UISCE ÉIREANN : IRISH WATER

Water Supply Project
Eastern and Midlands Region

Preliminary Options Appraisal Report

Volume 2
Appendices A,B,C & D

November 2015

UISCE ÉIREANN : IRISH WATER

Water Supply Project
Eastern and Midlands Region

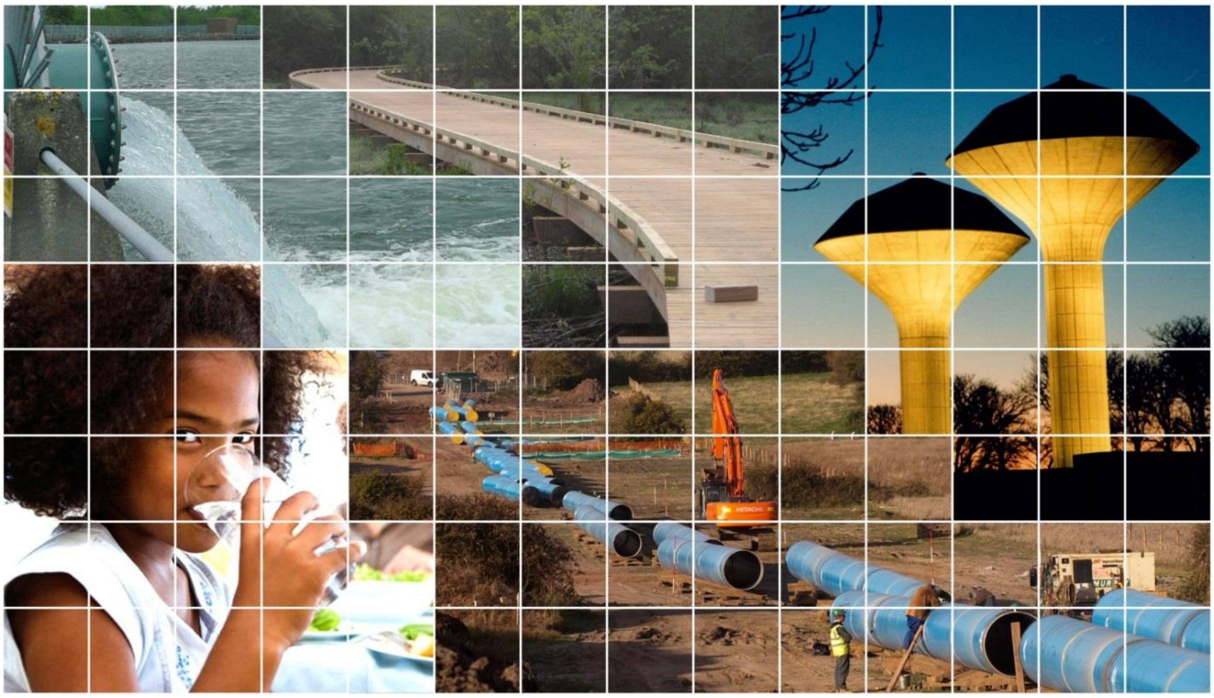
Appendix A

Project Road Map - Sequencing

Water Supply Project
Eastern and Midlands Region (WSP)

Appendix A: Project Road Map - Sequencing

October 2015 **F01**



Contents

1 Stages of Delivery – Sequencing of Key Activities

Section 2.2 makes reference to the project programme, or Road Map (Figure 2-3), to make a planning Application to An Bord Pleanála by Q2, 2017.

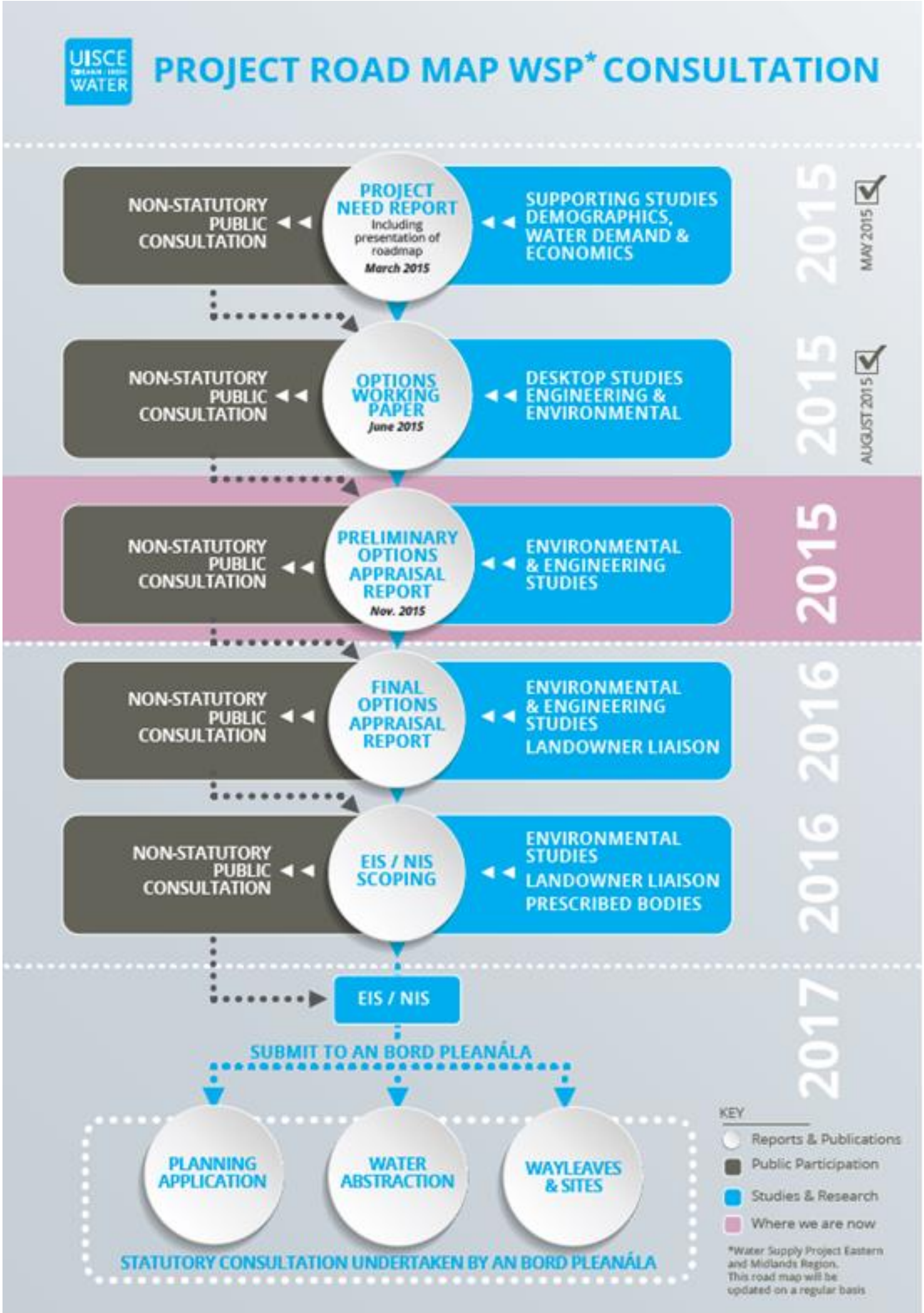


Figure 1-1 (from Section 2.2) Project Road Map

The Project Road Map incorporates 5 key stages of delivery where public consultation is an integral part of the options appraisal process; by the end of Stage 2 four reasonable, and technically viable, water supply options had been identified, namely:

i. Option F2 (North East Lough Derg with Storage);

ii. Option B (North East Lough Derg Direct);

iii. Option C (Parteen Basin Reservoir Direct); and

iv. Option H (Desalination).

Generally, the options appraisal process involves a number of distinct elements. Figure A-1 shows the relationship between these elements within the context of the Project Road Map.

In particular, Project Road Map Stage 2 was concerned with reviewing previous studies, identification of a short-list of technically viable options for further consideration, and establishing a robust methodology for determination of an emerging preferred option. This current Stage 3 implemented this methodology.

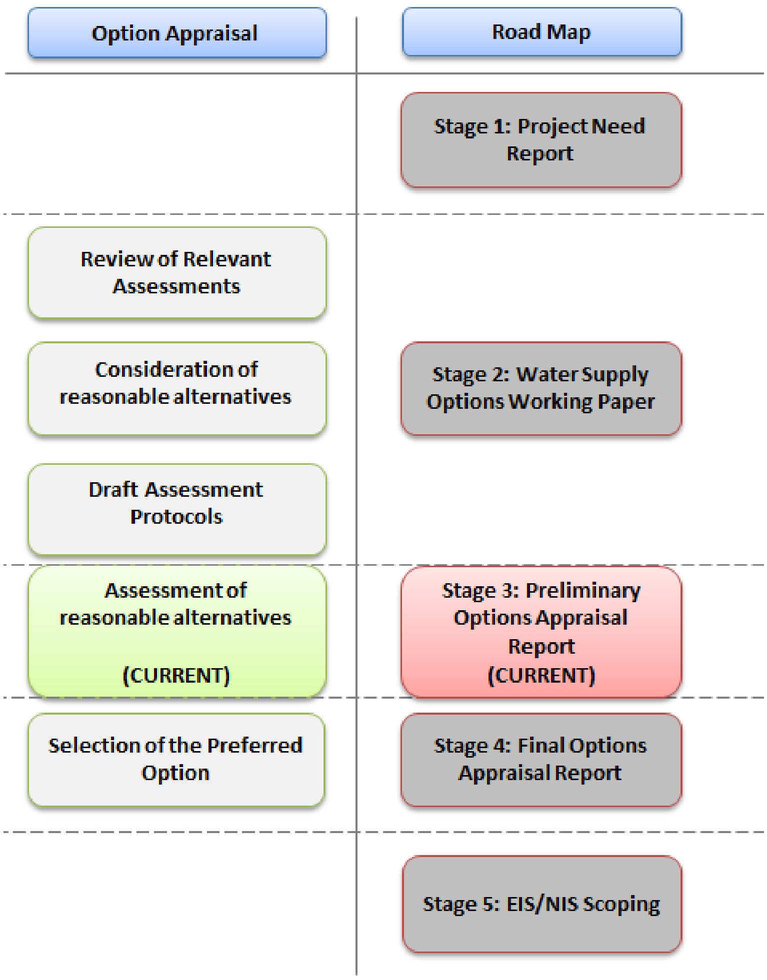


Figure A-2 Linkage between Option Appraisal and Project Road Map

Figure A-2 provides further detail on the various studies that informed the decision making process at each of the key stages of the options appraisal process.

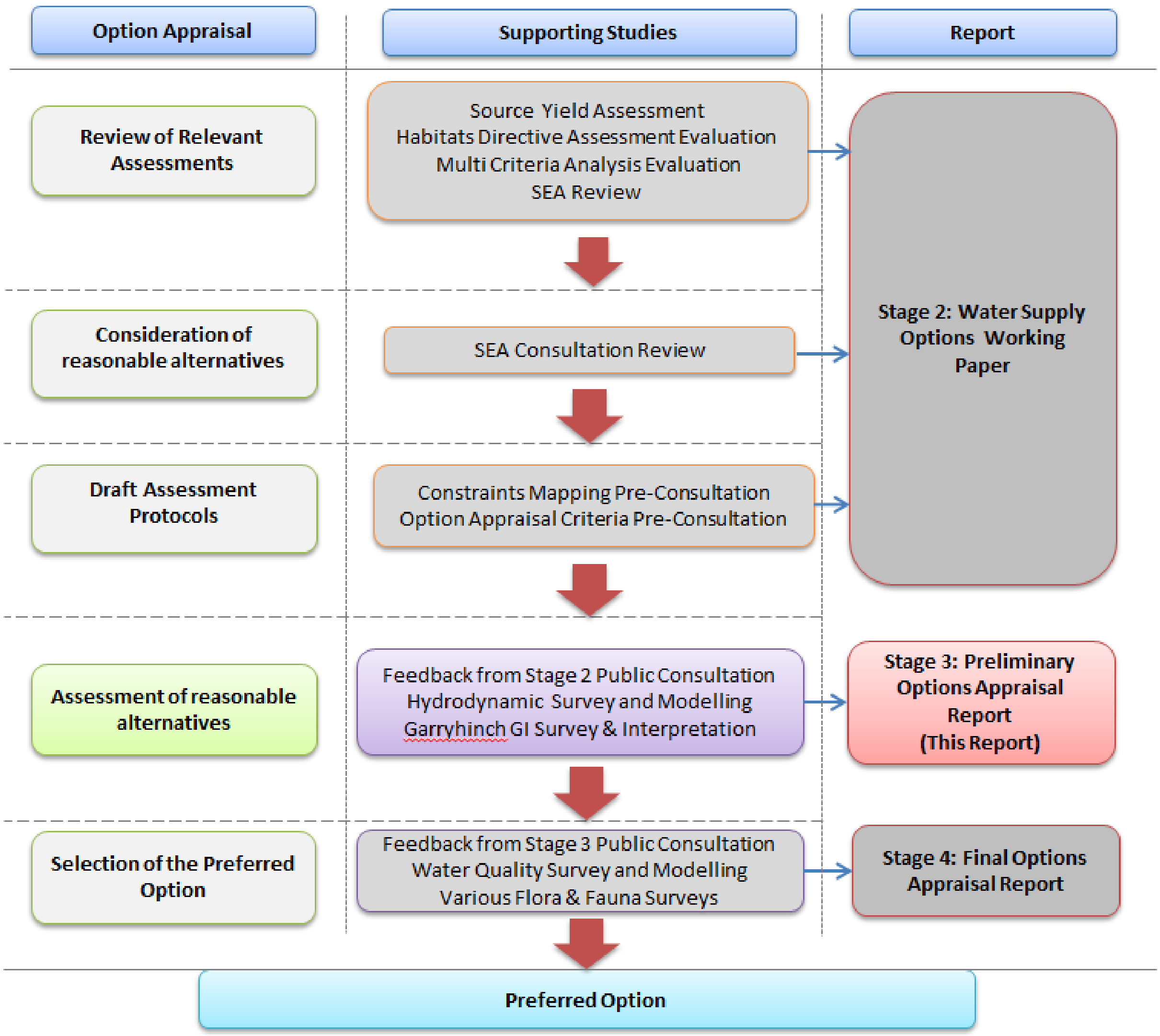


Figure A-2 Options Appraisal Methodology

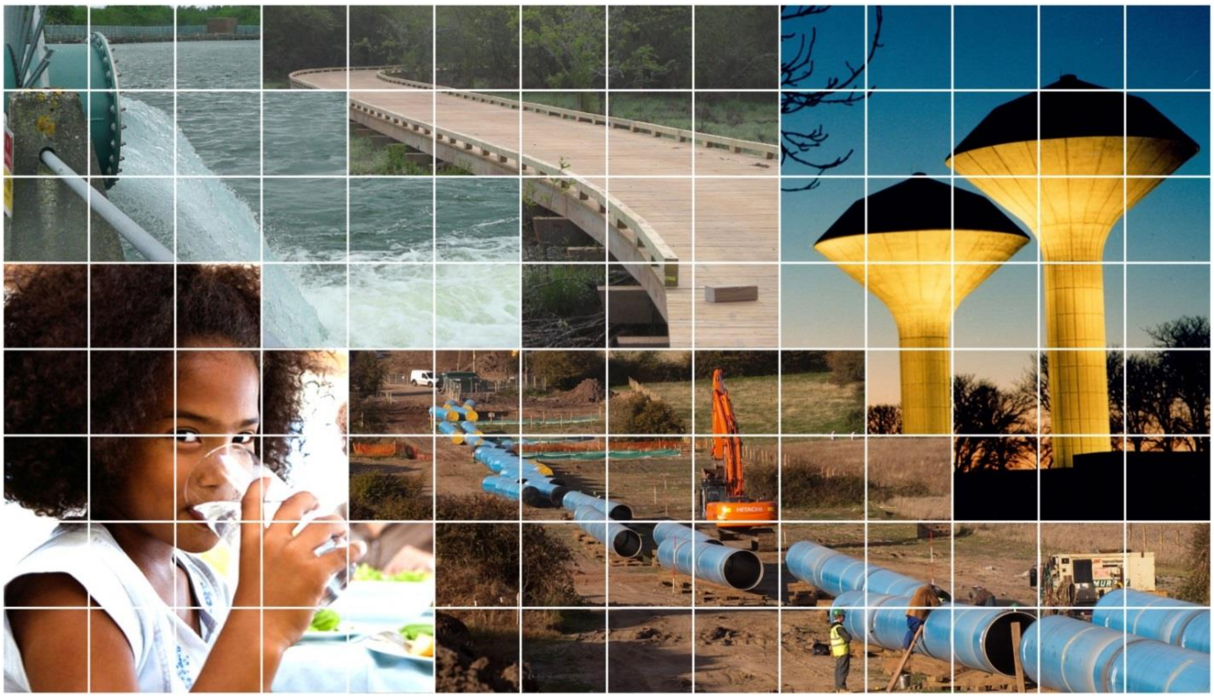
Water Supply Project
Eastern and Midlands Region

Appendix B
Site Selection Methodology

Water Supply Project
Eastern and Midlands Region (WSP)

Appendix B: Site Selection Methodology

June 2015 **F01**



JACOBS TOBIN
Patrick J. Tobin & Co. Ltd.

UISCE ÉIREANN : IRISH WATER

Document Control Sheet BPP 04 F8

Version 15; March 2013

Project: Water Supply Project – Eastern and Midlands Region (WSP)
Client: Irish Water **Project No:** 32105801
Document title: Site Selection Methodology
Ref. No: 20150615WSP1_ Site Selection Methodology_F01

	Originated by	Checked by	Reviewed by	
REVISION	NAME	NAME	NAME	
F01	Anthony Kerr	Patrick McGill	Donal Sheridan	
Approved by	Michael Garrick	As Project Manager I confirm that the above document(s) have been subjected to Jacobs' Check and Review procedure and that I **approve them for issue**	INITIALS MG	
	Neil Delaney		INITIALS	
DATE	15 June 2015	**Document status: For Client Review**		

REVISION	NAME	NAME	NAME	
Approved by		As Project Manager I confirm that the above document(s) have been subjected to Jacobs' Check and Review procedure and that I **approve them for issue**	INITIALS	
			INITIALS	
DATE		**Document status:**		

REVISION	NAME	NAME	NAME	
Approved by		As Project Manager I confirm that the above document(s) have been subjected to Jacobs' Check and Review procedure and that I **approve them for issue**	INITIALS	
			INITIALS	
DATE		**Document status:**		

REVISION	NAME	NAME	NAME	
Approved by		As Project Manager I confirm that the above document(s) have been subjected to Jacobs' Check and Review procedure and that I **approve them for issue**	INITIALS	
			INITIALS	
DATE		**Document status:**		

Contents

1 Site Selection Methodology

1.1 Introduction

As part of the Water Supply Project – Eastern and Midlands Region Project (WSP) Jacobs Tobin were appointed to progress a new water supply option through the entire planning process; as defined by its source, water transfer system and terminal point.

The requirement for the new water supply option has been outlined and detailed via a robust programme of previous assessments and studies prior to the Jacobs Tobin appointment. Jacobs Tobin have undertaken a review of these studies; firstly reconfirming the need for a new source[1] and then subsequently reviewing the potential new water supply options detailed in the Preliminary Report (2011) and Strategic Environmental Assessment (SEA) of 2008[2]. Specifically:

- Option A – Lough Ree (Direct)
- Option B – Lough Derg (Direct)
- Option C – Parteen Basin (Direct)
- Option D – Lough Ree and Lough Derg
- Option E – Lough Ree and Storage
- Option F – Lough Derg and Storage
    - Option F1 – Lough Derg and Storage (Rochfortbridge)
    - Option F2 – Lough Derg and Storage (Garryhinch)
- Option G –Lough Ree with Impoundment
- Option H – Desalination
- Option I – Groundwater
- Option J – Conjunctive use of the River Barrow and River Liffey

Following completion of the review process, six of the previously proposed water supply options were deemed to be unsuitable for further consideration.

The four remaining viable water options proposed by Jacobs Tobin for further consideration are as follows:

- DESALINATION - Option H
- LOUGH DERG (DIRECT) – Option B
- LOUGH DERG AND STORAGE – Option F2
- PARTEEN BASIN (DIRECT) – Option C

Having established the four remaining viable options, the next stages of the project will involve the identification of a Preferred Option.

This process will include, and will be informed by, the identification of suitable sites for locating of infrastructure associated with the WSP.

The aim of this report is to set out in detail the Site Selection Methodology which is to be implemented to identify these suitable sites.

[1] Project Need Report, March 2015

[2] Options Working Paper, June 2015

1.2 Background to the Site Selection Methodology

A key aspect in the development of the Site Selection Methodology presented within this report was the review of the comparative approach adopted previously in the SEA and the Plan.

Under this previous work, Dublin City Council (project sponsor at the time), recognising its' obligations under the SEA Directive and Irish law, prepared a Strategic Environmental Assessment (at two separate stages of development of the project) and published an SEA Statement, an Environmental Report and the Plan to address the following Objectives[3]:

- Objective 1 Avoid any deterioration in biodiversity, flora and fauna
- Objective 2 Preserve the integrity of fisheries
- Objective 3 Ensure that there is no adverse impact on achieving the objectives of the Water Framework Directive
- Objective 4 Avoid adverse changes to current levels, flows and retention times
- Objective 5 Minimise the contribution to climate change
- Objective 6 Minimise impact on energy use
- Objective 7 Minimise adverse impacts on sites, setting and items of cultural heritage including sites of architectural and archaeological heritage
- Objective 8 Minimise adverse significant impact on landscape quality and visual amenity
- Objective 9 Minimise impact on land use including agricultural systems and forestry
- Objective 10 Minimise impact on tourism and amenities
- Objective 11 Ensure the proposed abstractions do not detrimentally impact on communities
- Objective 12 Ensure economic growth for communities by provision of a quality water supply
- Objective 13 Maximise beneficial impact to human health by ensuring availability of good quality water supply
- Objective 14 Minimise adverse impact on soils, groundwater and geology.

The SEA Environmental Report identified the following constraints/requirements considered as part of the comparative approach used in the SEA:

- Suitable location for abstraction and raw water pumping station
- Suitable sites for location of Treatment Works
- Suitable sites for storage of raw water (some options)
- Suitable sites for future Booster Stations (if required)
- Suitable delivery point (Dublin)
- Suitable water supply delivery points (Midlands Local Authorities)
- Avoidance of Major Natural Constraints - Mountains / Lakes / Forests / Bogs / Mineral Extraction Areas / Rock
- Avoidance or minimisation of impacts on:
    - National Heritage Areas (NHA)
    - Special Protection Areas (SPA)
    - Special Areas of Conservation (SAC)

[3] Table 1.4, p14 SEA Phase 2 Environmental Statement (SEA Phase II) Environmental Report November 2008

- Known Archaeological Sites
- Avoidance of:
  - Existing Developments
  - Planned Developments
  - Motorways, High Voltage Electricity Pylons and Gas Transmission Pipelines
- Compliance with topography / elevation considerations consistent with the overall design philosophy of minimising pumping energy and optimisation of operational criteria.

However, the SEA Environmental Report also identified a number of information difficulties/data deficits associated within this methodology (outlined in Section 11.7.1). Furthermore Section 12 of the SEA Environmental Report reinforced these limitations, noting the additional work that would be required to support selection of any particular infrastructural site

"However the route corridors are only preliminary and these would go through detailed design and EIA in project stage."[4]

On the basis of the foregoing, combined with the availability of new information/data that was not available during the earlier SEA process, a Site Selection Methodology has been developed. This methodology is intended to address the information difficulties/deficits acknowledged within the SEA Environmental Report.

1.3 Overview of the Site Selection Methodology

Each of the four remaining viable options will require a combination of the following eight broad categories of infrastructure:

1. Raw water intake/drawoff pipes, shoreside/bankside abstraction chamber, abstraction pumping station, and raw water delivery pipelines to the Water Treatment Plant
2. Raw Water Storage Reservoir at Garryhinch [option F2 only]
3. Water Treatment Plant (WTP)
4. Treated water main lift and booster pumping stations and break pressure tank at booster pumping station(s)
5. Treated water trunk main transmission pipelines – plus ancillary valve chambers, scouring chambers, ancillary equipment
6. Termination Point Reservoir (TPR)
7. Mainlift pumping station at the TPR for onward pumping
8. Downstream delivery pipelines from the TPR

For the remainder of this report all of the eight infrastructure categories listed above will be referred to as '**Infrastructure Sites**'.

The identification of potential **"Infrastructure Sites"** will involve a combination of desk study and field surveys to identify, map, describe and evaluate potential **"Infrastructure Site"** options.

In every case the potential **"Infrastructure Sites"** shall be identified based upon a methodology which incorporates a combination of the following:

[4] p262 SEA Phase 2 Environmental Statement (SEA Phase II) Environmental Report November 2008

- The public and stakeholder inputs, including those previously submitted at the time of the SEA process in 2008.
- Aerial mapping/photography
- Constraints mapping
- Consideration of technical, environmental and social-economic factors (outlined in 150525WSP1_Options Working Paper_A01)
- Site visits/selected walkovers/field inspections

From the outset, the methodology (and implementation strategy) for the identification of the potential **"Infrastructure Sites"** will be based upon a hierarchy of 'total impact avoidance by design' whereby areas that can be environmentally impacted are avoided in full if possible.

However, given the nature and scale of the project and its receiving environment, it will not be possible to fully avoid all environmental impact, but good design nonetheless will seek to position **"Infrastructure Sites"** where such impact can be minimised. Where "total impact avoidance by design" is not feasible, the methodology will promote "impact mitigation by design".

1.4 A Two Part Methodology

Section 1.3 introduced eight broad categories of infrastructure and the terminology of "**Infrastructure Sites**".

"**Infrastructure Sites**" involving parts of category 1 plus category 5 & 8 will involve the construction mainly of pipelines along linear routes. In each case, the pipeline corridor and pipeline route selection work (which will be undertaken to identify the "Preferred Pipeline Route" for each of the individual pipelines) will involve the assessment of extended **linear corridors** running cross country.

However, "**Infrastructure Sites**" involving parts of category 1 plus category 2, 3, 4, 6 and 7 will involve the construction of facilities on single site locations. In each case, the site selection work (which will be required to identify the "Preferred Site" for each of the associated infrastructure components) will involve the assessment of individual **fixed site locations** at various locations across the country.

Due to the different nature of the two types of "Infrastructure Sites" – **linear corridors** v/s **fixed site locations** – a two part Site Selection Methodology, Part A and Part B, has been developed (and subsequently implemented) to identify the various preferred **"Infrastructure Sites"**[5].

- Part A – Site selection process for **linear corridor "Infrastructure Sites"** including:
  - Raw water abstraction drawoff/intake and pipelines (1)
  - Treated water trunk main transmission pipelines – plus ancillary valve chambers, scouring chambers, ancillary equipment (5)
  - Downstream delivery pipelines from the TPR (8)

[5] Confirming the feasibility of the potential **"Infrastructure Sites"** will be a linked process, whereby joint feasibility of sites and corridors may be tested.

- Part B – Site selection process for **fixed site location (non linear) "Infrastructure Sites"** including:
    - Raw water shoreside/bankside abstraction chamber and raw water abstraction pumping station (1)
    - Raw Water Storage Reservoir at Garryhinch (2)
    - Water treatment plant (WTP) (3)
    - Treated water main lift and booster pumping stations and break pressure tank at booster pumping stations (4)
    - Termination Point Reservoir (TPR) (6)
    - Mainlift pumping station at the TPR for onward pumping (7)

The Part A Site Selection Methodology will comprise five steps, as detailed later in Section 2.

The Part B Site Selection Methodology will comprise three steps, as detailed later in Section 3.[6]

Under each of the two parts of the Site Selection Methodology the project team will implement a robust site selection process. Specifically, the project team will adopt a structured approach to developing consensus, within a group communication process aimed at producing detailed critical examination and discussion.

As part of this process, the project team will convene a panel of experienced specialists, selected in the areas of expertise required for the relevant project part. The philosophy is that well informed specialists, using their insights and experience, are best equipped to reach a workable outcome, when engaged as a panel which is chaired and facilitated so that the project team work collectively.

The panel of experienced specialists will be engaged based upon the technical/environmental/socio economic constraints/requirements to be addressed under the relevant step of the methodology being implemented. The issues relating to each individual methodology will first be presented to the relevant experienced specialist/s through a formal statement of the siting and routing requirements, and each individual will respond independently of the other specialists. The independent responses will then be analysed, the issue will be re-presented and further iterations of the process will be undertaken as necessary. The approach will be based on the dynamic that the group will converge towards the optimum consensus through this process.

Within the site selection methodology, both Part A & Part B, the workshop and desk study work will be supported by site visits/selected walkovers/field inspections at various steps.

[6] It is noted that whilst the philosophy and approach adopted under this methodology, Part A and Part B, the WSP "Project Study Area" is nevertheless heavily constrained in some areas.

It is also noted that the presence, or influence of constraints, varies between the two parts of the site selection methodology. There is an acceptance that different specialisms/issues will be more influential in some geographic areas and less in others etc:

As an example, for **linear corridor "Infrastructure Sites"** the presence of housing densities (ribbon developments) will pose more of a constraint for pipeline corridor and pipeline route selection work when applying the Part A - Site Selection Methodology **but** less of a constraint for **fixed site location "Infrastructure Sites"** when applying the Part B - Site selection methodology

In the case of Part A of the site selection methodology, it is envisaged that the detailed site visits/selected walkovers/field inspections etc will not substantially commence until Step 5 of the 5 Step process (described in Section 2).

In the case of Part B of the site selection methodology, it is envisaged that the detailed site visits/selected walkovers/field inspections etc will not substantially commence until Step 3 of the 3 Step process (described in Section 3).

1.5 Supplied Datasets & Information

The Site Selection Methodology, Part A & Part B, will be implemented using datasets and information supplied and adopted for use during the various steps of the site selection process to be undertaken.

1.5.1 SEA Reports and Data

The details of the previous Consultant's SEA Reports and accompanying data were provided for review (see section 1.2). This informed the development of the Site Selection Methodology detailed within this report.

1.5.2 GIS Data

An extensive suite of GIS datasets were obtained for the project. The GIS datasets contain many of the constraints that relate to the "Project Study Area". A full listing of those GIS datasets currently identified for use are detailed in Appendix A.

The following range of specialists were engaged in identifying these datasets:

- Engineering
- Cultural Heritage
- Ecology
- Noise & Vibration
- Air Quality
- Traffic
- Landscape and Visual
- Agronomy
- Soils/Geology
- Water Quality/Hydrology
- Hydrogeology

Whilst every effort has been made to adopt an exhaustive list on the project, any additional relevant datasets that become available during the project, e.g. as part of the various public consultation processes envisaged, will be incorporated as appropriate during the subsequent stages of the Site Selection Methodology.

1.5.3 Aerial Photography/Mapping

Where required, the following aerial photography/mapping will be sourced for use during the various Steps of the Site Selection Methodology

- ESRI Aerial photography - Copyright © 2014 ESRI and its licensors (details on individual maps)
- Bing Photography – Copyright © 2014 Microsoft and its licensors (details on individual maps).

1.5.4 Stakeholder/Consultee Information

The project includes a number of rounds of external consultation (Ref Appendix B). Details of the output from these consultations will be included and considered during the implementation of the Site Selection Methodology presented within this report.

1.5.5 Other Miscellaneous Datasets

Where available and required through future assessment, a number of additional datasets may also be obtained and reviewed during the implementation of the Site Selection Methodology presented within this report.

Where these datasets are confidential/protected no related details will be included within the site selection final report outputs from the implementation of the site selection methodology.

1.6 Site Selection Methodology - Implementation

The Site Selection Methodology will be implemented in two Parts as follows:

- Part A – Site selection process for **linear corridors** involving a five step process.

- Part B – Site selection process for **fixed site locations** involving a three step process.

During each step, using appropriately selected constraints for that step, the project team will strive to minimise potential environmental impact during the selection of **"Infrastructure Sites"**. A top down approach to site selection to minimise impact will be adopted, with constraints/requirements ranked by the specialists into three categories as follows:

High Impact (*) - This category of constraint/requirement will be avoided where alternative options exist. It is a fixed constraint/requirement which could involve, for example:

- A technical design principle/condition/requirement that will be complied with as a design priority.
- An environmental principle/condition/requirement that will be complied with as a design priority. For example, a need to avoid potential impact on highly sensitive receptors such as priority species or habitats in Sites of European Importance [Special Areas of Conservation (SACs), Special Protection Areas (SPAs)].

Medium Impact (**) - This category of constraint/requirement is defined as one which should be avoided where alternative options exist. It is a fixed constraint/requirement similar in many respects to those outlined above. However, if it proves not to be possible/practical to comply with the constraint/requirement in full then a relaxation **could** be considered. For example:

- A technical design principle/condition/requirement that perhaps has to be relaxed – which may involve a changed design to incorporate a local accommodation – which under certain circumstances could be considered acceptable.
- An environmental principle/condition/requirement that ideally should be complied with to prevent an impact but could nevertheless be permitted if significant impacts can be avoided.

Low Impact (*)** - These categories of constraint/requirement relate primarily to technical constraints/requirements/issues. They are considered to be flexible constraints/requirements. For example:

- The flexibility to locally adjust the positioning of infrastructure to reflect local topographical conditions or to be sympathetic with local landscape/field pattern, form and boundaries or perhaps to take advantage of the presence of existing utility infrastructure and services.

The methodology applicable for each of the two Site Selection Methodology parts, Part A & Part B, are detailed in sections 2 & 3 of this report.

Each section, 2 & 3, also include the flow charts which will be used by the project team to detail the procedure/process followed under each of the two methodology parts.

2 Part A: Linear “Infrastructure Sites”

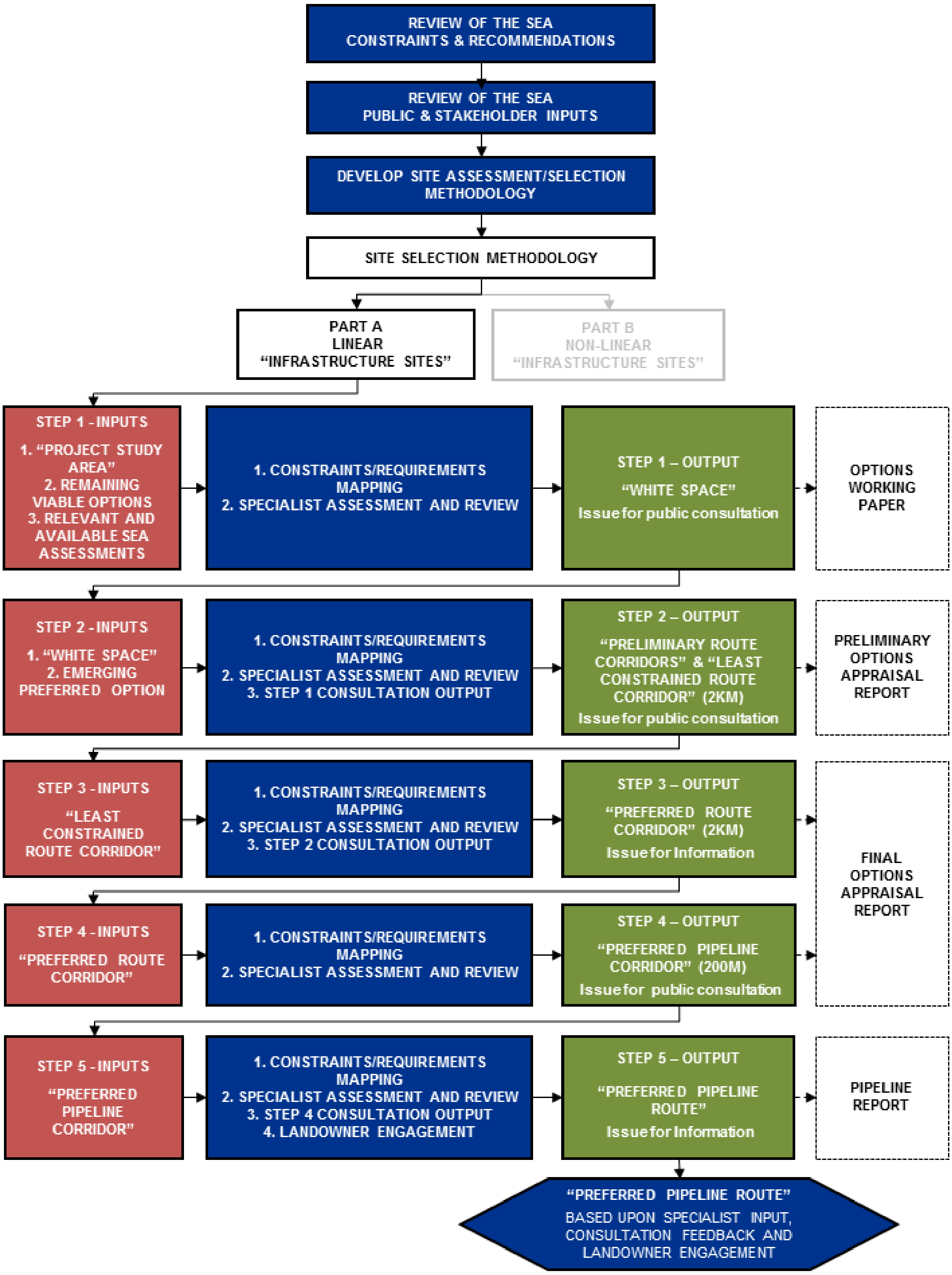
The Site Selection Methodology – Part A is applicable to the following **linear** infrastructure categories.

- Raw water abstraction drawoff/intake and pipelines[7] (1)
- Treated water trunk main transmission pipelines[5] (5)
- Downstream delivery pipelines from the TPR[5] (8)

The Site Selection Methodology – Part A is to involve a five step process, as detailed on the flow chart below. The methodology will be applied in a similar manner for each of the above project infrastructure categories.

Each of the five steps of the methodology is detailed in this section.

[7] plus ancillary valve chambers, scouring chambers, ancillary equipment etc

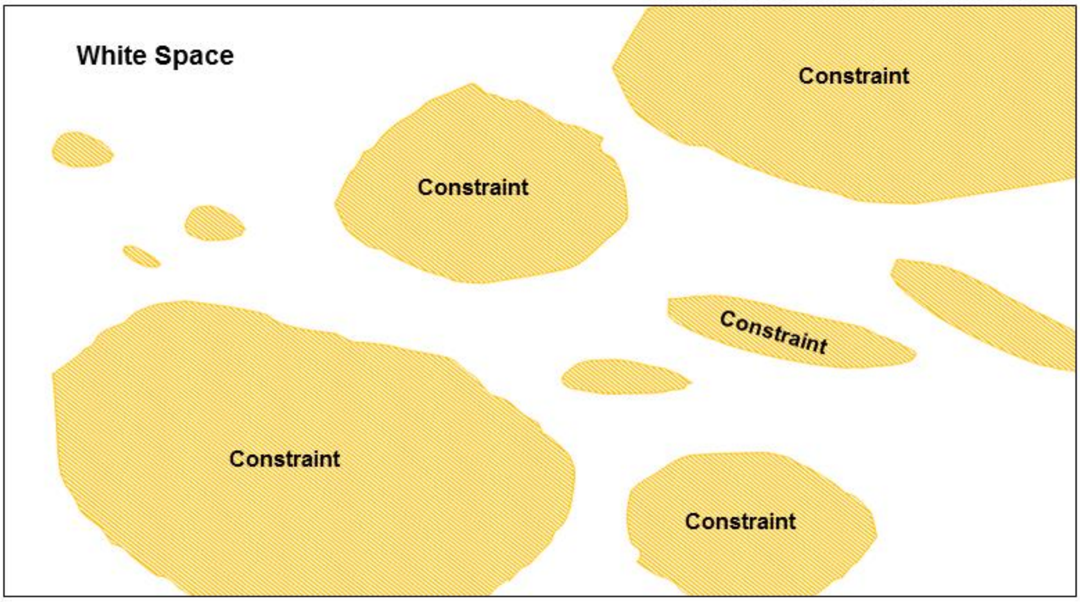

REVIEW OF THE SEA
CONSTRAINTS & RECOMMENDATIONS
REVIEW OF THE SEA
PUBLIC & STAKEHOLDER INPUTS
DEVELOP SITE ASSESSMENT/SELECTION METHODOLOGY
SITE SELECTION METHODOLOGY
PART A
LINEAR
“INFRASTRUCTURE SITES”
PART B
NON-LINEAR
“INFRASTRUCTURE SITES”
STEP 1 - INPUTS
1. “PROJECT STUDY AREA”
2. REMAINING VIABLE OPTIONS
3. RELEVANT AND AVAILABLE SEA ASSESSMENTS
1. CONSTRAINTS/REQUIREMENTS MAPPING
2. SPECIALIST ASSESSMENT AND REVIEW
STEP 1 – OUTPUT
“WHITE SPACE”
Issue for public consultation
OPTIONS WORKING PAPER
STEP 2 - INPUTS
1. “WHITE SPACE”
2. EMERGING PREFERRED OPTION
1. CONSTRAINTS/REQUIREMENTS MAPPING
2. SPECIALIST ASSESSMENT AND REVIEW
3. STEP 1 CONSULTATION OUTPUT
STEP 2 – OUTPUT
“PRELIMINARY ROUTE CORRIDORS” & “LEAST CONSTRAINED ROUTE CORRIDOR” (2KM)
Issue for public consultation
PRELIMINARY OPTIONS APPRAISAL REPORT
STEP 3 - INPUTS
“LEAST CONSTRAINED ROUTE CORRIDOR”
1. CONSTRAINTS/REQUIREMENTS MAPPING
2. SPECIALIST ASSESSMENT AND REVIEW
3. STEP 2 CONSULTATION OUTPUT
STEP 3 – OUTPUT
“PREFERRED ROUTE CORRIDOR” (2KM)
Issue for Information
FINAL OPTIONS APPRAISAL REPORT
STEP 4 - INPUTS
“PREFERRED ROUTE CORRIDOR”
1. CONSTRAINTS/REQUIREMENTS MAPPING
2. SPECIALIST ASSESSMENT AND REVIEW
STEP 4 – OUTPUT
“PREFERRED PIPELINE CORRIDOR” (200M)
Issue for public consultation
STEP 5 - INPUTS
“PREFERRED PIPELINE CORRIDOR”
1. CONSTRAINTS/REQUIREMENTS MAPPING
2. SPECIALIST ASSESSMENT AND REVIEW
3. STEP 4 CONSULTATION OUTPUT
4. LANDOWNER ENGAGEMENT
STEP 5 – OUTPUT
“PREFERRED PIPELINE ROUTE”
Issue for Information
PIPELINE REPORT
“PREFERRED PIPELINE ROUTE”
BASED UPON SPECIALIST INPUT, CONSULTATION FEEDBACK AND LANDOWNER ENGAGEMENT

2.1 Linear Corridor Methodology – Step 1

This step of the methodology has been completed. It involved only desk study work.

The aim of this step of the process was to identify “White Space” within the Water Supply “Project Study Area” (Ref. 150525WSP1_Options Working Paper _A01). See Step 1 diagram below.

Step 1



This step involved a high level screening exercise of Water Supply Project datasets/constraints from the dataset library as referred to previously in Section 1.5.1.

This constraints/requirements mapping strategy was based upon the philosophy of impact avoidance through careful infrastructure positioning.

The following project specialists were engaged in this process:

- Engineering
- Cultural Heritage
- Ecology
- Noise & Vibration
- Air Quality
- Traffic
- Landscape and Visual
- Agronomy
- Soils/Geology
- Water Quality/Hydrology
- Hydrogeology

The process was initiated by engaging specialists to independently assess and identify constraints/issues that would reflect their opening position for the selection of the “White Space” which would result in least impact, from their own specialist perspective. This approach facilitated an informed selection by each of the specialists, avoiding any element of group-conditioning of initial positions.

The panel of specialists were then convened at a workshop on 16th April 2015, with the initial assessment of constraints mapped and presented to the panel. The position of each of the specialists was subject to discussion and debate to collectively agree those constraints to be applied and to ensure that the constraints/requirements are aligned with those proposed in the SEA.

At conclusion of the workshop, group agreement was reached on the constraints that would define Step 1 of the methodology.

Subsequent to the workshop, the mapped constraints were then applied by the engineering specialists to develop the "White Space".

The constraints applied were limited to those categorised as high impact.

The above approach for Step 1 is detailed in the flow chart presented below in Figure 1.

The constraints being applied and the manner of using them to define the identified "White Space" are now being consulted upon publically so as to gather any relevant information that will inform the following Step 2 of the process.

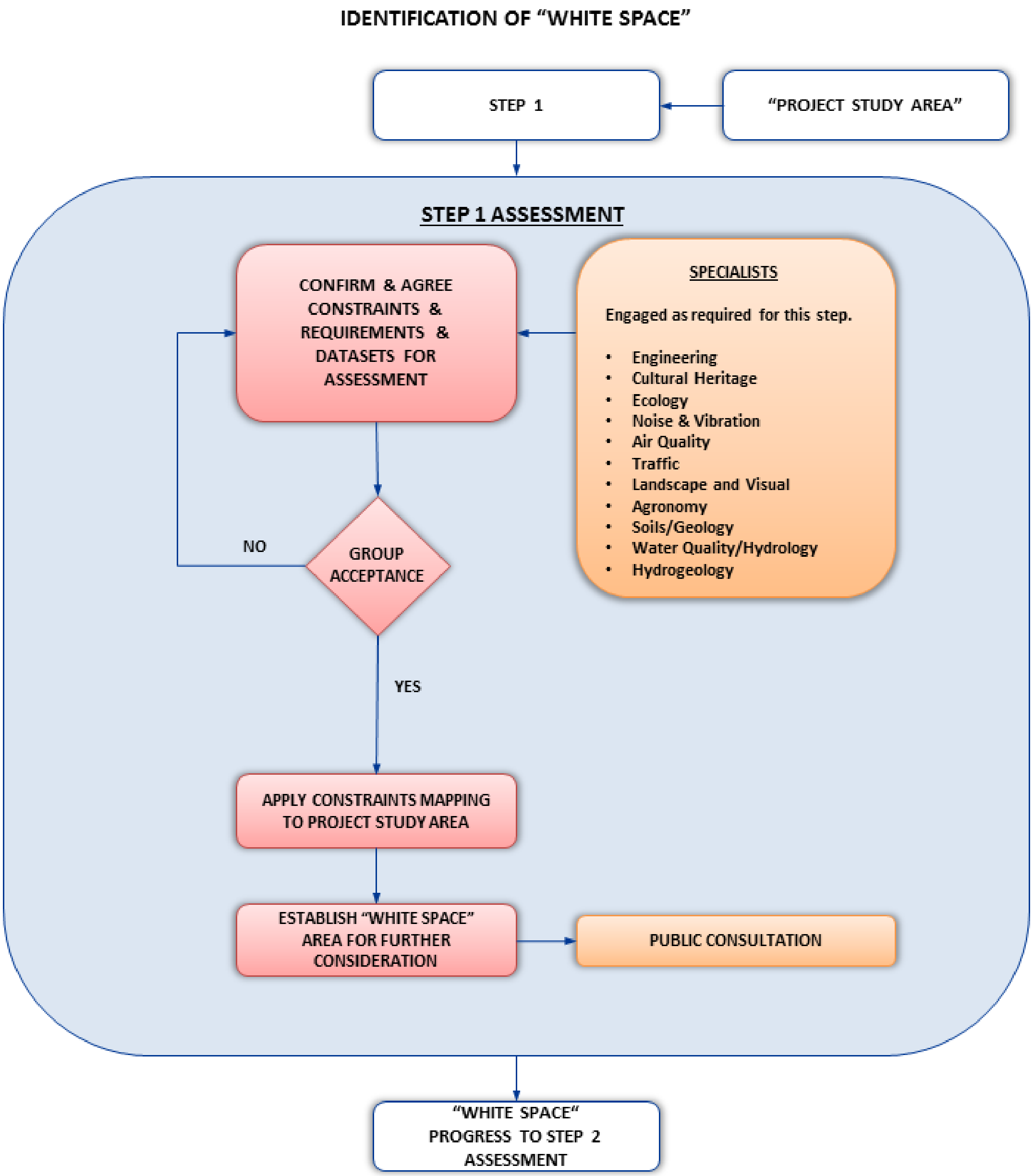

IDENTIFICATION OF "WHITE SPACE"
STEP 1
"PROJECT STUDY AREA"
STEP 1 ASSESSMENT
CONFIRM & AGREE CONSTRAINTS & REQUIREMENTS & DATASETS FOR ASSESSMENT
SPECIALISTS
Engaged as required for this step.
Engineering
Cultural Heritage
Ecology
Noise & Vibration
Air Quality
Traffic
Landscape and Visual
Agronomy
Soils/Geology
Water Quality/Hydrology
Hydrogeology
NO
GROUP ACCEPTANCE
YES
APPLY CONSTRAINTS MAPPING TO PROJECT STUDY AREA
ESTABLISH "WHITE SPACE" AREA FOR FURTHER CONSIDERATION
PUBLIC CONSULTATION
"WHITE SPACE" PROGRESS TO STEP 2 ASSESSMENT

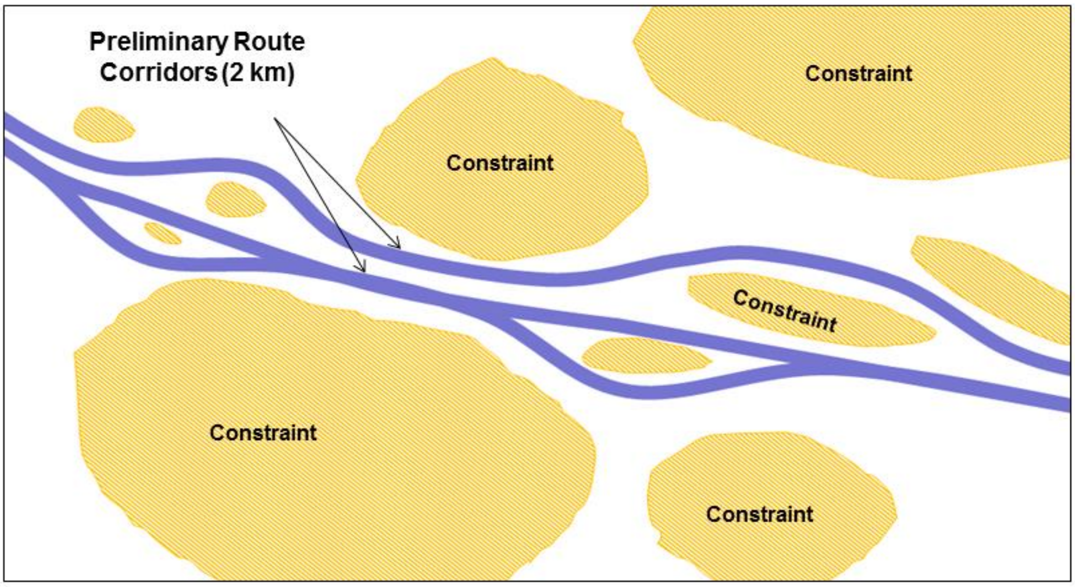
FIGURE 1

2.2 Linear Corridor Methodology – Step 2

This step of the methodology will involve primarily desk study work.

The aim of this step of the process is to identify "Preliminary Route Corridors" (approximately 2 km wide) and a "Least Constrained Route Corridor" (2 km wide approx.) from within the "White Space" selected/identified under the previous Step 1. See Step 2 diagram below.

Step 2



The selection of the "Preliminary Route Corridors" and "Least Constrained Route Corridor", as detailed under this Step 2 process, will be based upon the following:

- incorporation of feedback from the public consultation on the "White Space" identified/consulted upon under Step 1 of the process
- a further constraints/requirements mapping exercise, with the inclusion of an extended constraints/requirements dataset

This further constraints/requirements mapping will continue to be based upon the philosophy of impact avoidance through careful positioning of infrastructure. The constraints/requirements mapping will be substantially based upon selected Water Supply Project datasets from the dataset library as referred to previously in Section 1.5.1.

It should be noted that during this Step 2 constraints/requirements mapping exercise the project team will engage in a backward looking exercise to the previous Step 1 constraints/requirements mapping process to affirm the efficacy of that earlier process step.

During this Step 2 the following range of specialists will be engaged on an as needs basis:

- Engineering
- Cultural Heritage

- Ecology
- Noise & Vibration
- Air Quality
- Traffic
- Landscape and Visual
- Agronomy
- Soils/Geology
- Water Quality/Hydrology
- Hydrogeology

Initially all engaged project specialists will be requested to independently assess and identify constraints/issues that would reflect their opening position for the selection of the “Preliminary Route Corridors” which would result in least impact from their own specialist perspective. Each specialist does not work in isolation, however, and will have full access to the constraints/requirements of other disciplines, which will be available from the constraints/requirements mapping. This approach will facilitate an informed selection by each of the specialists, whereby any element of group-conditioning of initial positions can be deliberately avoided.

The issues submitted by each project specialist will also be informed by the mapping of the above constraints/requirements onto the previously identified “White Space” study area defined under Step 1. The preferred positions of each of the specialists will be subject to discussion and debate to ensure that their constraints/requirements are aligned with those proposed in the SEA, and that they are collectively generated and agreed by the project team.

Next the information from the various specialists will be used by the engineering specialist in conjunction with the technical constraints/requirements to develop “Preliminary Route Corridors” (2km wide approx). The developed “Preliminary Route Corridors” will then be presented back to the specialists for consideration.

Subsequently the “Preliminary Route Corridors” will be reviewed by the specialists through a project team engagement, with the intent of achieving consensus, in the view of the Project Team, on the “Least Constrained Route Corridor”. During this review any required refinements will be discussed and agreed between the specialists, and recorded. The output from this process (based upon an agreed outcome) will be the recommendation of the “Least Constrained Route Corridor” (2km wide approx.).

Once the constraints/requirements mapping has been applied across the “White Space” and the “Preliminary Route Corridors” and “Least Constrained Route Corridor” identified, this will be issued for public consultation. The feedback from the public consultation exercise will be used to inform the next step of the process, Step 3. Step 3 of the methodology will then proceed to identify/site the “preferred pipeline route corridor” - 2 km wide approx.

The above approach for Step 2 is detailed in the flow chart presented below in Figure 2.

IDENTIFICATION OF "PRELIMINARY ROUTE CORRIDORS" & "LEAST CONSTRAINED ROUTE CORRIDOR" (2KM WIDE APPROX)

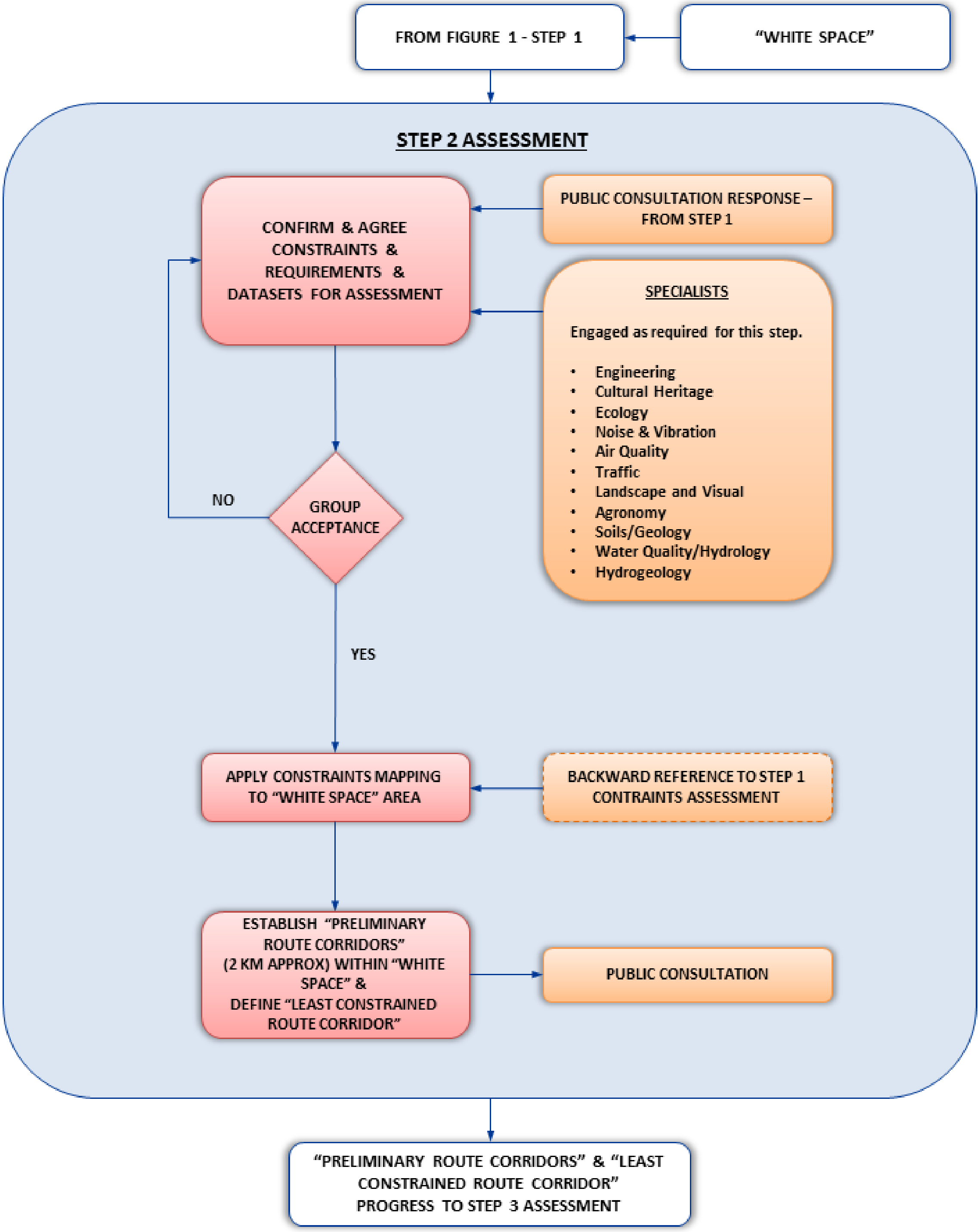


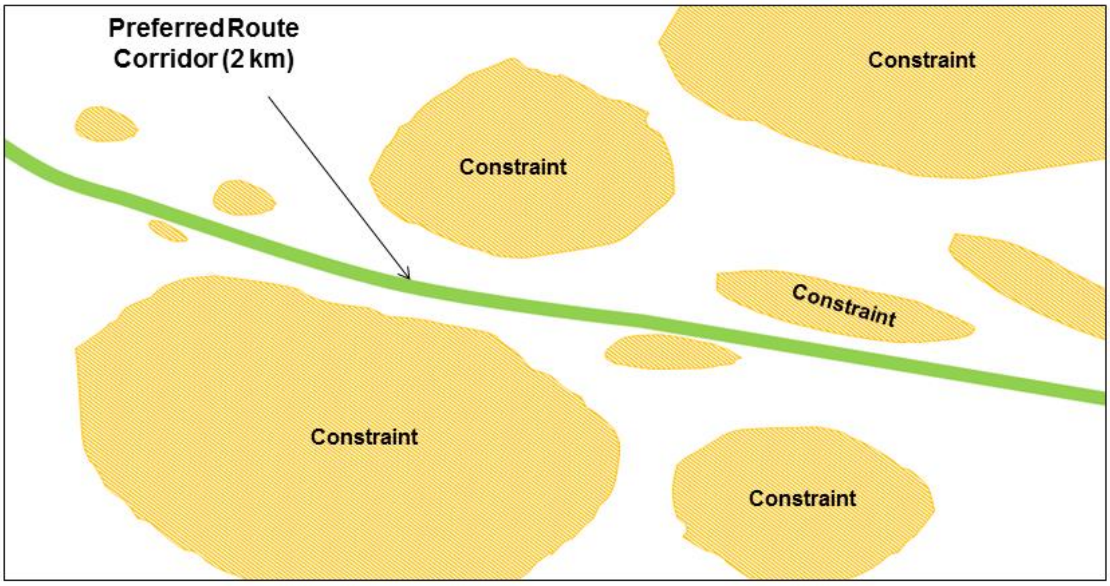
FIGURE 2

2.3 Linear Corridor Methodology – Step 3

This step of the methodology will involve primarily desk study work with limited/focused windscreen surveys where required.

The aim of this step of the process is to confirm the “Preferred Route Corridor” (2 km wide approx) from the “Preliminary Route Corridors” and “Least Constrained Route Corridor” selected/identified under the previous Step 2.

Step 3



The selection of the “Preferred Route Corridor”, as detailed under this Step 3 process will be based upon the following:

- incorporation of the feedback from the public consultation on the “Preliminary Route Corridors” and “Least Constrained Route Corridor” identified/consulted upon under Step 2 of the process
- a further constraints/requirements mapping exercise, with the inclusion of an extended constraints/requirements dataset as required

This further constraints/requirements mapping will continue to be based upon the philosophy of impact avoidance through careful positioning of infrastructure. The constraints/requirements mapping will be substantially based upon selected Water Supply Project datasets from the dataset library as referred to previously in Section 1.5.1.

It should be noted that during this Step 3 constraints/requirements mapping exercise the project team will engage in a backward looking exercise to the previous Step 1 and Step 2 constraints/requirements mapping process to affirm the efficacy of those earlier process steps.

During this Step 3 the following range of specialists will be engaged on an as needs basis:

- Engineering
- Cultural Heritage

- Ecology
- Noise & Vibration
- Air Quality
- Traffic
- Landscape and Visual
- Agronomy
- Soils/Geology
- Water Quality/Hydrology
- Hydrogeology

The engaged project specialists will be requested to review their selection of the "Least Constrained Route Corridor" and confirm their selection of a "Preferred Route Corridor", accounting for adjustment arising from consultation. This process will ensure reference to pertinent issues that may have arisen over the intervening period since Step 2, due cognisance of the public consultation process carried out in the previous stage, and alignment of proposals with the SEA.

Information from the various project specialists will be used by the engineering specialist to develop a "Preferred Route Corridor" (2km wide approx).

Through a project team engagement, with the intent of achieving consensus, the "Preferred Route Corridor" will be reviewed by the specialists. During this review any required refinements will be discussed and agreed between the specialists, and recorded. The output from this process (based upon an agreed outcome) will be the establishment of the "Preferred Route Corridor" 2km wide approx.

Once identified, the "Preferred Route Corridor" will be used to inform the next Step 4 of the process.

The above approach for Step 3 is detailed in the flow chart presented below in Figure 3.

The identified "Preferred Route Corridor" (2km) will not be notified to the public at this point. The next public consultation will be in Step 4 of the process, when the "Preferred Pipeline Corridor" (200 m) has been identified from within the "Preferred Route Corridor" identified under this step.

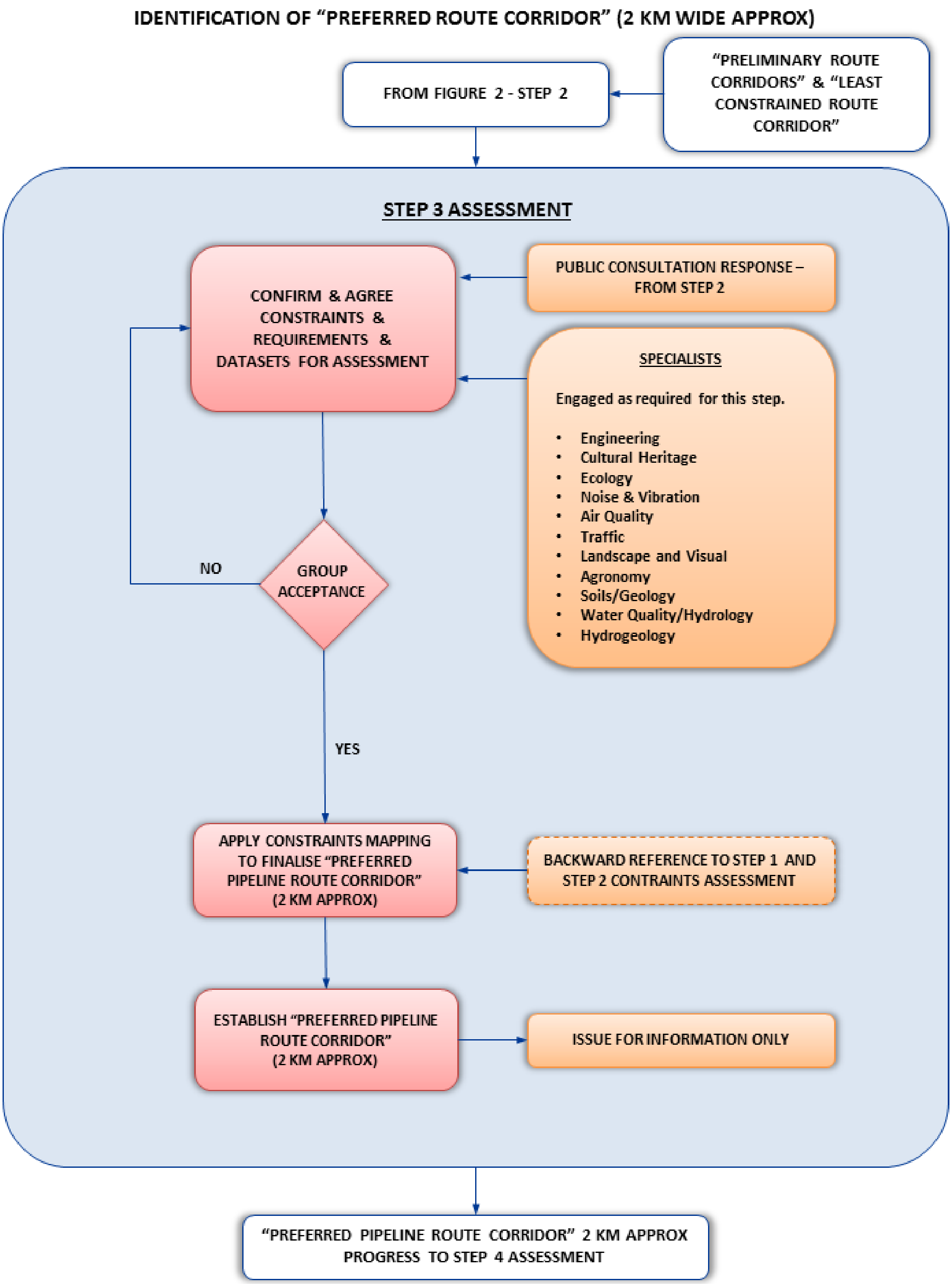

IDENTIFICATION OF "PREFERRED ROUTE CORRIDOR" (2 KM WIDE APPROX)
FROM FIGURE 2 - STEP 2
"PRELIMINARY ROUTE CORRIDORS" & "LEAST CONSTRAINED ROUTE CORRIDOR"
STEP 3 ASSESSMENT
CONFIRM & AGREE CONSTRAINTS & REQUIREMENTS & DATASETS FOR ASSESSMENT
PUBLIC CONSULTATION RESPONSE – FROM STEP 2
SPECIALISTS
Engaged as required for this step.
Engineering
Cultural Heritage
Ecology
Noise & Vibration
Air Quality
Traffic
Landscape and Visual
Agronomy
Soils/Geology
Water Quality/Hydrology
Hydrogeology
NO
GROUP ACCEPTANCE
YES
APPLY CONSTRAINTS MAPPING TO FINALISE "PREFERRED PIPELINE ROUTE CORRIDOR" (2 KM APPROX)
BACKWARD REFERENCE TO STEP 1 AND STEP 2 CONTRAINTS ASSESSMENT
ESTABLISH "PREFERRED PIPELINE ROUTE CORRIDOR" (2 KM APPROX)
ISSUE FOR INFORMATION ONLY
"PREFERRED PIPELINE ROUTE CORRIDOR" 2 KM APPROX PROGRESS TO STEP 4 ASSESSMENT

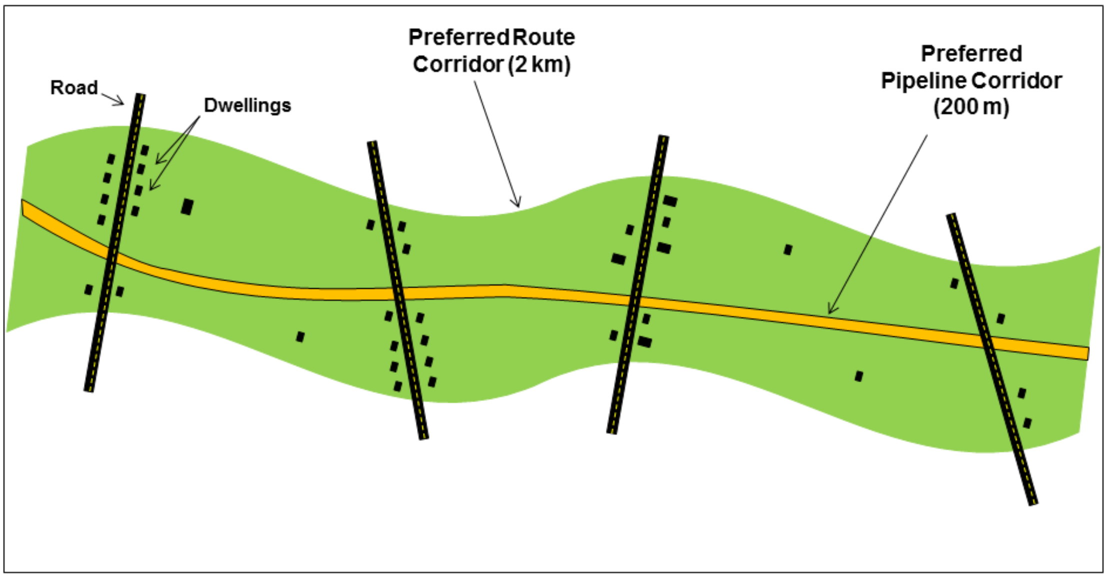
FIGURE 3

2.4 Linear Corridor Methodology – Step 4

This step of the methodology will involve desk study work supported by localised windscreen surveys/site visits.

The aim of this step of the process is to identify the “Preferred Pipeline Corridor”, approximately 200 m wide, from within the 2km “Preferred Route Corridor” selected/identified under the previous Step 3. See the Step 4 diagram below.

Step 4



The selection of the “Preferred Pipeline corridor”, as detailed under this Step 4 process, is undertaken on the basis of the following:

- a further constraints/requirements mapping exercise

This further constraints/requirements mapping will continue to be based upon the philosophy of impact avoidance through careful positioning of infrastructure. The constraints/requirements mapping will be substantially based upon selected Water Supply Project datasets from the dataset library as referred to previously in Section 1.5.1.

It should be noted that during this Step 4 constraints/requirements mapping exercise the project team will engage in a backward looking exercise to the previous Step 1, 2 & 3 constraints/requirements mapping process to affirm the efficacy of those earlier process steps.

During this Step 4 the following range of specialists will be engaged on an as needs basis:

- Engineering
- Cultural Heritage
- Ecology
- Noise & Vibration
- Air Quality
- Traffic

- Landscape and Visual
- Agronomy
- Soils/Geology
- Water Quality/Hydrology
- Hydrogeology

The outcome from the Step 3 process will be presented to the various project specialists to review, and define, a 200m “Preferred Pipeline Corridor”. Step 4 is an iterative process which will challenge the project specialists, through consensus, to refine a wide “Route Corridor” (2km) to a much narrower and focused “Pipeline Corridor” within the identified technical constraints / requirements.

The output from this process (based upon an agreed outcome) will be the establishment of the “Preferred Pipeline Corridor”, approximately 200 m wide.

The identified “Preferred Pipeline Corridor” will be consulted upon publically so as to gather any relevant information that will inform the next Step 5 of the process whereby the “Preferred Pipeline Route” will be identified/selected.

IDENTIFICATION OF "PREFERRED PIPELINE CORRIDOR" (200 M WIDE APPROX)

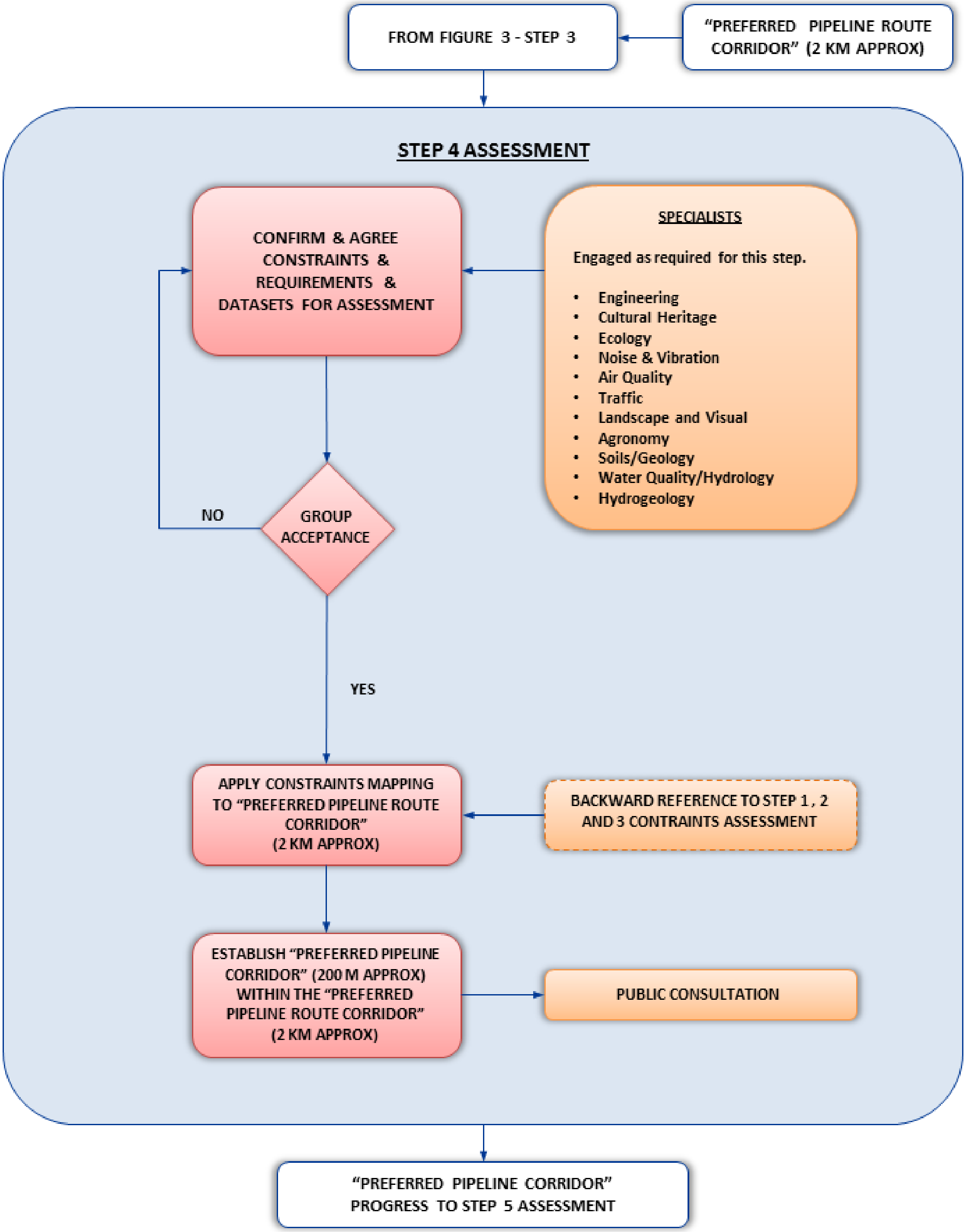


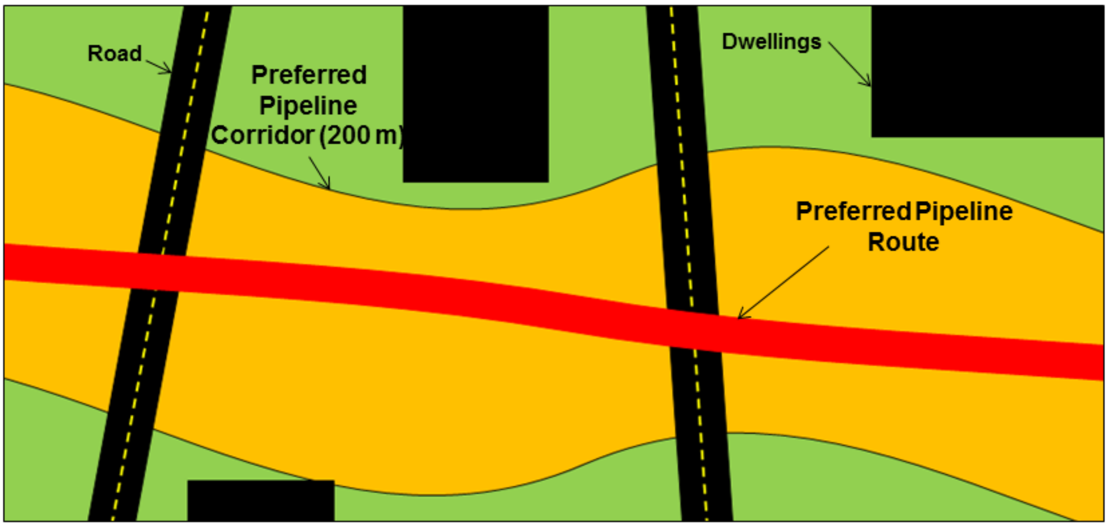
FIGURE 4

2.5 Linear Corridor Methodology – Step 5

This step of the methodology will involve desk study work supported by a focused field surveys/site visits programme.

The aim of this step of the process is to identify the “Preferred Pipeline Route” from within the “Preferred Pipeline Corridor” selected/identified under the previous Step 4. See the Step 5 diagram below

Step 5



The selection of the “Preferred Pipeline Route”, as detailed under this Step 5 process will be based upon the following:

- incorporation of the feed back from the public consultation on the “Preferred Pipeline Corridor” identified/consulted upon under Step 4 of the process
- a further constraints/requirements mapping exercise with the inclusion of an extended constraints/requirements dataset
- Landowner discussion/engagement

This further constraints/requirements mapping will continue to be based upon the philosophy of impact avoidance through careful positioning of infrastructure. The constraints/requirements mapping will be substantially based upon selected Water Supply Project datasets from the dataset library as referred to previously in Section 1.5.1.

It should be noted that during this Step 5 constraints/requirements mapping exercise the project team will engage in a backward looking exercise to the previous Step 1, 2, 3 & 4 constraints/requirements mapping process to affirm the efficacy of those earlier process steps.

During this Step 5 the following range of specialists will be engaged on an as needs basis:

- Engineering
- Cultural Heritage
- Ecology

- Noise & Vibration
- Air Quality
- Traffic
- Landscape and Visual
- Agronomy
- Soils/Geology
- Water Quality/Hydrology
- Hydrogeology

The outcome from the Step 4 process will be presented to the various project specialists to review, and refine, selection of the “Preferred Pipeline Corridor”.

This final Step 5 process will consider, in particular, the public consultation process carried out in the previous stage, any pertinent issues that may have arisen over the intervening period, but ensuring that at all times proposals are aligned with the SEA process.

This will be an iterative process with the objective of ‘fine tuning’ the technical constraints / requirements, and obtaining a consensus among the project specialists of a “Preferred Pipeline Route” that, given all things considered, mitigates the impact of the proposals.

The output from this process (based upon an agreed outcome) will be the “Preferred Pipeline Route” in the view of all the project specialists.

The identified “Preferred Pipeline Route” will not be subject to further Public Consultation; however engagement with affected landowners and communities will be an ongoing process.

The above approach for Step 5 is detailed in the flow chart presented below in Figure 5.

On completion of Step 5 of the process the “Preferred Pipeline Route” will have been selected.

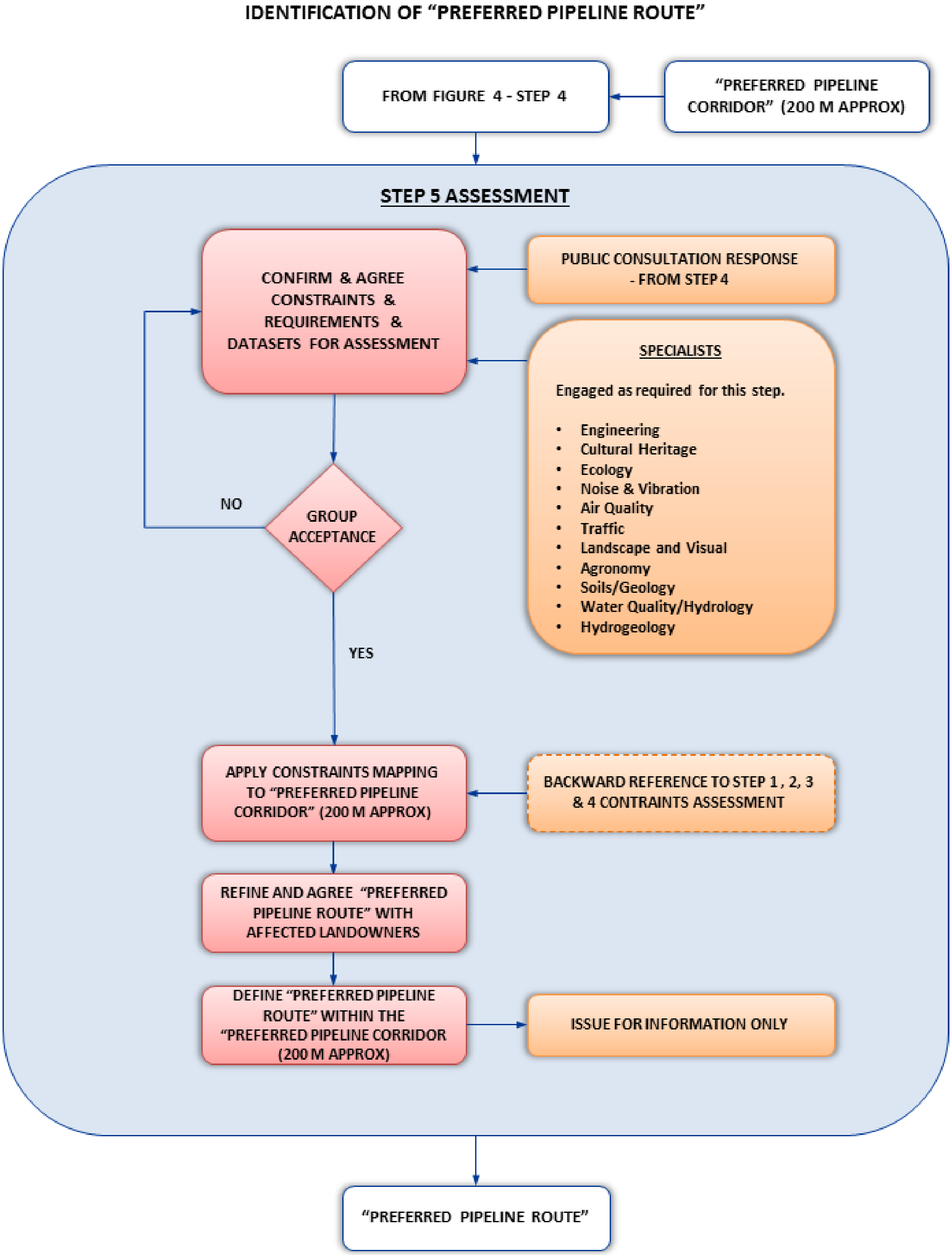

IDENTIFICATION OF "PREFERRED PIPELINE ROUTE"
FROM FIGURE 4 - STEP 4
"PREFERRED PIPELINE CORRIDOR" (200 M APPROX)
STEP 5 ASSESSMENT
CONFIRM & AGREE CONSTRAINTS & REQUIREMENTS & DATASETS FOR ASSESSMENT
PUBLIC CONSULTATION RESPONSE - FROM STEP 4
SPECIALISTS
Engaged as required for this step.
• Engineering
• Cultural Heritage
• Ecology
• Noise & Vibration
• Air Quality
• Traffic
• Landscape and Visual
• Agronomy
• Soils/Geology
• Water Quality/Hydrology
• Hydrogeology
NO
GROUP ACCEPTANCE
YES
APPLY CONSTRAINTS MAPPING TO "PREFERRED PIPELINE CORRIDOR" (200 M APPROX)
BACKWARD REFERENCE TO STEP 1, 2, 3 & 4 CONTRAINTS ASSESSMENT
REFINE AND AGREE "PREFERRED PIPELINE ROUTE" WITH AFFECTED LANDOWNERS
DEFINE "PREFERRED PIPELINE ROUTE" WITHIN THE "PREFERRED PIPELINE CORRIDOR (200 M APPROX)
ISSUE FOR INFORMATION ONLY
"PREFERRED PIPELINE ROUTE"

FIGURE 5

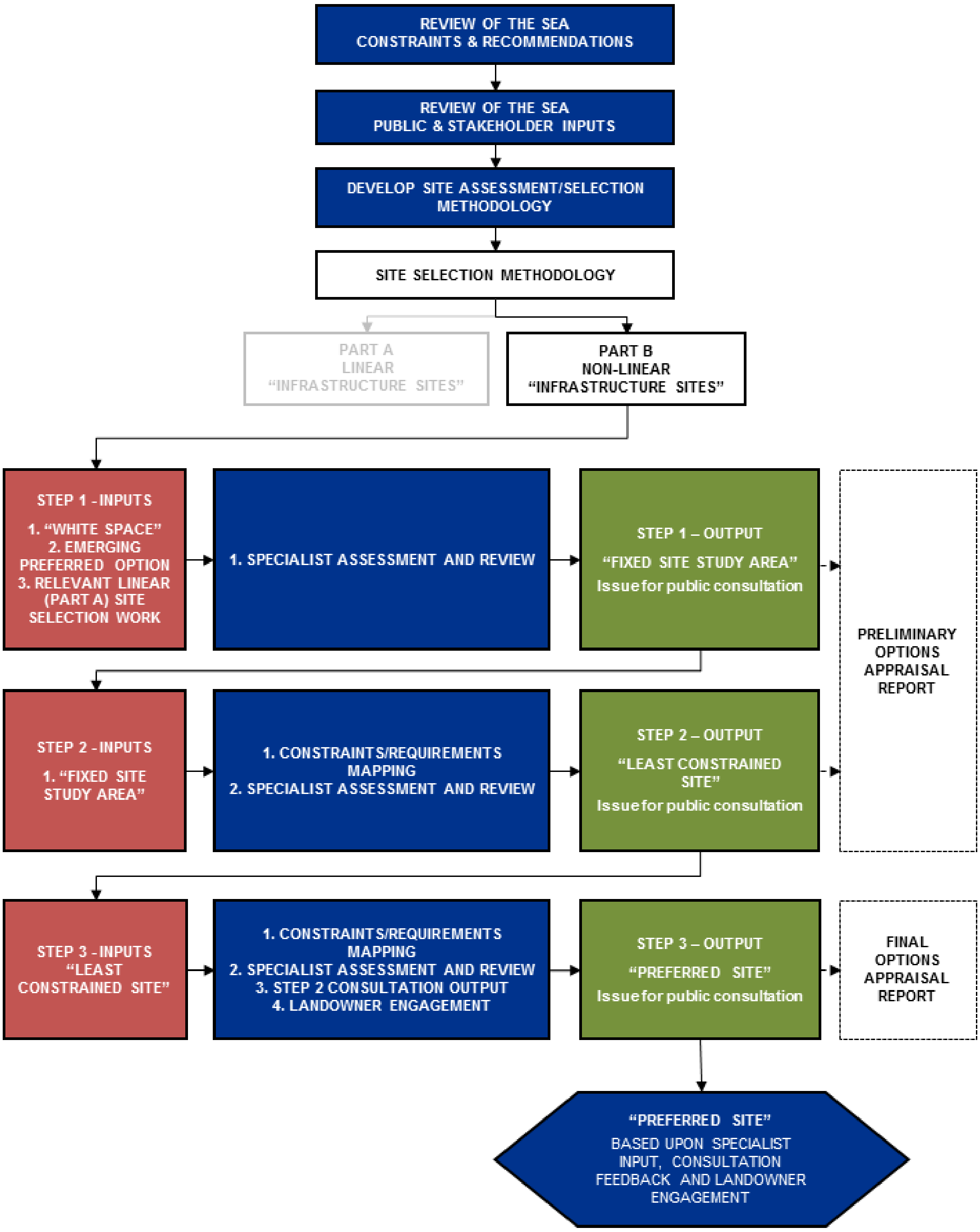
3 Part B: Non-Linear "Infrastructure Sites"

The Part B Site Selection Methodology is applicable to the following **Fixed Site Location** infrastructure categories.

- Raw water shoreside/bankside abstraction chamber and raw water abstraction pumping station (1)
- Raw Water Storage Reservoir at Garryhinch (2)
- Water treatment plant (WTP) (3)
- Treated water main lift and booster pumping stations and break pressure tank at booster pumping stations (4)
- Termination point reservoir (TPR) (6)
- Mainlift pumping station at the TPR for onward pumping (7)

The Part B Site Selection Methodology involves a three step process, as detailed on the flow chart overleaf. The methodology will be applied in a similar manner for each of the above project infrastructure components.

The three steps of the methodology are detailed in the following sections.


REVIEW OF THE SEA
CONSTRAINTS & RECOMMENDATIONS
REVIEW OF THE SEA
PUBLIC & STAKEHOLDER INPUTS
DEVELOP SITE ASSESSMENT/SELECTION METHODOLOGY
SITE SELECTION METHODOLOGY
PART A
LINEAR
"INFRASTRUCTURE SITES"
PART B
NON-LINEAR
"INFRASTRUCTURE SITES"
STEP 1 - INPUTS
1. "WHITE SPACE"
2. EMERGING PREFERRED OPTION
3. RELEVANT LINEAR (PART A) SITE SELECTION WORK
1. SPECIALIST ASSESSMENT AND REVIEW
STEP 1 – OUTPUT
"FIXED SITE STUDY AREA"
Issue for public consultation
PRELIMINARY OPTIONS APPRAISAL REPORT
STEP 2 - INPUTS
1. "FIXED SITE STUDY AREA"
1. CONSTRAINTS/REQUIREMENTS MAPPING
2. SPECIALIST ASSESSMENT AND REVIEW
STEP 2 – OUTPUT
"LEAST CONSTRAINED SITE"
Issue for public consultation
STEP 3 - INPUTS
"LEAST CONSTRAINED SITE"
1. CONSTRAINTS/REQUIREMENTS MAPPING
2. SPECIALIST ASSESSMENT AND REVIEW
3. STEP 2 CONSULTATION OUTPUT
4. LANDOWNER ENGAGEMENT
STEP 3 – OUTPUT
"PREFERRED SITE"
Issue for public consultation
FINAL OPTIONS APPRAISAL REPORT
"PREFERRED SITE"
BASED UPON SPECIALIST INPUT, CONSULTATION FEEDBACK AND LANDOWNER ENGAGEMENT

3.1 Non-linear Site Methodology – Step 1

This stage of the methodology will involve desk study work only.

The aim of this step is to identify a "Fixed Site Study Area", from within which non-linear "infrastructure sites" may most suitably be located.

The selection of the "Fixed Site Study Area" as detailed under this Step 1 process will be based on the following:

- the identified Emerging Preferred Option
- relevant Linear (part A) site selection work
- a specialist review exercise based upon Water Supply Project datasets from the GIS dataset library, as referred to previously in Section 1.5.1, drawing upon the specialist knowledge of the group.

The strategy will be based upon the philosophy of impact avoidance through careful infrastructure positioning.

During this Step 1 the following range of specialists will be engaged on an as needs basis:

- Engineering
- Cultural Heritage
- Ecology
- Noise & Vibration
- Air Quality
- Traffic
- Landscape and Visual
- Agronomy
- Soils/Geology
- Water Quality/Hydrology
- Hydrogeology

Initially all engaged project specialists will be requested to independently assess and identify issues that would reflect their opening position for the selection of the "Fixed Site Study Area" which would result in least impact from their own specialist perspective.

The preferred positions of each of the specialists will be subject to discussion and debate to ensure that their requirements are collectively generated and agreed by the project team.

Next the information from the various specialists will be used by the engineering specialist to develop the "Fixed Site Study Area". The developed "Fixed Site Study Area" will then be presented back to the specialists for consideration. During this review any required refinements will be discussed and agreed between the specialists, and recorded. The output from this process (based upon an agreed outcome) will be the establishment of the "Fixed Site Study Area".

Once identified, the "Fixed Site Study Area" will be used to inform the next Step 2 of the process. The above approach for Step 1 is detailed in the flow chart presented below in Figure 6.

IDENTIFICATION OF "FIXED SITE STUDY AREA",

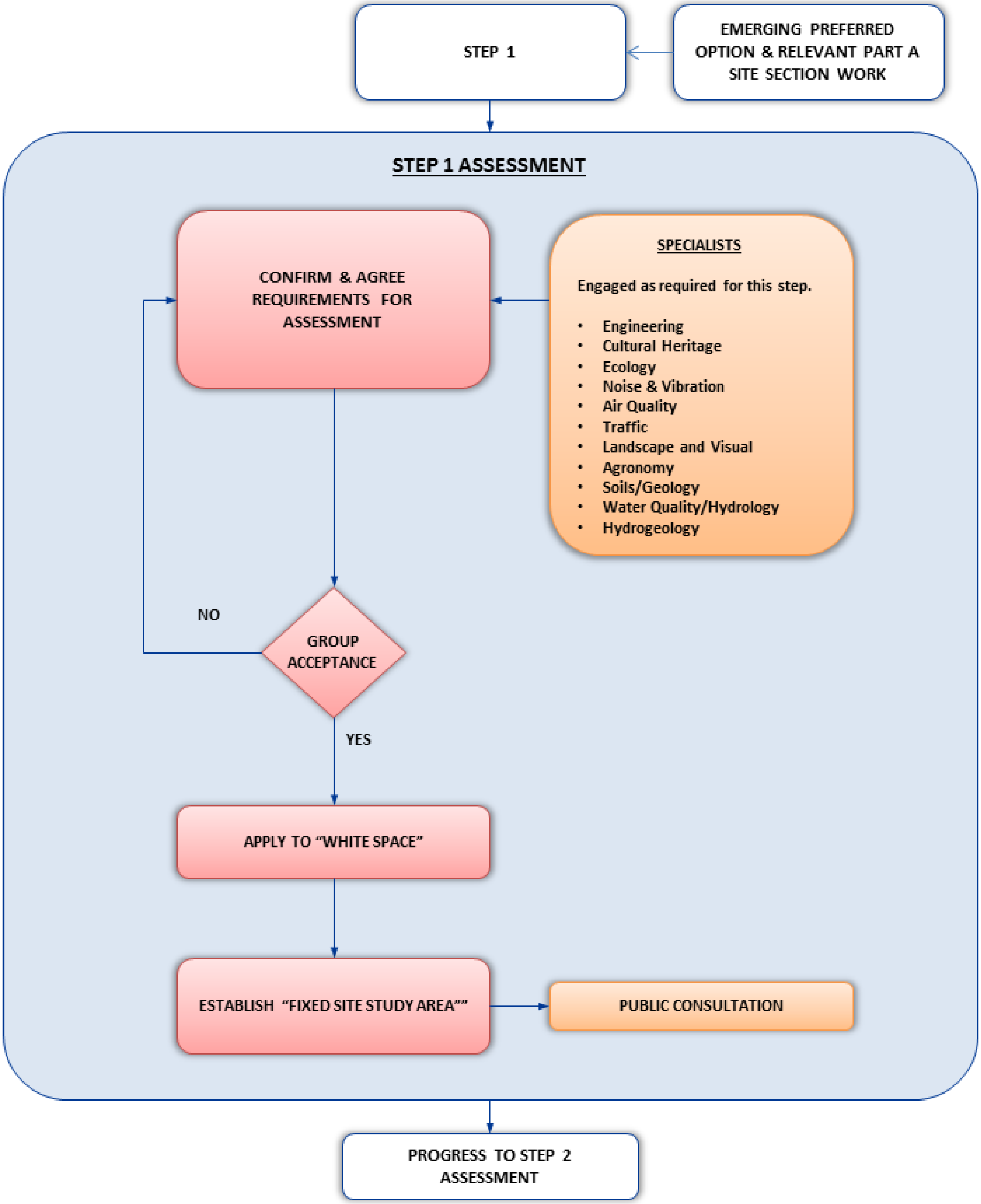
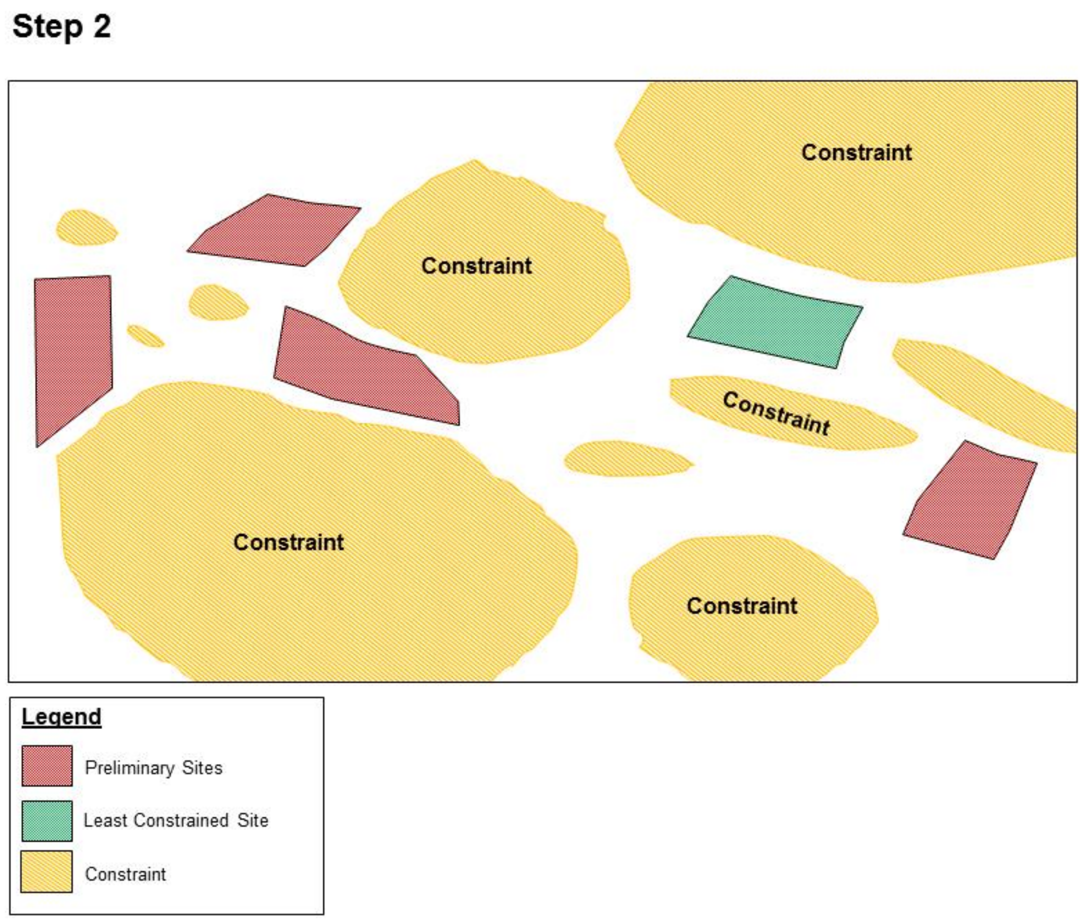


FIGURE 6

3.2 Non-linear Site Methodology – Step 2

This stage of the methodology will involve desk study work with limited/focused windscreen surveys as required.

The aim of this step is to identify “Preliminary Sites” and “A Least Constrained Site”, from within the “Fixed Site Study area" in which non-linear “infrastructure sites” may most suitably be located. See Step 1 diagram below.



The selection of the “Preliminary Sites” and “Least Constrained Site”, as detailed under this Step 1 process will be based on the following:

- A defined “Fixed Site Study Area”
- a constraints/requirements mapping exercise based upon Water Supply Project datasets from the GIS dataset library as referred to previously in Section 1.5.1.

The constraints/requirements mapping strategy will be based upon the philosophy of impact avoidance through careful infrastructure positioning.

During this Step 2 the following range of specialists will be engaged on an as needs basis:

- Engineering
- Cultural Heritage
- Ecology
- Noise & Vibration

- Air Quality
- Traffic
- Landscape and Visual
- Agronomy
- Soils/Geology
- Water Quality/Hydrology
- Hydrogeology

Initially all engaged project specialists will be requested to independently assess and identify issues that would reflect their opening position for the selection of the “Preliminary Sites” (from within the “Fixed Site Study Area”) which would result in least impact from their own specialist perspective. Each specialist does not work in isolation, however, and will have full access to the constraints/requirements of other disciplines, which are available from the constraints/requirements mapping. This approach will facilitate an informed selection by each of the specialists whereby any element of group-conditioning of initial positions can be deliberately avoided.

The issues submitted by each project specialist will also be informed by the mapping of constraints/requirements onto the “Fixed Site Study Area”. The preferred positions of each of the specialists will be subject to discussion and debate to ensure that their constraints/requirements are aligned with those proposed in the SEA, and that they are collectively generated and agreed by the project team.

Next the information from the various specialists will be used by the engineering specialist to develop the “Preliminary Sites”. The developed “Preliminary Sites” will then be presented back to the specialists for consideration

Subsequently the “Preliminary Sites” will be reviewed by the specialists through a project team engagement, with the intent of achieving consensus on the “Least Constrained Site”. During this review any required refinements will be discussed and agreed between the specialists, and recorded. The output from this process (based upon an agreed outcome) will be the establishment of the “Least Constrained Site”.

Once the constraints/requirements mapping has been applied across the “Infrastructure Study Area” and the “Preliminary Sites” identified along with the “Least Constrained Site”, this will be issued for public consultation.

The feedback from the public consultation exercise will be used to inform the next step of the process, Step 3.

The above approach for Step 2 is detailed in the flow chart presented below in Figure 7.

IDENTIFICATION OF "PRELIMINARY SITES" and "LEAST CONSTRAINED SITE"

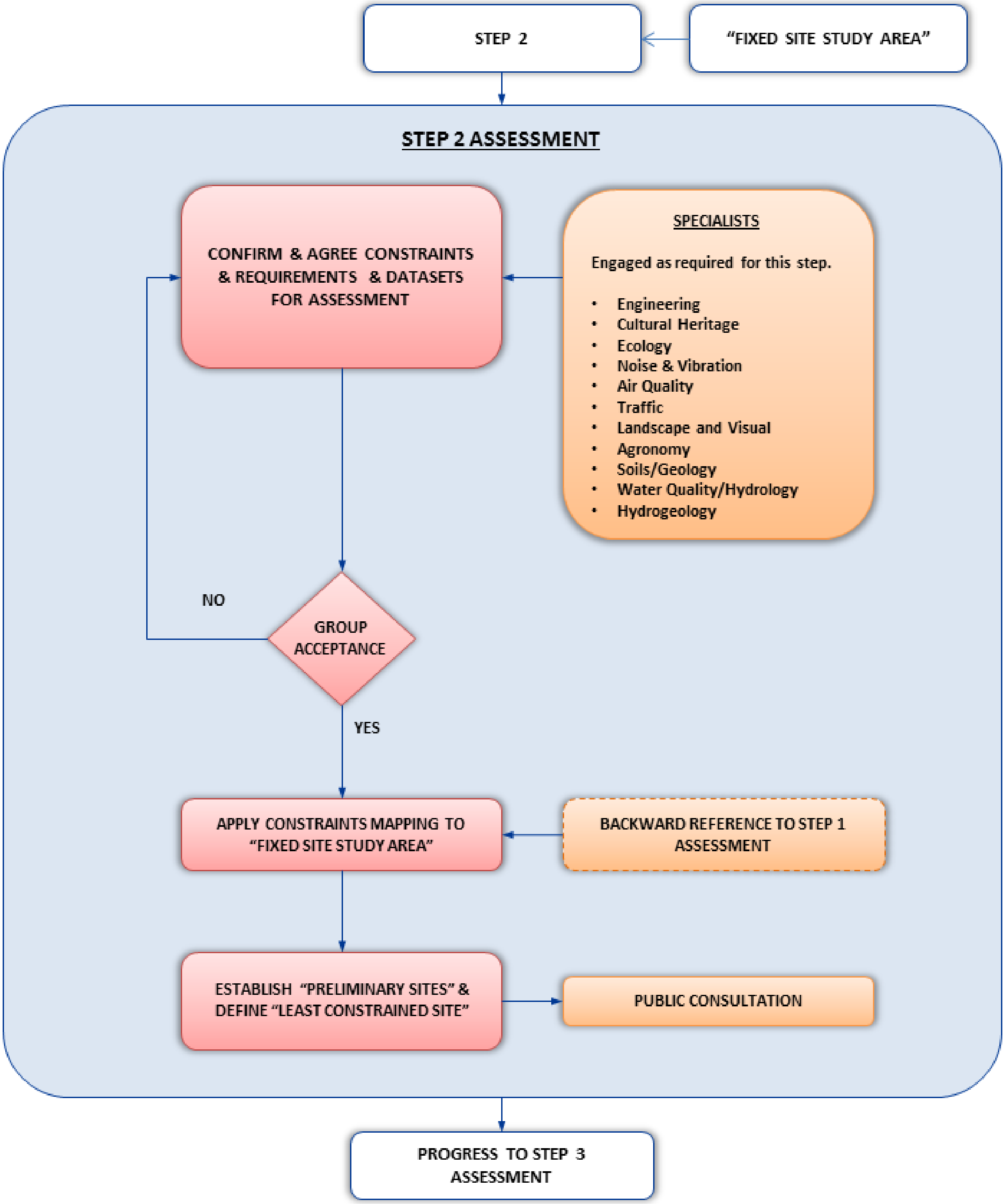
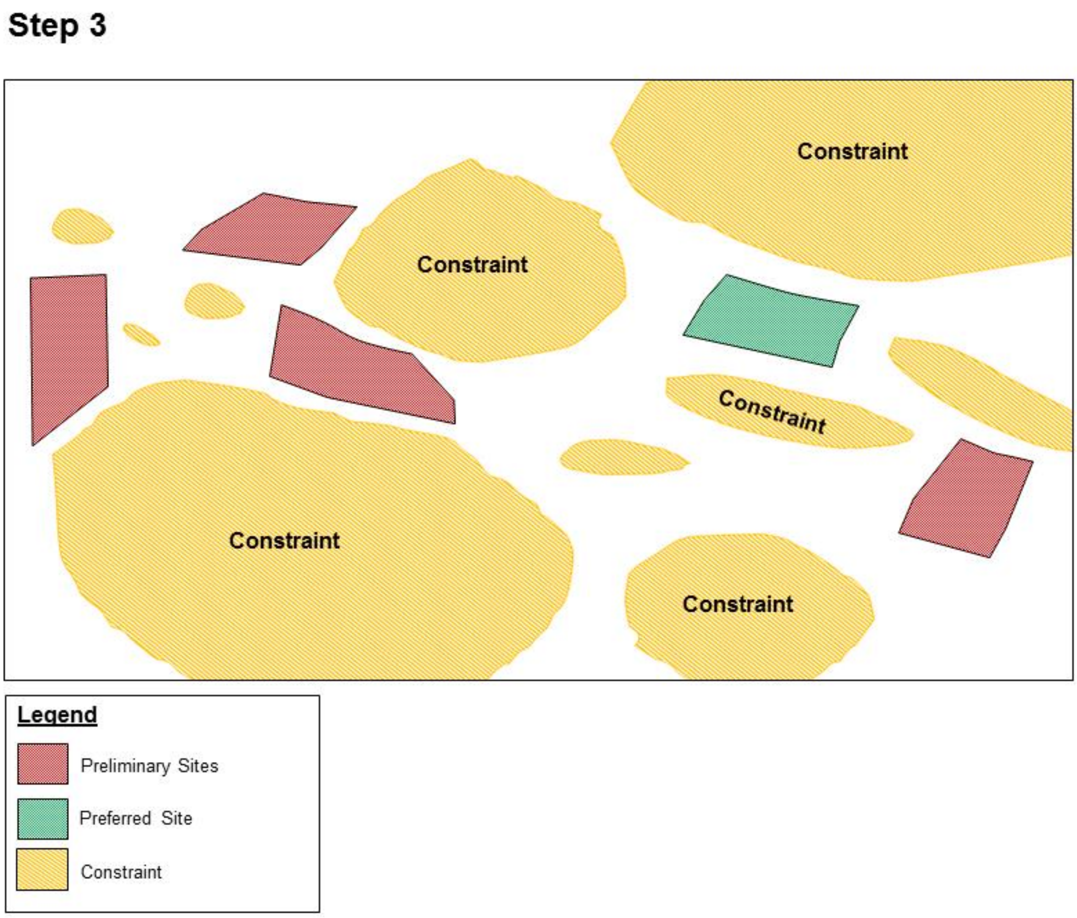


FIGURE 7

3.3 Fixed Site Methodology – Step 3

This step of the methodology will involve desk study work supported by a focused field surveys/site visits programme.

The aim of this step of the process is to identify a “Preferred Site” for locating the non-linear infrastructure component. See the Step 3 diagram below



The selection of the “Preferred Site”, as detailed under this Step 3 process will be based upon the following:

- incorporation of the feedback from the public consultation on the “Preliminary Potential Sites” and “Least Constrained Site” identified/consulted upon under Step 2 of the process
- a further constraints/requirements mapping exercise with the inclusion of an extended constraints/requirements dataset as required

This further constraints/requirements mapping will continue to be based upon the philosophy of impact avoidance through careful positioning of infrastructure. The constraints/requirements mapping will be substantially based upon selected Water Supply Project datasets from the dataset library as referred to previously in Section 1.5.1.

It should be noted that during this Step 3 constraints/requirements mapping exercise the project team will engage in a backward looking exercise to the previous Step 1 &

2 constraints/requirements mapping process to affirm the efficacy of those earlier process steps.

During this Step 3 the following range of specialists will be engaged on an as needs basis:

- Engineering
- Cultural Heritage
- Ecology
- Noise & Vibration
- Air Quality
- Traffic
- Landscape and Visual
- Agronomy
- Soils/Geology
- Water Quality/Hydrology
- Hydrogeology

The engaged project specialists will be requested to review their selection of the “Least Constrained Site” and confirm their selection of a “Preferred Site” (notwithstanding that this may not be “Least Constrained Site”). This process will ensure reference to pertinent issues that may have arisen over the intervening period since Step 2, due cognisance of the public consultation process carried out in the previous stage, and alignment of proposals with the SEA.

Information from the various project specialists will then be used by the engineering specialist to develop a “Preferred Site”.

The developed “Preferred Site” will then be presented back to the specialists for consideration. Through a project team engagement, with the intent of achieving consensus, the “Preferred Site” will be reviewed by the specialists. During this review any required refinements will be discussed and agreed between the specialists, and recorded. The output from this process (based upon an agreed outcome) will be the establishment of the “Preferred Site”.

The identified “Preferred Site” will be issued for public consultation. The feedback from the public consultation exercise will be used as a final confirmation of the “Preferred Site”.

The above approach for Step 3 is detailed in the flow chart presented below in Figure 8.

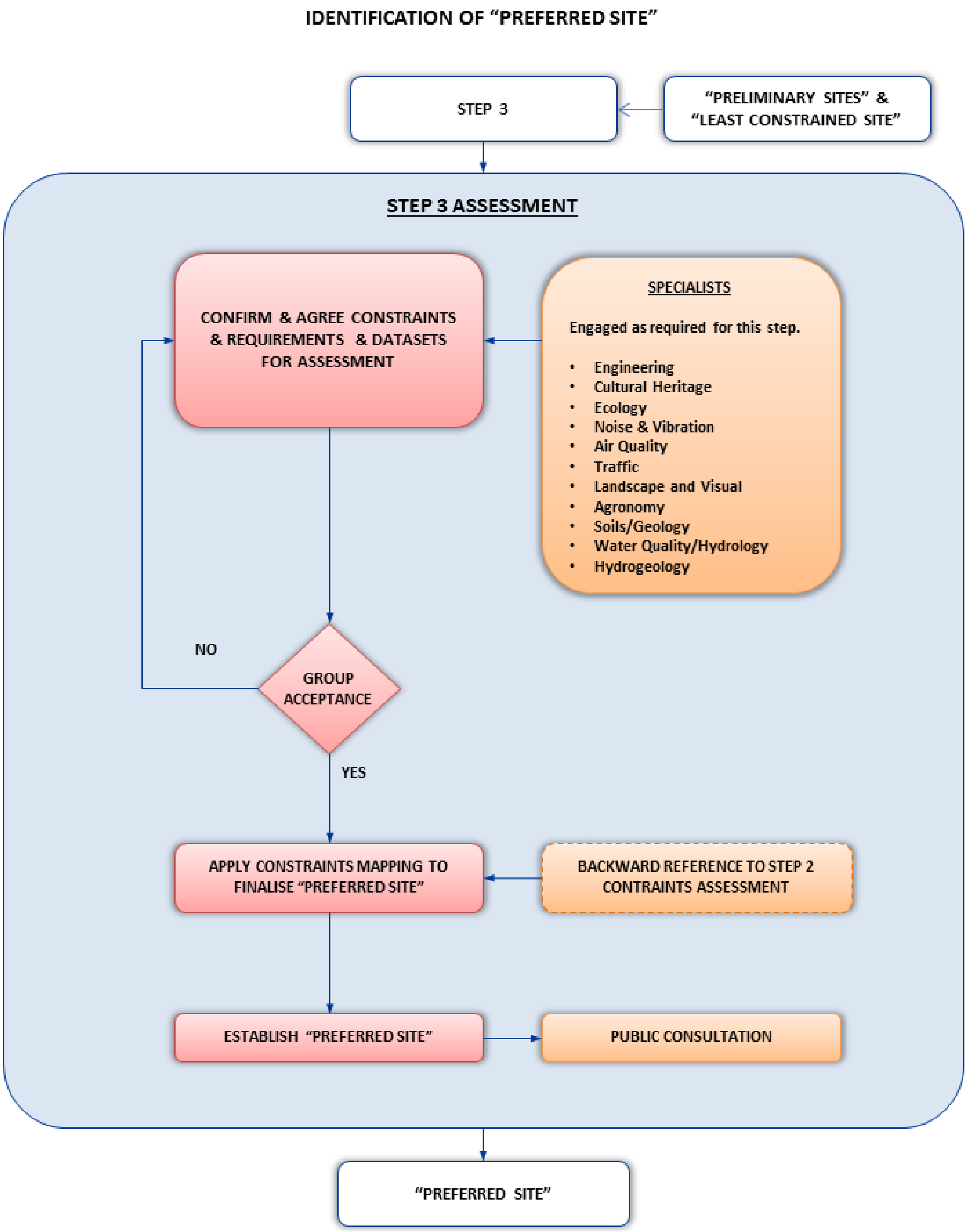

IDENTIFICATION OF "PREFERRED SITE"
STEP 3
"PRELIMINARY SITES" & "LEAST CONSTRAINED SITE"
STEP 3 ASSESSMENT
CONFIRM & AGREE CONSTRAINTS & REQUIREMENTS & DATASETS FOR ASSESSMENT
SPECIALISTS
Engaged as required for this step.
• Engineering
• Cultural Heritage
• Ecology
• Noise & Vibration
• Air Quality
• Traffic
• Landscape and Visual
• Agronomy
• Soils/Geology
• Water Quality/Hydrology
• Hydrogeology
NO
GROUP ACCEPTANCE
YES
APPLY CONSTRAINTS MAPPING TO FINALISE "PREFERRED SITE"
BACKWARD REFERENCE TO STEP 2 CONTRAINTS ASSESSMENT
ESTABLISH "PREFERRED SITE"
PUBLIC CONSULTATION
"PREFERRED SITE"

FIGURE 8

Appendix A Constraint Datasets

The following is the list of the GIS datasets that were obtained for the project.

Dataset	Source
Quarries	EPA
Landfills	EPA
Licensed IPPC Facilities	EPA
Water Treatment Plants	EPA
Waste Water Treatment Plants	EPA
Mines	EPA
National Monuments: - Subject to a preservation order (or temporary preservation order). - In the ownership or guardianship of the Minister for Arts, Heritage and the Gaeltacht or a Local Authority.	DoAHG
Settlements	CSO
Building Density (>100 per Km2)	Processed from Geodirectory (An Post)
Record of Protected Structures	local authority
Recreational Waters WFD Annex V (iii)	EPA
Limestone Pavement	NPWS
Pearl Mussels	NPWS
Nature Preserves	NPWS
Nature Preserves	NPWS
Pollardstown Fen	Processed Data (from GSI datasets)
Curragh Aquifer	Processed Data (from GSI datasets)
Ancient Woodlands	NPWS
Fens	NPWS
Turloughs	NPWS
Coastal Lagoon	NPWS
Intact Raised Bog	NPWS
Blanket Bog	NPWS

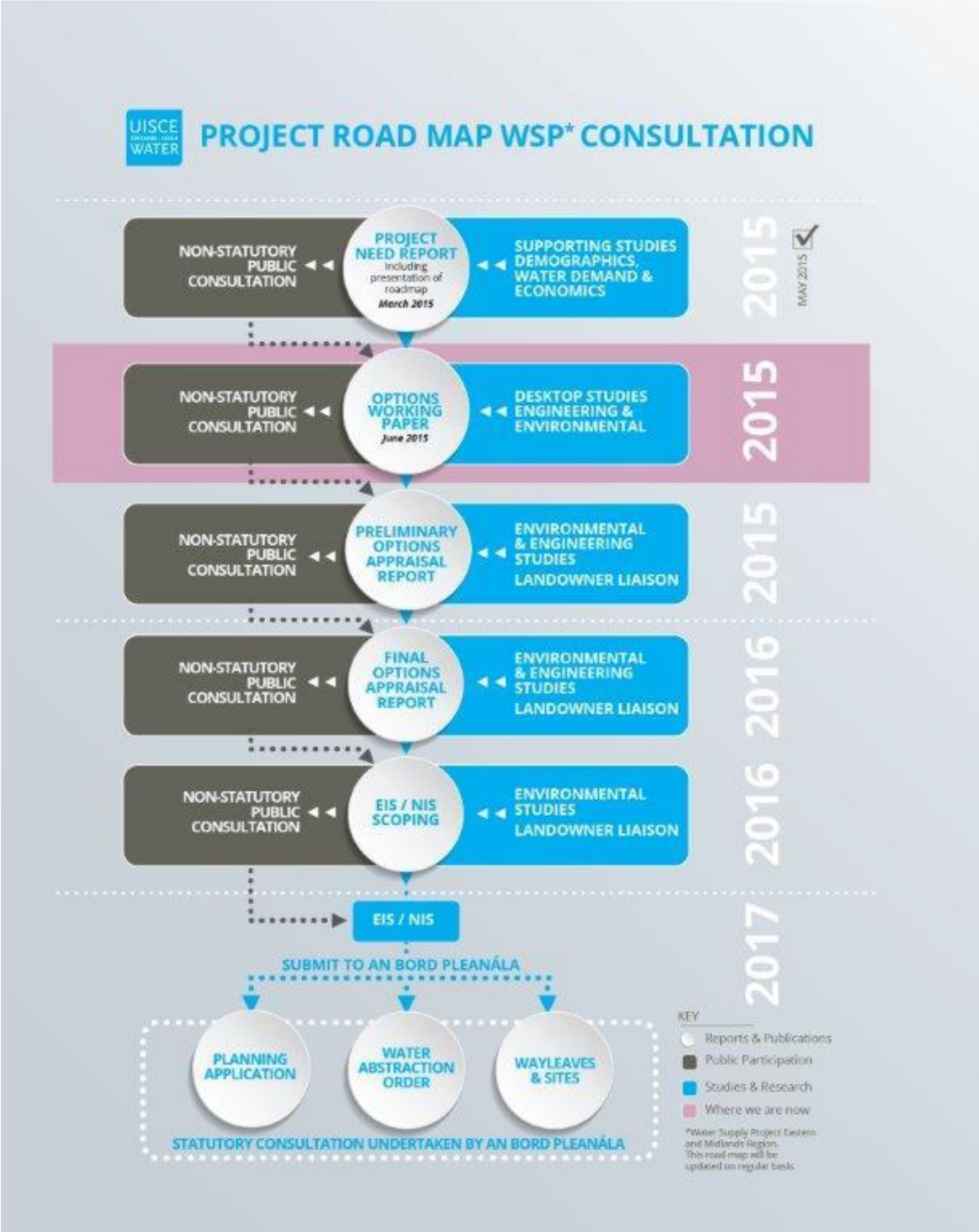
Salt Marsh	NPWS
Potential Turloughs	NPWS
Limestone Pavement	NPWS
Building Density (>50 per Km2)	Processed from Geodirectory (An Post)
Lakes WFD	EPA
Zoning Ireland	DoECLG
Geological Heritage Sites Exceptions do apply so review on a case by case basis.	GSI
Groundwater Vulnerability (Subsets include Extreme and Extreme Rock at Surface)	GSI
Karst Features	GSI
Record of Protected Structures RPS Dun Laoghaire Rathdown	local authority
Record of Protected Structures RPS Kilkenny	local authority
Record of Protected Structures RPS South Dublin	local authority
Record of Protected Structures RPS Wicklow	local authority
Wet Heath	Source NPWS: Significant Ecological Receptor sensitive to development. Evaluation will range between Local and International Importance
Floodplains	OPW
Coastal Floodplains	OPW - Irish Coastal Protection Strategy Study (ICPSS)
Coillte Forestry	Coillte
Salmonid Water Salmonid Regulations (S.I. 293 / 1988)	EPA
Waters used for the abstraction of drinking water WFD Annex V (i)	EPA
Areas designated to protect economically significant aquatic species WFD Annex V (ii)	EPA
Recreational Waters WFD Annex V (iii)	EPA
Tree Preservation Orders	local authority
Mineral Locations	GSI
Source Protection Area	GSI
Bathing Water Locations	EPA
WFD Coastal Water Bodies	EPA

WFD Transitional Water Bodies	EPA
National Trails, Walking routes and Cycle Routes	local authority
Dive Clubs	MIDA
Fishing Ports	MIDA
Marinas	MIDA
Moorings	MIDA
Sailing Clubs	MIDA
Surf Clubs	MIDA
Blue Marinas	MIDA
Water Abstraction Point	EPA
Windsurfing Schools	MIDA
Landscape Character Areas (Local Authorities)	local authority
Sensitive Land Cover Kilkenny	local authority
Views Prospects Local Authorities	local authority
Architectural Conservation Areas (ACA)	local authority
Record of Protected Structures (RPS)	local authority
County Geological Sites	GSI
National Parks should be included	NBDC
Forestry 12	Department Of Agriculture
Special Areas of Conservation (SAC) (Natura 2000 Sites)	NPWS
Special Protection Areas (SPA) (Natura 2000 Sites)	NPWS
Record of Monuments and Place (RMP)	DoAHG
Proposed Natural Heritage Areas (pNHA)	NPWS
Ramsar	NPWS
Unesco Sites	MIDA

Natural Heritage Areas (NHA)	NPWS
Native Woodland Survey 2010	NPWS
Local Authority Habitat Surveys	local authority
Important Bird Areas (Refuge for Fauna)	MIDA
Iwebs data Bird watch Ireland	BW Ireland
Wintering bird Site - International / National/ Regional	BW Ireland
I-webs Site Local	BW Ireland
Woodland Habitat	NPWS
Semi Natural Grasslands	NPWS
Raised Bog (un-surveyed) – vegetated	NPWS
Soil (Subsets Include different Bog Classes)	EPA

Subsoil (Subsets Include different Bog Classes)	EPA
Commonage Base Plan 2011	NPWS
Commonage Base Station 2011	NPWS
Commonage Base SU 2011	NPWS
High Power Electric Transmission Lines	ESB
WFD Groundwater Bodies	EPA
Groundwater Zones of Contribution	EPA
Blue Flag Beaches	MIDA
Fishing Spots	MIDA
Green Coast Award	MIDA
Surf Spots	MIDA
Contaminated Land	EPA, County Council

Appendix B Project Road Map



Water Supply Project
Eastern and Midlands Region

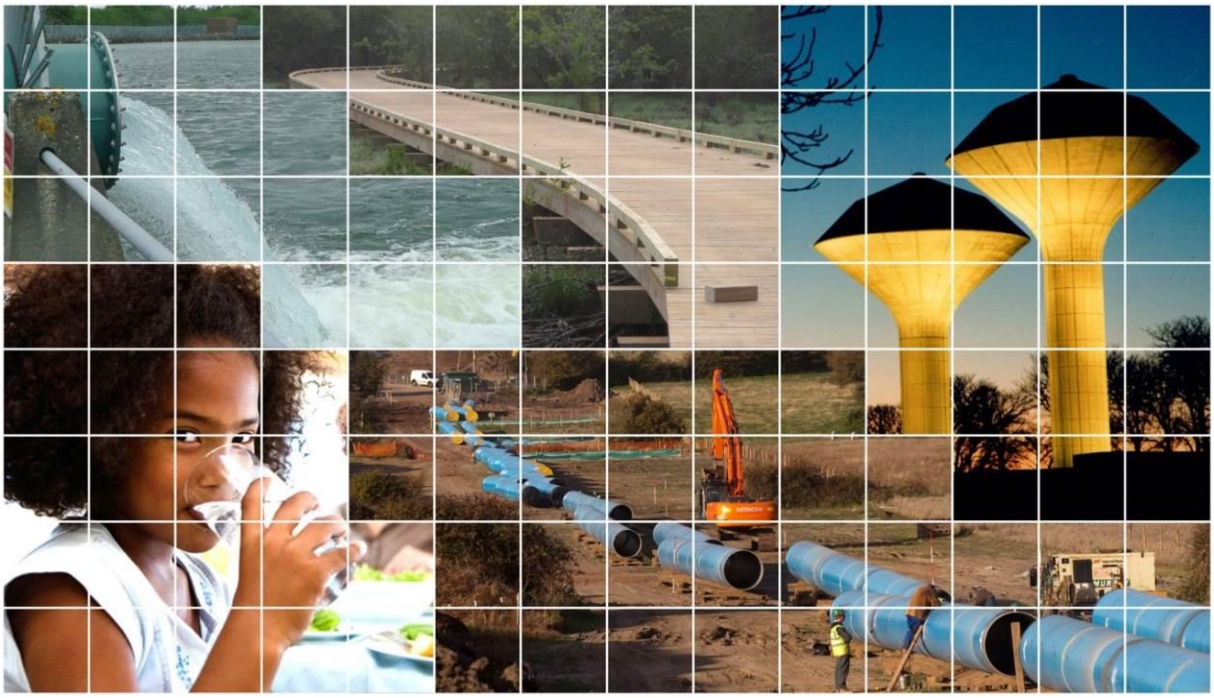
Appendix C

Hydrodynamic Modelling

Water Supply Project
Eastern and Midlands Region (WSP)

Appendix C: Hydrodynamic Modelling

October 2015 F02



Contents

Explanatory Statement to Hydrodynamic Model

This statement should be read in conjunction with the Hydrodynamic and Water Quality Modelling Report. It summarises the extent of surveys required to support the construction, verification and calibration of a computational model for Lough Derg / Parteen Basin, the scenarios applied and subsequent results; and provides additional commentary on the findings.
All 'Figures' referred to in this statement are referenced to the Hydrodynamic and Water Quality Modelling Report.

Scope of Water Quality Survey

The investigative studies have included a bathymetry survey, carried out in Q2-Q3 2015, of water depths throughout Lough Derg and Parteen Basin; survey data is now becoming available and will be used to refine the hydrodynamic model.
Note: this bathymetry survey data was not available by the time the First Pass Model had been completed (for the Preliminary Options Appraisal Report) but it will be included in later 'runs' as part of the Final Options Appraisal Report.

The studies have also included a Water Quality Survey Contract, which is ongoing and will continue to completion following an elapsed period of 26 months, from April 2015 to mid 2017.

The water quality survey scope includes deployment of equipment on the following scale:-

Measured Parameters	Methodology	Monitoring Locations
Water Flow and Current	Acoustic Doppler Current Profilers (ADCP)	4
Water Level	Water Level Recorder	6
Water Quality	Nutrient Analyser	5
	Manual Sampling	8
Water Treatability	Manual Sampling	8
Water Temperature	Thermistor chains	20
Meteorological Conditions	Meteorological Station	2
Plankton levels	Manual sampling	11

The survey will provide the following information:

- Water flow and current - using Acoustic Doppler Current Profilers (ADCP) to accurately assess current speeds at defined sections;
- Water level - using automatic water level recorders, which will be correlated with existing water level measurements;
- Continuous physiochemical water quality monitoring using moored stations (including automated nutrient analysers);
- Water quality spot sampling and laboratory analysis from the surface, mid-column and bottom of the lake water column at a fortnightly interval;

- Water quality spot sampling and laboratory analysis from the surface of the river column at key incoming tributaries;
- Water treatability sampling and laboratory analysis from the surface, mid and bottom of the lake water column;
- Continuous water temperature monitoring using thermistor chains;
- Meteorological monitoring to correlate the survey data with prevailing weather conditions using meteorological stations; and
- Plankton survey of the Lough (12 month period only).

Hydrodynamic Model

The objective of the hydrodynamic modelling, which is based on a MIKE 3 Flexible Mesh approach, is to assess the existing flushing characteristics of Lough Derg and Parteen Basin and to examine impacts on that arising from abstraction options. The flushing characteristics were assessed for the period from October 1994 to December 1995, this being the reference period for the calibration of models, and also because it encompassed periods of very high flow on the Shannon (January 1995) as well as periods of extreme low flows (August - September 1995).

The model ran scenarios for the following options:

i. Option F2 (North East Lough Derg with Storage)
ii. Option B (North East Lough Derg Direct)
iii. Option C (Parteen Basin Reservoir Direct)

Each of the options had to satisfy a water abstraction requirement of 350 Ml/d, as was referenced in the DCC Adopted Plan and SEA which were published in 2011. In the case of Options B and C this was a constant year-round abstraction regime. However, Option F2 was predicated on the following:

- A variable abstraction rate incorporating a 2 month storage volume at Garryhinch in the Midlands;
- An increased abstraction rate, from 350 Ml/d to 410 Ml/d, for a 10 month period in any given year to facilitate filling and storage at Garryhinch.
- For the other 2 months of the year, during the summer when river flows are at their lowest, abstraction would be curtailed to 50 Ml/d, the balance being drawn from the storage at Garryhinch and thereby potentially mitigating any adverse impact on lake retention regime that an all year-round abstraction might have.

A variation to Option F2 considered whether a larger storage, holding 3 months balancing volume rather than 2 months, would provide improved mitigation. In this situation 450 Ml/d were maintained over 9 months, with 50 Ml/d being abstracted over the longer 3 month period.

Options F2 and B were predicated on an abstraction form north east Lough Derg, however consideration was also afforded to an abstraction location farther south, in Youghal Bay, to investigate whether this gave substantially different results on residence times.

A total of 10 scenarios were modelled and reported on. These and their findings are summarised in the following Tables.

Scenario No.	Description	Notes	Comment
1	Winter - baseline (no abstraction)	This scenario simulated the existing hydrodynamic regime in Lough Derg during winter flow conditions.	Residence times are low in Lough Derg in winter but some spatial variation evident in bays.
2	Winter - constant abstraction (350Mld) in northeast Lough Derg **(Option B)**	This scenario simulated the hydrodynamic regime in Lough Derg during winter flow conditions with constant abstraction located in the north eastern corner of Lough Derg. This scenario had been investigated as Option B during the SEA process.	Abstraction in winter conditions has low impact on residence times in Lough Derg due to difference in relative magnitude of flows. Slight local reduction in residence time in the immediate vicinity of the abstraction intake.
3	Winter - variable abstraction in northeast Lough Derg (410 Mld:50 Ml/d) **(Option F2)**	This scenario simulated the hydrodynamic regime in Lough Derg during winter flow conditions with variable abstraction located in the north eastern corner of Lough Derg. This scenario is associated with raw water storage at Garryhinch in the midlands and had been investigated as Option F2 during the SEA process.	Abstraction in winter conditions has low impact on residence times in Lough Derg due to difference in relative magnitude of flows. Little difference between variable abstraction and constant abstraction under winter conditions
4	Winter - constant abstraction (350 Ml/d) in Parteen Basin **(Option C)**	This scenario simulated the hydrodynamic regime in Lough Derg during winter flow conditions with constant abstraction located in Parteen Basin. This scenario had been investigated as Option C during the SEA process.	No impact on residence time in Lough Derg.
5	Summer - baseline (no abstraction)	This scenario simulated the existing hydrodynamic regime in Lough Derg during summer low flow conditions.	Spatial variation evident in residence time under existing natural conditions (1995 drought year), evident from north to south and in lateral bays. Southern section above Killaloe has residence time above average for lake as a whole.

Scenario No.	Description	Notes	Comment
6	Summer - constant abstraction (350 Ml/d) in northeast Lough Derg **(Option B)**	This scenario simulated the hydrodynamic regime in Lough Derg during summer low flow conditions with constant abstraction located in the north eastern corner of Lough Derg. This scenario had been investigated as Option B during the SEA process	Worst case residence time impacts of order of 42 days in southern region of lake where baseline residence time is also elevated.
7	Summer - variable abstraction in northeast Lough Derg (410 Mld:50 Ml/d) **(Option F2)**	This scenario simulated the hydrodynamic regime in Lough Derg during summers flow conditions with a variable abstraction located in the north eastern corner of Lough Derg. This scenario is associated with raw water storage at Garryhinch in the midlands and had been investigated as Option F2 during the SEA process	Two months raw water storage does not appreciably mitigate residence time effects in southern Lough Derg over the Scenario 6 outcome. Prolonged duration of the drought in 1995 would bring about residence time impacts outside the time- capacity of raw water storage to mitigate them.
8	Summer - constant abstraction(350 Ml/d) in Parteen Basin **(Option C)**	This scenario simulated the hydrodynamic regime in Lough Derg during summer flow conditions with constant abstraction located in Parteen Basin. This scenario had been investigated as Option C during the SEA process.	No prolongation of residence times anywhere in Lough Derg. Intake in Parteen Basin would slightly reduce(improve) existing baseline residence time in the Basin and in the section north of Killaloe
9	Scenario Nine: Summer (450 Mld:50 Ml/d) variable abstraction in northeast Lough Derg	This scenario simulated the hydrodynamic regime in Lough Derg during summers flow conditions with a more prolonged variable abstraction located in the north eastern corner of Lough Derg. This scenario would be associated with a 50% increase in the volume of the raw water storage at Garryhinch.	Changing to a variable abstraction regime of 450 Ml/d over 9 months, and 50 Ml/d over 3 months, with larger raw water storage does not produce residence time improvements significantly different from Scenario 7. Duration of the drought in 1995 would still bring about local residence time impacts in the southern section of the lake, even with an increased balancing storage volume.
10	Summer – (410 Mld:50 Ml/d) variable abstraction in Youghal Bay	This scenario simulated the hydrodynamic regime in Lough Derg during summers flow conditions with a variable abstraction, but located in Youghal Bay.	Changing the point of abstraction from Slevoir Bay in norther east Lough Derg to Youghal Bay does not bring about a significant difference from Scenario 7 conditions

Report Structure

Section 2 of the Modelling Report details the model build, the manner in which boundary conditions were defined, the build-up of river flows from the main Shannon and fifteen smaller catchments draining directly to Lough Derg, and the necessary modifications to the boundary conditions which were required to account for evaporation effects and to bring the model into agreement with water levels recorded in the 1994/1995 period.

The approach to quantifying Residence Time is set out in Section 3, and is based on the Flushing Time method. This assumes a uniform distribution of a conservative virtual 'tracer' throughout the water body, and it then examines how the modelled concentration of that tracer varies with time, as inflows from the rivers (assumed to be at zero concentration of that virtual tracer) dilute it.

1.1.1 Model Scenarios - Winter Conditions

Scenario 1
In modelling the Winter Baseline (with no abstraction) condition, the model was first brought to equilibrium over the mid December 1994 –mid January 1995 period, and then run for the period from mid-January to mid-February 1995, with results as per Figure 19 of the First Pass Model Report.

With winter flows, the flushing times are short, as would be expected, less than 10 days in the main body of the upper lake, with more extended values of the order of 20 days in the innermost bays.

Scenarios 2, 3 and 4
Scenarios 2, 3 and 4 examine constant and variable abstraction in the north east of Lough Derg, and constant abstraction at Parteen Basin respectively. While the absolute values of residence time are shown visually in Figures 20, 21 and 22, the differences between these diagrams and the baseline (no abstraction) position is more relevant, and these can be seen in Figures 27, 28 and 29 respectively. The effects in wintertime, of constant or variable abstraction in the north east of Lough Derg, would be confined within Slevoir Bay, and would be minor, reflecting the small absolute value of the abstraction, compared to the wintertime Shannon flows through the system.

1.1.2 Model Scenarios - Summer Conditions

Scenario 5
In modelling the Summer Baseline (with no abstraction) condition, the model was first brought to equilibrium over the mid-March 1995 –mid-April 1995 period, and then run for the period from mid-April to 31st October 1995, a 215 day period, with results as shown in Figure 23 of the Report.

With late spring and summer flows, the flushing times are longer than with winter conditions, and significantly so in very dry conditions experienced in 1995, again as would be expected.

It is important to understand the dynamics taking place (Figure 23), and the baseline position where no water abstraction is applied, as it defines the baseline natural condition at present. The late spring hydrograph from mid-April continues to bring substantial inflows from the Shannon into the upper lake at Portumna. This inflow is capable of turning over the northern end of the water body with short residence times. However, as the summer proceeds, the falling hydrograph towards much lower inflows means that the onward displacement of the water body north of Killaloe and in the mid-lobes of Lough Derg (Scarriff Bay to Youghal Bay) towards Parteen Basin is slowed. There are elevated residence times in the southern end of the Lough, in the region of 180-210 days, with due regard to the important points mentioned on later model refinement with survey data, outlined in '*Issues with the Preliminary Model Results*' below. It is against this complex summer baseline position that the following scenarios dealing with abstraction must be considered.

Scenarios 6, 7 and 8
Scenarios 6, 7 and 8 examine constant and variable abstraction in the north east of Lough Derg, and constant abstraction at Parteen Basin respectively.

Again the absolute values of residence time are shown visually in Figures 24, 25 and 26, but it is the differences between these diagrams and the baseline (no water abstraction) position which is more relevant, and can be seen in Figures 30, 31 and 32 respectively.

A constant abstraction in Slevoir Bay (Scenario 6) would result in some local reduction in residence time in the bay itself (Figure 30), as water would be drawn there to the water supply intake. However, the reduction in flow passing through the lake, which arises because of the abstraction, is felt to the greatest extent in the southern end of the lake. Residence time is locally elevated in the east-west central lobes at Youghal Bay, but more significantly in the southern approaches to Killaloe, where increases up to 42 days at maximum are indicated. It should also be noted that the predicted increase in residence time is greatest where the natural summer background residence time in 1995 already exceeds the mean overall value to the greatest extent.

A variable abstraction in Slevoir Bay (Scenario 7) would still result in some local reduction in residence time in the bay itself (Figure 31), as water would be drawn there to the water supply intake. However, the incremental improvement in residence time shown between Figure 31 and Figure 30 is very small. The provision of two months raw water storage, intended to reduce abstraction from the lake in the two driest months of the summer, would not have sufficient volume to offset the prolonged low flows in the summer of 1995. At two months storage volume, it would not prevent reduction in flow passing through the lake at other times, which would continue to be felt most in the southern end of the lake, where again residence time is locally elevated in the east-west central lobes at Youghal Bay, and significantly in the southern approaches to Killaloe, where increases up to 42 days at maximum are still to be expected, even with curtailed abstraction facilitated by two months raw water storage.

There is little difference between Figure 31 for variable abstraction, and Figure 30 for constant abstraction, and the predicted increase in residence time continues to be greatest where the natural summer background residence time in 1995 already exceeds the mean overall value to the greatest extent.

Scenario 9 - *Considering larger raw water storage*
Scenario 9 was developed to test whether a larger raw water storage, up to three months in volume, could offset the effects of a more prolonged drought, such as 1995, where the impacts of prolonged low flows on Lough Derg 'outlast' the mitigating capacity of a two-month storage associated with Garryhinch. In the case of Scenario 9, a variable abstraction of 450 Ml/d for nine months, with 50 Ml/d for three months was modelled.

For the purposes of modelling this scenario, the timing of a curtailed discharge, using a finite 3 month storage volume, was positioned in the most beneficial part of the drought hydrograph, in 1995, and importantly, this can be done in hindsight which enables optimisation of storage use.

This commences raw water drafts from a three-month storage, at precisely the right starting date, in hindsight. It ends the draft from storage, at a time when recovery is evident, again in hindsight, in 1995 conditions. However, an operator of such a storage facility could only work on operating rules, looking forward in time. Under similar conditions recurring, it would be necessary to develop rules on when to commence abstraction from storage, without fore-knowledge of the duration or severity of the drought.

No *a priori* rule can hope to do better than have the storage reach just full, on the date it would be necessary to commence to draw from it. It is not possible to do better than have the full storage just when it is needed, and have a recovery under way in Lough Derg when it has just emptied. All *a priori* rules are attempts to be as efficient as possible, constrained by foresight, but none can do better in a given year than best fit, by hindsight, in that year, as was done in Scenario 9.

However, Figure 3 of Addendum No 1 for a three month storage is not discernibly better than Figure 31 for a two month storage. Section 7.3 of the Modelling Report , summarises the position:-

“All abstraction profiles (constant, 410:50 variable, and 450:50 variable) from the northeast of Lough Derg show significant increases in flushing times (maximum 42 days increase) in the middle and southern regions of the waterbody. The difference in impacts of the three abstraction regimes is visually indiscernible spatially.”

Scenario 10 *Changed point of abstraction*
Scenario 10 examines the changes which would accompany a variable abstraction at Youghal Bay, midway down the eastern shoreline of Lough Derg, in comparison with conditions already presented for abstraction at Slevoir Bay.

It is clear from Scenario 10 Figure 2, that the change of abstraction location from Slevoir Bay to Youghal Bay, does not significantly improve the residence time impacts in the area north of Killaloe, and this would also be the case with any other abstraction point between Youghal Bay and Slevoir Bay.

1.1.3 Issues with the Preliminary Model Results

The definitive position with modelling can only be arrived at with a full season of calibrating data, which is not available yet but will be available when the Final Options Appraisal Report is published in April 2016.

Low flows from the Shannon into Lough Derg at Portumna, are associated with very low current speeds, of the order of 10mm/s, and very small changes in water level, of the order of 5mm, can have significant effects on the calculation of flows. Wind effects on the lake, depending on strength and direction, can bring changes in water level across the lake surface, over short time periods. This is why the water quality survey contract has included accurate acoustic Doppler measurement of flows, and meteorological monitoring in the survey period. .

MARCON COMPUTATIONS INTERNATIONAL

Advanced Engineering and Environmental Solutions

Water Supply Project – Eastern and Midlands Region

DA2: Hydrodynamic and Water Quality Modelling

DA2.2: First Pass Modelling Report

Document No: **G201301_doc002_06.pdf**
Status: **Final**
Date: **02 – 10 - 2015**

Table of Contents

Addendum I: Scenario Nine: Summer - 450:50 variable abstraction in northeast Lough Derg

1. INTRODUCTION

As part of the Water Supply Project – Eastern and Midlands Region (WSP) project, MarCon Computations International were tasked with the Stage Deliverables Abstraction (DA) work package DA2: Hydrodynamic and Water Quality Model of Lough Derg.

This report details the work undertaken to fulfil the requirements of DA2. 2, the development of a 'First Pass' model based on existing available bathymetry and hydraulic data. The objective was to assess the existing flushing characteristics of Lough Derg and Parteen Basin and examine abstraction options considered in the original SEA process to determine if any changes in the flushing characteristics could be discerned.

The flushing characteristics of Lough Derg and Parteen Basin were assessed for the October 1994 – December 1995 time period. This period was chosen as it encompassed periods both of extreme high flows in the Shannon system (January 1995) and extreme low flows (August/September 1995). The 1994/1995 time period was also used as a reference year during the SEA process for calibration of models and options appraisal.

The MIKE 3 Flexible Mesh modelling approach has been adopted as the modelling system for the Lough Derg and Parteen Basin model.

2. MODEL DEVELOPMENT

This section describes the processes involved in developing the three dimensional hydrodynamic and solute transport model of Lough Derg and Parteen Basin. The model domain extends from Portumna Bridge in the north to Parteen Weir / Ardnacrusha Headrace in the south.

2.1. Bathymetry

The bathymetry of the study area was generated from three separate datasets; United Kingdom Hydrographic Office Admiralty Chart No. 5080 (1839-discontinued), ESB Parteen Basin cross section survey (1988), and Inland Waterways Association of Ireland's Charts Special Interest Group (CSIG) bathymetry soundings for Lough Derg (2013).

Differences between the UKHO Admiralty Chart (1839) and the CSIG bathymetry (2013) at coincident locations were analysed. The mean difference across the 4643 coincident locations was found to be +0.6m, with a standard deviation of 2.37m. Figure 1 presents the histogram plot of the analysis undertaken, with the number of occurrences on the Y-axis, and difference in depths on the X-axis. This agreement between both datasets can be considered to be quite good when accounting for the 174 year interval between surveys.

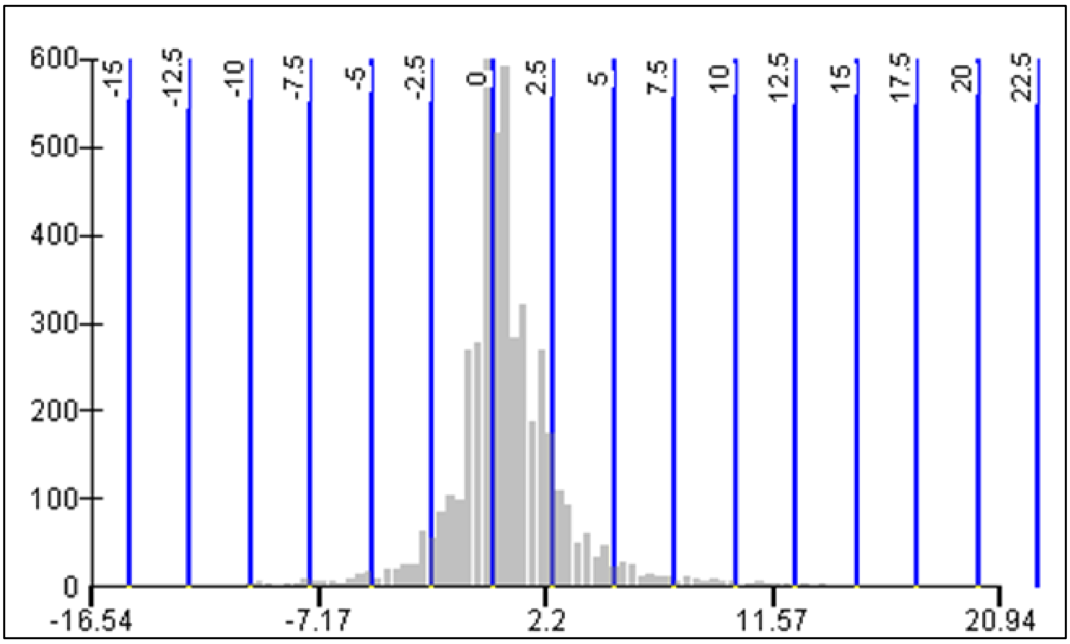


Figure 1: Histogram of differences between UKHO (1839) and CISG (2013) bathymetry.

There were insufficient coincident data points between the ESB cross sections of Parteen Basin (1988) and the CSIG (2013) dataset to warrant statistical analysis.

All three datasets were converted to Irish Transverse Mercator projection, referenced to a common datum at Killaloe, and interpolated to produce a seamless bathymetric map for Lough Derg and Parteen Basin at 100m resolution, as presented in Figure 2. The vertical datum used throughout this report is Ordnance Datum Poolbeg, the datum used by ESB for managing water levels on the Shannon system.

The resulting bathymetric dataset and the EPA's Water Framework Directive GIS shapefiles of Lough Derg and Parteen Basin were loaded into the MIKE 3 Flexible Mesh Generator. The extent of the shoreline was digitised at 250m intervals, creating the flexible mesh vertices for the computational grid.

The computational mesh was then generated by the MIKE 3 software, as presented in Figure 3. The narrow section of the water body at Killaloe/Ballina, joining Lough Derg to Parteen Basin was defined using a regular curvilinear grid and embedded within the flexible mesh, detail of which is presented in Figure 4.

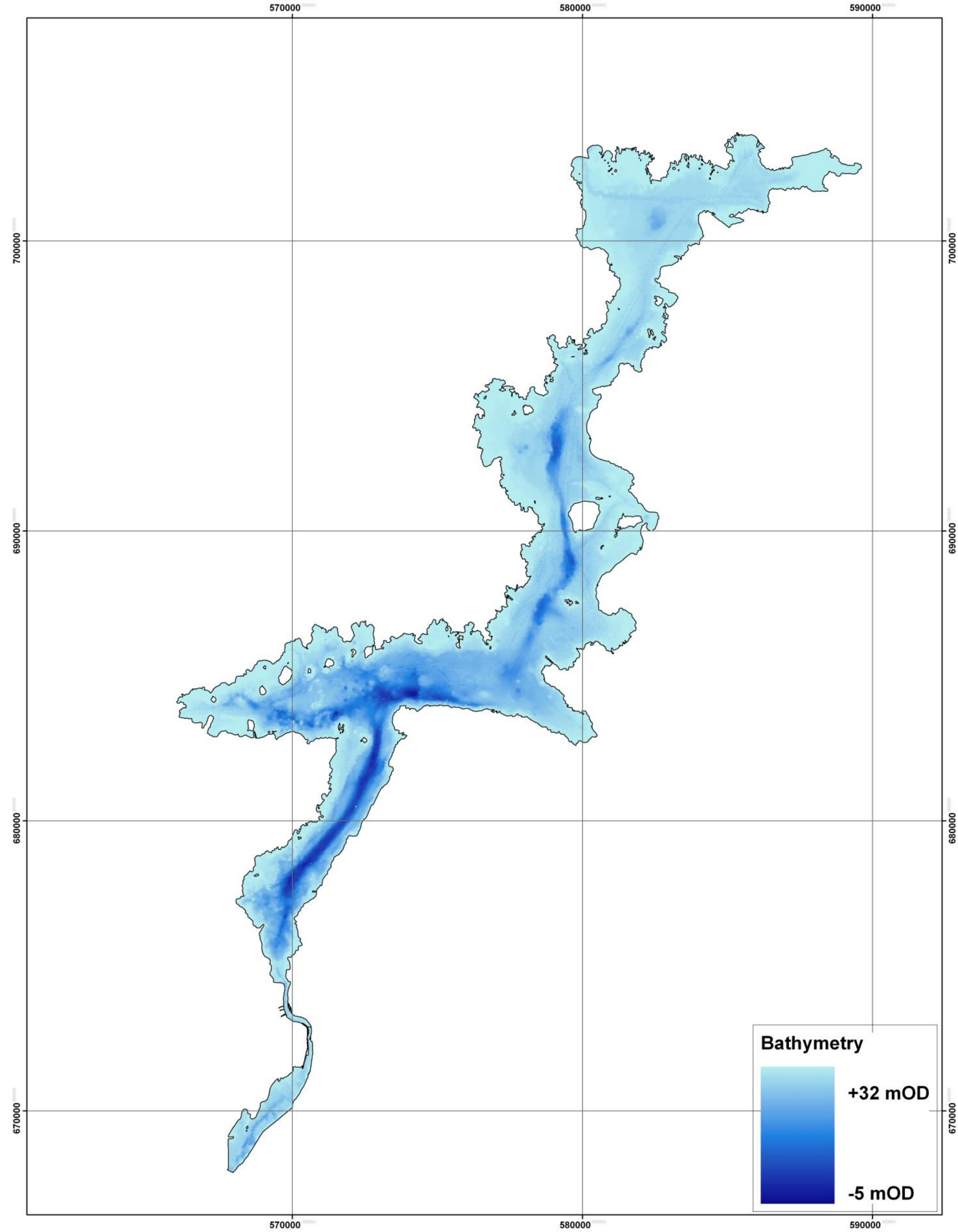


Figure 2: Lough Derg and Parteen Basin bathymetry

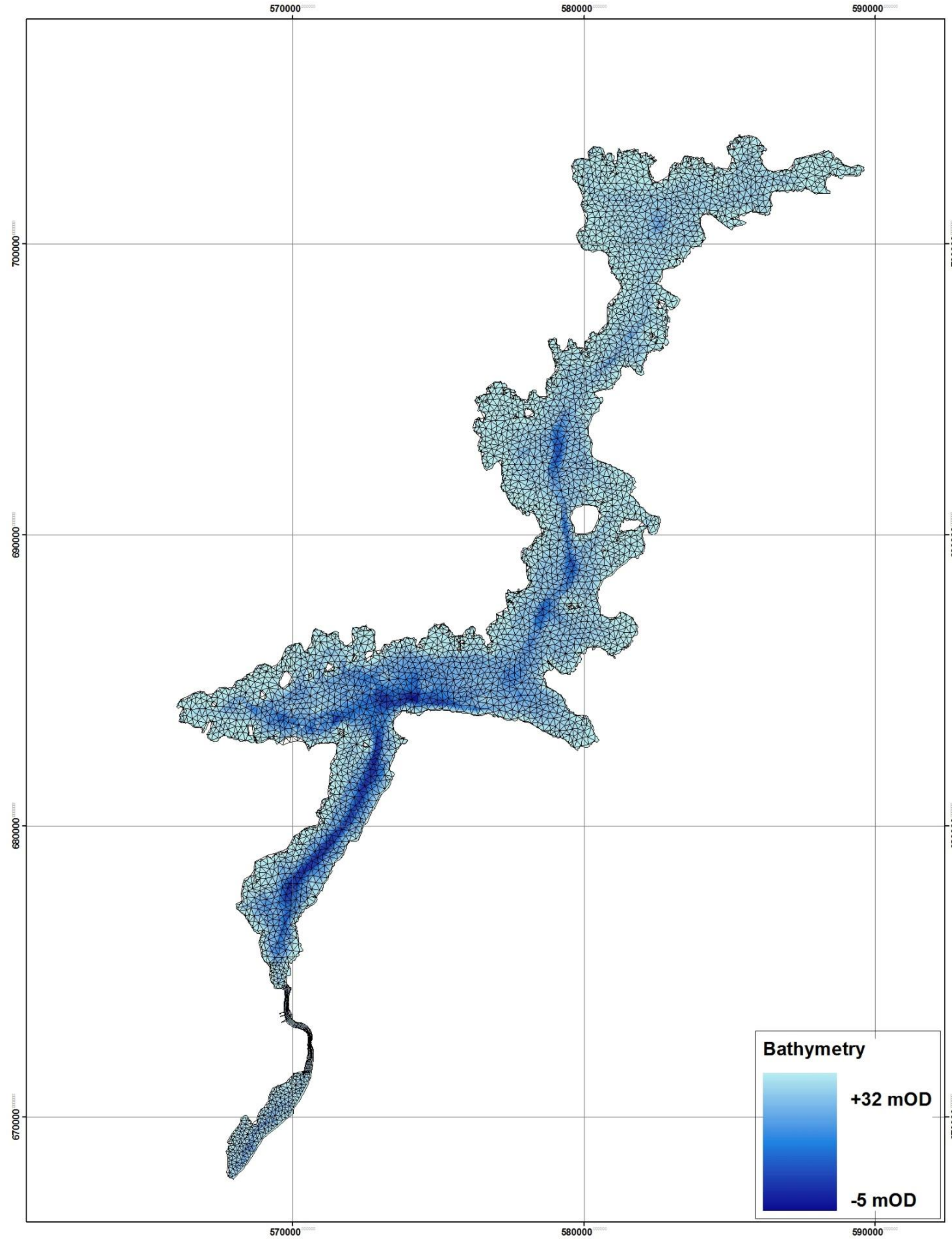


Figure 3: Lough Derg and Parteen Basin model mesh and bathymetry

/

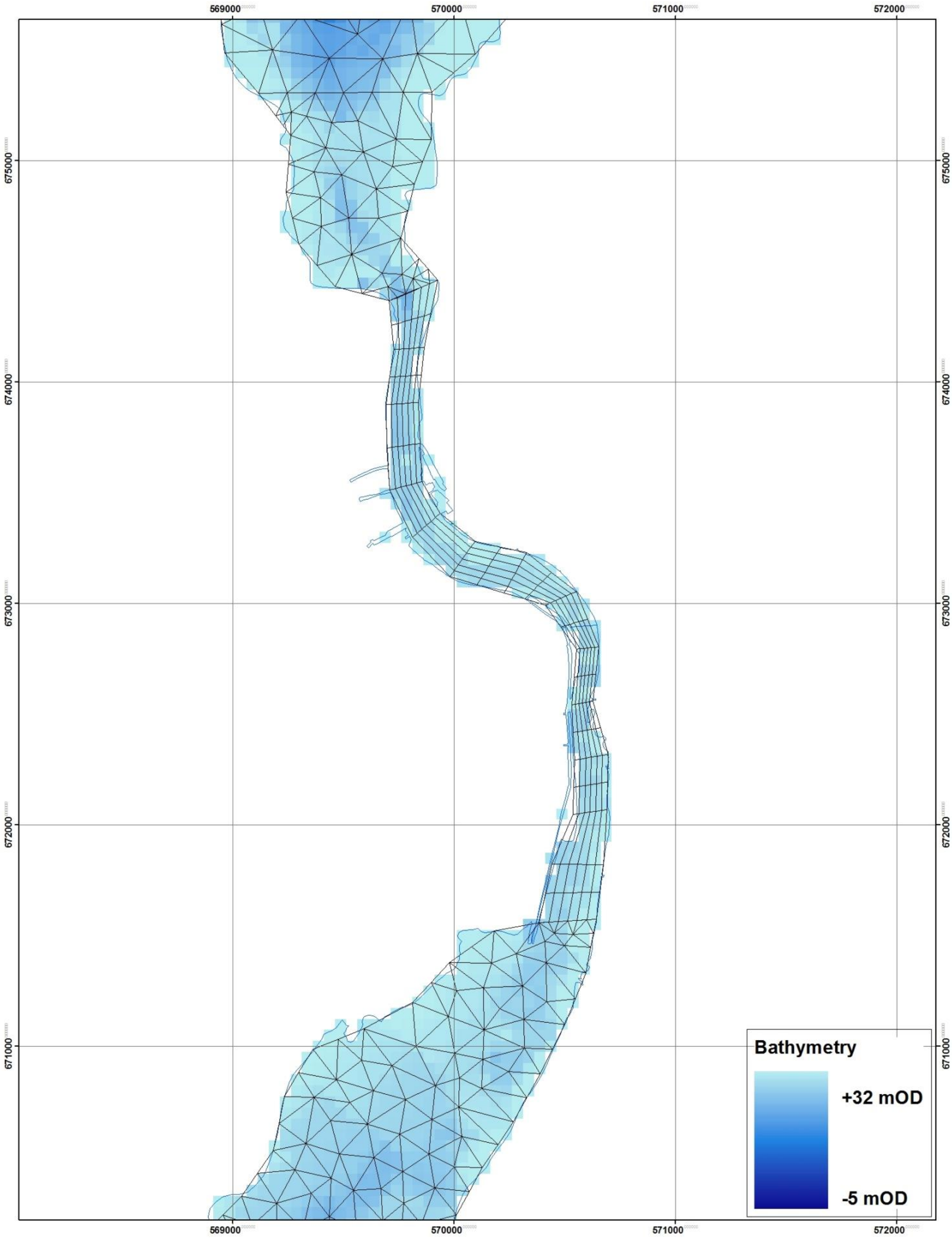


Figure 4: Detail of Lough Derg and Parteen Basin model mesh at Killaloe / Ballina.

2.2. Boundary Locations

A standard land/water interface boundary was defined to delineate the extent of the water body. The main in-flowing boundary specified to the model was the River Shannon, entering Lough Derg through Portumna Bridge. One out-flowing boundary was specified in Parteen Basin representing the combined outflow of Parteen Weir and Headrace Canal. Water level boundary conditions were also specified at both Portumna Bridge and Parteen Weir/Ardnacrusha Headrace.

Nineteen additional inflowing boundaries were specified, representing the rivers and streams draining the catchments surrounding Lough Derg and Parteen Basin. The locations of the nineteen river catchments are detailed in Figure 6. Diffuse run-off associated with the undrained catchments immediately surrounding the lake shore were not included in this current First Pass model.

No atmospheric or meteorological boundary conditions were specified to the model. Thus the model does not account for thermal stratification due to solar radiation effects, wind induced circulation patterns due to variations in wind speed and direction, nor effects of evaporation or precipitation.

2.3. Boundary Definitions

2.3.1. Water Levels

Water levels at both the upstream and downstream boundaries of the model study area were defined to the model from daily water levels recorded by ESB and made available to the project and are presented in Figure 5.

2.3.2. River Flows

During the SEA process a MIKE 11 model of the River Shannon system from Tarmonbarry to Killaloe/Ballina was developed and calibrated. This model was made available to the present study. The 1994/1995 time period chosen for the present study was one of the time periods used to calibrate the SEA MIKE 11 model. The main inflowing river boundary condition for the present study, the River Shannon at Portumna, was extracted from the calibrated MIKE 11 model at hourly intervals.

Four of the nineteen additional inflowing rivers had MIKE NAM catchment models developed and calibrated during the SEA process. Those catchments were; Ballyfinboy, Nenagh, Graney, and

Kilcrow. The river flows from those catchments for the 1994/1995 period were extracted at daily intervals from the respective calibrated NAM models.

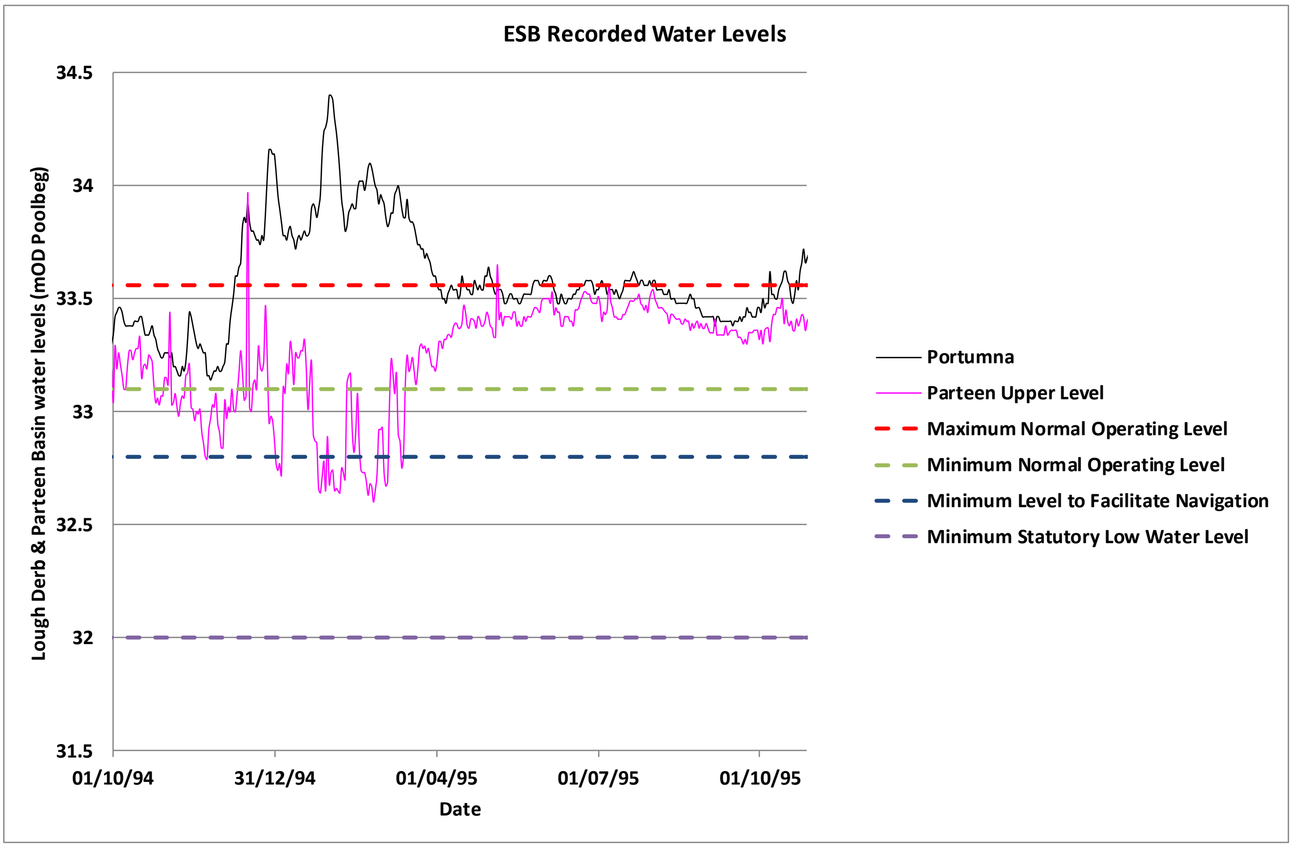


Figure 5: Recorded water levels at Portumna and Parteen Weir for period of present study

With the exception of the Kilmastulla catchment draining to Parteen Basin, none of the other fifteen catchments have established hydrometric stations. At the present stage of the WSP project, hydrological models have not been developed for these catchments.

Thus the river flows for the 1994/1995 period for the fifteen catchments draining to Lough Derg / Parteen Basin were calculated using gauged area transposition from adjoining / adjacent gauged catchments. The hydrographs for all inflows are presented in Figure 7. The hydrographs for the nineteen smaller river boundaries are presented separately in Figure 8 for clarity.

The River Shannon at Portumna, calculated from the previously developed MIKE 11 model accounted for 82.1% of the inflows to Lough Derg during the 1994/1995 period. The four river catchments with the previously calibrated MIKE NAM models accounted for 13.2%. The other fifteen river catchments combined, for which inflows were extrapolated based on gauge area

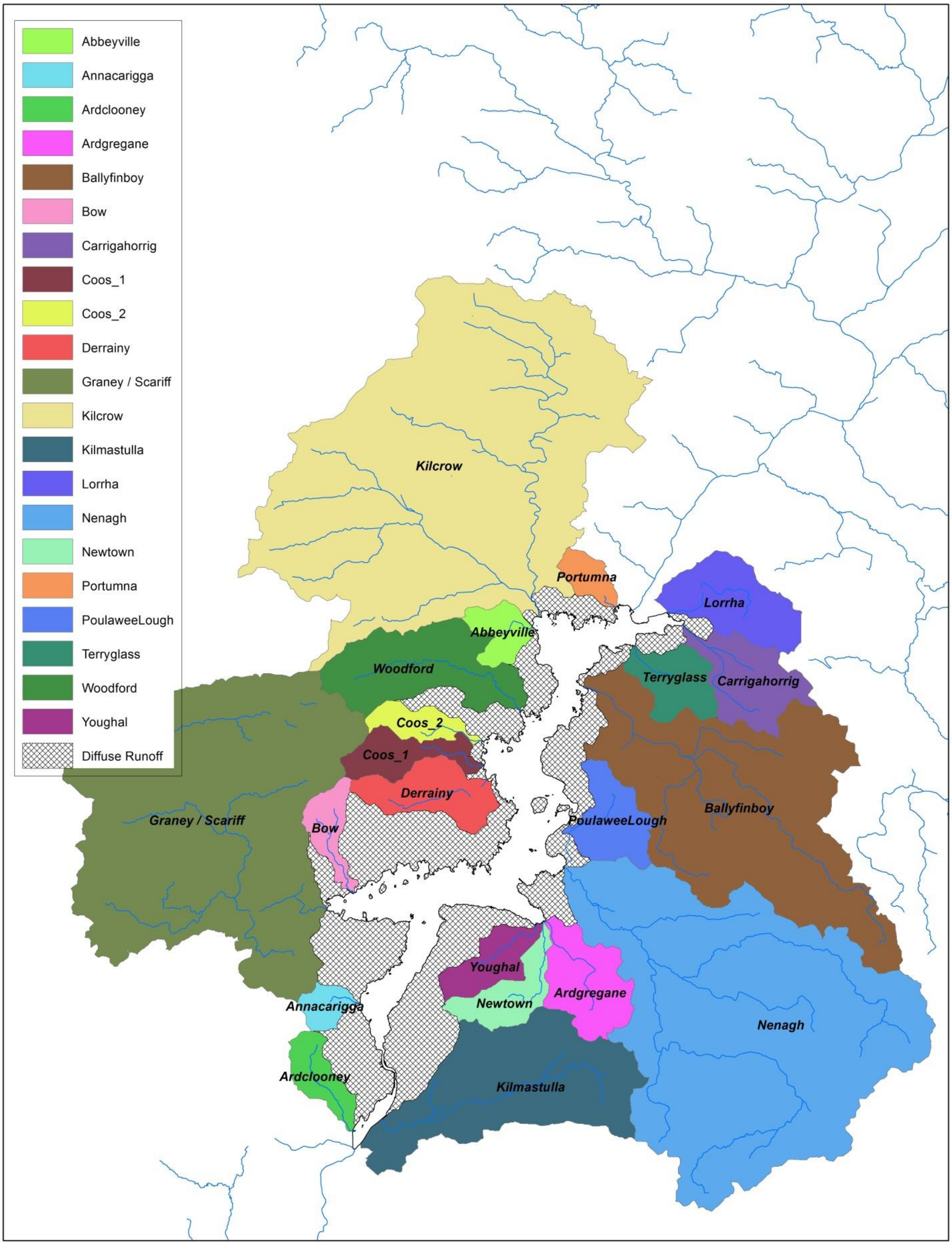


Figure 6: Locations of nineteen inflowing river catchment boundaries.

transposition, represented approximately 5% of the total inflows to Lough Derg / Parteen Basin, as shown in Figure 9.

The outflowing boundary condition represented the combined discharge down the Headrace Canal and through the sluices at Parteen Weir and was specified from average daily values provided by ESB for the 1994/1995 period. The outflow boundary was defined as the sum of the recorded daily average flow through Ardnacrusha and the calculated average daily flow through Parteen Weir.

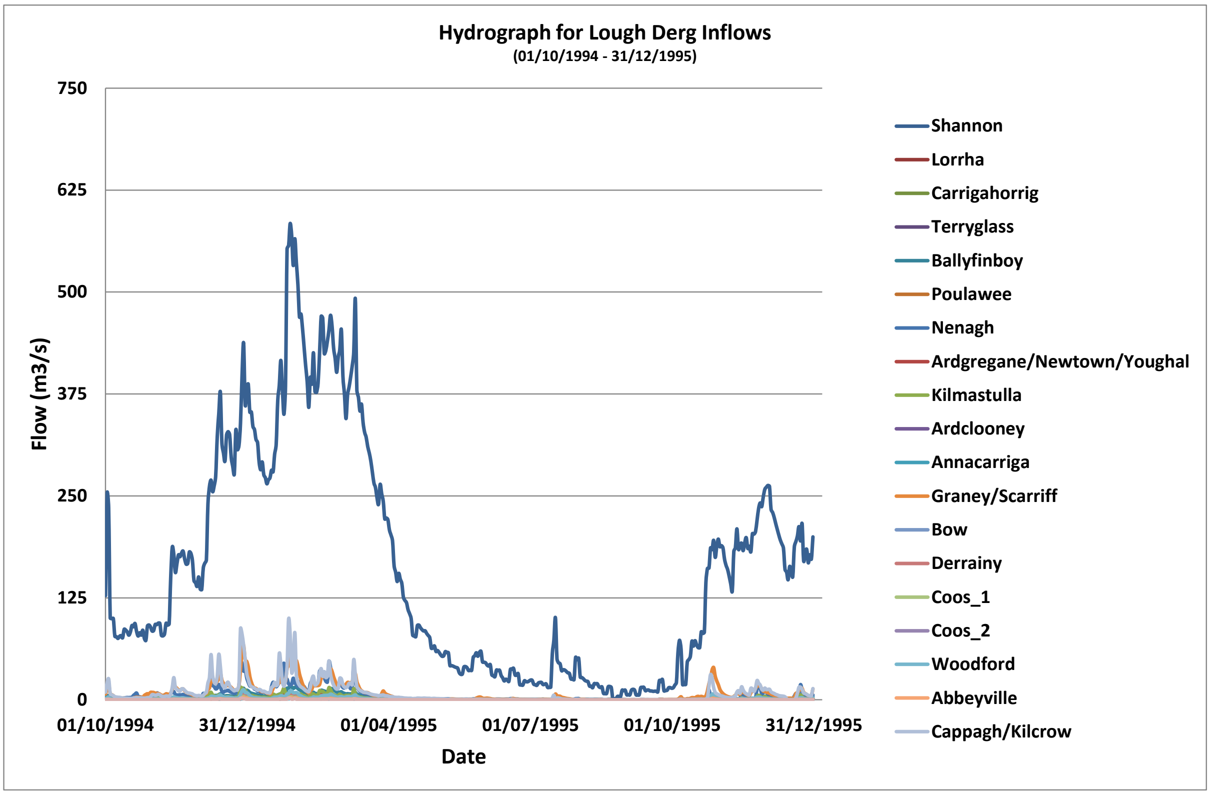


Figure 7: Hydrograph of all Lough Derg inflows (Oct 1994 – Dec 1995)

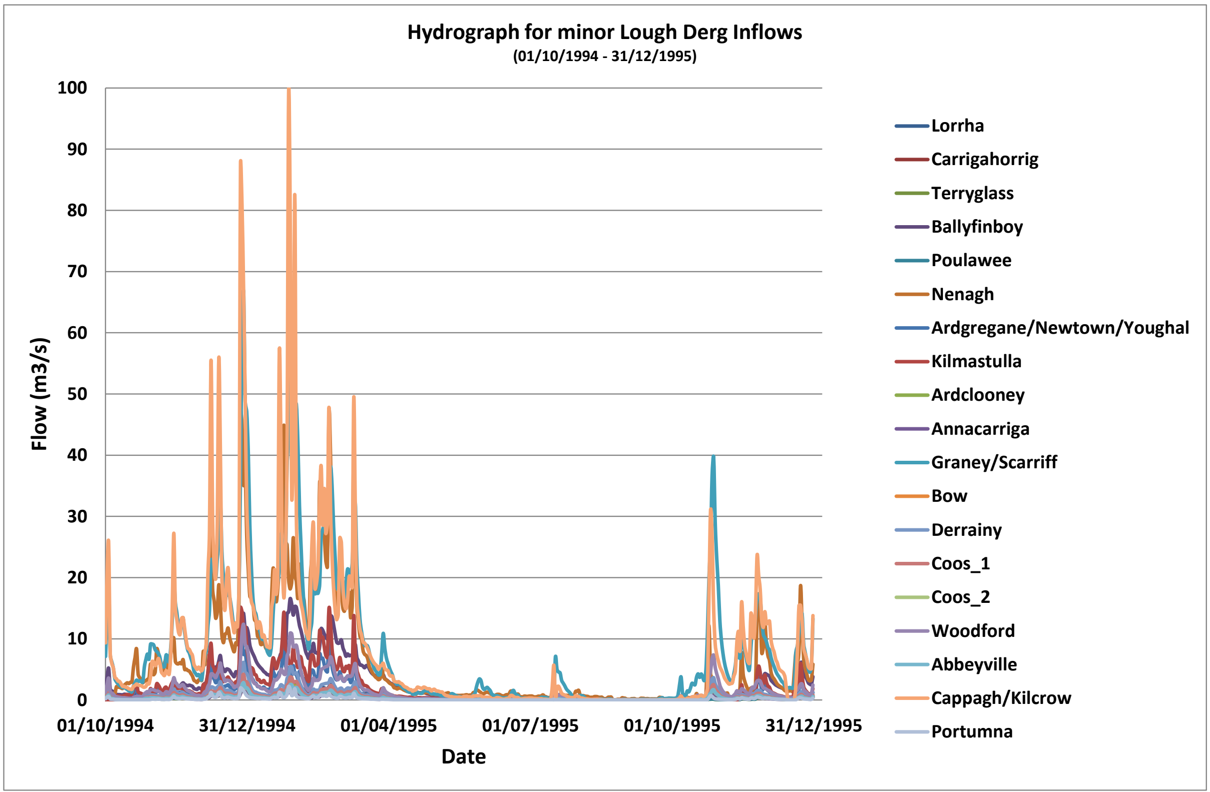


Figure 8: Hydrograph of Lough Derg inflows excluding River Shannon (Oct 1994 – Dec 1995)

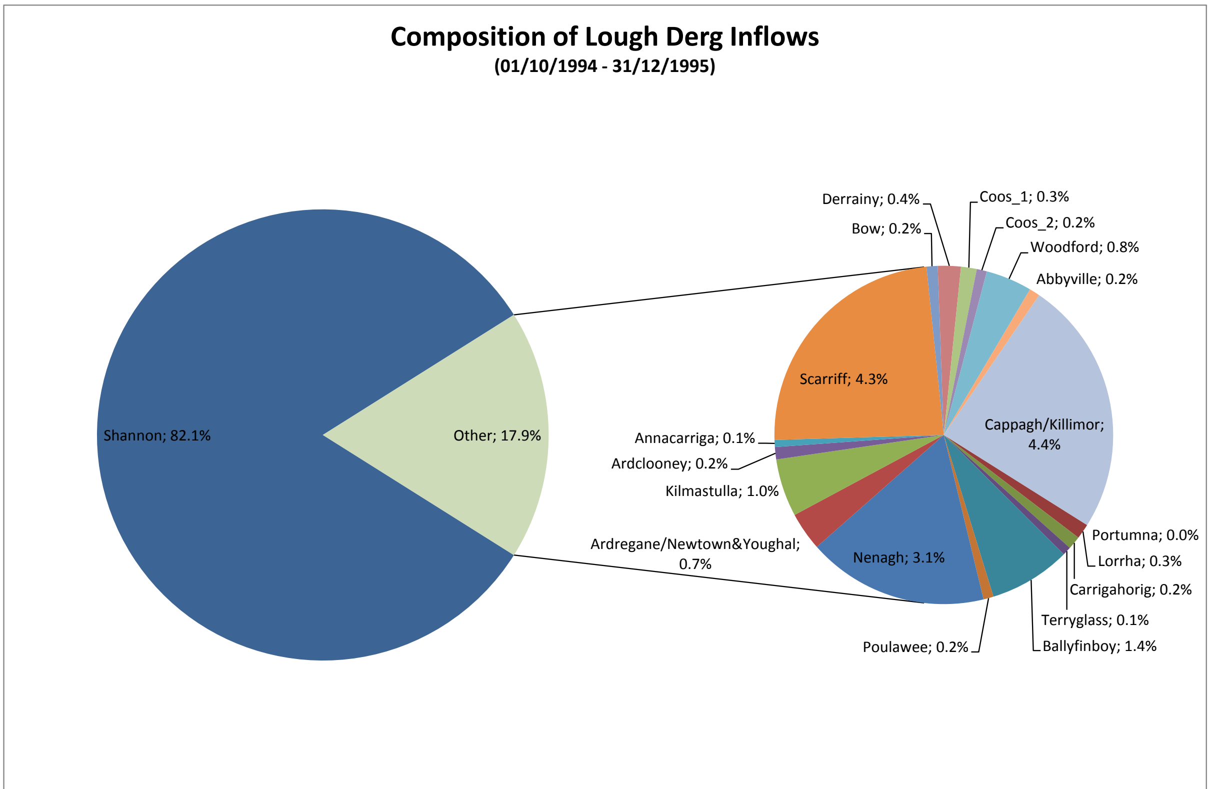


Figure 9: Composition of total Lough Derg inflows excluding diffuse inflows (Oct 1994 – Dec 1995)

2.4. Boundary Modifications

Preliminary simulations of the MIKE3 model over the 1994/1995 period identified that the model was over predicting the water surface levels in Lough Derg during the summer months when compared to recorded ESB data. This resulted from excess water in the model domain. It was determined that this over-prediction in water levels was primarily due to the exclusion of an evaporation boundary condition at the lake surface in the present 'First Pass' modelling.

To account for the change in volume of the lake water due to evaporation, recourse was made to the ESB's management strategy for the maintenance of water levels. The difference in water levels from one day to the next recorded across the Portumna, Killaloe and Parteen Weir water levels (and allowing for discharge through Parteen Weir and Ardnacrusha) produces a change in storage within Lough Derg and Parteen Basin. This daily change in storage is the balance of total inflowing waters to the lake less all discharges (incl. evaporation) over the course of a given day. Knowing the change in storage, and the discharges from the lake, it was possible to back-route the flows and calculate what the net inflow to the lake was for any given day. The ESB's recorded outflows and back-routed calculations for the Lough Derg inflows are presented in Figure 10.

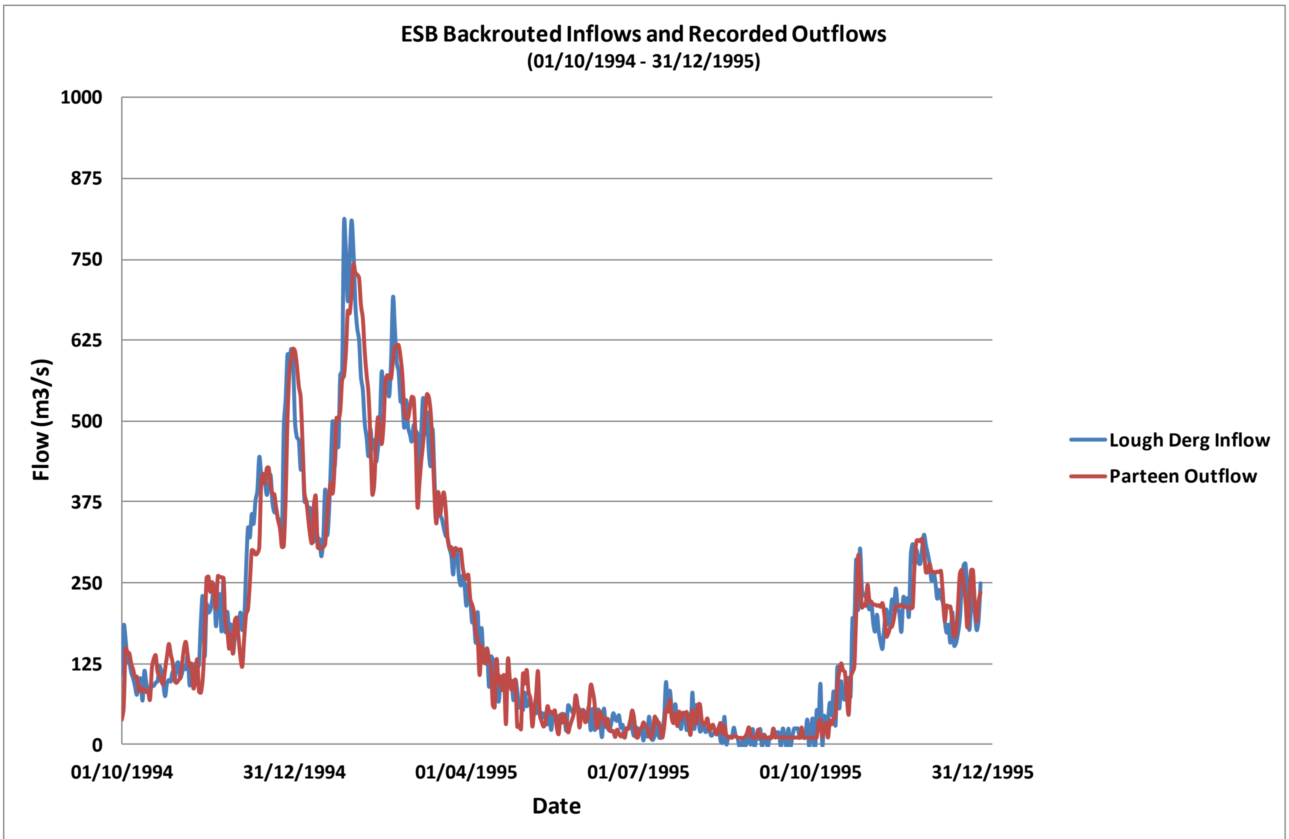


Figure 10: ESB back-routed inflows and recorded outflows.

The ESB's back-routed inflows to Lough Derg were compared against the total inflows modelled for the present study. This comparison was done for instantaneous inflows, as presented in Figure 11, and cumulative inflows as presented in Figure 12.

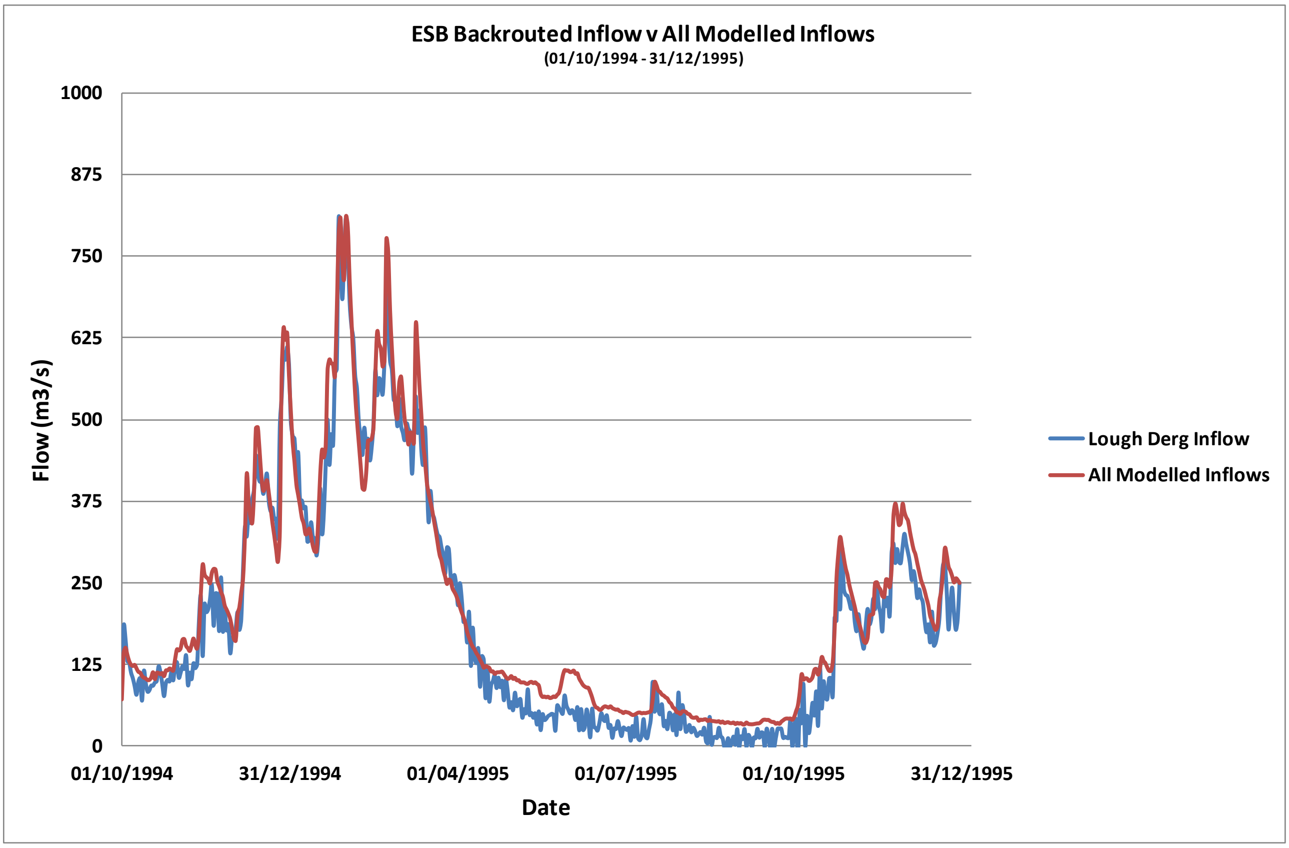


Figure 11: ESB Backrouted Inflows and All Modelled Inflows

The modelled inflows show relatively good agreement against the ESB's back-routed calculations during winter 1994-1995 and spring 1995, but the modelled inflows are appreciably greater than the calculated inflows during the April – October 1995 period as shown above.

This increase of flow through the lake during the summer and autumn seasons was attributed to the exclusion of the evaporation boundary layer at the lake's surface (as mentioned previously), rather than a systemic error in the modelling of the main Shannon inflow/outflow and the nineteen smaller river inflows.

This same issue was encountered during the SEA process when modelling the impacts of proposed abstraction profiles on the flushing times for Lough Derg. The approach used in the SEA modelling study was adopted for the present study and detailed below.

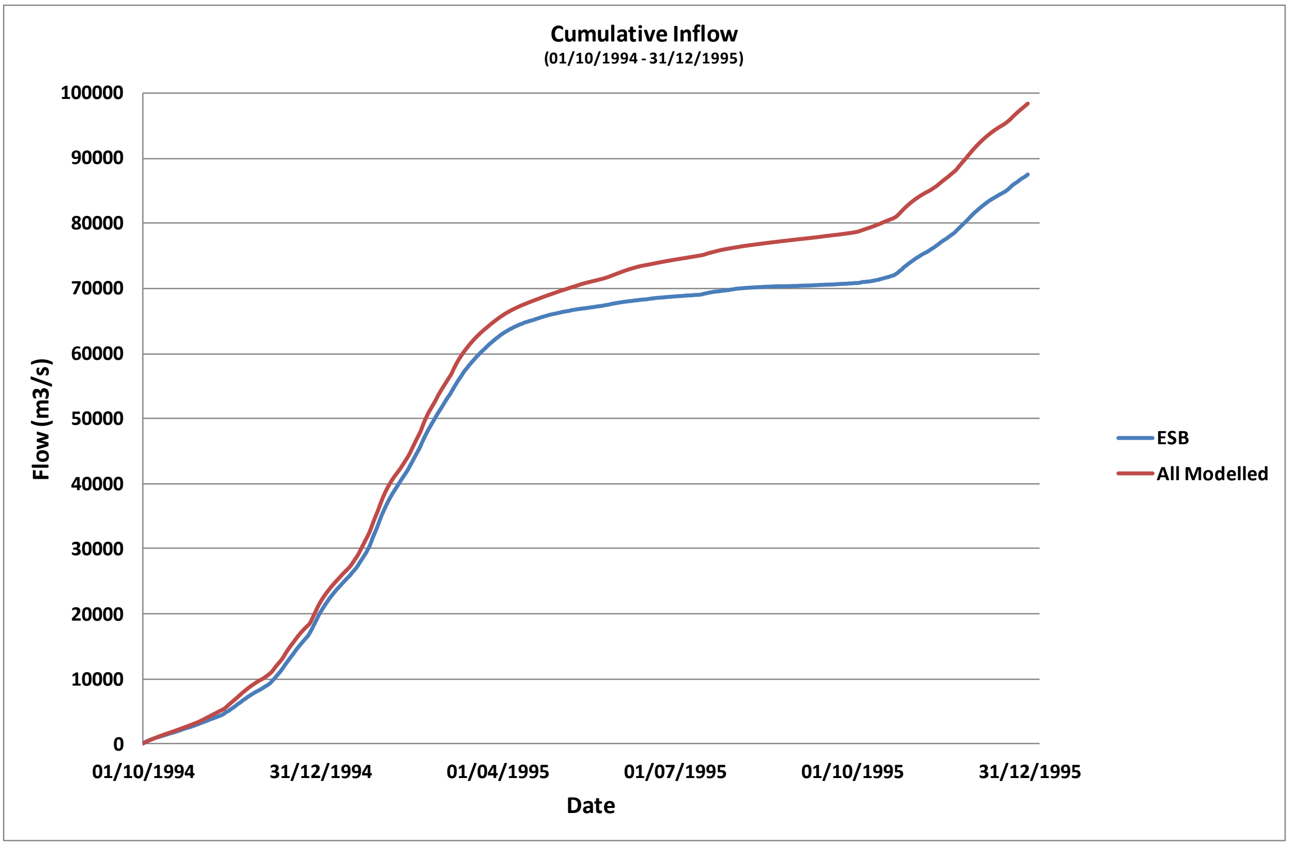


Figure 12: Cumulative ESB backrouted Inflows and Cumulative Modelled Inflows.

All inflows to Lough Derg were adjusted through the application of a correction factor, derived from the ESB's back-routed calculation of daily average flows into Lough Derg, which account for the effects of evaporation on the water body.

The correction factor applied an average weekly modification to the modelled inflows from 1st April 1995 to 31st October 1995. The effect of employing the correction factors is presented in Figure 13, showing all modelled inflows and corrected modelled inflows against the ESB's back-routed calculated inflow.

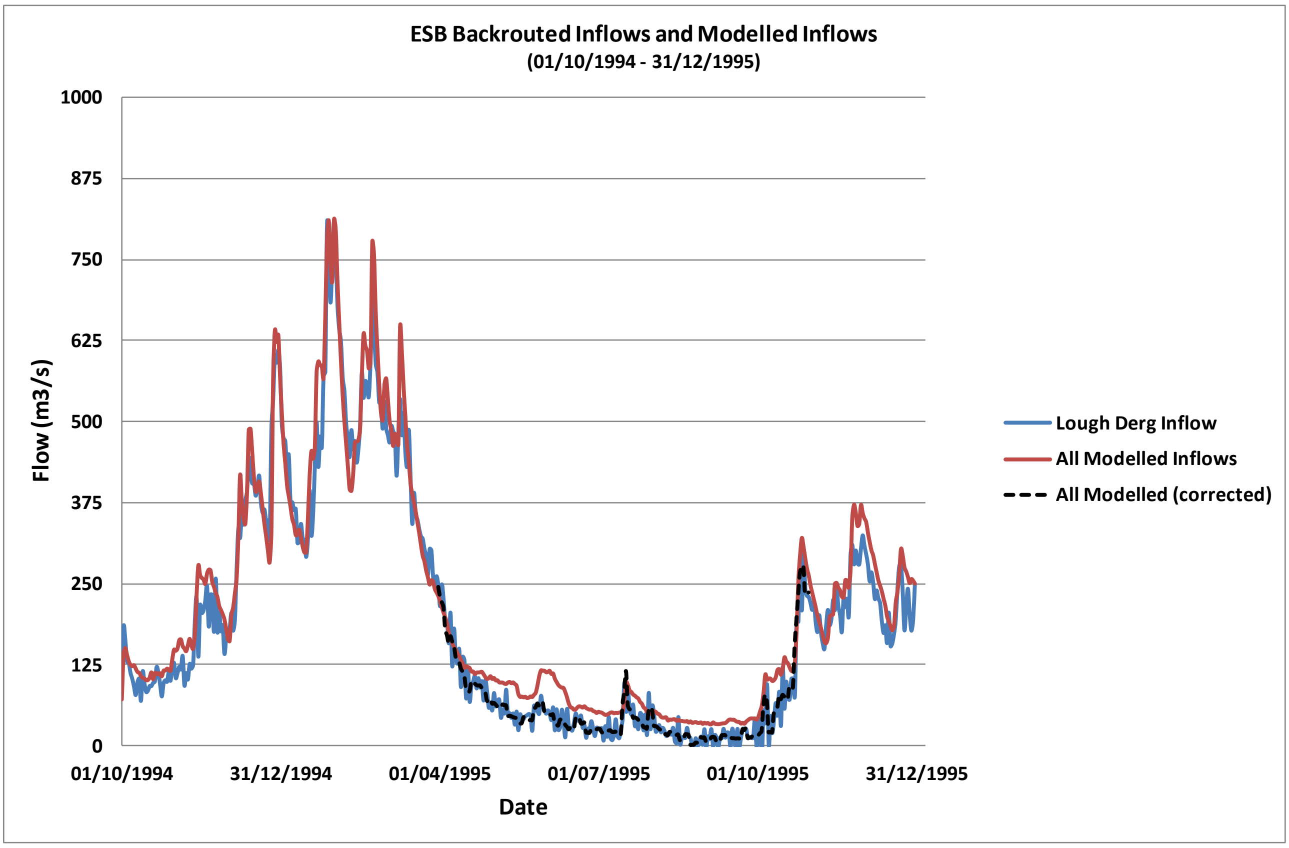


Figure 13: ESB back-routed inflows, all modelled inflows and corrected modelled inflows

3. FLUSHING TIME METHOD

Many definitions of the term flushing time exist in the literature and it is often used interchangeably with other characteristics describing the water exchange processes, predominantly with the term residence time. The definition of flushing time used in this study is described as follows.

Considering that the mass of material contained within a certain area in a reservoir at time t=0 to be M_0, and the amount of the material which still remains in that area of the reservoir at time t to be $M_{(t)}$, the flushing time distribution function, ψ(t), of the material can be defined as:

$$\varphi(t) = -\frac{1}{M_o}\frac{dM(t)}{dt} \quad (1)$$

$M_{(t)}$ then is the amount of the material whose flushing time is larger than t. Thus, the average flushing time, T_f, is given by:

$$T_f = \int_0^{\infty} t\varphi(t)\,dt \quad (2)$$

Introducing a remnant function, r(t), such that:

$$r(t) = \frac{M(t)}{M_o} \qquad (3)$$

equation (2) can be re-written to show that:

$$T_f = \int_0^\infty r(t)dt \qquad (4)$$

For a reservoir of constant volume, the mass of the material in equations (1) and (3) can be replaced by its concentration. It has also been shown in literature that in a well-mixed body of water T_f equals the e-folding time, T_e, which is the time required to reduce the initial mass of an instantaneous injection of a tracer by a factor of e, (ie. to approximately 37% of initial concentration).

This definition of flushing time is based on detailed spatial distribution of tracer in the waterbody and on tracking temporal changes of its content, and therefore it can be easily applied in conjunction with numerical model simulations to examine spatio-temporal transport pathways in the waterbody.

To summarise, the flushing time for each computational cell in the model domain can be calculated as the time required to reduce the initial concentration of a solute to 37% of that initial value.

4. MODEL SCENARIOS

4.1. Scenario One: Winter - baseline (no abstraction)

This scenario simulated the existing hydrodynamic regime in Lough Derg during winter flow conditions.

The model was initialised from cold start conditions of zero velocity fields with an initial water surface level of 33.3m OD commensurate with recorded data.

All in-flowing and out-flowing boundaries were specified with the respective flows in accordance with the hydrographs previously presented.

The model was spun up for a 31 day period to ensure a realistic hydrodynamic regime had developed throughout the water body, from 15th Dec 1994 to 15th Jan 1995, at which point a hot-start restart file was created.

The flushing time analysis simulation was then initialised from the hot-start file on 15th Jan 1994 and executed for a 31 day period from 15th Jan 1995 to 15th Feb 1995.

An initial 100.0 mg/l concentration of conservative tracer was specified uniformly throughout the water body. All inflowing rivers were specified with a constant 0.0 mg/l concentration.

4.2. Scenario Two: Winter - constant abstraction in northeast Lough Derg

This scenario simulated the hydrodynamic regime in Lough Derg during winter flow conditions with constant abstraction located in the northeastern corner of Lough Derg at coordinates 588500E 702800N. This scenario had been investigated as Option B during the SEA process.

The abstraction was defined at a constant rate of 350 Ml/day (4.05 m^3/s). The flow through the downstream boundary at Parteen Weir / Ardnacrusha Headrace was reduced accordingly to compensate for the abstraction rate. The abstraction profile and compensated outflows through Parteen Weir / Ardnacrusha Headrace are presented in Figure 14. The compensated outflow required to offset the abstraction rate is indistinguishable from the baseline (uncompensated) outflow even when plotted using a logarithmic scale.

The model was initialised from cold start conditions of zero velocity fields with and initial water surface level of 33.3m OD commensurate with recorded data.

The model was spun up for a 31 day period to ensure a realistic hydrodynamic regime had developed throughout the water body, from 15th Dec 1994 to 15th Jan 1995, at which point a hot-start restart file was created.

The flushing time analysis simulation was then initialised from the hot-start file on 15th Jan 1994 and was executed for a 31 day period from 15th Jan 1995 to 15th Feb 1995.

An initial 100.0 mg/l concentration of conservative tracer was specified uniformly throughout the water body. All inflowing rivers were specified with a constant 0.0 mg/l concentration.

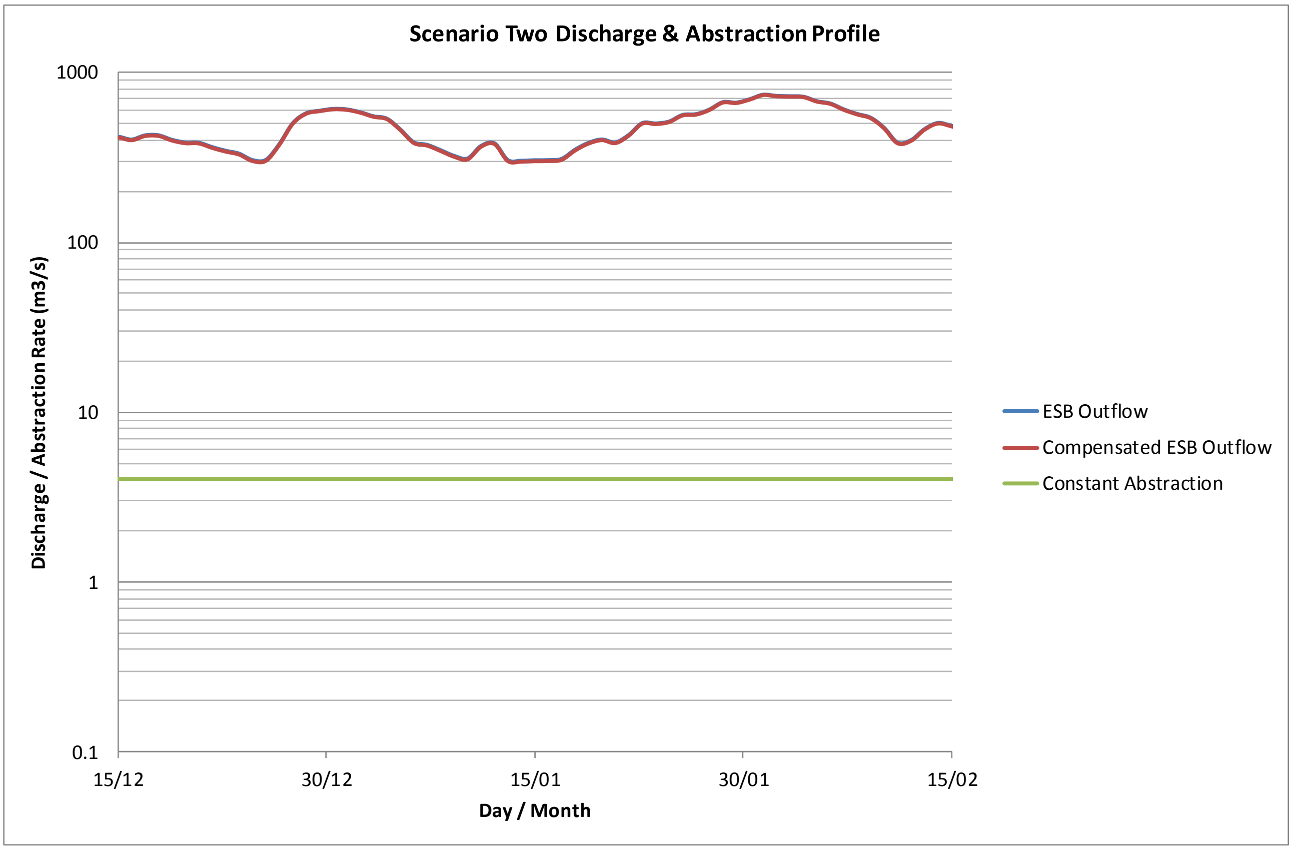


Figure 14: Scenario Two - ESB Discharge Profiles and Abstraction Profile

4.3. Scenario Three: Winter - variable abstraction in northeast Lough Derg

This scenario simulated the hydrodynamic regime in Lough Derg during winter flow conditions with variable abstraction located in the northeastern corner of Lough Derg at coordinates 588500E 702800N. This scenario is associated with raw water storage at Garryhinch in the midlands and had been investigated as Option F2 during the SEA process.

The abstraction was defined as having a variable rate of abstraction over the course of a year. For two months of the year, from 15th August to 15th October the abstraction operates at a rate of 50 Ml/day (0.579 m^3/s), for the remaining 10 months of the year the abstraction operates at a rate of 410 Ml/day (4.745 m^3/s). The flow through the downstream boundary at Parteen Weir / Ardnacrusha Headrace was reduced accordingly to compensate for the variable abstraction rate. The abstraction profile and modified combined outflow through Parteen Weir / Ardnacrusha Headrace are presented in Figure 15. The compensated outflow required to offset the abstraction rate is indistinguishable from the baseline (uncompensated) outflow even when plotted using a logarithmic scale.

The model was initialised from cold start conditions of zero velocity fields with an initial water surface level of 33.3m OD commensurate with recorded data.

The model was spun up for a 31 day period to ensure a realistic hydrodynamic regime had developed throughout the water body, from 15th Dec 1994 to 15th Jan 1995, at which point a hot-start restart file was created. The flushing time analysis simulation was then initialised from the hot-start file on 15th Jan 1994 and was executed for a 31 day period from 15th Jan 1995 to 15th Feb 1995.

An initial 100.0 mg/l concentration of conservative tracer was specified uniformly throughout the water body. All inflowing rivers were specified with a constant 0.0 mg/l concentration.

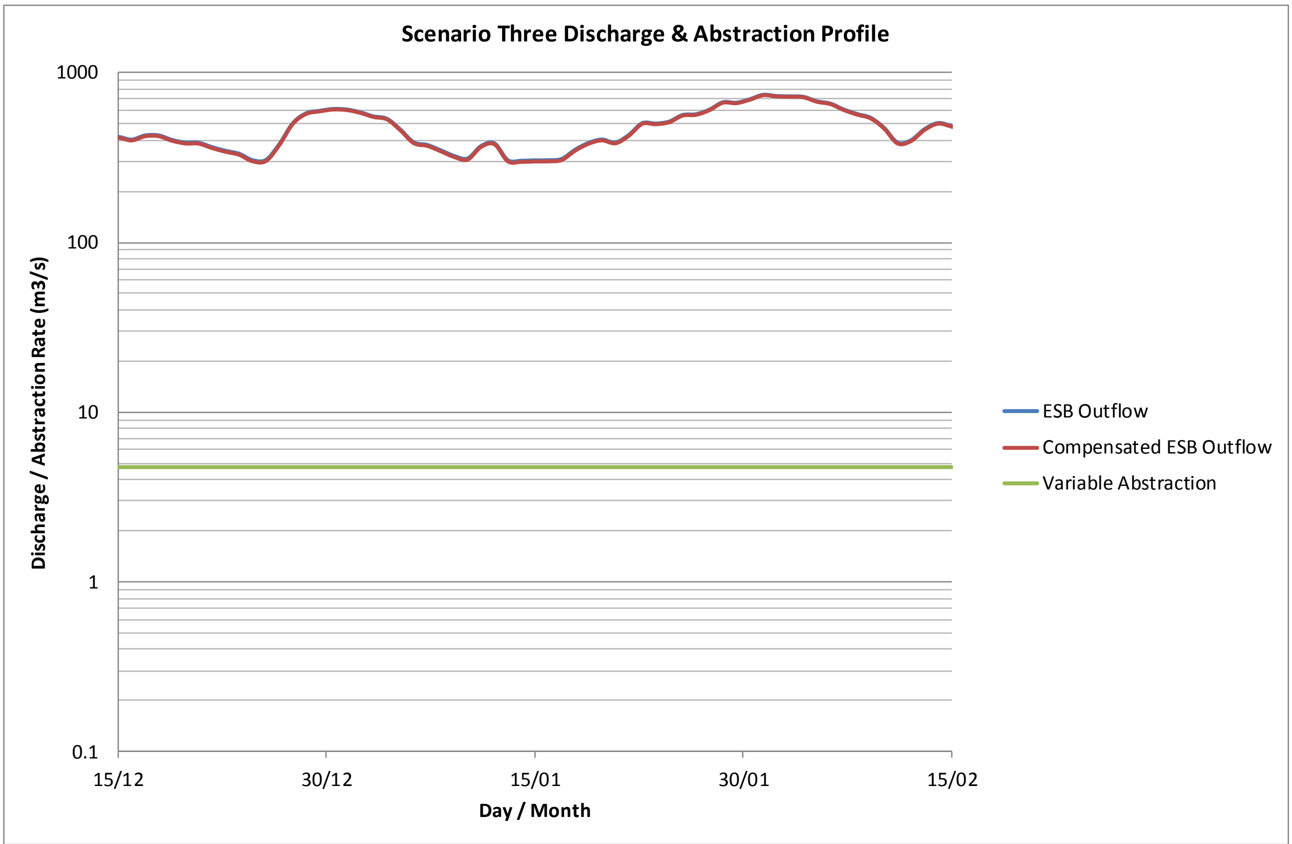


Figure 15: Scenario Three - ESB Discharge Profiles and Abstraction Profile

4.4. Scenario Four: Winter - constant abstraction in Parteen Basin

This scenario simulated the hydrodynamic regime in Lough Derg during winter flow conditions with constant abstraction located in Parteen Basin at coordinates 570000E 670800N. This scenario had been investigated as Option C during the SEA process.

The abstraction was defined at a constant rate of 350 Ml/day ($4.05m^3/s$). The flow through the downstream boundary at Parteen Weir / Ardnacrusha Headrace was reduced accordingly to compensate for the abstraction rate. The abstraction profile and compensated outflows through Parteen Weir / Ardnacrusha Headrace are presented previously in Figure 14.

The model was initialised from cold start conditions of zero velocity fields with an initial water surface level of 33.3m OD commensurate with recorded data.

The model was spun up for a 31 day period to ensure a realistic hydrodynamic regime had developed throughout the water body, from 15th Dec 1994 to 15th Jan 1995, at which point a hot-start restart file was created.

The flushing time analysis simulation was then initialised from the hot-start file on 15th Jan 1994 and was executed for a 31 day period from 15th Jan 1995 to 15th Feb 1995.

An initial 100.0 mg/l concentration of conservative tracer was specified uniformly throughout the water body. All inflowing rivers were specified with a constant 0.0 mg/l concentration.

4.5. Scenario Five: Summer - baseline (no abstraction)

This scenario simulated the existing hydrodynamic regime in Lough Derg during summer low flow conditions.

The model was initialised from cold start conditions of zero velocity fields with an initial water surface level of 33.3m OD commensurate with recorded data.

All in-flowing and out-flowing boundaries were specified with the respective flows from the hydrographs previously presented.

The model was spun up for a 31 day period to ensure a realistic hydrodynamic regime had developed throughout the water body, from 1st Mar 1995 to 1st Apr 1995, at which point a hot-start restart file was created.

The flushing time analysis simulation was then initialised from the hot-start file on 1st Apr 1994 and was executed for a 215 day period from 1st Apr 1995 to 31st Oct 1995.

An initial 100.0 mg/l concentration of conservative tracer was specified uniformly throughout the water body. All inflowing rivers were specified with a constant 0.0 mg/l concentration.

4.6. Scenario Six: Summer - constant abstraction in northeast Lough Derg

This scenario simulated the hydrodynamic regime in Lough Derg during summer low flow conditions with constant abstraction located in the northeastern corner of Lough Derg at coordinates 588500E 702800N. This scenario had been investigated as Option B during the SEA process.

The abstraction was defined at a constant rate of 350 Ml/day (4.05 m^3/s). The flow through the downstream boundary at Parteen Weir / Ardnacrusha Headrace was reduced accordingly to compensate for the abstraction rate, whilst maintaining the statutory minimum flow of $10m^3/s$ to the natural course of the River Shannon through Parteen Weir.

For the majority of the time this resulted in no change in water level as the abstraction was compensated for by reducing the Ardnacrusha power generation flow. However, during periods when Ardnacrusha was not generating power (i.e. drought periods) the simulated abstraction continues abstracting water. This resulted in additional water being abstracted from the system during drought conditions. Once the drought had concluded the deficit in water volume was recovered by reducing the Ardnacrusha power generation flow, until such time as water levels return to what they would have been had there been no abstraction.

The abstraction profile and compensated outflows through Parteen Weir / Ardnacrusha Headrace are presented below in Figure 16. The changes to water level due to the constant abstraction regime are presented in Figure 17.

The model was initialised from cold start conditions of zero velocity fields with an initial water surface level of 33.3m OD commensurate with recorded data.

The model was spun up for a 31 day period to ensure a realistic hydrodynamic regime had developed throughout the water body, from 1st Mar 1995 to 1st Apr 1995, at which point a hot-start restart file was created.

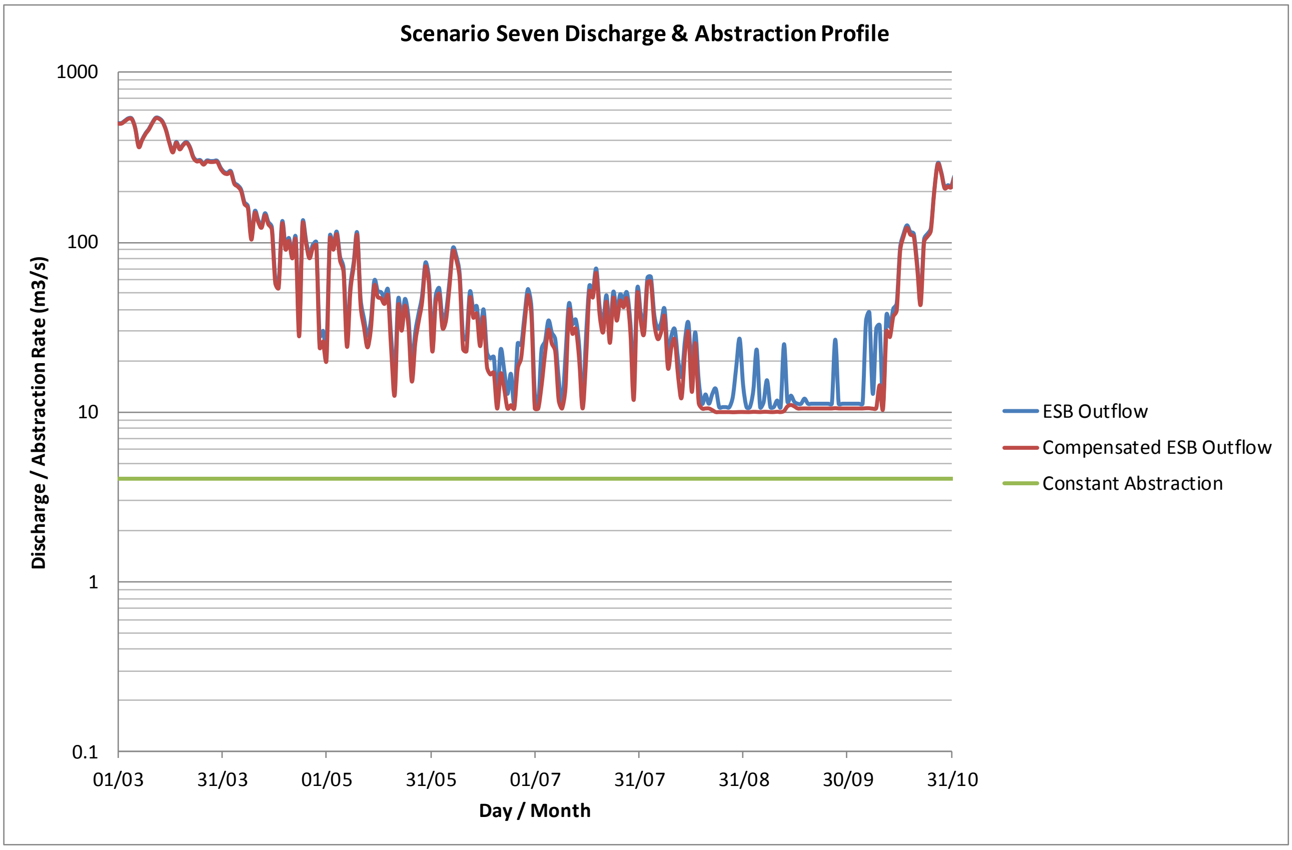


Figure 16: Scenario Six - ESB Discharge Profiles and Abstraction Profile

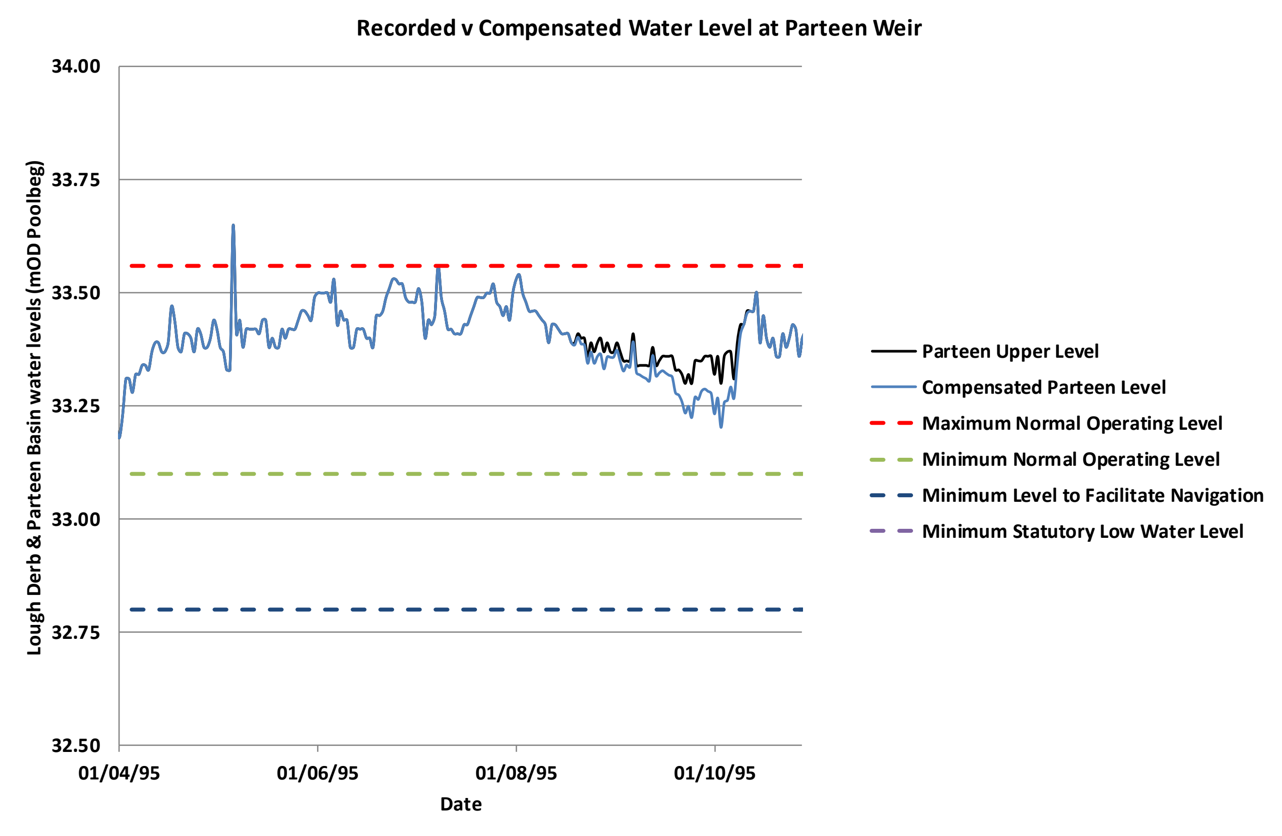


Figure 17: Scenario Six – Recorded v Compensated water levels due to constant abstraction profile.

The flushing time analysis simulation was then initialised from the hot-start file on 1st Apr 1994 and was executed for a 215 day period from 1st Apr 1995 to 31st Oct 1995.

An initial 100.0 mg/l concentration of conservative tracer was specified uniformly throughout the water body. All inflowing rivers were specified with a constant 0.0 mg/l concentration.

4.7. Scenario Seven: Summer - variable abstraction in northeast Lough Derg

This scenario simulated the hydrodynamic regime in Lough Derg during summers flow conditions with a variable abstraction located in the northeastern corner of Lough Derg at coordinates 588500E 702800N. This scenario is associated with raw water storage at Garryhinch in the midlands and had been investigated as Option F2 during the SEA process

The abstraction was defined as having a variable rate of abstraction over the course of a year. For two months of the year, from 15th August to 15th October the abstraction operates at a rate of 50 Ml/day (0.579 m^3/s), for the remaining 10 months of the year the abstraction operates at a rate of 410 Ml/day (4.745 m^3/s).

The flow through the downstream boundary at Parteen Weir / Ardnacrusha Headrace was reduced accordingly to compensate for the variable abstraction rate, whilst maintaining the statutory minimum flow of 10m^3/s to the natural course of the River Shannon through Parteen Weir. This proposed abstraction profile resulted in no change in water level.The abstraction profile and compensated outflows through Parteen Weir / Ardnacrusha Headrace are presented in Figure 18.

The model was initialised from cold start conditions of zero velocity fields with an initial water surface level of 33.3m OD commensurate with recorded data.

The model was spun up for a 31 day period to ensure a realistic hydrodynamic regime had developed throughout the water body, from 1st Mar 1995 to 1st Apr 1995, at which point a hot-start restart file was created. The flushing time analysis simulation was then initialised from the hot-start file on 1st Apr 1994 and was executed for a 215 day period from 1st Apr 1995 to 31st Oct 1995.

An initial 100.0 mg/l concentration of conservative tracer was specified uniformly throughout the water body. All inflowing rivers were specified with a constant 0.0 mg/l concentration.

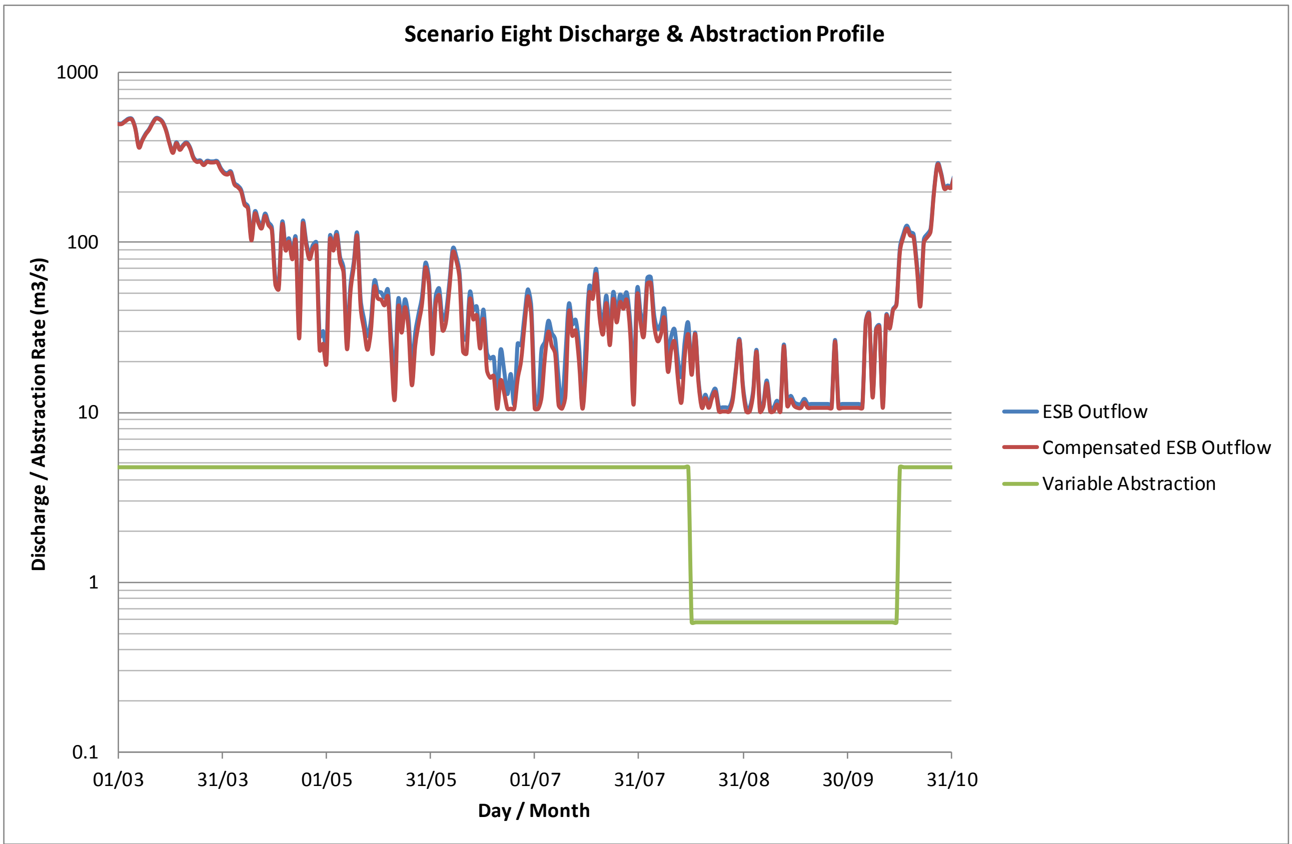


Figure 18: Scenario Seven - ESB Discharge Profiles and Abstraction Profile

4.8. Scenario Eight: Summer - constant abstraction in Parteen Basin

This scenario simulated the hydrodynamic regime in Lough Derg during summer flow conditions with constant abstraction located in Parteen Basin at coordinates 570000E 670800N. This scenario had been investigated as Option C during the SEA process.

The abstraction was defined at a constant rate of 350 Ml/day (4.05m^3/s). The flow through the downstream boundary at Parteen Weir / Ardnacrusha Headrace was reduced accordingly to compensate for the abstraction rate, whilst maintaining the statutory minimum flow of 10m^3/s to the natural course of the River Shannon through Parteen Weir.

Similar to scenario six (northeast constant abstraction), for the majority of the time this resulted in no change in water level as the abstraction was compensated for by reducing the Ardnacrusha power generation flow. However, during periods when Ardnacrusha was not generating power (i.e. drought periods) the simulated abstraction continues abstracting water. This resulted in additional water being abstracted from the system during drought conditions. Once the drought had concluded the deficit in water volume was recovered by reducing the Ardnacrusha power generation flow, until such time as water levels return to what they would have been had there been no abstraction.

The abstraction profile and compensated outflows through Parteen Weir / Ardnacrusha Headrace were presented previously in Figure 16. The changes to water level due to the constant abstraction regime wre presented previously in Figure 17.

The model was initialised from cold start conditions of zero velocity fields with an initial water surface level of 33.3m OD commensurate with recorded data.

The model was spun up for a 31 day period to ensure a realistic hydrodynamic regime had developed throughout the water body, from 1st Mar 1995 to 1st Apr 1995, at which point a hot-start restart file was created.

The flushing time analysis simulation was then initialised from the hot-start file on 1st Apr 1994 and was executed for a 215 day period from 1st Apr 1995 to 31st Oct 1995.

An initial 100.0 mg/l concentration of conservative tracer was specified uniformly throughout the water body. All inflowing rivers were specified with a constant 0.0 mg/l concentration.

4.9. Summary of Scenarios

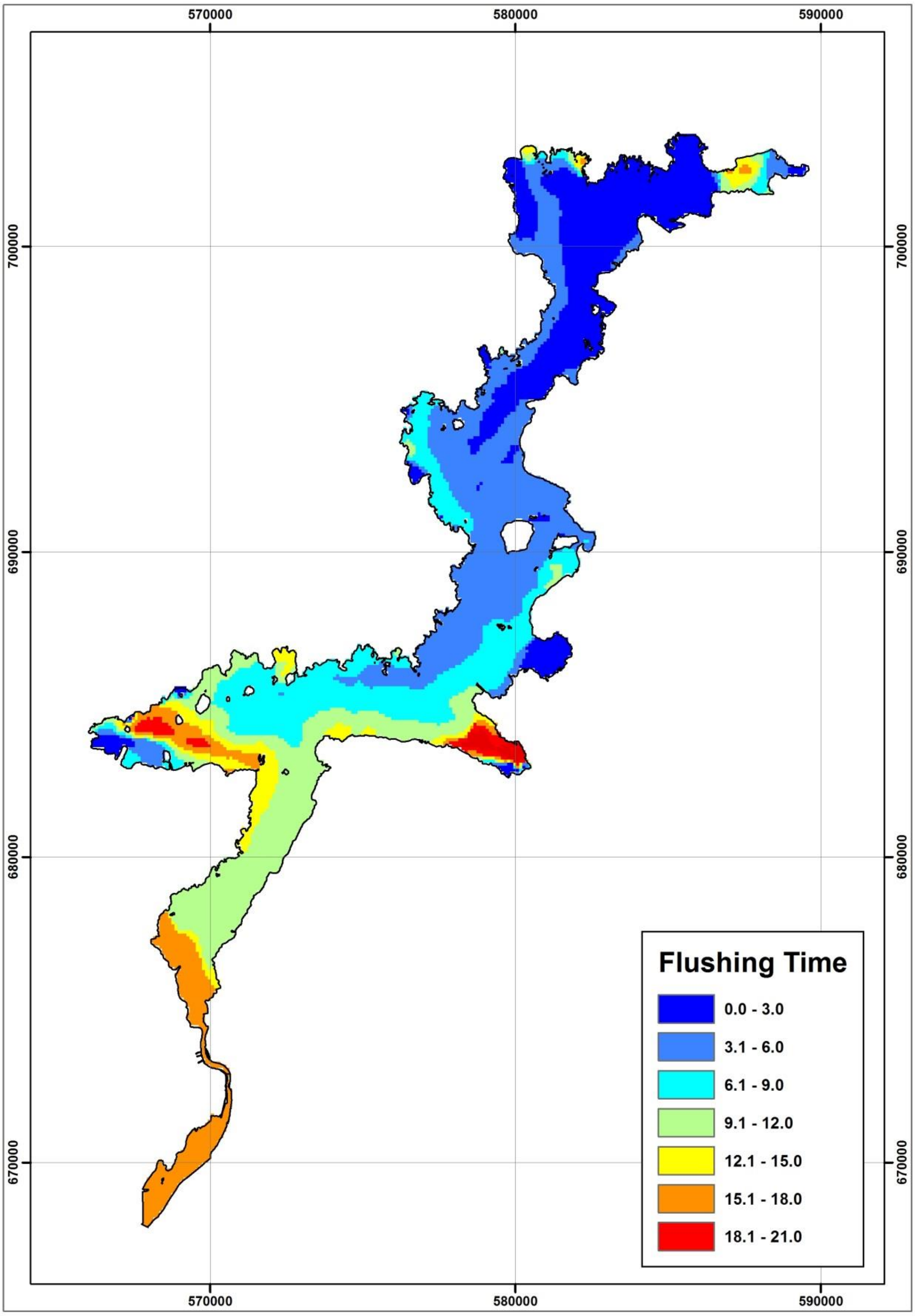
The above scenarios are summarised in the table below.

Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
1	n/a	n/a	Winter	15/12/94 – 15/01/95	15/01/95 – 15/02/95
2	Northeast	350 Ml/d			
3	Northeast	410 / 50 Ml/d			
4	Parteen	350 Ml/d			
5	n/a	n/a	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95
6	Northeast	350 Ml/d			
7	Northeast	410 / 50 Ml/d			
8	Parteen	350 Ml/d			

5. MODEL RESULTS

The results from the eight model scenarios are presented in this section. The results presented are the spatially varying flushing times as calculated for each scenario, along with a table defining the parameters of the scenario.

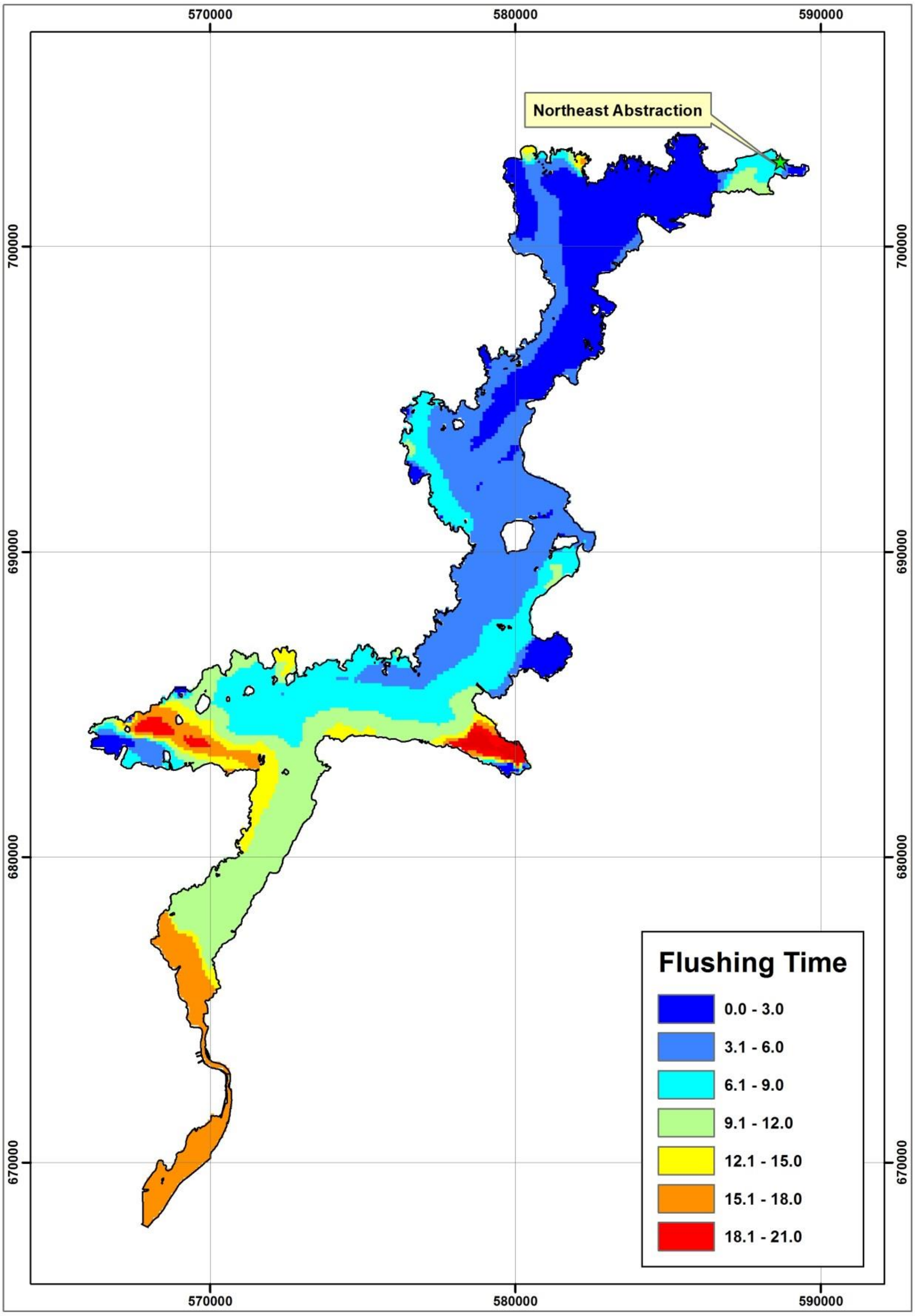
5.1. Scenario One: Winter - baseline (no abstraction)



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
1	n/a	n/a	Winter	15/12/94 – 15/01/95	15/01/95 – 15/02/95

Figure 19: Scenario One: Flushing Time

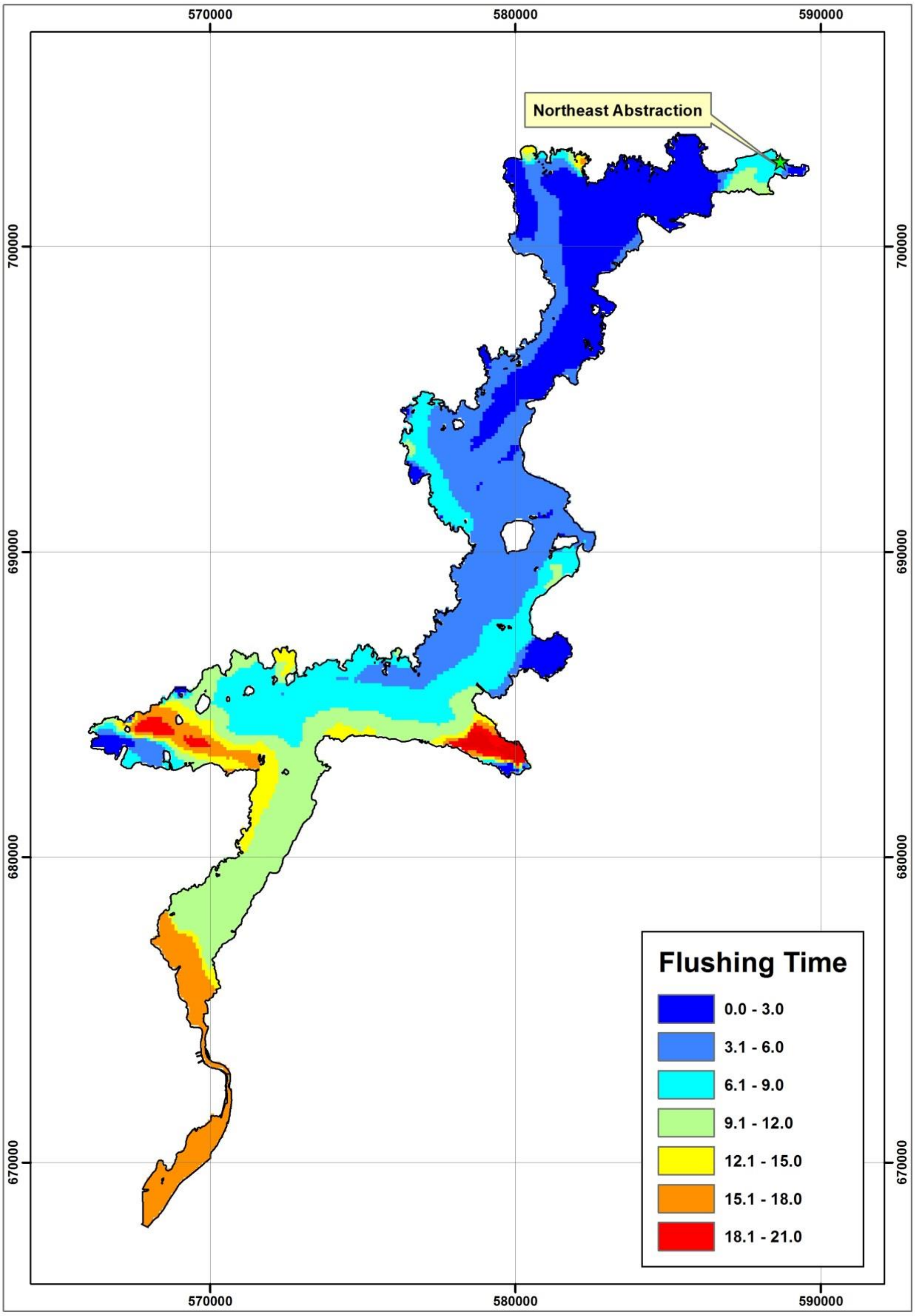
5.2. Scenario Two: Winter - constant abstraction in northeast Lough Derg



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
2	Northeast	350 Ml/d	Winter	15/12/94 – 15/01/95	15/01/95 – 15/02/95

Figure 20: Scenario Two: Flushing Time

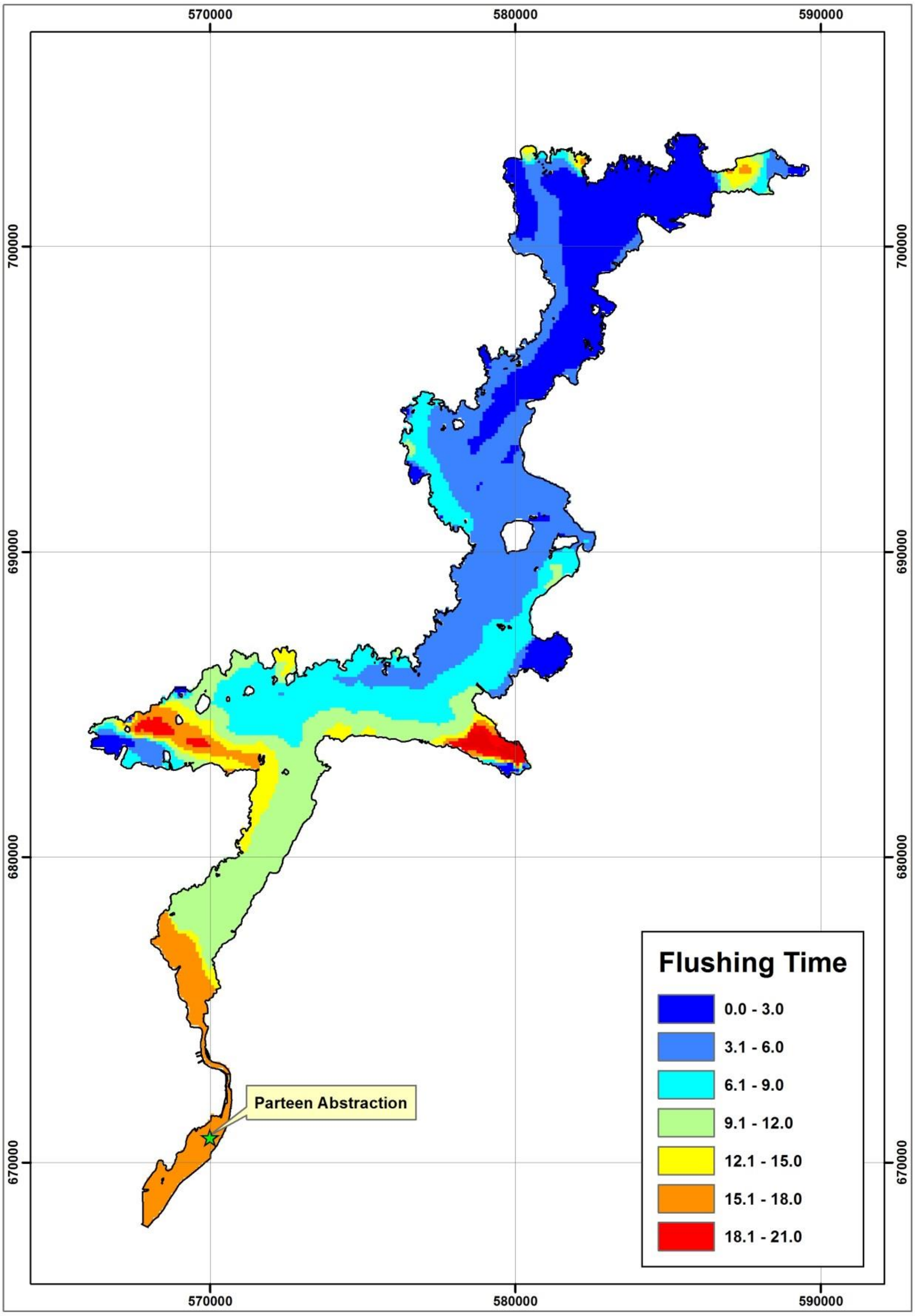
5.3. Scenario Three: Winter - variable abstraction in northeast Lough Derg



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
3	Northeast	410:50 Ml/d	Winter	15/12/94 – 15/01/95	15/01/95 – 15/02/95

Figure 21: Scenario Three: Flushing Time

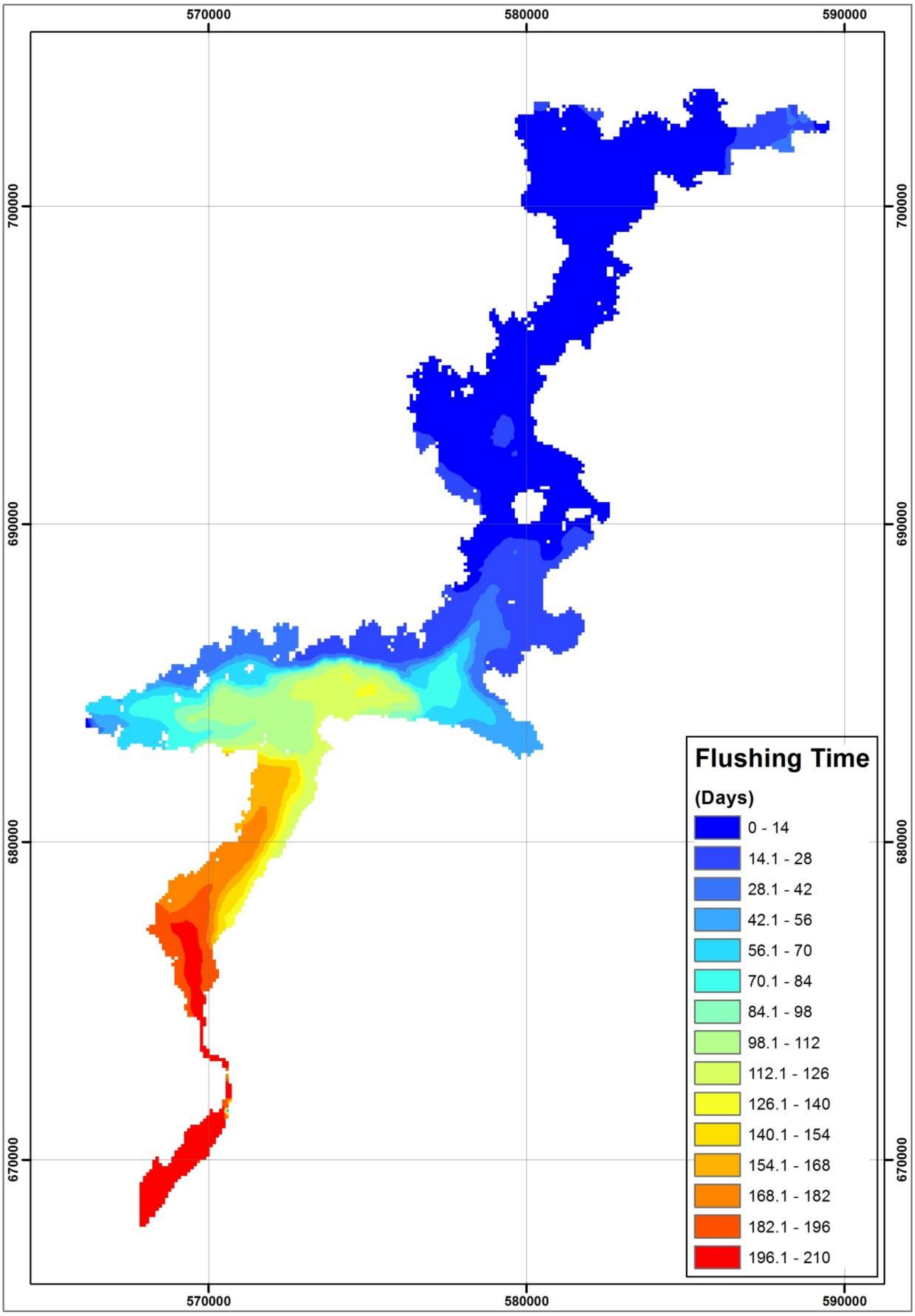
5.4. Scenario Four: Winter - constant abstraction in Parteen Basin



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
4	Parteen	350 Ml/d	Winter	15/12/94 – 15/01/95	15/01/95 – 15/02/95

Figure 22: Scenario Four: Flushing Time

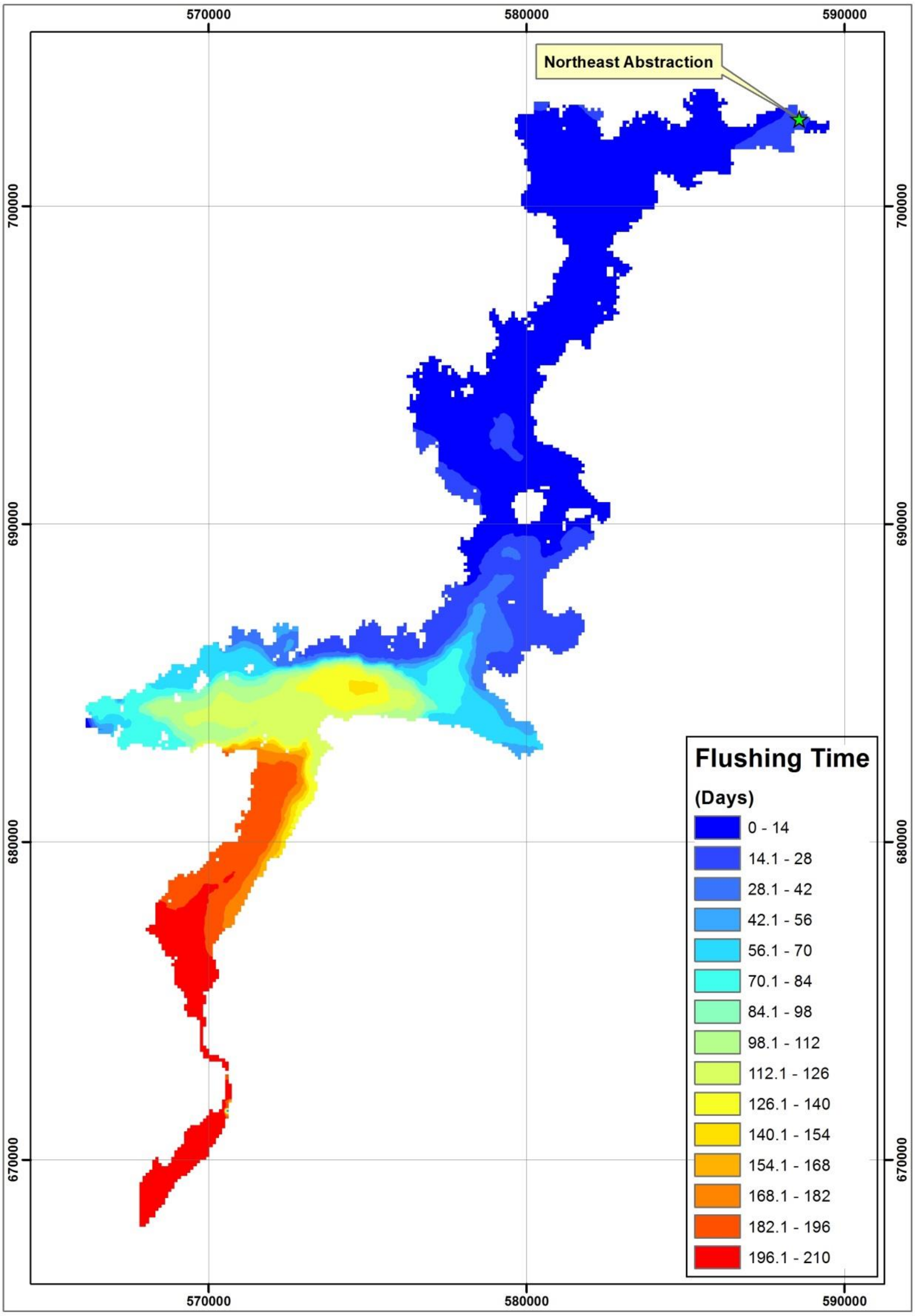
5.5. Scenario Five: Summer - baseline (no abstraction)



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
5	n/a	n/a	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95

Figure 23: Scenario Five: Flushing Time

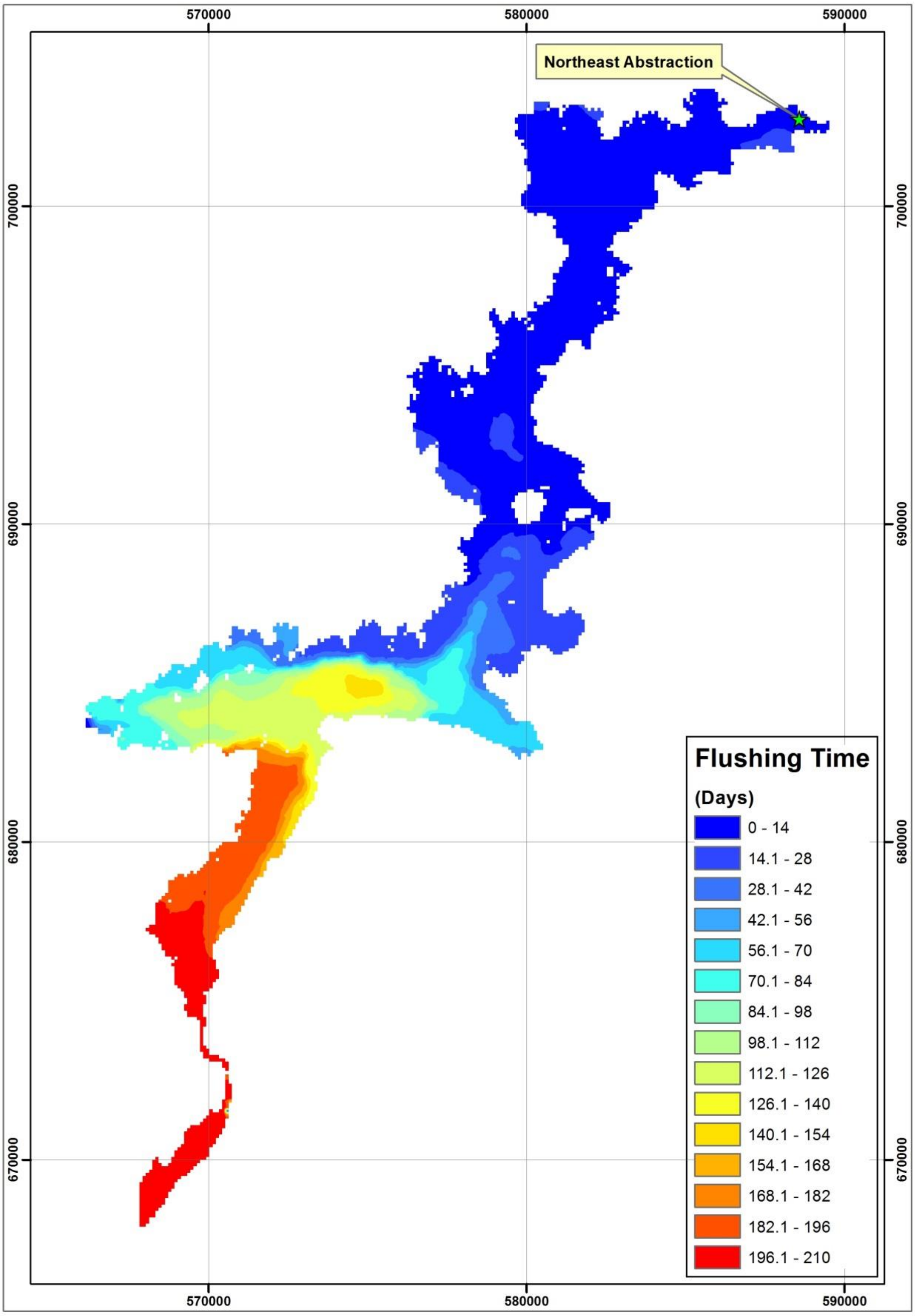
5.6. Scenario Six: Summer - constant abstraction in northeast Lough Derg



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
6	Northeast	350 Ml/d	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95

Figure 24: Scenario Six: Flushing Time

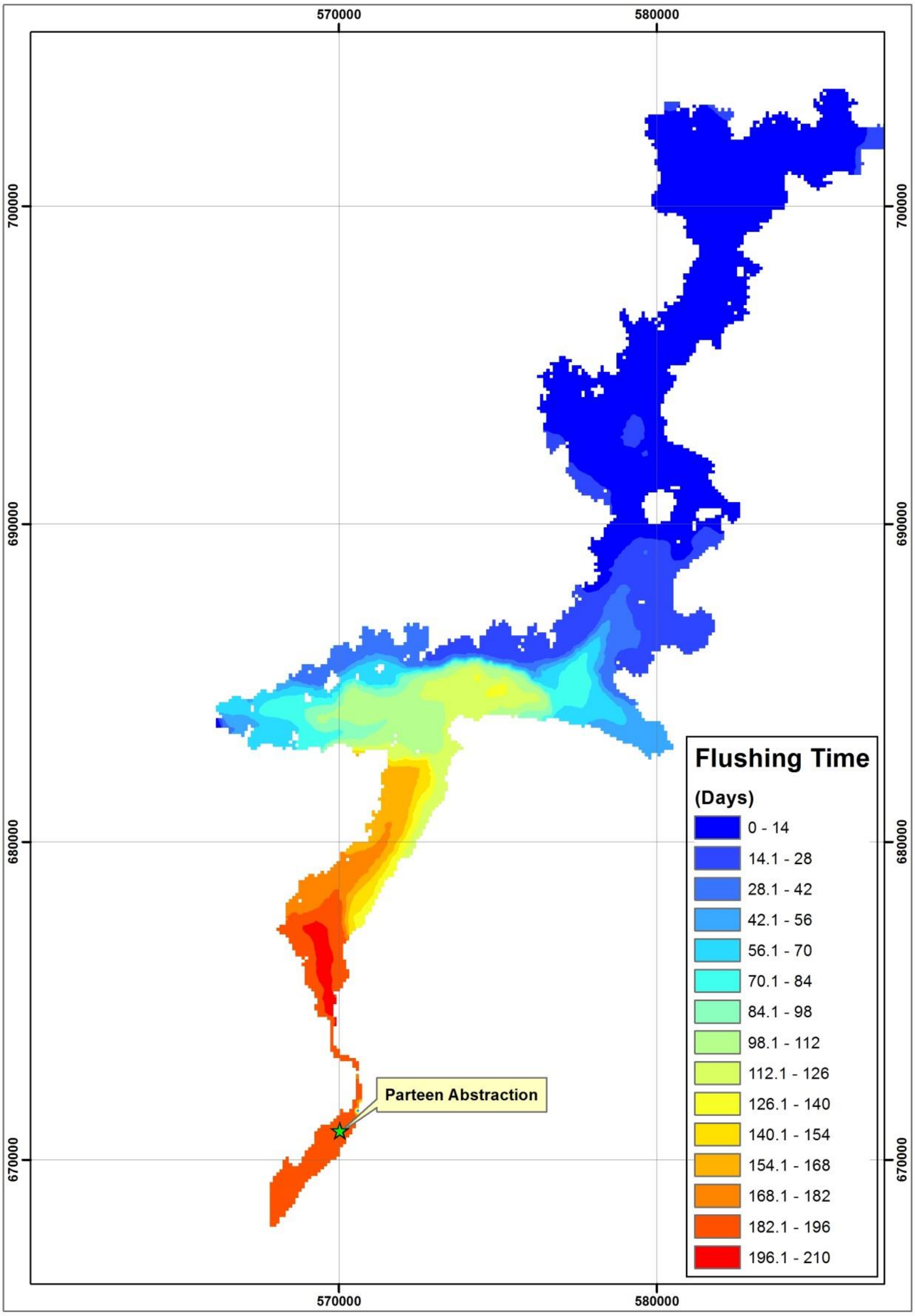
5.7. Scenario Seven: Summer - variable abstraction in northeast Lough Derg



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
7	Northeast	410:50 Ml/d	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95

Figure 25: Scenario Seven: Flushing Time

5.8. Scenario Eight: Summer - constant abstraction in Parteen Basin



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
8	Parteen	350 Ml/d	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95

Figure 26: Scenario Eight: Flushing Time

6. ANALYSIS

Visual inspection of the above figures showed that there were significant spatial differences in flushing times throughout the Lough Derg and Parteen Basin waterbody for both winter and summer periods.

There was also a significant difference in the flushing times between summer and winter periods. Longest flushing times during winter months were approximately 21 days. Longest flushing time during summer months were approximately 210 days, a ten-fold increase over winter flushing times.

The locations featuring the shorter values of flushing time presented in the above figures are predicted to be faster to respond to changes in pollutant concentrations from the principal riverine input, namely the River Shannon. The corollary is that the areas with the longest flushing times were predicted to be the slowest to respond to changing pollutant loadings, and thus susceptible to excess nutrient accumulations.

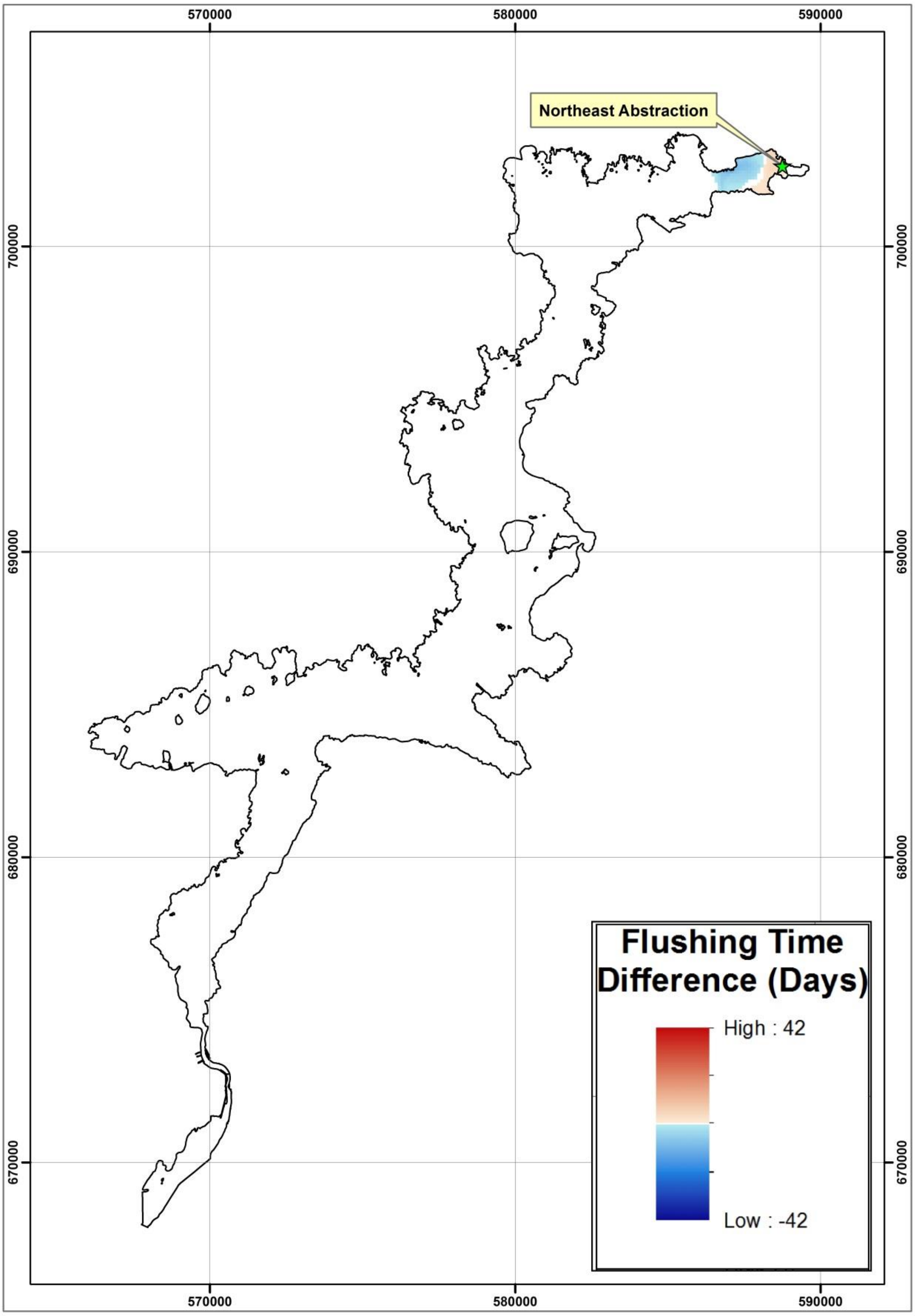
To determine if any of the modelled abstraction options resulted in significant changes to the flushing characteristics of the waterbody the following method was adopted; the calculated flushing time distributions for each modelled abstraction option were subtracted from the calculated baseline (no-abstraction) flushing times.

The resulting difference in flushing time was then plotted throughout the waterbody to determine the potential effects on flushing times above normal baseline conditions due to the various abstraction options. In all analyses, any small change in flushing time (+/-1 day) was blanked out.

The abstraction scenarios outlined in the table below are presented in the figures following.

<table>
<tr><th>Scenario</th><th>Abstraction Location</th><th>Rate</th><th>Season</th><th>Spin-up Period</th><th>Simulation Period</th></tr>
<tr><td>2</td><td>Northeast</td><td>350 Ml/d</td><td rowspan="3">Winter</td><td rowspan="3">15/12/94 – 15/01/95</td><td rowspan="3">15/01/95 – 15/02/95</td></tr>
<tr><td>3</td><td>Northeast</td><td>410 / 50 Ml/d</td></tr>
<tr><td>4</td><td>Parteen</td><td>350 Ml/d</td></tr>
<tr><td>6</td><td>Northeast</td><td>350 Ml/d</td><td rowspan="3">Summer</td><td rowspan="3">01/03/95 – 01/04/95</td><td rowspan="3">01/04/95 – 31/10/95</td></tr>
<tr><td>7</td><td>Northeast</td><td>410 / 50 Ml/d</td></tr>
<tr><td>8</td><td>Parteen</td><td>350 Ml/d</td></tr>
</table>

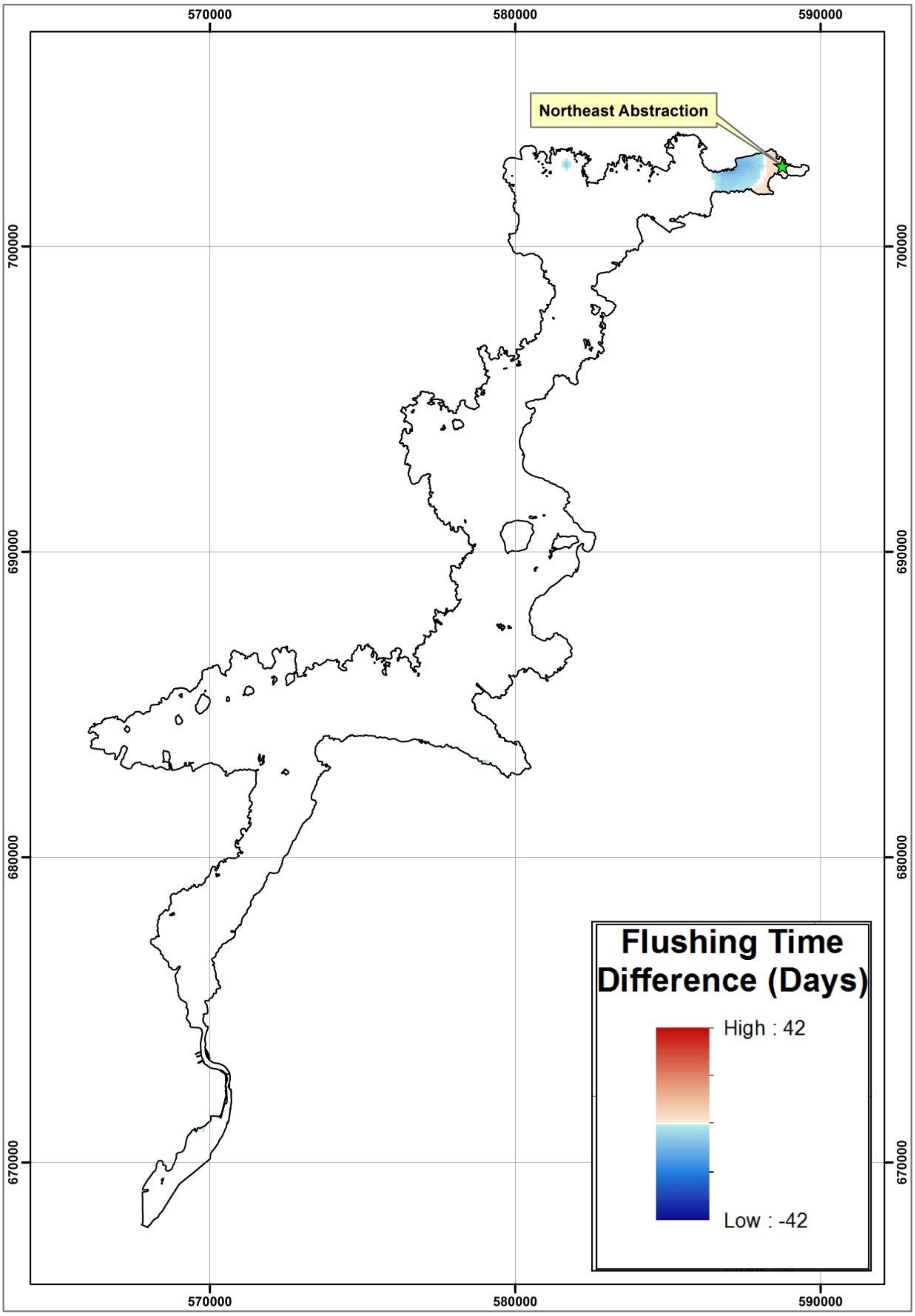
Scenario Two: Winter - constant abstraction in northeast Lough Derg



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
2	Northeast	350 Ml/d	Winter	15/12/94 – 15/01/95	15/01/95 – 15/02/95

Figure 27: Scenario Two impact on Flushing Time

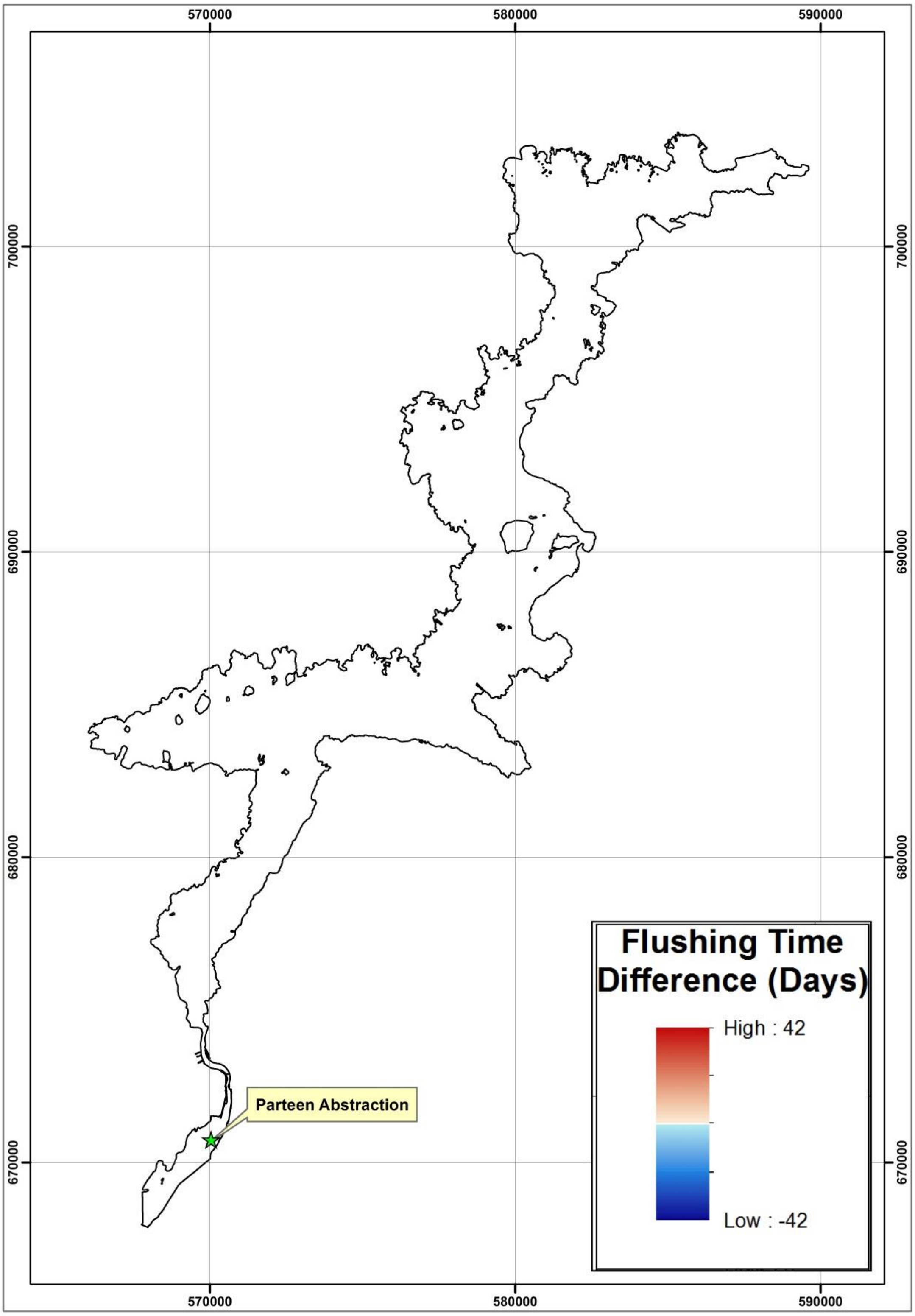
Scenario Three: Winter - variable abstraction in northeast Lough Derg



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
3	Northeast	410:50 Ml/d	Winter	15/12/94 – 15/01/95	15/01/95 – 15/02/95

Figure 28: Scenario Three impact on Flushing Time

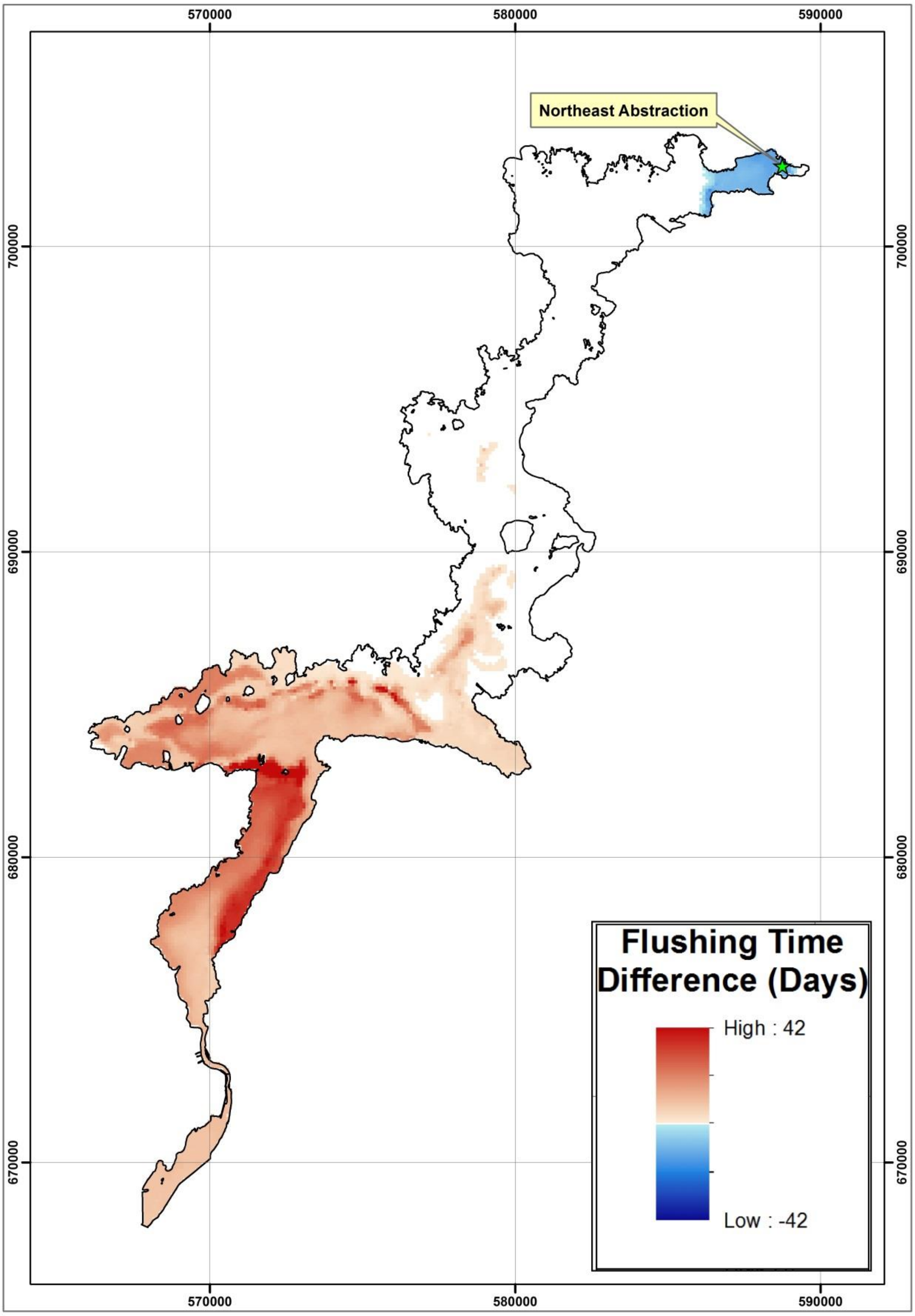
Scenario Four: Winter - constant abstraction in Parteen Basin



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
4	Parteen	350 Ml/d	Winter	15/12/94 – 15/01/95	15/01/95 – 15/02/95

Figure 29: Scenario Four impact on Flushing Time

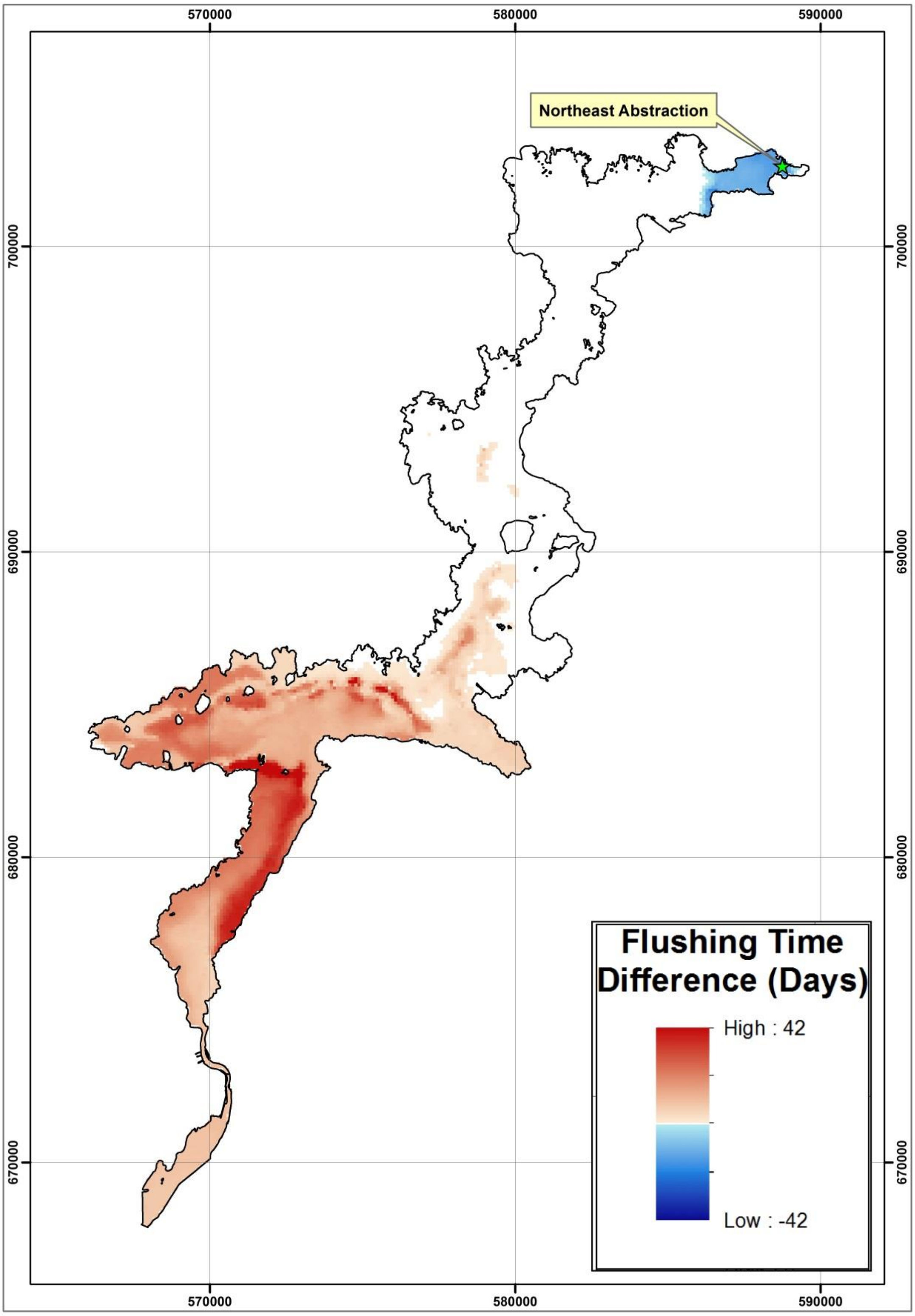
Scenario Six: Summer - constant abstraction in northeast Lough Derg



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
6	Northeast	350 Ml/d	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95

Figure 30: Scenario Six impact on Flushing Time

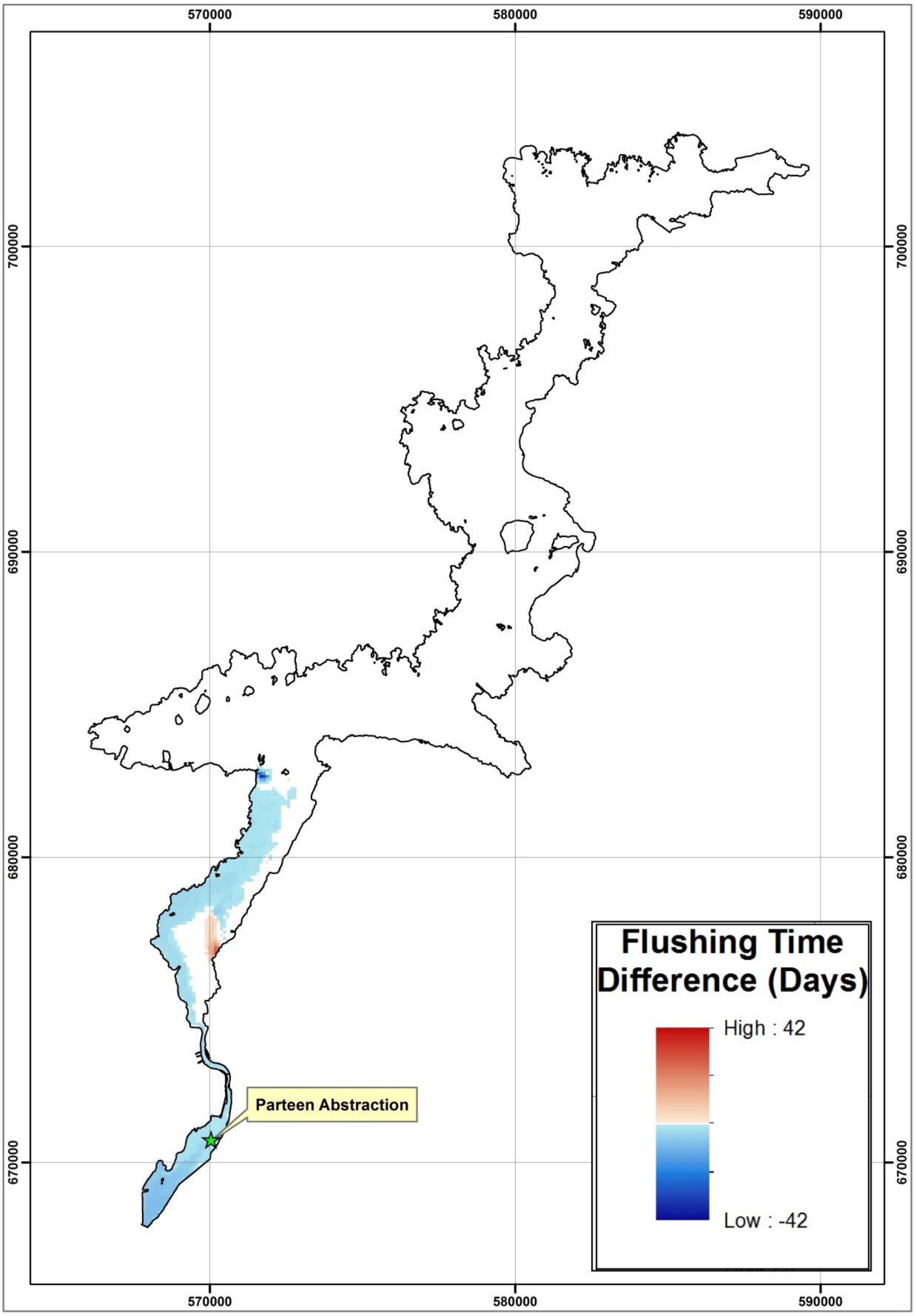
Scenario Seven: Summer - variable abstraction in northeast Lough Derg



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
7	Northeast	410:50 Ml/d	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95

Figure 31: Scenario Seven impact on Flushing Time

Scenario Eight: Summer - constant abstraction in Parteen Basin



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
8	Parteen	350 Ml/d	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95

Figure 32: Scenario Eight impact on Flushing Time

7. DISCUSSION

7.1. Winter Period

Figure 27 to Figure 29 showing the effects of abstracting from Lough Derg / Parteen Basin during winter (high flow) conditions indicate that there was little to no change in flushing times in Lough Derg / Parteen Basin for either constant or variable abstractions from the north east of Lough Derg nor constant abstraction from Parteen Basin.

The main reason was that the average flows through the system for the period of simulation (15/01/1995 – 15/02/1995) were approximately 525 m^3/s. The constant abstraction rate of 4.05 m^3/s represented less than 1% of the average flow. The variable abstraction rate of 4.74 m^3/s also represented less than 1% of the average flow.

7.1.1. Northeast abstraction

Scenarios involving an abstraction from northeast of Lough Derg at either constant or variable rates during winter high flow conditions exhibit a reduction in the flushing time to the west of the abstraction point, and a corresponding increase in flushing time to the east of the abstraction point (Figure 27 & Figure 28). This is due to the abstraction's effect on the hydraulic flows, diverting water from the main flow in the Shannon into Slevoir Bay, thus increasing the water flow rate and rate of exchange of material. The increase in flushing time to the east of the abstraction point is due to the higher flow rates entering Slevoir Bay from the main flow of the Shannon, thus impounding to some extent the waters to the east of the abstraction point.

7.1.2. Parteen Basin abstraction

The scenario involving abstraction from Parteen Basin at constant rate during winter high flow conditions exhibits no change in flushing time characteristics when compared with the baseline conditions (Figure 29).

7.2. Summer Period

Figure 30 to Figure 32**Error! Reference source not found.** showing the effects of abstracting from Lough Derg / Parteen Basin during summer (low flow) conditions indicate that there were significant changes in flushing times in

Lough Derg / Parteen Basin when abstracting from the northeast of Lough Derg versus abstracting from Parteen Basin.

7.2.1. Northeast abstraction

Scenarios involving an abstraction from the northeast of Lough Derg at either constant or variable rates during summer low flow conditions exhibit a large increase (maximum +42 days) in flushing times in the middle and southern portions of Lough Derg when compared with the baseline conditions (Figure 30 & Figure 31).

A histogram of the differences between the Summer baseline (scenario five) and constant abstraction (scenario six) were analysed. The mean difference in flushing times was +11.92 days, with a standard deviation of 10.40 days. Figure 33 presents the histogram plot of the analysis undertaken, with the number of data points on the Y-axis, and difference in flushing times on the X-axis.

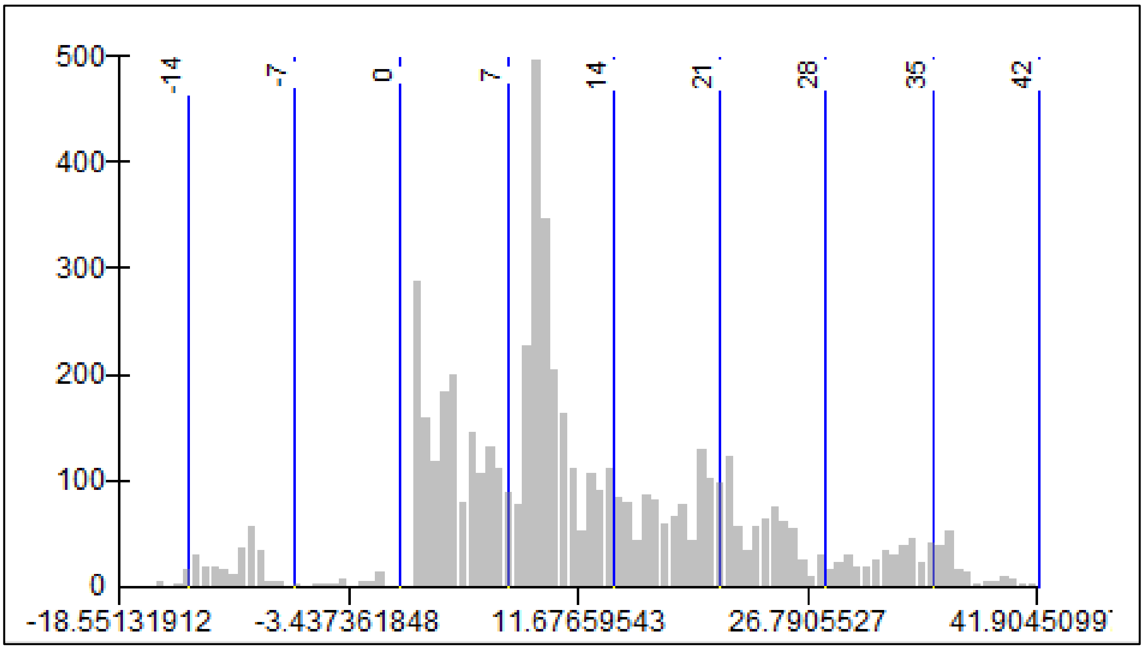


Figure 33: Scenario Seven (northeast constant abstraction) impact on Summer Flushing Times

A histogram of the differences between the Summer baseline (scenario five) and variable abstraction (scenario seven) were analysed. The mean difference in flushing times was +12.52 days, with a standard deviation of 10.72 days. Figure 34 presents the histogram plot of the analysis undertaken, with the number of data points on the Y-axis, and difference in flushing times on the X-axis.

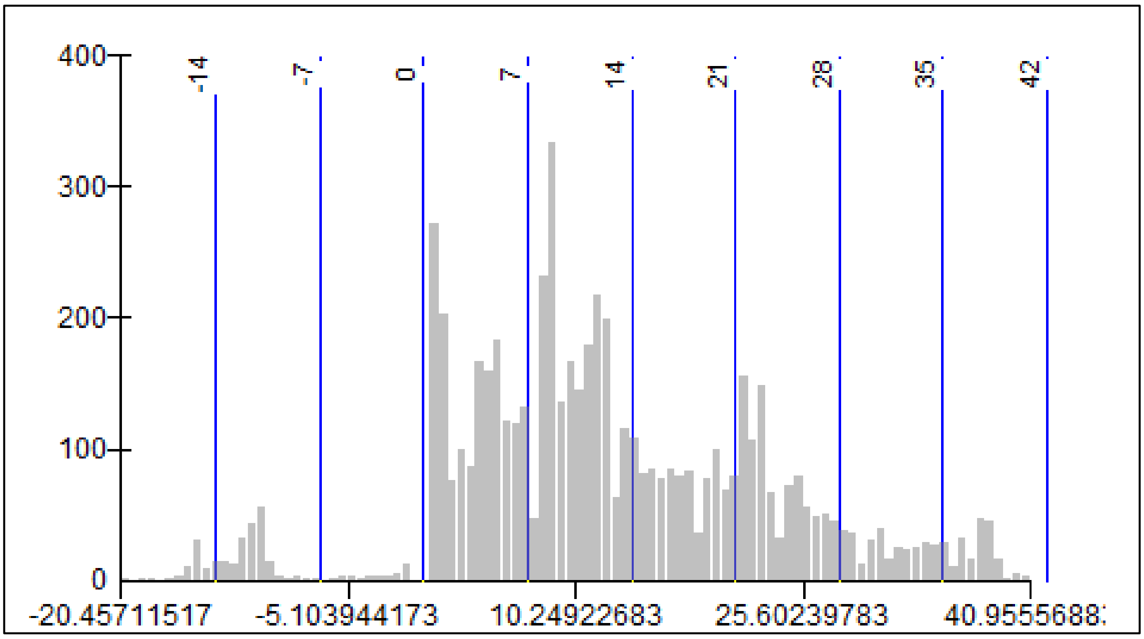


Figure 34: Scenario Eight (northeast variable abstraction) impact on Summer Flushing Times

The reason for the large increase in flushing times in the southern portion of Lough Derg / Parteen Basin was that the flows through the system for the period of simulation (01/04/1995 – 31/10/1995) were in general very low. For both constant and variable rates, the abstraction represented a very high percentage of that flow at the northeastern abstraction location. This resulted in a much reduced volume of water passing on through the system.

Both constant and variable abstraction regimes from the northeast of Lough Derg show significant increases in flushing times (42 days increase) in the middle and southern regions of the waterbody. The difference in impacts of both abstraction regimes is indiscernible spatially when comparing Figure 30 with Figure 31. The gross statistics describing the changes to flushing times for each abstraction regime are also very similar. This would indicate that there would be no noticeable differences in impacts on flushing times in Lough Derg between a constant abstraction and a variable abstraction regime.

7.2.2. Parteen Basin abstraction

The scenario involving abstraction from Parteen Basin at a constant rate during summer low flow conditions exhibit a slight improvement to flushing time characteristics (3 days decrease) in the southernmost regions Lough Derg and Parteen Basin when compared with the baseline conditions.

The reason the Parteen Basin abstraction did not cause any increase in the flushing time of Lough Derg was that the flow of water had already passed through the lake prior to encountering the abstraction point in Parteen Basin.

The small decreases in flushing time in the southern part of Lough Derg due to the constant abstraction regime in Parteen Basin was due to the acceleration of through-flow associated with the slight draw-down in lake water surface level when compared to the baseline condition. This draw-down in lake water level was a result of facilitating the constant abstraction regime during low flow summer conditions whilst maintaining the statutory flow through Parteen Weir to the natural course of the River Shannon, as discussed in Section 2.3 previously.

In the case of waterbodies, such as Lough Derg and Parteen Basin, that are not well-mixed horizontally (as evidenced from Figure 19 & **Error! Reference source not found.**), knowledge of the spatial detail in the distribution of flushing times may prove crucial when assessing its impact on water quality.

Due to higher exchange rates, water masses characterized by a short flushing time value experience more frequent changes in water quality parameters than those with long flushing times, in response to changes in water quality of ambient waters. It should be noted that the methodology adopted for this study was not pollutant specific and depicted only the general physical mixing processes in the system.

7.3. Addendum I: Scenario Nine.

A histogram of the differences between the Summer baseline (scenario five) and the 450:50 variable abstraction (scenario nine) profiles for northeast Lough Derg were analysed. The mean difference in flushing times was +6.56 days, with a standard deviation of 10.14 days.

The reason for the large increase in flushing times in the southern portion of Lough Derg / Parteen Basin was that the flows through the system for the period of simulation (01/04/1995 – 31/10/1995) were in general very low. For the 450:50 variable abstraction rate, the abstraction represented a very high percentage of that flow at the northeastern abstraction location. This resulted in a much reduced volume of water passing on through the system.

All abstraction profiles (constant, 410:50 variable, and 450:50 variable) from the northeast of Lough Derg show significant increases in flushing times (maximum 42 days increase) in the middle and southern regions of the waterbody. The difference in impacts of the three abstraction regimes is visually indiscernible spatially.

8. CONCLUSIONS

The 'First Pass' preliminary modelling exercise was undertaken to determine whether any changes in flushing characteristics of Lough Derg / Parteen Basin could be ascertained due to a number of potential abstraction locations and abstraction regimes.

Based on the results of the model it has been found that little to no changes in flushing time characteristics arise during high flow winter conditions. Those changes in flushing time that were in evidence were localised to the actual abstraction location.

Based on the results from the model it has been found that significant changes in flushing time characteristics arise during low flow summer time conditions.

The most significant changes in flushing time in Lough Derg were of the order of +42 days for an abstraction located at the northeast of Lough Derg. There was little to no discernible difference to changes in flushing times due to one abstraction profile over another (constant v variable) at that location.

The predicted flushing time results presented above for the 1995 period can be considered to approximate a worst case scenario, occurring as they did during one of the longest recorded periods of drought flows in the River Shannon system.

Water Supply Project – Eastern and Midlands Region

DA2: Hydrodynamic and Water Quality Modelling

DA2.2: First Pass Modelling Report

Addendum I: Scenario Nine: Summer - 450:50 variable abstraction in northeast Lough Derg

Document No: G201301_doc002_06_AddendumI.pdf
Status: Final
Date: 02– 10 - 2015

Table of Contents

1. MODEL SCENARIO

1.1. Scenario Nine: Summer - 450:50 variable abstraction in NE Lough Derg

This scenario simulated the hydrodynamic regime in Lough Derg during summers flow conditions with a variable abstraction located in the northeastern corner of Lough Derg at coordinates 588500E 702800N. This scenario is associated with raw water storage at Garryhinch in the midlands and had been investigated as Option F2 during the SEA process

The abstraction was defined as having a variable rate of abstraction over the course of a year. For three months of the year, from 15th July to 15th October the abstraction operates at a rate of 50 Ml/day (0.579 m^3/s), for the remaining 9 months of the year the abstraction operates at a rate of 450 Ml/day (5.208m^3/s).

The flow through the downstream boundary at Parteen Weir / Ardnacrusha Headrace was reduced accordingly to compensate for the variable abstraction rate, whilst maintaining the statutory minimum flow of 10m^3/s to the natural course of the River Shannon through Parteen Weir. This proposed abstraction profile resulted in no change in water level. The abstraction profile and compensated outflows through Parteen Weir / Ardnacrusha Headrace are presented in Figure 1 .

The model was initialised from cold start conditions of zero velocity fields with an initial water surface level of 33.3m OD commensurate with recorded data.

The model was spun up for a 31 day period to ensure a realistic hydrodynamic regime had developed throughout the water body, from 1st Mar 1995 to 1st Apr 1995, at which point a hot-start restart file was created. The flushing time analysis simulation was then initialised from the hot-start file on 1st Apr 1994 and was executed for a 215 day period from 1st Apr 1995 to 31st Oct 1995.

An initial 100.0 mg/l concentration of conservative tracer was specified uniformly throughout the water body. All inflowing rivers were specified with a constant 0.0 mg/l concentration.

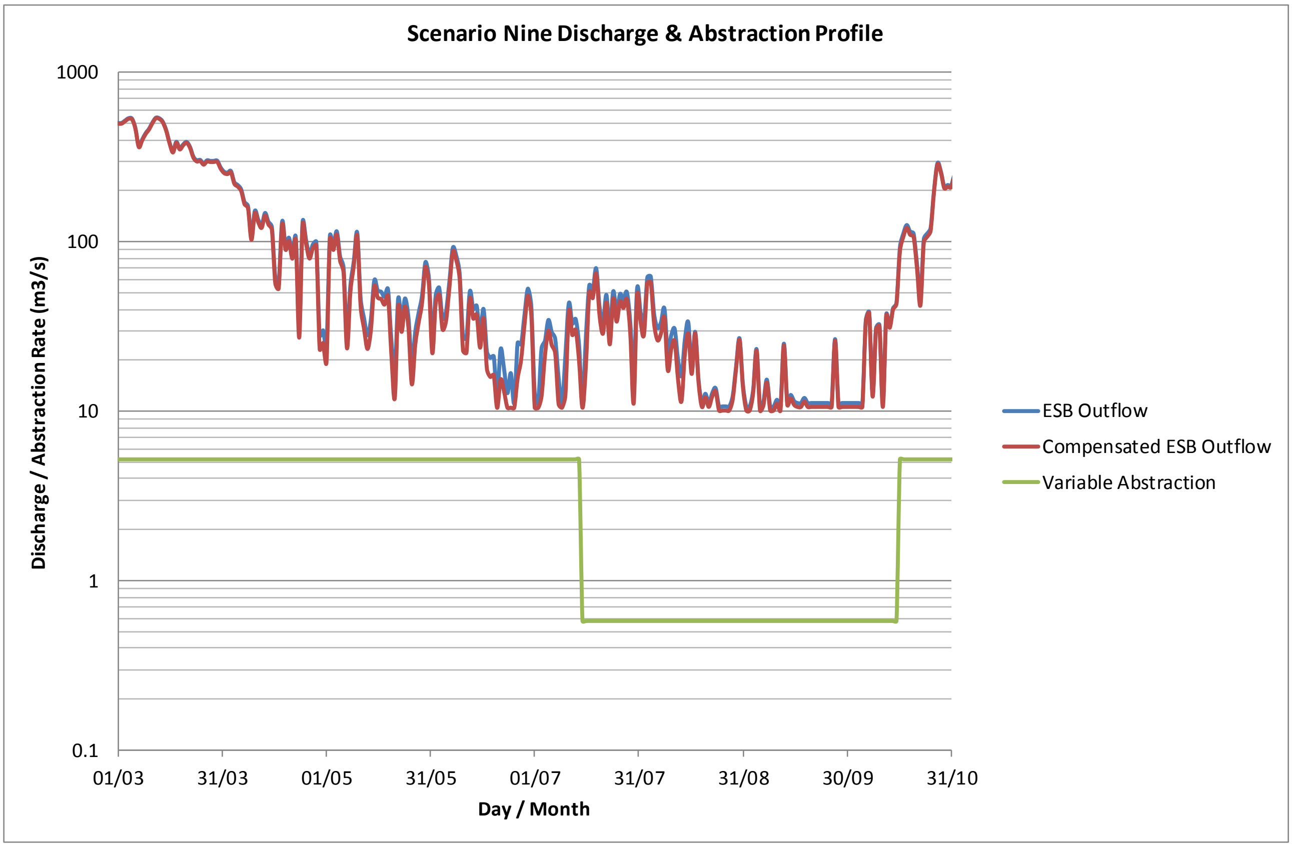
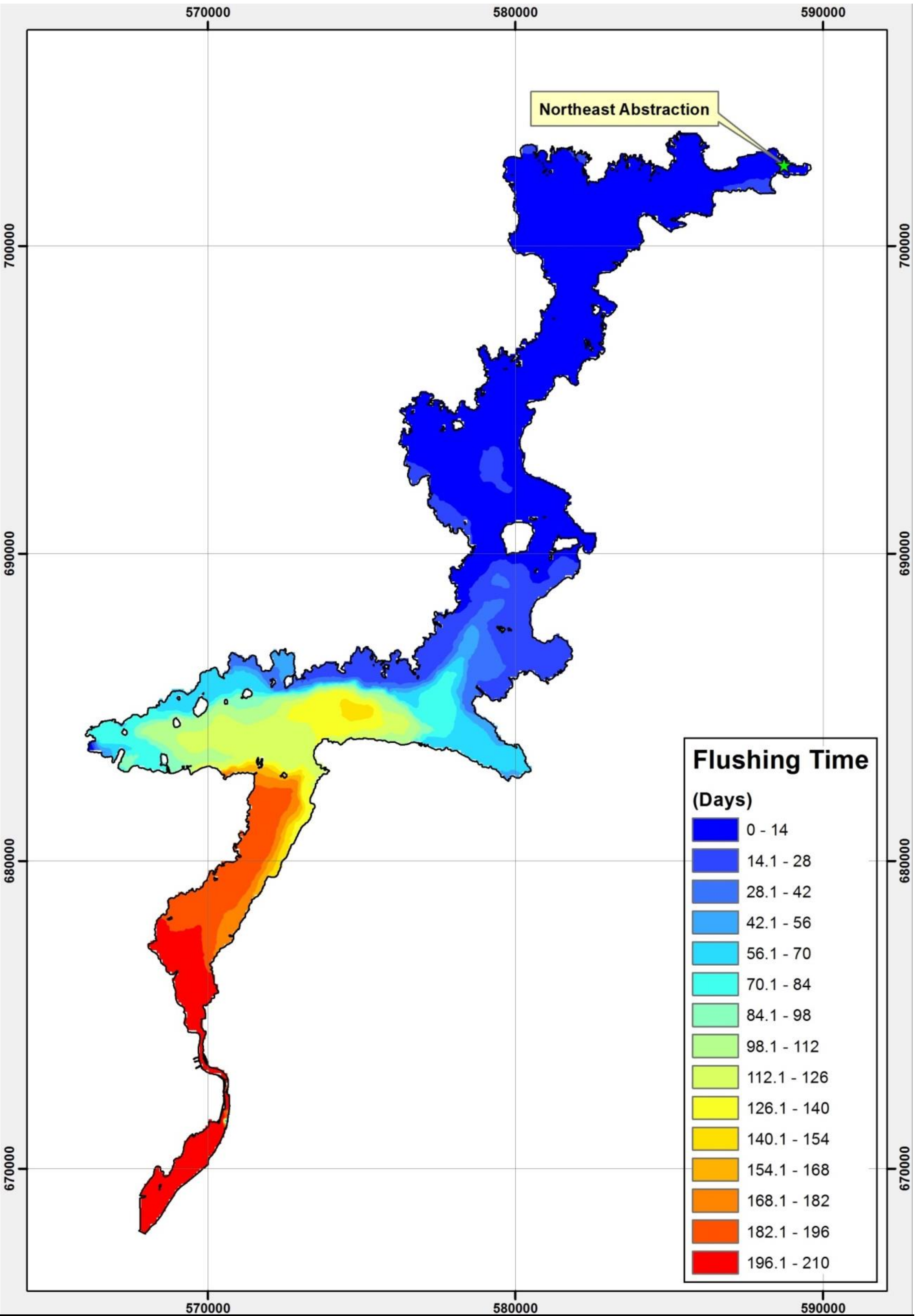


Figure 1: Scenario nine - ESB Discharge Profiles and Abstraction Profile

2. MODEL RESULTS

The result presented from the model scenario on the following page is the spatially varying flushing times as calculated, along with a table defining the parameters of the scenario.

2.1. Scenario Nine: Summer – 450:50 variable abstraction in NE Lough Derg



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
9	Northeast	450:50 Ml/d	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95

Figure 2: Scenario Nine Flushing Time

3. ANALYSIS

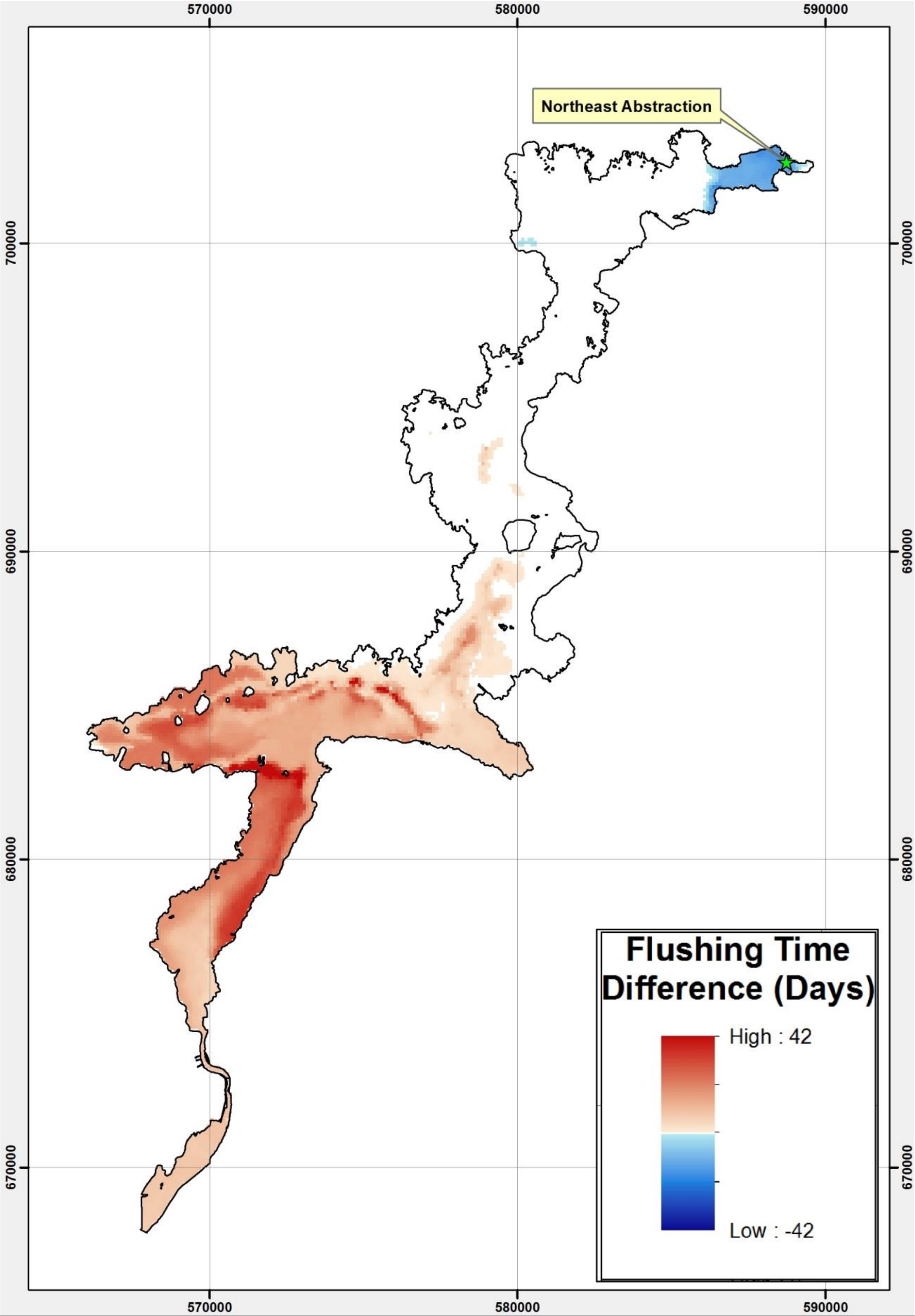
Visual inspection of the above figure shows that there were significant spatial differences in flushing times throughout the Lough Derg and Parteen Basin waterbody for the summer periods. Longest flushing time during summer months were approximately 210 days.

The locations featuring the shorter values of flushing time presented in the figure are predicted to be faster to respond to changes in pollutant concentrations from the principal riverine input, namely the River Shannon. The corollary is that the areas with the longest flushing times were predicted to be the slowest to respond to changing pollutant loadings, and thus susceptible to excess nutrient accumulations.

To determine if the modelled abstraction option resulted in significant changes to the flushing characteristics of the waterbody the following method was adopted; the calculated flushing time distributions for the modelled abstraction option was subtracted from the calculated baseline (no-abstraction) flushing times.

The resulting difference in flushing time was then plotted throughout the waterbody to determine the potential effects on flushing times above normal baseline conditions due to the abstraction options. In all analyses, any small change in flushing time (+/-1 day) was blanked out.

Scenario Nine: Summer - variable abstraction in northeast Lough Derg



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
9	Northeast	410:50 Ml/d	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95

Figure 3: Scenario Nine impact on Flushing Time

4. DISCUSSION

A histogram of the differences between the Summer baseline (scenario five) and the 450:50 variable abstraction (scenario nine) were analysed. The mean difference in flushing times was +6.56 days, with a standard deviation of 10.14 days. The histogram plot of the analysis undertaken is presented below, with the number of data points on the Y-axis, and difference in flushing times on the X-axis.

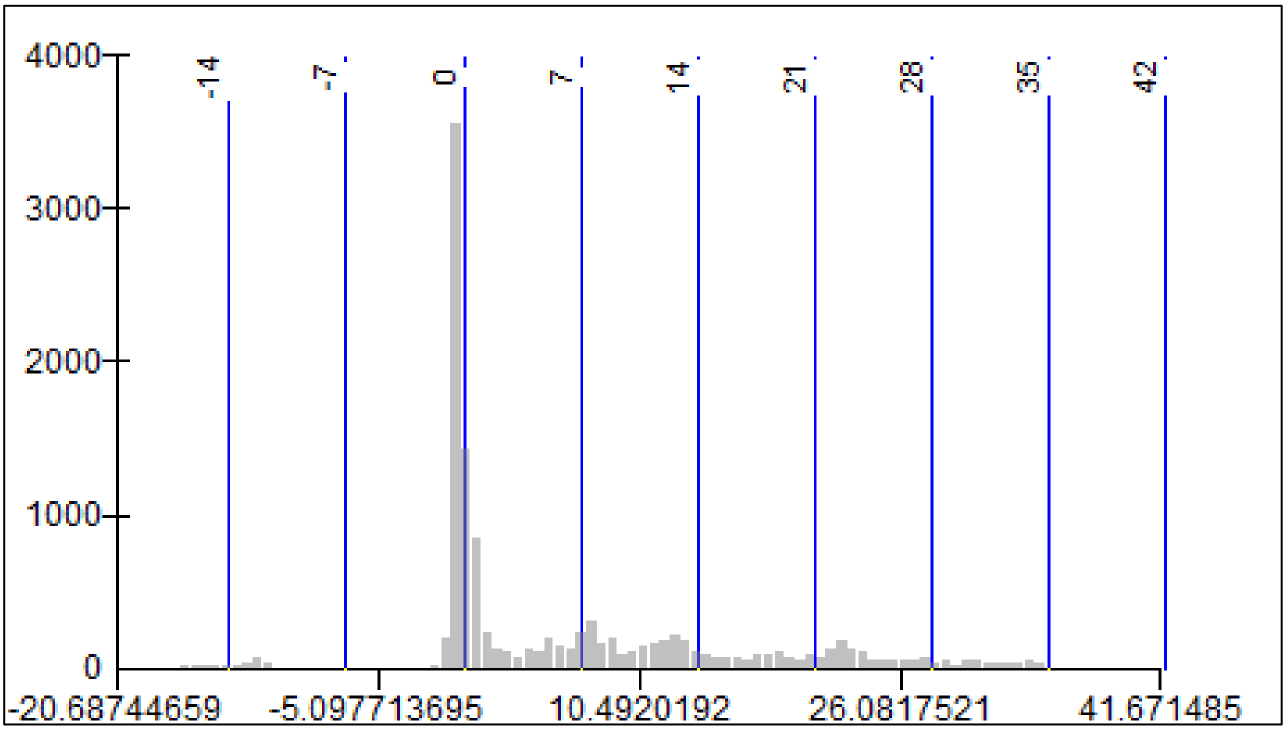


Figure 4: Scenario Nine (northeast 450:50 abstraction) impact on Summer Flushing Times

The reason for the large increase in flushing times in the southern portion of Lough Derg / Parteen Basin was that the flows through the system for the period of simulation (01/04/1995 – 31/10/1995) were in general very low. For the 450:50 variable abstraction rate, the abstraction represented a very high percentage of that flow at the northeastern abstraction location. This resulted in a much reduced volume of water passing on through the system.

The constant, 410:50 variable, and 450:50 abstraction regimes from the northeast of Lough Derg show significant increases in flushing times (maximum 42 days increase) in the middle and southern regions of the waterbody. The difference in impacts of the three abstraction regimes is visually indiscernible spatially.

5. CONCLUSIONS

The ‘First Pass’ preliminary modelling exercise was undertaken to determine whether any changes in flushing characteristics of Lough Derg / Parteen Basin could be ascertained due to a number of potential abstraction locations and abstraction regimes.

Based on the results from the model it has been found that significant changes in flushing time characteristics arise during low flow summer time conditions.

The most significant changes in flushing time in Lough Derg were of the order of +42 days for an abstraction located at the northeast of Lough Derg. There was little to no discernible difference to changes in flushing times due to one abstraction profile over another.

Water Supply Project – Eastern and Midlands Region

DA2: Hydrodynamic and Water Quality Modelling

DA2.2: First Pass Modelling Report

Addendum II: Scenario Ten: Summer - 410:50 variable abstraction in Youghal Bay

Document No: G201301_doc002_07_AddendumII.pdf
Status: Final
Date: 13– 10 - 2015

Table of Contents

1. MODEL SCENARIO

1.1. Scenario Ten: Summer - 410:50 variable abstraction in Youghal Bay

This scenario simulated the hydrodynamic regime in Lough Derg during summers flow conditions with a variable abstraction located in Youghal Bay at coordinates 579500E 683500N. This scenario is associated with raw water storage at Garryhinch in the midlands and had been investigated as Option F2 during the SEA process

The abstraction was defined as having a variable rate of abstraction over the course of a year. For two months of the year, from 15th August to 15th October the abstraction operates at a rate of 50 Ml/day (0.579 m3/s), for the remaining 10 months of the year the abstraction operates at a rate of 410 Ml/day (4.745 m3/s).

The flow through the downstream boundary at Parteen Weir / Ardnacrusha Headrace was reduced accordingly to compensate for the variable abstraction rate, whilst maintaining the statutory minimum flow of 10m3/s to the natural course of the River Shannon through Parteen Weir. This proposed abstraction profile resulted in no change in water level. The abstraction profile and compensated outflows through Parteen Weir / Ardnacrusha Headrace are presented in Figure 1 .

The model was initialised from cold start conditions of zero velocity fields with an initial water surface level of 33.3m OD commensurate with recorded data.

The model was spun up for a 31 day period to ensure a realistic hydrodynamic regime had developed throughout the water body, from 1st Mar 1995 to 1st Apr 1995, at which point a hot-start restart file was created. The flushing time analysis simulation was then initialised from the hot-start file on 1st Apr 1994 and was executed for a 215 day period from 1st Apr 1995 to 31st Oct 1995.

An initial 100.0 mg/l concentration of conservative tracer was specified uniformly throughout the water body. All inflowing rivers were specified with a constant 0.0 mg/l concentration.

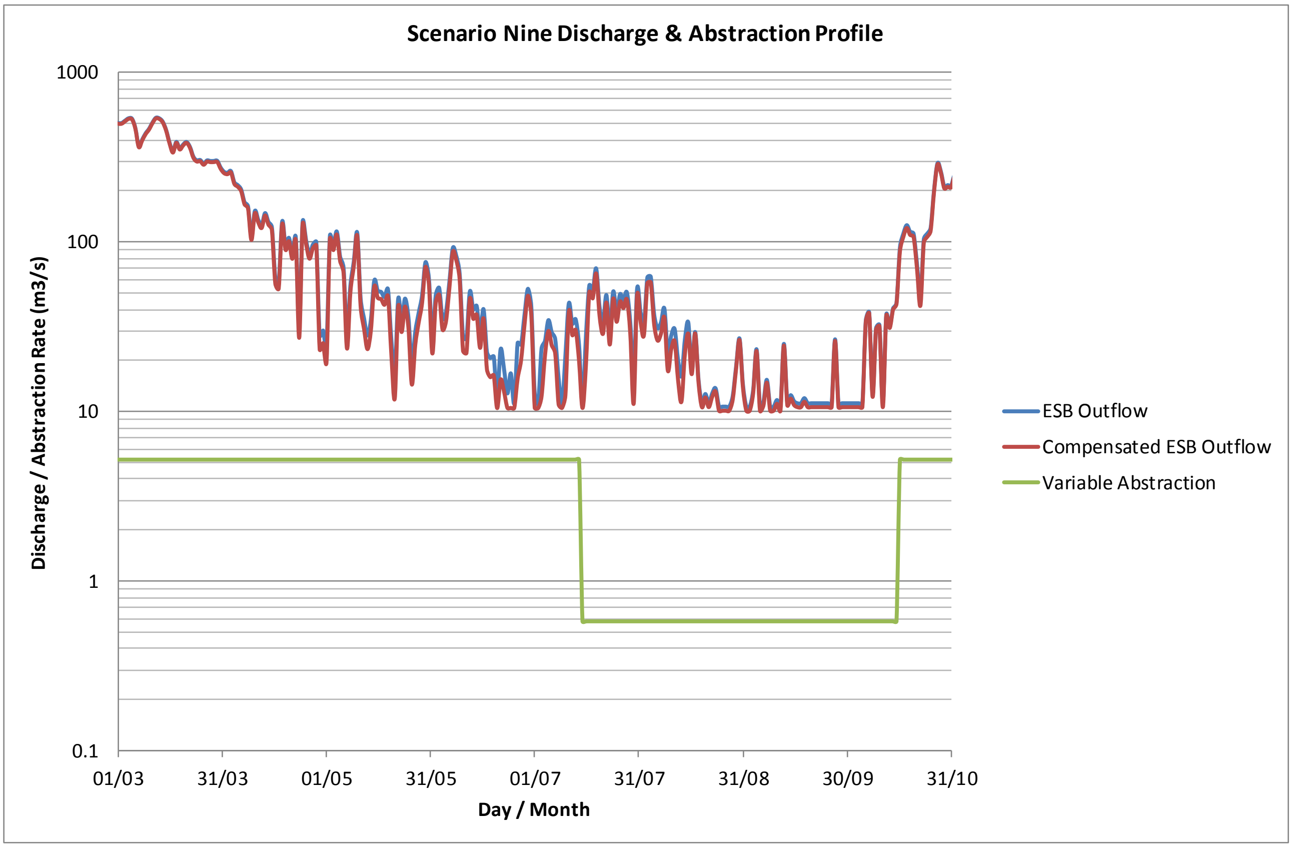
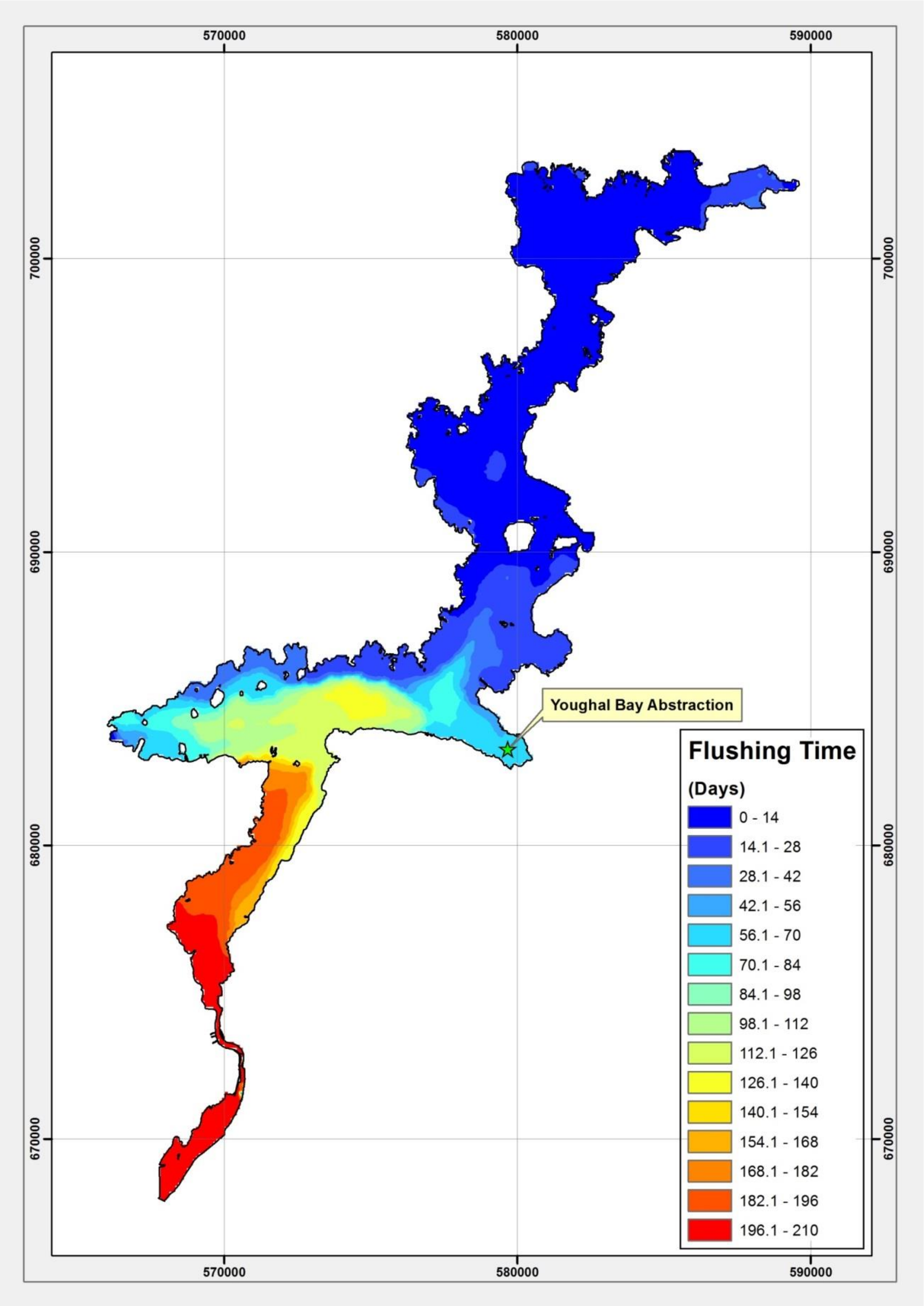


Figure 1: Scenario nine - ESB Discharge Profiles and Abstraction Profile

2. MODEL RESULTS

The result presented from the model scenario on the following page is the spatially varying flushing times as calculated, along with a table defining the parameters of the scenario.

2.1. Scenario Ten: Summer – 410:50 variable abstraction in Youghal Bay



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
10	Youghal	410:50 Ml/d	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95

Figure 2: Scenario Ten Flushing Time

3. ANALYSIS

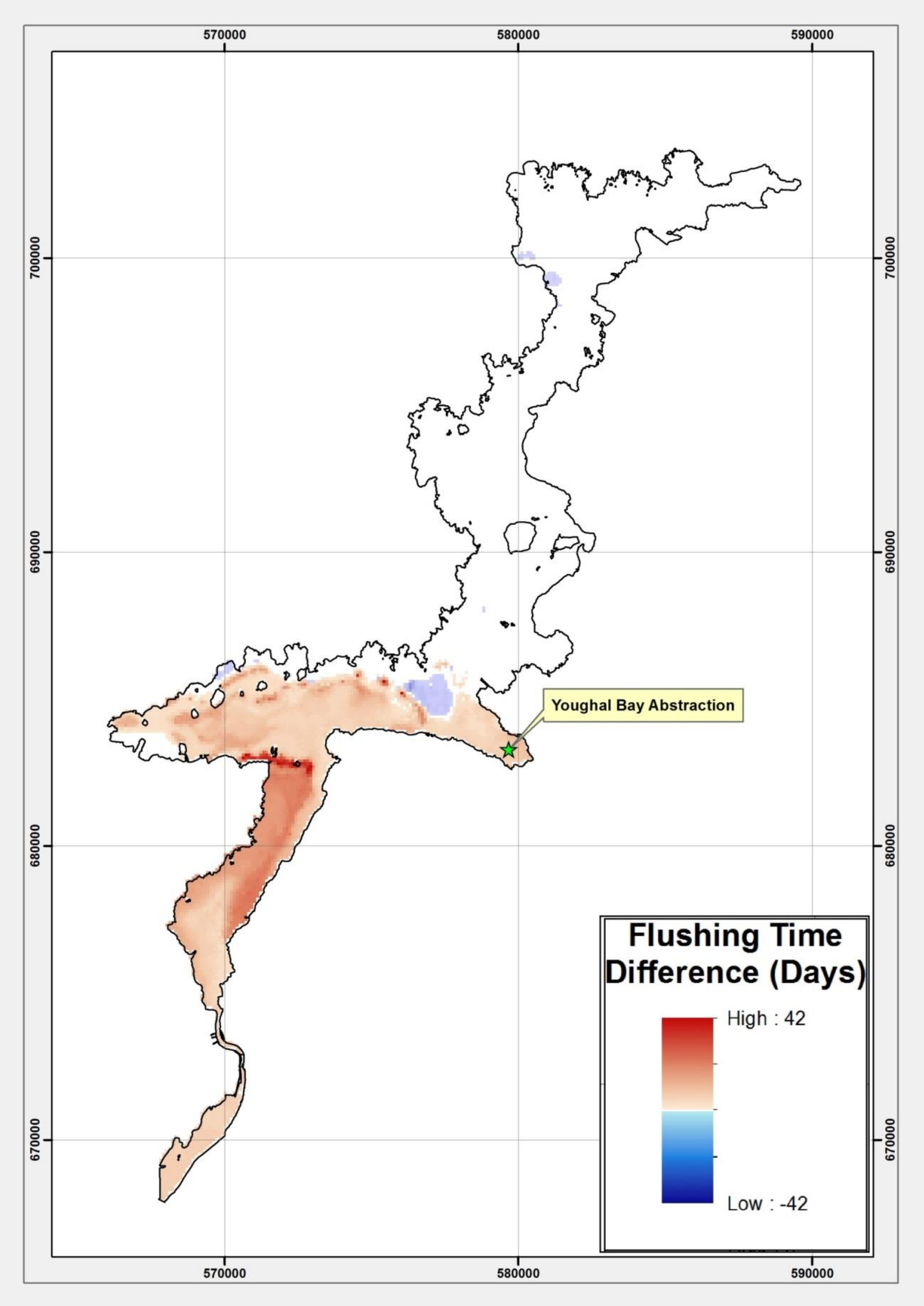
Visual inspection of the above figure shows that there were significant spatial differences in flushing times throughout the Lough Derg and Parteen Basin waterbody for the summer periods. Longest flushing time during summer months were approximately 210 days.

The locations featuring the shorter values of flushing time presented in the figure are predicted to be faster to respond to changes in pollutant concentrations from the principal riverine input, namely the River Shannon. The corollary is that the areas with the longest flushing times were predicted to be the slowest to respond to changing pollutant loadings, and thus susceptible to excess nutrient accumulations.

To determine if the modelled abstraction option resulted in significant changes to the flushing characteristics of the waterbody the following method was adopted; the calculated flushing time distributions for the modelled abstraction option was subtracted from the calculated baseline (no-abstraction) flushing times.

The resulting difference in flushing time was then plotted throughout the waterbody to determine the potential effects on flushing times above normal baseline conditions due to the abstraction options. In all analyses, any small change in flushing time (+/-1 day) was blanked out.

Scenario Ten: Summer - variable abstraction in Youghal Bay



Scenario	Abstraction Location	Rate	Season	Spin-up Period	Simulation Period
10	Youghal	410:50 Ml/d	Summer	01/03/95 – 01/04/95	01/04/95 – 31/10/95

Figure 3: Scenario Ten impact on Flushing Time

4. DISCUSSION

The reason for the increase in flushing times in the central and southern portions of Lough Derg / Parteen Basin was that the flow through the system for the period of simulation (01/04/1995 – 31/10/1995) were in general very low. For the 410:50 variable abstraction rate, the abstraction represented a very high percentage of that flow at the location on the western shore approximately half way down the lake. This resulted in a much reduced volume of water passing on through the remaining lake system.

The 410:50 variable abstraction regime from Youghal Bay shows significant increases in flushing times in the middle and southern regions of the waterbody.

5. CONCLUSIONS

The ‘First Pass’ preliminary modelling exercise was undertaken to determine whether any changes in flushing characteristics of Lough Derg / Parteen Basin could be ascertained due to a number of potential abstraction locations and abstraction regimes.

Based on the results from the model it has been found that significant changes in flushing time characteristics arise during low flow summer time conditions.

The most significant changes in flushing time in Lough Derg were of the order of +42 days for an abstraction located at the northeast of Lough Derg, with the magnitude of the impact decreasing the further down through the lake system the abstraction point was located.

Water Supply Project
Eastern and Midlands Region

Appendix D
Garryhinch Review Report

Water Supply Project – Eastern and Midlands Region

Preliminary Options Appraisal Report
Appendix D – Garryhinch Review Report

October 2015 **Revision F02**

Table of Contents

1 Introduction

1.1 Introduction

Appendix G of the Preliminary Report of 2010 examines the civil and soils engineering aspects of the raw water storage reservoir options. In particular it examines the recommended storage site at Garryhinch, which was part of Option F2 of the SEA. Option F2 was the provisionally recommended option, subject to water quality surveying and modelling on Lough Derg, but also subject to subsoil investigations at Garryhinch. Appendix G of the Preliminary Report was a comprehensive assessment of three possible raw water storage sites in the midlands, but focussing on Garryhinch, supported by volumetric analysis of excavation, re-use calculations for embankment materials, and borrow area sizing for winning of rock and stone material on site, all within the limits of the subsoil investigation work at the preliminary stage of design.

The Preliminary Report acknowledged the need for further assessment of risks to be considered in the design and the authors list a number of risks, which were to be addressed in further investigations before the question of feasibility of a raw water storage system at Garryhinch is definitively settled. These included:-

- Catastrophic failure risks with flooding
- Greater than expected reworking requirement on silt/clay, or the requirement for synthetic lining
- Risk of karst features resulting in seepage or washout and calling for remedial work
- Greater than expected depth to bedrock
- Groundwater being higher than predicted, or seasonal artesian effects, both with dewatering and uplift consequences,
- Greater than expected peat excavation depths
- Environmental impacts from working area runoff.

Further subsoil investigations were carried out at Garryhinch Bog in late 2014 and early 2015, as part of the Water Supply Project, to supplement the subsoil investigation at the preliminary stage of design.

This Report discusses the interpretation of the supplementary subsoil investigation data as part of the appraisal of the risks associated with the construction a large scale storage system at Garryhinch Bog.

1.2 Garryhinch Bog

The site at Garryhinch is owned by Bord na Móna and it is a former major sod peat production facility. It is located north of the R423 Portarlington to Mountmellick road and east of the N80 road between Mountmellick and Tullamore. The site area is approximately 580 hectares.

The site at Garryhinch has an Integrated Pollution Control Licence (503-01) issued by the EPA and which covers a large area of the Allen Group of peatlands in Laois, Offaly and Kildare.

The River Barrow flows to the west and south of Garryhinch Bog and is designated as a Special Area of Conservation (cSAC) as shown in Figure 1.1.

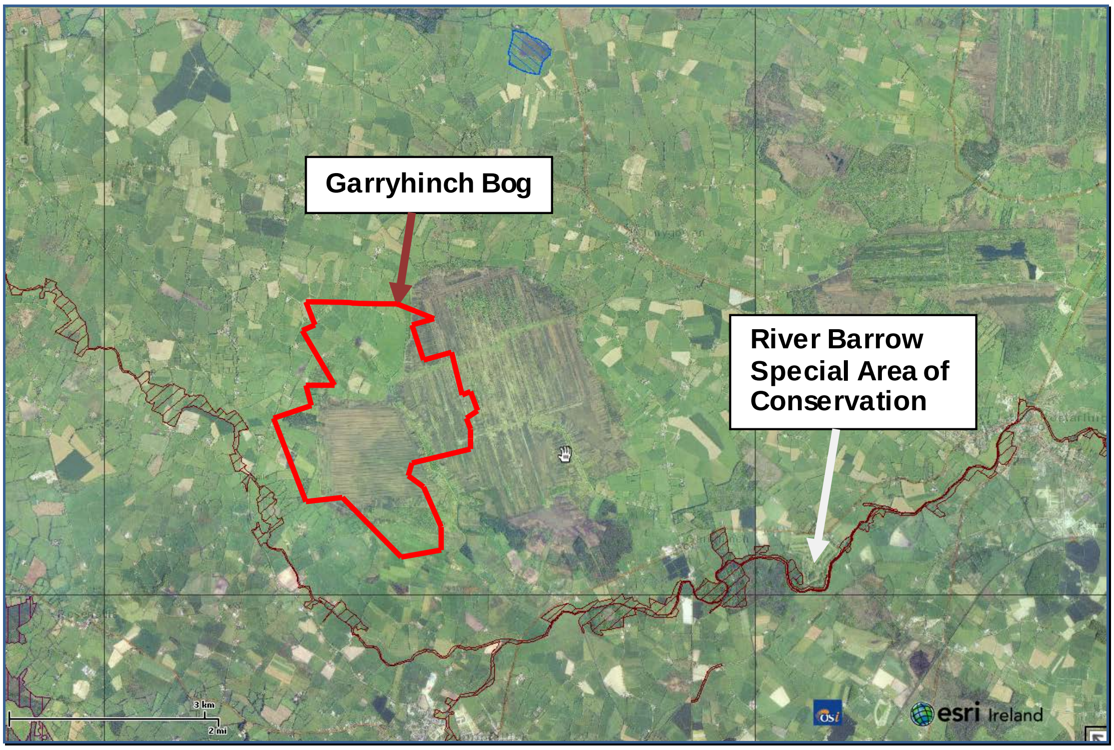


Figure 1.1: Conservation Areas – River Barrow Special Area of Conservation

2 Preliminary Report

2.1 Preliminary Report Options for Storage

The Preliminary Report examined three design options with respect to the provision of raw water storage at Garryhinch Bog, as follows:

- Option 1 – Initial Design Concept
- Option 2 – Curved embankments
- Option 3 – Cut to fill balance approach

For the three options it is envisaged that the reservoir would be constructed in three separate cells, two outer cells and an inner cell.

The layout of Option 1 incorporates linear embankments with a typical height of 6m incorporating 1m of freeboard, 4m of active storage and 1m minimum depth of water at the base of the reservoir. The layout incorporates three reservoirs with all three functioning in the same manner, i.e. the water level in each reservoir may be drawn down by up to 4m.

The layout of Option 2 incorporates curved embankments for the three reservoirs. The concept is based on the following:

- The water level within the two outer reservoirs would fluctuate by a maximum of 3m with a minimum depth of 1m maintained across the bases.
- The water level within the central reservoir would fluctuate by a maximum of 6m.
- The central reservoir would be used to augment the outer reservoirs.

Option 3 envisages the three reservoirs being constructed with a cut to fill balance by excavating through the peat and into the underlying silt. The base of the reservoirs would be founded within the silts at the base of a sand and gravel horizon which would be excavated for reuse as general embankment fill. The floor of the reservoirs would be taken below the groundwater table, thus requiring uplift pressure to be addressed. Option 3 was only considered in brief in the Preliminary Report as it was recognised that further detailed site investigation and testing would be required to ascertain the suitability and distribution of soil deposits on site, as well as the seasonal fluctuation of the ground water table.

2.2 Sludge Storage

The proposal put forward in the Preliminary Report for a facility at Garryhinch also included sludge residue storage on site, in six sludge lagoons to be constructed with the same technology as the reservoirs. The six lagoons would have a total plan area of approximately 175,000m^2 and a total stored volume of 450,000m^3. This area would have its own strip excavation, lining and earthworks requirement.

3 Ground Conditions

3.1 Geology of Garryhinch Area

This section briefly describes the relevant characteristics of the geological materials that underlie the Garryhinch site. It includes a framework for the assessment of groundwater that will follow in later sections. Bedrock information was taken from a desk-based survey of available data, which comprised the following:

- County Offaly Groundwater Protection Scheme (Daly *et al*, 1998)
- County Laois Groundwater Protection Scheme (Deakin *et al*, 2004)
- Geology Of Tipperary: A Geological Description Of Tipperary And Adjoining Parts Of Laois, Kilkenny, Offaly, Clare And Limerick, To Accompany Bedrock Geology 1:100,000 Scale Map, Sheet 18, Tipperary. (Archer, *et al* 2003)
- Geology of Galway-Offaly: A Geological Description of Galway-Offaly and adjacent parts of Westmeath, Tipperary, Laois, Clare and Roscommon with accompanying Bedrock Geology 1:100,000 Scale Map, Sheet 15, Galway-Offaly. (Gately *et al*, 2005)
- Information from geological mapping in the nineteenth century.
- IDL Factual and Interpretative Reports 2015

The site is underlain by Waulsortian Formation with an area of mapped Dolomitised Waulsortian located to the east. The Waulsortian Formation is comprised of pale grey crystalline, fossiliferous fine-grained unbedded limestones, with fossiliferous or pale cherty shaly interbeds. The Ballysteen Formation which underlies the Waulsortian Limestones is mapped to the west of the overall site. The Ballysteen formation is comprised of well bedded bioclastic limestones and argillaceous shales.

Based on a review of the borehole logs from the recent site investigation works, and referring to Drawing 1001 in Appendix A of this report, the majority of boreholes are undolomitised with the exception of RC80 and RC81 located to the south of the site. Dolomitisation is a process whereby calcium ions are replaced by magnesium ions in the crystal lattice, converting the mineral Calcite (CaCO3) to Dolomite (CaMg(CO3)2). Because the magnesium carbonate has a different crystal structure, it creates additional void space in the rock, and can advance the development of permeability and, in some cases, karstification (Deakin *et al*, 2004).

Figure 3.1 shows the classification of bedrock in the Garryhinch Area, which is Carboniferous Limestone. The majority of the site contains Waulsortian Limestone and is typically a massive unbedded lime-mudstone.

The Geological Survey of Ireland does not indicate any karst features within the Garryhinch site. However, Waulsortian Limestone is known to contain karst features. The scope of the site investigation included the identification, through various methods, of any karst features underlying the Garryhinch site.

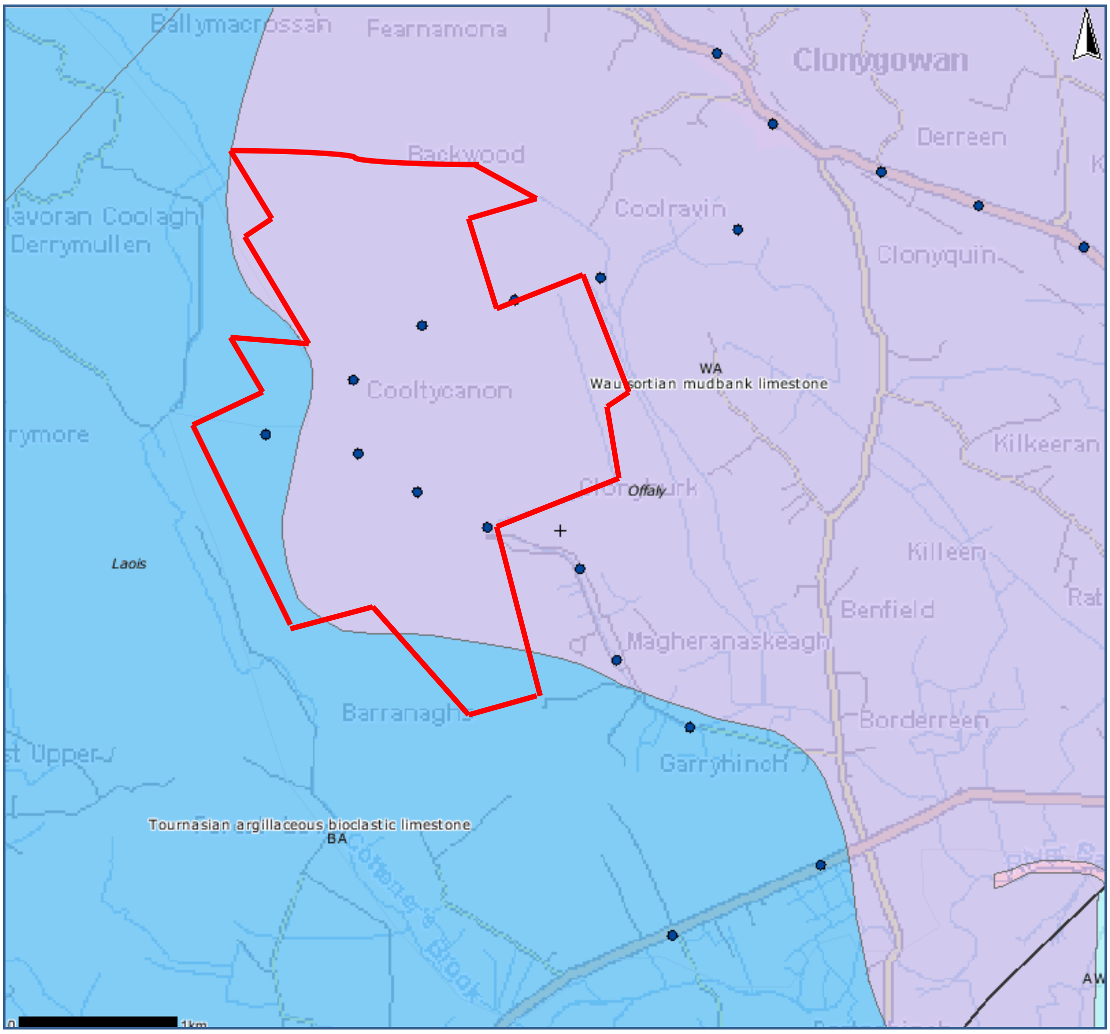


Figure 3.1**:* ***Bedrock Types in the Garryhinch Area

Figure 3.2 shows the classification of sub-soil types in the Garryhinch Area, which is Peat for the entirety of the site.

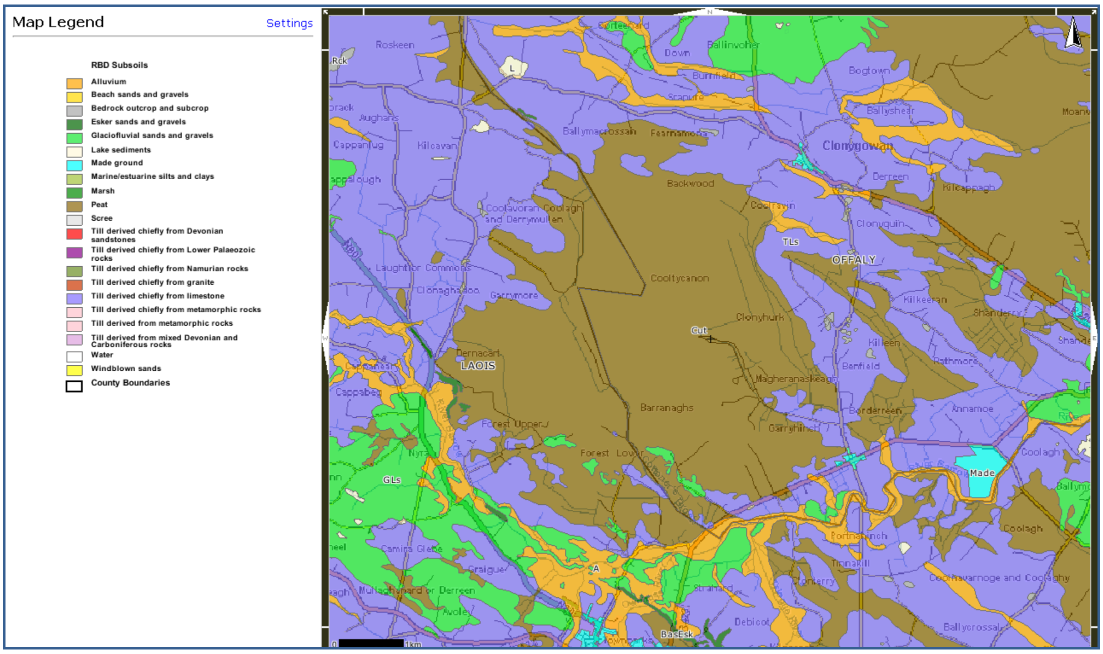


***Figure 3.2**:   Sub-Soil Types in the Garryhinch Area*

Figure 3.3 shows the bedrock aquifer in the Garryhinch Area. The bedrock aquifer underlying the majority of the Garryhinch site is classified as a Locally Important Aquifer and which is moderately productive only in local zones. The National Draft Bedrock Aquifer Map also shows that the Garryhinch site also borders a Regionally Important Aquifer that is karstified. Again the site investigation was scoped to include the identification of any karst features underlying the Garryhinch site.

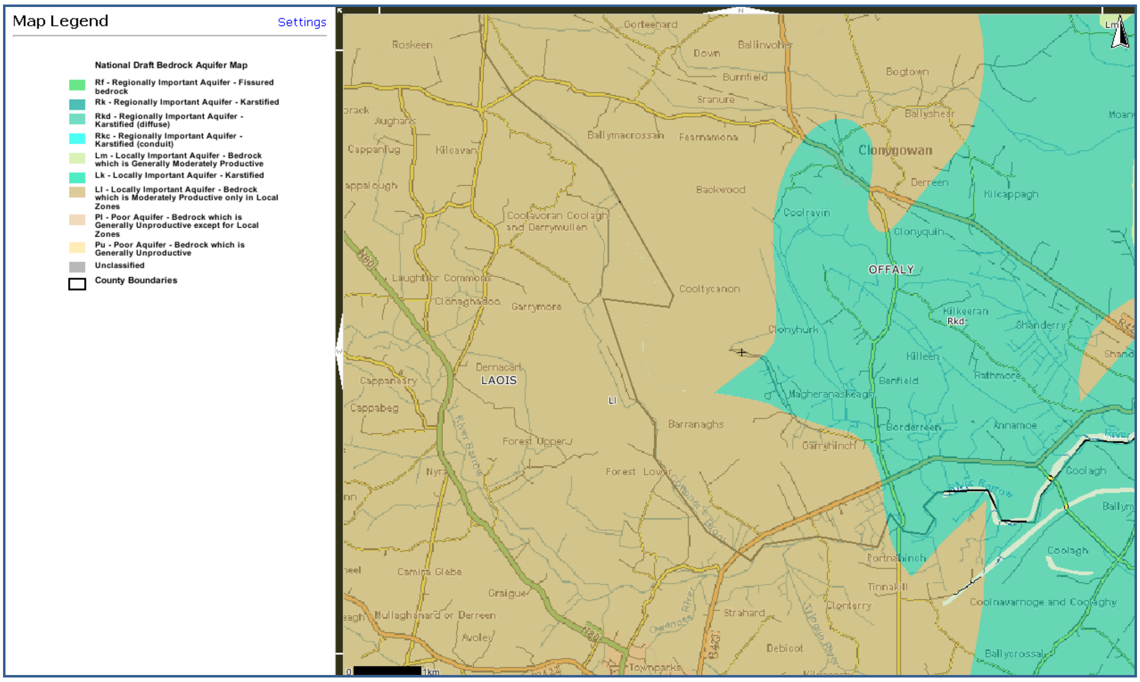


***Figure 3.3:**   Bedrock Aquifer in the Garryhinch Area*

3.2 Historical Site Investigations at Garryhinch

In 2009 a series of trial pits (25 in total) was carried out by RPS across the Garryhinch Site and this was supplemented by seismic and resistivity profiles carried out by APEX Geoservices. Laboratory testing was also carried out in 2009 on the deposits encountered in the trial pits below the upper peat layer.

The site investigation indicated a mean depth of peat of 1.2m overlying a mean depth of 1m to 3m of silty sand, with low plasticity in clays present. The natural moisture content of the samples encountered below the peat ranged from 24.4% to 9.2% with an average of circa 14%. The average permeability of this material was 9.96×10^{-6} m/s, but local departures at 10×10^{-3} and 10×10^{-5} were detected where sand and gravel was encountered, so that permeable zones, estimated at 20% of the floor area of the reservoir, were recognised as needing to be mapped and addressed using bentonite enhanced soils (BES). The permeability of the clay material is a question which the authors recommended should be verified.

The Preliminary Report recognised that additional site investigation works would be required to supplement the available ground condition data in order to develop the design of the water retaining structures.

3.3 Site Investigation Contract

Irish Drilling was appointed by Irish Water in October 2014 to carry out a detailed investigation of the ground conditions at the Garryhinch site to support previous investigation works at the site. The fieldwork was carried out between November 2014 and March 2015.

The scope of the fieldwork included:

- 91 light cable percussion (Shell & Auger) boreholes;
- 35 rotary core boreholes;
- 135 trial pits;
- 322 dynamic probes (DPH);
- 1 Macintosh probe;
- 5 DTH boreholes;
- In-situ Shear Vane Tests in trial pits;
- Standard Penetration Tests in boreholes;
- Packer Permeability Testing in rotary core boreholes;
- Undisturbed soil sampling;
- Disturbed bulk and jar soil sampling;
- Groundwater sampling;
- Standpipe installations to monitor groundwater;
- Geophysical Survey;
- Borehole pumping tests.

Laboratory testing was also carried out and included the following scope on soil and rock samples as appropriate:

- Natural Moisture Content;
- Atterberg Limits;
- Particle Size Distribution;
- Sedimentation;
- Compaction;
- Consolidation;

- Permeability;
- Chemical (pH, Sulphate, Chloride);
- Organic Content;
- Density, Compaction, Permeability (0%, 3% and 5% Bentonite Mix);
- Point Load for rock samples;
- Uniaxial Compressive Strength for rock samples.

3.4 Description of Site Based on Subsoil Investigation

Peat was encountered at the surface throughout the site with the thickness of the peat layer varying between 0.4m and 3.9m. The thickness of peat is generally greater around the perimeter of the site, with depths of between 2m and 3m encountered, and with thicknesses greater than 3.5m encountered along the northern and eastern boundaries of the site. The peat thickness in the interior of the site is generally between 0.5m and 1.5m.

The peat is generally very soft to soft and occasionally firm and of extremely high plasticity. Natural moisture contents of up to 569% and undrained shear strengths of between 5 kN/m^2 and 21 kN/m^2 were measured.

Beneath the peat there are deposits of firm to stiff and very stiff gravelly sandy silt with cobbles and boulders. There are areas of the site where granular soils predominate in the form of silty sand and silty sand and gravel. Figure 3.4 shows the locations where sands and gravels were encountered in boreholes and trial pits.

Rock was encountered at between 1.5m and 30.1m below ground level across the Garryhinch site. The rock is limestone and is generally classified as strong to very strong, grey, massive and fine to coarse grained. Discontinuities vary from closely to widely spaced and generally dip at an angle of between 25 and 50 degrees with local variations.

The extent of Geophysics Surveys carried out at the Garryhinch site is shown in Figure 3.5. Figure 3.6 shows the 2D Resistivity Lines A and B while Figure 3.7 shows the Lines I and J.

The 2D Resistivity Lines A, B and C indicate karstified features within the rock and this is verified by the rotary cores and boreholes conducted in this area of the site.

The rotary cores encountered ‘poor’ and highly weathered rock conditions with evidence of karstification in the eastern area of the site covering an area of approximately 300m to 500m in width and approximately 800m in length. This area is shown in Figure 3.8 and is located close to the Regionally Important Aquifer that is known to be karstified.

The 2D Resistivity Line J also indicates karst limestone near the western boundary of the site, as shown on Figure 3.8.

It should be noted that, while the geophysics survey and confirmatory boreholes have established the presence of karst features in the areas shown in Figure 3.8, it is not possible to establish effective absence of such features in the site between these two areas.

It is also noted from three of the pumping wells drilled on the site that cavities were encountered in the rock as follows:

- WH02 – cavity encountered at 40m to 47m depth below ground level
- WH03 – clay bands encountered at 25m depth below ground level
- WH04 – cavity 0,5m wide encountered at 50m depth below ground level.

The locations of the three pumping wells are shown in Figure 3.9.

The risks associated with the construction of the proposed storage reservoirs in the karst areas are discussed in Section 5 of this Report.

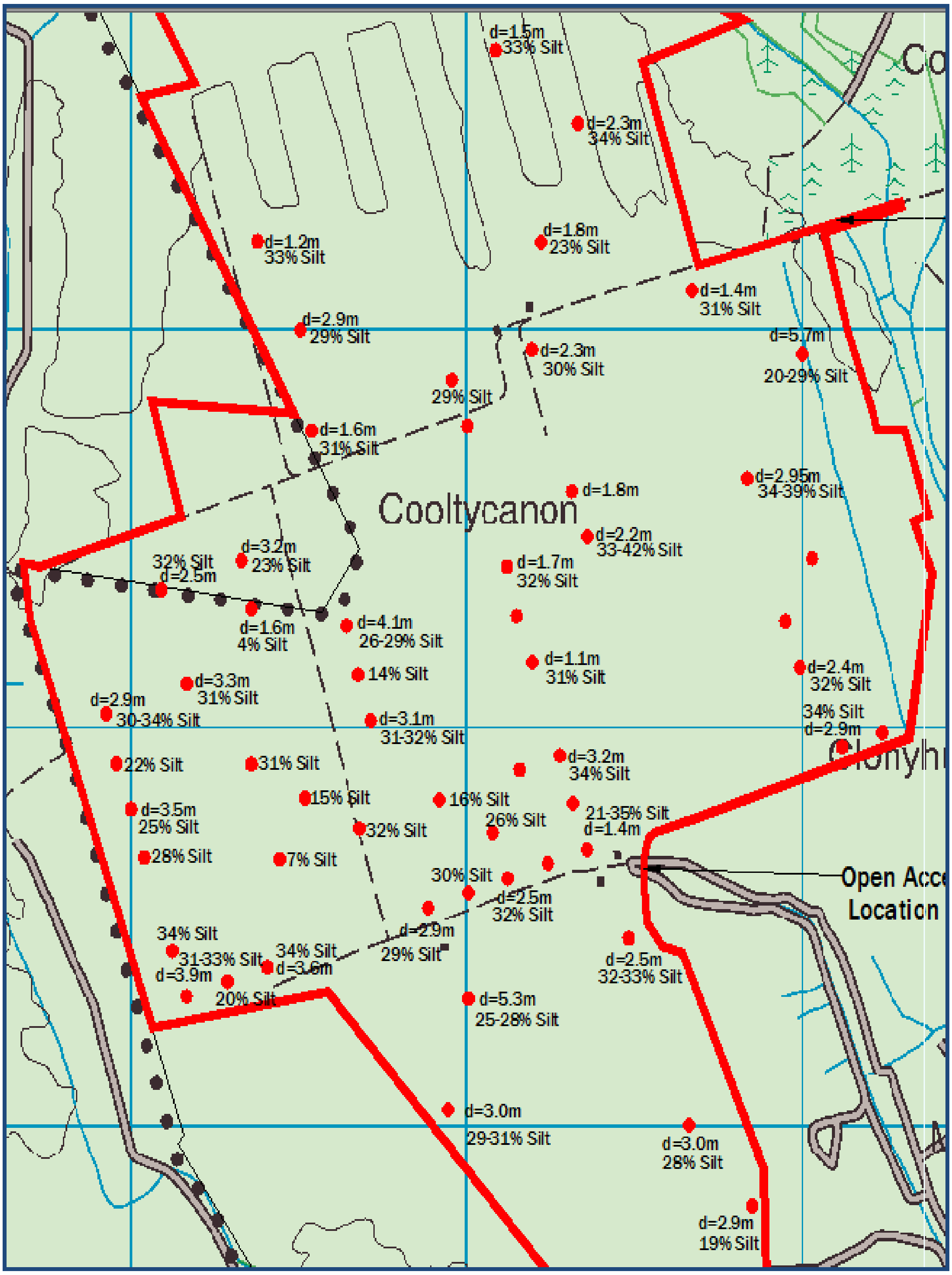


Figure 3.4: Locations of Sands and Gravels

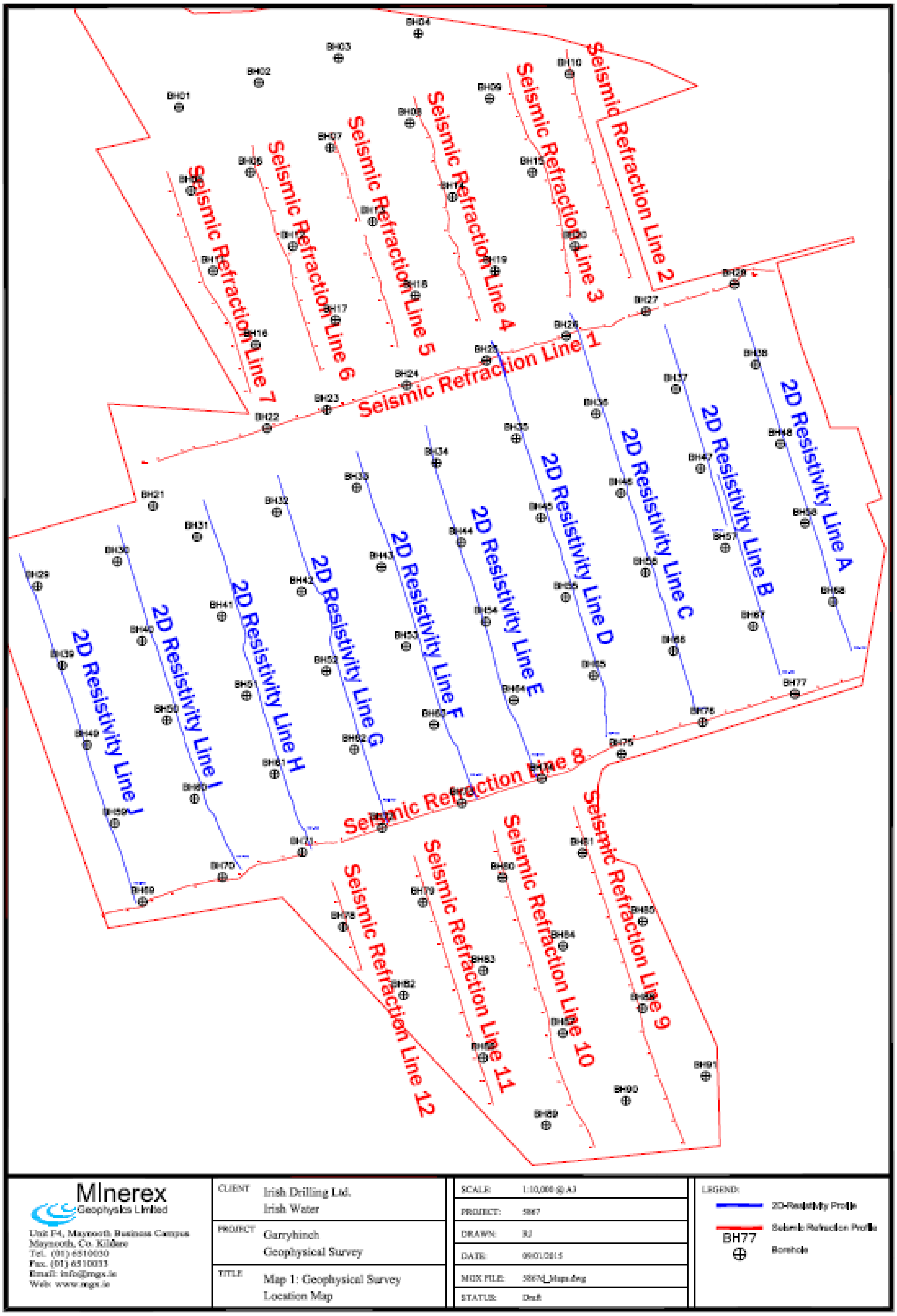


Figure 3.5: Extent of Geophysics Surveys carried out at Garryhinch

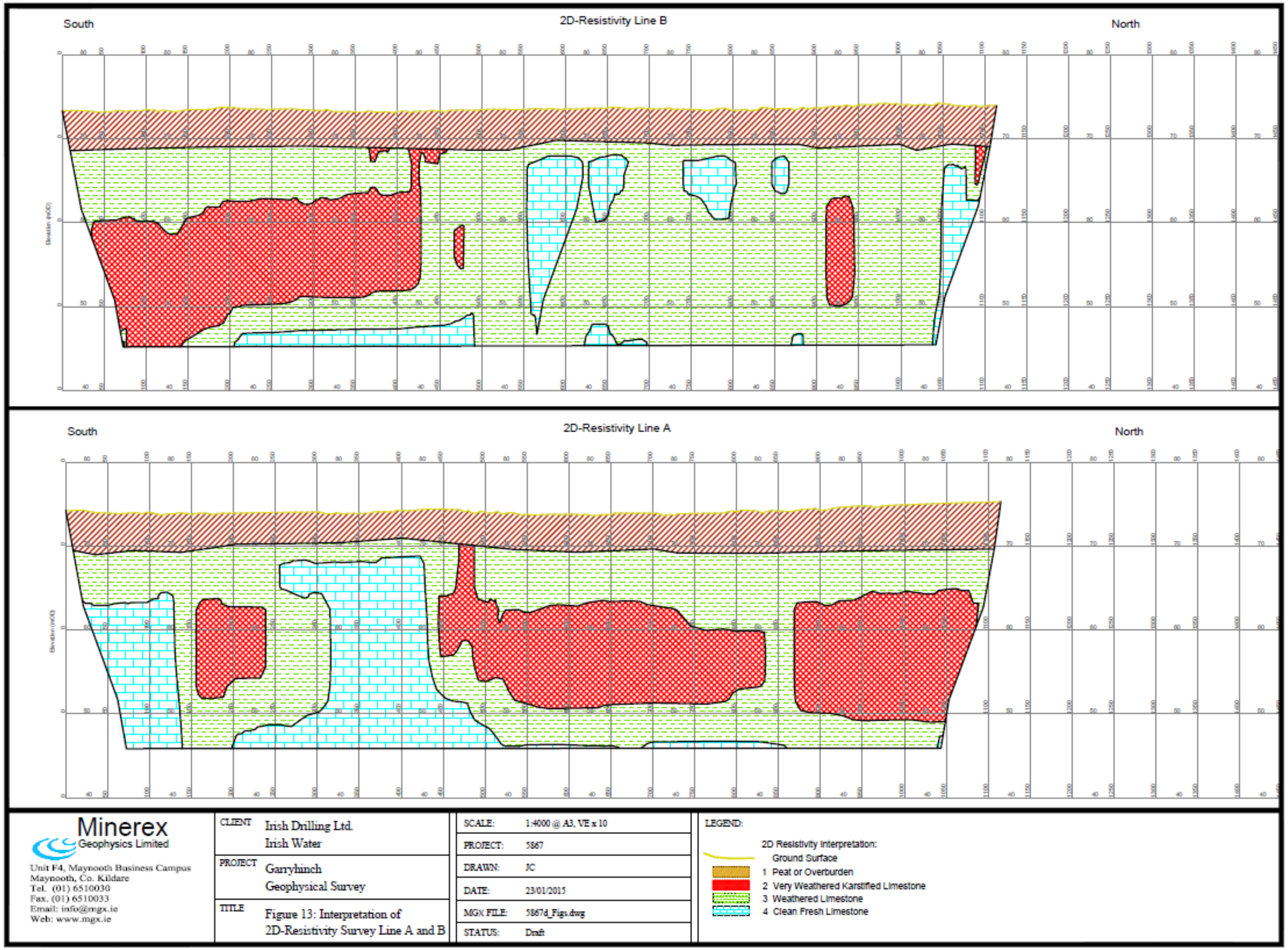


Figure 3.6: Interpretation of 2D Resistivity Lines A and B

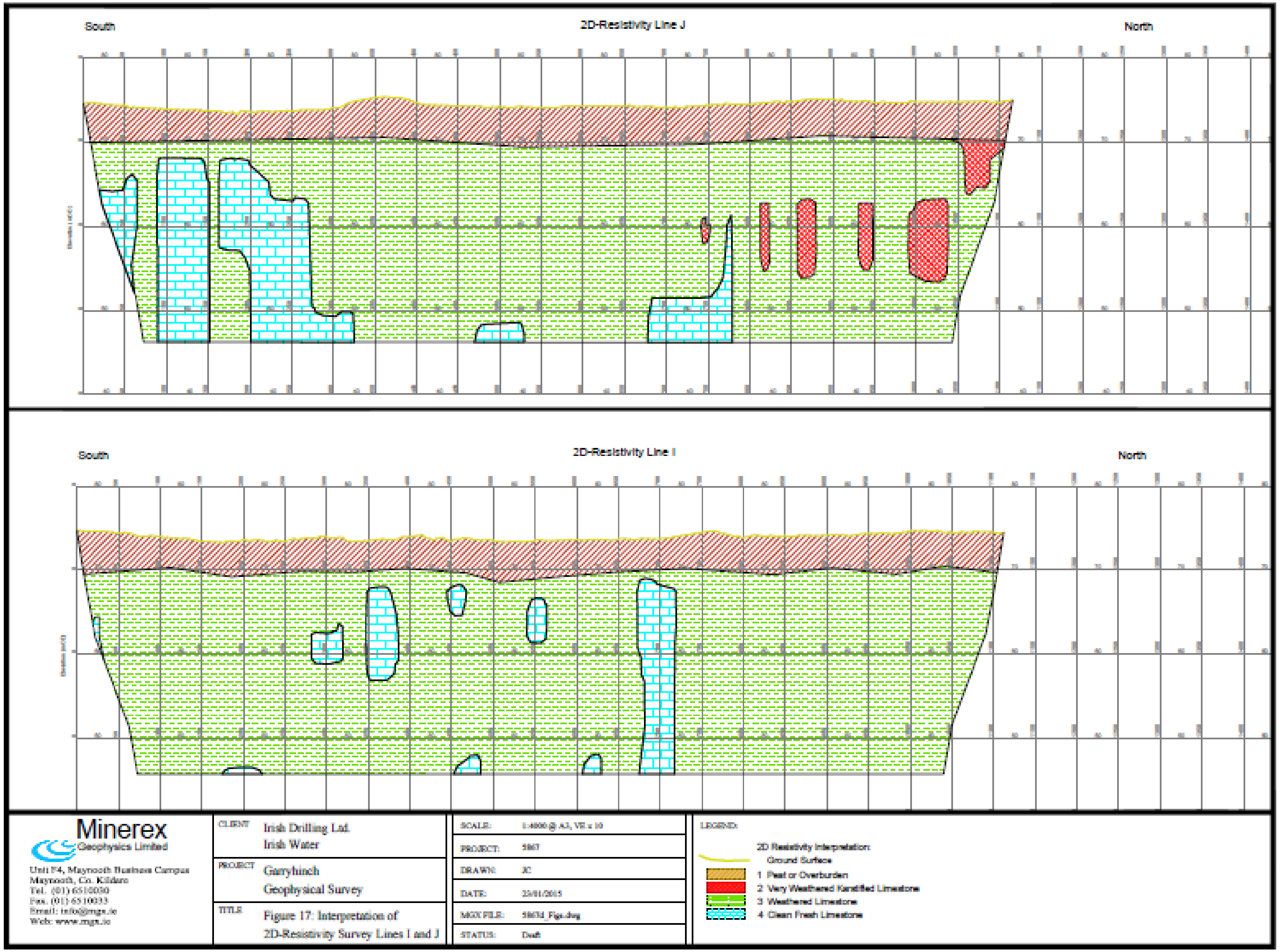


Figure 3.7: Interpretation of 2D Resistivity Lines I and J

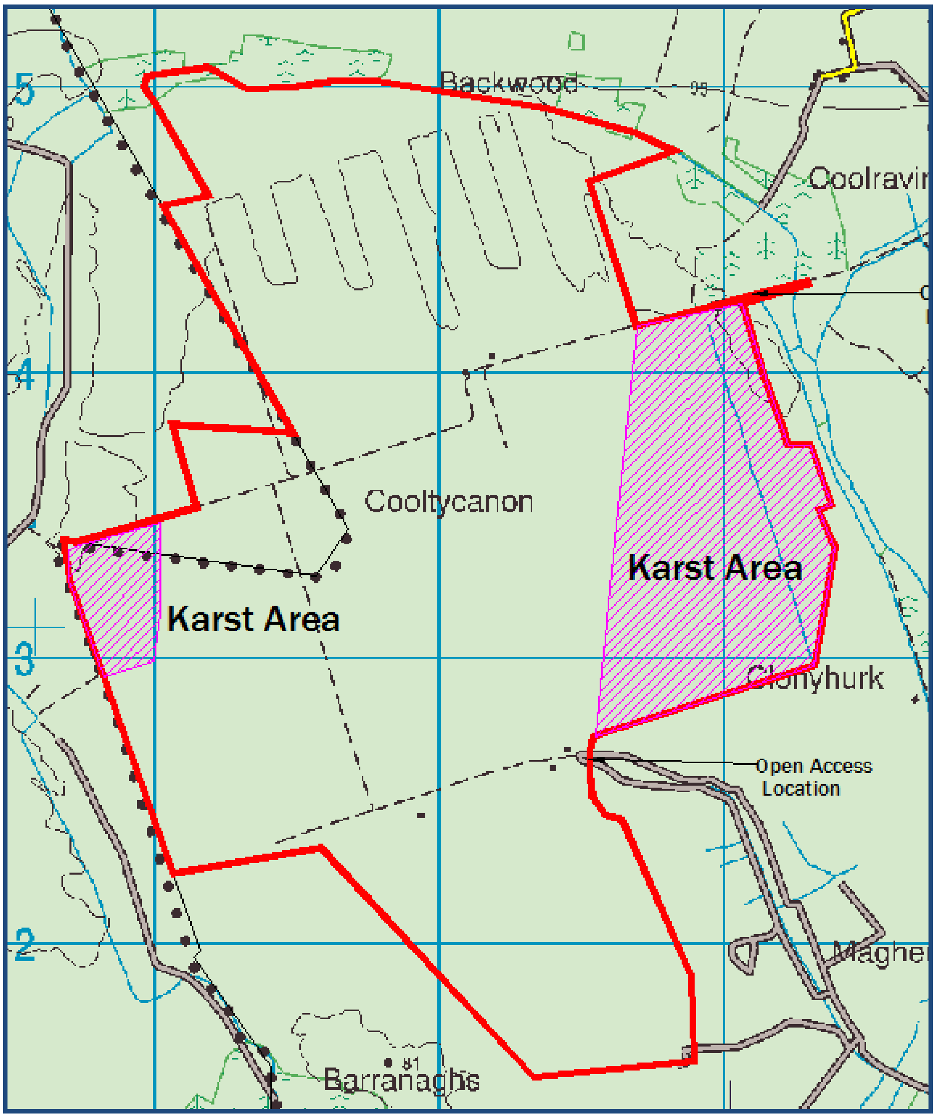


Figure 3.8: Identified Areas of Karst Features

3.5 Groundwater

The Site Investigation Contract included the installation of twenty six standpipes and standpipe piezometers throughout the site. The locations of the installations are shown in Figure 3.9.

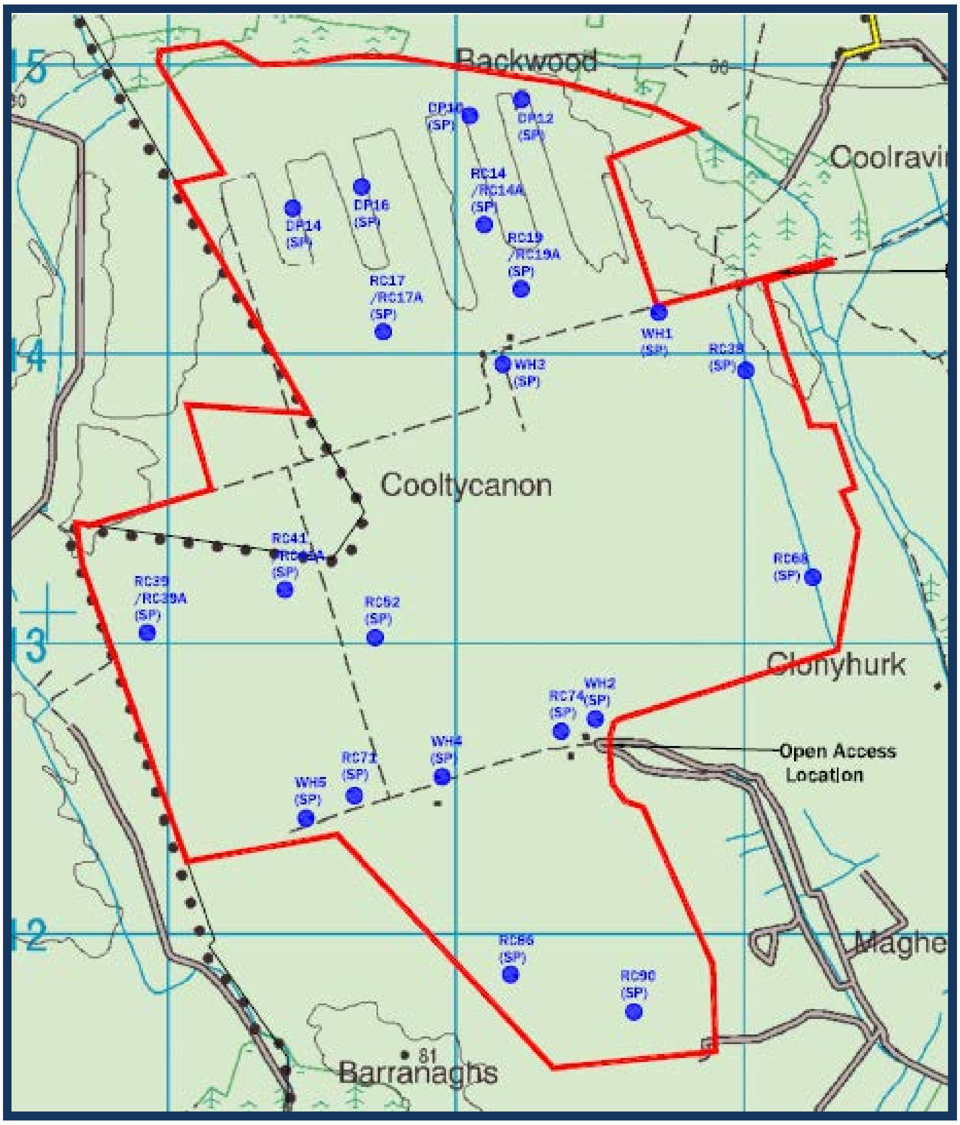


Figure 3.9: Location of Standpipes for Water Level Monitoring (SP = Standpipe)

Water readings from the installations indicate that, in March 2015, the water table was generally between existing ground level and 3.20m below existing ground level. In most cases the depth to water table was less than 1m below ground level with the depth to water table averaging 0.7m over 26 monitoring locations. At 16 monitoring locations the depth to water table from ground level was less than 0.5m.

The March 2015 water table level recorded in the central area of the site and in the area identified for the proposed borrow pit was less than 1m below ground level. Within the footprint of the proposed reservoirs, as set out in the Preliminary Report, the depth to the water table was also less than 1m below ground level at all monitoring locations. Trial pits excavated in these areas of the site in November 2014 showed generally similar groundwater levels.

The greater depth to water was recorded in the monitoring locations closer to the site boundaries where ground levels are slightly higher than in the centre of the site. Overall, across the site, the water level generally varied from 75.5mOD to 71.8mOD and the gradient in water level is from north to south towards the River Barrow. This is a factor to be borne in mind in terms of environmental implications of dewatering and of excavated material disposal at depth, beneath the normal groundwater table for the site.

It should be noted that in March 2015 rainfall amounts recorded at various weather stations throughout Ireland were above the long term average.

Raw Water Storage Option 3, which entails excavation through the peat and silt into the deeper layers of sand and gravel in a cut-and-fill approach, would be very problematic from both the construction and operation perspective due to the high ground water levels and fluctuations in the ground water level.

Problems that would arise during the construction phase include;

- dewatering of the silts and clays which have low permeability would require an extensive network of dewatering points.
- a large scale treatment system would be required for discharges from the dewatering operation in order to mitigate against potential environmental impacts on the River Barrow SAC.
- the likely timescale required for drying the silts for re-use as a low permeability layer for the base of the reservoir would result in an extended construction programme.

Problems that would arise during the operational phase include;

- the base of the reservoirs would be below the water table and would be subject to uplift pressures when the water level within the reservoirs is lowered.
- measures to counteract uplift pressures, such as well point pumping and a pumped drainage network, would form a significant cone of depression that would extend beyond the site boundary.
- significant mitigation measures would be required to ensure that drainage of this scale does not impact on the environment including the River Barrow SAC.

During May 2015 water table levels dropped by between 0.2m and 1.6m. Similar to the recorded rainfall in March throughout Ireland, in the month of May 2015 rainfall amounts were also above the long term average. The majority of the soils underlying the peat layer remain within the water table during early summer (May 2015) and this was also the case in early July 2015.

The groundwater table is expected to have seasonal fluctuations in response to rainfall and drought. The karstic nature of the bedrock is such that these seasonal fluctuations are likely to respond rapidly to the rainfall events which cause them. This rapidly varying water table is a factor to be considered in embankment design and in measures to prevent flotation of a raw water reservoir in a near-empty condition.

There was no evidence of artesian water conditions during the site investigation.

4 Appraisal of Preliminary Designs

4.1 Preliminary Report Designs

The Preliminary Designs presented in the Preliminary Report were based on data obtained from 25 trial pits spread throughout the site and some seismic and resistivity profiles across the extent of Garryhinch Bog.

The following Table 4.1 presents the findings of the Preliminary Report site investigations in respect of the depth of the various soil layers.

Depths Below Ground Level	Base of Peat	Base of Sand / Gravel	Top of Silt	Top of Rock / Refusal	Water Strikes
Minimum	0.3	1.85	0	2.2	0.4
Maximum	2.5	4.70	4.7	7.1	4.8
Average	1.2	3.0	0.8	4.0	2.5

***Table 4.1**: Summary of Preliminary Report Site Investigation Findings*

The Preliminary Report site investigation data has now been supplemented by a comprehensive site investigation across the site, incorporating 135 open excavation trial pits, 91 boreholes, 322 dynamic probes and 35 rotary cores.

The supplementary site investigation shows that the depth of peat is similar to the depth ranges identified in the Preliminary Report. It also presents a basis for more detailed quantification of the amount of peat to be excavated in the construction of the reservoirs and provides additional information on the soils underlying the peat layer.

Boreholes and rotary cores were carried out in order to identify the rock levels underlying the site and generally indicate rock at between 1.5m and 30.1m depth below existing ground level. The supplementary site investigation data indicates that rock at large depth exists on the site. The impact of this on the design proposals needs to be assessed, in regions where previously much shallower rock head was identified in the Preliminary Report, particularly in the context of regions with potential karst features. The supplementary site investigation data, obtained from the rotary cores, provides additional information with respect to potential karst features on the site, with karst features identified at, or close to the underside of the overburden. This is relevant to potential voids beneath the proposed reservoir, to the mobility of groundwater and the development of pressures. The risks associated with the construction of a large scale storage reservoir in areas of karst are discussed in detail in Section 5 of this Report but, in summary, include:

- The risk of the unpredictable occurrence, extent and depth of underground cavities which may lead to inadequate foundation support for reservoir embankments and base
- The risk of storing additional water above a karst area, which would promote increased seepage through the weathered rock and may include further karstification with the risk of caverns occurring with the consequent potential for collapse.

- The risk inherent in karst areas of sinkhole collapse caused by lowering the groundwater table to facilitate construction and to prevent uplift pressure during operation.

In March, May and July 2015 the recorded depths from ground level to the water table in the installed standpipes and standpipe piezometers were generally less than those encountered in the 25 trial pits excavated in January 2009. This means that ground water will have a greater impact on construction and operation of the reservoirs than was originally allowed for in the Preliminary Report. In the Preliminary Report the average depth to the water table was estimated at 2.5m and it was concluded that groundwater control may not be as problematic as with other potential sites at Derryarkin and Drumman. Some of the negative aspects of the potential sites at Derryarkin and Drumman included:

- Sheet piling or Bentonite slurry walls with pumping would be required to control groundwater ingress into excavations.
- Water near surface creating a large pressure head for any deep excavation.
- Groundwater near surface level and discharge to areas outside the bounds of the excavation would lead to recharge of the sands and gravels and thus increasing the pressure head.

The negative aspects of the potential sites at Derryarkin and Drumman identified in the Preliminary Report would now equally apply to the Garryhinch site. The supplementary site investigation has shown that water table levels at Garryhinch are higher than those on which the Preliminary Report designs were based, being in fact close to ground level throughout the site. Water levels have a significant influence on the design and construction of the reservoirs and the consequences of the higher water table levels encountered in this subsoil investigation are discussed later in this report (refer Sections 4.3, 4.4 and 4.8).

4.2 Design Basis for Options 1 and 2

The design basis for Storage Design Options 1 and 2 as presented in the Preliminary Report included:

- Stripping the peat from the footprint of the reservoir and embankments.
- The creation of raw water storage reservoirs by the construction of 6m high embankments.
- The sourcing of construction materials and rock for the embankments from within the site in a borrow pit area.
- The construction and sealing of the embankments using a blinding layer, a low permeability liner or Geosynthetic Clay Liner, a separation Geotextile for protection and rock armour for erosion protection.
- Construction of the reservoir on top of the silt/clay layer, utilising its low permeability as a barrier seal and thus avoiding the need to import liner material.
- Bentonite enhancement of the sands and gravels towards the south of the site so as to reduce the permeability in this area. (Approximately 20% of the floor area of the reservoirs was considered to require bentonite enhancement).
- The silt/clay would be left intact with little excavation or grading except for at unacceptably high or low points.

The Preliminary Report also identified design issues with these two Options, including:

- The silt and clay may not provide a 100% suitable seal and may require reworking to reduce its permeability.
- Sheet piling or bentonite slurry walls with pumping might be required to control groundwater ingress into excavations.
- The silt and clay materials may not provide a competent horizon for the trafficking of conventional and low load bearing plant across the site and haul roads may need to be constructed.

4.3 Excavation of Peat

The peat at Garryhinch is characterised as very soft (as low as 5kPa) and saturated with moisture contents as high as 569%. This is likely to result in unstable excavations and the peat may become slurry-like in places, making removal and transportation difficult.

The depth of peat is generally at its greatest at the perimeter of the site where the outer raw water reservoir embankments are proposed. Movement in the existing peat from outside the permanent footprint of the proposed works into the excavation area is therefore a significant risk when working with such materials. It is noted that there are some peat harvesting operations continuing at Garryhinch, and the prospect of continued harvesting to minimise the peat remaining at the start of construction is recognised.

Nonetheless, in excavating the remaining peat over such a large area, considerable traffic movements will be required. Trafficking the soils located beneath the peat will result in rapid softening on exposure to groundwater and rainfall. In addition any excavations in sandy soils below the water table, either in the formation of the embankments or in forming a level base for the reservoirs, are likely to encounter running sand.

Consideration would therefore have to be given to using alternative excavation methods to conventional excavators, such as the use of draglines and / or peat harvesting methods.

Dewatering of the Garryhinch site would make the excavation of the peat easier, and we have experience within the team of working with Bord na Móna experts on optimum dewatering, transport and deposition of large volumes of peat in the west of Ireland. The scale of dewatering required would be extensive on a site the size of Garryhinch. In deciding to dewater the peat, consideration would have to be given to

- the timeframe involved,
- the seasonal variations in water levels and
- the scale of treatment required for any discharges in order to prevent environmental impacts on aquifers and designated sites.

Pump tests were carried out on-site in September 2015 to determine, *inter alia*, the feasibility of dewatering the site. The pump tests carried out in two well points at Garryhinch show that a high density of dewatering points would be required throughout the footprint of the reservoirs in order to dewater effectively the extensive area of peat on the site. For example, pumping at a rate of 11.75m^3/hr at well point WH02 (refer Figure 3.9) lowered the ground water level by 3.21m within WH02 but at a distance of approximately 90m at standpipe BH74 (refer Figure 3.9) the ground water level was only lowered by 0.38m.

Activities at Garryhinch are licensed by the EPA under an Integrated Pollution Control Licence which limits the discharge of suspended solids to water courses to 35mg/l and silt ponds for drainage water must achieve the following minimum performance criteria (flood periods excepted):

- Maximum flow velocity < 10 cm/s
- Silt design capacity of lagoons, minimum $50m^3$ per nett hectare of bog serviced.

Based on a footprint for the reservoirs and embankments of 340 hectares, a silt lagoon volume of $17,000m^3$ would be required for drainage water to comply with the licence. A dewatering system to facilitate the excavation of the peat from this footprint would require the provision of a silt lagoon many multiples of the size required for natural drainage water. In excavating peat to the scale required to facilitate construction of the embankment and reservoirs, the amount of suspended solids will be significant in soft saturated conditions. It is likely (from our experience at similar scale at Bellanaboy Gas Terminal in Co Mayo) that a water treatment plant would be required to remove suspended solids for the scale of dewatering required for a site of this extent. Local drains on site are unlikely to have the capacity to convey such volumes of water and extensive upgrade would be required. Furthermore, operations to dewater the site must comply with the Groundwater Regulations, 2010, where:

- discharges liable to cause groundwater pollution shall be controlled so as to prevent or limit the input of pollutants into groundwater;
- the direct discharge of pollutants into groundwater is prohibited.

Under the Groundwater Regulations pumped groundwater associated with the construction or maintenance of civil engineering works may be permitted subject to a requirement for prior authorisation, provided such discharges and the conditions imposed, do not compromise the achievement of the environmental objectives established for the body of groundwater into which the discharge is made.

Local drains discharge to the River Barrow, which is close by and is designated as a Special Area of Conservation. Strict standards for discharge to the River Barrow Special Area of Conservation would apply in order to ensure that the conservation objectives are not compromised.

Conservation objectives include:

- To maintain the favourable conservation condition of White-clawed crayfish which is present throughout the SAC. Water quality required of at least Q3-4.
- To restore the favourable conservation condition of Brook lamprey throughout the watercourse.
- To restore the favourable conservation condition of Salmon. Water quality required of at least Q4.

The status of the freshwater pearl mussel (*Margaritifera margaritifera*) as a qualifying Annex II species for the River Barrow and River Nore SAC is currently under review. The outcome of this review will determine whether a site-specific conservation objective is set for this species. This must be regarded as a significant latent project risk for discharge of excavation dewatering flows, even if treated to a very high standard. Over the three day pump test, the electrical conductivity of the water pumped from WH03 was on average 722µS/cm. An electrical conductivity value of greater than 500µS/cm would indicate that the water may not be suitable for certain species of fish or macroinvertebrates and appropriate treatment would be required for dewatered groundwater before allowing discharges that would eventually drain to the River Barrow SAC.

4.4 Stockpiling and Disposal of Peat

The preliminary design for Garryhinch envisaged that excavated peat would either be disposed of on-site or used as landscaping fill. The proposal for on-site disposal of peat included creating a borrow pit by quarrying rock for re-use in embankment construction and backfilling it with excavated peat, all in an area that has a high groundwater table. The area identified for the quarried rock borrow pit is located to the south of the Garryhinch site and slopes towards the River Barrow SAC, which, at its closest, is 0.6km south of the site.

In order to dispose of the peat on site or to use it as landscaping fill it would first need to be stockpiled before space becomes available for it in the quarried rock borrow pit. Peat has a potential for instability even at very low slope angles (to 5^o) and it would not be recommended to stockpile the peat in embankments higher than 1m in order to reduce the risk of instability. This recommendation is based on the finding of the additional investigations of the nature of the peat and the groundwater table at Garryhinch. As peat depths are already of the order of 1m, there are significant logistical issues with sourcing stockpile areas on a site where the footprint of the storage reservoirs and proposed borrow pit area account for circa 90% of the total site area. The borrow pit would not become available for on-site disposal of the peat until such time as all materials for the construction of the embankments are excavated. It is likely that the rock from the borrow pit would need to be excavated in advance and also stockpiled on-site for later use in the embankment construction. Early excavation of the borrow pit would allow the pit to be used as the disposal location for the excavated peat, but this would be subject to environmental acceptability of disposal of such material, below the groundwater table, where the water level gradient is toward the River Barrow, and where such groundwater flows are part of baseflow in the River.

Once the fibrous structure of the peat is broken in the initial lift, it must be placed into semi permanent repositories to allow it dry out before it can be excavated again. The length of time that this process may take is heavily dependent upon drainage and weather conditions and the depth of the stockpile itself. At Garryhinch, where there is a high ground water table and limited free space for shallow stockpiling of peat, it is likely that it would take more than one season to dry out the peat. Large scale movement of peat entails many difficulties as we would have experienced on large infrastructural projects in this country such as our work with Bord na Móna at Srahmore in County Mayo, in relation to the Corrib Gas Project.

There are also some significant issues that need to be considered with respect to disposal of the peat within the borrow pit at levels below the water table, such as:

- Filling of the bottom two metres of the borrow pit is likely to be relatively easy to achieve using conventional methods; however filling above this level will require alternative means as the peat will not be suitable for traffic.
- The borrow pit is predominantly below the groundwater table and continuous dewatering would be required during the deposition of peat. The control of suspended solids in the dewatering process would present a significant challenge.
- The plan area and depth of the borrow pit will not permit reach from the sides of the pit.
- The peat could be pumped into the borrow pit but would need to be in a near liquid state for this operation. The volume and depth of the liquid in the borrow pit is likely to present a significant health and safety risk at least until

such time as a firm crust develops over time. Even then, if dewatering ceases, the recovery of the groundwater table to its natural level could weaken any solid crust that had formed.

- As outlined above, the borrow pit is predominantly below the groundwater table and continuous dewatering would be required during the pumping of peat into the borrow pit (see sub-section 4.8 below). The control of suspended solids in the dewatering process would present a more significant challenge in this instance.

The potential for use of the peat as landscaping fill is discussed in Section 4.5.

4.5 Embankment Construction

The proposed embankments were envisaged in the Preliminary Report as being constructed as follows:

- The peat layer beneath the embankments would be removed.
- The embankments would be constructed from material won from borrow pits opened on site, predominantly quarried rock.
- Rock embankments would be free draining, thereby alleviating any pore pressure build-up as a result of leaks that may destabilise or erode the embankment.
- For the most part, the embankments would be formed directly on the silt / clay layer exposed by stripping out the peat.
- Where the embankment is constructed on cohesive material, relief drains would be installed within the embankment to channel the water away and alleviate any pore water pressure build up.
- The inner slopes of the embankment would be sealed with a liner system; HDPE liner, PVC liner, Geosynthetic Clay layer or Natural Low Permeability Clay.
- Erosion protection would be placed on the inner embankment slopes in the form of graded rock armour or stone rip-rap, sourced from an on-site borrow pit.
- Erosion protection of the outer slopes and crests would be in the form of a grassed surface.
- The outer slope of the embankment structure would have a slope of 1:2 but could be reduced if the fill material is stable at the reduced slopes. It was envisaged in the Preliminary Report that the outer slope would be landscaped with peat to a slope of 1:5.
- The crests of the embankments would be 5m wide to allow vehicular access.
- The inner slope of the embankments would have a slope of 1:3.
- At the toe of the inner slope a cement / bentonite slurry cut off wall would be constructed. It was envisaged in the Preliminary Report that this would extend down to rock level and that the depths involved were in the range of 2m to 5m.

The removal of the peat beneath the footprint of the embankments is recommended in the preliminary design and this is supported by the finding of the supplementary site investigation information. It is advisable to remove the peat before placing of embankment fill in order to minimise the risk of circular slip failure and minimise the short-term and the long-term (creep) settlement that would occur in the peat. The supplementary site investigation measured the co-efficient of volume change (m_v) in the peat, which is used to estimate primary consolidation settlements under embankments. Based on an embankment height of 6m and a typical measured m_v

value of 3.3 m^2/MN, it is expected that primary consolidation settlement of the order of 1.3m would occur where there is a depth of 3m of peat below the embankment. This is significant settlement and would require staged construction of the embankment in order to construct it safely, as discussed below. In addition to primary consolidation settlement there would be secondary settlement due to the organic nature of the peat and this could easily be of the order of 300mm over 20 years and would be expected to continue long after 20 years.

Achieving a 6m embankment height over very soft and unstable peat would be extremely difficult with respect to achieving safe consolidation. The embankment would need to be constructed in stages, allowing each stage to consolidate the peat to a level where another stage or height could be constructed without the risk of failure of the lower layer(s). This form of construction would be very slow and protracted, typically requiring consolidation for a period of 1.0 to 1.6 years based on a peat depth of 3m and Cv (coefficient of consolidation) values of 1.8 to 2.9m^2/year, as measured during the laboratory consolidation tests on peat samples. This form of construction would also require careful design and monitoring with the use of in-situ instrumentation such as piezometers, magnetic extensometers, settlement plates, inclinometer tubing, etc. Use of ground improvement in the form of vertical drains at very close spacing could be employed to accelerate the rate of settlement but the treatment and disposal of water would be an issue, as discussed elsewhere. The use of geo-grids could be considered to allow more load to be applied in a shorter time period, but this is unlikely to overcome other issues such as ‘squeezing out’ of very soft peat below a large embankment.

Stabilising the peat under the embankments is unlikely to be an option as previous experience of stabilising with additives in Irish peats has not met with much success, probably due to the typically extreme high natural moisture content and extremely high organic content in the peat.

The recommendation to construct the embankments using rock is well founded as it would minimise or prevent a dangerous build up of pore water pressure within the embankment material that could lead to instability. The supplementary site information indicates that the re-use of existing soils for embankment construction will not be practical because the soils are at or near saturation, due to the very shallow water table, and drying out to achieve an optimum moisture content and maximum dry density is likely to be impractical on this scale.

The outer slopes of embankment structure would be recommended at a slope of no steeper than 1:2. The inner slopes of embankments would be recommended at a slope of no steeper than 1:3. This is in keeping with the preliminary design proposals.

Peat, as stated earlier, has a potential for instability even at very low slope angles (to 5^o) and it would be recommended not to stockpile the peat in embankments higher than 1m in order to reduce the risk of instability. Given that there is in excess of 1m of peat over the entire site this presents a significant logistical problem for stockpiling of the peat at Garryhinch in the area outside the boundaries of the storage reservoirs. Consideration would have to be given to stockpiling off site for later re-use or disposal. The landscaping of the outer slope of the embankment with peat at a slope of 1:5 is likely to cause instability issues based on the information available from the supplementary site investigation of the peat. The preference would be to landscape the embankment with topsoil and grass.

The preliminary design envisaged a cement / bentonite slurry cut off wall at the toe of the inner slope of the embankment. It was envisaged in the Preliminary Report that this would extend down to rock level and that the depths involved were in the range of 2m to 5m based on available site investigation data. The supplementary site investigation data however shows much more significant variations in rock level, particularly in the eastern area of the site where depths to rock were recorded between 2.7m and 42.8m below ground level. The variable rock depth is consistent with the geophysical surveys of the area, which identified potential for karst features. The eastern area of the site presents significant risk of seepage and a cement / bentonite slurry cut off wall is not practical in karst areas with potential for large voids. There is also a risk that other zones of high permeability will exist beneath the cut off wall, which would negate the effectiveness of such a structure. It is very difficult to quantify this risk with standard site investigation techniques and a large scale on-site model would be required in order to identify many of the potential problems.

4.6 Sludge Lagoons

The Preliminary Report proposed the treatment of water works sludges within sludge lagoons. There are other options for the treatment of water works sludges that would need to be evaluated as part of an overall water treatment plant design. This report focuses only on the constructability of the option of sludge lagoons at the Garryhinch site.

The preliminary design for the sludge lagoons envisaged six units having typical internal dimensions of 100m by 200m with an embankment height of 3.5m. The construction envisaged removal of the peat layer and re-grading the underlying silts to achieve a flat base.

The supplementary site investigation data shows that the area identified for the location of the sludge lagoons has potential karst features that would increase the potential risk of failure of the sludge lagoon bases and embankments. There would potentially be significant environmental risks associated with failure of a sludge lagoon given the proximity to the Regionally Important Aquifer and the proximity to the River Barrow SAC.

4.7 Permeability of Soils for Reservoir Base

The Preliminary Report design for the reservoir base was developed on the basis of the successful finding, at Preliminary Report stage, of significant silt / clay beneath the peat with average permeability of 9.96×10^{-6} m/s. The Preliminary Report also recognised that materials vary across the site, from clean sand and gravel to a mixture of gravelly silt and cleaner silt and clay. It was therefore recognised that some areas will have higher permeability and may act as a drain resulting in drainage of the stored water in the reservoirs or as a route for rapid development of groundwater pressures. The Preliminary Report recognises that the high permeability areas would need to be treated by in-situ mixing with bentonite to achieve acceptable permeability and also that it may be necessary to partially rework and re-compact the upper horizon of silt/clay in order to ensure a uniform low permeability layer across the base of the reservoirs.

The permeability of the soils beneath the peat and above the bedrock was estimated in the Preliminary Report, based on particle size distribution curves and the Hazen Formula. The assessment concluded:

- The silt and clay material has a moderate to low permeability.
- The method of estimation is likely to underestimate the true in-situ conditions.
- The average permeability of thirteen samples was 9.96×10^{-6}m/s.
- The sand and gravel material have a permeability of 10×10^{-3} to 10×10^{-5}m/s and represent permeable zones.

The scope of the supplementary site investigation included several methods to measure permeability of the soils encountered throughout the site and included:

- Particle size distribution and the Hazen Formula
- Constant Head Permeability Tests
- Rising and Falling Head Tests
- Packer tests in rock.

Overall, the wide variety of soils on the site produces a wide variation in permeability as the test results outlined below show:

- A sample of sand from a trial pit contained 4% silt and has a permeability of 4.8×10^{-4} m/s. The sands therefore have high permeability similar to that outlined in the Preliminary Report.

- Sandy coarse gravels with low silt content have permeability of 9.0×10^{-5}m/s (7% silt) to 3.2×10^{-6}m/s (14% silt). Again this is similar to that outlined in the Preliminary Report, particularly for the lower percentage silt content gravels.

- Generally sands containing of the order of 25% silt have permeability of 1.2×10^{-7}m/s to 8.4×10^{-8}m/s, and this is lower than the average permeability outlined in the Preliminary Report.

- Generally gravels containing of the order of 30% silt have permeability of 1.3×10^{-8}m/s to 8.4×10^{-8}m/s.

- Soils with high silt content have permeability of 10^{-8}m/s to 10^{-10}m/s, which is significantly lower than the average permeability outlined in the Preliminary Report.

- Rock has permeability of 1.1×10^{-6}m/s to 8.4×10^{-7}m/s.

- In the area of the site identified as karstified the potential for high permeability is significant.

Overall the sands and gravels with high silt content and the silty soils, where encountered on the site, have sufficiently low permeability to provide the barrier seal envisaged by the Preliminary Report design and in all cases exceed the average estimate in the Preliminary Report. Suitable permeability for a storage reservoir would typically be 1×10^{-7} m/s.

As recognised in the Preliminary Report the site contains soils with high permeability, assumed to cover of the order of 20% of the site area in the Preliminary Report, where sand with low silt content and sandy coarse gravels with low silt content are encountered. The supplementary site investigation information would indicate that the majority of the soils on the site contain a high level of silt and would suggest that the 20% estimate in the Preliminary Report is conservative. The supplementary site investigation information indicates that sands and gravels with low silt content (less than 20% silt) occur in the central part of the western area of the site (refer Figure 3.4). Where encountered, the silt content of the sands and gravels varied from 4% to 16%. The estimated area containing sands and gravels with low silt content is approximately 6% of the overall footprint of the reservoirs. It is however likely that other pockets of sands and gravels with low silt content exist throughout the site and it would be prudent at this stage, on a site of this nature and scale, to maintain a reasonably conservative approach and allow for encountering high permeability soils over 10% of the site.

The low silt content soils would require bentonite addition so as to lower the permeability. Permeability testing of sandy gravelly silt with a permeability of 9.3×10^{-10}m/s shows that, with the addition of 3% and 5% bentonite that the permeability is lowered to 2.0×10^{-10} m/s and 1.4×10^{-10} m/s respectively. Permeability testing of silty sand with a permeability of 1.1×10^{-9} m/s shows that with the additional of 3% and 5% bentonite that the permeability is lowered to 2.0×10^{-10} m/s and 1.8×10^{-10} m/s respectively. The trials show that the application of bentonite enhancement results in significant lowering of the permeability of the soils encountered at Garryhinch.

The use of trammels would typically be required to enhance the soils with Bentonite. Operation of trammels would require a stable working platform for heavy machinery and this would carry a high risk in a peat area overlying soft soils and containing a high water table.

4.8 Quarried Rock Borrow Pit

The Preliminary Report identified that limestone rock exists below the peat and soils and this rock would provide suitable aggregate for the construction of the embankments. The location of the identified quarried rock borrow pit is to the southern end of the site in an area where it was believed that the rock was of the order of 5m below ground level. The supplementary site investigation shows that rock levels vary generally from 3.5m to 7.1m in this area of the Garryhinch site, with an average rock depth 5.8m. There was however one rotary core in which the depth to competent rock was 15.5m.

The volume of fill required for the reservoir embankments is 1.6 million cubic metres. Additional material will be required to construct haul roads within the site and to upgrade the access routes to the site and it was estimated in the Preliminary Report that the volume of aggregate required would be approximately 50,000m³. The total aggregate requirement equates to a borrow pit of 600m x 600m on plan by 5.7m deep in rock. When accounting for excavation of the overlying peat and soils and the grading of these materials, it was estimated that the plan area required would be of the order of 675m x 675m and would be some 5m below the water table.

It was recognised in the Preliminary Report that the borrow pit would require a large amount of dewatering as the water table was anticipated to be close to the rockhead. It was also recognised that the excavation of the borrow pit and the associated dewatering would have implications for the hydrogeology and hydrology of the area and would need to be considered in detail.

The dewatering of the borrow pit would potentially have a large zone of influence and large volumes of water for disposal due to the depth of excavation required to source the volume of material required on the site. The environmental impact of this could have consequences for the conservation objectives of the River Barrow SAC.

It was envisaged in the Preliminary Report that the borrow pit excavation would be staged with the embankment construction and, as areas of the borrow pit are fully exploited, they could provide a tip area for the stripped peat. It was also recognised in the Preliminary Report that there may be issues with regard to the deposition of peat and potential contamination of the aquifer. As discussed above, a number of issues have been identified with respect to the deposition of the peat in the borrow pit based on the findings of the supplementary site investigation data. In addition the 2010 Groundwater Regulations stipulate that:

- discharges liable to cause groundwater pollution shall be controlled so as to prevent or limit the input of pollutants into groundwater;
- the direct discharge of pollutants into groundwater is prohibited.

Under the Groundwater Regulations pumped groundwater associated with the construction or maintenance of civil engineering works may be permitted subject to a requirement for prior authorisation provided such discharges, and the conditions imposed, do not compromise the achievement of the environmental objectives established for the body of groundwater into which the discharge is made.

The supplementary site investigation data shows that depths to rock in the identified borrow pit area varies from 3.5m to 7.1m with an average of approximately 5.8m depth. A depth of 13.5m to competent rock was however encountered in a single rotary core location to the south of the site. While the supplementary site investigation information generally complements the conclusions of the Preliminary Report with respect to the average depth to rock in the identified borrow pit area it is now estimated that the depth of the borrow pit would have to be approximately 1m deeper than originally envisaged.

Water level monitoring carried out as part of the recent site investigation shows that groundwater levels in the borrow pit area of Garryhinch in March 2015 were typically 0.1m to 0.3m below ground level and in July 2015 were typically 1.0m to 1.7m below ground level. The 2015 site investigation data shows that the water table is significantly above the rockhead and, in Spring 2015, was close to the surface. The difficulty in dewatering and quarrying rock from this area is therefore greater than was envisaged in the Preliminary Report.

The supplementary site investigation data indicates that rock in the borrow pit area can be excavated at slopes of 1:1 and this aligns with the assumptions of the Preliminary Report.

Pump tests were carried out in September 2015 to determine in-situ permeability in the borrow pit area and to determine the feasibility of dewatering on this large scale. The pump test carried out in pumping well WH02 would be indicative of conditions in the borrow pit area. The 72 hour pump test was only capable of lowering the water table at WH02 by 3.21m when pumping at a rate of 11.75m^3/hr. The closest monitoring well was located some 90m from the pump test location in borehole BH74. The water level drawdown in BH74 was only 0.38m. This pump test, and a second pump test carried out in pumping well WH03, indicate that there is a high groundwater recharge in the Garryhinch Bog area. When the duration of the pump test was completed and the pumping stopped in WH02 the ground water level rose by 2.1m in a period of 3 hours. In pumping well WH03 the recharge was almost instantaneous when the pumping was stopped.

Due to the limiting factor of the diameter of the borehole, the pump test carried out in WH02, near the location of the borrow pit, was not capable of lowering the water level in the well hole to the extent that would be necessary to quarry the rock. Dewatering at the rate necessary to lower the groundwater level in the potential borrow pit area would be to a scale that it would be difficult to ensure protection of the conservation conditions in the River Barrow SAC.

The volume of water generated by dewatering a site as large as Garryhinch will be significant. It is estimated, based on the outcomes of the pumped well tests, that if a 45 hectare portion of the site, similar to the area of the proposed borrow pit, were to be dewatered, and the water table lowered by approximately 3m, the volume of water generated would be of the order of 1,200m^3/hr (0.33m^3/s). In fact the water level in the borrow pit area of Garryhinch Bog would have to be lowered by approximately 10m in order to quarry the amount of rock required to construct the reservoir embankments. Dewatering at the rate necessary to lower the groundwater level in the potential borrow pit area would be on a scale that would make it difficult to ensure protection of the conservation conditions in the River Barrow SAC.

There is also an associated health and safety risk of having people and machinery working at such depth in a dewatered area. The likelihood and impact of dewatering pumps failing and the water table rapidly recovering its natural level, (as witnessed in WH03 during the pump tests) will need to be assessed carefully.

4.9 Landscaping

The landscaping of the embankments was envisaged in the preliminary design to be carried out using peat, graded at a slope of 1:5 or less. It was recognised that the slope angle would depend on the moisture content and strength of the excavated peat. The preliminary costs for the embankment however included for the outer sides of the embankments to be topsoiled and seeded. The inclusion of costs for topsoiling and seeding is likely to account for the fact that the landscaping of the outer slope of the embankment with peat at a slope of 1:5 would cause instability issues and this is confirmed as likely based on the information available from the supplementary site investigation of the peat.

4.10 Construction Traffic

The supplementary site investigation data indicates that most of the excavation and construction is likely to be in materials which contain varying amount of cohesive material. The medium dense to dense and firm to stiff soils in their in-situ state should be suitable to support most construction traffic. However these soils will soften rapidly under periods of prolonged rainfall or under conditions of inadequate drainage. When the soils get wet and soften then there will be trafficking problems. Many boreholes encountered very soft to soft to firm clayey and silty soils and loose soils which are likely to rut significantly under construction traffic.

5 Significant Risks

5.1 Risk Associated with Karst Limestone

A significant area to the eastern part of the Garryhinch site is underlain by karst limestone, with the risk of solution features and particularly cavities. The unpredictable occurrence, extent and depth of underground cavities, which may lead to inadequate foundation support for the reservoir embankments and base, presents a significant risk of failure of the storage reservoirs. Storing additional water above this area will promote increased seepage through the weathered rock and may include further karstification with, at worst, the risk of caverns occurring with the consequent potential for collapse. Lowering the groundwater table to facilitate construction and to prevent uplift pressure during operation can cause sinkhole collapse in karst areas. Collapse of a cavern within the footprint of a storage reservoir of this scale and significance would cause significant problems.

The western area of the Garryhinch site has potential for karst features and in addition the geophysical survey identified potential for further extents of weathered rock.

Options to minimise the risk include:

- re-shaping of the storage reservoirs such that there is no extension into the identified karst regions. Even after re-shaping the storage reservoirs there remains a potential risk that karst features may exist in other parts of the site.
- lining of the bases of the reservoir so as to minimise seepage.

Re-shaping of the storage reservoir would potentially require a significant extension into the identified borrow pit meaning that materials for construction of the reservoir embankments would have to be sourced elsewhere. The identified areas containing karstified and weathered rock are unlikely to have sufficient quantity of suitable materials and there would therefore be a need for the importation of materials to the site for construction of the embankments. The volume of rock to be imported for the embankment structure could be reduced by using sands and gravels from the site, where they could be used for the inner core material, but the volume of surplus materials will be limited and probably insignificant when compared to overall embankment volume required.

With no borrow pit available on the site, off-site disposal would become necessary with consequent traffic and environmental impacts.

Furthermore, as pointed out in sub-section 3.4 above, while the site investigation has established the presence of karst features in the areas described, it is not possible to establish effective absence of such features in the site between these two areas. Therefore, reshaping the reservoirs may not avoid having karst features underneath the floor of the completed reservoirs. There is a risk then that, in the autumn months when water levels in the reservoirs are at their lowest, heavy rainfall could cause rapid recharge of the groundwater levels below the reservoir, resulting in upward pressures that could not be balanced by the volume of water in storage. In such circumstances it is possible that the floor of the reservoir could be deformed, or even breached, by the upward pressures.

The options to minimise the risk associated with the karst limestone within the site will add significantly to the overall construction costs of a raw water storage reservoir system at Garryhinch.

5.2 Programming and Costs Risk

The risks associated with the technical issues surrounding the construction of the reservoir cells have a negative impact on the ability to programme effectively the duration of the works, manage production efficiency and consequently control the out-turn cost of the works.

5.3 Other Residual Risks

Section 8.1.2 of Appendix G of the Preliminary Report listed a number of risks that require further consideration. The supplementary site investigation has clarified the status of some of these risks, as set out below.

RISK IDENTIFIED IN PRELIMINARY REPORT	COMMENT FOLLOWING SUPPLEMENTARY SITE INVESTIGATION WORKS	STATUS OF RISK
Catastrophic failure [of the reservoir embankments] resulting in flooding of surrounding lands and property	The stability of the storage embankments remains a significant risk for this site where karst features may exist in the underlying soils and rock. Failure of an outer embankment could have catastrophic consequences given the volume of water that could be held in storage. The shear strength of the silts, in the areas where the embankments are to be constructed, may vary considerably and use of stage construction, foundation strengthening, or excavation of undesirable material may be required during the construction stage, all of which would result in an increase to the construction costs. This would apply equally to the proposed sludge lagoons.	High
The silt/clay may not provide a sufficient seal throughout the site and require additional reworking to render it acceptable	The site investigation shows that while sands and gravels exist in the subsoil there is a sufficiently high level of silt in the samples taken, giving a low enough permeability to seal the majority of the site, Nonetheless treatment with bentonite will be necessary across an estimated 10% of the site.	Medium
The silt/clay may not provide a sufficient seal throughout the site and require the installation of a liner system across the base	Given the low permeability found in the majority of tested samples, it is not expected that a liner will be required to seal the site.	Low

RISK IDENTIFIED IN PRELIMINARY REPORT	COMMENT FOLLOWING SUPPLEMENTARY SITE INVESTIGATION WORKS	STATUS OF RISK
Karst may exist within the bedrock beneath the footprint of the reservoirs and seepage may result in washout and collapse requiring additional works to remediate or mitigate any impact.	Karst conditions were found on site, raising the risk of seepage and collapse. The supplementary site investigation data shows that the area identified for the location of the sludge lagoons has karst features that would increase significantly the potential risk of failure of the sludge lagoon bases and embankments.	High
The depth to rock is deeper than expected resulting in additional costs	It was envisaged in the Preliminary Report that a cement/bentonite slurry cut-off wall at the inner toe of embankments would extend down to rock level to depths 2m to 5m below ground level. The supplementary site investigation data however shows much more significant variations in rock level, particularly in the eastern area of the site where depths to rock were recorded between 2.7m and 42.8m below ground level.	High
Groundwater is higher than predicted and the site requires significant dewatering measures	Water levels on the site throughout the year are close to existing ground level. Recent pump tests on site suggest that dewatering of the site will be difficult	High
Groundwater is higher than predicted resulting in uplift pressures	Removing on average 1m depth of peat, the base of the reservoir would be below the water table. A high water table presents a risk of applying an uplift pressure on the reservoir that would require other measures to eliminate the risk.	High
Potential seasonal fluctuations in groundwater levels resulting in artesian water pressure following removal of peat	There was no evidence of artesian water conditions during the site investigation.	Low
Insufficient compaction of embankment fills or localised soft spots beneath the embankment footprint resulting in unacceptable settlements	After stripping the peat from the works areas, the foundation surface for the embankments will be in a loose condition and in need of compaction. In the silty and clayey foundation soils which have a high water content and a high degree of saturation due to the high water table, attempts to compact the surface with heavy sheepsfoot or rubber-tired rollers will only remould the soil and disturb it, and only lightweight compaction equipment should be used. However, in using lightweight compaction equipment compressible material that may have been overlooked in the stripping of the peat may remain.	High
The depth of peat is thicker than predicted, resulting in additional excavation, haulage and deposition costs	It is noted that there are some peat harvesting operations continuing at Garryhinch, and the prospect of continued harvesting to minimise the peat remaining at the start of construction is recognised.	Medium

RISK IDENTIFIED IN PRELIMINARY REPORT	COMMENT FOLLOWING SUPPLEMENTARY SITE INVESTIGATION WORKS	STATUS OF RISK
Deposition of peat within the excavated borrow pit may have adverse effects on the hydrogeology of the bedrock aquifer	The site investigation encountered ‘poor’ and highly weathered rock conditions with evidence of karstification in the eastern area of the site. This area is located close to the Regionally Important Aquifer, which is known to be karstified. The risk of contamination of the aquifer from deposition of peat in borrow pits cannot therefore be discounted. Compliance with the requirements of the 2010 Groundwater Regulations will present an ongoing risk during the construction stage and will require significant control and monitoring arrangements during dewatering processes.	High
Surface water from the excavation and deposition of peat and other construction activities may cause suspended solid matter to enter local surface water features	The volume of water generated by dewatering the site to the extent indicated by recent site investigation and pump tests increases the difficulty of avoiding (and therefore the risk of) contamination of the River Barrow SAC.	High
Oil and fuel pollution (from accidental spillage or inappropriate storage procedures)	The pumping requirement for dewatering operations will be such that large quantities of oil and diesel may need to be stored on-site to keep large pumps in operation, raising the risk of pollution from oil or fuel spillage.	High

Close coordination between design and construction will be necessary to thoroughly orient the construction personnel as to the project design intent, ensure that new field information acquired during construction is assimilated into the design, and ensure that the project is constructed according to the intent of the design.

6 Cost Estimate

6.1 Preliminary Report Cost Estimates

The Preliminary Report estimated the cost of constructing Options 1 and 2 as follows:

- Option 1 Cost Estimate €40,662,632 excluding VAT
- Option 2 Cost Estimate €45,317,946 excluding VAT

6.2 Updated Cost Estimates

The supplementary subsoil investigation works identified risks that must be addressed in order to ensure the integrity of the proposed reservoir. The three most significant risks relate to:

1. the discovery of a significant extent of karst limestone on the site;
2. the high groundwater table throughout the site and consequent dewatering operations
3. management of peat on-site and the possible need to dispose of it off-site; and
4. the permeability of the sands and gravels encountered on the site.

These risks need to be factored into the cost estimate for the construction of proposed reservoir.

The Preliminary Report cost estimate for Option 1 has been used as the base cost and the cost estimates associated with the identified risks have been applied in preparing an updated cost estimate.

The updated cost estimate for the construction of the proposed reservoir system at Garryhinch Bog is presented in Table 6.2.

Description	Cost Estimate €
Preliminary Report Option 1 Cost Estimate	40,662,632
Measures to Minimise Risk Associated with Karst Limestone	
Importation of materials for embankments	16,330,000
Disposal of peat off site	11,045,000
Measures to Minimise Risk Associated with High Groundwater	
Process for treatment of groundwater following dewatering including monitoring of risk to the groundwater	4,000,000
Measures to Minimise Seepage Through Sands and Gravels	
Groundwater level control system or uplift pressure control	5,700,000
Scale Model of embankment	2,000,000
Total Updated Cost Estimate	**79,737,632**

***Table 6.1**: Updated Cost Estimate for Reservoir Storage System*

7 Summary

Subsoil investigations were carried out at Garryhinch Bog in late 2014 and early 2015, as part of the Water Supply Project, to supplement the subsoil investigation at the preliminary stage of design in 2009.

This Report discusses the interpretation of the supplementary subsoil investigation data as part of the appraisal of the risks associated with the construction a large scale raw water storage system and treatment facility at Garryhinch Bog.

The significant risks identified include:

- The stability of the storage embankments for proposed reservoirs and sludge lagoons is a significant risk where karst features may exist in the underlying soils and rock. The shear strength of silts on which embankments may be built is such as to represent a risk of unacceptably high settlement of embankments; ground improvement works may be required with resulting increased cost risks.
- Karst features were identified in a large area to the east of the site and in an area to the west of the site, increasing the risks of seepage and instability of embankments.
- The karst features also introduce the risk of a situation whereby, in autumn months, the floor of a near empty reservoir would be vulnerable, in heavy rainfall conditions, to rapid groundwater recovery underneath the reservoir causing uplift and deformation, or even a breach, of the reservoir floor.
- Depths to rock across the site are greater than envisaged in the Preliminary Report, increasing the risk of higher construction costs.
- High groundwater levels exist throughout the year and throughout the site. Water levels were measured at close to the surface level in March 2015 and by May 2015 the water levels dropped by variable amounts in the range of 0.2m to 1.6m. Pump tests conducted on-site in September 2015 indicate that any dewatering operation will be difficult and will introduce significant cost, programming and environmental risks.
- Dewatering to the scale required at Garryhinch is likely to represent a significant risk to the conservation objectives of the River Barrow SAC.
- Dewatering to the scale required at Garryhinch is likely to represent a significant risk to the protection objectives of the 2010 Groundwater Regulations.
- Dewatering pumping equipment of the scale required will require significant quantities of oil and fuel storage on site, with the consequent risk of a pollution incident from these stores.
- Quarrying rock from a borrow pit in the south of the site and deposition of excavated peat in this borrow pit will require working at 10-11m depths in dewatered site. A failure of the dewatering pumps and consequent rapid recovery of the groundwater levels would represent a significant risk to people working in such a borrow pit.
- It is possible that the borrow pit area identified in the Preliminary Report would have to be used as part of the reservoir storage area so as to avoid construction of the reservoir over the identified karst areas. The required materials for the construction of the embankments would therefore have to be imported resulting in programming, traffic management and increased cost risks.
- If the identified borrow pit is not available to accept excavated peat, disposal

of peat will likely have to be off site resulting in programming, traffic management and increased cost risks.

The updated cost estimate for the construction of the proposed reservoir system at Garryhinch Bog is €80m.

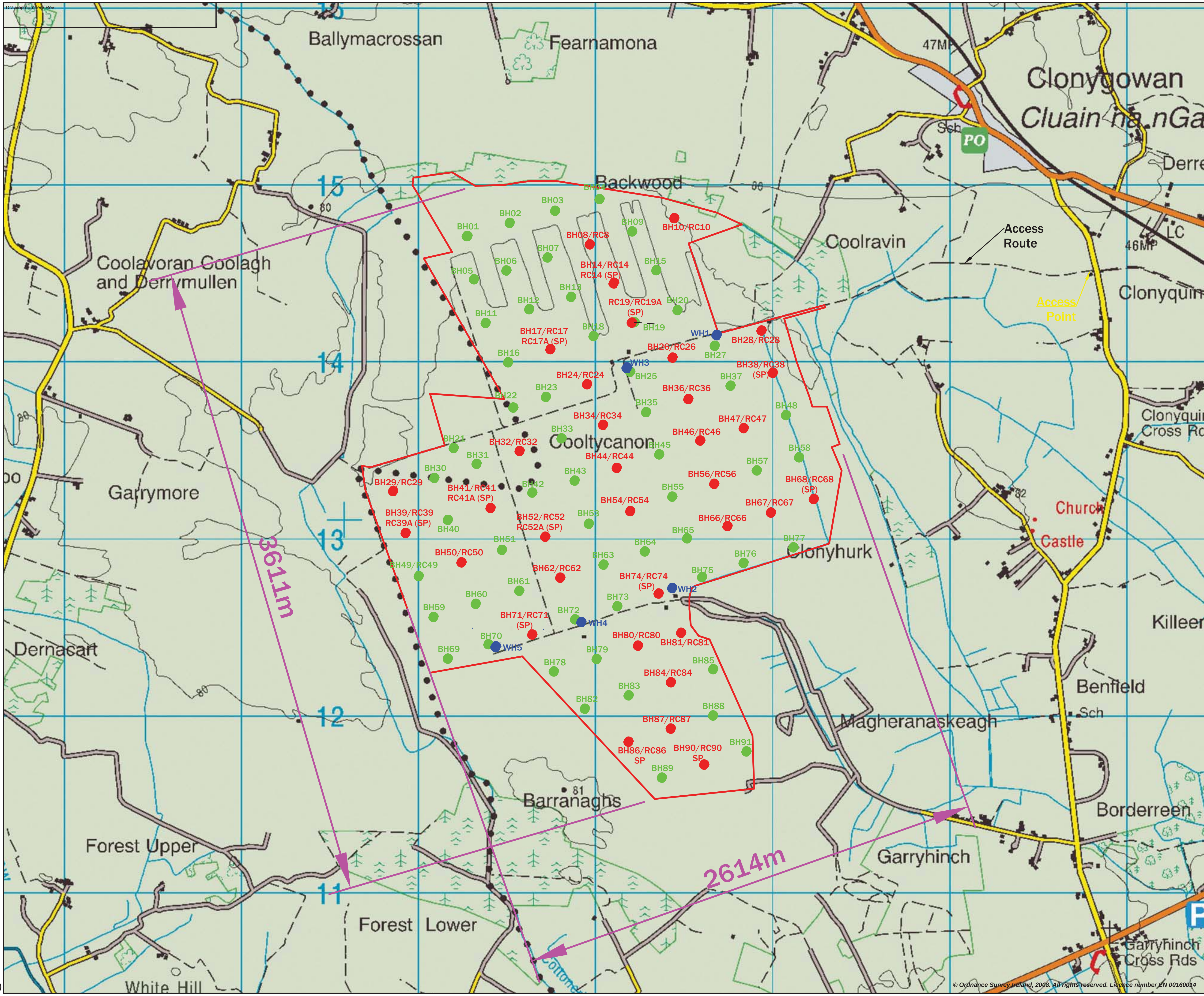
8 Conclusion

The primary intended purpose of the proposed Raw Water Storage at Garryhinch is to mitigate the impact on residence time in Lough Derg, resulting from year-round abstraction from the North East quadrant of the lough, by permitting reduced lake abstraction during two summer months, with the balance being made up by water held in storage in Garryhinch. The effectiveness of the raw water storage in meeting that primary purpose is examined in Appendix C, which details hydrodynamic modelling results. It is concluded there, that seasonally variable abstraction, together with two (or even three) months raw water storage, would not effectively mitigate local residence time impacts within Lough Derg in a dry year such as 1995.

The subsoil investigation results at Garryhinch indicate the presence of karst bedrock in two areas of the site, as well as a generally more elevated water table than expected, greater than predicted variability in depth to bedrock, and the prospect of difficult dewatering conditions based on groundwater pumping tests. It anticipates design challenges on expected embankment settlement, and on reservoir underfloor drainage conditions. It highlights significant issues related to construction, to the disposal of unsuitable material, and to the environmental impacts of dewatering discharges. The subsoil investigation has also highlighted cost, soils engineering and programming risks which are present, and which contribute to a significantly increased estimated cost of construction.

Overall, recognising the environmental conclusions elsewhere in the Report on residence time and invasive species transfer risks, and considering the conclusions drawn from the site investigation, it is not recommended that storage of raw water at Gerryhinch be pursued.

Appendix A - Drawings Showing Scope of Site Investigation



Notes:

IRELAND SITE LOCATION MAP

LEGEND

GEO LINE LOCATION	
BORE HOLE LOCATION	BH
TRIAL PIT LOCATION	
BORE HOLE/FOLLOW ON ROTARY	BH/RC
STAND PIPE LOCATION	SP
DYNAMIC PROBES	
WELL HOLE LOCATIONS	WH

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
A	28022014	First Issue	DC	PC	DC	MMD

JACOBS TOBIN

Client: UISCE ÉIREANN IRISH WATER

Project: WATER SUPPLY PROJECT

Drawing title: (I.D.L AS BUILT) SITE INVESTIGATION LAYOUT PLAN SHOWING LOCATION OF PROPOSED BORE HOLES

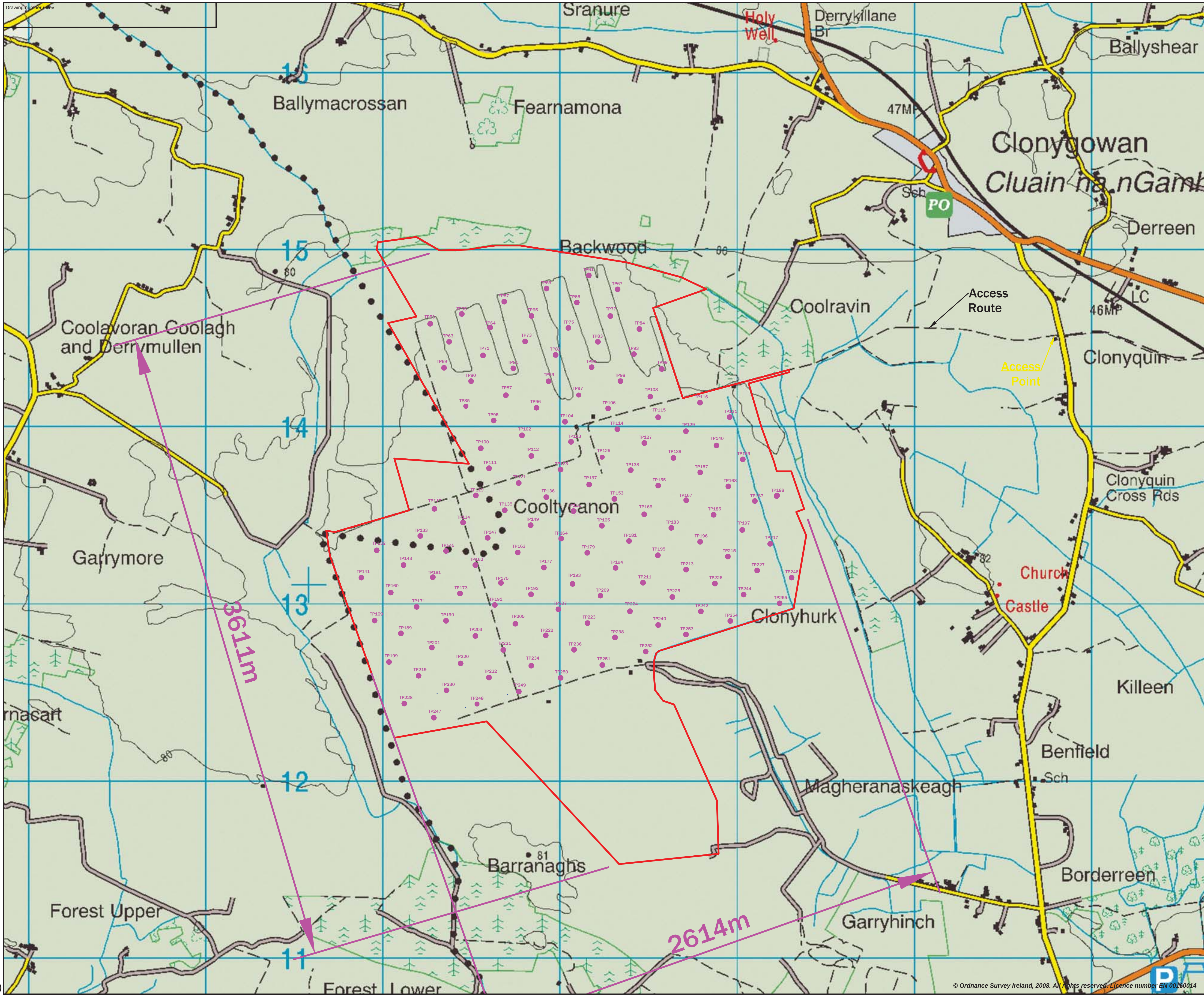
Drawing status: DRAFT

Scale	1:10,000@ A1	DO NOT SCALE
Jacobs No.		
Client no.		
Drawing number	I.D.L 1001	Rev A

This drawing is not to be used in whole or part other than for the intended purpose and project as defined on this drawing. Refer to the contract for full terms and conditions.

C:\Users\Maurice.IRISHDRILLING\Desktop\Garryhinch\FW__Garryhinch\Discovery Maps - Garryhinch - Rev B.dwg - 03/25/15 12:44:01 - 3003 Boreholes - ################

Drawing number / Rev



C:\Users\Maurice.IRISHDRILLING\Desktop\Garyhinch\FW__Garryhinch\Discovery Maps - Garryhinch - Rev B.dwg - 03/25/15 12:54:30 - 3004 Trial Pits - ######

Notes:

IRELAND SITE LOCATION MAP

LEGEND

GEO LINE LOCATION

BORE HOLE LOCATION

TRIAL PIT LOCATION TP

STAND PIPE LOCATION

DYNAMIC PROBES

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
A	28022014	First Issue	DC	PC	DC	MMD

JACOBS TOBIN

Client

UISCE ÉIREANN : IRISH WATER

Project

WATER SUPPLY PROJECT

Drawing title

I.D.L (AS BUILT) SITE INVESTIGATION LAYOUT PLAN SHOWING LOCATION OF PROPOSED TRIAL PITS

Drawing status

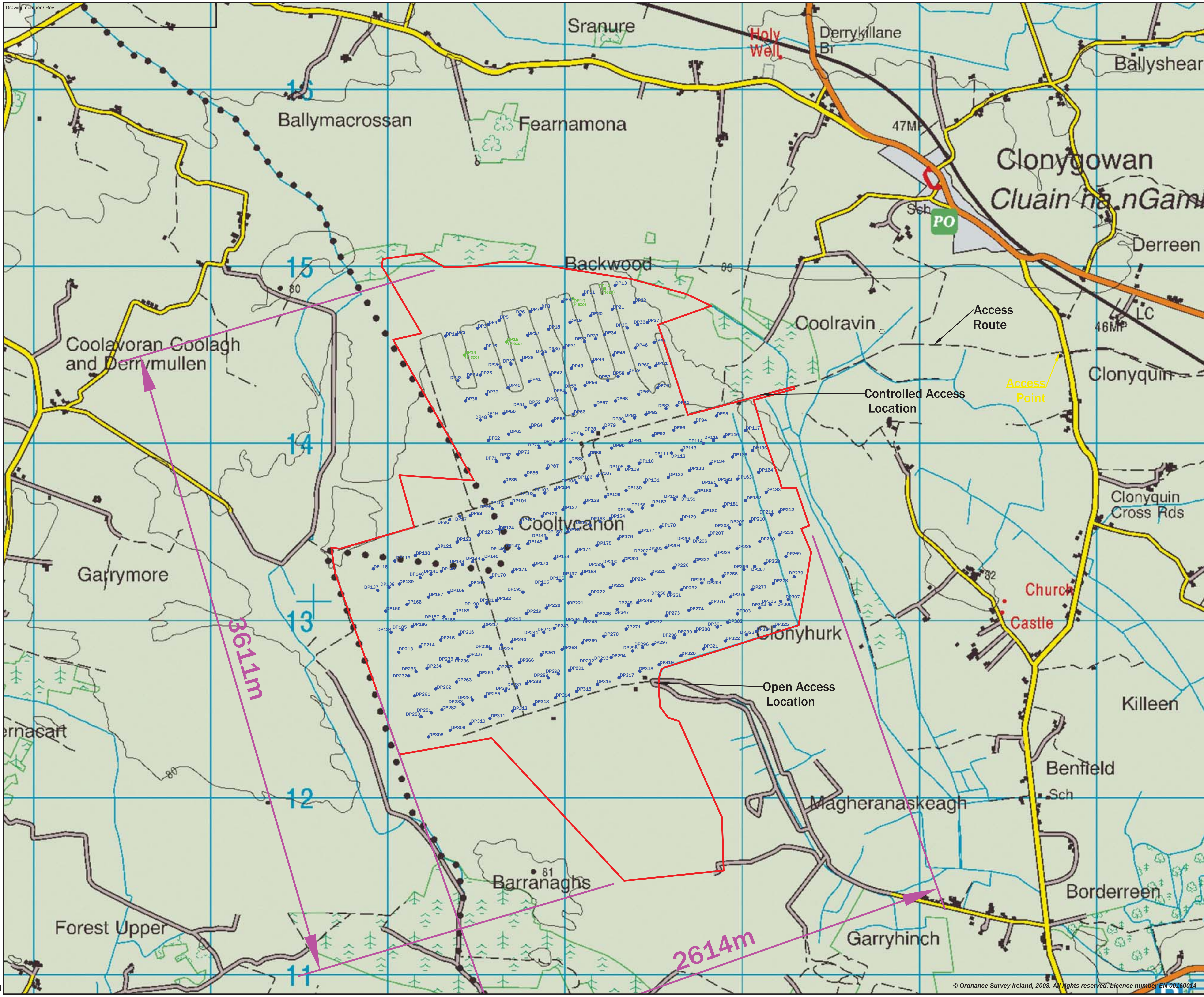
DRAFT

Scale	1:10,000@ A1	DO NOT SCALE
Jacobs No.		
Client no.		

Drawing number: I.D.L 1002 — Rev: A

This drawing is not to be used in whole or part other than for the intended purpose and project as defined on this drawing. Refer to the contract for full terms and conditions.

Drawing number / Rev



Notes:

IRELAND SITE LOCATION MAP

LEGEND

GEO LINE LOCATION

BORE HOLE LOCATION

TRIAL PIT LOCATION

PIEZO PIPE LOCATION

DYNAMIC PROBES

Rev	Rev. Date	Purpose of revision	Drawn	Checkd	Rev'd	Apprv'd
A	28022014	First Issue	DC	PC	DC	MMD

JACOBS TOBIN

Client
UISCE WATER

Project
WATER SUPPLY PROJECT

Drawing title
I.D.L (AS BUILT) SITE INVESTIGATION LAYOUT PLAN SHOWING LOCATION OF PROPOSED DYNAMIC PROBES

Drawing status
DRAFT

Scale	1:10,000@ A1	DO NOT SCALE
Jacobs No.		
Client no.		

Drawing number: I.D.L 1003
Rev: A

This drawing is not to be used in whole or part other than for the intended purpose and project as defined on this drawing. Refer to the contract for full terms and conditions.

C:\Users\Maurice.IRISHDRILLING\Desktop\Garyhinch\Garyhinch PDFs report\Discovery Maps - Garryhinch - Rev B.dwg - 03/25/15 14:45:03 - 3006 Probes - ######

Appendix B - Geophysics Report

Garryhinch

Co. Offaly

Geophysical Survey

Report Status: Draft

MGX Project Number:5967

MGX File Ref: 5867d-005.doc

23rd January 2015

Confidential Report To:

Irish Drilling Ltd.
Old Galway Road
Loughrea
Co. Galway

Report submitted by :
Minerex Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Ireland
Tel.: 01-6510030
Fax.: 01-6510033
Email: info@mgx.ie

Issued by:

Ruth Jackson (Senior Geophysicist)

Hartmut Krahn (Senior Geophysicist)

Minerex Geophysics Limited

Subsurface Geophysical Investigations

EXECUTIVE SUMMARY

1. Minerex Geophysics Ltd. (MGX) carried out a geophysical survey consisting of 2D-Resistivity and seismic refraction (p-wave) for the ground investigation at Garryhinch Bog, County Offaly.
2. The main objectives of the survey were to determine ground conditions, estimate the depth to rock and overburden thickness, reduce the risk of encountering unknown subsurface conditions, including cavities and voids, during construction.
3. Ground conditions were modelled with three to five layers that represent the transition from soft overburden to strong rock.
4. The depth to top of strong rock varies between 1.5 and 16m bgl. and this rock would require breaking/blasting for removal.
5. The data generally shows a transition from overburden to weathered limestone to a clean limestone. Considerable areas within the limestone are karstified or anomalous (faulted or fractured).
6. Peat covers almost the entire survey area with depths ranging from quite shallow (0.2m) to depths in the range of 3.6m. There were only 2 sections of seismic refraction profiles (Line 4 & 11) where no peat was located. The surface layer in this case was a gravelly silt or clay like material.
7. Strong, good and fresh rock occurring at shallow depth within the proposed construction depth of the reservoir would require breaking and blasting during the construction. Where clean limestone is concerned these areas of shallow rock would be indicated in the resistivity data at locations where highest resistivities occur very shallow.
8. There are considerable areas mapped within the rock and visible on the resistivity interpretations that can be considered karstified or anomalous.
9. The interpretation presented here will be reviewed once borehole logs become available.

CONTENTS

List of Tables, Maps and Figures:

1. INTRODUCTION

1.1 Background

Minerex Geophysics Ltd. (MGX) carried out a geophysical survey for the Garryhinch Bog – Site investigation Works. The survey consisted of 2D-Resistivity and seismic refraction (p-wave). The survey was commissioned by Irish Drilling Limited, acting on behalf Irish Water.

The role of geophysics as a non-destructive fast method is to allow later targeted direct investigations.

1.2 Objectives

The main objectives of the geophysical survey were:

- To determine the ground conditions under the site
- To determine the depth to rock and overburden thickness
- To detect lateral changes within the geological layers
- To map the extent of the soft ground layers
- To reduce the risk of encountering unknown or unexpected subsurface conditions

1.3 Site Description

The site is a worked out Bord Na Mona production bog.

It is located north of the R432 between Portarlington and Mountmellick and has an area of approximately 580 hectares.

A large portion of the survey area to the north is forested and the site is still, in part, utilised by local contractors for the production of sod peat.

Drainage ditches run in a north-south direction with approximately 250m spacing between them. The geophysics profiles were designed to run alongside these drains to allow for continuous profiles to be acquired. The exception to this was seismic refraction line 1 & 8 which run in a west-east direction along the headlands left continuous and uninterrupted by the drainage ditches and peat production.

For the most part elevations across the survey area range from 73 – 78 mOD.

1.4 Geology

The overburden geology consists of visible peat with occasional silty sandy overburden exposed and some cobbles or boulders lying on the ground surface.

The bedrock geological map of Galway-Offaly (GSI, 2003) indicates that the survey area is underlain by Carboniferous lithologies. The Waulsortian Formation (indicated in the eastern part of the site) is described as massive unbedded lime-mudstone and the Ballysteen Formation (indicated on the western part of the site) is described as fossiliferous dark-grey muddy limestone. Considering the peat cover and lack of rock outcrop the bedrock geological map can be taken as indicative only.

The main regional tectonic fault direction is South-West to North-East.

The Waulsortian Formation can be karstified due to the clean nature of the limestone. The Ballysteen formation has some argillaceous mud content and is therefore little or not karstified.

1.5 Report

This report includes the results and interpretation of the geophysical survey. Maps, figures and tables are included to illustrate the results of the survey. More detailed descriptions of geophysical methods and measurements can be found in GSEG (2002), Milsom (1989) and Reynolds (1997).

The client provided maps of the site and the digital versions were used as the background map in this report. Elevations were surveyed on site and are used in the vertical sections.

The interpretative nature and the non-invasive survey methods must be taken into account when considering the results of this survey and Minerex Geophysics Limited, while using appropriate practice to execute, interpret and present the data, give no guarantees in relation to the existing subsurface.

2. GEOPHYSICAL SURVEY

2.1 Methodology

The methodology was given in the tender documents and consisted of seismic refraction in the northern and southern part and of 2D-Resistivity in the central part.

The survey locations are indicated on Map 1. The survey lines and lengths are tabulated in Table 1.

Table 1: Geophysical Survey Lines

Profile/Method	Length
Seismic Refraction Line 1	1932
Seismic Refraction Line 2	714
Seismic Refraction Line 3	714
Seismic Refraction Line 4	719
Seismic Refraction Line 5	681
Seismic Refraction Line 6	712
Seismic Refraction Line 7	714
Seismic Refraction Line 8	2402
Seismic Refraction Line 9	1069
Seismic Refraction Line 10	1006
Seismic Refraction Line 11	787
Seismic Refraction Line 12	284
2D-Resistivity Line A	1112
2D-Resistivity Line B	1110
2D-Resistivity Line C	1260
2D-Resistivity Line D	1244
2D-Resistivity Line E	1110
2D-Resistivity Line F	1109
2D-Resistivity Line G	1109
2D-Resistivity Line H	1108
2D-Resistivity Line I	1106

All geophysical surveys are acquired, processed and reported in accordance with British Standards BS 5930:1999 +A2:2010 ‘Code of Practice for Site Investigations’.

2.2 2D-Resistivity

2D-Resistivity profiles were surveyed with electrode spacing of 5m, up to 64 electrodes per set-up and a maximum length of 315m per profile. The readings were taken in roll-along mode along each line in order to obtain continuous coverage to a depth of 25 m bgl. The readings were taken with a Tigre Resistivity Meter, Imager Cables, stainless steel electrodes, laptop and ImagerPro acquisition software.

During 2D-Resistivity surveying data is acquired in the form of linear profiles using a suite of metal electrodes. A current is injected into the ground via a pair of electrodes while a potential difference is measured across a second pair of electrodes. This allows for the recording of the apparent resistivity in a two-dimensional arrangement below the profile. The data is inverted after the survey to obtain a model of subsurface resistivities. The generated model resistivity values and their spatial distribution can then be related to typical values for different geological materials.

2D-Resistivity has previously proven zones of anomalous rock/karstified rock with lateral extents of 5 m and more.

2.3 Seismic Refraction

The seismic survey consisted of p-wave seismic refraction profiling along the lines indicated on Map 1. Each of the individual set-ups consisted of up to 24 geophones with 3 m spacing, resulting in lengths of 69m per set-up. Adjacent profiles were concatenated into the long lines. The recording equipment consisted of a 24 Channel GEOMETRICS ES-3000 engineering seismograph with 4.5 Hz vertical geophones. The seismic energy source consisted of a hammer and plate on soil or a seismograph gun in peat covered areas. A zero delay trigger was used to start the recording. Seven shot points per p-wave profile were used.

In the seismic refraction survey method a p-wave is generated by a source at the surface resulting in energy travelling through surface layers directly and along boundaries between layers of differing seismic wave velocities. Processing of the seismic data allows geological layer thicknesses and boundaries to be established.

Seismic Refraction generally determines the depth to horizontal or near horizontal layers where the compaction/strength/rock quality changes with an accuracy of 10 – 20% of depth to that layer. Where low velocity layers or shadow zones are present or where layers dip with more than 20 degrees angle the accuracy becomes much less.

2.4 Site Work

The data acquisition was carried out between the 12th of November and 6th of February 2015. The weather conditions were variable throughout the acquisition period. Health and safety standards were adhered to at all times.

The locations and elevations were surveyed with a TRIMBLE RTK-GPS to accuracy < 0.02m.

3. RESULTS AND INTERPRETATION

The interpretation of geophysical data was carried out utilising the known response of geophysical measurements, typical physical parameters for subsurface features that may underlay the site, and the experience of the authors.

3.1 2D-Resistivity Profiles

The 2D-Resistivity data was positioned and inverted with the RES2DINV inversion package. Overlapping and roll-along profiles were concatenated for a joint inversion. The programme uses a smoothness constrained least-squares inversion method to produce a 2D model of the subsurface model resistivities from the recorded apparent resistivity values. Three variations of the least squares method are available and for this project the Jacobian Matrix was recalculated for the first three iterations, then a Quasi-Newton approximation was used for subsequent iterations. Each dataset was inverted using seven iterations resulting in a typical RMS error of < 3.0%. The resulting models were colour contoured with the same resistivity scale for all profiles and they are displayed as cross sections (Figures 1 - 5).

The resistivities cover a range typical for materials from peat and clay to bedrock. The ranges have been taken into the consideration for the integrated interpretation.

Table 2 summarises the interpretation of the 2D-Resistivity. Interpreted cross sections are shown in Figures 13 - 17. The interpretation has been made based on the range of resistivities and the appearance and relative location to each other of resistivities.

Table 2: Summary of Interpretation of Resistivities

Layer	**General Resistivity Range (Ohmm)**	**Interpretation**
1	< 600	Mainly Peat or Overburden
2	< 100	Very weathered karstified Limestone
3	100 – 800	Weathered Limestone
4	> 800	Clean fresh Limestone

3.2 Seismic Refraction Data

The seismic refraction data was positioned and processed with the SEISIMAGER software package to give a layered model of the subsurface. The numbers of layers has been determined by analysing the seismic traces and between 3 and 5 layers were used in the models. All seismic profiles were subject to a standardised processing sequence which consisted of a topographic correction which was based on integrated elevation data, first break picking, tomographic inversion, travel-time computation via ray-tracing and velocity modelling. Residual deviations of typically 0.4 to 1.8 msec RMS have been obtained for each profile. Following each processing stage QC procedures were adhered to. The resulting layer boundaries are shown as thick lines (Figure 6 - 12). The average seismic velocities obtained within the layers are annotated on the sections as bold black numbers.

Layer 1 has a thickness of between 0.2 – 3.6 m and seismic velocities of less than or equal to 300 m/s. This layer is composed of very soft peat or organic material with a soft/loose stiffness/compaction.

Layer 2 with a velocity range of 310 – 500 m/s was modelled in areas where there was no peat present; on seismic line 4 and 11. The velocity indicates a soft or loose overburden material.

Layer 3 velocities of 1200 – 1900 m/s indicate predominantly overburden with stiff or dense compaction. The thickness varies between 0.4 and 7.6 m.

Layer 4 velocities of 2100 – 2800 m/s indicate a weathered rock that varies in thickness between 0.5 and 13 m. The layer can also contain very dense highly consolidated overburden.

Strong rock is indicated by seismic velocities of > 3000 m/s and the top of this strong rock varied between 1.5 and 16.4 m.

Table 3 summarises the interpretation of the seismic refraction velocities. The stiffness/compaction and the rock strength/quality have been estimated from the seismic velocity. The estimation of the excavatability for the bedrock has been made according to the caterpillar chart published in Reynolds (1997). The geotechnical assessment for rippability will have to take factors like rock type and jointing into account and the estimation in this report is solely based on the seismic velocities. The proposed works may not require the excavation of rock though the assessment for rippability gives a good indication about the strength of the rock. Interpreted cross sections are shown in Figures 18 – 24.

Table 3: Summary of Interpretation of Seismic Velocities

Layer	General Seismic Velocity Range (m/sec)	Stiffness/ Compaction or Rock Strength/ Quality	Interpretation	Estimated Excavation Method
1	≤300	Very Soft	Peat or Organic Matter	Diggable
2	310 - 500	Soft or Loose	Overburden – Gravelly Silt/Clay	Diggable
3	1200 – 1900	Stiff or Dense	Overburden	Diggable
4	2100 – 2800	Poor to fair rock Or very stiff or very dense	Weathered Rock or Highly consolidated Overburden	Diggable/rippable to marginal rippable
5	> 3000	Good to very good rock	Strong competent Rock	Breaking & Blasting

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made:

- The geophysical surveys carried out at Garryhinch show that the subsurface geology consists of carboniferous lithologies.
- The data generally shows a transition from overburden to weathered limestone to a clean limestone. Considerable areas within the limestone are karstified or anomalous (faulted or fractured).
- Recommendations have been made already regarding carrying out targeted follow on rotary core holes.
- These anomalous zones could contain significant amounts of ground water.
- When considering the construction of a water storage reservoir some ground conditions can be more difficult to deal with. Conditions like soft ground, shallow rock and anomalous rock are highlighted below.
- **Soft Ground:** Peat covers almost the entire survey area with depths ranging from quite shallow (0.2m) to depths in the range of 3.6m. There were only 2 sections of seismic refraction profiles (Line 4 & 11) where no peat was located. The surface layer in this case was a gravelly silt or clay like material.
- **Shallow Rock:** Strong, good and fresh rock occurring at shallow depth within the proposed construction depth of the reservoir would require breaking and blasting during the construction. Where clean limestone is concerned these areas of shallow rock would be indicated in the resistivity data at locations where highest resistivities occur very shallow.
- **Karstified/Anomalous Rock:** There are considerable areas mapped within the rock and visible on the resistivity interpretations that can be considered karstified or anomalous. A comparison with the targeted rotary core hole logs will bring clarification.
- The interpretation presented here should be reviewed once any additional geotechnical data becomes available.

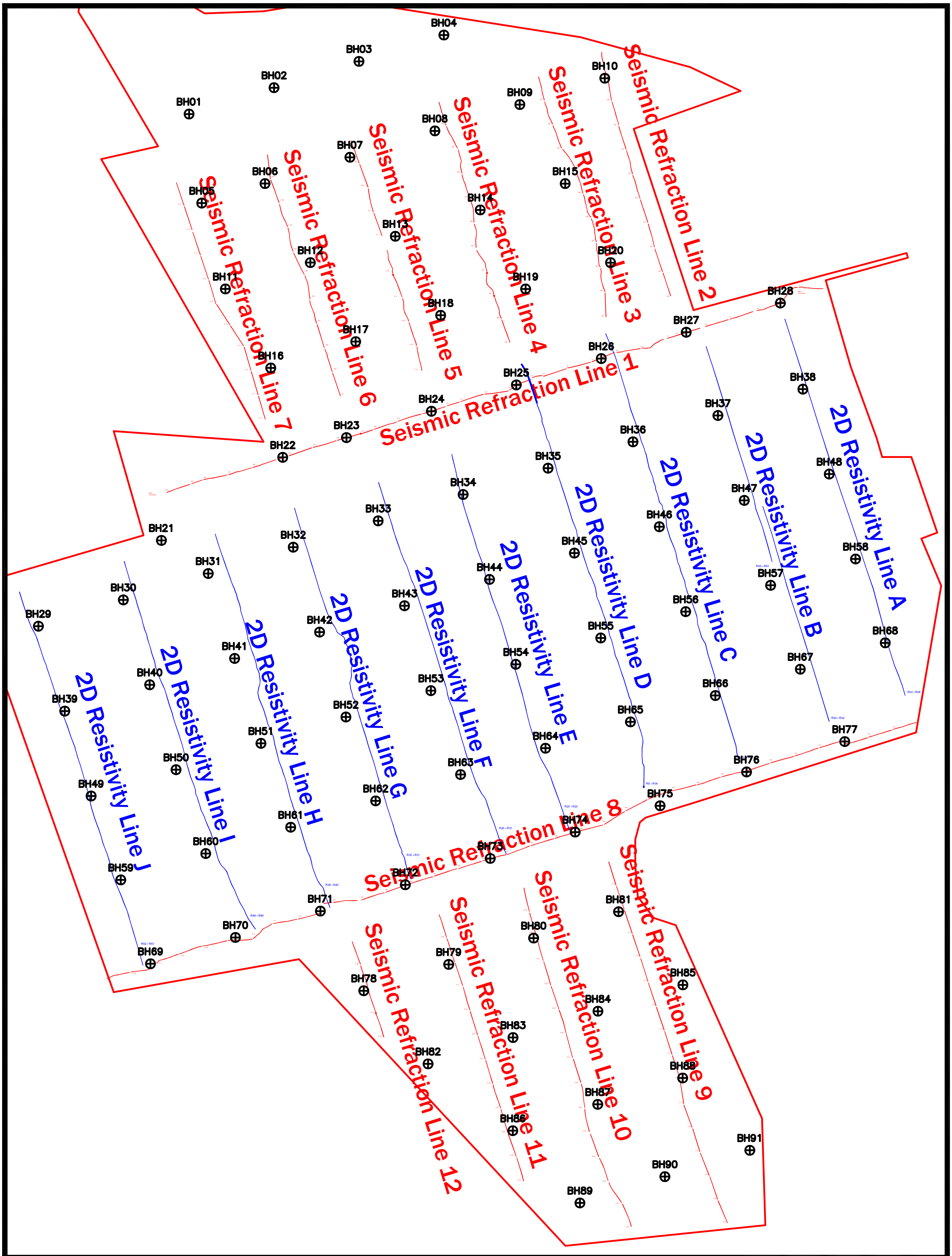
5. REFERENCES

1. **GSEG 2002.** Geophysics in Engineering Investigations. Geological Society Engineering Geology Special Publication 19, London, 2002.

2. **GSI, 2003.** Geology of Galway-Offaly. Geological Survey of Ireland 2003.

3. **Milsom, 1989.** Field Geophysics. John Wiley and Sons.

4. **Reynolds, 1997.** An Introduction to Applied and Environmental Geophysics. John Wiley and Son.



Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Map 1: Geophysical Survey Location Map

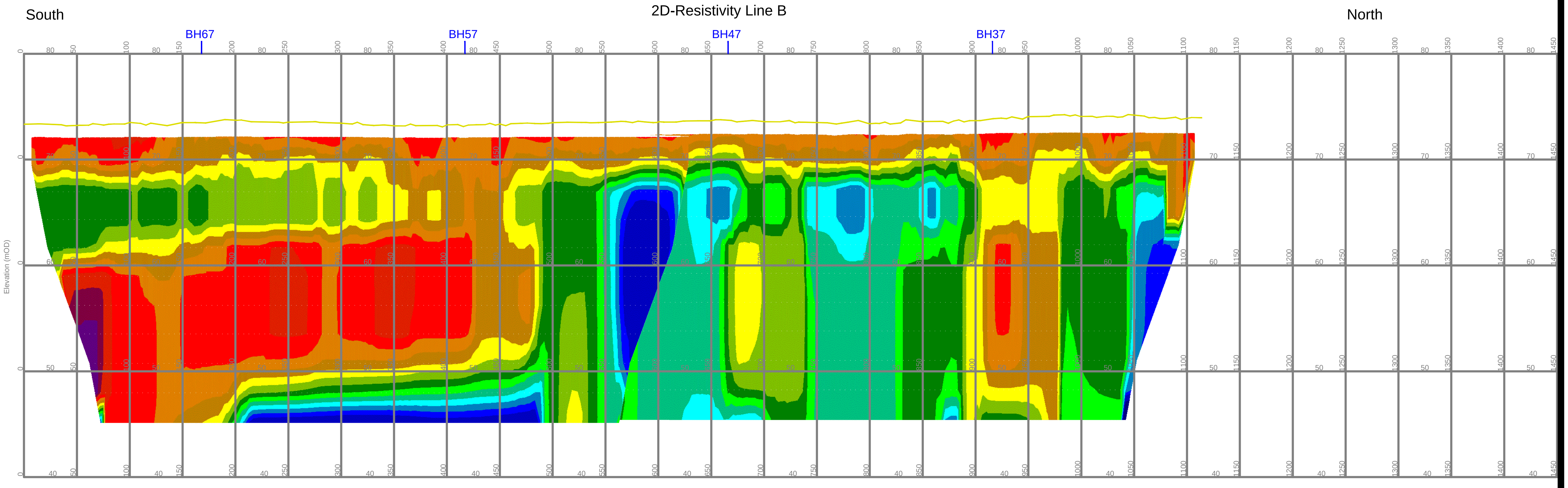
SCALE:	1:10,000 @ A3
PROJECT:	5867
DRAWN:	RJ
DATE:	09/01/2015
MGX FILE:	5867d_Maps.dwg
STATUS:	Draft

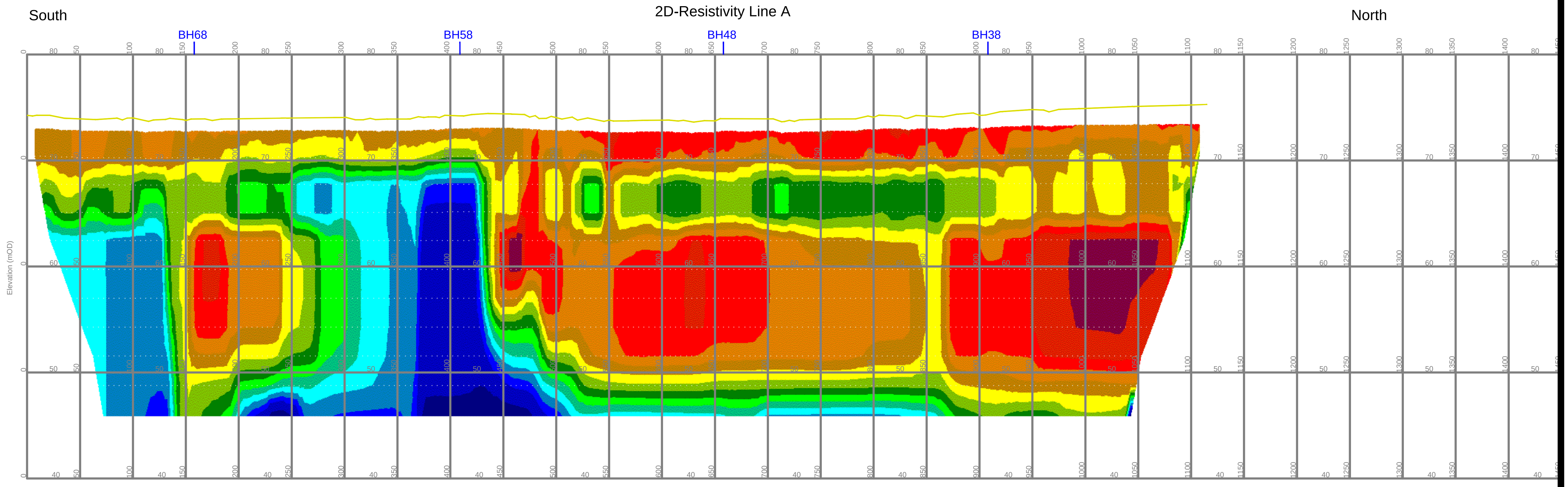
LEGEND:

2D-Resistivity Profile

Seismic Refraction Profile

BH77 Borehole





Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 1: Models of 2D-Resistivity Survey Line A and B

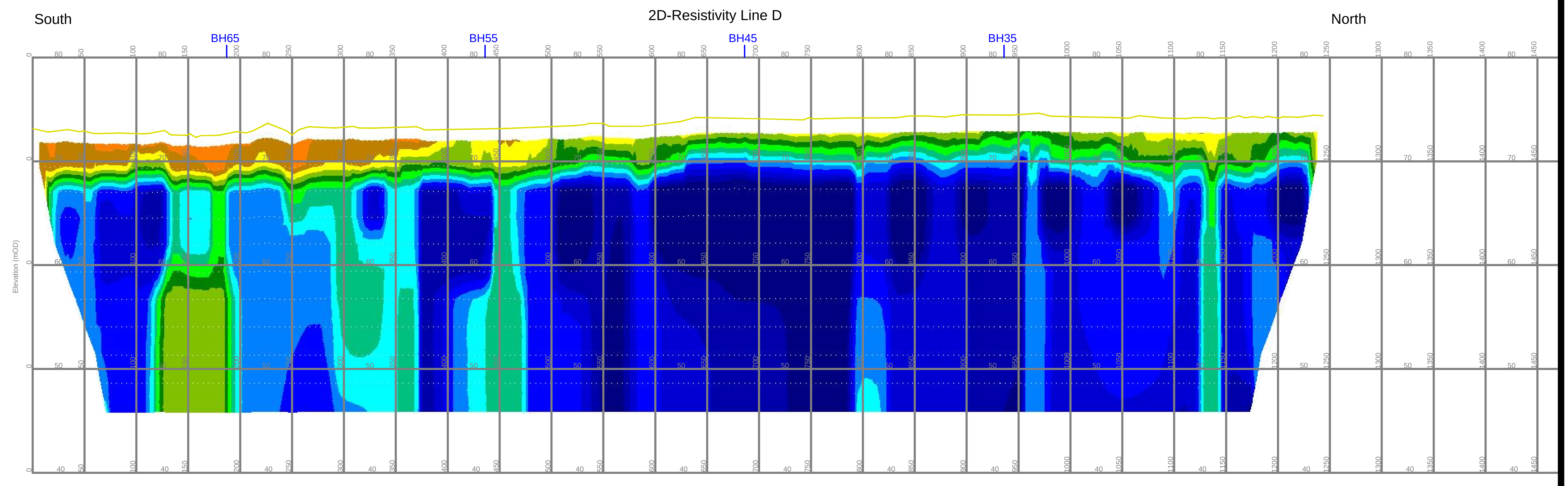
SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	RJ
DATE:	09/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

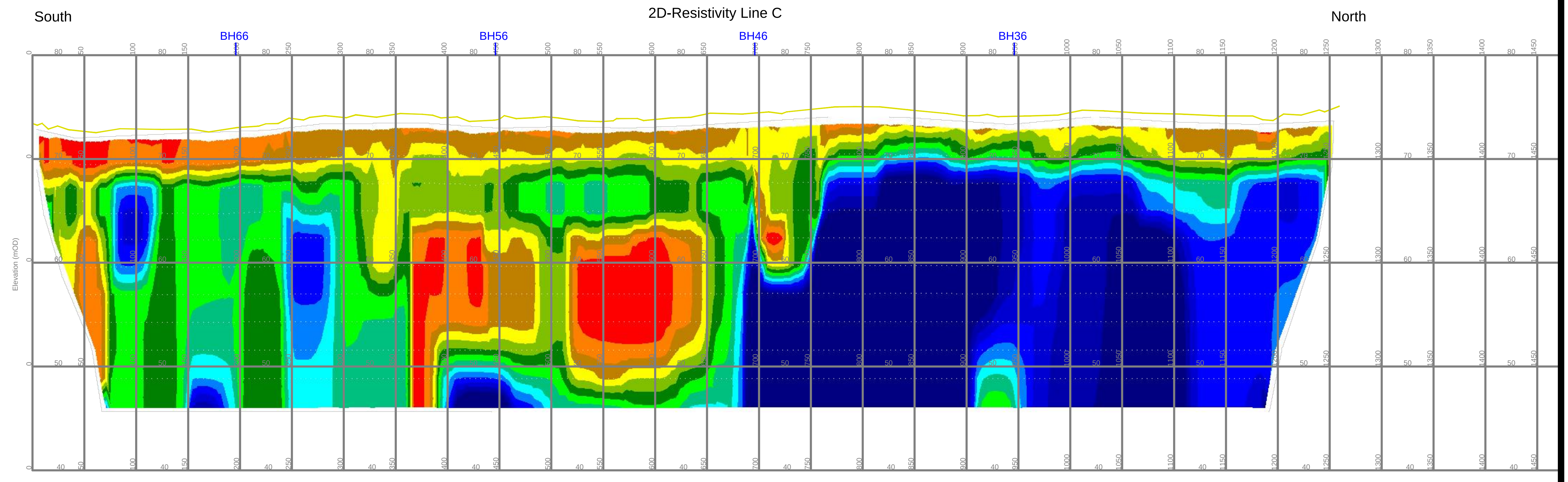
LEGEND:

BH38 Indicates Borehole on or near Line

Resistivities (Ohmm) for 2D-Resistivity Model

25.0 50.0 100 200 400 800 1600 3200





Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 2: Models of 2D-Resistivity Survey Line C and D

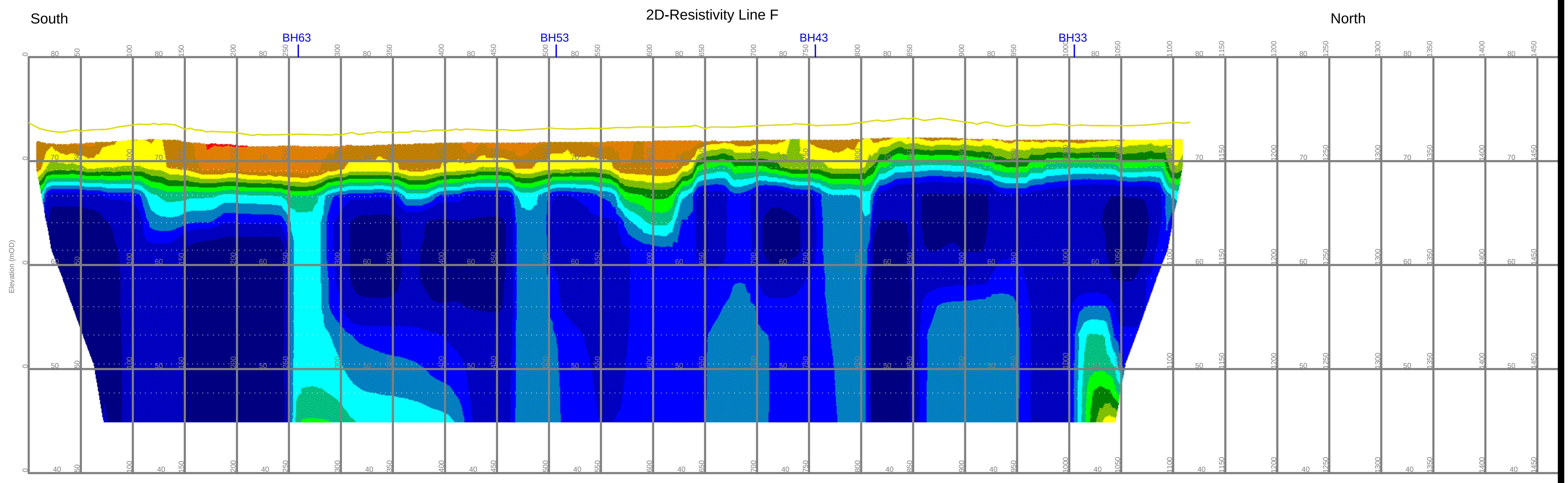
SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	RJ
DATE:	09/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

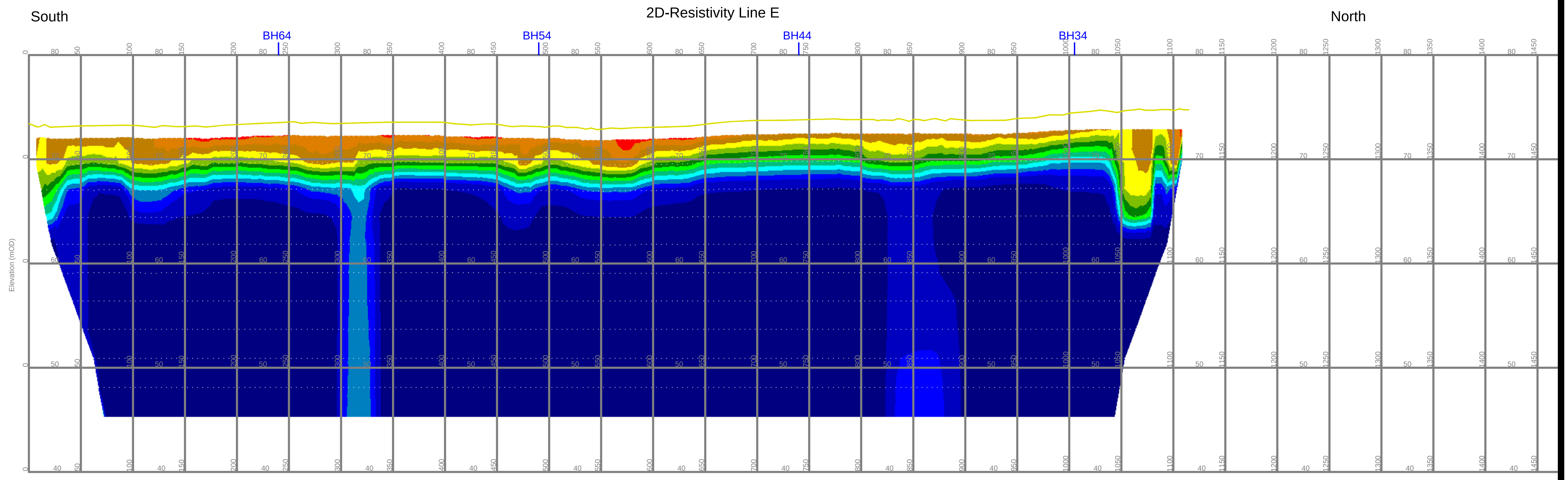
LEGEND:

BH38 Indicates Borehole on or near Line

Resistivities (Ohmm) for 2D-Resistivity Model

25.0 50.0 100 200 400 800 1600 3200





Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 3: Models of 2D-Resistivity Survey Lines E and F

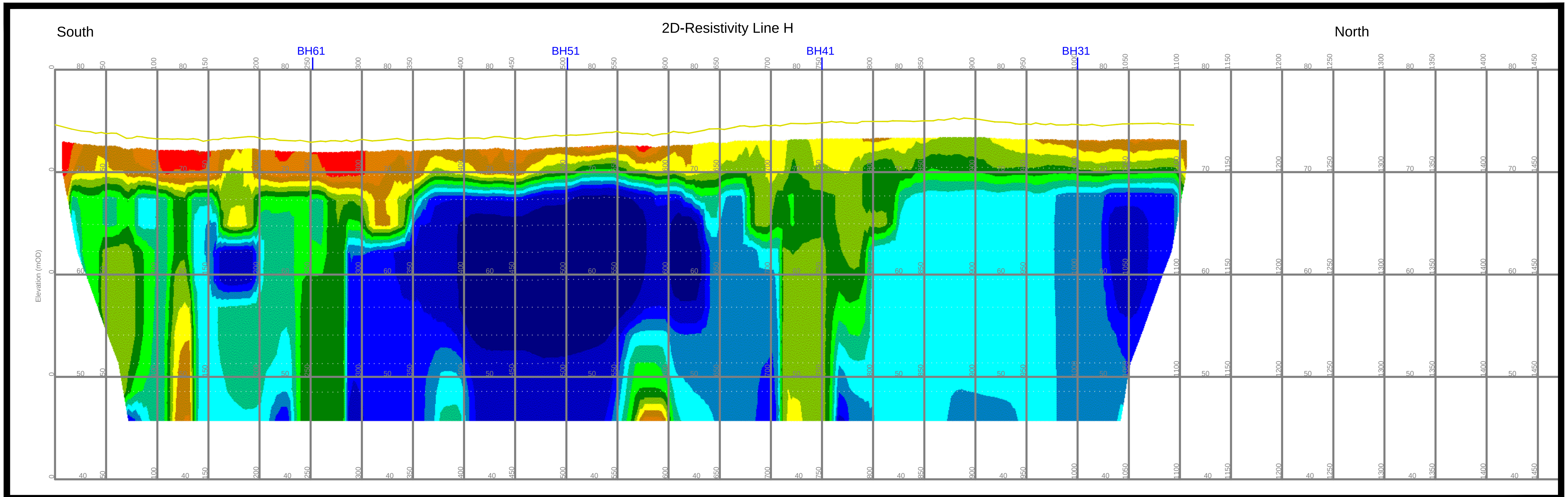
SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	RJ
DATE:	09/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

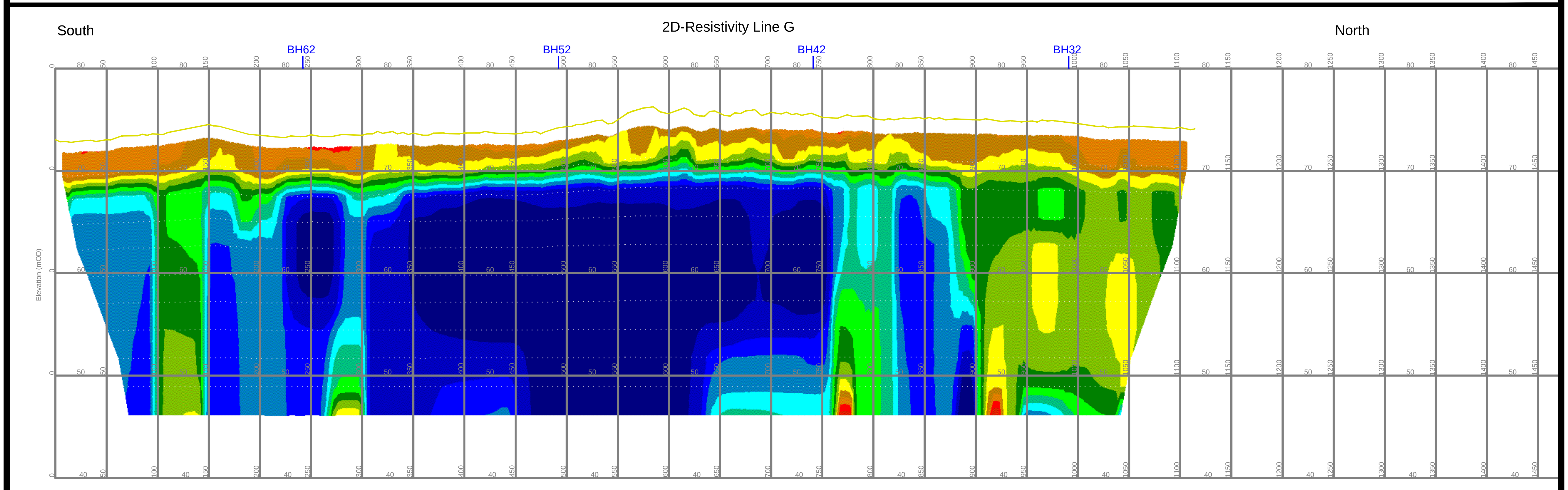
LEGEND:

BH38 Indicates Borehole on or near Line

Resistivities (Ohmm) for 2D-Resistivity Model

25.0 50.0 100 200 400 800 1600 3200





Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 4: Models of 2D-Resistivity Survey Lines G and H

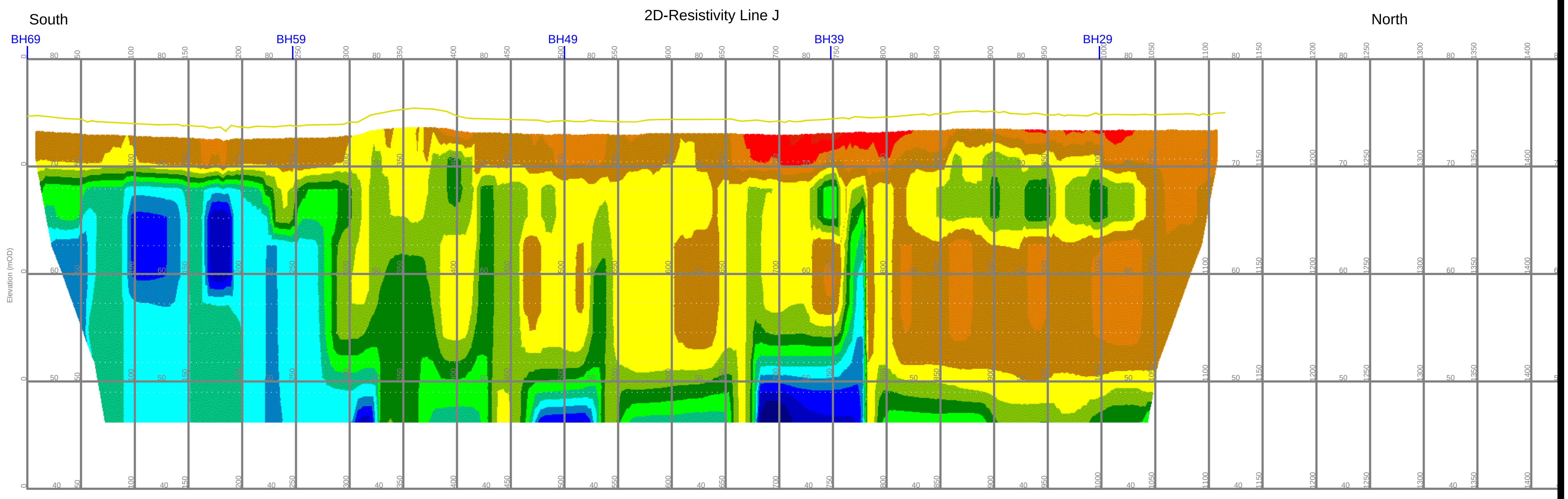
SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	RJ
DATE:	09/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

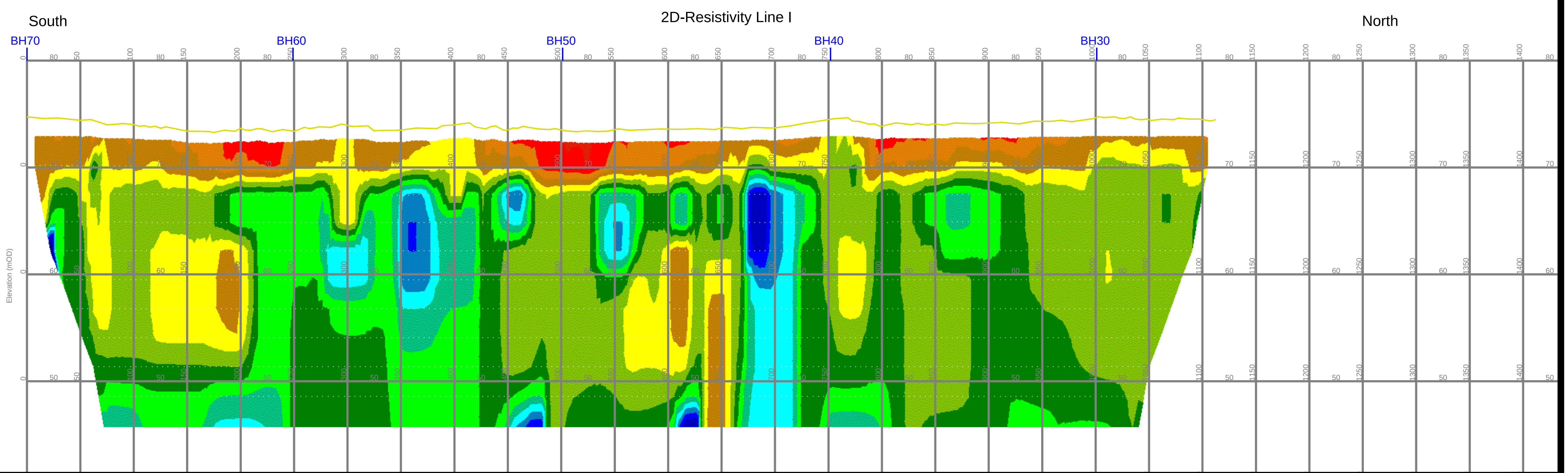
LEGEND:

BH38 Indicates Borehole on or near Line

Resistivities (Ohmm) for 2D-Resistivity Model

25.0 50.0 100 200 400 800 1600 3200





Minerex Geophysics Limited	CLIENT	Irish Drilling Ltd. Irish Water	SCALE: 1:4000 @ A3, VE x 10
			PROJECT: 5867
	PROJECT	Garryhinch Geophysical Survey	DRAWN: JC
			DATE: 19/01/2015
	TITLE	Figure 5: Models of 2D-Resistivity Survey Lines I and J	MGX FILE: 5867d_Figs.dwg
			STATUS: Draft

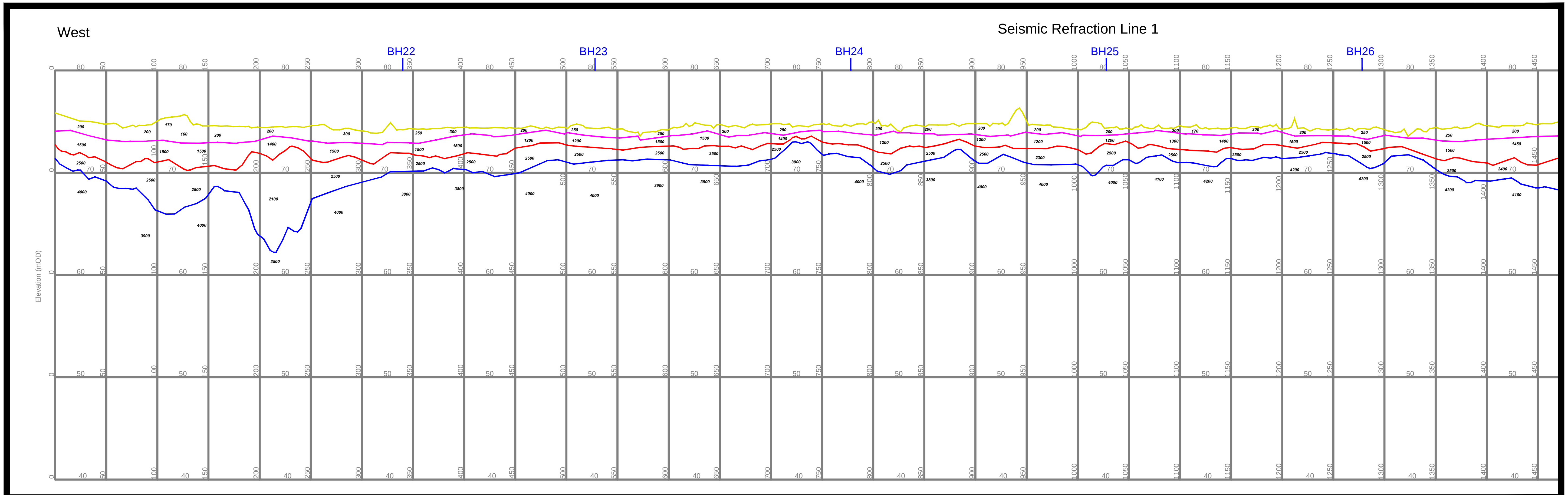
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

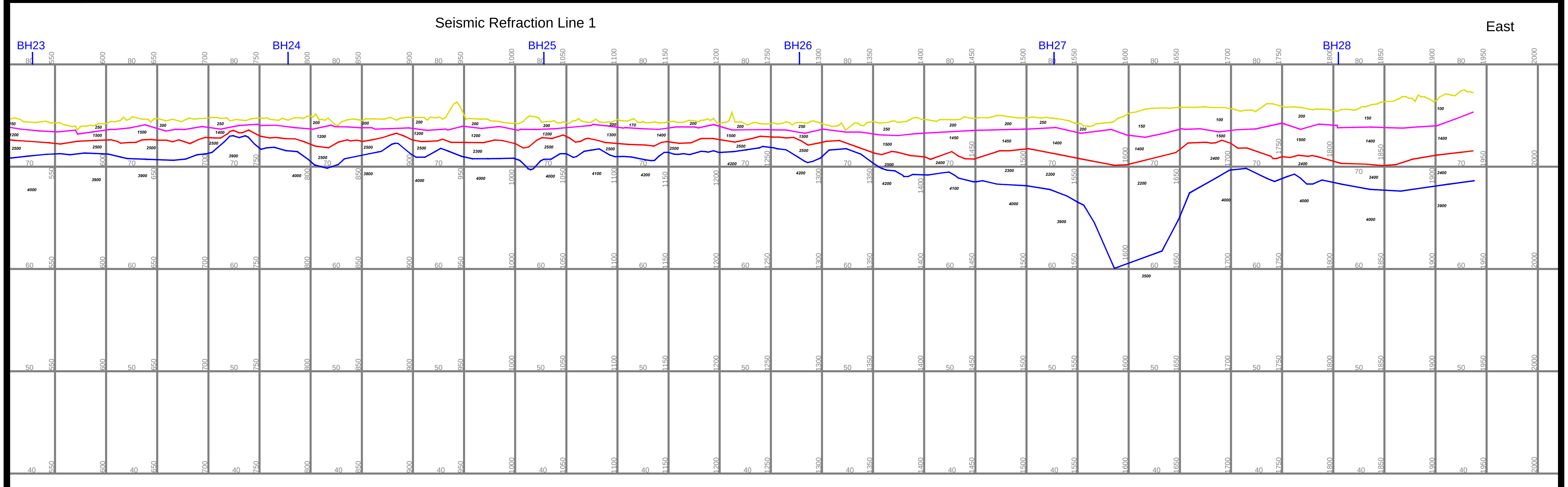
LEGEND:

BH38 Indicates Borehole on or near Line

Resistivities (Ohmm) for 2D-Resistivity Model

25.0 50.0 100 200 400 800 1600 3200





Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 6: Models of Seismic Refraction Survey Line 1

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	RJ
DATE:	09/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

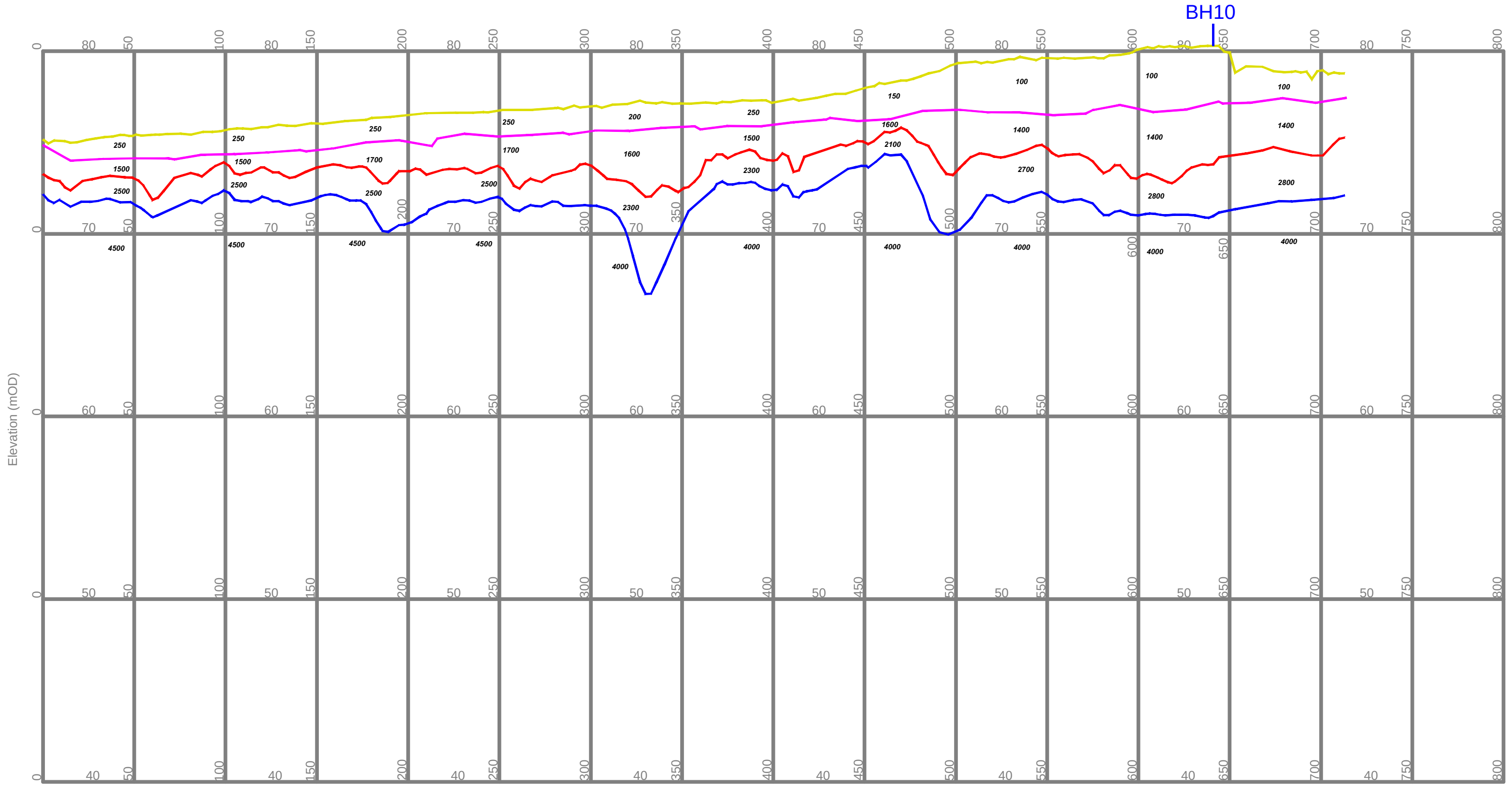
LEGEND:

1500 Seismic Velocity in m/s
Layers from Seismic Refraction Model:
Ground Surface/Top of Layer 1 (<=300 m/s)
Top of Layer 2 (310 - 500 m/s)
Top of Layer 3 (1200 - 1900 m/s)
Top of Layer 4 (2100 - 2800 km/s)
Top of Layer 5 (> 3000 km/s)

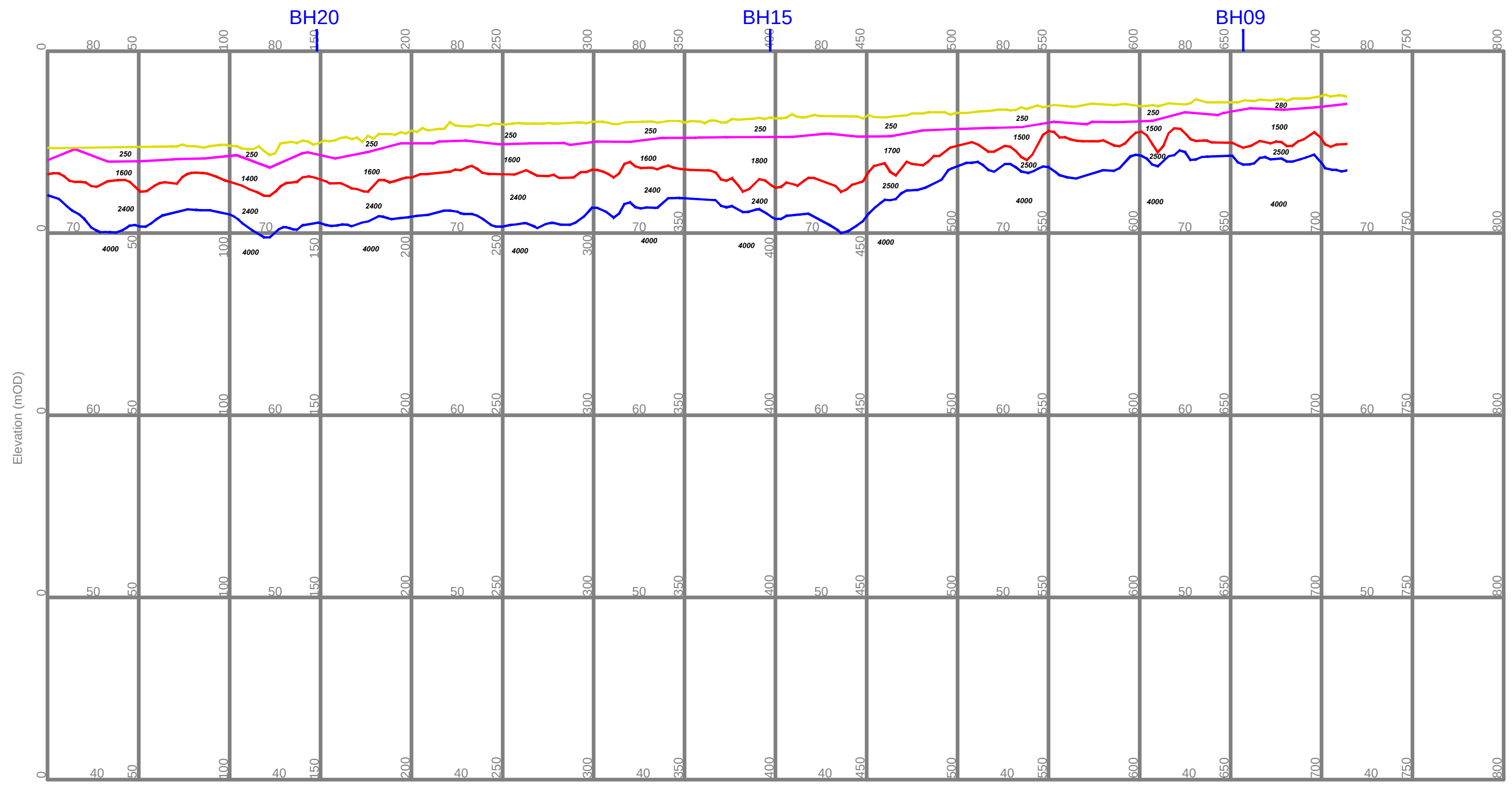
BH38 Indicates Borehole on or near Line

Penetration Limit for Seismic Refraction

South Seismic Refraction Line 2 North



South Seismic Refraction Line 3 North



Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 7: Models of Seismic Refraction Survey Line 2 and 3

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	19/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

1500 Seismic Velocity in m/s

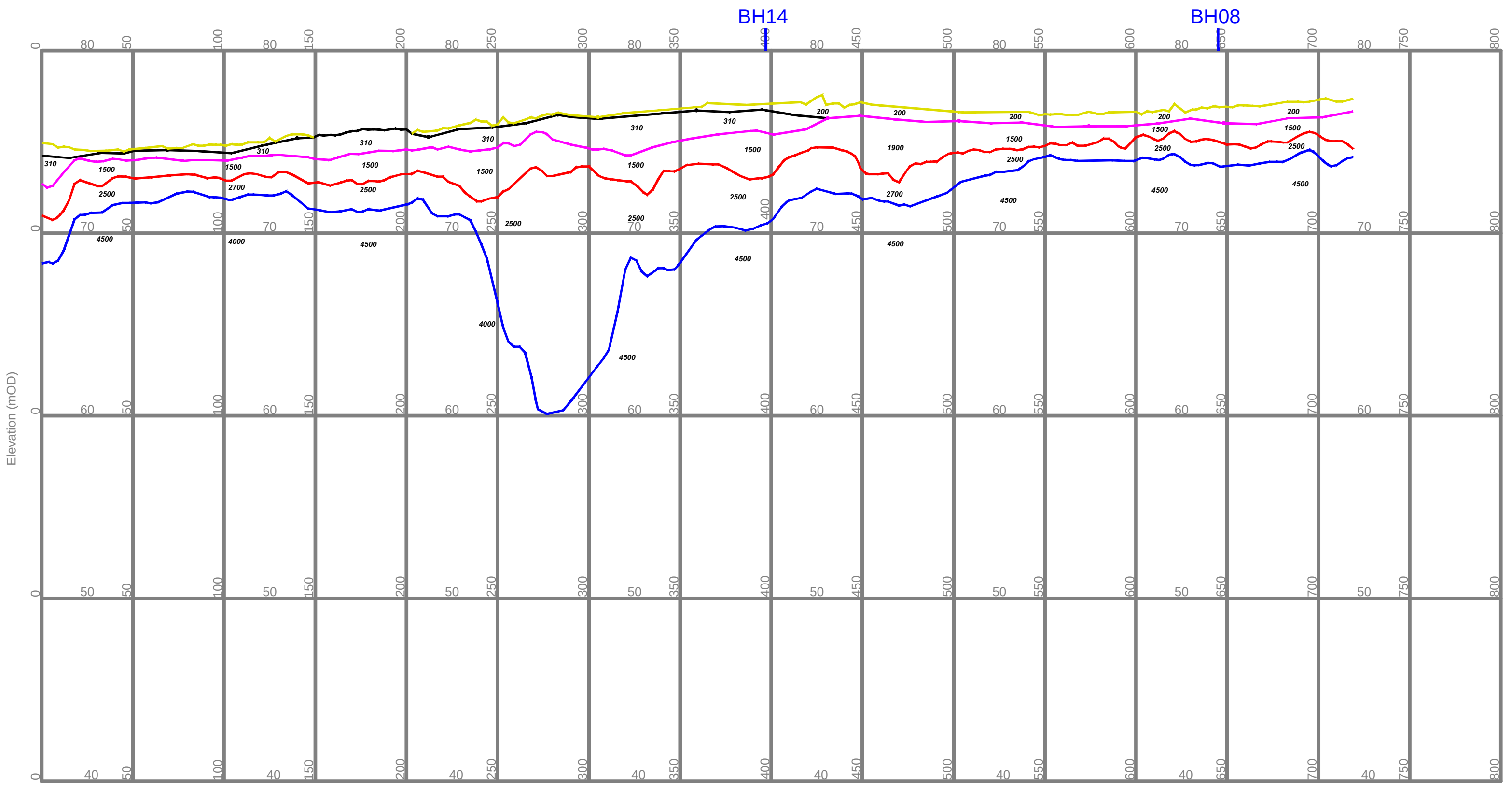
BH38 Indicates Borehole on or near Line

Layers from Seismic Refraction Model:
- Ground Surface/Top of Layer 1 (<=300 m/s)
- Top of Layer 2 (310 - 500 m/s)
- Top of Layer 3 (1200 - 1900 m/s)
- Top of Layer 4 (2100 - 2800 km/s)
- Top of Layer 5 (> 3000 km/s)

South

Seismic Refraction Line 4

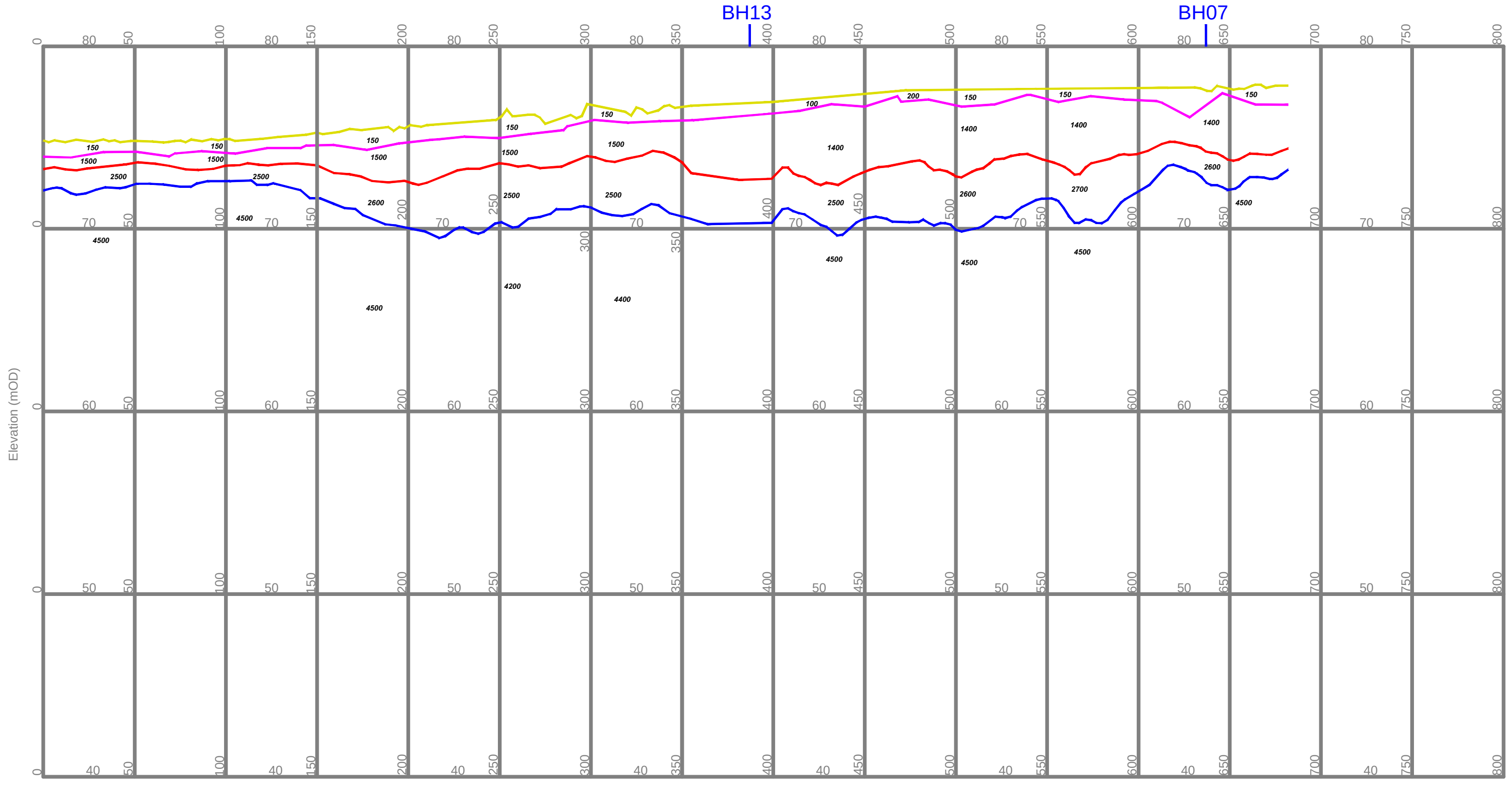
North



South

Seismic Refraction Line 5

North



Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 8: Models of Seismic Refraction Survey Line 4 and 5

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	19/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

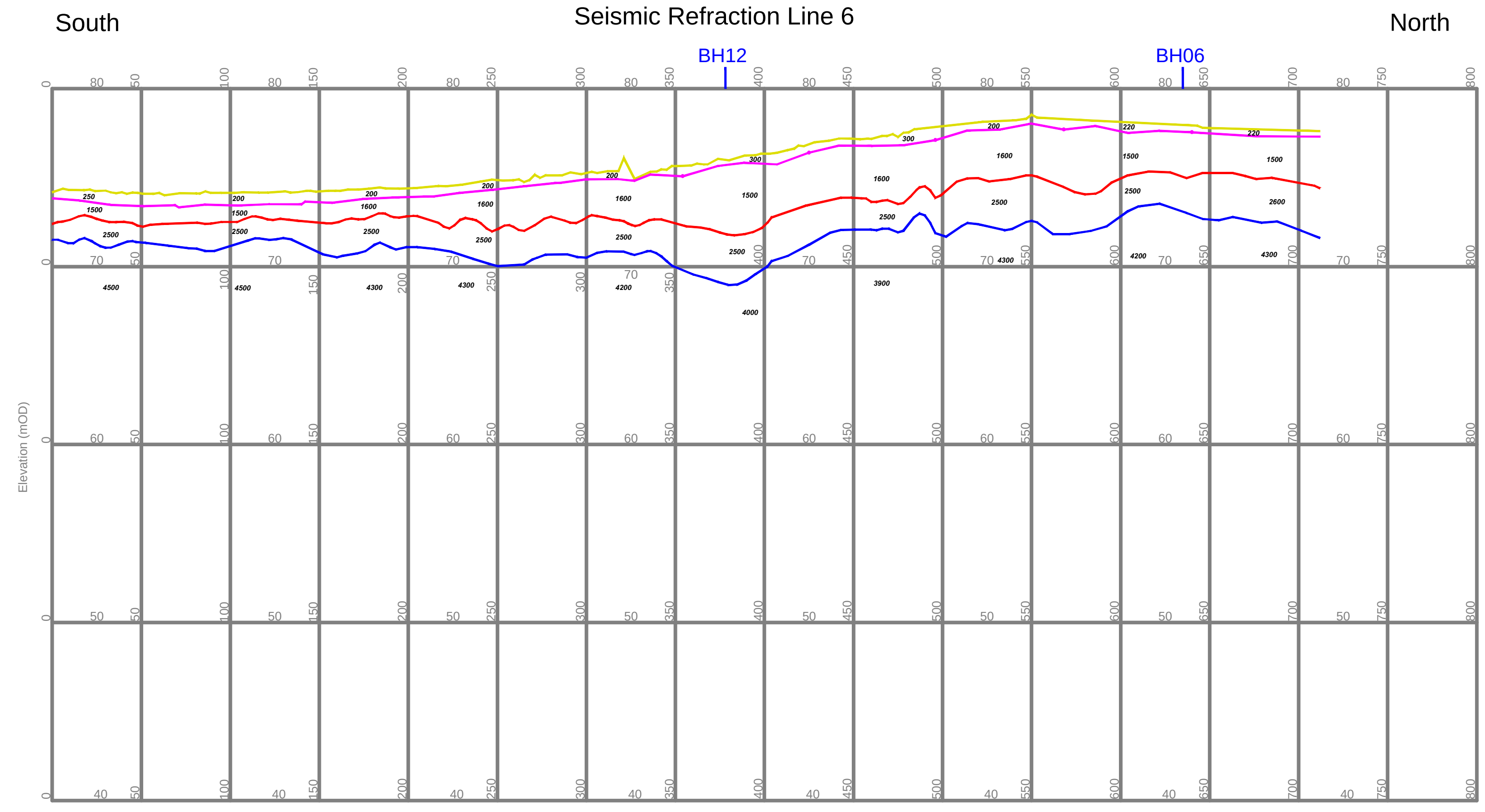
LEGEND:

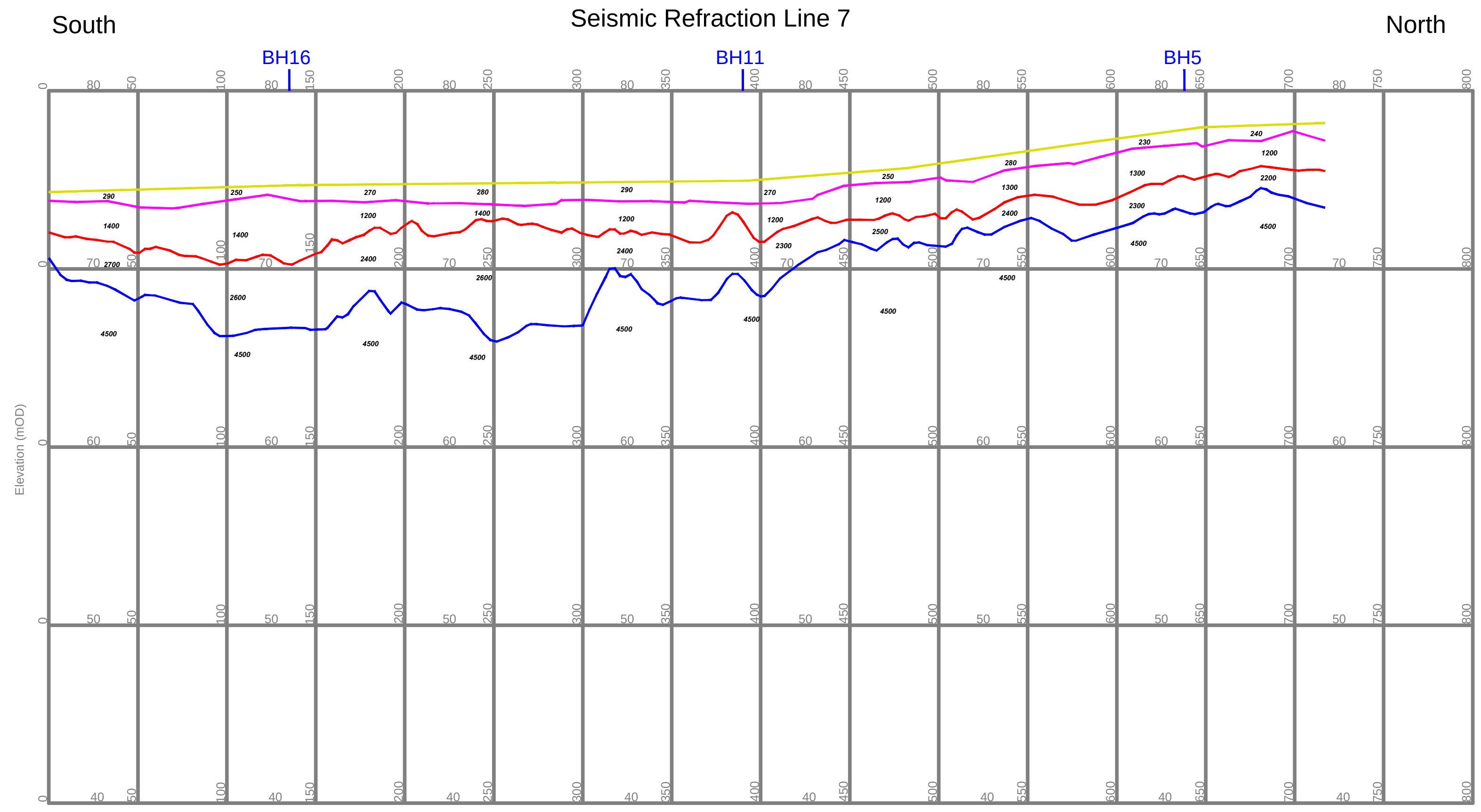
1500 Seismic Velocity in m/s

Layers from Seismic Refraction Model:

- Ground Surface/Top of Layer 1 (<=300 m/s)
- Top of Layer 2 (310 - 500 m/s)
- Top of Layer 3 (1200 - 1900 m/s)
- Top of Layer 4 (2100 - 2800 km/s)
- Top of Layer 5 (>3000 km/s)

BH38 Indicates Borehole on or near Line





Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 9: Models of Seismic Refraction Survey Line 6 and 7

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	19/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

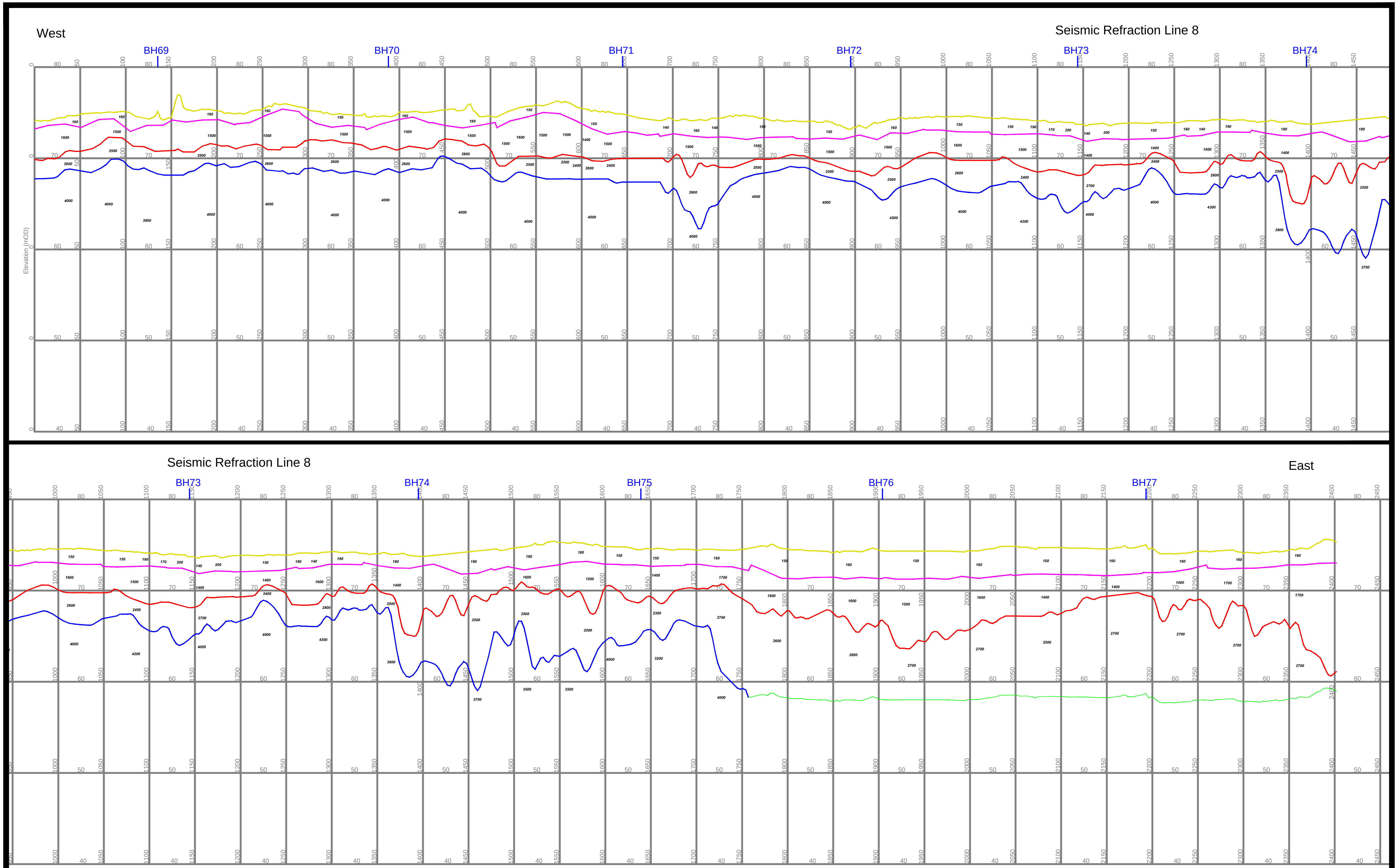
LEGEND:

1500 Seismic Velocity in m/s

Layers from Seismic Refraction Model:

- Ground Surface/Top of Layer 1 (<=300 m/s)
- Top of Layer 2 (310 - 500 m/s)
- Top of Layer 3 (1200 - 1900 m/s)
- Top of Layer 4 (2100 - 2800 km/s)
- Top of Layer 5 (> 3000 km/s)

BH38 Indicates Borehole on or near Line



Minerex Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 10: Models of Seismic Refraction Survey Line 8

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	19/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

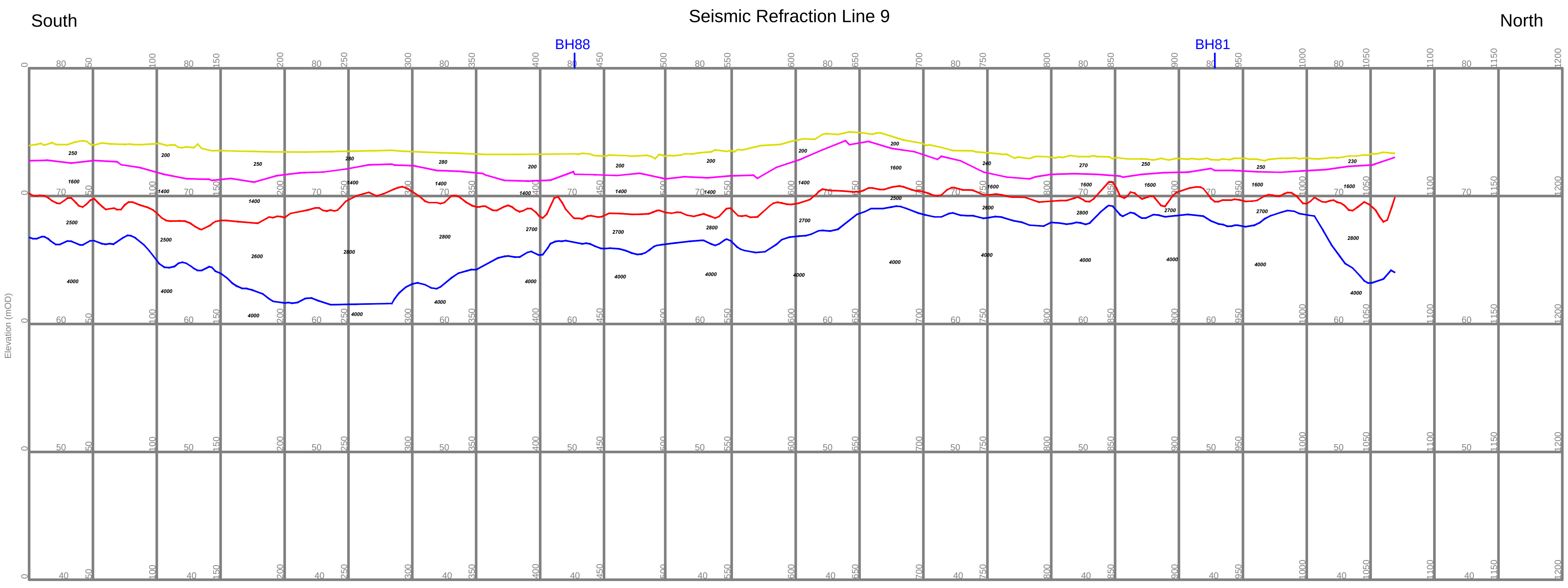
1500 Seismic Velocity in m/s

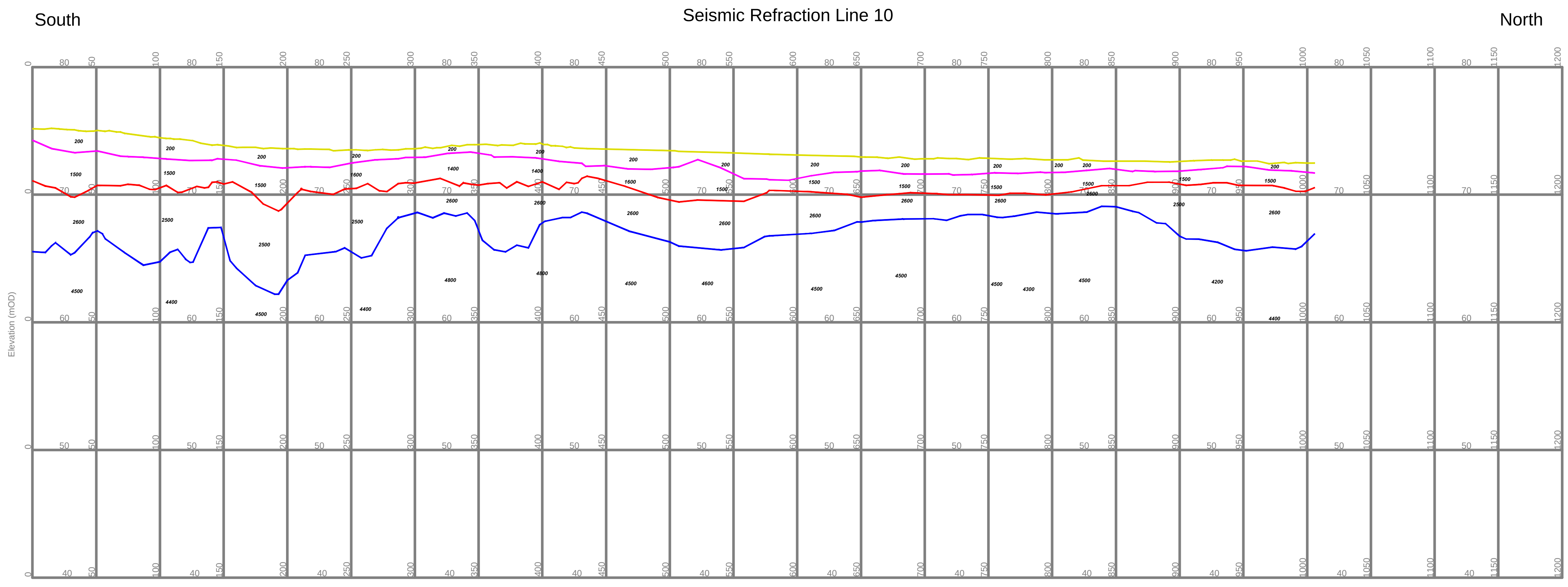
Layers from Seismic Refraction Model:

- Ground Surface/Top of Layer 1 (<=300 m/s)
- Top of Layer 2 (310 - 500 m/s)
- Top of Layer 3 (1200 - 1900 m/s)
- Top of Layer 4 (2100 - 2800 km/s)
- Top of Layer 5 (> 3000 km/s)

BH38 Indicates Borehole on or near Line

Penetration Limit for Seismic Refraction





Minerex Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 11: Models of Seismic Refraction Survey Line 9 and 10

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	19/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

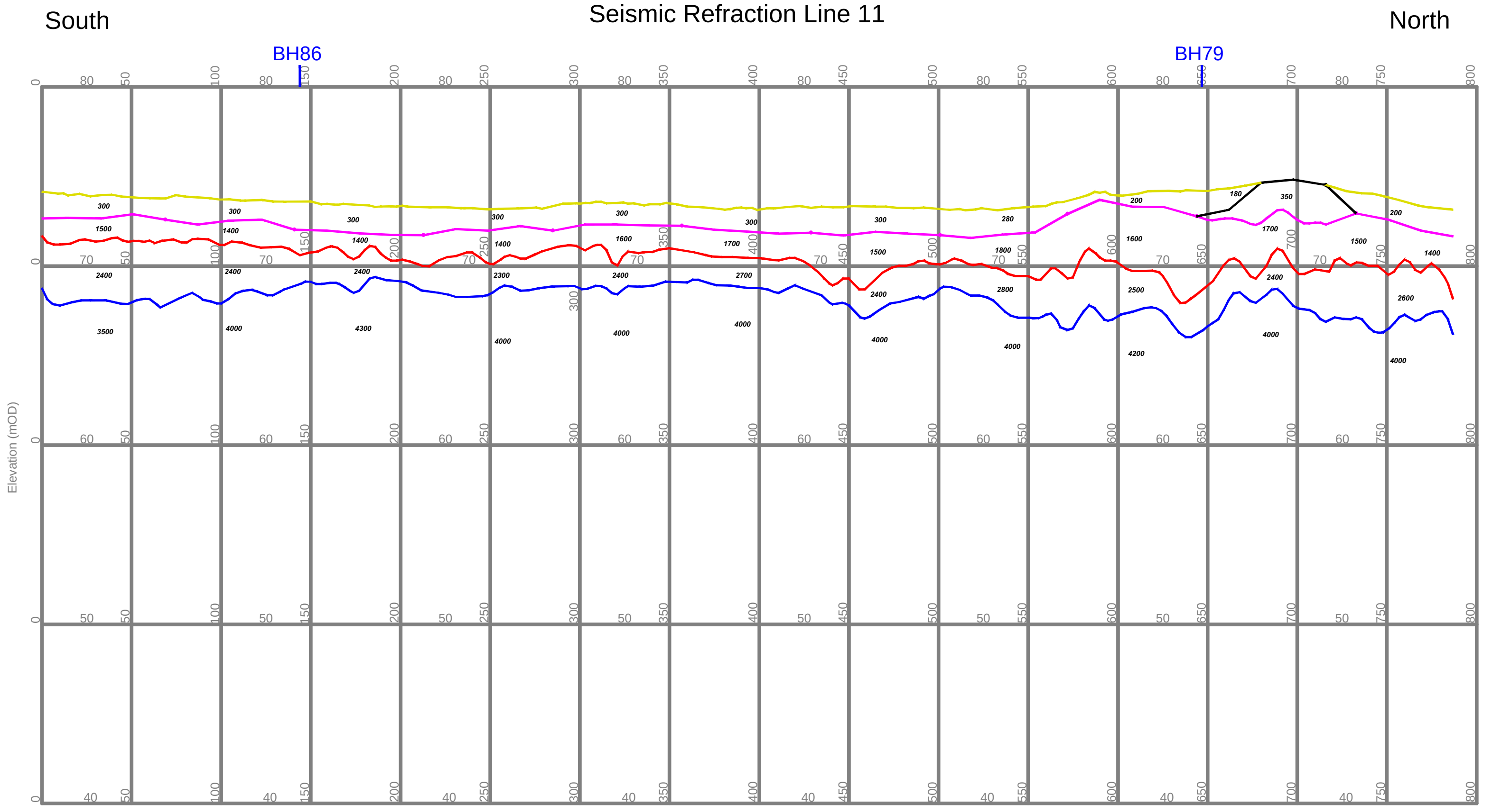
LEGEND:

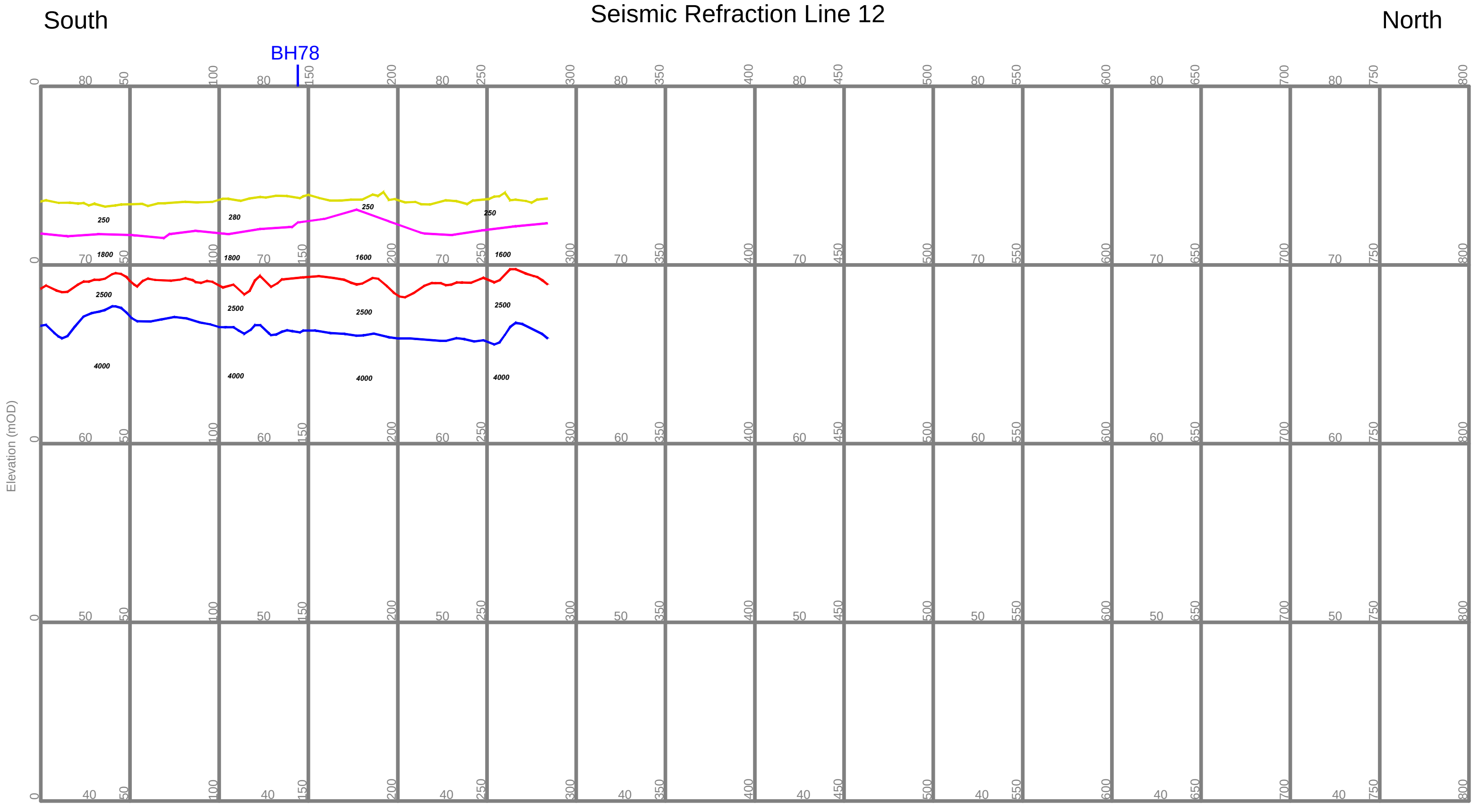
1500 Seismic Velocity in m/s

BH38 Indicates Borehole on or near Line

Layers from Seismic Refraction Model:

- Ground Surface/Top of Layer 1 (<=300 m/s)
- Top of Layer 2 (310 - 500 m/s)
- Top of Layer 3 (1200 - 1900 m/s)
- Top of Layer 4 (2100 - 2800 km/s)
- Top of Layer 4 (> 3000 km/s)





Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 12: Models of Seismic Refraction Survey Line 11 and 12

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	19/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

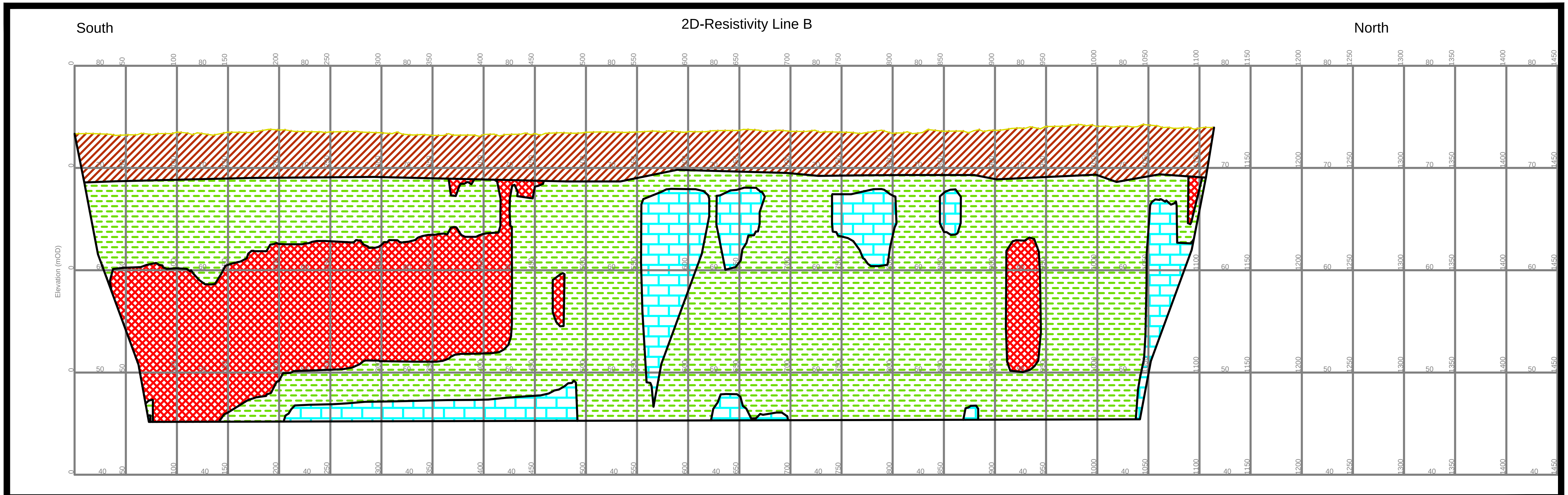
LEGEND:

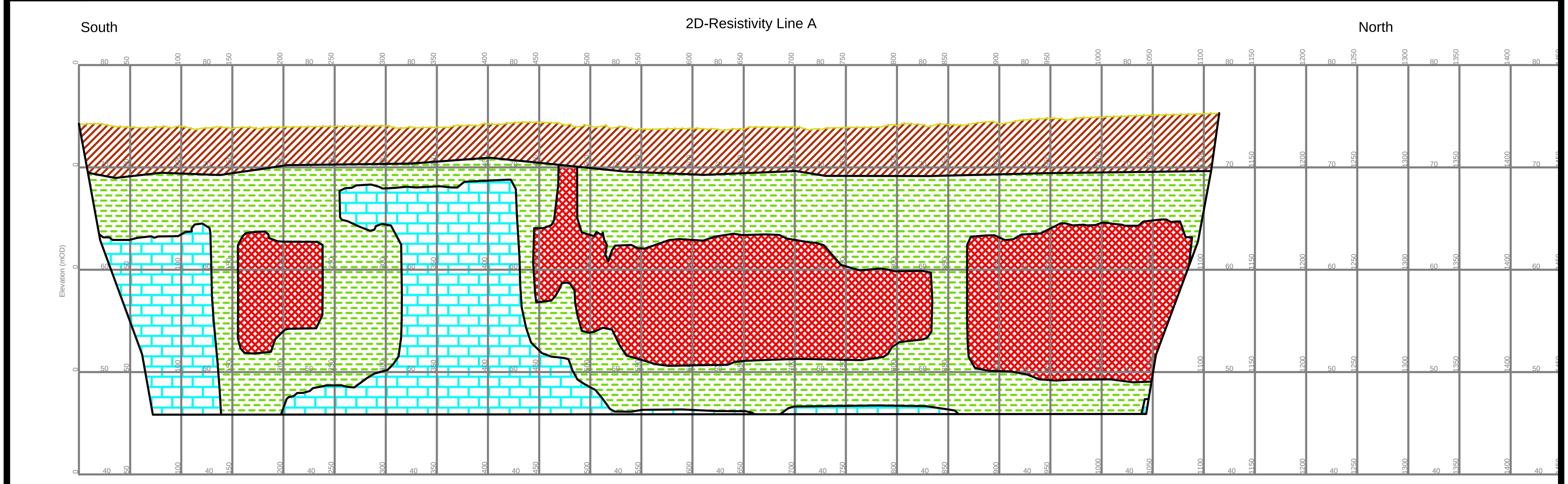
1500 Seismic Velocity in m/s

Layers from Seismic Refraction Model:

- Ground Surface/Top of Layer 1 (<=300 m/s)
- Top of Layer 2 (310 - 500 m/s)
- Top of Layer 3 (1200 - 1900 m/s)
- Top of Layer 4 (2100 - 2800 km/s)
- Top of Layer 4 (> 3000 km/s)

BH38 Indicates Borehole on or near Line





Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

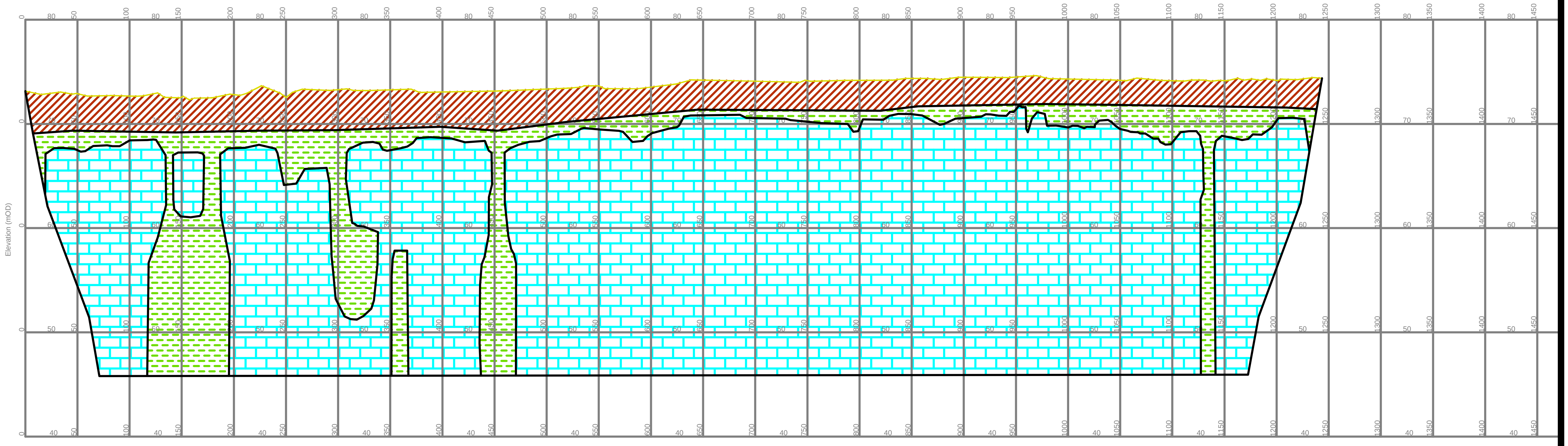
CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 13: Interpretation of 2D-Resistivity Survey Line A and B

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	23/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

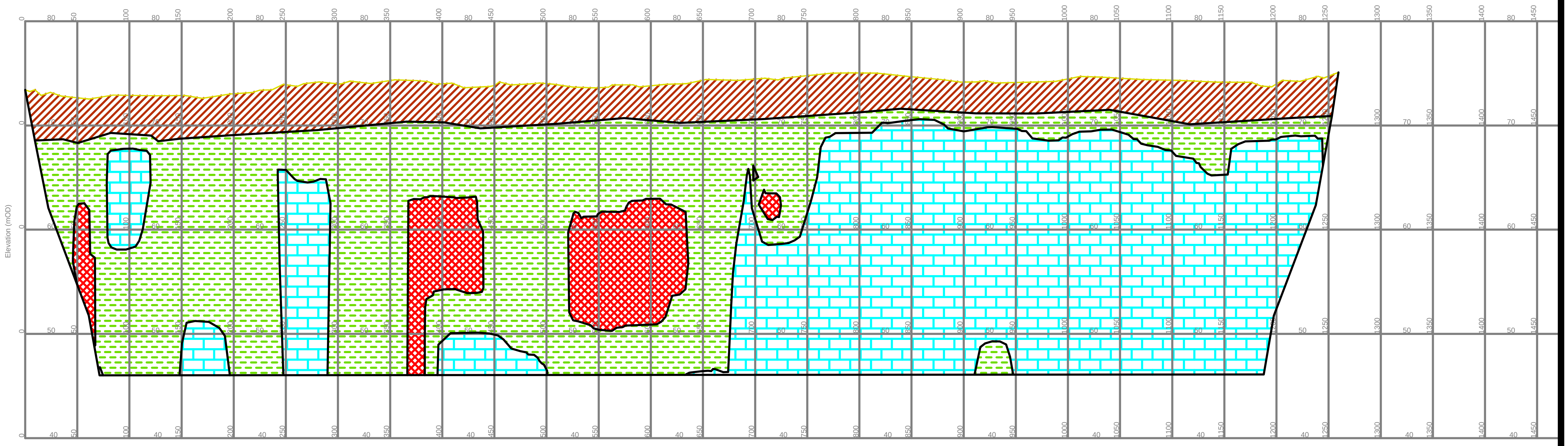
LEGEND:

2D Resistivity Interpretation:
- Ground Surface
- 1 Peat or Overburden
- 2 Very Weathered Karstified Limestone
- 3 Weathered Limestone
- 4 Clean Fresh Limestone

South | 2D-Resistivity Line D | North



South | 2D-Resistivity Line C | North



Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 14: Interpretation of 2D-Resistivity Survey Line C and D

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	23/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

2D Resistivity Interpretation:

Ground Surface

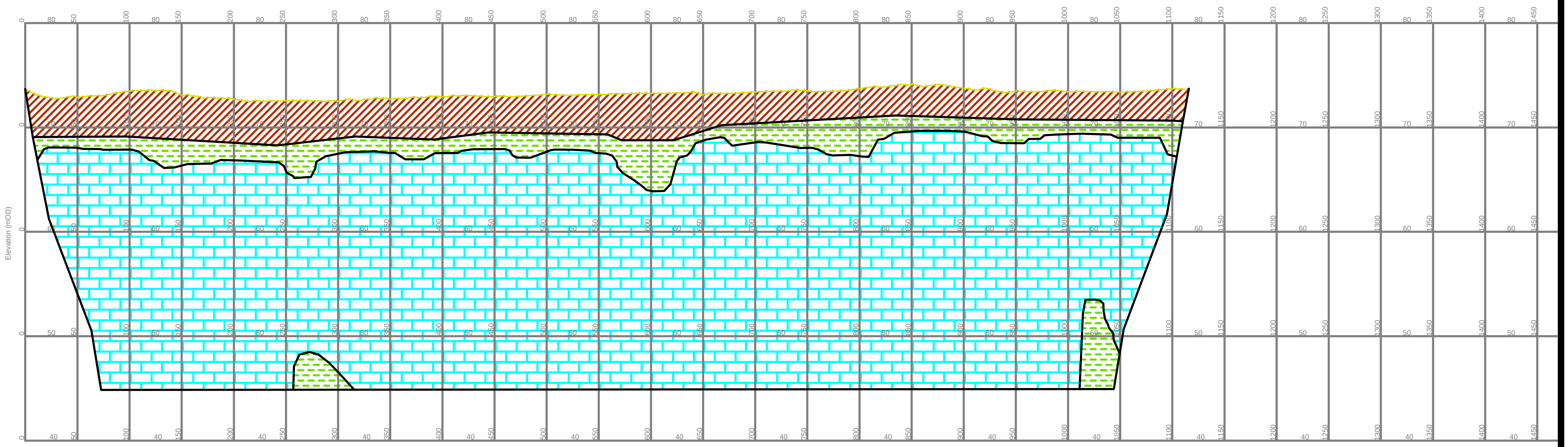
1 Peat or Overburden

2 Very Weathered Karstified Limestone

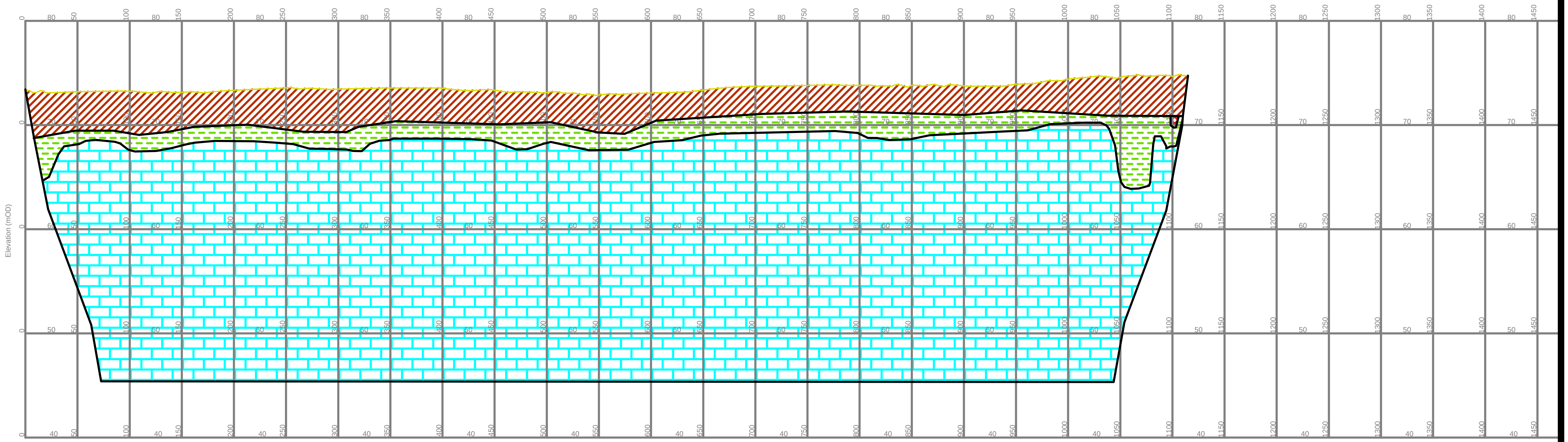
3 Weathered Limestone

4 Clean Fresh Limestone

2D-Resistivity Line F



2D-Resistivity Line E



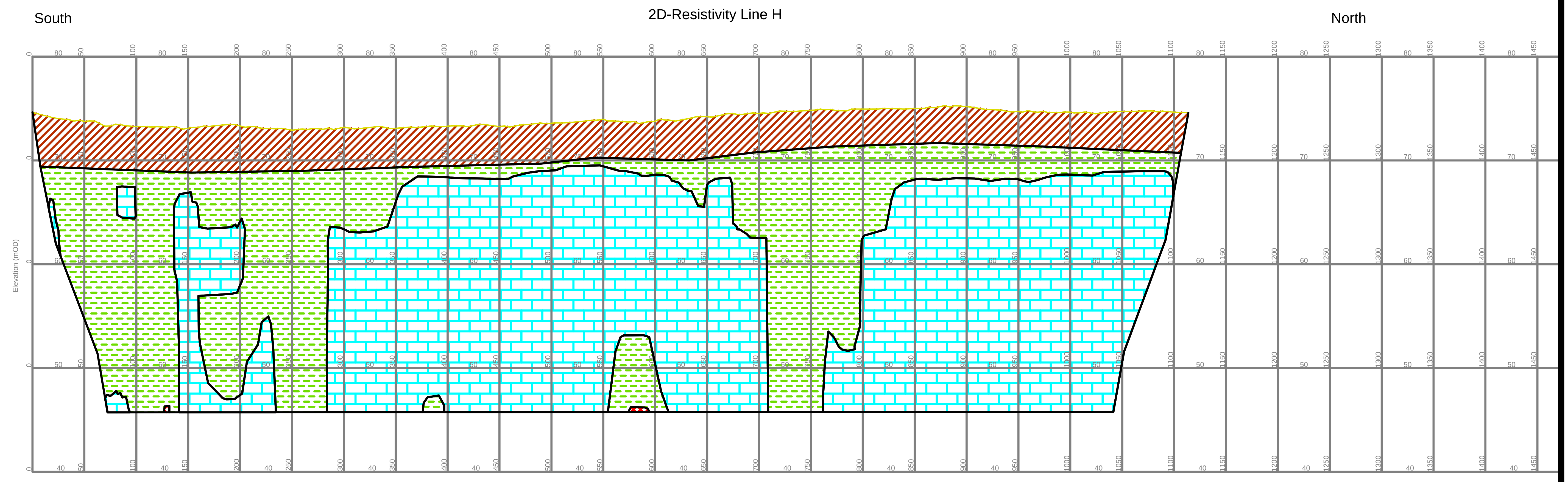
Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

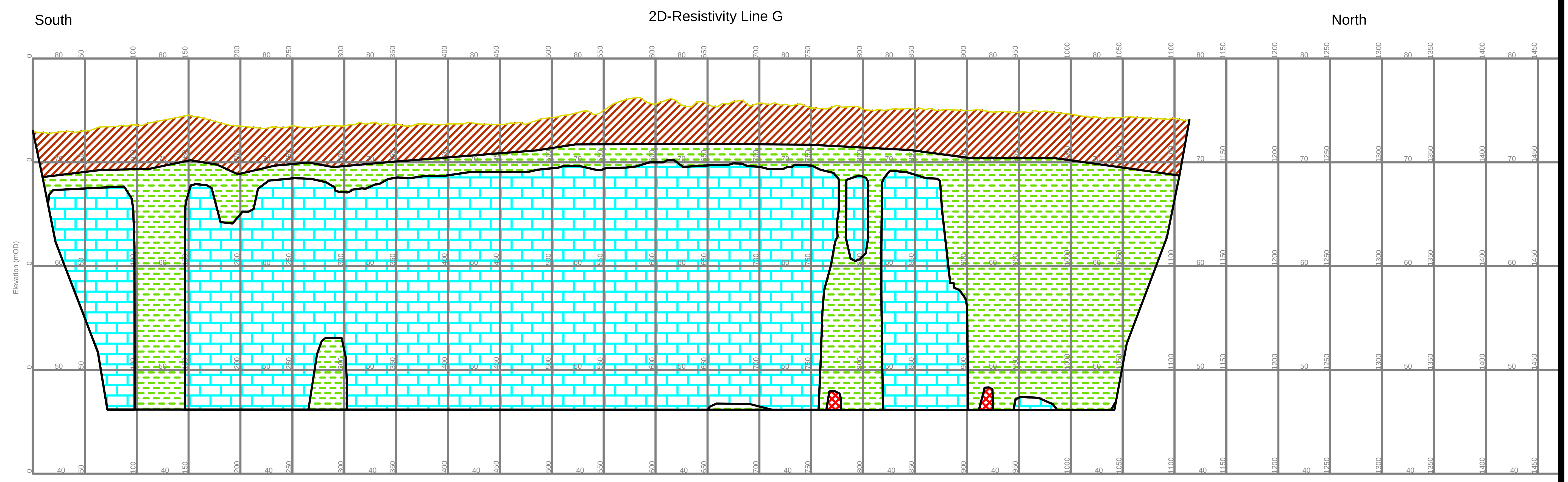
CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 15: Interpretation of 2D-Resistivity Survey Lines E and F

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	23/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

2D Resistivity Interpretation:
- Ground Surface
- 1 Peat or Overburden
- 2 Very Weathered Karstified Limestone
- 3 Weathered Limestone
- 4 Clean Fresh Limestone





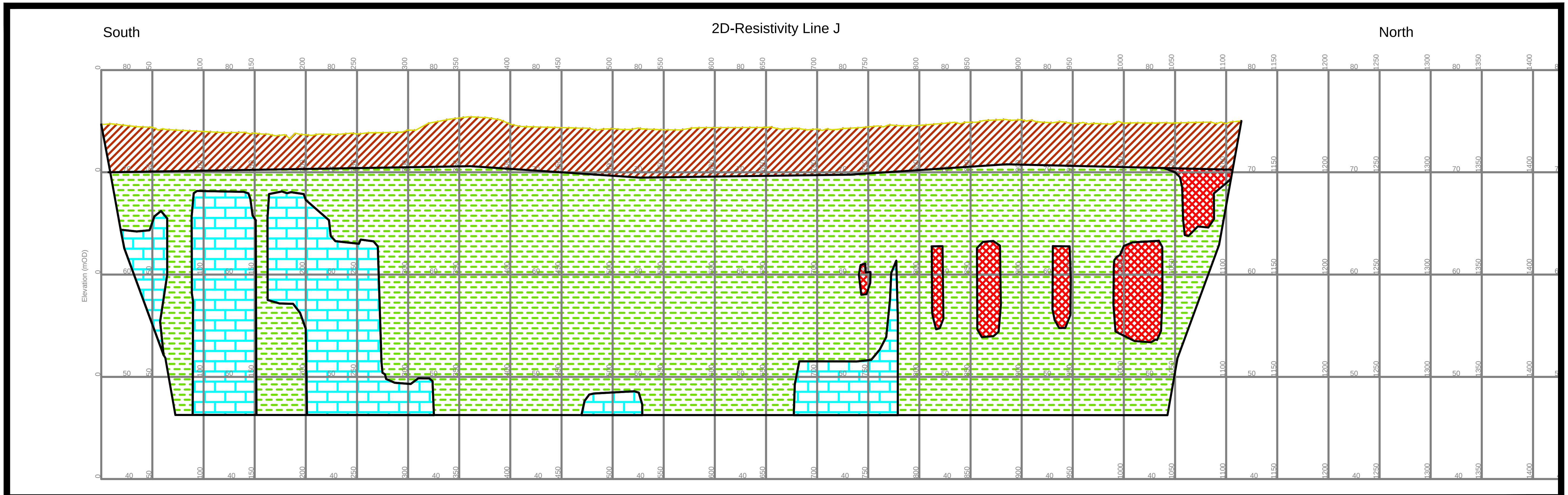
Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

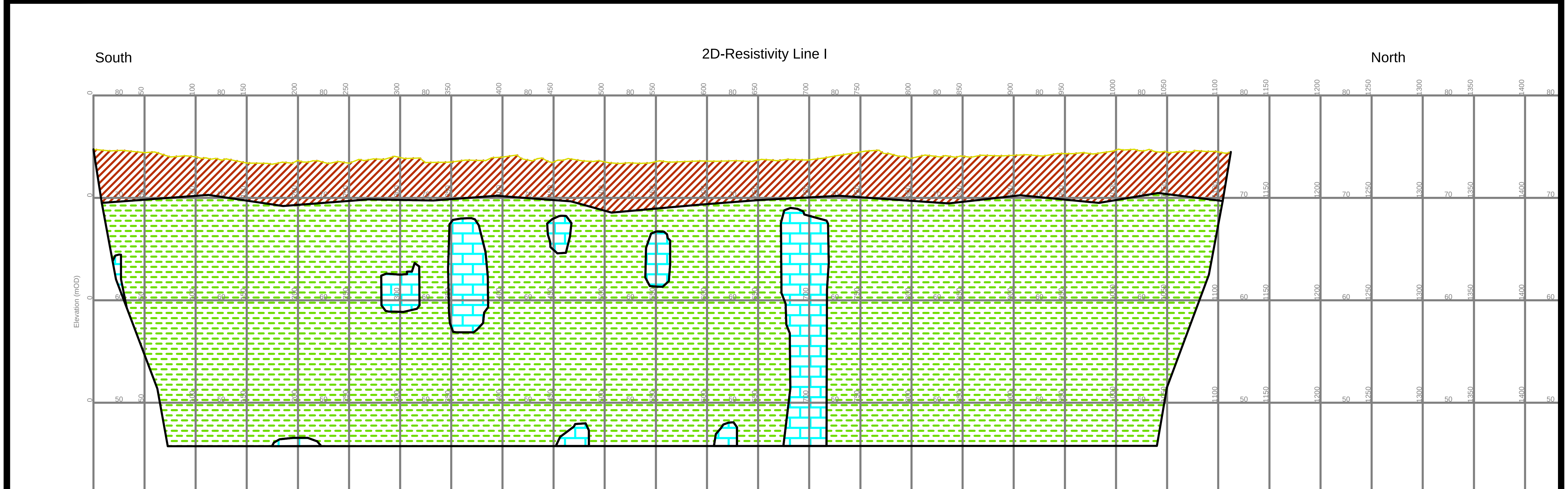
CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 16: Interpretation of 2D-Resistivity Survey Lines G and H

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	23/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

2D Resistivity Interpretation:
- Ground Surface
- 1 Peat or Overburden
- 2 Very Weathered Karstified Limestone
- 3 Weathered Limestone
- 4 Clean Fresh Limestone





Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 17: Interpretation of 2D-Resistivity Survey Lines I and J

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	23/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

2D Resistivity Interpretation:

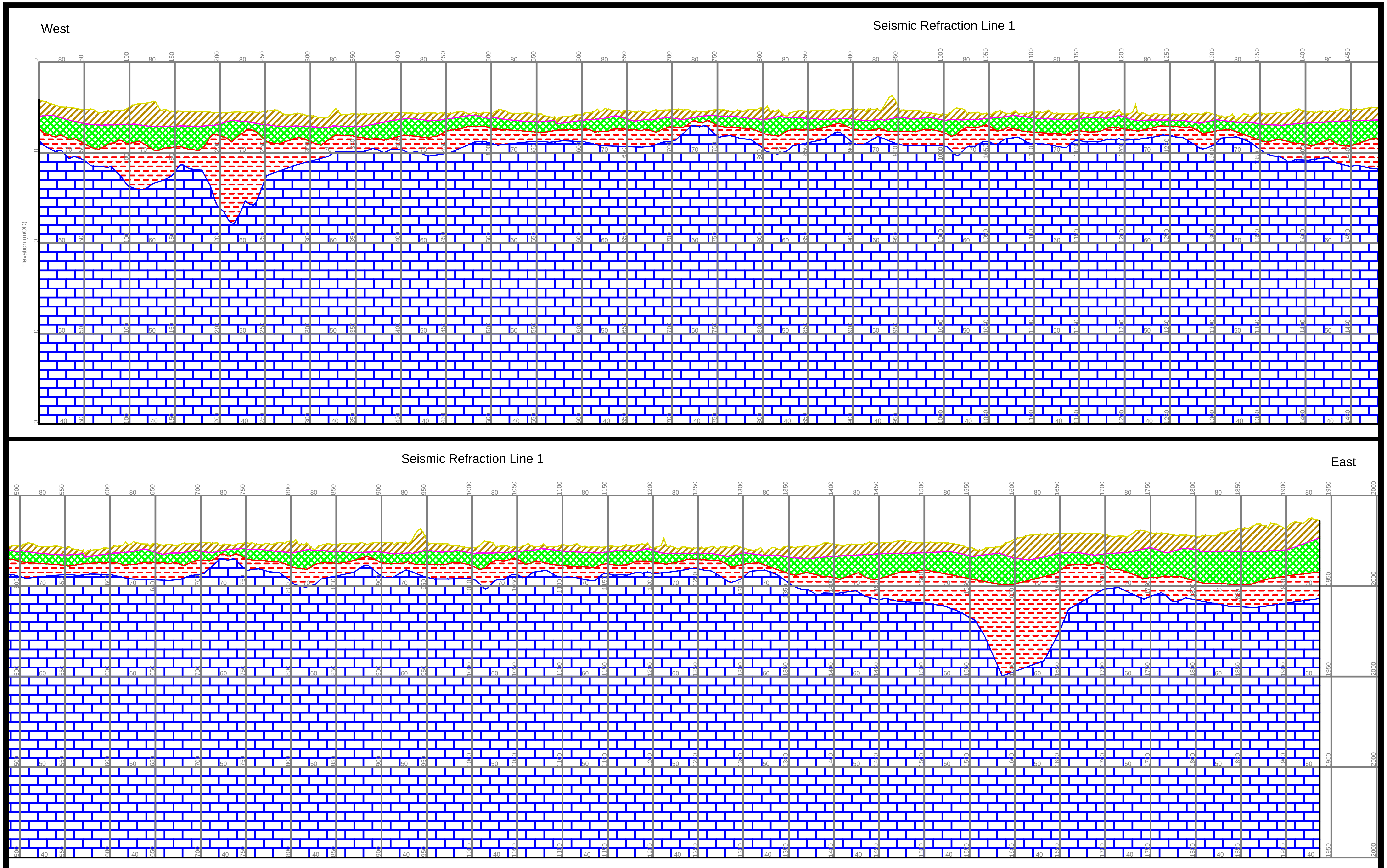
Ground Surface

1 Peat or Overburden

2 Very Weathered Karstified Limestone

3 Weathered Limestone

4 Clean Fresh Limestone



Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

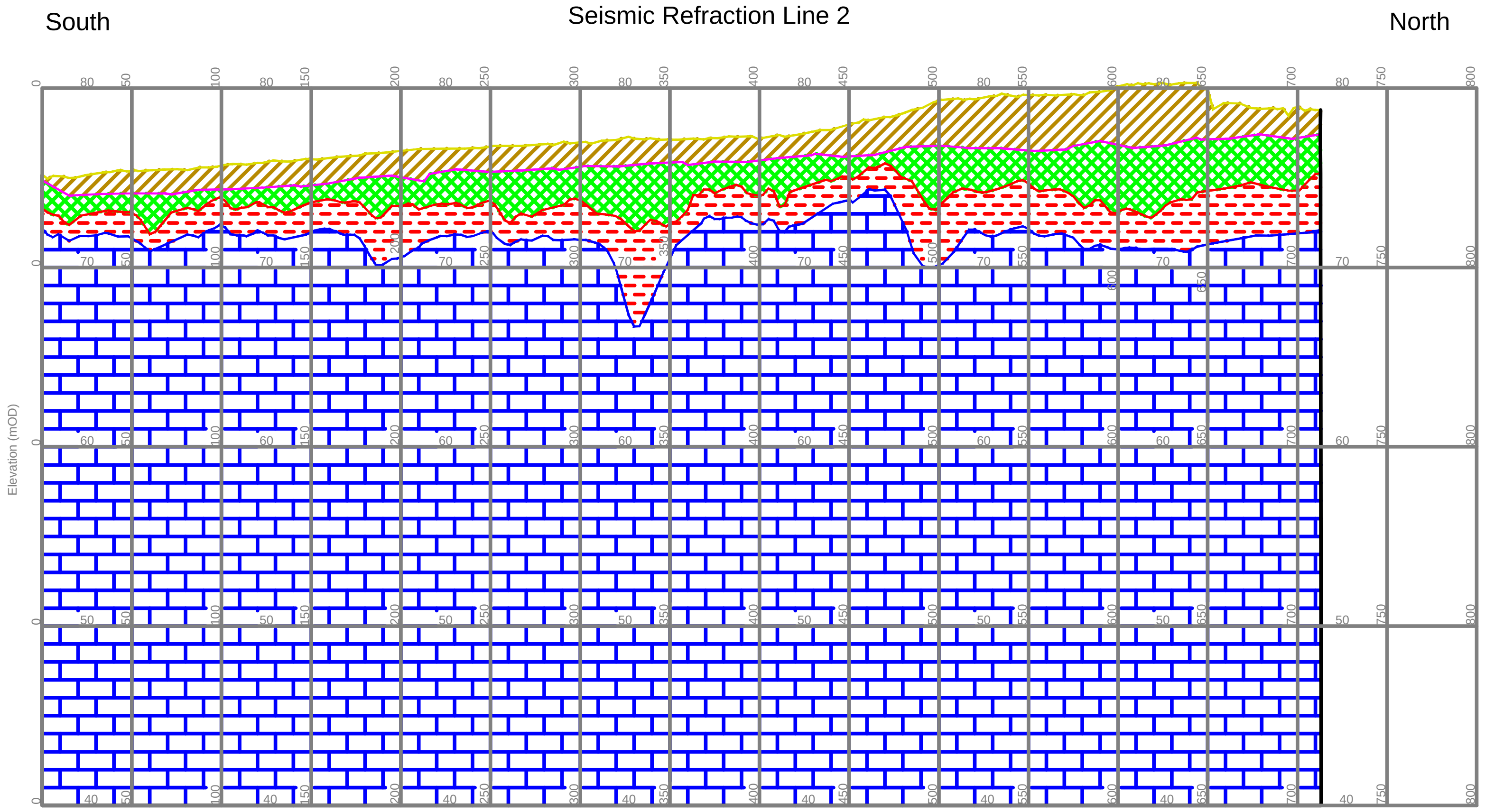
CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 18: Interpretaion of Seismic Refraction Survey Line 1

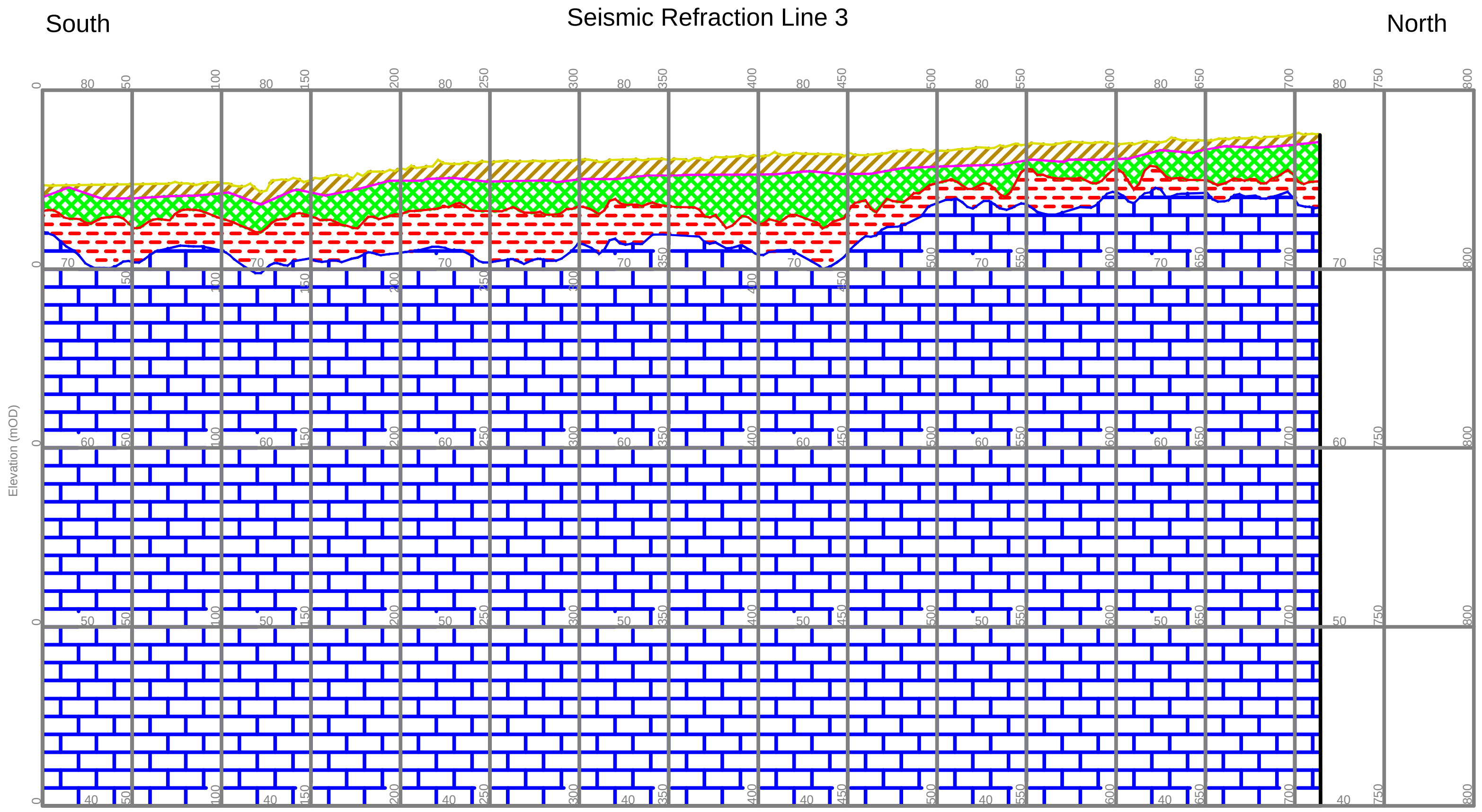
SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	20/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

Seismic Refraction Interpretation:

1 Very Soft Peat or Organic Matter
2 Soft or Loose Overburden (Gravelly Silt or Clay)
3 Stiff or Dense Overburden
4 Poor to Fair Weathered Rock or Very Stiff or Very Dense Highly Consolidated Overburden
5 Good to Very Good Strong Competent Limestone





Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

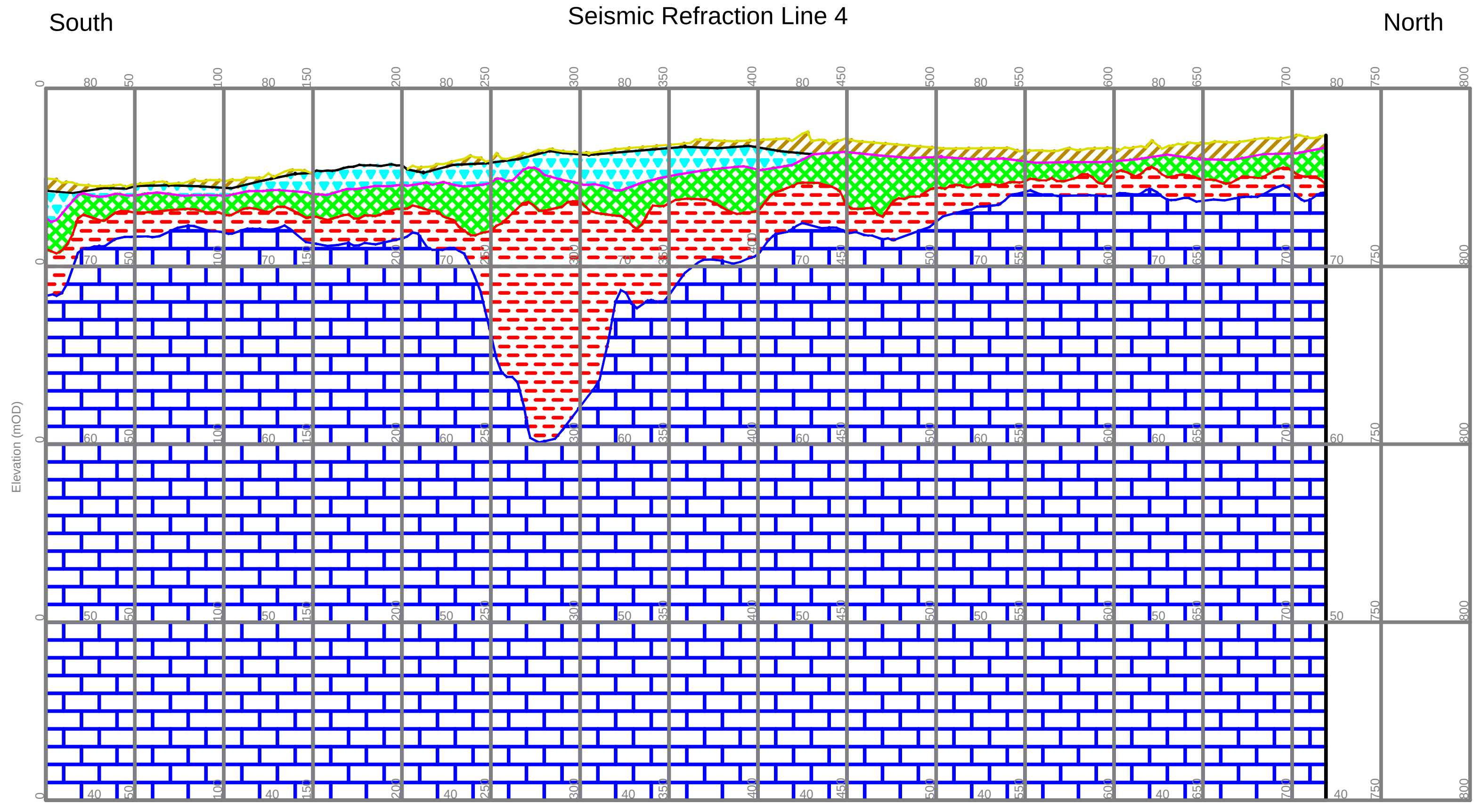
CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 19: Interpretation of Seismic Refraction Survey Line 2 and 3

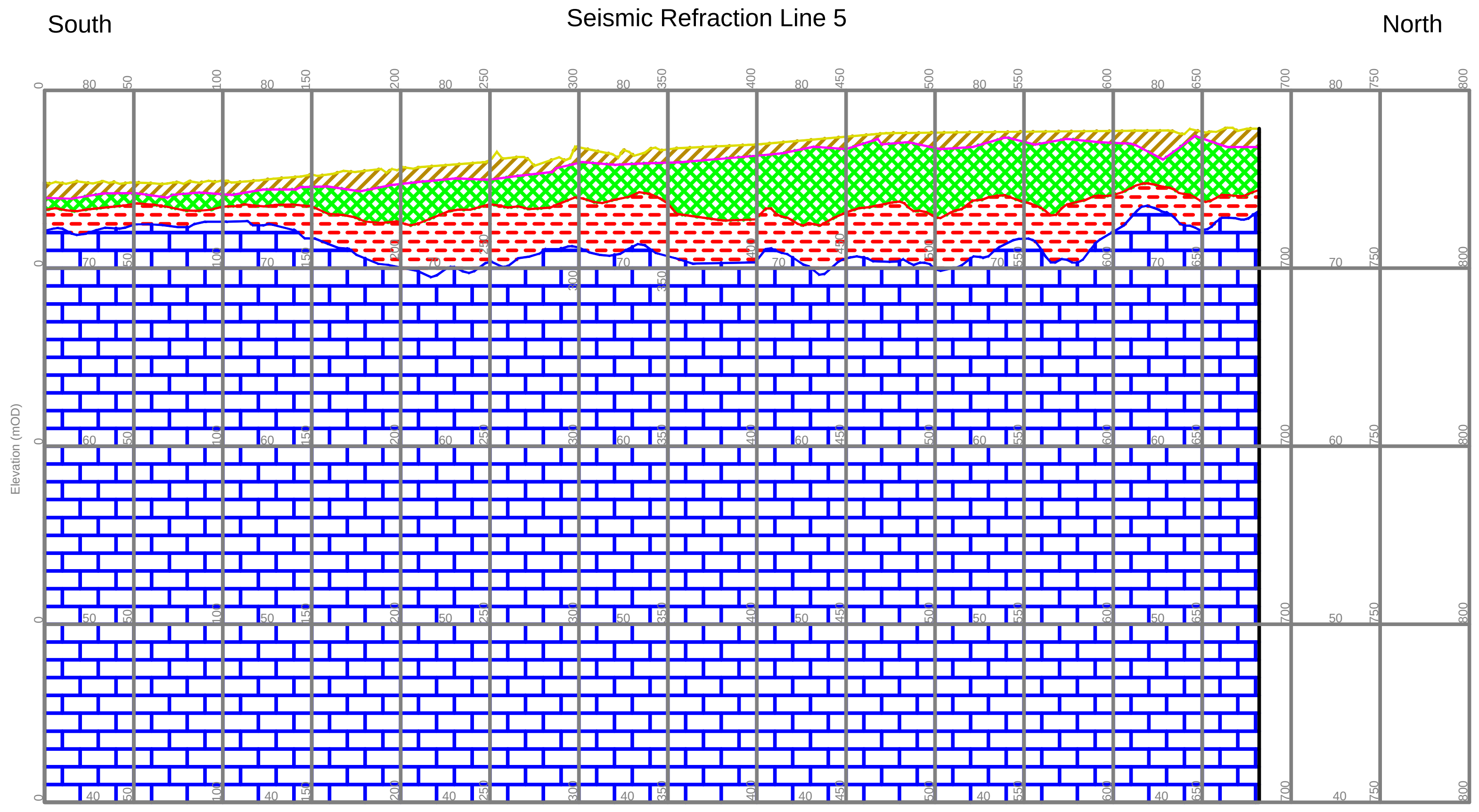
SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	23/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

Seismic Refraction Interpretation:

1 Very Soft Peat or Organic Matter
2 Soft or Loose Overburden (Gravelly Silt or Clay)
3 Stiff or Dense Overburden
4 Poor to Fair Weathered Rock or Very Stiff or Very Dense Highly Consolidated Overburden
5 Good to Very Good Strong Competent Limestone





Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 20: Interpretation of Seismic Refraction Survey Line 4 and 5

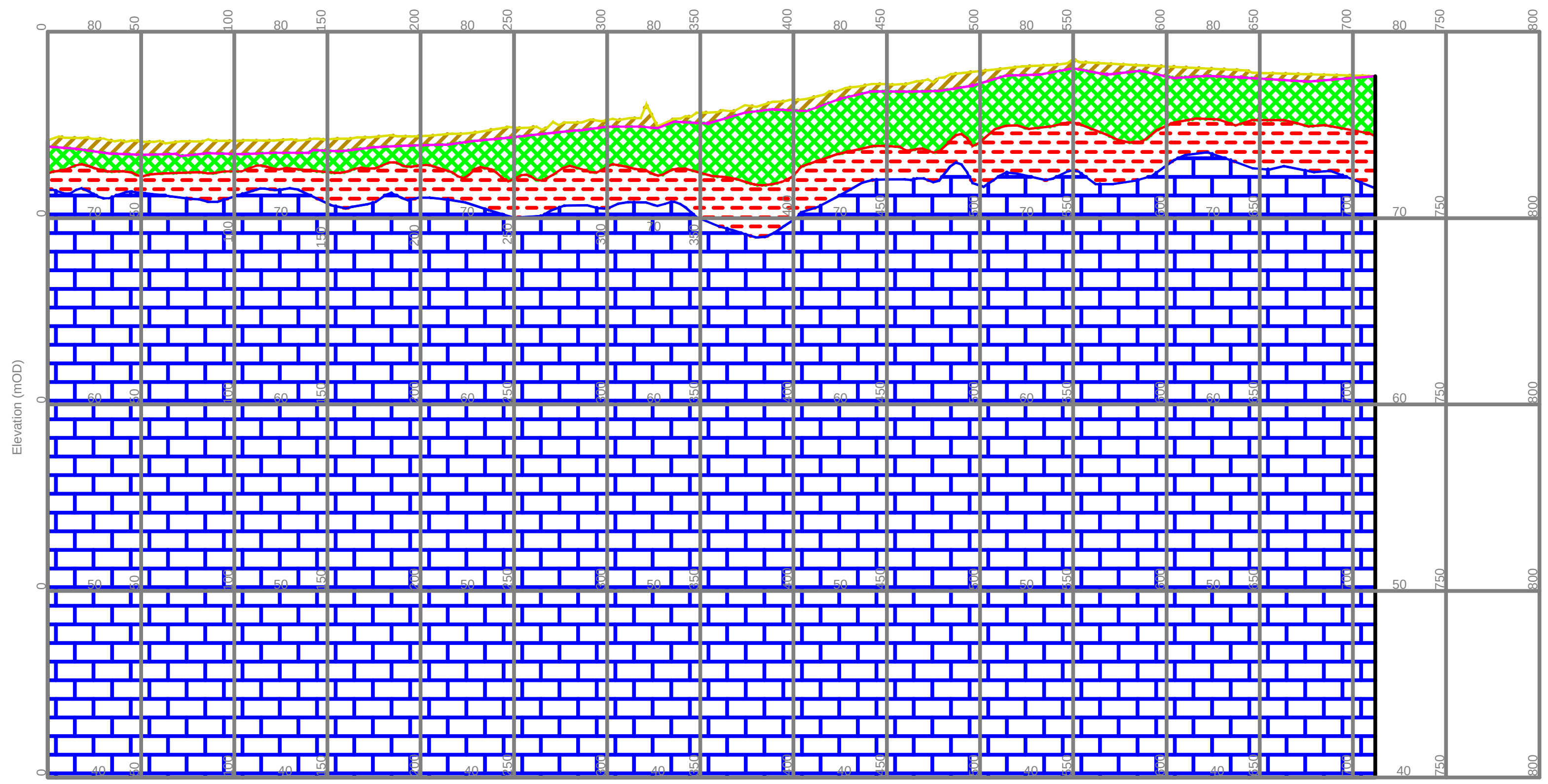
SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	23/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

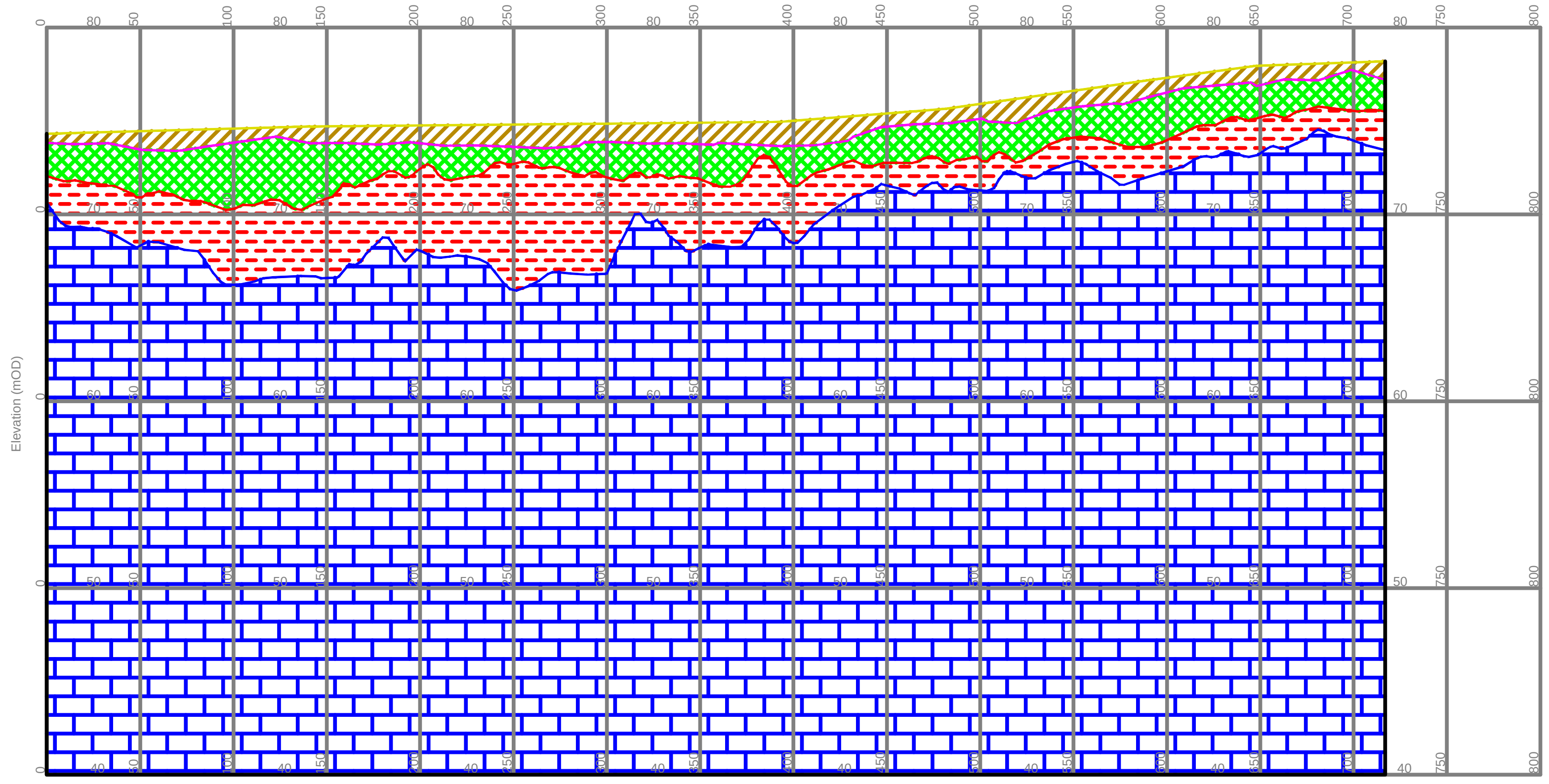
Seismic Refraction Interpretation:

1 Very Soft Peat or Organic Matter
2 Soft or Loose Overburden (Gravelly Silt or Clay)
3 Stiff or Dense Overburden
4 Poor to Fair Weathered Rock or Very Stiff or Very Dense Highly Consolidated Overburden
5 Good to Very Good Strong Competent Limestone

South Seismic Refraction Line 6 North



South Seismic Refraction Line 7 North



Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

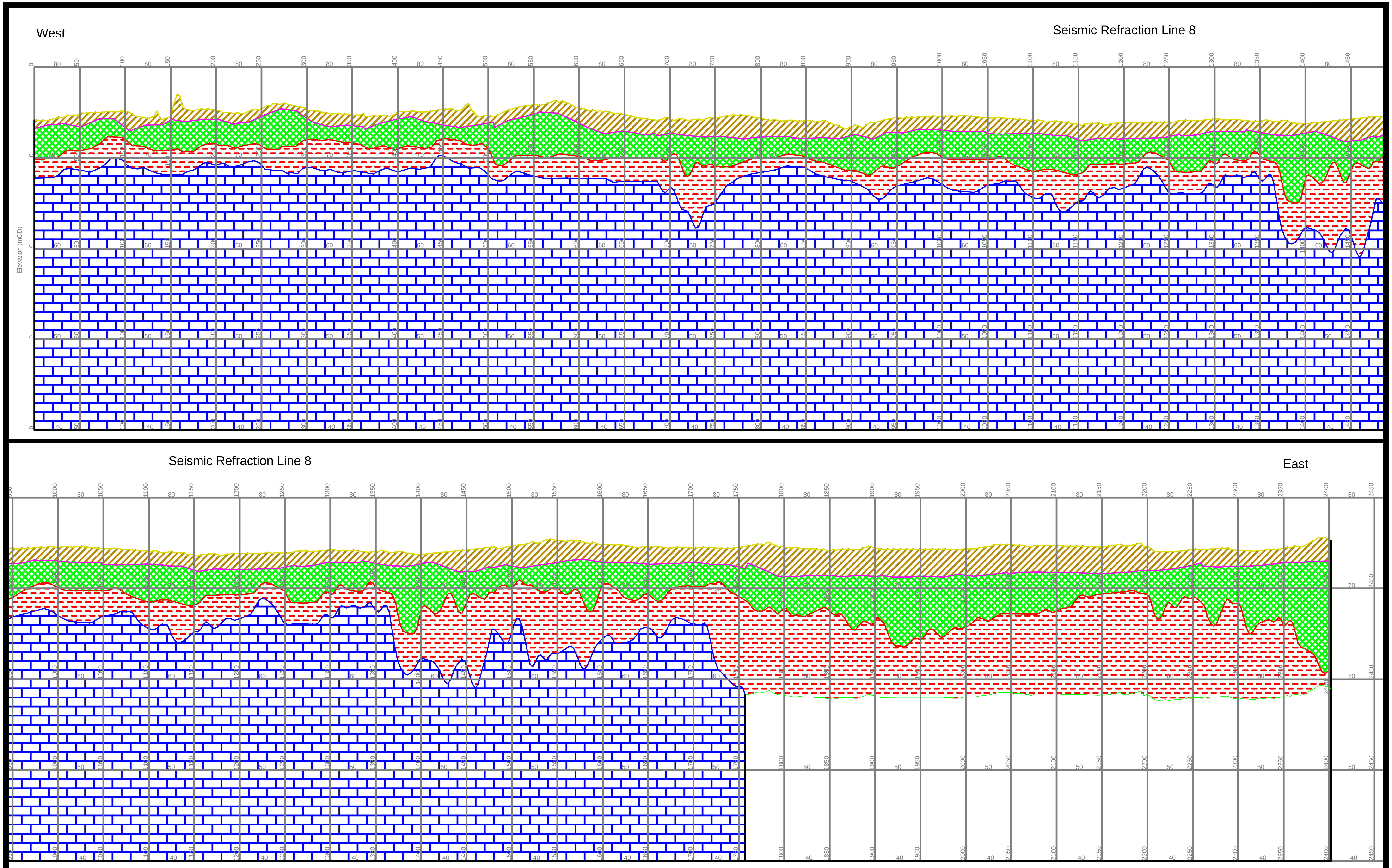
CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 21: Interpretation of Seismic Refraction Survey Line 6 and 7

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	23/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

Seismic Refraction Interpretation:

1 Very Soft Peat or Organic Matter
2 Soft or Loose Overburden (Gravelly Silt or Clay)
3 Stiff or Dense Overburden
4 Poor to Fair Weathered Rock or Very Stiff or Very Dense Highly Consolidated Overburden
5 Good to Very Good Strong Competent Limestone



Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

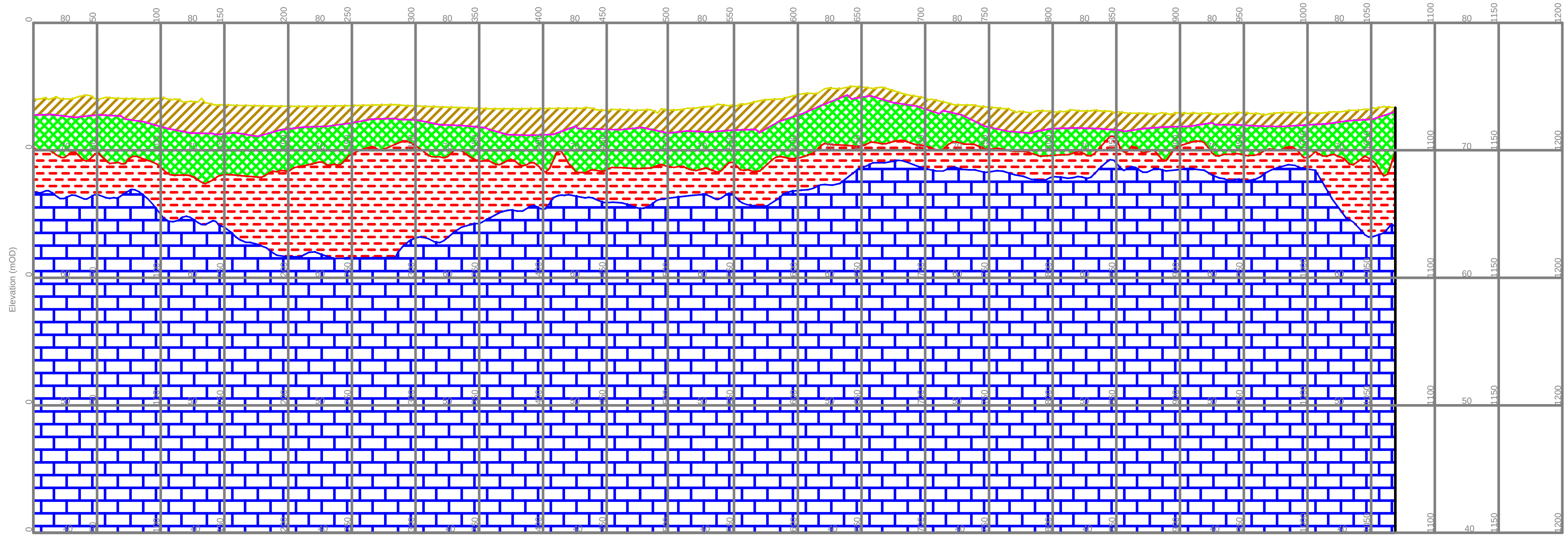
CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 22: Interpretation of Seismic Refraction Survey Line 8

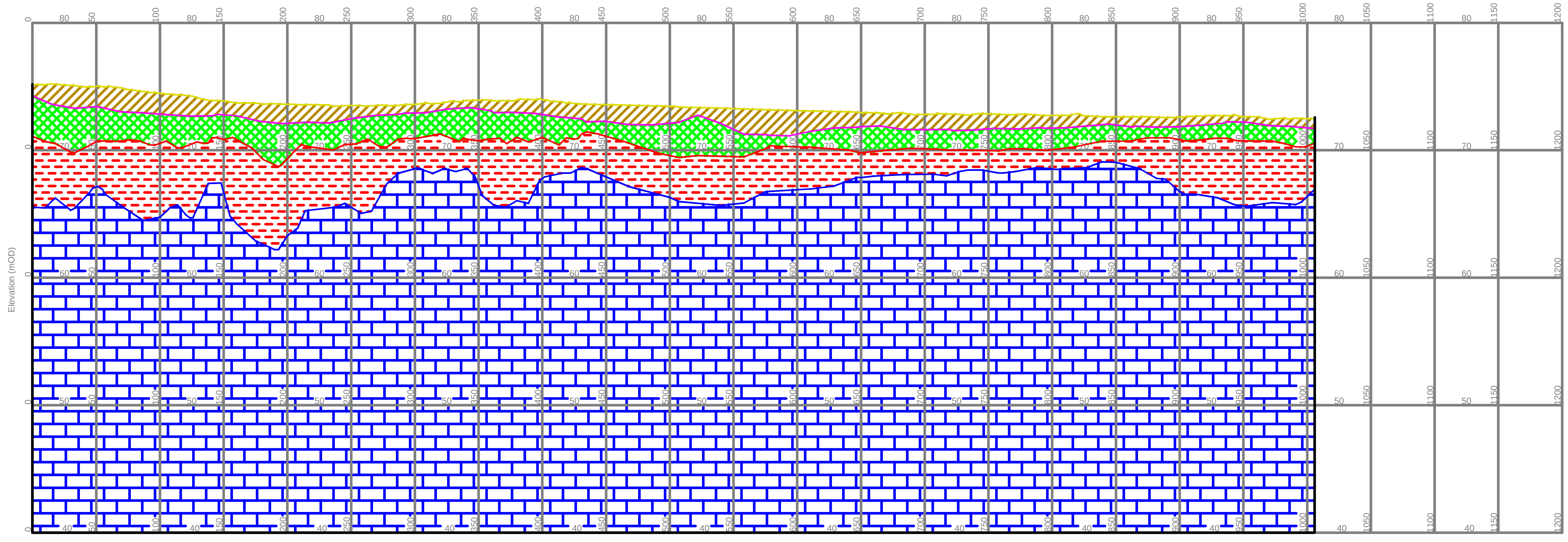
SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	23/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

Seismic Refraction Interpretation:

1 Very Soft Peat or Organic Matter
2 Soft or Loose Overburden (Gravelly Silt or Clay)
3 Stiff or Dense Overburden
4 Poor to Fair Weathered Rock or Very Stiff or Very Dense Highly Consolidated Overburden
5 Good to Very Good Strong Competent Limestone





Minerex
Geophysics Limited
Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 23: Interpretation of Seismic Refraction Survey Line 9 and 10

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	23/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

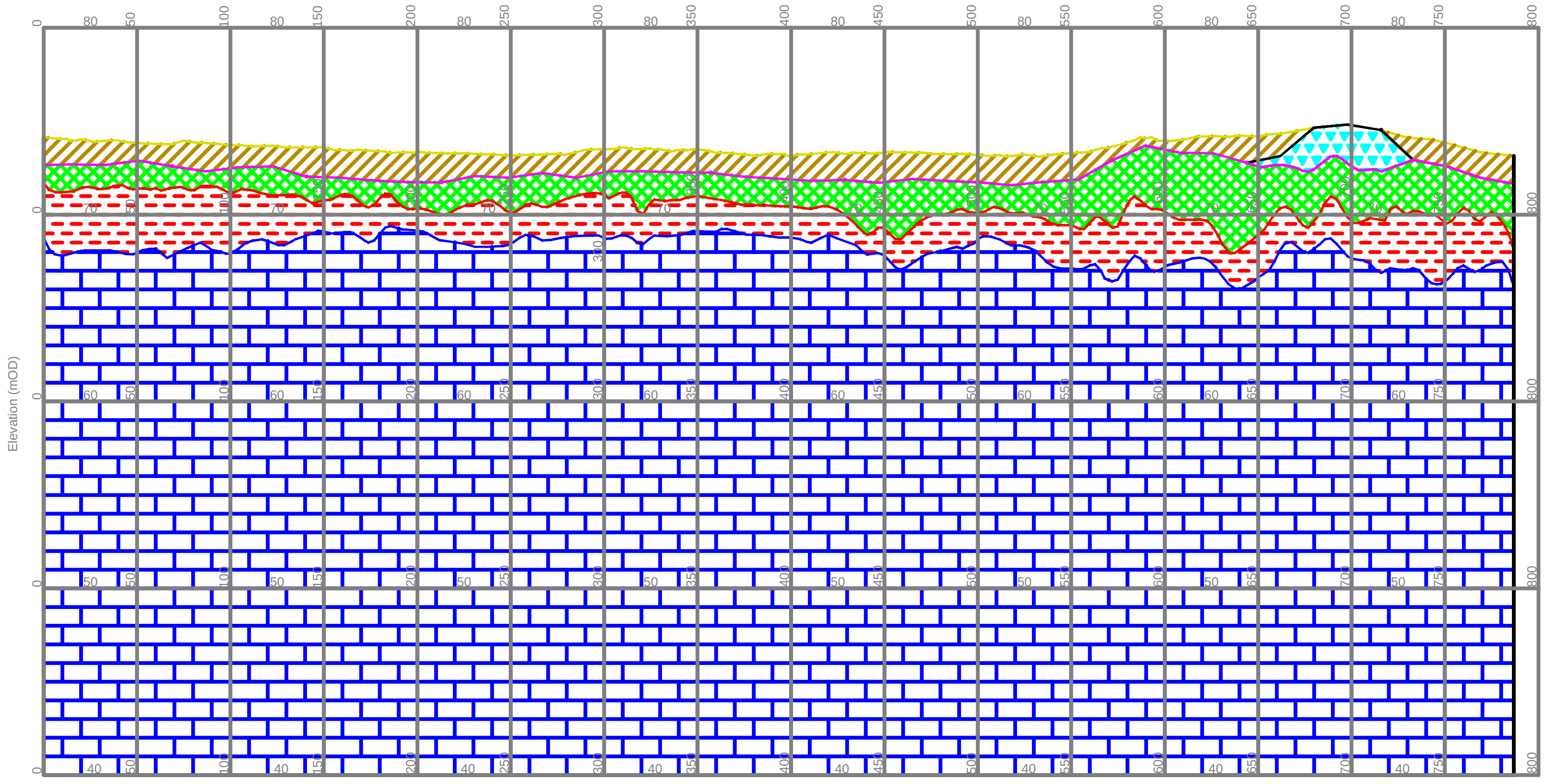
Seismic Refraction Interpretation:

1 Very Soft Peat or Organic Matter
2 Soft or Loose Overburden (Gravelly Silt or Clay)
3 Stiff or Dense Overburden
4 Poor to Fair Weathered Rock or Very Stiff or Very Dense Highly Consolidated Overburden
5 Good to Very Good Strong Competent Limestone

South

Seismic Refraction Line 11

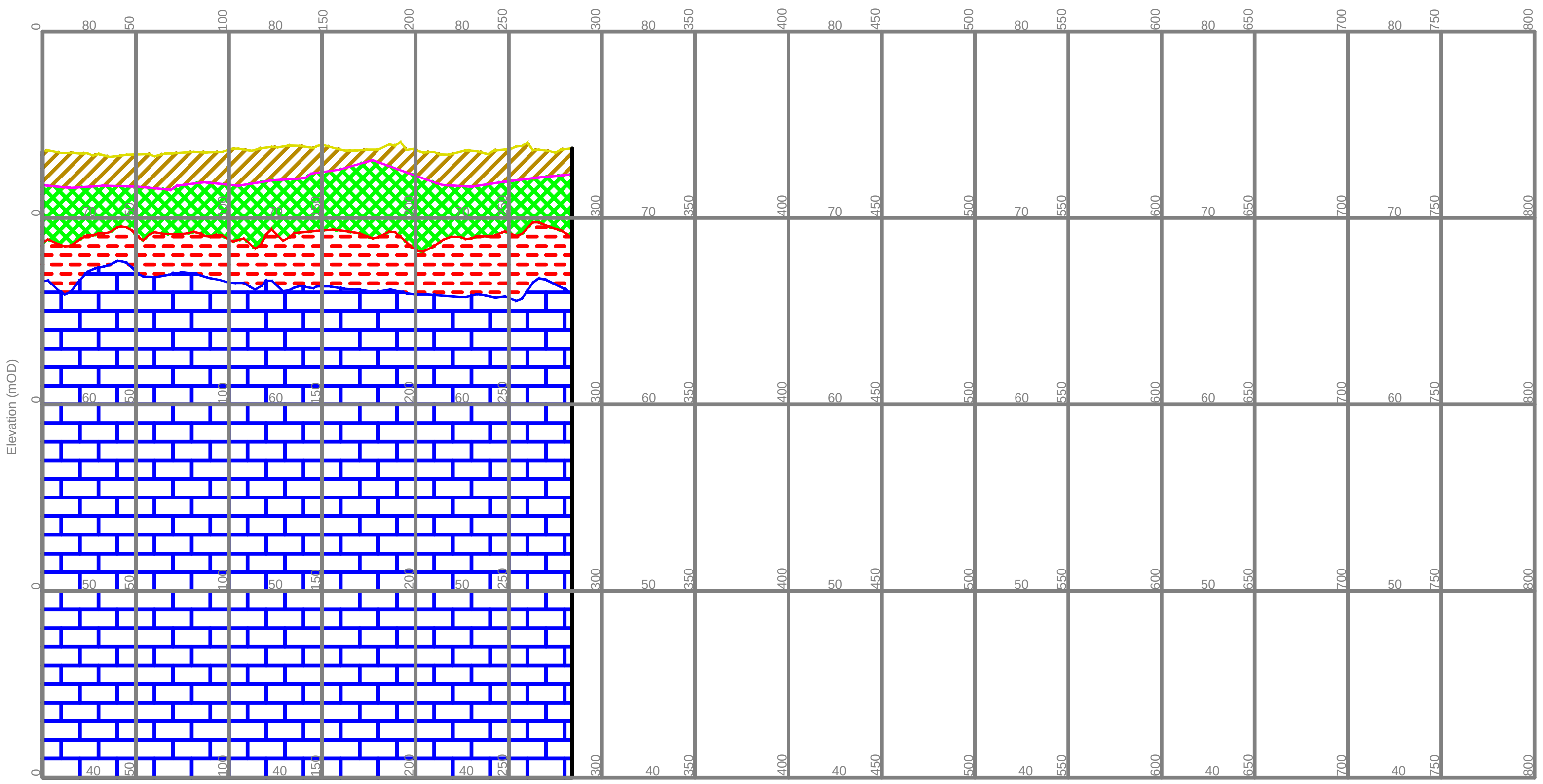
North



South

Seismic Refraction Line 12

North



Minerex
Geophysics Limited

Unit F4, Maynooth Business Campus
Maynooth, Co. Kildare
Tel. (01) 6510030
Fax. (01) 6510033
Email: info@mgx.ie
Web: www.mgx.ie

CLIENT	Irish Drilling Ltd. Irish Water
PROJECT	Garryhinch Geophysical Survey
TITLE	Figure 24: Interpretation of Seismic Refraction Survey Line 11 and 12

SCALE:	1:4000 @ A3, VE x 10
PROJECT:	5867
DRAWN:	JC
DATE:	23/01/2015
MGX FILE:	5867d_Figs.dwg
STATUS:	Draft

LEGEND:

Seismic Refraction Interpretation:

1 Very Soft Peat or Organic Matter
2 Soft or Loose Overburden (Gravelly Silt or Clay)
3 Stiff or Dense Overburden
4 Poor to Fair Weathered Rock or Very Stiff or Very Dense Highly Consolidated Overburden
5 Good to Very Good Strong Competent Limestone

Appendix C- Pumping Test Factual Report

HYDRO ENVIRONMENTAL SERVICES

22 Lower Main St
Dungarvan
Co.Waterford
Ireland

tel: +353 (0)58 44122
fax: +353 (0)58 44244
email: info@hydroenvironmental.ie
web: www.hydroenvironmental.ie

PUMPING TEST FACTUAL REPORT

GARRYHINCH BOG, CO. LAOIS

FINAL REPORT

Prepared for:

IRISH DRILLING LTD

Prepared by:

HYDRO-ENVIRONMENTAL SERVICES

REPORT NO.: P1304
REPORT DATE: 29th September 2015

DOCUMENT INFORMATION

DOCUMENT TITLE:	**PUMPING TEST FACTUAL REPORT – GARRYHINCH BOG, CO. LAOIS**
ISSUE DATE:	**29TH SEPTEMBER 2015**
PROJECT NUMBER:	**P1304**
PROJECT REPORTING HISTORY:	**None**
CURRNET REVISION NO:	**P1304-FINAL REPORT**
AUTHOR(S):	**MICHAEL GILL** **DAVID BRODERICK**
SIGNED:	Michael Gill ___________________________ **Michael Gill B.A., B.A.I., M.Sc., MIEI** **Managing Director – Hydro-Environmental Services**

Disclaimer:
This report has been prepared by HES with all reasonable skill, care and diligence within the terms of the contract with the client, incorporating our terms and conditions and taking account of the resources devoted to it by agreement with the client. We disclaim any responsibility to the client and others in respect of any matters outside the scope of the above. This report is confidential to the client and we accept no responsibility of whatsoever nature to third parties to whom this report, or any part thereof, is made known. Any such party relies upon the report at their own risk.

TABLE OF CONTENTS

FIGURES

TABLES IN TEXT

APPENDICES

PLATES

1.0 PUMPING TEST

1.1 INTRODUCTION

Hydro-Environmental Services (HES) were commissioned by Irish Drilling Ltd (IDL) to complete a 72 hour pumping test on two water wells at Garryhinch Bog, Co. Laois. The two pumping wells (WH02 and WH03) were drilled by Dempsey Drilling Ltd.

Pumping well WH02 was drilled to a depth of 47 metres below ground level (mbgl) at co-ordinate E246422 N212700 where the ground elevation is at 73.81m OD (Ordnance Datum). Pumping well WH03 was drilled to a depth of 60mbgl at co-ordinate E246166 N213949 where the ground elevation is at 75.12m OD. Both pumping wells are located in the vicinity of a cutaway raised bog. A total of fifteen on-site investigation boreholes were used to monitoring groundwater levels during the pumping tests. The investigation boreholes were drilled by Irish Drilling Ltd. A drillers log for both pumping wells, which includes well yield estimates, is shown as Appendix I. A well location map is shown as Figure 1.

The purpose of the pumping test was to acquire data in order to determine bedrock aquifer properties. The analysis and interpretation of the pumping test data is beyond the scope of this report. This factual report provides recorded water level data from the pumping test and subsequent recovery period along with well pumping (discharge) rates. Field groundwater hydrochemistry data, which was measured regularly throughout the tests, are also presented.

1.2 PUMPING TEST SETUP & METHODOLOGY

For the pumping tests a 4” electrical submersible pump was installed in both pumping wells. A single phase pump was installed in WH02 and a three phase pump was installed in WH03 as the latter had the higher estimated yield. Both wells were completed at a diameter of 125mm and therefore a 4” pump was the maximum pump size that could be installed. A discharge line (of 2” lay flat) was used to direct the discharge into nearby bog drains. The distance between the pumping wells and their discharge point was approximately 50m.

A mechanical meter was connected along the discharge line at both wells and a gate valve was also included (in-line) at each well to allow regulation/variation of the discharge rate (flow), as required. The pumps was powered by a diesel generator (24KV) located at each pumping well. A photograph of the typical setup is shown in Plate A below.

A “Diver”[1] water level datalogger was installed in each pumping well and the closest monitoring wells to allow continuous monitoring of water levels during the test. Manual water level monitoring was undertaken in the remainder of the monitoring wells (see further below for details).

The data loggers in the pumping wells and closest monitoring wells were programmed to record every 2 minute and 30 minutes respectively[2]. Regular manual dip readings were taken during pumping test also. The data loggers also allowed recording of groundwater temperature.

Manual water level monitoring in the pumping wells during the test was completed at the intervals shown in Table A below. This was completed by means of manual dips and acquisition of data from the installed datalogger. Discharge monitoring (flow and hydrochemistry) were undertaken at the wellhead. Manual water level monitoring in the monitoring wells was completed regularly during the test.

[1]Water level pressure transducers with inbuilt datalogger. (http://www.slb.com/content/services/additional/water/monitoring/dataloggers/index.asp).

[2] To reduce report appendices size water level data are provided at 10 minute intervals for WH02 and WH03 (refer to Appendix III for data logger water level)

The pumping test was completed in accordance with BS5930: 1999 – Code of practice for site investigations, and with BS6316: 1992 Code of practice for test pumping of water wells.

Plate A: Typical Pumping Test Setup (shown below at WH02)

Table A. Groundwater level monitoring frequencies for Pumping Wells

Time Interval	Monitoring Frequency
0-10 mins	Every 30 seconds
10-20 mins	Every 2 minutes
20-60 mins	Every 5 minutes
60-180 mins	Every 15 minutes
180 to 360 minutes	Every 30 minutes
360 to completion	Every 60 minutes

1.3 PUMPING TEST DETAILS

The pumping test starting times for each well were staggered to allow the influence (if any) of each pumping well on groundwater levels to be determined. Staggering of the starting times allows the interpreter to establish if groundwater levels at each monitoring well is being influenced by one or both of the pumping wells. Both wells were pumped for a duration of 72 hours. The test on WH03 was commenced at 19:30 on 7th September and the test on WH02 was commenced at 12:10 on 8th September 2015.

1.4 PUMPING TEST RESULTS

Both pumping wells were pumped at the maximum rate of the submersible pump. The average pumping rate during the test for WH02 and WH03 was 11.77m^3/hour (282m^3/day) and 6.4m^3/hour (153m^3/day) respectively. These pumping rates achieved a drawdown of 3.209m and 6.832m in WH02 and WH03 at the end of the test respectively. With the exception of monitoring well BH74, the drawdown in the monitoring wells was negligible if any. The drawdown in BH74 was due to pumping in WH02 only. There was no evidence of an overlap of drawdown as a result of both wells pumping.

The majority, if not all of the drawdown in the other monitoring wells can be attributed to the natural recession of the groundwater table. As stated above in the report, the period before test and during the test was dry and warm.

Recovery of groundwater levels in WH03 and WH02 was monitored until 11:00 on 11th September and 14:30 on 13th September 2015 respectively. The water level in WH02 and WH03 had recovered to 70% and 99% of the static water level respectively. Of the monitoring wells, only BH74 was monitored for recovery as the negligible drawdown in the other monitoring wells was most likely not due to natural recession and not pumping.

Static water levels recorded in the pumping wells and observation wells prior to the start of the pumping test are summarised in Table B. The drawdown data recorded at the end of the pumping period are summarised in Table C.

Table B: Pre-Test Static Water Levels

Well ID	Water Level (m OD)
WH02	72.08
WH03	73.79
WH01	71.80
WH04	71.64
WH05	70.66
BH14	72.34
BH17	73.11
BH19	72.35
BH38	72.91
BH39	73.21
BH41	73.36
BH52	72.49
BH71	69.35

Table C. Total Drawdown at the end of the Pumping Test.

Well ID	Drawdown (m)	Distance from WH02 pumping well (km)	Distance from WH03 pumping well (km)
WH02	3.209	0	1.28
WH03	6.832	1.28	0
WH01	0.010	1.47	0.56
WH04	0.015	0.55	1.48
WH05	0.010	1.05	1.77
BH14	0	1.75	0.48
BH17	0.04	1.5	0.45
BH19	0.05	1.5	0.27
BH38	0.01	1.35	0.82
BH39	0.015	1.48	1.58
BH41	0	1.12	1.13

BH52	0.03	0.76	1.08
BH71	0	0.84	1.64
BH74	0.379	0.09	1.32
BH86	0.015	0.95	2.16
BH90	0.02	1.05	2.32
BH68	0.01	0.94	1.29

Water level data plotted with well discharge for the pumping wells is shown as Figure 2 and Figure 3. Water level plots for the monitoring wells are shown in Figure 4 and Figure 5. Figure 4 shows the monitoring wells in the vicinity of pumping well WH02 and Figure 5 shows the monitoring wells in the vicinity of pumping well WH03.

All water level data recorded on-site during the test are presented in Appendix II. Datalogger water level data for WH02, WH03 and BH74 are presented in Appendix III. Barometric pressure recorded on-site was used to correct datalogger water level data for atmospheric pressure variation. Pumping test discharge data are presented in Appendix IV.

1.5 HYDROCHEMISTRY

Field groundwater hydrochemistry parameters (Temperature, Electrical Conductivity and pH) of the discharge water were recorded at both pumping wells head using a calibrated YSI 556 multi-meter probe. Calibration was undertaken using a standard solution. Readings are shown in Table D below.

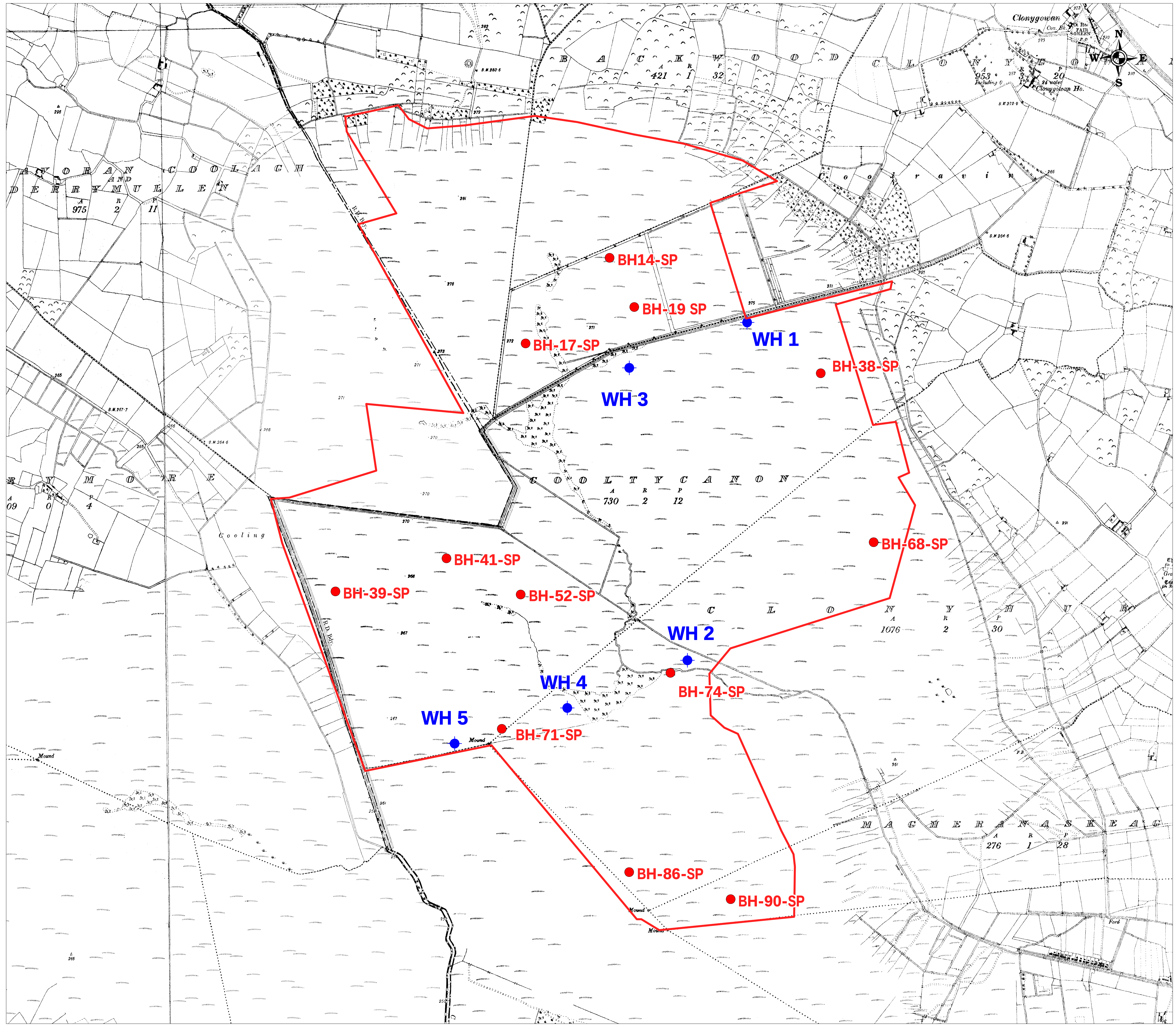
Table D: Unstable Groundwater Chemistry Data during the Pumping Test.

Date	Time	Electrical Conductivity (μS/cm)	Temperature (° C)	pH [H^+ ion]
Pumping Well WH02				
08/09/2015	15:00	380	11.2	8.1
08/09/2015	20:32	382	11.3	8.1
09/09/2015	09:35	383	11.6	8.0
09/09/2015	18:25	384	11.1	8.2
10/09/2015	08:00	382	11.6	8.1
10/09/2015	20:45	382	11.6	8.1
11/09/2015	12:00	380	11.1	8.2
Pumping Well WH03				
07/09/2015	21:00	755	13.1	7.1
08/09/2015	07:50	753	13.0	7.1
08/09/2015	14:30	753	13.1	7.2
09/09/2015	10:00	725	13.2	7.1
09/09/2015	17:15	723	12.2	7.5
10/09/2015	11:00	670	12.1	7.8
10/09/2015	19:10	678	12.2	7.5

2.0 REFERENCES

British Standards Institution	1992	BS6316 - Code of Practice for Test Pumping of Water Wells.
British Standards Institution	1999	BS5930 - Code of Practice for Site Investigations.

FIGURES



LEGEND:

Site Boundary

Borehole (With Stand Pipe)

Water Well (WH)

HYDRO ENVIRONMENTAL SERVICES
22 Lower Main St
Dungarvan
Co.Waterford
Ireland
tel: +353 (0)58 44122
fax: +353 (0)58 44244
email: info@hydroenvironmental.ie
web: www.hydroenvironmental.ie

Client: Irish Drilling Ltd	
Job: Garryhinch Bog Pumping Tests	
Title: Well Location Map	
Figure No: 1	
Drawing No: P1304-A3-0915-001-00A	
Sheet Size: A3	Project No: P1304
Scale: - 1:10000	Drawn By: GB
Date: - 17/09/2015	Checked By: MG

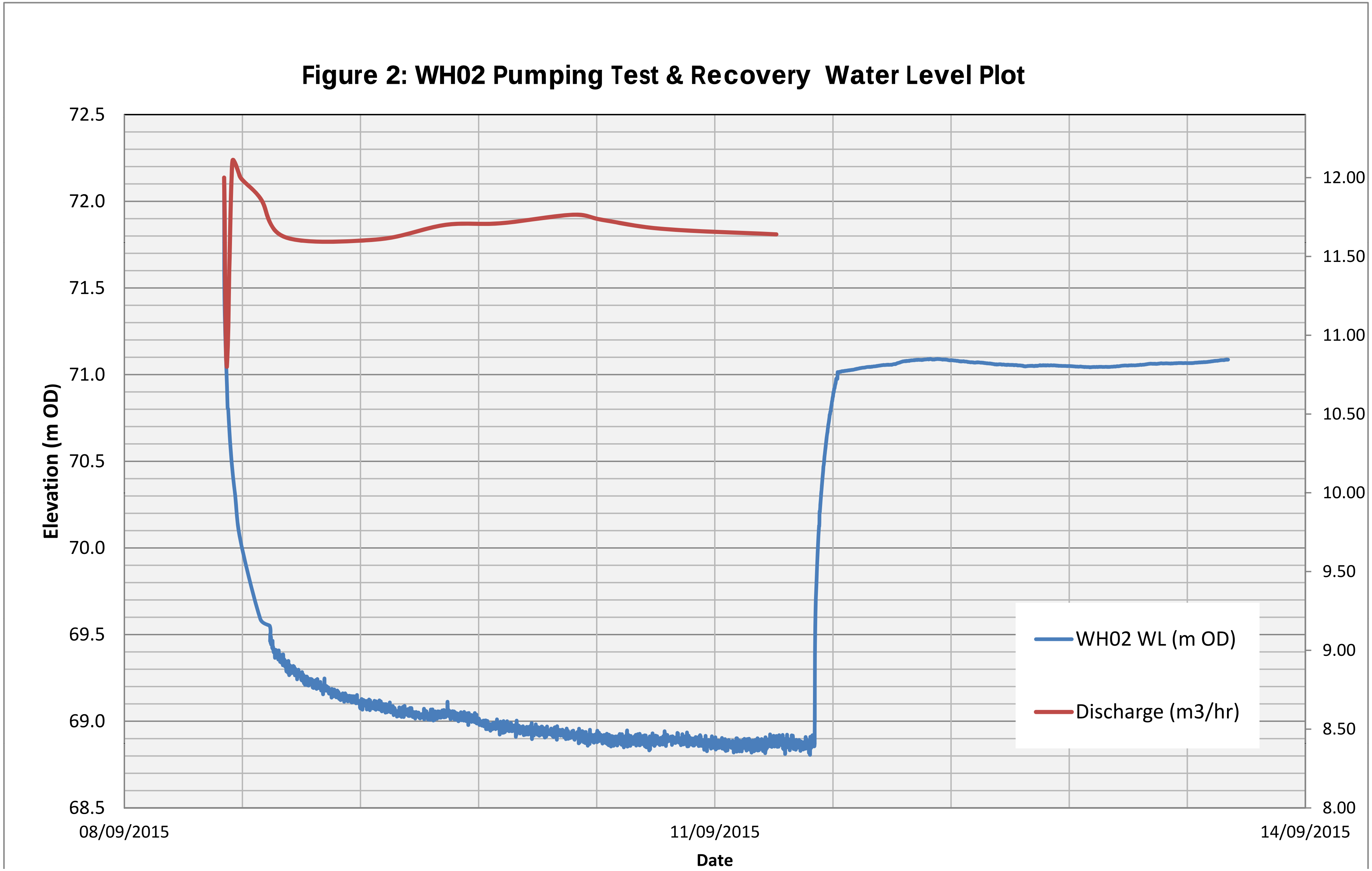


Figure 2: WH02 Pumping Test & Recovery Water Level Plot
Elevation (m OD)
72.5
72.0
71.5
71.0
70.5
70.0
69.5
69.0
68.5
12.00
11.50
11.00
10.50
10.00
9.50
9.00
8.50
8.00
08/09/2015
11/09/2015
14/09/2015
Date
WH02 WL (m OD)
Discharge (m3/hr)

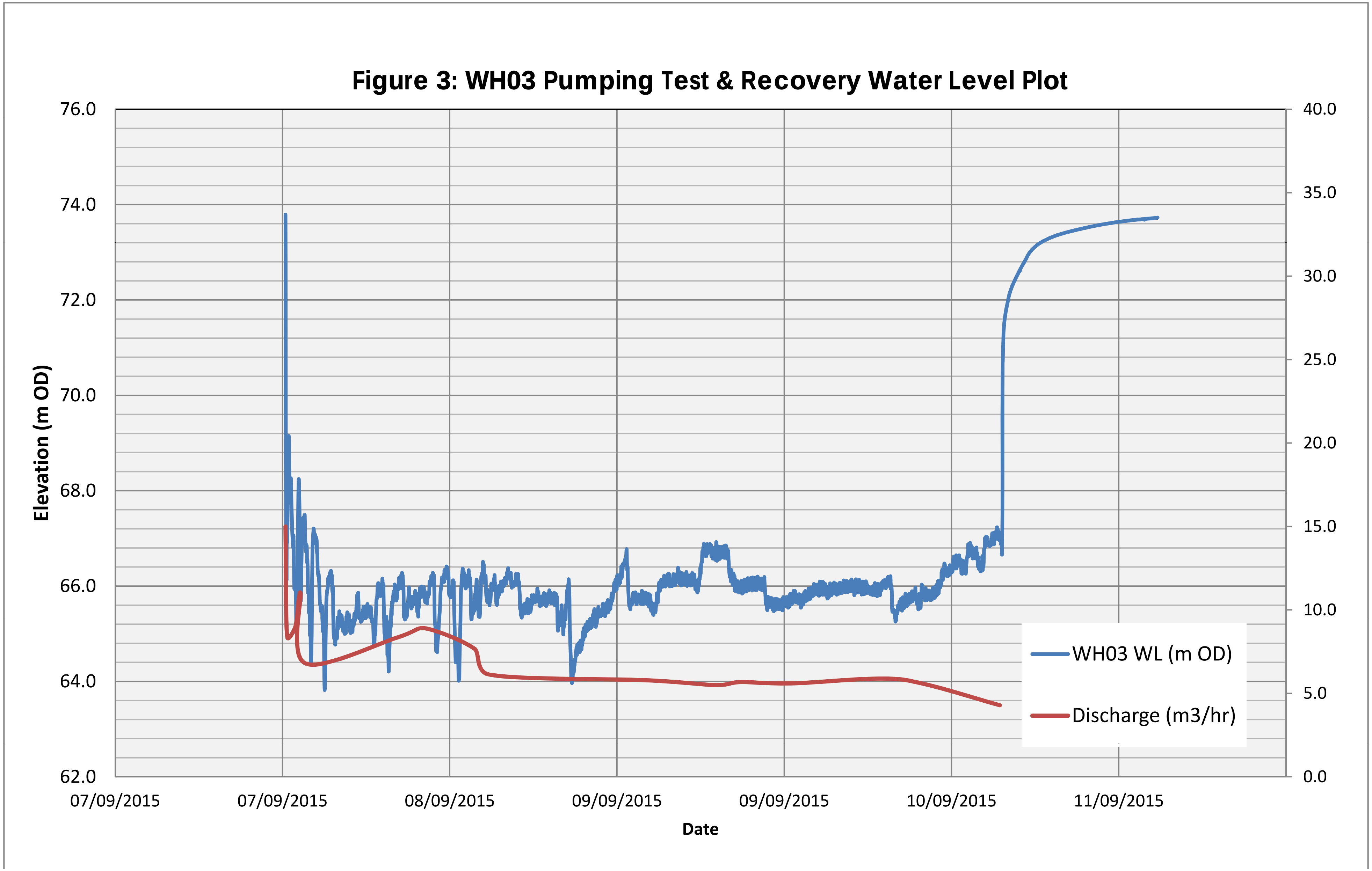


Figure 3: WH03 Pumping Test & Recovery Water Level Plot
Elevation (m OD)
76.0
74.0
72.0
70.0
68.0
66.0
64.0
62.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
07/09/2015
07/09/2015
08/09/2015
09/09/2015
09/09/2015
10/09/2015
11/09/2015
Date
WH03 WL (m OD)
Discharge (m3/hr)

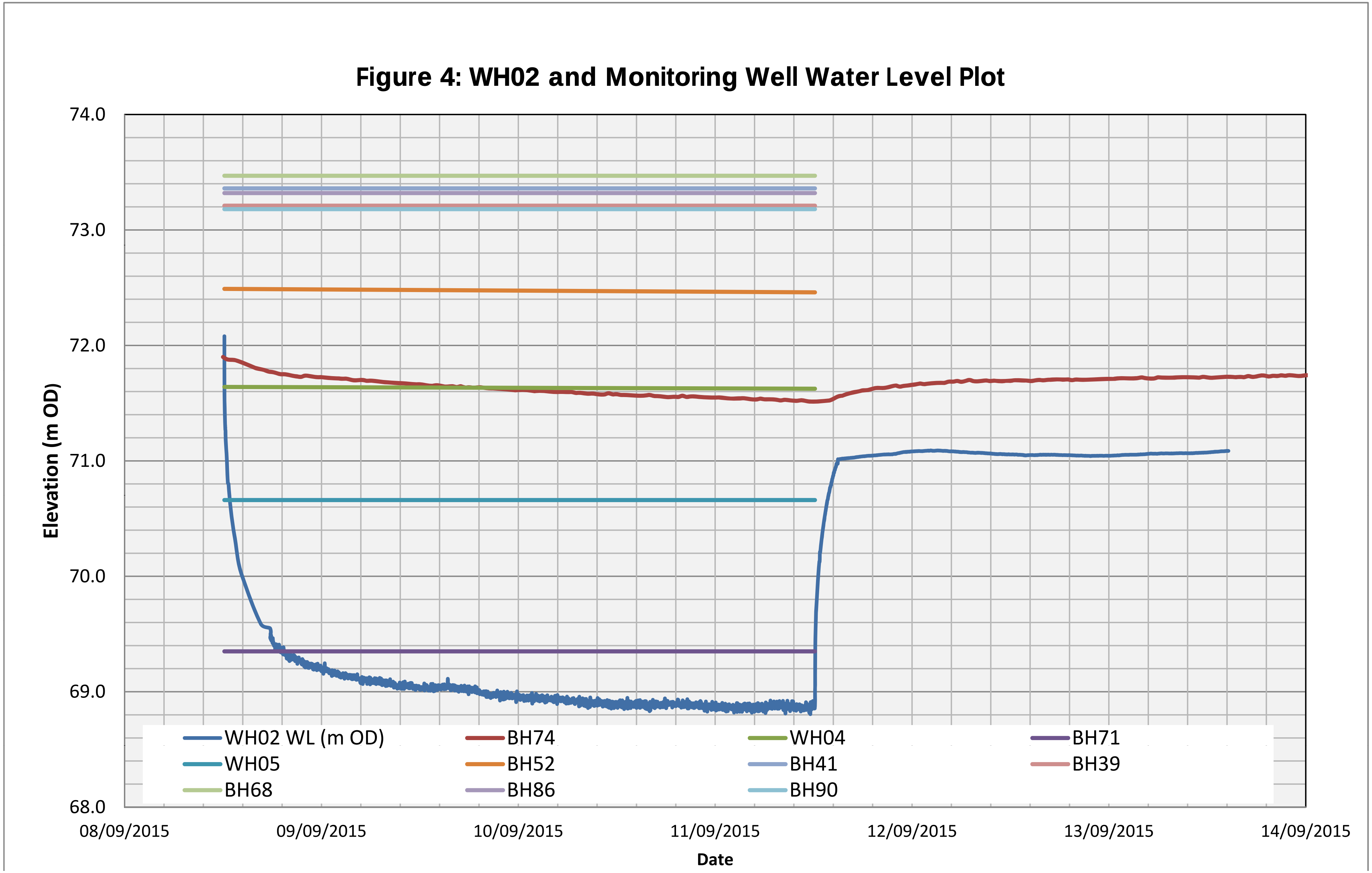


Figure 4: WH02 and Monitoring Well Water Level Plot
Elevation (m OD)
74.0
73.0
72.0
71.0
70.0
69.0
68.0
08/09/2015
09/09/2015
10/09/2015
11/09/2015
12/09/2015
13/09/2015
14/09/2015
Date
WH02 WL (m OD)
BH74
WH04
BH71
WH05
BH52
BH41
BH39
BH68
BH86
BH90

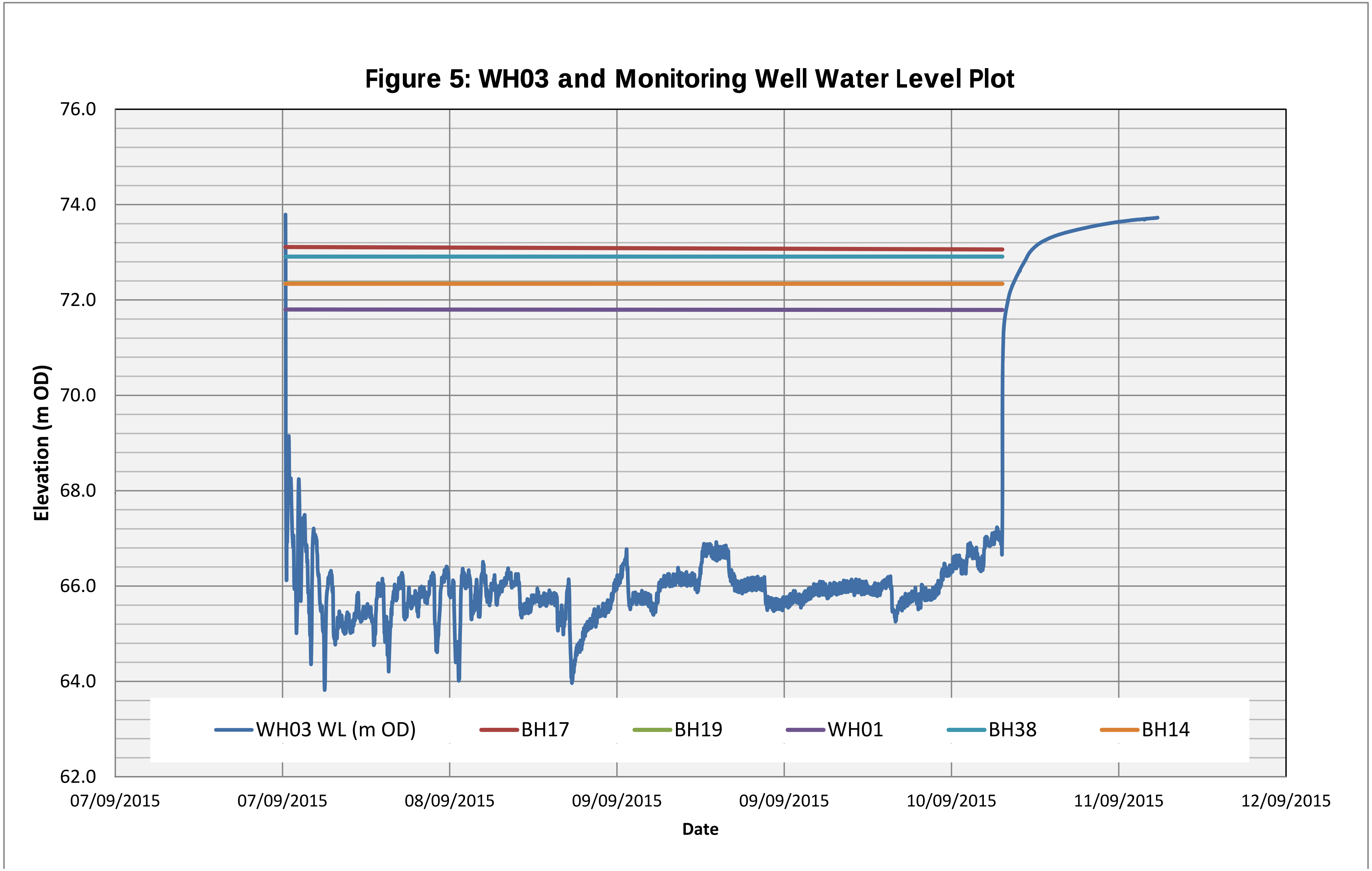


Figure 5: WH03 and Monitoring Well Water Level Plot
Elevation (m OD)
76.0
74.0
72.0
70.0
68.0
66.0
64.0
62.0
WH03 WL (m OD)
BH17
BH19
WH01
BH38
BH14
07/09/2015
07/09/2015
08/09/2015
09/09/2015
09/09/2015
10/09/2015
11/09/2015
12/09/2015
Date

APPENDIX I
DRILLERS SUMMARY PUMPING WELL LOG

Garryhinch Bog
Well Hole Summary

Borehole:	Co-Ordinates:	Driller Remarks:
WH 01	246673.8E 214130.9N 75.42mOD	Bedrock encountered at 3m depth, very broken rock to 10m depth. Drilled to 60m depth. 200mm steel casing to 6m depth. 150mm pvc casing to 10m depth. 125mm slotted pvc pipe installed to 60m depth due to fractured rock encountered and risk of borehole cave. Water strike 1 at 15m; estimated yield of 300 gallons per hour. Water strike 2 at 40m: estimated yield of 300 gallons per hour.
WH 02	246422.4E 212700.9N 73.81mOD	Bedrock encountered at 5m depth, very broken rock to 10m depth. Drilled to 47m depth. 200mm steel casing to 6m depth. 150mm pvc casing to 10m depth. 125mm slotted pvc pipe installed to 47m depth due to fractured rock encountered and risk of borehole cave.Cavity encountered at 40m to 47m depth. Water strike 1 at 40m: estimated yield of 10,000 gallons per hour. Borehole abandoned at 47m depth due to risk of borehole collapsing on bit.
WH 03	246166.5E 213945.8N 75.12mOD	Bedrock encountered at 4m depth, very broken rock to 10m depth. Drilled to 60m depth. 200mm steel casing to 6m depth. 150mm pvc casing to 10m depth. 125mm slotted pvc pipe installed to 60m depth due to fractured rock encountered and risk of borehole cave. Water strike 1 at 12m; estimated yield of 500 gallons per hour. Water strike 2 at 58m: estimated yield of 2,000 gallons per hour. Clay bands encountered around 25m depth.
WH 04	245909E 212508.3N 73.64mOD	Bedrock encountered at 6m depth, broken rock to 10m depth. Drilled to 60m depth. 200mm steel casing to 6m depth. 150mm pvc casing to 10m depth. 125mm slotted pvc pipe installed to 60m depth due to fractured rock encountered and risk of borehole cave.Cavity encountered at 50m, 0.50m wide. Water strike 1 at 42m: estimated yield of 250 gallons per hour.
WH 05	245425.7E 212368.8N 75.12mOD	Bedrock encountered at 12m depth, very broken rock to 14m depth. Drilled to 63m depth. 200mm steel casing to 13m depth. 150mm pvc casing to 14m depth. 125mm slotted pvc pipe installed to 63m depth due to fractured rock encountered and risk of borehole cave. Water strike 1 at 12m; estimated yield of 100 gallons per hour. Water strike 2 at 29m: estimated yield of 350 gallons per hour.

APPENDIX II
ALL WATER LEVEL DATA

Project: Garryhinch Bog	**Date: 08/09/2015 - 11/09/2015**
Site: Garryhinch Bog, Co. Laois	**Grid Reference:** **E 246422**
Well No.: WH02	**N 212700**
Distance (r) from pumping well (m): 0	**Type of Test: Constant rate 72 Hour**
Static Water Level below Datum (mbd): 2.23	
Datum on pumping well: Top of Casing (74.31m OD)	
Flow/discharge meter reading at pump switch on (m^3 or L): 3499m3	
Flow/discharge meter reading at pump switch off (m^3 or L): 4340.5m3	
Site Sketch:	**Comments:**
Recorded by: DB	**Weather: Dry and warm**

Time		**Pumping Well WH03**		**Discharge**		**Obs Wells**			
Time (mins)	**Time (hrs)**	**PW Water level (mbd)**	**PW Drawdown (m)**	**Discharge rate (m^3/day)**	**Discharge Total (m^3)**	**time (hrs)**	**Water level (mbd)**	**time (hrs)**	**Water level (mbd)**
0.5		2.690	0.460						
1		2.790	0.560						
1.5		2.810	0.580						
2		2.850	0.620						
2.5		2.870	0.640						
3		2.900	0.670						
3.5		2.930	0.700						
4		2.950	0.720						
4.5		2.970	0.740						
5		2.990	0.760						
6		3.010	0.780						
7		3.040	0.810						
8		3.050	0.820						
9		3.120	0.890						
10		3.135	0.905						
12		3.180	0.950						
14		3.210	0.980						
16		3.260	1.030						
18		3.300	1.070						
20		3.365	1.135						
22		3.400	1.170						
24		3.463	1.233						
26		3.500	1.270						
28		3.505	1.275						
30		3.510	1.280						
35		3.600	1.370						
40		3.623	1.393						
45		3.680	1.450						
50		3.750	1.520						
55		3.810	1.580						
60	1	3.860	1.630						
75		3.923	1.693						
90		4.030	1.800						
105		4.190	1.960						
120	2	4.270	2.040						
150		4.350	2.120						
180	3	4.523	2.293						
210		4.685	2.455						
240	4	4.720	2.490						
300	5	4.805	2.575						
360	6	4.896	2.666						
420	7	4.934	2.704						
480	8	5.033	2.803						

Project:			Date:						
Time		Pumping Well - WH02		Discharge		Obs Wells			
Time (mins)	Time (hrs)	PW Water level (mbd)	PW Drawdown (m)	Discharge rate (m3/day)	Discharge Total (m3)		Water level (mbd)		Water level (mbd)
540	9	5.045	2.815						
600	10	5.063	2.833						
720	12	5.134	2.904						
840	14	5.175	2.945						
960	16	5.197	2.967						
1080	18	5.216	2.986						
1200	20	5.242	3.012						
1320	22	5.221	2.991						
1440	24	5.288	3.058						
1560	26	5.291	3.061						
1680	28	5.277	3.047						
1800	30	5.305	3.075						
1920	32	5.321	3.091						
2040	34	5.317	3.087						
2160	36	5.363	3.133						
2520	42	5.377	3.147						
2880	48	5.423	3.193						
3240	54	5.429	3.199						
3600	60	5.442	3.212						
3960	66	5.602	3.372						
4320	72	5.439	3.209						

Project: Garryhinch Bog	**Date: 07/09/2015 - 10/09/2015**
Site: Garryhinch Bog, Co. Laois	**Grid Reference:** **E 246166**
Well No.: WH03	**N 213945**
Distance (r) from pumping well (m): 0	**Type of Test: Constant rate 72 Hour**
Static Water Level below Datum (mbd): 1.83	
Datum on pumping well: Top of Casing (75.62m OD)	
Flow/discharge meter reading at pump switch on (m^3 or L): 2783m3	
Flow/discharge meter reading at pump switch off (m^3 or L): 3243m3	
Site Sketch:	**Comments:**
Recorded by: DB	**Weather: Dry and warm**

Time		**Pumping Well WH03**		**Discharge**		**Obs Wells**			
Time (mins)	**Time (hrs)**	**PW Water level (mbd)**	**PW Drawdown (m)**	**Discharge rate (m^3/day)**	**Discharge Total (m^3)**	**time (hrs)**	**Water level (mbd)**	**time (hrs)**	**Water level (mbd)**
0.5		4.300	2.470						
1		5.300	3.470						
1.5		6.200	4.370						
2		6.480	4.650						
2.5		7.240	5.410						
3		8.800	6.970						
3.5		8.840	7.010						
4		8.880	7.050						
4.5		9.153	7.323						
5		9.600	7.770						
6		9.400	7.570						
7		9.000	7.170						
8		8.393	6.563						
9		8.653	6.823						
10		8.703	6.873						
12		8.374	6.544						
14		7.701	5.871						
16		7.045	5.215						
18		6.731	4.901						
20		6.478	4.648						
22		6.981	5.151						
24		7.657	5.827						
26		7.865	6.035						
28		7.811	5.981						
30		7.604	5.774						
35		7.901	6.071						
40		8.420	6.590						
45		8.805	6.975						
50		8.927	7.097						
55		9.418	7.588						
60	1	9.502	7.672						
75		8.134	6.304						
90		9.543	7.713						
105		8.188	6.358						
120	2	8.711	6.881						
150		10.210	8.380						
180	3	8.545	6.715						
210		9.995	8.165						
240	4	11.228	9.398						
300	5	10.844	9.014						
360	6	10.603	8.773						
420	7	10.323	8.493						
480	8	10.183	8.353						

Project:			Date:						
Time		Pumping Well - WH03		Discharge		Obs Wells			
Time (mins)	Time (hrs)	PW Water level (mbd)	PW Drawdown (m)	Discharge rate (m3/day)	Discharge Total (m3)		Water level (mbd)		Water level (mbd)
540	9	10.640	8.810						
600	10	10.793	8.963						
720	12	10.322	8.492						
840	14	9.900	8.070						
960	16	9.433	7.603						
1080	18	9.401	7.571						
1200	20	9.434	7.604						
1320	22	9.597	7.767						
1440	24	9.995	8.165						
1560	26	10.004	8.174						
1680	28	10.460	8.630						
1800	30	10.492	8.662						
1920	32	10.178	8.348						
2040	34	9.157	7.327						
2160	36	9.989	8.159						
2520	42	8.949	7.119						
2880	48	9.577	7.747						
3240	54	9.537	7.707						
3600	60	9.600	7.770						
3960	66	9.437	7.607						
4320	72	8.662	6.832						

APPENDIX III
DATALOGGER WATER LEVEL DATA

P1304								
Garryhinch Bog Pumping Tests								
All data logger water level data for WH03								
Date & Time	**WL (mbcl)**	**Water Level (mOD)**	**Date & Time**	**WL (mbcl)**	**Water Level (mOD)**	**Date & Time**	**WL (mbcl)**	**Water Level (mOD)**
07/09/2015 19:30	1.830	73.790	08/09/2015 00:20	10.628	64.992	08/09/2015 05:10	9.612	66.008
07/09/2015 19:40	8.703	66.917	08/09/2015 00:30	10.844	64.776	08/09/2015 05:20	9.582	66.038
07/09/2015 19:50	6.478	69.142	08/09/2015 00:40	10.719	64.901	08/09/2015 05:30	10.793	64.827
07/09/2015 20:00	7.604	68.016	08/09/2015 00:50	10.294	65.326	08/09/2015 05:40	10.394	65.226
07/09/2015 20:10	8.420	67.200	08/09/2015 01:00	10.309	65.311	08/09/2015 05:50	11.154	64.466
07/09/2015 20:20	8.927	66.693	08/09/2015 01:10	10.301	65.319	08/09/2015 06:00	10.624	64.996
07/09/2015 20:30	9.502	66.118	08/09/2015 01:20	10.495	65.125	08/09/2015 06:10	10.225	65.395
07/09/2015 20:40	10.124	65.496	08/09/2015 01:30	10.603	65.017	08/09/2015 06:20	9.797	65.823
07/09/2015 20:50	7.374	68.246	08/09/2015 01:40	10.409	65.211	08/09/2015 06:30	9.791	65.829
07/09/2015 21:00	9.543	66.077	08/09/2015 01:50	10.329	65.291	08/09/2015 06:40	9.808	65.812
07/09/2015 21:10	8.622	66.998	08/09/2015 02:00	10.585	65.035	08/09/2015 06:50	9.641	65.979
07/09/2015 21:20	8.319	67.301	08/09/2015 02:10	10.431	65.189	08/09/2015 07:00	9.532	66.088
07/09/2015 21:30	8.711	66.909	08/09/2015 02:20	10.453	65.167	08/09/2015 07:10	9.494	66.126
07/09/2015 21:40	9.121	66.499	08/09/2015 02:30	10.323	65.297	08/09/2015 07:20	9.549	66.071
07/09/2015 21:50	9.713	65.907	08/09/2015 02:40	9.985	65.635	08/09/2015 07:30	10.322	65.298
07/09/2015 22:00	10.210	65.410	08/09/2015 02:50	9.961	65.659	08/09/2015 07:40	10.270	65.350
07/09/2015 22:10	9.613	66.007	08/09/2015 03:00	10.311	65.309	08/09/2015 07:50	9.890	65.730
07/09/2015 22:20	8.414	67.206	08/09/2015 03:10	10.348	65.272	08/09/2015 08:00	10.032	65.588
07/09/2015 22:30	8.545	67.075	08/09/2015 03:20	10.052	65.568	08/09/2015 08:10	10.009	65.611
07/09/2015 22:40	8.922	66.698	08/09/2015 03:30	10.183	65.437	08/09/2015 08:20	9.878	65.742
07/09/2015 22:50	9.373	66.247	08/09/2015 03:40	10.035	65.585	08/09/2015 08:30	9.914	65.706
07/09/2015 23:00	9.995	65.625	08/09/2015 03:50	10.210	65.410	08/09/2015 08:40	9.826	65.794
07/09/2015 23:10	10.040	65.580	08/09/2015 04:00	10.275	65.345	08/09/2015 08:50	10.256	65.364
07/09/2015 23:20	10.576	65.044	08/09/2015 04:10	10.362	65.258	08/09/2015 09:00	9.659	65.961
07/09/2015 23:30	11.228	64.392	08/09/2015 04:20	10.608	65.012	08/09/2015 09:10	9.627	65.993
07/09/2015 23:40	9.748	65.872	08/09/2015 04:30	10.640	64.980	08/09/2015 09:20	9.783	65.837
07/09/2015 23:50	9.570	66.050	08/09/2015 04:40	9.874	65.746	08/09/2015 09:30	9.900	65.720
08/09/2015 00:00	9.515	66.105	08/09/2015 04:50	9.561	66.059	08/09/2015 09:40	9.757	65.863
08/09/2015 00:10	9.445	66.175	08/09/2015 05:00	9.815	65.805	08/09/2015 09:50	9.757	65.863

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
08/09/2015 10:00	9.550	66.070	08/09/2015 15:30	9.434	66.186	08/09/2015 21:00	9.940	65.680
08/09/2015 10:10	9.532	66.088	08/09/2015 15:40	9.822	65.798	08/09/2015 21:10	10.023	65.597
08/09/2015 10:20	9.420	66.200	08/09/2015 15:50	9.861	65.759	08/09/2015 21:20	9.965	65.655
08/09/2015 10:30	10.419	65.201	08/09/2015 16:00	10.020	65.600	08/09/2015 21:30	10.004	65.616
08/09/2015 10:40	10.846	64.774	08/09/2015 16:10	9.568	66.052	08/09/2015 21:40	10.027	65.593
08/09/2015 10:50	10.668	64.952	08/09/2015 16:20	9.653	65.967	08/09/2015 21:50	9.964	65.656
08/09/2015 11:00	10.128	65.492	08/09/2015 16:30	9.387	66.233	08/09/2015 22:00	9.707	65.913
08/09/2015 11:10	9.607	66.013	08/09/2015 16:40	9.963	65.657	08/09/2015 22:10	9.870	65.750
08/09/2015 11:20	9.434	66.186	08/09/2015 16:50	9.862	65.758	08/09/2015 22:20	9.792	65.828
08/09/2015 11:30	9.433	66.187	08/09/2015 17:00	9.637	65.983	08/09/2015 22:30	9.764	65.856
08/09/2015 11:40	9.214	66.406	08/09/2015 17:10	9.605	66.015	08/09/2015 22:40	9.784	65.836
08/09/2015 11:50	9.363	66.257	08/09/2015 17:20	9.638	65.982	08/09/2015 22:50	10.467	65.153
08/09/2015 12:00	9.714	65.906	08/09/2015 17:30	9.597	66.023	08/09/2015 23:00	10.341	65.279
08/09/2015 12:10	9.771	65.849	08/09/2015 17:40	9.565	66.055	08/09/2015 23:10	10.160	65.460
08/09/2015 12:20	9.504	66.116	08/09/2015 17:50	9.280	66.340	08/09/2015 23:20	10.424	65.196
08/09/2015 12:30	10.587	65.033	08/09/2015 18:00	9.383	66.237	08/09/2015 23:30	10.460	65.160
08/09/2015 12:40	11.152	64.468	08/09/2015 18:10	9.574	66.046	08/09/2015 23:40	10.013	65.607
08/09/2015 12:50	10.892	64.728	08/09/2015 18:20	9.536	66.084	08/09/2015 23:50	9.743	65.877
08/09/2015 13:00	10.883	64.737	08/09/2015 18:30	9.522	66.098	09/09/2015 00:00	9.677	65.943
08/09/2015 13:10	9.629	65.991	08/09/2015 18:40	9.561	66.059	09/09/2015 00:10	11.179	64.441
08/09/2015 13:20	9.313	66.307	08/09/2015 18:50	9.418	66.202	09/09/2015 00:20	11.593	64.027
08/09/2015 13:30	9.401	66.219	08/09/2015 19:00	9.699	65.921	09/09/2015 00:30	11.196	64.424
08/09/2015 13:40	9.498	66.122	08/09/2015 19:10	10.225	65.395	09/09/2015 00:40	10.998	64.622
08/09/2015 13:50	9.392	66.228	08/09/2015 19:20	10.095	65.525	09/09/2015 00:50	10.940	64.680
08/09/2015 14:00	9.451	66.169	08/09/2015 19:30	9.995	65.625	09/09/2015 01:00	10.888	64.732
08/09/2015 14:10	10.316	65.304	08/09/2015 19:40	10.179	65.441	09/09/2015 01:10	10.900	64.720
08/09/2015 14:20	10.201	65.419	08/09/2015 19:50	10.136	65.484	09/09/2015 01:20	10.799	64.821
08/09/2015 14:30	10.126	65.494	08/09/2015 20:00	10.032	65.588	09/09/2015 01:30	10.492	65.128
08/09/2015 14:40	9.612	66.008	08/09/2015 20:10	10.069	65.551	09/09/2015 01:40	10.448	65.172
08/09/2015 14:50	9.951	65.669	08/09/2015 20:20	9.928	65.692	09/09/2015 01:50	10.371	65.249
08/09/2015 15:00	10.268	65.352	08/09/2015 20:30	9.921	65.699	09/09/2015 02:00	10.463	65.157
08/09/2015 15:10	9.410	66.210	08/09/2015 20:40	9.877	65.743	09/09/2015 02:10	10.498	65.122
08/09/2015 15:20	9.110	66.510	08/09/2015 20:50	9.939	65.681	09/09/2015 02:20	10.436	65.184

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
09/09/2015 02:30	10.119	65.501	09/09/2015 08:00	9.871	65.749	09/09/2015 13:30	8.949	66.671
09/09/2015 02:40	10.475	65.145	09/09/2015 08:10	9.896	65.724	09/09/2015 13:40	8.885	66.735
09/09/2015 02:50	10.283	65.337	09/09/2015 08:20	10.066	65.554	09/09/2015 13:50	8.744	66.876
09/09/2015 03:00	10.148	65.472	09/09/2015 08:30	9.992	65.628	09/09/2015 14:00	8.857	66.763
09/09/2015 03:10	10.253	65.367	09/09/2015 08:40	10.167	65.453	09/09/2015 14:10	8.798	66.822
09/09/2015 03:20	10.228	65.392	09/09/2015 08:50	9.897	65.723	09/09/2015 14:20	8.820	66.800
09/09/2015 03:30	10.178	65.442	09/09/2015 09:00	9.605	66.015	09/09/2015 14:30	8.936	66.684
09/09/2015 03:40	10.086	65.534	09/09/2015 09:10	9.528	66.092	09/09/2015 14:40	8.977	66.643
09/09/2015 03:50	10.134	65.486	09/09/2015 09:20	9.627	65.993	09/09/2015 14:50	9.083	66.537
09/09/2015 04:00	9.930	65.690	09/09/2015 09:30	9.496	66.124	09/09/2015 15:00	9.053	66.567
09/09/2015 04:10	9.925	65.695	09/09/2015 09:40	9.630	65.990	09/09/2015 15:10	9.037	66.583
09/09/2015 04:20	9.913	65.707	09/09/2015 09:50	9.563	66.057	09/09/2015 15:20	8.956	66.664
09/09/2015 04:30	9.578	66.042	09/09/2015 10:00	9.364	66.256	09/09/2015 15:30	8.845	66.775
09/09/2015 04:40	9.520	66.100	09/09/2015 10:10	9.565	66.055	09/09/2015 15:40	8.917	66.703
09/09/2015 04:50	9.392	66.228	09/09/2015 10:20	9.619	66.001	09/09/2015 15:50	8.836	66.784
09/09/2015 05:00	9.517	66.103	09/09/2015 10:30	9.435	66.185	09/09/2015 16:00	9.050	66.570
09/09/2015 05:10	9.480	66.140	09/09/2015 10:40	9.567	66.053	09/09/2015 16:10	9.409	66.211
09/09/2015 05:20	9.320	66.300	09/09/2015 10:50	9.507	66.113	09/09/2015 16:20	9.469	66.151
09/09/2015 05:30	9.157	66.463	09/09/2015 11:00	9.299	66.321	09/09/2015 16:30	9.363	66.257
09/09/2015 05:40	9.031	66.589	09/09/2015 11:10	9.545	66.075	09/09/2015 16:40	9.478	66.142
09/09/2015 05:50	9.288	66.332	09/09/2015 11:20	9.596	66.024	09/09/2015 16:50	9.521	66.099
09/09/2015 06:00	9.972	65.648	09/09/2015 11:30	9.370	66.250	09/09/2015 17:00	9.655	65.965
09/09/2015 06:10	10.035	65.585	09/09/2015 11:40	9.586	66.034	09/09/2015 17:10	9.580	66.040
09/09/2015 06:20	9.986	65.634	09/09/2015 11:50	9.617	66.003	09/09/2015 17:20	9.552	66.068
09/09/2015 06:30	9.897	65.723	09/09/2015 12:00	9.454	66.166	09/09/2015 17:30	9.543	66.077
09/09/2015 06:40	9.857	65.763	09/09/2015 12:10	9.409	66.211	09/09/2015 17:40	9.634	65.986
09/09/2015 06:50	9.859	65.761	09/09/2015 12:20	9.507	66.113	09/09/2015 17:50	9.703	65.917
09/09/2015 07:00	9.853	65.767	09/09/2015 12:30	9.403	66.217	09/09/2015 18:00	9.519	66.101
09/09/2015 07:10	9.979	65.641	09/09/2015 12:40	9.693	65.927	09/09/2015 18:10	9.634	65.986
09/09/2015 07:20	9.911	65.709	09/09/2015 12:50	9.675	65.945	09/09/2015 18:20	9.609	66.011
09/09/2015 07:30	9.989	65.631	09/09/2015 13:00	9.580	66.040	09/09/2015 18:30	9.656	65.964
09/09/2015 07:40	9.756	65.864	09/09/2015 13:10	9.235	66.385	09/09/2015 18:40	9.448	66.172
09/09/2015 07:50	9.996	65.624	09/09/2015 13:20	9.122	66.498	09/09/2015 18:50	9.433	66.187

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
09/09/2015 19:00	9.570	66.050	10/09/2015 00:30	9.757	65.863	10/09/2015 06:00	9.709	65.911
09/09/2015 19:10	9.674	65.946	10/09/2015 00:40	9.594	66.026	10/09/2015 06:10	9.672	65.948
09/09/2015 19:20	9.461	66.159	10/09/2015 00:50	9.786	65.834	10/09/2015 06:20	9.647	65.973
09/09/2015 19:30	9.577	66.043	10/09/2015 01:00	9.674	65.946	10/09/2015 06:30	9.700	65.920
09/09/2015 19:40	9.742	65.878	10/09/2015 01:10	9.524	66.096	10/09/2015 06:40	9.804	65.816
09/09/2015 19:50	10.008	65.612	10/09/2015 01:20	9.755	65.865	10/09/2015 06:50	9.658	65.962
09/09/2015 20:00	10.056	65.564	10/09/2015 01:30	9.537	66.083	10/09/2015 07:00	9.755	65.865
09/09/2015 20:10	9.884	65.736	10/09/2015 01:40	9.799	65.821	10/09/2015 07:10	9.591	66.029
09/09/2015 20:20	9.872	65.748	10/09/2015 01:50	9.829	65.791	10/09/2015 07:20	9.650	65.970
09/09/2015 20:30	9.902	65.718	10/09/2015 02:00	9.773	65.847	10/09/2015 07:30	9.600	66.020
09/09/2015 20:40	10.119	65.501	10/09/2015 02:10	9.603	66.017	10/09/2015 07:40	9.593	66.027
09/09/2015 20:50	9.967	65.653	10/09/2015 02:20	9.813	65.807	10/09/2015 07:50	9.605	66.015
09/09/2015 21:00	10.085	65.535	10/09/2015 02:30	9.589	66.031	10/09/2015 08:00	9.482	66.138
09/09/2015 21:10	10.068	65.552	10/09/2015 02:40	9.759	65.861	10/09/2015 08:10	9.500	66.120
09/09/2015 21:20	10.046	65.574	10/09/2015 02:50	9.782	65.838	10/09/2015 08:20	9.611	66.009
09/09/2015 21:30	9.850	65.770	10/09/2015 03:00	9.739	65.881	10/09/2015 08:30	10.097	65.523
09/09/2015 21:40	9.947	65.673	10/09/2015 03:10	9.552	66.068	10/09/2015 08:40	10.172	65.448
09/09/2015 21:50	9.944	65.676	10/09/2015 03:20	9.769	65.851	10/09/2015 08:50	10.339	65.281
09/09/2015 22:00	10.074	65.546	10/09/2015 03:30	9.749	65.871	10/09/2015 09:00	10.034	65.586
09/09/2015 22:10	9.823	65.797	10/09/2015 03:40	9.521	66.099	10/09/2015 09:10	9.947	65.673
09/09/2015 22:20	9.918	65.702	10/09/2015 03:50	9.600	66.020	10/09/2015 09:20	9.884	65.736
09/09/2015 22:30	9.943	65.677	10/09/2015 04:00	9.746	65.874	10/09/2015 09:30	10.019	65.601
09/09/2015 22:40	9.723	65.897	10/09/2015 04:10	9.645	65.975	10/09/2015 09:40	10.076	65.544
09/09/2015 22:50	9.964	65.656	10/09/2015 04:20	9.719	65.901	10/09/2015 09:50	9.803	65.817
09/09/2015 23:00	9.937	65.683	10/09/2015 04:30	9.677	65.943	10/09/2015 10:00	9.945	65.675
09/09/2015 23:10	9.881	65.739	10/09/2015 04:40	9.644	65.976	10/09/2015 10:10	9.964	65.656
09/09/2015 23:20	9.927	65.693	10/09/2015 04:50	9.500	66.120	10/09/2015 10:20	9.924	65.696
09/09/2015 23:30	10.008	65.612	10/09/2015 05:00	9.525	66.095	10/09/2015 10:30	9.842	65.778
09/09/2015 23:40	9.903	65.717	10/09/2015 05:10	9.696	65.924	10/09/2015 10:40	9.900	65.720
09/09/2015 23:50	9.925	65.695	10/09/2015 05:20	9.567	66.053	10/09/2015 10:50	9.917	65.703
10/09/2015 00:00	9.842	65.778	10/09/2015 05:30	9.550	66.070	10/09/2015 11:00	9.988	65.632
10/09/2015 00:10	9.667	65.953	10/09/2015 05:40	9.554	66.066	10/09/2015 11:10	9.866	65.754
10/09/2015 00:20	9.838	65.782	10/09/2015 05:50	9.594	66.026	10/09/2015 11:20	9.811	65.809

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
10/09/2015 06:00	9.709	65.911	10/09/2015 11:30	9.817	65.803	10/09/2015 17:00	8.941	66.679
10/09/2015 06:10	9.672	65.948	10/09/2015 11:40	9.835	65.785	10/09/2015 17:10	9.150	66.470
10/09/2015 06:20	9.647	65.973	10/09/2015 11:50	9.728	65.892	10/09/2015 17:20	9.302	66.318
10/09/2015 06:30	9.700	65.920	10/09/2015 12:00	9.856	65.764	10/09/2015 17:30	8.989	66.631
10/09/2015 06:40	9.804	65.816	10/09/2015 12:10	9.716	65.904	10/09/2015 17:40	8.846	66.774
10/09/2015 06:50	9.658	65.962	10/09/2015 12:20	9.747	65.873	10/09/2015 17:50	8.776	66.844
10/09/2015 07:00	9.755	65.865	10/09/2015 12:30	9.715	65.905	10/09/2015 18:00	8.758	66.862
10/09/2015 07:10	9.591	66.029	10/09/2015 12:40	9.872	65.748	10/09/2015 18:10	8.729	66.891
10/09/2015 07:20	9.650	65.970	10/09/2015 12:50	9.617	66.003	10/09/2015 18:20	8.715	66.905
10/09/2015 07:30	9.600	66.020	10/09/2015 13:00	9.788	65.832	10/09/2015 18:30	8.516	67.104
10/09/2015 07:40	9.593	66.027	10/09/2015 13:10	9.598	66.022	10/09/2015 18:40	8.745	66.875
10/09/2015 07:50	9.605	66.015	10/09/2015 13:20	9.585	66.035	10/09/2015 18:50	8.602	67.018
10/09/2015 08:00	9.482	66.138	10/09/2015 13:30	9.437	66.183	10/09/2015 19:00	8.519	67.101
10/09/2015 08:10	9.500	66.120	10/09/2015 13:40	9.147	66.473	10/09/2015 19:10	8.488	67.132
10/09/2015 08:20	9.611	66.009	10/09/2015 13:50	9.378	66.242	10/09/2015 19:20	8.529	67.091
10/09/2015 08:30	10.097	65.523	10/09/2015 14:00	9.244	66.376	10/09/2015 19:30	8.662	66.958
10/09/2015 08:40	10.172	65.448	10/09/2015 14:10	9.326	66.294	10/09/2015 19:40	4.161	71.459
10/09/2015 08:50	10.339	65.281	10/09/2015 14:20	9.349	66.271	10/09/2015 19:50	3.887	71.733
10/09/2015 09:00	10.034	65.586	10/09/2015 14:30	9.317	66.303	10/09/2015 20:00	3.705	71.915
10/09/2015 09:10	9.947	65.673	10/09/2015 14:40	9.173	66.447	10/09/2015 20:10	3.536	72.084
10/09/2015 09:20	9.884	65.736	10/09/2015 14:50	9.253	66.367	10/09/2015 20:20	3.419	72.201
10/09/2015 09:30	10.019	65.601	10/09/2015 15:00	9.190	66.430	10/09/2015 20:30	3.319	72.301
10/09/2015 09:40	10.076	65.544	10/09/2015 15:10	8.975	66.645	10/09/2015 20:40	3.243	72.377
10/09/2015 09:50	9.803	65.817	10/09/2015 15:20	9.060	66.560	10/09/2015 20:50	3.173	72.447
10/09/2015 10:00	9.945	65.675	10/09/2015 15:30	9.361	66.259	10/09/2015 21:00	3.100	72.520
10/09/2015 10:10	9.964	65.656	10/09/2015 15:40	9.311	66.309	10/09/2015 21:10	3.032	72.588
10/09/2015 10:20	9.924	65.696	10/09/2015 15:50	9.359	66.261	10/09/2015 21:20	2.965	72.655
10/09/2015 10:30	9.842	65.778	10/09/2015 16:00	8.968	66.652	10/09/2015 21:30	2.901	72.719
10/09/2015 10:40	9.900	65.720	10/09/2015 16:10	8.896	66.724	10/09/2015 21:40	2.840	72.780
10/09/2015 10:50	9.917	65.703	10/09/2015 16:20	8.765	66.855	10/09/2015 21:50	2.778	72.842
10/09/2015 11:00	9.988	65.632	10/09/2015 16:30	9.010	66.610	10/09/2015 22:00	2.709	72.911
10/09/2015 11:10	9.866	65.754	10/09/2015 16:40	8.990	66.630	10/09/2015 22:10	2.649	72.971
10/09/2015 11:20	9.811	65.809	10/09/2015 16:50	8.988	66.632	10/09/2015 22:20	2.602	73.018

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
10/09/2015 22:30	2.563	73.057	11/09/2015 04:00	2.102	73.518	11/09/2015 09:30	1.927	73.693
10/09/2015 22:40	2.528	73.092	11/09/2015 04:10	2.093	73.527	11/09/2015 09:40	1.926	73.694
10/09/2015 22:50	2.497	73.123	11/09/2015 04:20	2.086	73.534	11/09/2015 09:50	1.922	73.698
10/09/2015 23:00	2.468	73.152	11/09/2015 04:30	2.080	73.540	11/09/2015 10:00	1.917	73.703
10/09/2015 23:10	2.442	73.178	11/09/2015 04:40	2.073	73.547	11/09/2015 10:10	1.915	73.705
10/09/2015 23:20	2.420	73.200	11/09/2015 04:50	2.065	73.555	11/09/2015 10:20	1.912	73.708
10/09/2015 23:30	2.398	73.222	11/09/2015 05:00	2.058	73.562	11/09/2015 10:30	1.909	73.712
10/09/2015 23:40	2.381	73.239	11/09/2015 05:10	2.052	73.568	11/09/2015 10:40	1.905	73.715
10/09/2015 23:50	2.364	73.256	11/09/2015 05:20	2.046	73.574	11/09/2015 10:50	1.902	73.718
11/09/2015 00:00	2.346	73.274	11/09/2015 05:30	2.038	73.582	11/09/2015 11:00	1.900	73.720
11/09/2015 00:10	2.330	73.290	11/09/2015 05:40	2.034	73.586			
11/09/2015 00:20	2.316	73.304	11/09/2015 05:50	2.027	73.593			
11/09/2015 00:30	2.301	73.319	11/09/2015 06:00	2.021	73.599			
11/09/2015 00:40	2.287	73.333	11/09/2015 06:10	2.016	73.604			
11/09/2015 00:50	2.274	73.346	11/09/2015 06:20	2.010	73.610			
11/09/2015 01:00	2.261	73.359	11/09/2015 06:30	2.003	73.617			
11/09/2015 01:10	2.250	73.370	11/09/2015 06:40	1.998	73.622			
11/09/2015 01:20	2.240	73.380	11/09/2015 06:50	1.994	73.626			
11/09/2015 01:30	2.229	73.391	11/09/2015 07:00	1.988	73.632			
11/09/2015 01:40	2.220	73.400	11/09/2015 07:10	1.983	73.637			
11/09/2015 01:50	2.210	73.410	11/09/2015 07:20	1.978	73.642			
11/09/2015 02:00	2.200	73.420	11/09/2015 07:30	1.974	73.646			
11/09/2015 02:10	2.191	73.429	11/09/2015 07:40	1.970	73.650			
11/09/2015 02:20	2.182	73.438	11/09/2015 07:50	1.966	73.654			
11/09/2015 02:30	2.174	73.446	11/09/2015 08:00	1.960	73.660			
11/09/2015 02:40	2.166	73.454	11/09/2015 08:10	1.956	73.664			
11/09/2015 02:50	2.157	73.463	11/09/2015 08:20	1.953	73.667			
11/09/2015 03:00	2.148	73.472	11/09/2015 08:30	1.948	73.672			
11/09/2015 03:10	2.140	73.480	11/09/2015 08:40	1.943	73.677			
11/09/2015 03:20	2.132	73.488	11/09/2015 08:50	1.939	73.681			
11/09/2015 03:30	2.124	73.496	11/09/2015 09:00	1.937	73.683			
11/09/2015 03:40	2.116	73.504	11/09/2015 09:10	1.933	73.687			
11/09/2015 03:50	2.109	73.511	11/09/2015 09:20	1.931	73.689			

P1304
Garryhinch Bog Pumping Tests
All data logger water level data for WH02

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
08/09/2015 17:50	4.857	69.453	08/09/2015 22:40	5.081	69.229	09/09/2015 03:30	5.191	69.119
08/09/2015 18:00	4.852	69.458	08/09/2015 22:50	5.085	69.225	09/09/2015 03:40	5.165	69.145
08/09/2015 18:10	4.896	69.414	08/09/2015 23:00	5.109	69.201	09/09/2015 03:50	5.194	69.116
08/09/2015 18:20	4.901	69.409	08/09/2015 23:10	5.083	69.227	09/09/2015 04:00	5.166	69.144
08/09/2015 18:30	4.907	69.403	08/09/2015 23:20	5.110	69.200	09/09/2015 04:10	5.179	69.131
08/09/2015 18:40	4.911	69.399	08/09/2015 23:30	5.108	69.202	09/09/2015 04:20	5.183	69.127
08/09/2015 18:50	4.902	69.408	08/09/2015 23:40	5.091	69.219	09/09/2015 04:30	5.193	69.117
08/09/2015 19:00	4.968	69.342	08/09/2015 23:50	5.106	69.204	09/09/2015 04:40	5.207	69.103
08/09/2015 19:10	4.934	69.376	09/09/2015 00:00	5.133	69.177	09/09/2015 04:50	5.205	69.105
08/09/2015 19:20	4.987	69.323	09/09/2015 00:10	5.134	69.176	09/09/2015 05:00	5.196	69.114
08/09/2015 19:30	4.953	69.357	09/09/2015 00:20	5.119	69.191	09/09/2015 05:10	5.187	69.123
08/09/2015 19:40	4.984	69.326	09/09/2015 00:30	5.120	69.190	09/09/2015 05:20	5.219	69.091
08/09/2015 19:50	5.003	69.307	09/09/2015 00:40	5.133	69.177	09/09/2015 05:30	5.223	69.087
08/09/2015 20:00	4.962	69.348	09/09/2015 00:50	5.135	69.175	09/09/2015 05:40	5.213	69.097
08/09/2015 20:10	5.033	69.277	09/09/2015 01:00	5.139	69.171	09/09/2015 05:50	5.185	69.125
08/09/2015 20:20	4.995	69.315	09/09/2015 01:10	5.139	69.171	09/09/2015 06:00	5.211	69.099
08/09/2015 20:30	4.999	69.311	09/09/2015 01:20	5.132	69.178	09/09/2015 06:10	5.216	69.094
08/09/2015 20:40	5.011	69.299	09/09/2015 01:30	5.142	69.168	09/09/2015 06:20	5.234	69.076
08/09/2015 20:50	5.008	69.302	09/09/2015 01:40	5.134	69.176	09/09/2015 06:30	5.192	69.118
08/09/2015 21:00	5.020	69.290	09/09/2015 01:50	5.172	69.138	09/09/2015 06:40	5.244	69.066
08/09/2015 21:10	5.045	69.265	09/09/2015 02:00	5.151	69.159	09/09/2015 06:50	5.239	69.071
08/09/2015 21:20	5.051	69.259	09/09/2015 02:10	5.175	69.135	09/09/2015 07:00	5.203	69.107
08/09/2015 21:30	5.050	69.260	09/09/2015 02:20	5.163	69.147	09/09/2015 07:10	5.234	69.076
08/09/2015 21:40	5.028	69.282	09/09/2015 02:30	5.175	69.135	09/09/2015 07:20	5.249	69.061
08/09/2015 21:50	5.051	69.259	09/09/2015 02:40	5.168	69.142	09/09/2015 07:30	5.226	69.084
08/09/2015 22:00	5.075	69.235	09/09/2015 02:50	5.185	69.125	09/09/2015 07:40	5.244	69.066
08/09/2015 22:10	5.063	69.247	09/09/2015 03:00	5.181	69.129	09/09/2015 07:50	5.261	69.049
08/09/2015 22:20	5.102	69.208	09/09/2015 03:10	5.173	69.137	09/09/2015 08:00	5.258	69.052
08/09/2015 22:30	5.066	69.244	09/09/2015 03:20	5.179	69.131	09/09/2015 08:10	5.242	69.068

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
09/09/2015 08:20	5.253	69.057	09/09/2015 13:50	5.280	69.030	09/09/2015 19:20	5.305	69.005
09/09/2015 08:30	5.259	69.051	09/09/2015 14:00	5.264	69.046	09/09/2015 19:30	5.319	68.991
09/09/2015 08:40	5.243	69.067	09/09/2015 14:10	5.291	69.019	09/09/2015 19:40	5.324	68.986
09/09/2015 08:50	5.275	69.035	09/09/2015 14:20	5.263	69.047	09/09/2015 19:50	5.339	68.971
09/09/2015 09:00	5.241	69.069	09/09/2015 14:30	5.289	69.021	09/09/2015 20:00	5.329	68.981
09/09/2015 09:10	5.259	69.051	09/09/2015 14:40	5.275	69.035	09/09/2015 20:10	5.321	68.989
09/09/2015 09:20	5.270	69.040	09/09/2015 14:50	5.274	69.036	09/09/2015 20:20	5.337	68.973
09/09/2015 09:30	5.278	69.032	09/09/2015 15:00	5.287	69.023	09/09/2015 20:30	5.337	68.973
09/09/2015 09:40	5.267	69.043	09/09/2015 15:10	5.286	69.024	09/09/2015 20:40	5.333	68.977
09/09/2015 09:50	5.257	69.053	09/09/2015 15:20	5.271	69.039	09/09/2015 20:50	5.330	68.980
09/09/2015 10:00	5.227	69.083	09/09/2015 15:30	5.257	69.053	09/09/2015 21:00	5.319	68.991
09/09/2015 10:10	5.221	69.089	09/09/2015 15:40	5.264	69.046	09/09/2015 21:10	5.331	68.979
09/09/2015 10:20	5.272	69.038	09/09/2015 15:50	5.296	69.014	09/09/2015 21:20	5.339	68.971
09/09/2015 10:30	5.269	69.041	09/09/2015 16:00	5.252	69.058	09/09/2015 21:30	5.328	68.982
09/09/2015 10:40	5.279	69.031	09/09/2015 16:10	5.277	69.033	09/09/2015 21:40	5.340	68.970
09/09/2015 10:50	5.234	69.076	09/09/2015 16:20	5.258	69.052	09/09/2015 21:50	5.349	68.961
09/09/2015 11:00	5.234	69.076	09/09/2015 16:30	5.285	69.025	09/09/2015 22:00	5.345	68.965
09/09/2015 11:10	5.286	69.024	09/09/2015 16:40	5.268	69.042	09/09/2015 22:10	5.317	68.993
09/09/2015 11:20	5.285	69.025	09/09/2015 16:50	5.291	69.019	09/09/2015 22:20	5.344	68.966
09/09/2015 11:30	5.262	69.048	09/09/2015 17:00	5.298	69.012	09/09/2015 22:30	5.339	68.971
09/09/2015 11:40	5.278	69.032	09/09/2015 17:10	5.287	69.023	09/09/2015 22:40	5.310	69.000
09/09/2015 11:50	5.260	69.050	09/09/2015 17:20	5.305	69.005	09/09/2015 22:50	5.340	68.970
09/09/2015 12:00	5.291	69.019	09/09/2015 17:30	5.269	69.041	09/09/2015 23:00	5.359	68.951
09/09/2015 12:10	5.288	69.022	09/09/2015 17:40	5.309	69.001	09/09/2015 23:10	5.354	68.956
09/09/2015 12:20	5.288	69.022	09/09/2015 17:50	5.280	69.030	09/09/2015 23:20	5.367	68.943
09/09/2015 12:30	5.286	69.024	09/09/2015 18:00	5.262	69.048	09/09/2015 23:30	5.354	68.956
09/09/2015 12:40	5.258	69.052	09/09/2015 18:10	5.305	69.005	09/09/2015 23:40	5.369	68.941
09/09/2015 12:50	5.253	69.057	09/09/2015 18:20	5.314	68.996	09/09/2015 23:50	5.307	69.003
09/09/2015 13:00	5.277	69.033	09/09/2015 18:30	5.279	69.031	10/09/2015 00:00	5.366	68.944
09/09/2015 13:10	5.274	69.036	09/09/2015 18:40	5.284	69.026	10/09/2015 00:10	5.363	68.947
09/09/2015 13:20	5.291	69.019	09/09/2015 18:50	5.304	69.006	10/09/2015 00:20	5.369	68.941
09/09/2015 13:30	5.293	69.017	09/09/2015 19:00	5.320	68.990	10/09/2015 00:30	5.355	68.955
09/09/2015 13:40	5.305	69.005	09/09/2015 19:10	5.296	69.014	10/09/2015 00:40	5.346	68.964

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
10/09/2015 00:50	5.377	68.933	10/09/2015 06:20	5.388	68.922	10/09/2015 11:50	5.415	68.895
10/09/2015 01:00	5.375	68.935	10/09/2015 06:30	5.376	68.934	10/09/2015 12:00	5.437	68.873
10/09/2015 01:10	5.347	68.963	10/09/2015 06:40	5.400	68.910	10/09/2015 12:10	5.423	68.887
10/09/2015 01:20	5.342	68.968	10/09/2015 06:50	5.412	68.898	10/09/2015 12:20	5.400	68.910
10/09/2015 01:30	5.370	68.940	10/09/2015 07:00	5.398	68.912	10/09/2015 12:30	5.441	68.869
10/09/2015 01:40	5.321	68.989	10/09/2015 07:10	5.378	68.932	10/09/2015 12:40	5.386	68.924
10/09/2015 01:50	5.377	68.933	10/09/2015 07:20	5.409	68.901	10/09/2015 12:50	5.408	68.902
10/09/2015 02:00	5.348	68.962	10/09/2015 07:30	5.433	68.877	10/09/2015 13:00	5.403	68.907
10/09/2015 02:10	5.328	68.982	10/09/2015 07:40	5.372	68.938	10/09/2015 13:10	5.448	68.862
10/09/2015 02:20	5.367	68.943	10/09/2015 07:50	5.367	68.943	10/09/2015 13:20	5.455	68.855
10/09/2015 02:30	5.363	68.947	10/09/2015 08:00	5.431	68.879	10/09/2015 13:30	5.431	68.879
10/09/2015 02:40	5.377	68.933	10/09/2015 08:10	5.390	68.920	10/09/2015 13:40	5.427	68.883
10/09/2015 02:50	5.386	68.924	10/09/2015 08:20	5.385	68.925	10/09/2015 13:50	5.411	68.899
10/09/2015 03:00	5.383	68.927	10/09/2015 08:30	5.451	68.859	10/09/2015 14:00	5.405	68.905
10/09/2015 03:10	5.354	68.956	10/09/2015 08:40	5.392	68.918	10/09/2015 14:10	5.407	68.903
10/09/2015 03:20	5.386	68.924	10/09/2015 08:50	5.411	68.899	10/09/2015 14:20	5.414	68.896
10/09/2015 03:30	5.375	68.935	10/09/2015 09:00	5.388	68.922	10/09/2015 14:30	5.405	68.905
10/09/2015 03:40	5.372	68.938	10/09/2015 09:10	5.414	68.896	10/09/2015 14:40	5.424	68.886
10/09/2015 03:50	5.385	68.925	10/09/2015 09:20	5.398	68.912	10/09/2015 14:50	5.382	68.928
10/09/2015 04:00	5.386	68.924	10/09/2015 09:30	5.404	68.906	10/09/2015 15:00	5.399	68.911
10/09/2015 04:10	5.372	68.938	10/09/2015 09:40	5.364	68.946	10/09/2015 15:10	5.395	68.915
10/09/2015 04:20	5.401	68.909	10/09/2015 09:50	5.424	68.886	10/09/2015 15:20	5.439	68.871
10/09/2015 04:30	5.377	68.933	10/09/2015 10:00	5.420	68.890	10/09/2015 15:30	5.401	68.909
10/09/2015 04:40	5.397	68.913	10/09/2015 10:10	5.413	68.897	10/09/2015 15:40	5.431	68.879
10/09/2015 04:50	5.376	68.934	10/09/2015 10:20	5.406	68.904	10/09/2015 15:50	5.421	68.889
10/09/2015 05:00	5.383	68.927	10/09/2015 10:30	5.389	68.921	10/09/2015 16:00	5.478	68.832
10/09/2015 05:10	5.372	68.938	10/09/2015 10:40	5.423	68.887	10/09/2015 16:10	5.429	68.881
10/09/2015 05:20	5.376	68.934	10/09/2015 10:50	5.382	68.928	10/09/2015 16:20	5.406	68.904
10/09/2015 05:30	5.366	68.944	10/09/2015 11:00	5.440	68.870	10/09/2015 16:30	5.446	68.864
10/09/2015 05:40	5.382	68.928	10/09/2015 11:10	5.410	68.900	10/09/2015 16:40	5.418	68.892
10/09/2015 05:50	5.413	68.897	10/09/2015 11:20	5.456	68.854	10/09/2015 16:50	5.410	68.900
10/09/2015 06:00	5.390	68.920	10/09/2015 11:30	5.414	68.896	10/09/2015 17:00	5.438	68.872
10/09/2015 06:10	5.377	68.933	10/09/2015 11:40	5.416	68.894	10/09/2015 17:10	5.427	68.883

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
10/09/2015 17:20	5.412	68.898	10/09/2015 22:50	5.444	68.866	11/09/2015 04:20	5.471	68.839
10/09/2015 17:30	5.432	68.878	10/09/2015 23:00	5.425	68.885	11/09/2015 04:30	5.442	68.868
10/09/2015 17:40	5.423	68.887	10/09/2015 23:10	5.441	68.869	11/09/2015 04:40	5.464	68.846
10/09/2015 17:50	5.436	68.874	10/09/2015 23:20	5.454	68.856	11/09/2015 04:50	5.461	68.849
10/09/2015 18:00	5.385	68.925	10/09/2015 23:30	5.425	68.885	11/09/2015 05:00	5.424	68.886
10/09/2015 18:10	5.429	68.881	10/09/2015 23:40	5.442	68.868	11/09/2015 05:10	5.448	68.862
10/09/2015 18:20	5.413	68.897	10/09/2015 23:50	5.412	68.898	11/09/2015 05:20	5.434	68.876
10/09/2015 18:30	5.409	68.901	11/09/2015 00:00	5.416	68.894	11/09/2015 05:30	5.421	68.889
10/09/2015 18:40	5.424	68.886	11/09/2015 00:10	5.442	68.868	11/09/2015 05:40	5.470	68.840
10/09/2015 18:50	5.418	68.892	11/09/2015 00:20	5.449	68.861	11/09/2015 05:50	5.442	68.868
10/09/2015 19:00	5.411	68.899	11/09/2015 00:30	5.434	68.876	11/09/2015 06:00	5.440	68.870
10/09/2015 19:10	5.418	68.892	11/09/2015 00:40	5.446	68.864	11/09/2015 06:10	5.402	68.908
10/09/2015 19:20	5.422	68.888	11/09/2015 00:50	5.431	68.879	11/09/2015 06:20	5.458	68.852
10/09/2015 19:30	5.381	68.929	11/09/2015 01:00	5.451	68.859	11/09/2015 06:30	5.447	68.863
10/09/2015 19:40	5.432	68.878	11/09/2015 01:10	5.429	68.881	11/09/2015 06:40	5.412	68.898
10/09/2015 19:50	5.426	68.884	11/09/2015 01:20	5.481	68.829	11/09/2015 06:50	5.434	68.876
10/09/2015 20:00	5.430	68.880	11/09/2015 01:30	5.442	68.868	11/09/2015 07:00	5.447	68.863
10/09/2015 20:10	5.435	68.875	11/09/2015 01:40	5.428	68.882	11/09/2015 07:10	5.395	68.915
10/09/2015 20:20	5.399	68.911	11/09/2015 01:50	5.440	68.870	11/09/2015 07:20	5.442	68.868
10/09/2015 20:30	5.402	68.908	11/09/2015 02:00	5.444	68.866	11/09/2015 07:30	5.395	68.915
10/09/2015 20:40	5.416	68.894	11/09/2015 02:10	5.423	68.887	11/09/2015 07:40	5.446	68.864
10/09/2015 20:50	5.403	68.907	11/09/2015 02:20	5.430	68.880	11/09/2015 07:50	5.390	68.920
10/09/2015 21:00	5.416	68.894	11/09/2015 02:30	5.462	68.848	11/09/2015 08:00	5.443	68.867
10/09/2015 21:10	5.411	68.899	11/09/2015 02:40	5.485	68.825	11/09/2015 08:10	5.423	68.887
10/09/2015 21:20	5.410	68.900	11/09/2015 02:50	5.436	68.874	11/09/2015 08:20	5.433	68.877
10/09/2015 21:30	5.433	68.877	11/09/2015 03:00	5.483	68.827	11/09/2015 08:30	5.451	68.859
10/09/2015 21:40	5.401	68.909	11/09/2015 03:10	5.425	68.885	11/09/2015 08:40	5.431	68.879
10/09/2015 21:50	5.418	68.892	11/09/2015 03:20	5.429	68.881	11/09/2015 08:50	5.436	68.874
10/09/2015 22:00	5.424	68.886	11/09/2015 03:30	5.463	68.847	11/09/2015 09:00	5.431	68.879
10/09/2015 22:10	5.451	68.859	11/09/2015 03:40	5.415	68.895	11/09/2015 09:10	5.437	68.873
10/09/2015 22:20	5.434	68.876	11/09/2015 03:50	5.475	68.835	11/09/2015 09:20	5.442	68.868
10/09/2015 22:30	5.433	68.877	11/09/2015 04:00	5.456	68.854	11/09/2015 09:30	5.393	68.917
10/09/2015 22:40	5.423	68.887	11/09/2015 04:10	5.411	68.899	11/09/2015 09:40	5.438	68.872

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
11/09/2015 09:50	5.470	68.840	11/09/2015 15:20	3.293	71.017	11/09/2015 20:50	3.254	71.056
11/09/2015 10:00	5.447	68.863	11/09/2015 15:30	3.291	71.019	11/09/2015 21:00	3.253	71.057
11/09/2015 10:10	5.431	68.879	11/09/2015 15:40	3.290	71.020	11/09/2015 21:10	3.253	71.057
11/09/2015 10:20	5.437	68.873	11/09/2015 15:50	3.289	71.021	11/09/2015 21:20	3.253	71.057
11/09/2015 10:30	5.458	68.852	11/09/2015 16:00	3.287	71.023	11/09/2015 21:30	3.253	71.057
11/09/2015 10:40	5.437	68.873	11/09/2015 16:10	3.287	71.023	11/09/2015 21:40	3.252	71.058
11/09/2015 10:50	5.439	68.871	11/09/2015 16:20	3.285	71.025	11/09/2015 21:50	3.250	71.060
11/09/2015 11:00	5.468	68.842	11/09/2015 16:30	3.284	71.026	11/09/2015 22:00	3.250	71.060
11/09/2015 11:10	5.412	68.898	11/09/2015 16:40	3.283	71.027	11/09/2015 22:10	3.246	71.064
11/09/2015 11:20	5.464	68.846	11/09/2015 16:50	3.282	71.028	11/09/2015 22:20	3.243	71.067
11/09/2015 11:30	5.464	68.846	11/09/2015 17:00	3.280	71.030	11/09/2015 22:30	3.241	71.069
11/09/2015 11:40	5.455	68.855	11/09/2015 17:10	3.278	71.032	11/09/2015 22:40	3.238	71.072
11/09/2015 11:50	5.457	68.853	11/09/2015 17:20	3.277	71.033	11/09/2015 22:50	3.235	71.075
11/09/2015 12:00	5.450	68.860	11/09/2015 17:30	3.275	71.035	11/09/2015 23:00	3.234	71.076
11/09/2015 12:10	5.439	68.871	11/09/2015 17:40	3.273	71.037	11/09/2015 23:10	3.232	71.078
11/09/2015 12:20	4.589	69.721	11/09/2015 17:50	3.272	71.038	11/09/2015 23:20	3.232	71.078
11/09/2015 12:30	4.371	69.939	11/09/2015 18:00	3.270	71.040	11/09/2015 23:30	3.231	71.079
11/09/2015 12:40	4.203	70.107	11/09/2015 18:10	3.270	71.040	11/09/2015 23:40	3.230	71.080
11/09/2015 12:50	4.083	70.227	11/09/2015 18:20	3.269	71.041	11/09/2015 23:50	3.229	71.081
11/09/2015 13:00	3.978	70.332	11/09/2015 18:30	3.267	71.043	12/09/2015 00:00	3.228	71.082
11/09/2015 13:10	3.884	70.426	11/09/2015 18:40	3.266	71.044	12/09/2015 00:10	3.227	71.083
11/09/2015 13:20	3.801	70.509	11/09/2015 18:50	3.266	71.044	12/09/2015 00:20	3.227	71.083
11/09/2015 13:30	3.727	70.583	11/09/2015 19:00	3.265	71.045	12/09/2015 00:30	3.225	71.085
11/09/2015 13:40	3.654	70.656	11/09/2015 19:10	3.264	71.046	12/09/2015 00:40	3.226	71.084
11/09/2015 13:50	3.598	70.712	11/09/2015 19:20	3.263	71.047	12/09/2015 00:50	3.224	71.086
11/09/2015 14:00	3.541	70.769	11/09/2015 19:30	3.262	71.048	12/09/2015 01:00	3.225	71.085
11/09/2015 14:10	3.498	70.812	11/09/2015 19:40	3.261	71.049	12/09/2015 01:10	3.226	71.084
11/09/2015 14:20	3.452	70.858	11/09/2015 19:50	3.260	71.050	12/09/2015 01:20	3.225	71.085
11/09/2015 14:30	3.410	70.900	11/09/2015 20:00	3.258	71.052	12/09/2015 01:30	3.223	71.087
11/09/2015 14:40	3.368	70.942	11/09/2015 20:10	3.257	71.053	12/09/2015 01:40	3.223	71.087
11/09/2015 14:50	3.335	70.975	11/09/2015 20:20	3.256	71.054	12/09/2015 01:50	3.222	71.088
11/09/2015 15:00	3.297	71.013	11/09/2015 20:30	3.255	71.055	12/09/2015 02:00	3.222	71.088
11/09/2015 15:10	3.295	71.015	11/09/2015 20:40	3.255	71.055	12/09/2015 02:10	3.221	71.089

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
12/09/2015 02:20	3.220	71.090	12/09/2015 07:50	3.240	71.070	12/09/2015 13:20	3.258	71.052
12/09/2015 02:30	3.223	71.087	12/09/2015 08:00	3.239	71.071	12/09/2015 13:30	3.258	71.052
12/09/2015 02:40	3.223	71.087	12/09/2015 08:10	3.240	71.070	12/09/2015 13:40	3.261	71.049
12/09/2015 02:50	3.222	71.088	12/09/2015 08:20	3.240	71.070	12/09/2015 13:50	3.263	71.047
12/09/2015 03:00	3.221	71.089	12/09/2015 08:30	3.241	71.069	12/09/2015 14:00	3.262	71.048
12/09/2015 03:10	3.220	71.090	12/09/2015 08:40	3.241	71.069	12/09/2015 14:10	3.260	71.050
12/09/2015 03:20	3.220	71.090	12/09/2015 08:50	3.242	71.068	12/09/2015 14:20	3.260	71.050
12/09/2015 03:30	3.221	71.089	12/09/2015 09:00	3.244	71.066	12/09/2015 14:30	3.259	71.051
12/09/2015 03:40	3.223	71.087	12/09/2015 09:10	3.245	71.065	12/09/2015 14:40	3.259	71.051
12/09/2015 03:50	3.223	71.087	12/09/2015 09:20	3.246	71.064	12/09/2015 14:50	3.261	71.049
12/09/2015 04:00	3.223	71.087	12/09/2015 09:30	3.246	71.064	12/09/2015 15:00	3.261	71.049
12/09/2015 04:10	3.224	71.086	12/09/2015 09:40	3.247	71.063	12/09/2015 15:10	3.260	71.050
12/09/2015 04:20	3.225	71.085	12/09/2015 09:50	3.248	71.062	12/09/2015 15:20	3.259	71.051
12/09/2015 04:30	3.227	71.083	12/09/2015 10:00	3.249	71.061	12/09/2015 15:30	3.258	71.052
12/09/2015 04:40	3.228	71.082	12/09/2015 10:10	3.251	71.059	12/09/2015 15:40	3.256	71.054
12/09/2015 04:50	3.227	71.083	12/09/2015 10:20	3.251	71.059	12/09/2015 15:50	3.258	71.052
12/09/2015 05:00	3.228	71.082	12/09/2015 10:30	3.251	71.059	12/09/2015 16:00	3.257	71.053
12/09/2015 05:10	3.229	71.081	12/09/2015 10:40	3.251	71.059	12/09/2015 16:10	3.257	71.053
12/09/2015 05:20	3.229	71.081	12/09/2015 10:50	3.250	71.060	12/09/2015 16:20	3.257	71.053
12/09/2015 05:30	3.231	71.079	12/09/2015 11:00	3.253	71.057	12/09/2015 16:30	3.257	71.053
12/09/2015 05:40	3.231	71.079	12/09/2015 11:10	3.252	71.058	12/09/2015 16:40	3.257	71.053
12/09/2015 05:50	3.233	71.077	12/09/2015 11:20	3.253	71.057	12/09/2015 16:50	3.257	71.053
12/09/2015 06:00	3.234	71.076	12/09/2015 11:30	3.254	71.056	12/09/2015 17:00	3.256	71.054
12/09/2015 06:10	3.233	71.077	12/09/2015 11:40	3.253	71.057	12/09/2015 17:10	3.257	71.053
12/09/2015 06:20	3.234	71.076	12/09/2015 11:50	3.253	71.057	12/09/2015 17:20	3.256	71.054
12/09/2015 06:30	3.234	71.076	12/09/2015 12:00	3.254	71.056	12/09/2015 17:30	3.257	71.053
12/09/2015 06:40	3.235	71.075	12/09/2015 12:10	3.254	71.056	12/09/2015 17:40	3.258	71.052
12/09/2015 06:50	3.237	71.073	12/09/2015 12:20	3.254	71.056	12/09/2015 17:50	3.259	71.051
12/09/2015 07:00	3.238	71.072	12/09/2015 12:30	3.256	71.054	12/09/2015 18:00	3.259	71.051
12/09/2015 07:10	3.239	71.071	12/09/2015 12:40	3.255	71.055	12/09/2015 18:10	3.259	71.051
12/09/2015 07:20	3.239	71.071	12/09/2015 12:50	3.255	71.055	12/09/2015 18:20	3.260	71.050
12/09/2015 07:30	3.240	71.070	12/09/2015 13:00	3.257	71.053	12/09/2015 18:30	3.260	71.050
12/09/2015 07:40	3.241	71.069	12/09/2015 13:10	3.257	71.053	12/09/2015 18:40	3.260	71.050

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
12/09/2015 18:50	3.260	71.050	13/09/2015 00:20	3.265	71.045	13/09/2015 05:50	3.248	71.062
12/09/2015 19:00	3.261	71.049	13/09/2015 00:30	3.264	71.046	13/09/2015 06:00	3.247	71.063
12/09/2015 19:10	3.260	71.050	13/09/2015 00:40	3.263	71.047	13/09/2015 06:10	3.246	71.064
12/09/2015 19:20	3.261	71.049	13/09/2015 00:50	3.264	71.046	13/09/2015 06:20	3.245	71.065
12/09/2015 19:30	3.261	71.049	13/09/2015 01:00	3.262	71.048	13/09/2015 06:30	3.245	71.065
12/09/2015 19:40	3.262	71.048	13/09/2015 01:10	3.262	71.048	13/09/2015 06:40	3.246	71.064
12/09/2015 19:50	3.263	71.047	13/09/2015 01:20	3.261	71.049	13/09/2015 06:50	3.245	71.065
12/09/2015 20:00	3.264	71.046	13/09/2015 01:30	3.260	71.050	13/09/2015 07:00	3.245	71.065
12/09/2015 20:10	3.264	71.046	13/09/2015 01:40	3.258	71.052	13/09/2015 07:10	3.245	71.065
12/09/2015 20:20	3.264	71.046	13/09/2015 01:50	3.258	71.052	13/09/2015 07:20	3.246	71.064
12/09/2015 20:30	3.264	71.046	13/09/2015 02:00	3.257	71.053	13/09/2015 07:30	3.246	71.064
12/09/2015 20:40	3.264	71.046	13/09/2015 02:10	3.258	71.052	13/09/2015 07:40	3.246	71.064
12/09/2015 20:50	3.265	71.045	13/09/2015 02:20	3.258	71.052	13/09/2015 07:50	3.246	71.064
12/09/2015 21:00	3.266	71.044	13/09/2015 02:30	3.257	71.053	13/09/2015 08:00	3.245	71.065
12/09/2015 21:10	3.265	71.045	13/09/2015 02:40	3.257	71.053	13/09/2015 08:10	3.244	71.066
12/09/2015 21:20	3.266	71.044	13/09/2015 02:50	3.256	71.054	13/09/2015 08:20	3.244	71.066
12/09/2015 21:30	3.267	71.043	13/09/2015 03:00	3.256	71.054	13/09/2015 08:30	3.243	71.067
12/09/2015 21:40	3.268	71.042	13/09/2015 03:10	3.257	71.053	13/09/2015 08:40	3.243	71.067
12/09/2015 21:50	3.267	71.043	13/09/2015 03:20	3.256	71.054	13/09/2015 08:50	3.243	71.067
12/09/2015 22:00	3.266	71.044	13/09/2015 03:30	3.255	71.055	13/09/2015 09:00	3.244	71.066
12/09/2015 22:10	3.266	71.044	13/09/2015 03:40	3.255	71.055	13/09/2015 09:10	3.244	71.066
12/09/2015 22:20	3.266	71.044	13/09/2015 03:50	3.253	71.057	13/09/2015 09:20	3.243	71.067
12/09/2015 22:30	3.266	71.044	13/09/2015 04:00	3.254	71.056	13/09/2015 09:30	3.244	71.066
12/09/2015 22:40	3.266	71.044	13/09/2015 04:10	3.253	71.057	13/09/2015 09:40	3.244	71.066
12/09/2015 22:50	3.265	71.045	13/09/2015 04:20	3.253	71.057	13/09/2015 09:50	3.244	71.066
12/09/2015 23:00	3.265	71.045	13/09/2015 04:30	3.251	71.059	13/09/2015 10:00	3.244	71.066
12/09/2015 23:10	3.265	71.045	13/09/2015 04:40	3.250	71.060	13/09/2015 10:10	3.244	71.066
12/09/2015 23:20	3.266	71.044	13/09/2015 04:50	3.249	71.061	13/09/2015 10:20	3.243	71.067
12/09/2015 23:30	3.266	71.044	13/09/2015 05:00	3.247	71.063	13/09/2015 10:30	3.242	71.068
12/09/2015 23:40	3.265	71.045	13/09/2015 05:10	3.247	71.063	13/09/2015 10:40	3.241	71.069
12/09/2015 23:50	3.266	71.044	13/09/2015 05:20	3.248	71.062	13/09/2015 10:50	3.241	71.069
13/09/2015 00:00	3.266	71.044	13/09/2015 05:30	3.248	71.062	13/09/2015 11:00	3.240	71.070
13/09/2015 00:10	3.266	71.044	13/09/2015 05:40	3.248	71.062	13/09/2015 11:10	3.240	71.070

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
13/09/2015 11:20	3.239	71.071						
13/09/2015 11:30	3.239	71.071						
13/09/2015 11:40	3.238	71.072						
13/09/2015 11:50	3.238	71.072						
13/09/2015 12:00	3.237	71.073						
13/09/2015 12:10	3.236	71.074						
13/09/2015 12:20	3.235	71.075						
13/09/2015 12:30	3.234	71.076						
13/09/2015 12:40	3.233	71.077						
13/09/2015 12:50	3.232	71.078						
13/09/2015 13:00	3.231	71.079						
13/09/2015 13:10	3.230	71.080						
13/09/2015 13:20	3.230	71.080						
13/09/2015 13:30	3.228	71.082						
13/09/2015 13:40	3.227	71.083						
13/09/2015 13:50	3.226	71.084						
13/09/2015 14:00	3.227	71.083						
13/09/2015 14:10	3.225	71.085						
13/09/2015 14:20	3.224	71.086						
13/09/2015 14:30	3.224	71.086						

P1304								
Garryhinch Bog Pumping Tests								
All data logger water level data for BH74								
Date & Time	**WL (mbcl)**	**Water Level (mOD)**	**Date & Time**	**WL (mbcl)**	**Water Level (mOD)**	**Date & Time**	**WL (mbcl)**	**Water Level (mOD)**
08/09/2015 12:00	2.777	71.873	09/09/2015 02:30	2.952	71.698	09/09/2015 17:00	3.017	71.633
08/09/2015 12:30	2.790	71.860	09/09/2015 03:00	2.951	71.699	09/09/2015 17:30	3.013	71.637
08/09/2015 13:00	2.803	71.847	09/09/2015 03:30	2.949	71.701	09/09/2015 18:00	3.014	71.636
08/09/2015 13:30	2.817	71.833	09/09/2015 04:00	2.957	71.693	09/09/2015 18:30	3.019	71.631
08/09/2015 14:00	2.832	71.818	09/09/2015 04:30	2.955	71.695	09/09/2015 19:00	3.022	71.628
08/09/2015 14:30	2.847	71.803	09/09/2015 05:00	2.959	71.691	09/09/2015 19:30	3.022	71.628
08/09/2015 15:00	2.855	71.795	09/09/2015 05:30	2.962	71.688	09/09/2015 20:00	3.025	71.625
08/09/2015 15:30	2.863	71.787	09/09/2015 06:00	2.967	71.683	09/09/2015 20:30	3.028	71.622
08/09/2015 16:00	2.876	71.774	09/09/2015 06:30	2.971	71.679	09/09/2015 21:00	3.031	71.619
08/09/2015 16:30	2.881	71.769	09/09/2015 07:00	2.971	71.679	09/09/2015 21:30	3.033	71.617
08/09/2015 17:00	2.889	71.761	09/09/2015 07:30	2.976	71.674	09/09/2015 22:00	3.038	71.612
08/09/2015 17:30	2.900	71.750	09/09/2015 08:00	2.977	71.673	09/09/2015 22:30	3.038	71.612
08/09/2015 18:00	2.899	71.751	09/09/2015 08:30	2.980	71.670	09/09/2015 23:00	3.035	71.615
08/09/2015 18:30	2.905	71.745	09/09/2015 09:00	2.980	71.670	09/09/2015 23:30	3.038	71.612
08/09/2015 19:00	2.913	71.737	09/09/2015 09:30	2.985	71.665	10/09/2015 00:00	3.041	71.609
08/09/2015 19:30	2.918	71.732	09/09/2015 10:00	2.988	71.662	10/09/2015 00:30	3.047	71.603
08/09/2015 20:00	2.923	71.727	09/09/2015 10:30	2.987	71.663	10/09/2015 01:00	3.044	71.606
08/09/2015 20:30	2.912	71.738	09/09/2015 11:00	2.992	71.658	10/09/2015 01:30	3.044	71.606
08/09/2015 21:00	2.915	71.735	09/09/2015 11:30	2.998	71.652	10/09/2015 02:00	3.047	71.603
08/09/2015 21:30	2.921	71.729	09/09/2015 12:00	3.000	71.650	10/09/2015 02:30	3.052	71.598
08/09/2015 22:00	2.925	71.725	09/09/2015 12:30	2.995	71.655	10/09/2015 03:00	3.054	71.596
08/09/2015 22:30	2.925	71.725	09/09/2015 13:00	2.999	71.651	10/09/2015 03:30	3.053	71.597
08/09/2015 23:00	2.928	71.722	09/09/2015 13:30	3.007	71.643	10/09/2015 04:00	3.053	71.597
08/09/2015 23:30	2.933	71.717	09/09/2015 14:00	3.006	71.644	10/09/2015 04:30	3.054	71.596
09/09/2015 00:00	2.934	71.716	09/09/2015 14:30	3.004	71.646	10/09/2015 05:00	3.054	71.596
09/09/2015 00:30	2.935	71.715	09/09/2015 15:00	3.011	71.639	10/09/2015 05:30	3.062	71.588
09/09/2015 01:00	2.939	71.711	09/09/2015 15:30	3.004	71.646	10/09/2015 06:00	3.061	71.589
09/09/2015 01:30	2.938	71.712	09/09/2015 16:00	3.015	71.635	10/09/2015 06:30	3.065	71.585
09/09/2015 02:00	2.946	71.704	09/09/2015 16:30	3.012	71.638	10/09/2015 07:00	3.069	71.581

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
10/09/2015 07:30	3.067	71.583	11/09/2015 00:00	3.108	71.542	11/09/2015 16:30	3.040	71.610
10/09/2015 08:00	3.072	71.578	11/09/2015 00:30	3.112	71.538	11/09/2015 17:00	3.038	71.612
10/09/2015 08:30	3.076	71.574	11/09/2015 01:00	3.110	71.540	11/09/2015 17:30	3.030	71.620
10/09/2015 09:00	3.075	71.575	11/09/2015 01:30	3.109	71.541	11/09/2015 18:00	3.020	71.630
10/09/2015 09:30	3.065	71.585	11/09/2015 02:00	3.108	71.542	11/09/2015 18:30	3.018	71.632
10/09/2015 10:00	3.074	71.576	11/09/2015 02:30	3.113	71.537	11/09/2015 19:00	3.019	71.631
10/09/2015 10:30	3.073	71.577	11/09/2015 03:00	3.117	71.533	11/09/2015 19:30	3.014	71.636
10/09/2015 11:00	3.079	71.571	11/09/2015 03:30	3.119	71.531	11/09/2015 20:00	3.005	71.645
10/09/2015 11:30	3.080	71.570	11/09/2015 04:00	3.112	71.538	11/09/2015 20:30	2.998	71.652
10/09/2015 12:00	3.081	71.569	11/09/2015 04:30	3.118	71.532	11/09/2015 21:00	3.007	71.643
10/09/2015 12:30	3.084	71.566	11/09/2015 05:00	3.117	71.533	11/09/2015 21:30	3.001	71.649
10/09/2015 13:00	3.086	71.564	11/09/2015 05:30	3.117	71.533	11/09/2015 22:00	2.997	71.653
10/09/2015 13:30	3.086	71.564	11/09/2015 06:00	3.121	71.529	11/09/2015 22:30	2.992	71.658
10/09/2015 14:00	3.084	71.566	11/09/2015 06:30	3.127	71.523	11/09/2015 23:00	2.987	71.663
10/09/2015 14:30	3.079	71.571	11/09/2015 07:00	3.121	71.529	11/09/2015 23:30	2.981	71.669
10/09/2015 15:00	3.087	71.563	11/09/2015 07:30	3.126	71.524	12/09/2015 00:00	2.986	71.664
10/09/2015 15:30	3.090	71.560	11/09/2015 08:00	3.128	71.522	12/09/2015 00:30	2.980	71.670
10/09/2015 16:00	3.092	71.558	11/09/2015 08:30	3.130	71.520	12/09/2015 01:00	2.979	71.671
10/09/2015 16:30	3.098	71.552	11/09/2015 09:00	3.125	71.525	12/09/2015 01:30	2.974	71.676
10/09/2015 17:00	3.098	71.552	11/09/2015 09:30	3.131	71.519	12/09/2015 02:00	2.975	71.675
10/09/2015 17:30	3.095	71.555	11/09/2015 10:00	3.137	71.513	12/09/2015 02:30	2.974	71.676
10/09/2015 18:00	3.097	71.553	11/09/2015 10:30	3.136	71.514	12/09/2015 03:00	2.963	71.687
10/09/2015 18:30	3.086	71.564	11/09/2015 11:00	3.137	71.513	12/09/2015 03:30	2.964	71.686
10/09/2015 19:00	3.096	71.554	11/09/2015 11:30	3.134	71.516	12/09/2015 04:00	2.958	71.692
10/09/2015 19:30	3.092	71.558	11/09/2015 12:00	3.129	71.521	12/09/2015 04:30	2.965	71.685
10/09/2015 20:00	3.092	71.558	11/09/2015 12:30	3.126	71.524	12/09/2015 05:00	2.958	71.692
10/09/2015 20:30	3.096	71.554	11/09/2015 13:00	3.110	71.540	12/09/2015 05:30	2.949	71.701
10/09/2015 21:00	3.100	71.550	11/09/2015 13:30	3.092	71.558	12/09/2015 06:00	2.960	71.690
10/09/2015 21:30	3.099	71.551	11/09/2015 14:00	3.086	71.564	12/09/2015 06:30	2.961	71.689
10/09/2015 22:00	3.103	71.547	11/09/2015 14:30	3.073	71.577	12/09/2015 07:00	2.957	71.693
10/09/2015 22:30	3.103	71.547	11/09/2015 15:00	3.063	71.587	12/09/2015 07:30	2.954	71.696
10/09/2015 23:00	3.101	71.549	11/09/2015 15:30	3.054	71.596	12/09/2015 08:00	2.959	71.691
10/09/2015 23:30	3.104	71.546	11/09/2015 16:00	3.049	71.601	12/09/2015 08:30	2.956	71.694

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
12/09/2015 09:00	2.958	71.692	13/09/2015 01:30	2.935	71.715	13/09/2015 18:00	2.919	71.731
12/09/2015 09:30	2.961	71.689	13/09/2015 02:00	2.933	71.717	13/09/2015 18:30	2.913	71.737
12/09/2015 10:00	2.956	71.694	13/09/2015 02:30	2.927	71.723	13/09/2015 19:00	2.915	71.735
12/09/2015 10:30	2.957	71.693	13/09/2015 03:00	2.934	71.716	13/09/2015 19:30	2.909	71.741
12/09/2015 11:00	2.951	71.699	13/09/2015 03:30	2.937	71.713	13/09/2015 20:00	2.913	71.737
12/09/2015 11:30	2.952	71.698	13/09/2015 04:00	2.937	71.713	13/09/2015 20:30	2.908	71.742
12/09/2015 12:00	2.954	71.696	13/09/2015 04:30	2.926	71.724	13/09/2015 21:00	2.911	71.739
12/09/2015 12:30	2.954	71.696	13/09/2015 05:00	2.929	71.721	13/09/2015 21:30	2.914	71.736
12/09/2015 13:00	2.959	71.691	13/09/2015 05:30	2.929	71.721	13/09/2015 22:00	2.914	71.736
12/09/2015 13:30	2.953	71.697	13/09/2015 06:00	2.930	71.720	13/09/2015 22:30	2.908	71.742
12/09/2015 14:00	2.949	71.701	13/09/2015 06:30	2.929	71.721	13/09/2015 23:00	2.910	71.740
12/09/2015 14:30	2.953	71.697	13/09/2015 07:00	2.926	71.724	13/09/2015 23:30	2.913	71.737
12/09/2015 15:00	2.948	71.702	13/09/2015 07:30	2.925	71.725	14/09/2015 00:00	2.902	71.748
12/09/2015 15:30	2.947	71.703	13/09/2015 08:00	2.926	71.724	14/09/2015 00:30	2.903	71.747
12/09/2015 16:00	2.944	71.706	13/09/2015 08:30	2.927	71.723	14/09/2015 01:00	2.905	71.745
12/09/2015 16:30	2.944	71.706	13/09/2015 09:00	2.926	71.724	14/09/2015 01:30	2.903	71.747
12/09/2015 17:00	2.947	71.703	13/09/2015 09:30	2.929	71.721	14/09/2015 02:00	2.905	71.745
12/09/2015 17:30	2.944	71.706	13/09/2015 10:00	2.922	71.728	14/09/2015 02:30	2.895	71.755
12/09/2015 18:00	2.951	71.699	13/09/2015 10:30	2.927	71.723	14/09/2015 03:00	2.894	71.756
12/09/2015 18:30	2.945	71.705	13/09/2015 11:00	2.930	71.720	14/09/2015 03:30	2.901	71.749
12/09/2015 19:00	2.947	71.703	13/09/2015 11:30	2.928	71.722	14/09/2015 04:00	2.900	71.750
12/09/2015 19:30	2.948	71.702	13/09/2015 12:00	2.927	71.723	14/09/2015 04:30	2.900	71.750
12/09/2015 20:00	2.946	71.704	13/09/2015 12:30	2.921	71.729	14/09/2015 05:00	2.899	71.751
12/09/2015 20:30	2.946	71.704	13/09/2015 13:00	2.923	71.727	14/09/2015 05:30	2.899	71.751
12/09/2015 21:00	2.943	71.707	13/09/2015 13:30	2.924	71.726	14/09/2015 06:00	2.902	71.748
12/09/2015 21:30	2.942	71.708	13/09/2015 14:00	2.925	71.725	14/09/2015 06:30	2.895	71.755
12/09/2015 22:00	2.940	71.710	13/09/2015 14:30	2.923	71.728	14/09/2015 07:00	2.900	71.750
12/09/2015 22:30	2.940	71.710	13/09/2015 15:00	2.925	71.725	14/09/2015 07:30	2.902	71.748
12/09/2015 23:00	2.941	71.709	13/09/2015 15:30	2.916	71.734	14/09/2015 08:00	2.902	71.748
12/09/2015 23:30	2.936	71.714	13/09/2015 16:00	2.923	71.727	14/09/2015 08:30	2.903	71.747
13/09/2015 00:00	2.933	71.717	13/09/2015 16:30	2.919	71.731	14/09/2015 09:00	2.901	71.749
13/09/2015 00:30	2.936	71.714	13/09/2015 17:00	2.911	71.739	14/09/2015 09:30	2.903	71.747
13/09/2015 01:00	2.936	71.714	13/09/2015 17:30	2.911	71.739	14/09/2015 10:00	2.904	71.746

Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)	Date & Time	WL (mbcl)	Water Level (mOD)
14/09/2015 10:30	2.906	71.744						
14/09/2015 11:00	2.901	71.749						

APPENDIX IV
DISCHARGE DATA

P1304

Garryhinch Bog Pumping Tests

Pumping Test Discharge Data

Well ID	Date / Time	Time lapsed (min)	Meter Reading (m3)	m3/hr
WH02	08/09/2015 12:10	0	3499.0	
	08/09/2015 12:30	20	3503.0	12.0
	08/09/2015 13:10	60	3510.2	10.8
	08/09/2015 14:10	120	3522.3	12.1
	08/09/2015 16:36	266	3551.5	12.0
	08/09/2015 19:38	448	3587.5	11.9
	09/09/2015 06:44	1114	3716.5	11.6
	09/09/2015 15:08	1618	3814.0	11.6
	09/09/2015 21:48	2018	3892.0	11.7
	10/09/2015 06:46	2556	3997.0	11.7
	10/09/2015 10:10	2760	4037.0	11.8
	10/09/2015 17:40	3210	4125.0	11.7
	11/09/2015 07:30	4040	4286.5	11.7
	11/09/2015 11:40	4290	4335.0	11.6
	11/09/2015 12:10	4320	4340.5	11.0
WH03	07/09/2015 19:30	0	2783.0	
	07/09/2015 19:40	10	2785.5	15.0
	07/09/2015 20:30	60	2792.5	8.4
	07/09/2015 21:00	90	2797.0	9.0
	07/09/2015 21:30	120	2802.5	11.0
	08/09/2015 07:00	690	2867.0	6.8
	08/09/2015 09:30	840	2888.0	8.4
	08/09/2015 14:30	1140	2932.5	8.9
	08/09/2015 16:00	1230	2944.0	7.7
	09/09/2015 07:56	2186	3041.5	6.1
	09/09/2015 14:46	2596	3081.0	5.8
	09/09/2015 17:08	2738	3094.0	5.5
	09/09/2015 22:20	3050	3123.5	5.7
	10/09/2015 07:00	3570	3172.0	5.6
	10/09/2015 11:20	3830	3197.5	5.9
	10/09/2015 19:16	4306	3242.0	5.6
	10/09/2015 19:30	4320	3243.0	4.3