0.0043 0.0049	30,100,300,1000 20,000
Mercury	0.001[1]		0.001		0.0005	All	0.0005	All
Molybdenum	0.07[2]	0.0002	0.01	0.043	0.025	All	0.023	All
Nickel	0.02[1]		0		0 0.000084	30,100,300,1000 20,000	0 0.00007	30,100,300,1000 20,000
Lead	0.025[1]	0.001	0.003	0.006	0.005	All	0.005	All
Antimony	0.005[1]	0.003	0.003	0.004	0.00383	All	0.00384	All
Selenium	0.01[1]	0.0012	0.002	0.005	0.0043	All	0.0043	All
Zinc	5[3]	0.002	0.02	0.169	0.085 0.086	30,100,300,1000 20,000	0.083	All
Chloride	250	18	32.64	57	50.89 51.16 51.62 51.47 50.80	30 100 300 1000 20000	52.14 52.9 53.9 53.58 51.16	30 100 300 1000 20000
Fluoride	1[1]	0.1	0.257	0.4	0.36	All	0.35 0.36 0.37	30,20,000 100,300 1000
Sulphate	250[1]	5.08	49.08	244.77	142 141	30 100, 300, 1000, 20000	143 144 145	30, 100, 20000 300 1000

[1] S.I. 278/2007 European Communities (Drinking Water) (No.2) Regulations 2007
[2] WHO Health
[3] UK Drinking Water Standard

The results presented in **Table 5.7** illustrate that arsenic is the only contaminant to exceed Drinking Water Standards at the receptor.

As outlined above, the exceedence of arsenic is due to the background concentration of arsenic included in the model. The maximum concentration of arsenic modelled was 0.014 mg/l which is 0.004 mg/l above the drinking water standard. These results demonstrate that arsenic concentrations, elevated above background levels, will not be present down-gradient.

As outlined in previous sections, a large element of conservatism has been built into the model as it does not account for the real unsaturated zone which is present on the site.

5.3.2.2 Sensitivity Analysis

A sensitivity analysis was undertaken to assess the impact that changing certain parameters would have on the model. The model was shown to be sensitive to changes in the parameters outlined below:

- **Leachate head**: The leachate heads have a large influence on the model results. When the leachate heads increase to 5 m the model becomes unstable and the results reported are unreliable.
- **Management control period:** As discussed previously models were created for two management control periods, 35 years and 20,000 years. The management control period influences the leachate head and thus the leakage from the cells making the model results sensitive to this input parameter
- **Aquifer parameters:** The model is sensitive to the aquifer parameters such as the aquifer thickness, porosity, gradient and permeability values. These values influence the amount of dilution which takes place in the aquifer. The values assigned were based on extensive experience on working in the Irish context and as such are reasonable.
- **Retardation:** Contaminants were allowed to be retarded as they moved through each pathway. Conservative contaminant-specific retardation parameters were chosen (the lowest of quoted ranges).

The model was also slightly sensitive to changes in other parameters such as the moisture content of the unsaturated zone. However, the changes did not have a significant influence on the results of the model.

The sensitivity analysis indicated that the parameters chosen for the model are the most appropriate and in some cases are highly conservative.

5.3.2.3 Discussion

The results of the modelling indicate that with all the mitigation measures in place, no significant impact will be observed at the down-gradient receptor.

The LandSim models are shown to be highly dependent on the leachate heads. The models become unstable if leachate heads are specified which are too high for the underlying barrier to sustain.

The scenarios where the leachate heads reached 5 m became unstable and the results could not be relied upon. However, it should be reiterated that the leachate heads will not be allowed to reach 5m and the leachate heads will be managed at all times during the operation and aftercare period of the landfill.

The aftercare of the site will be managed and the licence for the site will not be surrendered until the EPA is satisfied that there is no unacceptable risk to the environment from the site.

5.4 Model Discussion And Conclusion

A detailed hydrogeological investigation in 2010 was undertaken on the MEHL site in order to develop a conceptual model for the site using site specific data that describes the groundwater system in the vicinity of the site. Additional investigation was undertaken in 2013 and the CSM was updated based on this.

The LandSim modelling was updated to reflect queries from the EPA and changes in the CSM based on additional information. Separate models were created for the hazardous and non-hazardous cells and were run for a number of scenarios, including varying the leachate heads.

The hazardous cells were amended from the original model to reflect the following changes:

- The formation level of the landfill cells has been raised to 104.5 mOD.
- The unsaturated zone thickness has been reduced to 2 m across the site.
- Representation of the hazardous waste as a constant source rather than a declining source
- Increasing the leachate head in hazardous cells to 2 m and 5 m

A summary of the results of the hazardous models are presented below:

- No 'hazardous substances' (List 1) predicted to be in groundwater beneath the site (and therefore none detected at the phantom receptor well);
- No contaminants at concentrations above Drinking Water Standards predicted to be present at the phantom well receptor.

The results of the LandSim modelling indicate the risk to groundwater quality at wells down gradient of the hazardous cells will be insignificant.

The non-hazardous models were amended from the original models to reflect the following changes:

- The formation level of the landfill cells has been raised to 104.5 mOD. This has also led to a change in the area of the base of the landfill.
- The vertical pathway has been removed from beneath the non-hazardous cells.
- Only the artificial replacement layer beneath the non-hazardous cells have been modelled as the unsaturated zone. The 'real' unsaturated zone was not included in the model allowing an additional element of conservatism to be built into the model
- Increasing the leachate head in hazardous and non-hazardous cells to 2 m and 5 m

- The non-hazardous models were run with management control periods of 35 and 20,000 (infinity) years.

A summary of the results of the non-hazardous model are presented below:

- The models with high leachate heads are unstable and the results unreliable. However, those with those with the predicted lower heads were stable and the results reliable.
- No 'hazardous substances' (List 1) predicted to be in groundwater beneath the site (and therefore none detected at the phantom receptor well);
- 'Non-hazardous pollutants' (List 2), metals, chloride and sulphate predicted to be present in groundwater beneath the site above Drinking Water Standards after 20,000 years;
- No contaminants at concentrations above Drinking Water Standards predicted to be present at the phantom well receptor.

The results of the LandSim modelling indicate the risk to groundwater quality at wells down gradient of the site will be insignificant.

Although the modelling is designed to represent the landfill and surrounding environment it should be noted that these results are considered conservative for the following reasons:

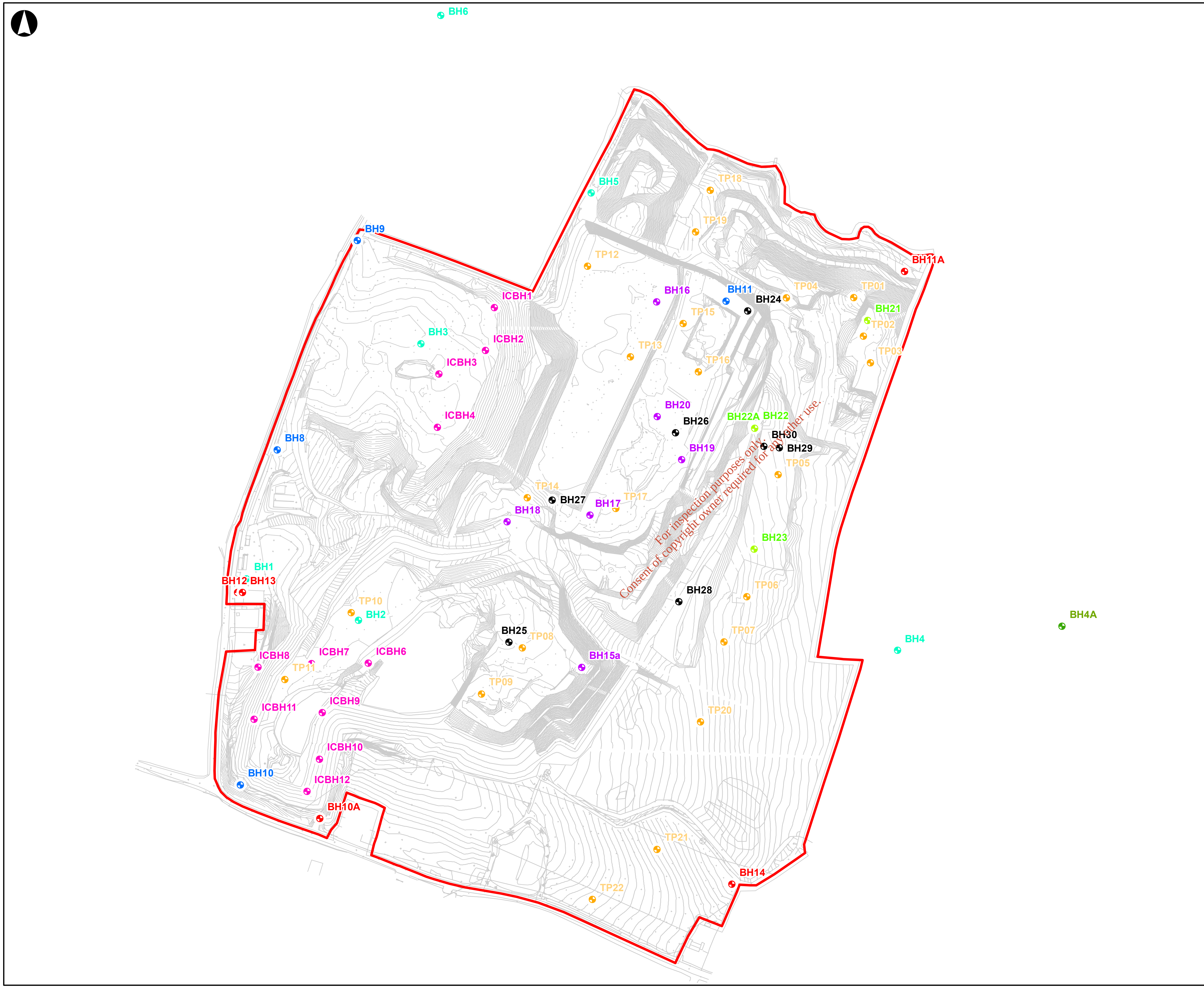
- Lower liner (0.5 m of material with a hydraulic conductivity of $1x10^{-9}$ m/s) within the DAC system has not been modelled.
- The natural unsaturated zone beneath the non-hazardous cells has not been modelled.

A Groundwater and Surface Water Monitoring Plan, incorporating level and quality monitoring, will be a requirement of the waste licence.

A Closure Restoration and Aftercare Management Plan (CRAMP) will be developed and submitted to the Environmental Protection Agency for approval. Following the cessation of operation at the site the CRAMP will be implemented to the satisfaction of the Environmental Protection Agency.

Figures

A3



Legend

- MEHL Proposed Planning and Waste Licence Boundary
- 1989 boreholes
- 1998 monitoring wells
- 2001 monitoring wells
- 2007 monitoring wells
- 2008 monitoring well
- 2010 monitoring wells
- 2010 geotechnical boreholes
- 2010 trial pits
- 2013 monitoring wells

Issue	Date	By	Chkd	Appd
P1	23-08-13	CB	RL	RL

Metres
0 50 100 200

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Client
MEHL

Job Title
EPA Waste Licence Application W0129-03. Response to EPA Article 16: Groundwater

**Figure 1.
All site investigations to date
(1989 - 2013)**

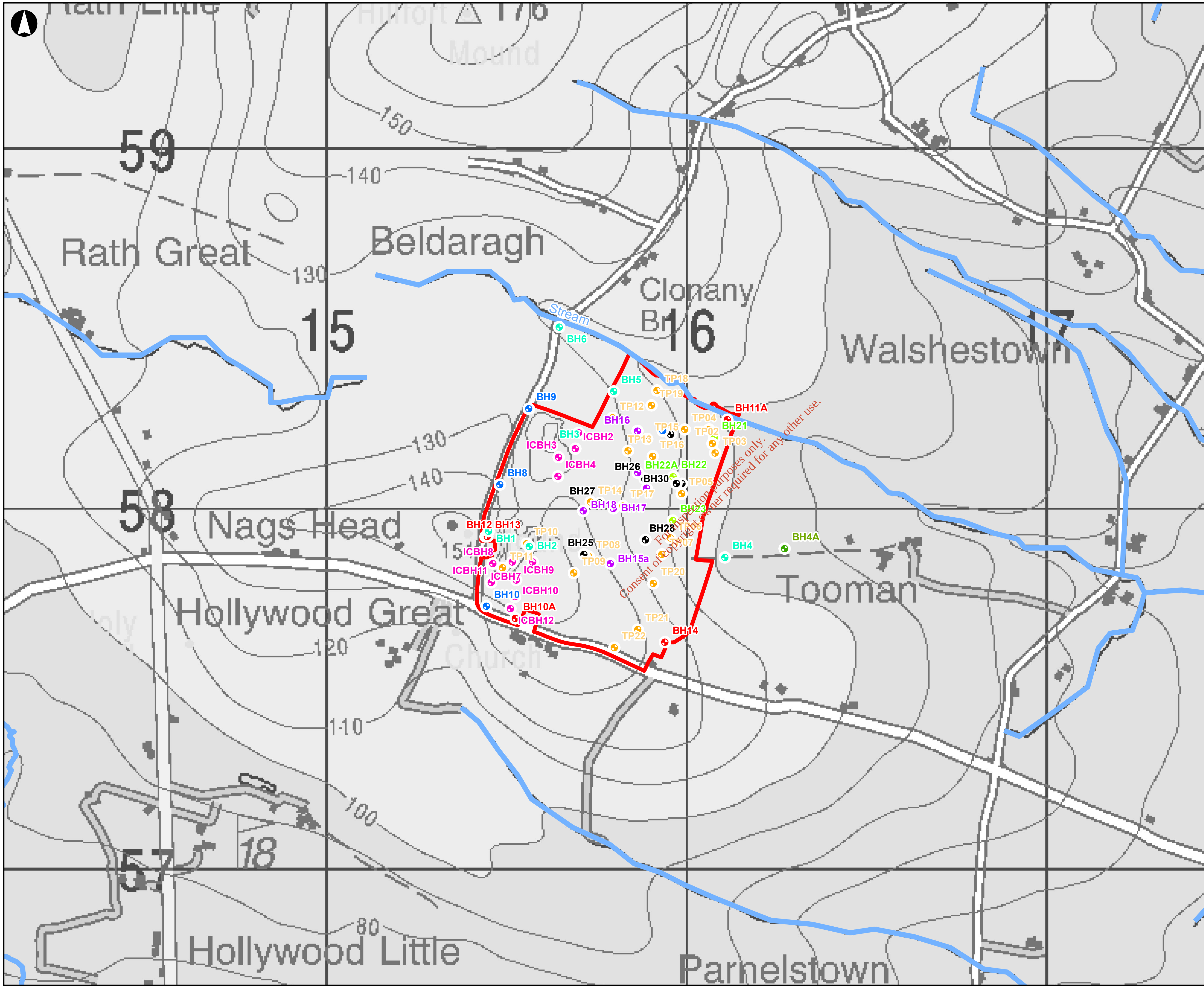
Scale at A3
1:3,625

Job No	Drawing Status
326877.01	Final

Drawing No	Issue
001	P1

MXD Location: J:\D6800-D6899\D6877\6_Graphics\30\GIS\WLA 2013\mxd\Site investigation locations.mxd

A3



Legend

- MEHL Proposed Planning and Waste Licence Boundary
- Water courses
- 1989 boreholes
- 1998 monitoring wells
- 2001 monitoring wells
- 2007 monitoring wells
- 2008 monitoring well
- 2010 monitoring wells
- 2010 geotechnical boreholes
- 2010 trial pits
- 2013 monitoring wells

Issue	Date	By	Chkd	Appd
P1	23-08-13	CB	RL	RL

Metres

0 137.5 275 550

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Job Title

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**Figure 2.
All site investigations to date
on regional topographic map**

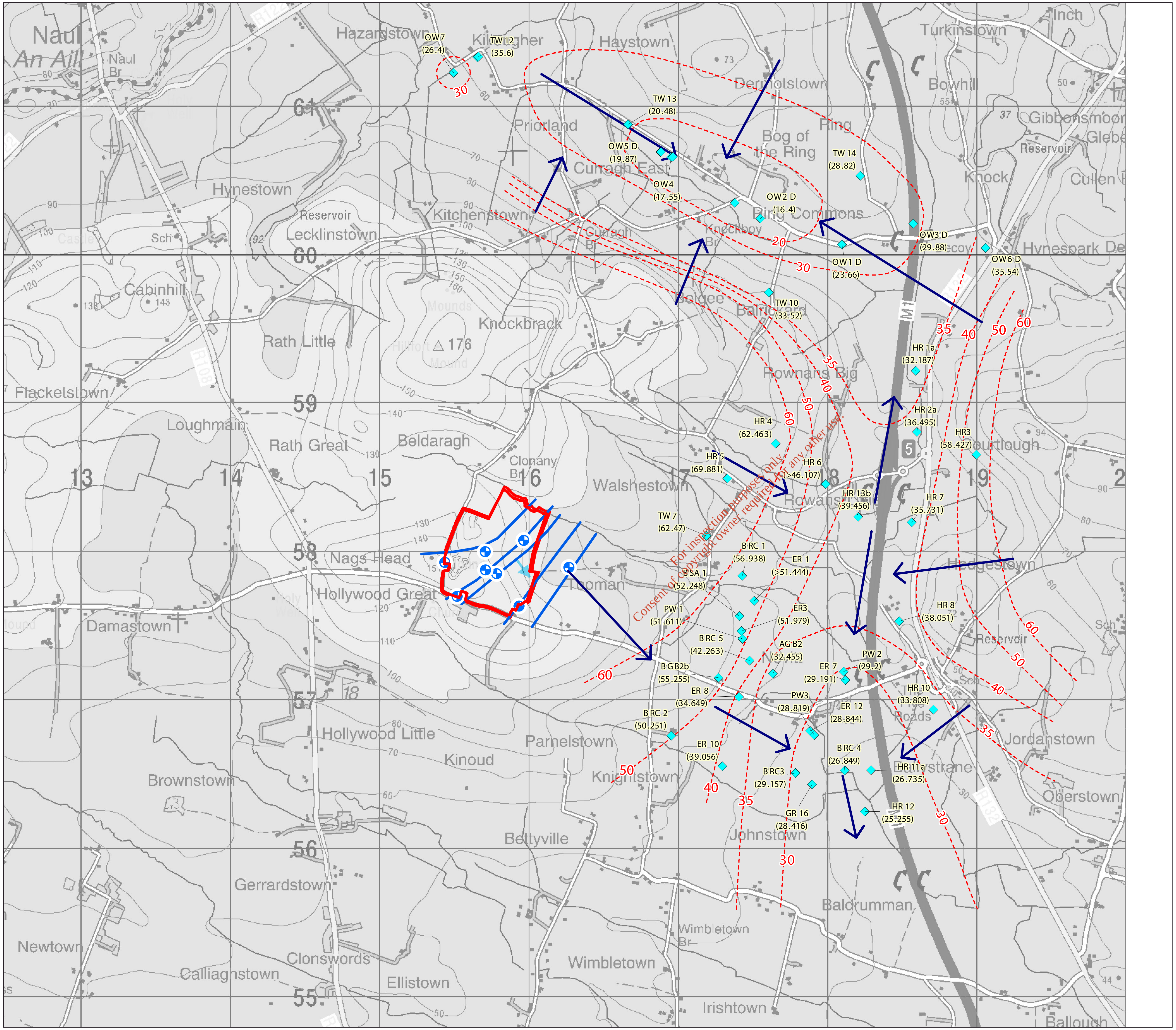
Scale at A3

1:10,000

Job No	Drawing Status
326877.01	Final

Drawing No	Issue
002	P1

MXD Location: J:\D6800-D6899\D6877\6_Graphics\30\GIS\WLA 2013\mxd\Figure 2 regional topoSite investigation locations.mxd



0 metres 140

Scale 1:25,00

Ordnance Survey Ireland Licence Number EN 0004910 © Government of Ireland

Legend

MEHL Proposed Planning and Waste Licence Boundary

Loughshinny Flow Direction

Loughshinny Approximate Groundwater Level Contours

Legend:

Data from Fingal Landfill, Groundwater Contours Bedrock 24th June 2005, Appendix 5.1 (Dwg No. Mi0182)

(51.72) Waterlevel mAOD)

30 Groundwater Contour (mAOD)

Groundwater Flow Direction

ARUP

patel tonra ltd environmental solutions

Manahan Planners Chartered Town Planning Consultants

M.E.H.L Hollywood

Murphy Environmental Hollywood Ltd

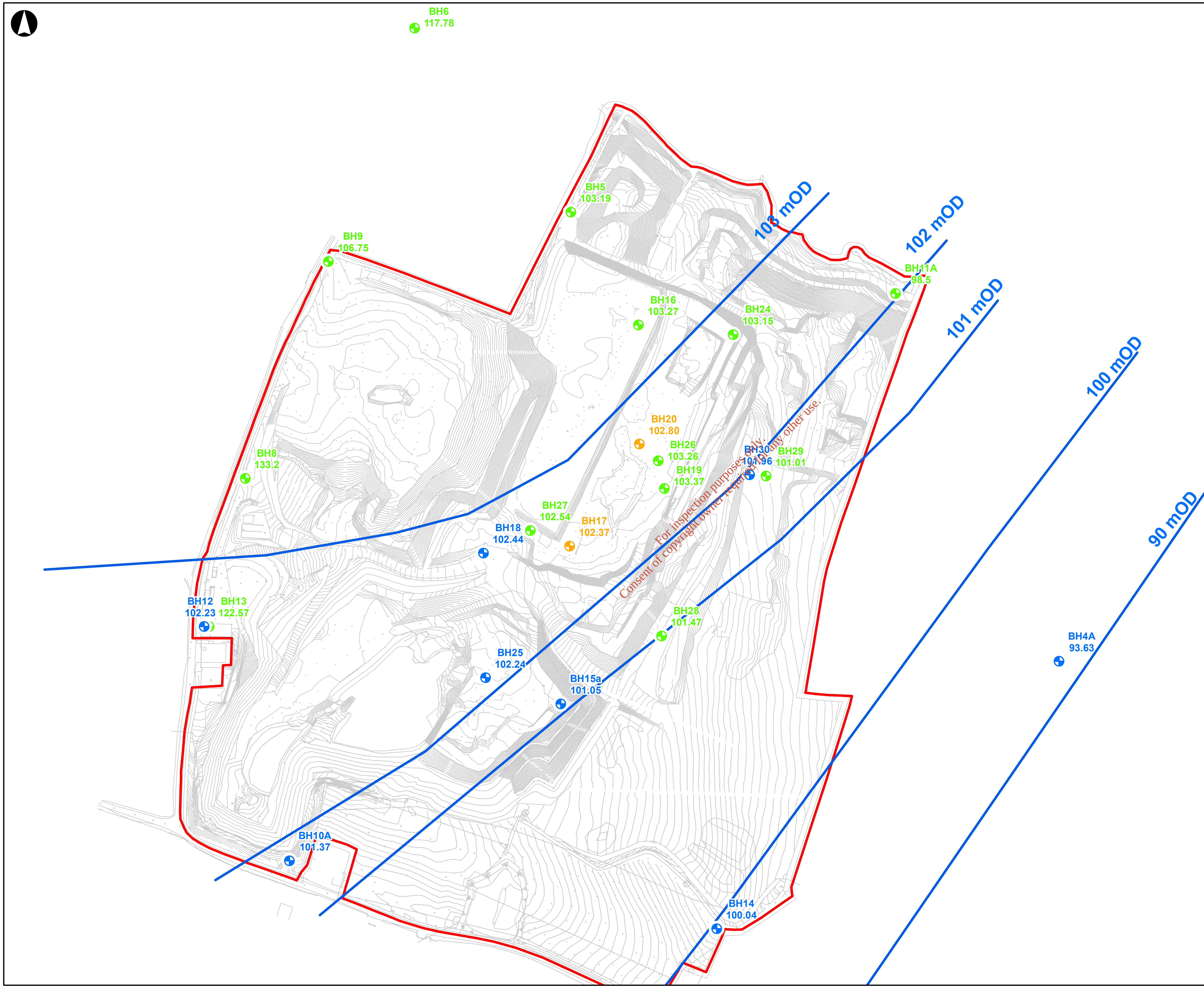
MEHL Integrated Waste Management Facility

Hollywood Great, Nags Head, Naul, Co Dublin

Regional Groundwater Flow

Figure 3

A3



Legend

- MEHL Proposed Planning and Waste Licence Boundary
- Monitoring wells in the aquifer (Visean: Loughshinny Fm)
- Monitoring wells in the aquitard (Namurian aged formations)
- Wells screened in aquifer and aquitard
- Loughshinny Fm contours

Issue	Date	By	Chkd	Appd
P1	23-08-13	CB	RL	RL

Metres
0 45 90 180

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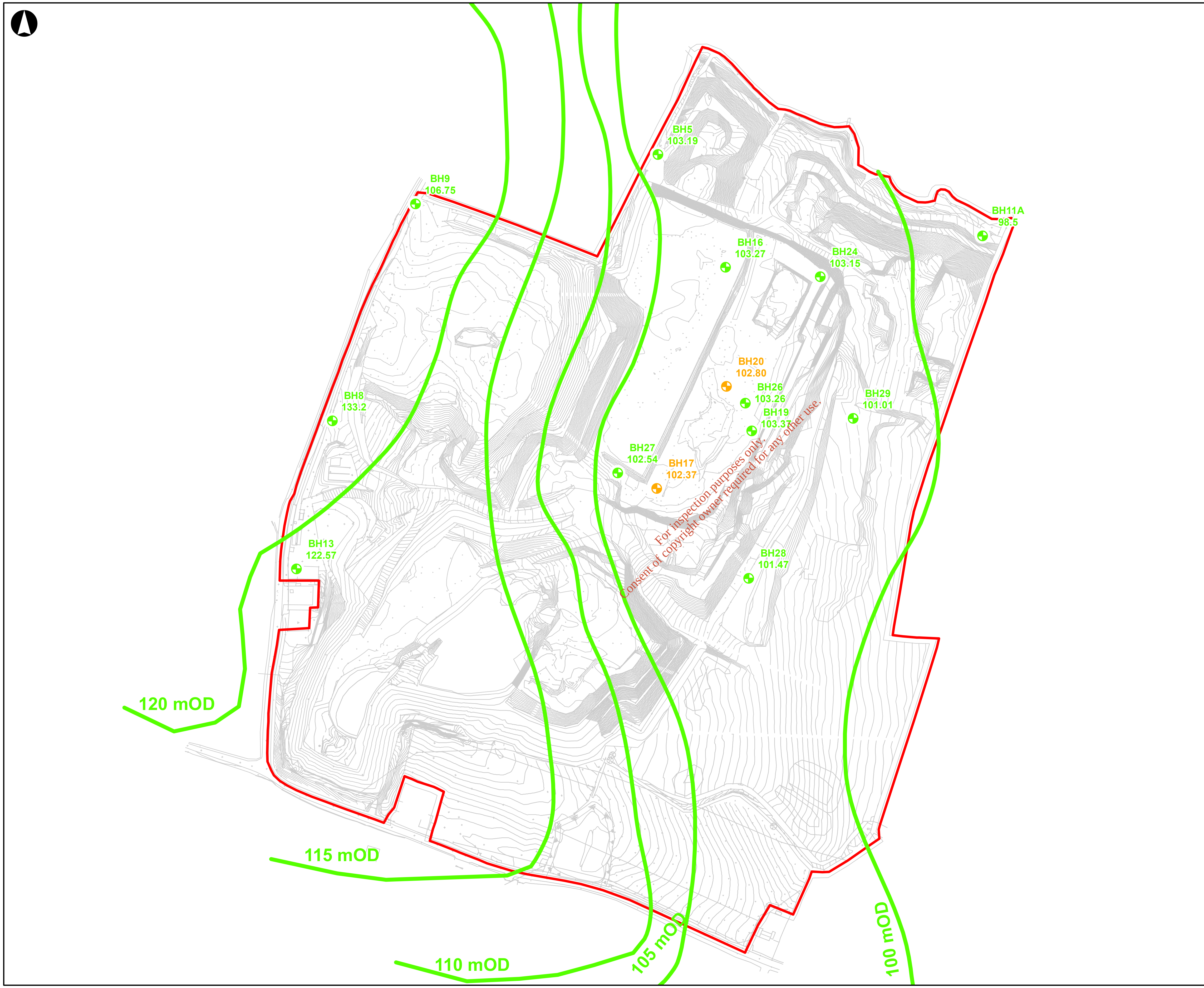
**Figure 4.
Groundwater levels and contours:
Loughshinny Formation
8th July 2013**

Scale at A3
1:3,500

Job No	Drawing Status
326877.30	Final

Drawing No	Issue
004	P1

A3



Legend

- MEHL Proposed Planning and Waste Licence Boundary
- Monitoring wells in the aquitard (Namurian aged formations)
- Wells screened in aquifer and aquitard
- Namurian groundwater contours

Issue	Date	By	Chkd	Appd
P1	23-08-13	CB	RL	RL

Metres
0 45 90 180

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Job Title
EPA Waste Licence Application W0129-03. Response to EPA Article 16: Groundwater

**Figure 5.
Groundwater levels and contours:
Namurian Formations
8th July 2013**

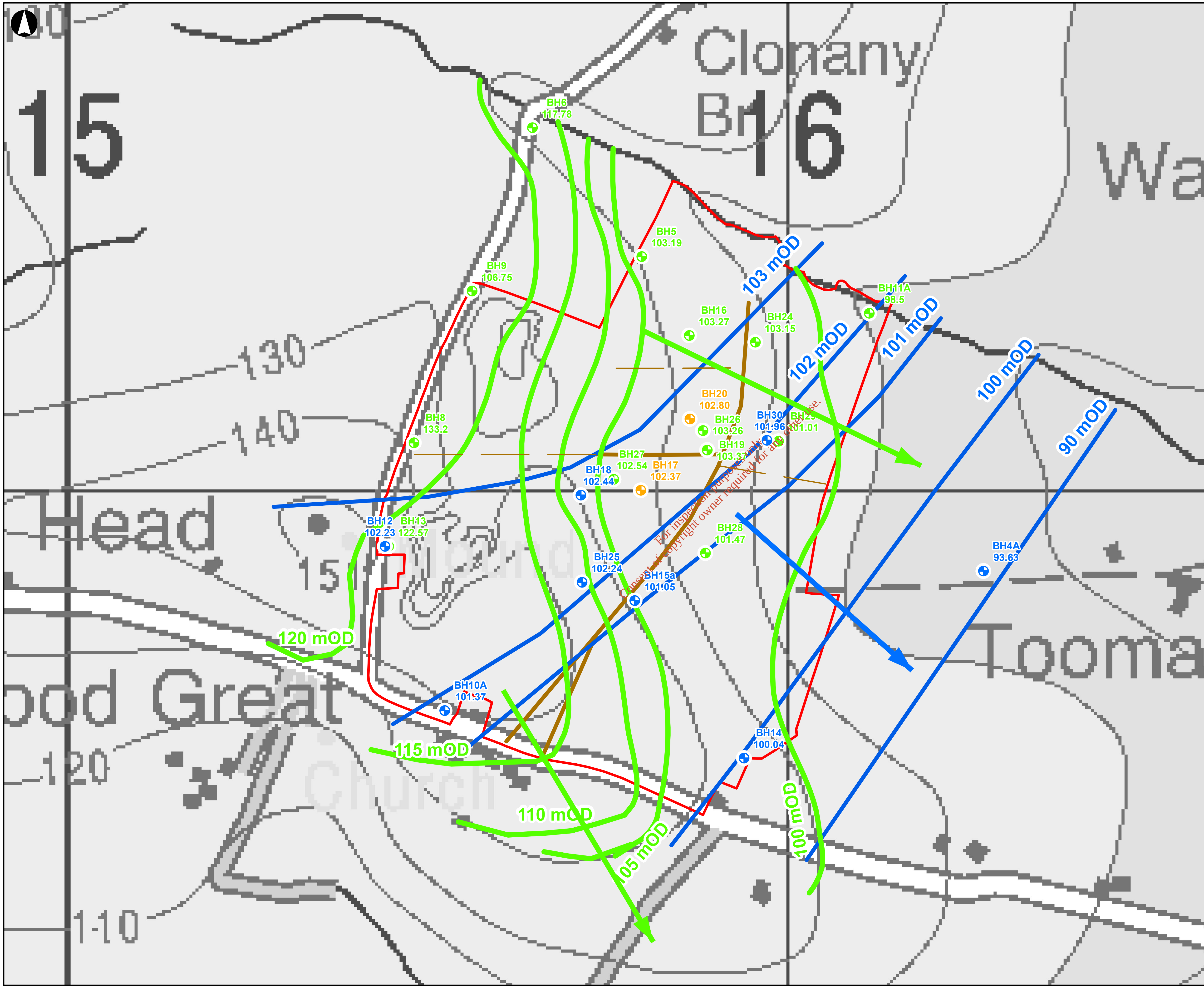
Scale at A3
1:3,500

Job No	Drawing Status
326877.01	**Final**

Drawing No	Issue
005	**P1**

MXD Location: J:\D6800-D6899\D6877\6_Graphics\30\GIS\WLA 2013\mxd\Namurian contours.mxd

A3



Legend

- MEHL Proposed Planning and Waste Licence Boundary
- Monitoring wells in the aquifer (Visean: Loughshinny Fm)
- Monitoring wells in the aquitard (Namurian aged formations)
- Wells screened in aquifer and aquitard
- Possible Fault/Fracture
- Possible faulted boundaries
- Namurian groundwater contours
- Loughshinny groundwater contours
- Namurian groundwater flow direction
- Loughshinny groundwater flow direction

P1	23-08-13	CB	RL	RL
Issue	Date	By	Chkd	Appd

Metres
0 65 130 260

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Client
MEHL

Job Title
EPA Waste Licence Application W0129-03. Response to EPA Article 16: Groundwater

**Figure 6.
Groundwater levels and contours: Loughshinny and Namurian Formations, 8th July 2013**

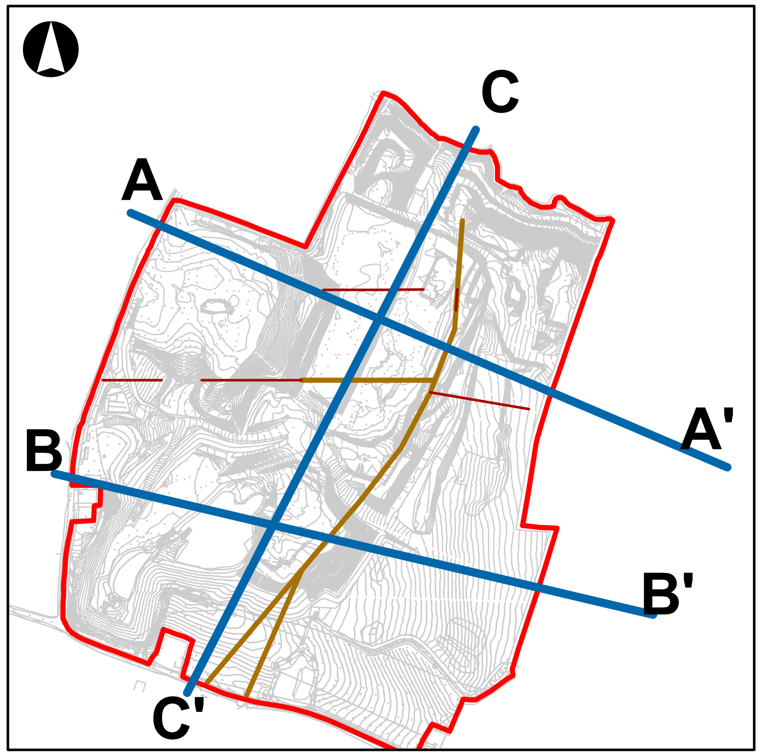
Scale at A3
1:5,000

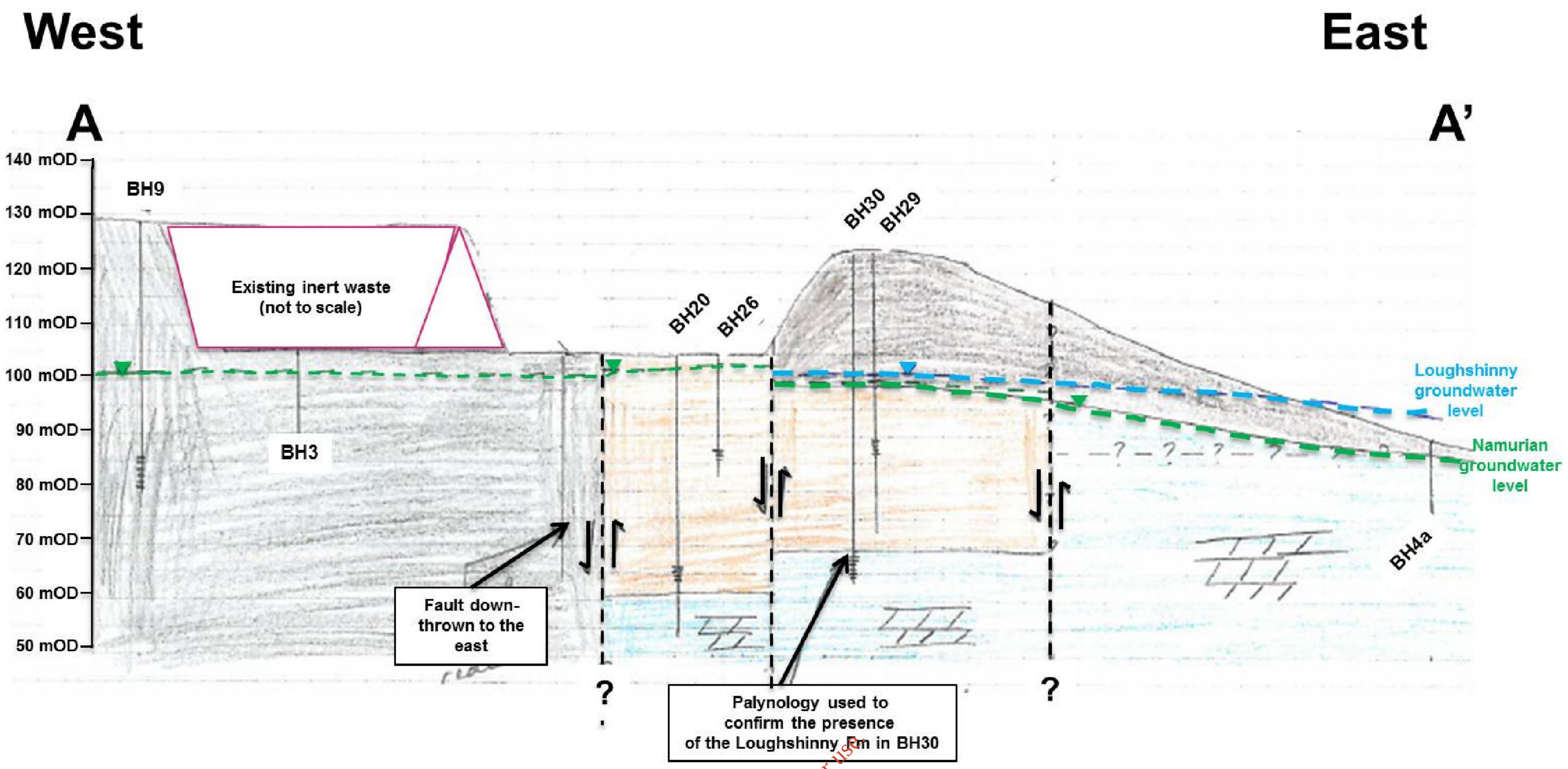
Job No	Drawing Status
326877.01	Final

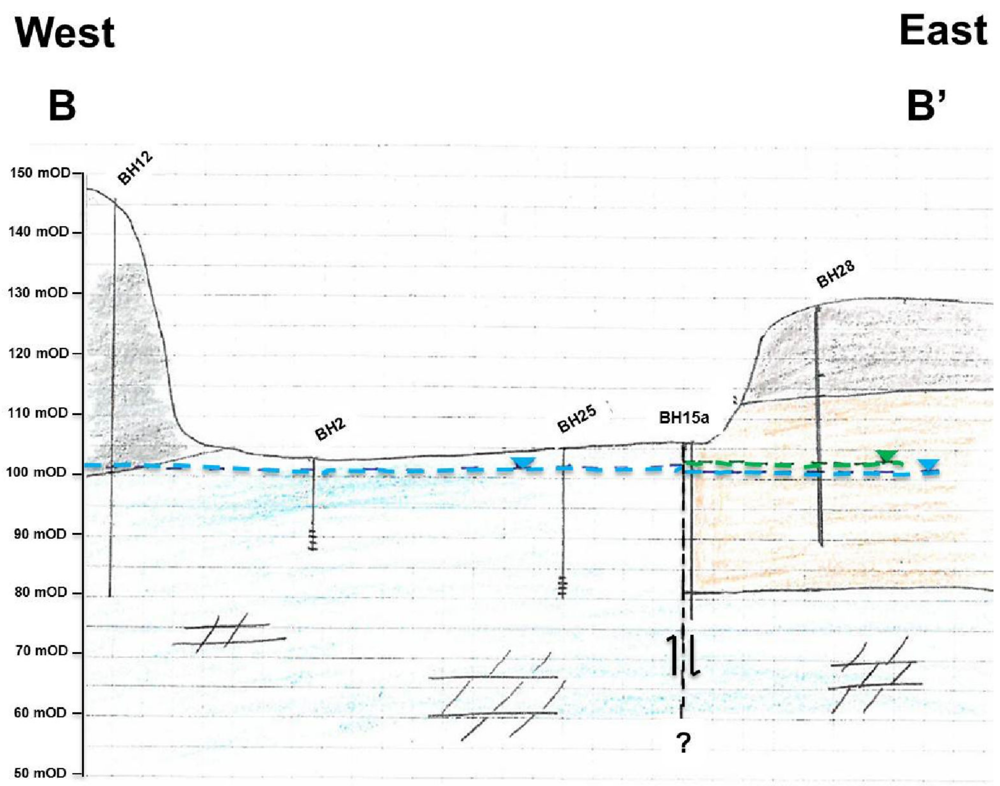
Drawing No	Issue
005	P1

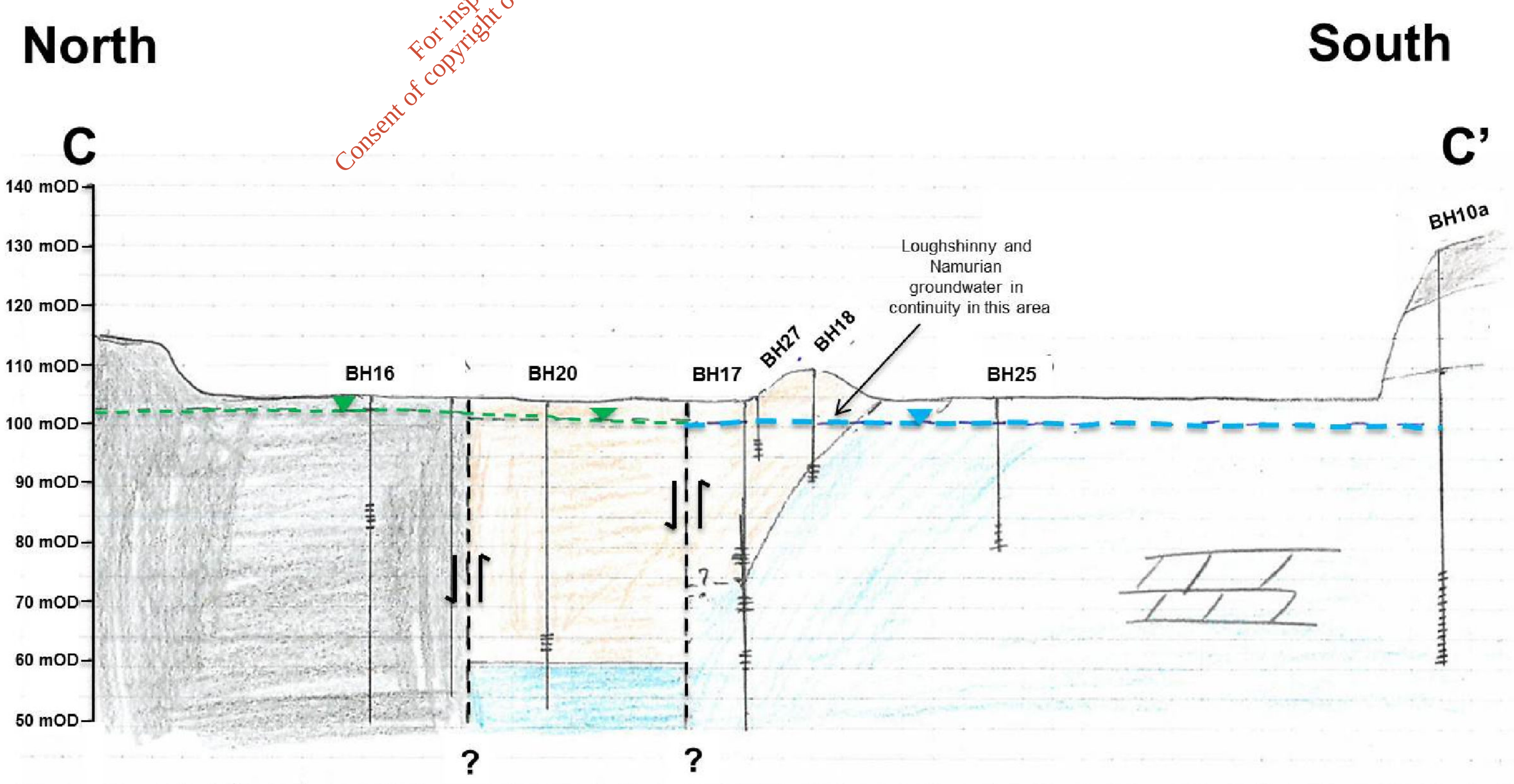
MXD Location: J:\D6800-D6899\D6877\6_Graphics\30\GIS\WLA 2013\mxd\Namurian contours.mxd

A3









Legend

- MEHL Proposed Planning and Waste Licence Boundary
- Possible Fault/Fracture
- PossFaultedContact
- Cross section location

Key:

- Boulder clay
- Walshestown Formation
- Balrickard Formation
- Loughshinny Formation
- Faulting
- Namurian groundwater levels
- Loughshinny groundwater levels

Cross sections not to scale.
Approximate vertical scale: 1:100
Approximate horizontal scale: 1:3,500

Issue	Date	By	Chkd	Appd
P1	23-08-13	CB	RL	RL

Metres
0 137.5 275 550

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Job Title
EPA Waste Licence Application W0129-03. Response to EPA Article 16: Groundwater

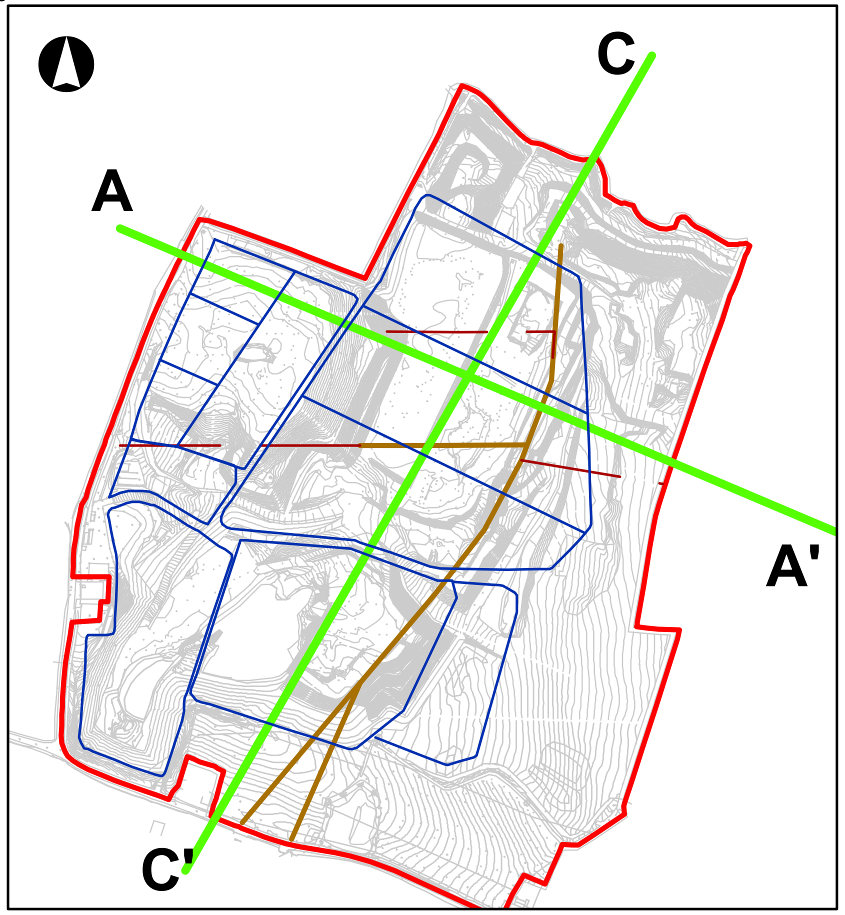
**Figure 7.
Geological cross sections**

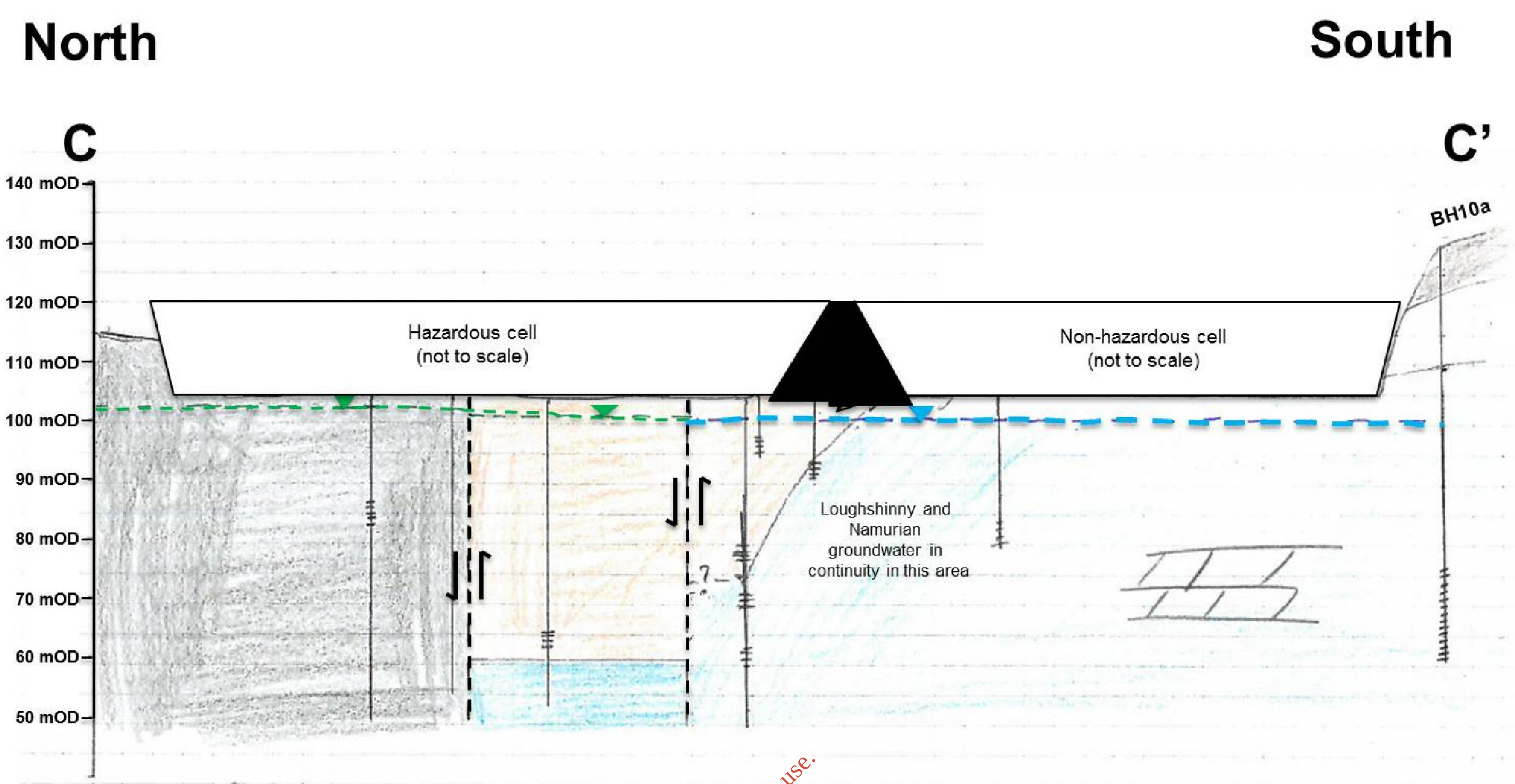
Scale at A3
1:10,000

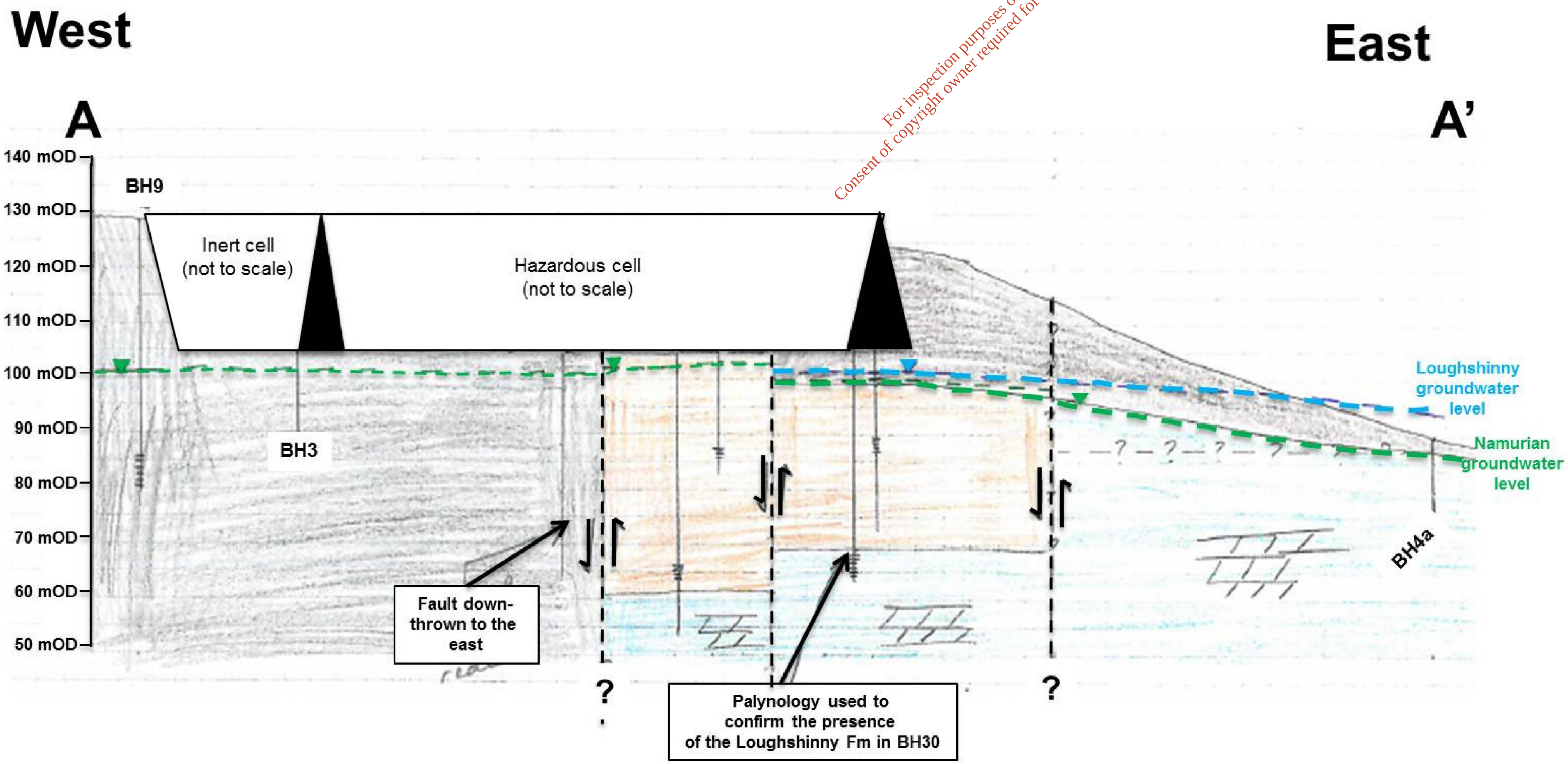
Job No	Drawing Status	
326877.30	Final	
Drawing No		Issue
007		P1

MXD Location: J:\D6800-D6899\D6877\6_Graphics\30\GIS\WLA 2013\mxd\Figure 7 x sxn locations.mxd

A3







Legend

- MEHL Proposed Planning and Waste Licence Boundary
- Possible Fault/Fracture
- PossFaultedContact
- Waste cell layout
- CSM locations

Key:

- Boulder clay
- Walshestown Formation
- Balrickard Formation
- Loughshinny Formation
- Faulting
- Namurian groundwater levels
- Loughshinny groundwater levels

Cross sections not to scale.
Approximate vertical scale: 1:100
Approximate horizontal scale: 1:3,500

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Issue	Date	By	Chkd	Appd
P1	23-08-13	CB	RL	RL

Metres
0 110 220 440

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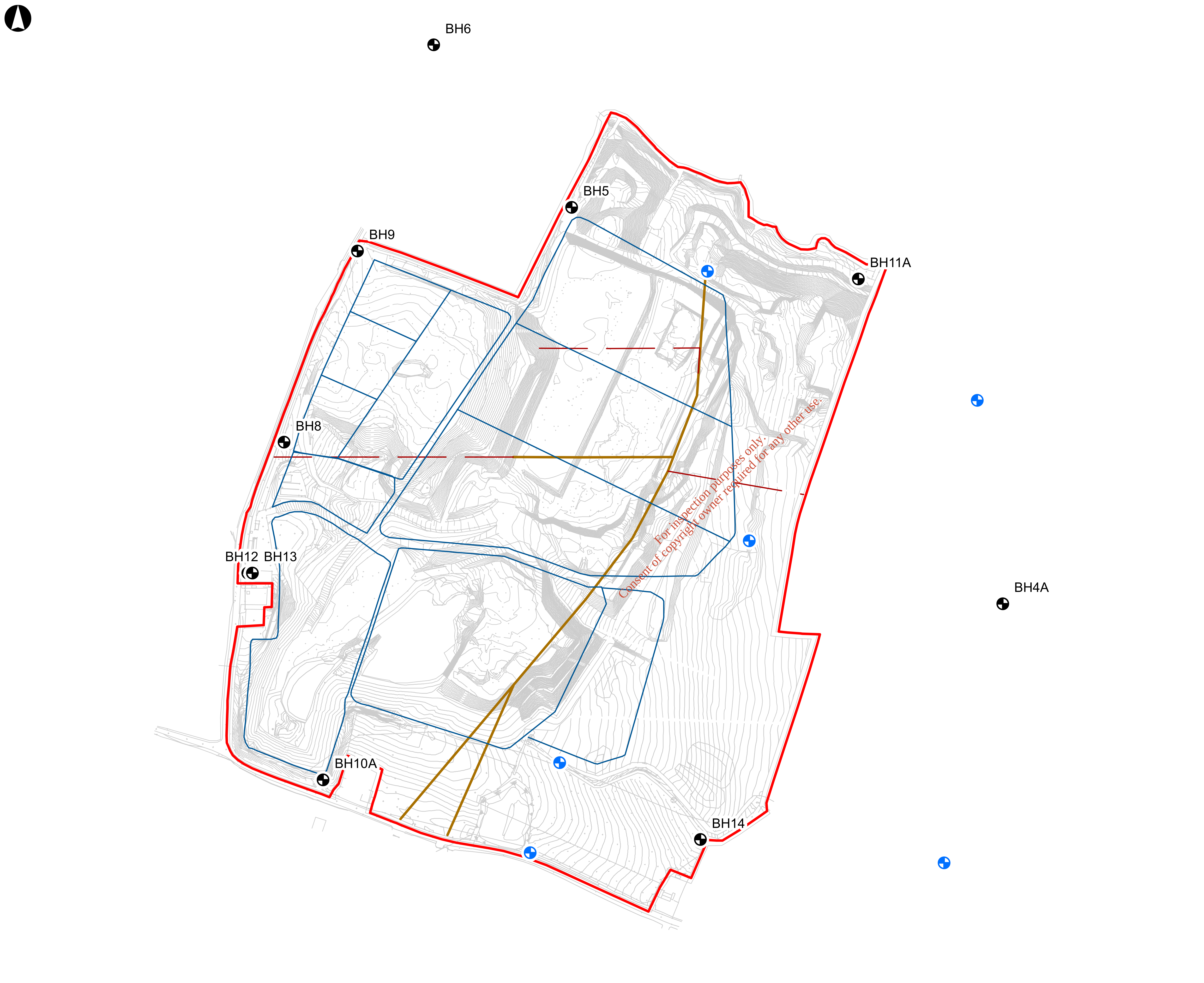
Figure 8.
Conceptual site model

Scale at A3
1:8,000

Job No	Drawing Status
326877.30	Final

Drawing No	Issue
008	P1

A3



Legend

- MEHL Proposed Planning and Waste Licence Boundary
- Waste cell layout
- Proposed additional monitoring points
- Existing EPA Licence W0129-02 Monitoring Boreholes
- Possible Fault/Fracture
- PossFaultedContact

Issue	Date	By	Chkd	Appd
P1	23-08-13	CB	RL	RL

Metres
0 55 110 220

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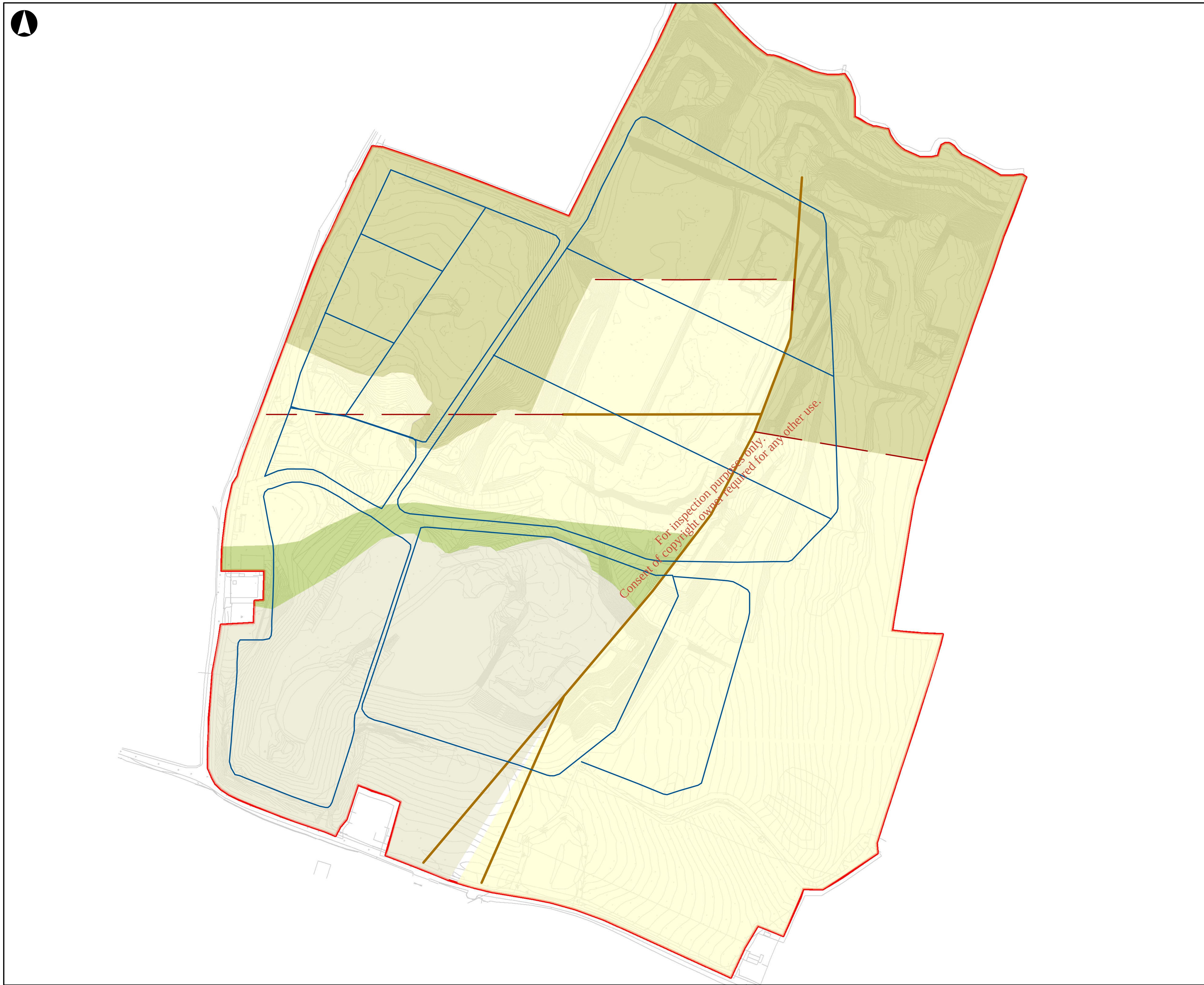
**Figure 9.
Proposed groundwater monitoring locations**

Scale at A3
1:4,000

Job No	Drawing Status
326877.01	**Final**

Drawing No	Issue
009	**P1**

A3



Legend

- MEHL Proposed Planning and Waste Licence Boundary
- Waste cell layout
- Possible Fault/Fracture
- PossFaultedContact

Geological formations

- WL - Walshestown Formation
- BC - Balrickard Formation
- DR - Donore Formation
- LO - Loughshinny Formation

Issue	Date	By	Chkd	Appd
P1	23-08-13	CB	RL	RL

Metres
0 40 80 160

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**Figure 10.
Site specific geological map**

Scale at A3
1:3,200

Job No	Drawing Status
326877.01	**Final**

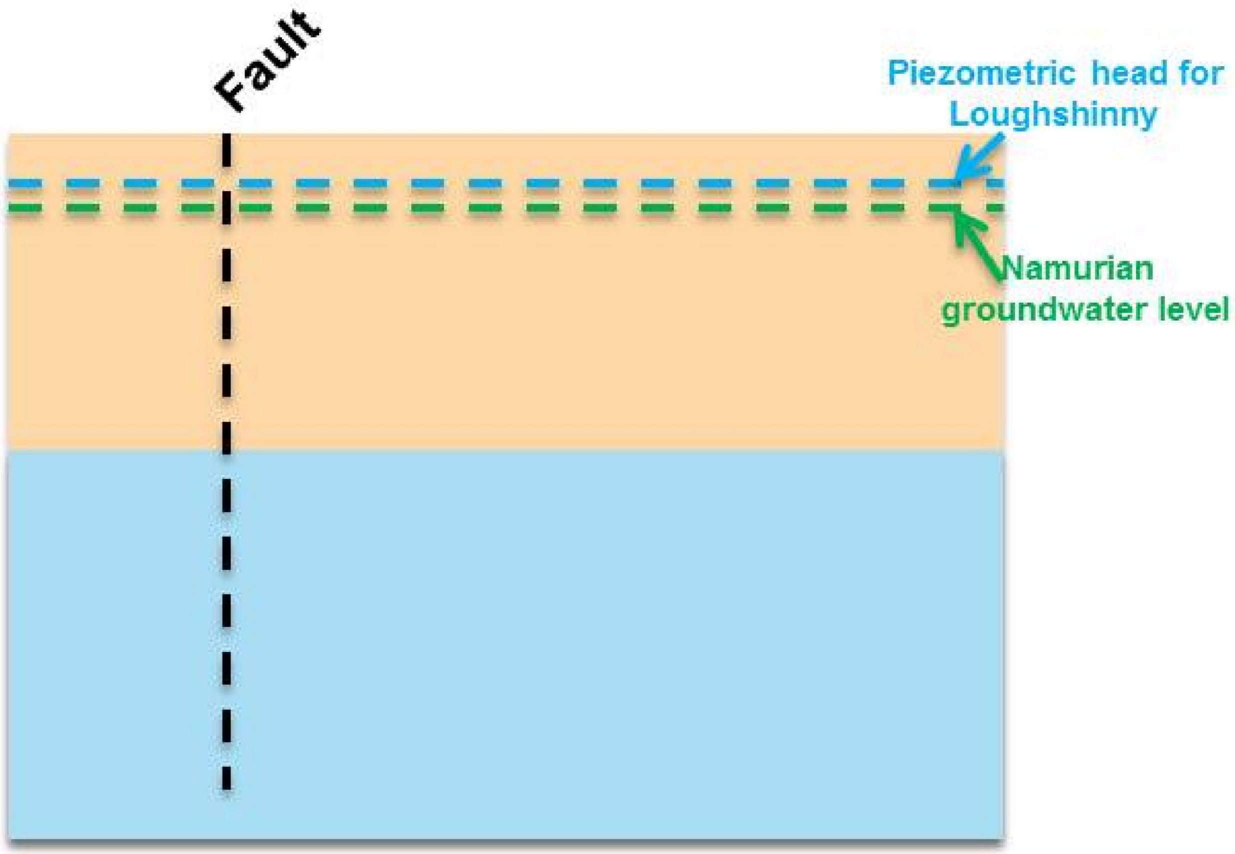
Drawing No	Issue
010	**P1**

MXD Location: J:\D6800-D6899\D6877\6_Graphics\30\GIS\WLA 2013\mxd\Figure 10 site specific geology.mxd

A

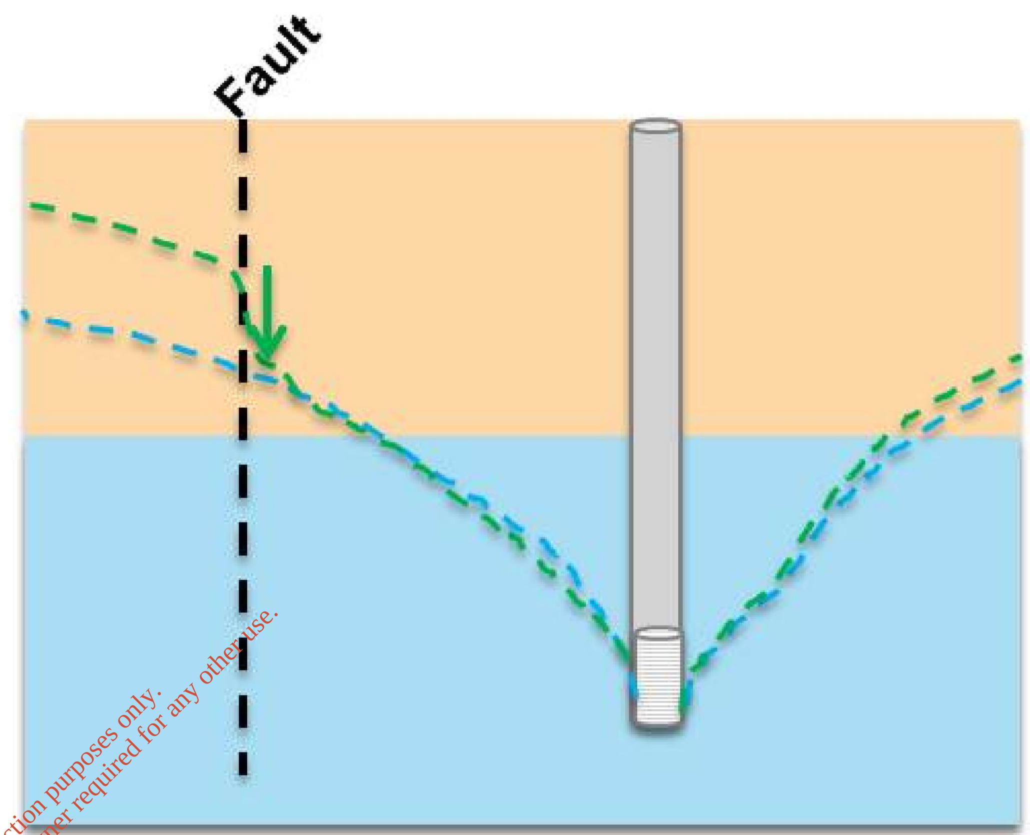
Static scenario

Groundwater in Namurian and Loughshinny are separate



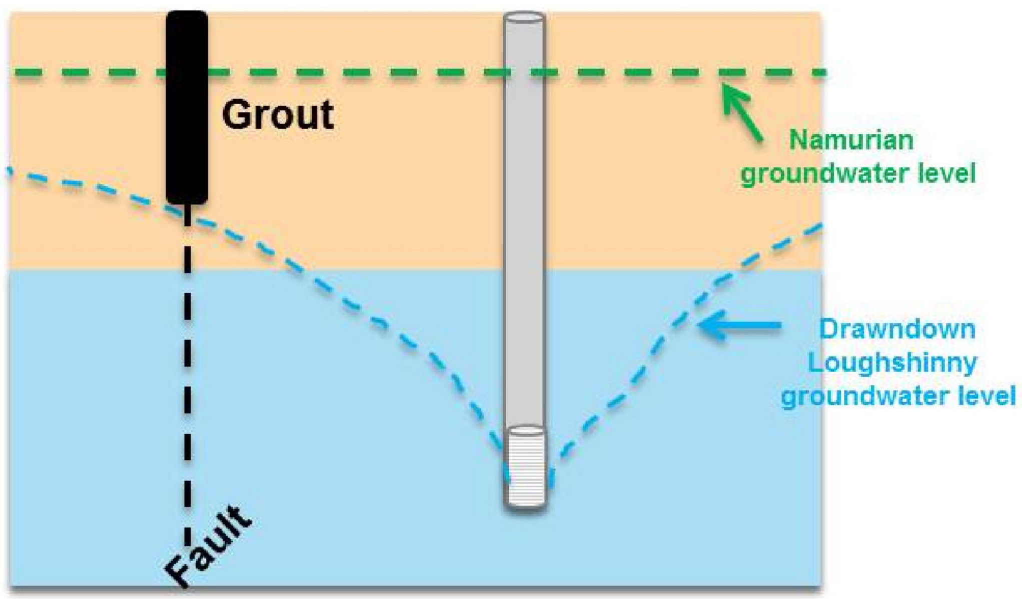
Pumping scenario

Pumping from the Loughshinny causes groundwater in the Namurian to also be drawndown via the faults



Grouting scenario

Grouting of the fault removes the pathway for Namurian water to be drawn down by pumping of the Loughshinny Formation



Issue	Date	By	Chkd	Appd
P1	23-08-13	CB	RL	RL

Metres
0 137.5 275 550

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Figure 11. Conceptual drawing of drawdown in the fault

Scale at A3
1:10,000

Job No	Drawing Status
326877.30	**Final**

Drawing No	Issue
011	**P1**

MXD Location: J:\D6800-D6899\D6877\6_Graphics\30\GIS\WLA 2013\mxd\Figure 10 drawdown.mxd