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A19.9

Barrier Effect Assessment with Visual Modflow Software: Seatown-Fosterstown, Dardistown, and O'Connell St.

BARRIER EFFECT ASSESSMENT WITH VISUAL MODFLOW SOFTWARE. SEATOWN-FOSTERSTOWN. DARDISTOWN. O'CONELL

PROJECT:	**METROLINK. CHARLEMONT STATION (DUBLIN, IRELAND)**
REF.:	**EGINF55-02/21. REV.:01**
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Review Date EGINF123-16/09/20

ED.	DATE	GEN.	REV.	APP.	DETAILS OF ISSUE
0	27/02/2021	CMG/RSS	RSS		Issued for Information
1	31/03/2021	CMG/RSS	RSS		Issued for Information

NOTES

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1 INTRODUCTION

Due to the construction of diaphragm walls below the current ground level, we must consider the position of the groundwater level inside the ground for two reasons. First, its impact on the design and execution of the projected works must be considered. Secondly, the continuity of the groundwater level on both sides of the alignment must be ensured once the works have been completed in order not to create waterproof barriers that interrupt the flow. The hydrogeological conditions of the study area must be analysed and the appropriate corrective measures must be planned in the event of changes in the groundwater level are introduced.

The sectors of the MetroLink alignment where the barrier effect has been studied are the reference sections where the tunnel will be built with the cut & cover system:

- **Sector between Seatown and Fosterstown with diaphragm walls**
- **Dardistown sector with diaphragm walls**
- **O'Conell Street Station**

To carry out this study, as a starting point, the project is available (add information available from the GSI, etc.)

- MetroLink Phase 1 Ground Investigation (Final Report). Report No.: 18-1076. Date: November 2019. Author: Causeway Geotech
- Old Metro North Ground Investigation.
- Geological Survey Ireland Spatial Resources.
- Geotechnical Design Report, Document No.:ML1-JAI-GEO-ROUT_XX-RP-Y-00004. Revision: P04.1. Date:16/04/2020. Author: JACOBS-IDOM
- Geotechnical Drawings: ML1-JAI-GEOT-ROUT_XX-M2-Y-00021
- Pumping Test: MetroLink-R132 Swords- North& South Areas, Swords Road and Portal 2
- Sections Drawings: Book 2- Alignment & Sections, ML1-JAI-RTA-SC**_XX-DR-Y-04000 (where ** are values from 01 to 16)
- Geological Survey Ireland data and maps.

The calculations have been made using **Visual MODFLOW** software. This software simulates the groundwater flow or, more precisely, the evolution of the levels under specific conditions. The software performs a saturated flow 3D model using the finite difference method.

2 MATHEMATICAL MODEL

2.1 INTRODUCTION

Given the existing hydrogeological subsoil conditions and the modifications induced by the construction of the projected MetroLink, a numerical simulation has been considered necessary to assess the possible effects and the effectiveness of the corrective measures proposed and pre-dimensioned by an analytical calculation method.

Specifically, the possible effects that could foreseeably occur in relation to the groundwater flow are linear and affect relatively large areas. Furthermore, these effects have relevant implications in the operation of the hydrogeological systems traversed. Linear conditions can produce permanent modifications of the groundwater flow. Changes in groundwater flow occur when permanent barriers or semi-barriers are created because they reduce the section through which the groundwater flows. These barriers are generated by the diaphragm walls of the tunnel and the stations. Creating barriers could have the following effects:

- "Stagnation" effect. Elevation of the piezometric level produced upstream of the generated barrier or semi-barrier.
- "Reservoir" effect. It will be produced on the generated semi-barrier.
- "Lamination" effect. Reduction produced in the groundwater circulation flow downstream of the generated barrier o semi-barrier. Furthermore, a rise in the piezometric level will occur in the areas where the flow rate increases.

On the other hand, the lowering of groundwater level in areas with highly deformable materials can generate significant settlements. This may affect the stability of nearby buildings.

For these reasons, modification of the hydraulic regime should be avoided as far as possible. This can be controlled by a wide piezometer network.

2.2 CONCEPTUAL MODEL

The first step in hydrogeological modelling is the development of a conceptual model. A conceptual model is a simplified representation that includes the definition of the study domain, boundary conditions, sources, and areas of the different materials.

In addition, the recharge of each area, the permeabilities of each layer, etc… must be quantified.

The conceptual model must represent the area conditions that can influence the result as closely as possible and also in the most simplified way possible.

The next step is to build a numerical model with the information stored in the conceptual model. In order to do this, we must follow the next instructions.

1. Identify the different local sources and drains in the model. Define the boundary conditions: rivers, lakes, flow barriers ...
2. Identify recharge and evapotranspiration areas.
3. Define the different permeabilities for each material
4. Make a first simplified estimation of the model mesh.
5. Refine the model mesh, develop the model, run it and calibrate it.

It is often necessary to repeat some steps of the process.

The requirements of the conceptual model are met and presented under **Section 4**.

2.3 DESCRIPTION OF THE MODFLOW PROGRAM

The Visual MODFLOW software has been used to model this problem. Specifically, version 4.6 of the software developed by Waterloo Hydrogeologic.

The Visual MODFLOW package is a pre-processor and a postprocessor for three different software products: MODFLOW, Modpath and MT3D. It allows you to enter input data intuitively and display the analysis results graphically.

MODFLOW is a 3D finite difference program for saturated soils and it was developed by United States Geological Survey. The program is divided into a series of packages that develop specific tasks. The pre-processor generates the data input files for each package.

The algorithm used is applicable in the following cases:

- Saturated flow

- Porous medium
- Constant temperature and density

This program works with finite element model where you can define waterproof barriers that simulate interference with diaphragm walls.

3 LIMITS AND GRID OF MODELS

To simulate the hydraulic behaviour in the porous materials that intersect the diaphragm walls, a large-scale hydrogeological model is developed.

Different scenarios will be modelled. First, the current state will be carried out and then the different future states. Comparing the results obtained, the interferences of the projected works with flow can be observed.

To delimit the modelling domains, the following guidelines have been considered:

- The sea water sheet (eastern part of the models) supposes an unlimited source of water, which translates into a constant height of the water sheet
- The flow is produced towards the sea, admitting it as a discharge edge.
- In the lateral direction, the limits of the model have been made to coincide with individual flow lines.
- The river simulation is carried out through the module integrated in Visual MODFLOW, RIV: River package
- The permeability of diaphragm walls is very low therefore they represent a horizontal barrier to the groundwater flow.

Gravels are considered to constitute a semi-confined aquifer arranged on healthy rock.

Three different hydraulic models have been made where the following stations have been studied:

- Seatown-Swords Central-Fosterstown.
- Dardistown.
- O’Connell Street Station

Each model has been made in a rectangular area delimited by the following coordinates:

<table>
<tr><th rowspan="2">STATION</th><th colspan="2">Lower left corner</th><th colspan="2">Upper right corner</th></tr>
<tr><th>X</th><th>Y</th><th>X</th><th>Y</th></tr>
<tr><td>Seatown-Swords</td><td>683846</td><td>5925552</td><td>686726</td><td>5927827</td></tr>
<tr><td>O'Connell</td><td>681861</td><td>5914322</td><td>682737</td><td>5915184</td></tr>
<tr><td>Dardistown</td><td>681504</td><td>5921143</td><td>683408</td><td>5922468</td></tr>
</table>

Table 3-1. UTM coordinates of the limits of each model

The following figures show the limits with UTM coordinates of each model:

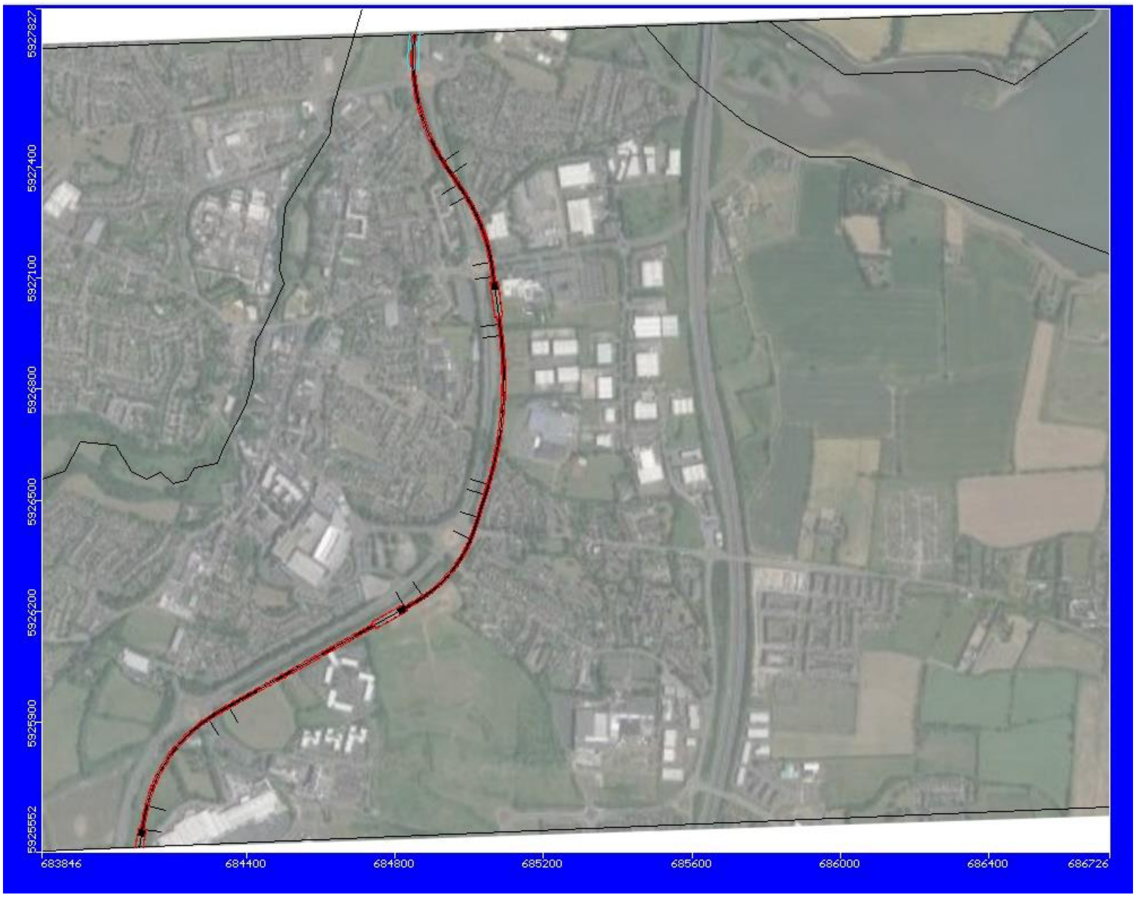

Figure 3-1. MODFLOW Model Extensions Seatown-Fosterstown

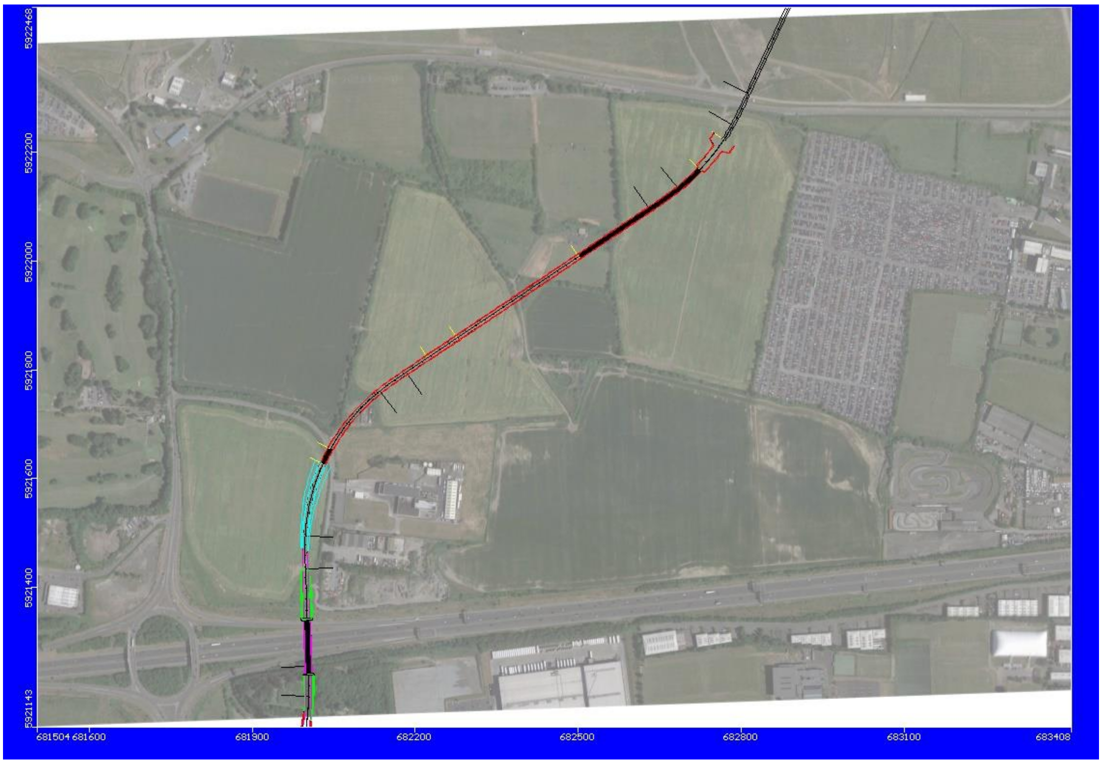

Figure 3-2. MODFLOW Model Extensions Dardistown

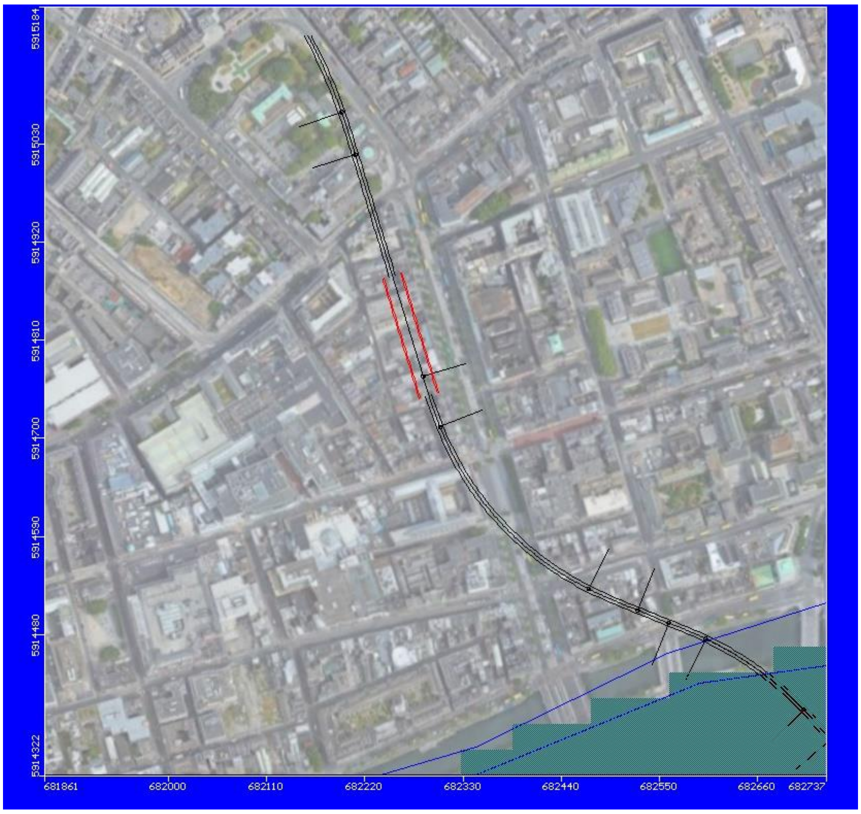

Figure 3-3. MODFLOW Model Extensions for O'Conell

These surfaces are meshed in a 100 m side grid, which is later refined in the areas where it is necessary. Specifically, in the study areas, the calculation grid is 20x20 m cells near the alignment and in the control section and Head Observation Wells it is 10x10 m.

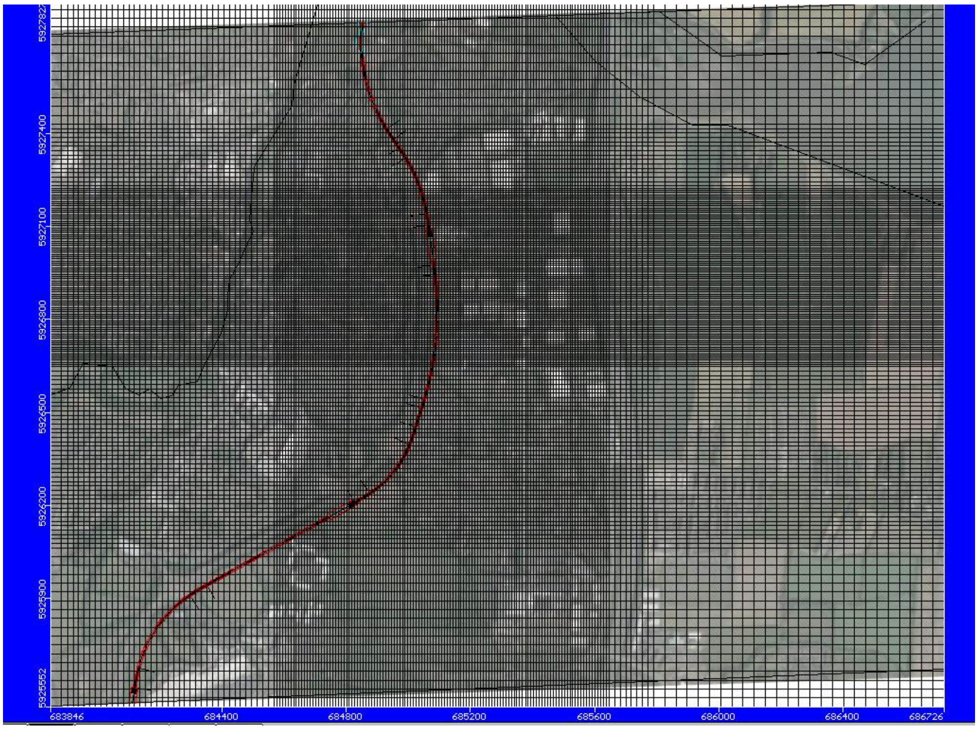

Figure 3-4. Model Grid. Seatown-Fosterstown

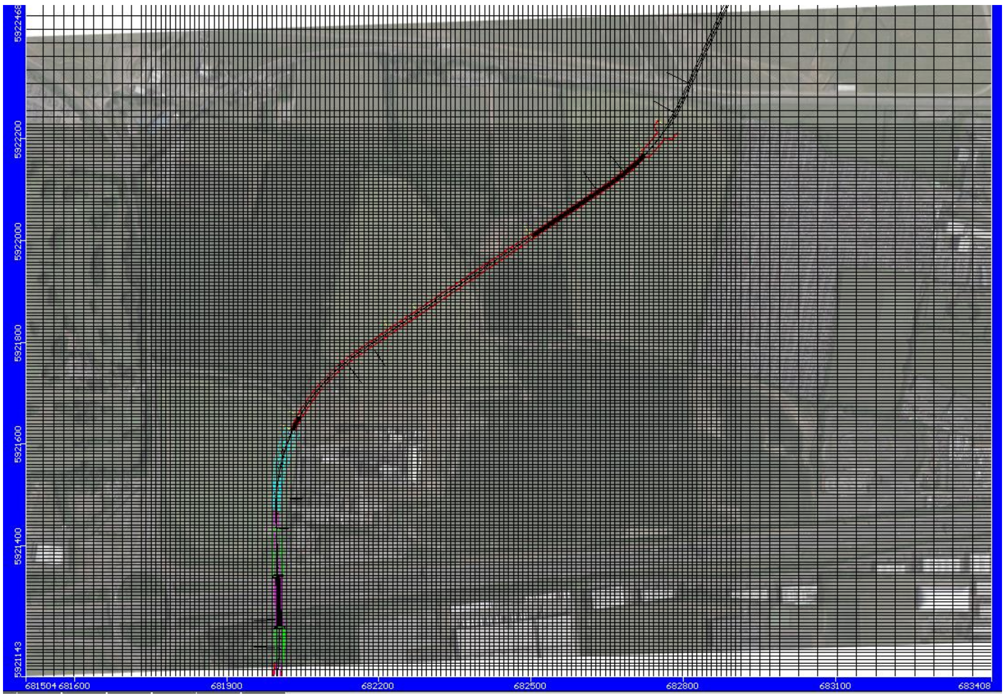

Figure 3-5. Model Grid. Dardistown

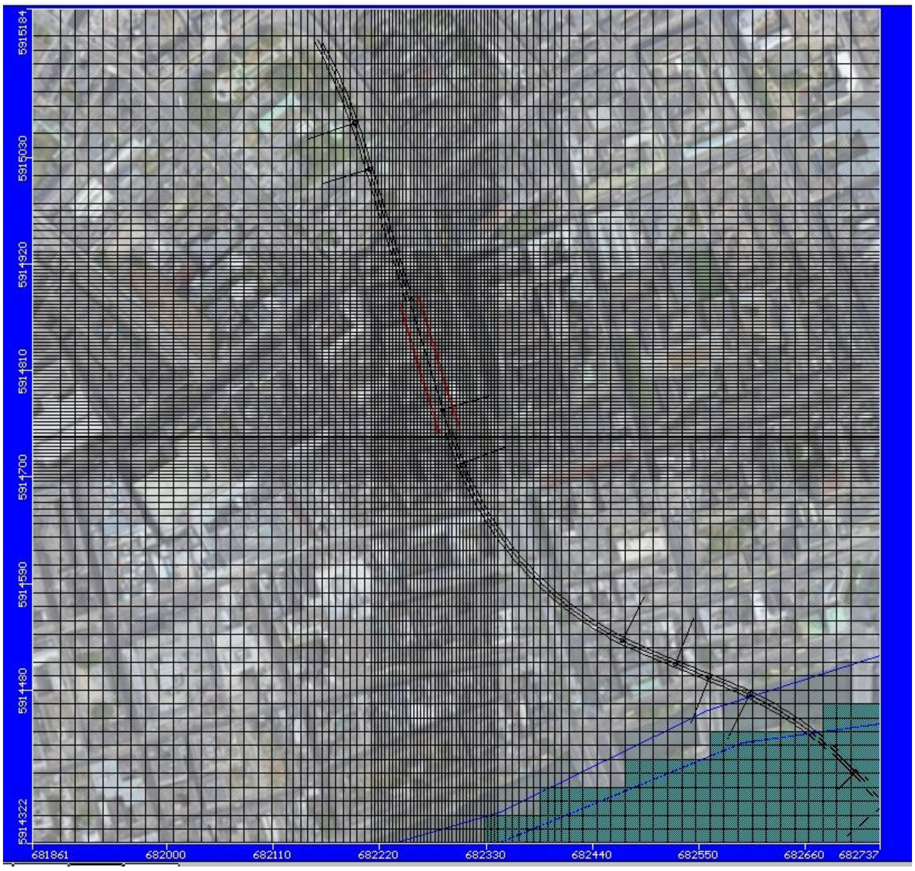

Figure 3-6. Model Grid. Seatown-Fosterstown

4 INPUT DATA

As input data, topographic, stratigraphic and groundwater level data from geotechnical survey boreholes have been collected. In addition, the information available from the **Geological Survey Ireland Spatial Resources** has been used.

The list of boreholes used by the GIS for each study area are shown in the tables that are included in the following sections.

4.1 INITIAL CONDITIONS

The following initial conditions have been included for each model:

- A fixed elevation of the water table is established for the sea water surface.
- In the lateral direction, the limits of the model have been made to coincide with individual flow lines.

- The Ward river is introduced into the Seatown-Fosterstown model adjusted to the terrain topography using the MODFLOW module. A bottom thickness equal to 1 m has been assigned with a mean conductance of 50 m^2/d. The width of the river adopted is 10 m
- A minimum distance from the central part of the MetroLink alignments to the edges of 300 m has been established, so it is far enough away not to affect the study area.
- To establish the initial piezometry of the model, the reading of the phreatic level of the available wells, both from the project and from the GSI, has been taken as a reference.

4.2 STRATIGRAPHY

For hydrogeological modelling, subsurface component materials have been grouped into three categories.

- The Dublin Boulder Clay (DBC). The primary superficial deposit overlying bedrock in Dublin
- Base of drift deposits with top weathered rock. Composed of sand and gravel layers with erratic boulders.
- Rock Base

Specifically, for each area studied:

STATION	DBC	Gravel	Rock Mass
Seatown-Fosterstown	QBR-QBL	BoD	CMUP-CMLO
O'Connell	QBL	BoD	CTO
Dardistown	QBR	BoD	CLU

Table 4-1. Stratigraphy assigned to each sector

Information about the height of the different layers is included in the Table 4-2, Table 4-3 and Table 4-4

The following figures show a 3D view of the terrain layers generated in each model, the assignment of permeabilities and the topographic plan of each one of them.

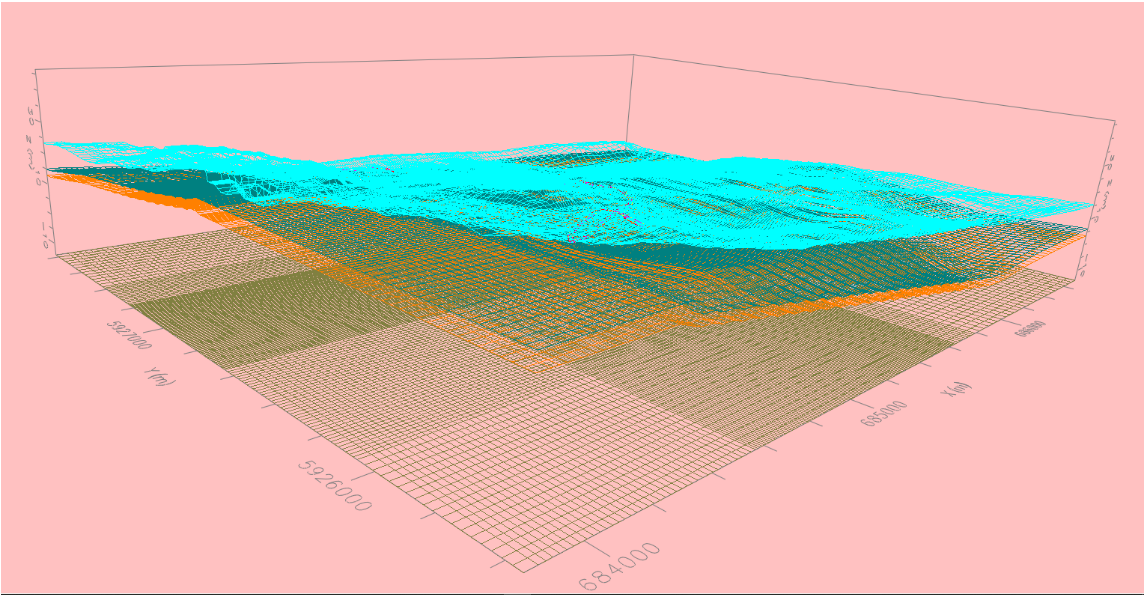

Figure 4-1. Stratigraphy: 3D Grid of the different levels. Seatown-Fosterstown Sector

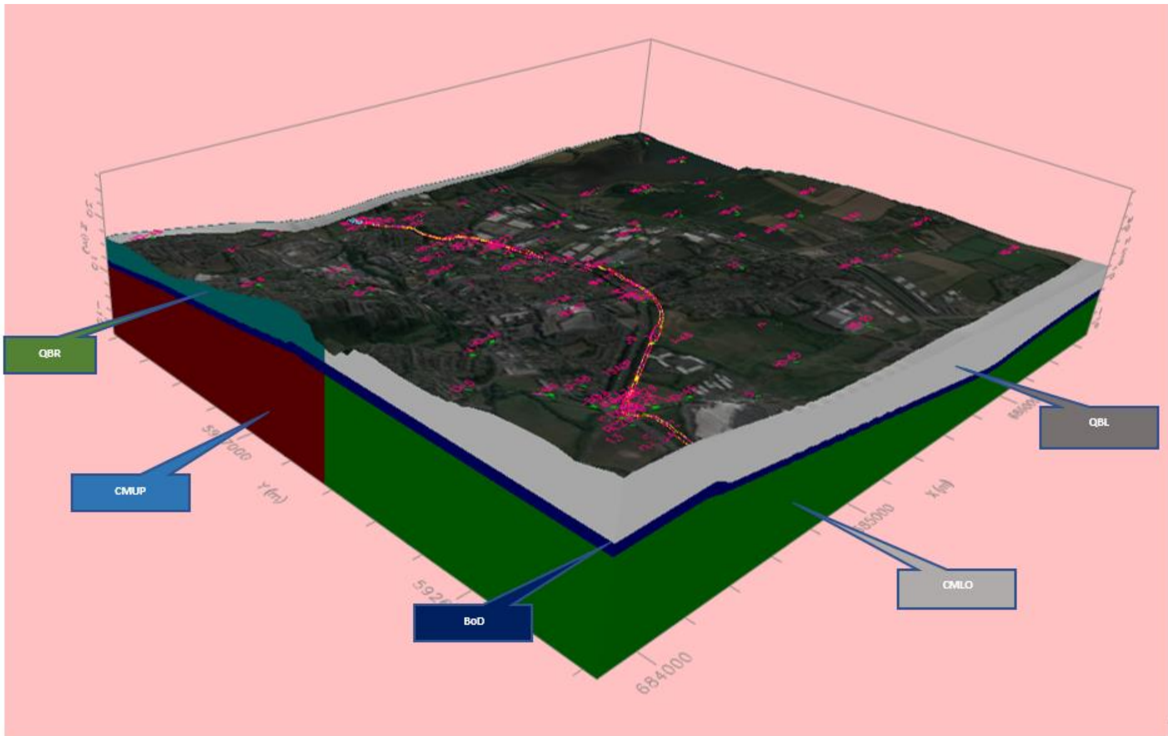

Figure 4-2. Stratigraphy: 3D view of the different levels and permeabilities. Seatown-Fosterstown Sector

Figure 4-3. Cut by alignment: 3D view of the different levels and permeabilities. Seatown-Fosterstown Sector

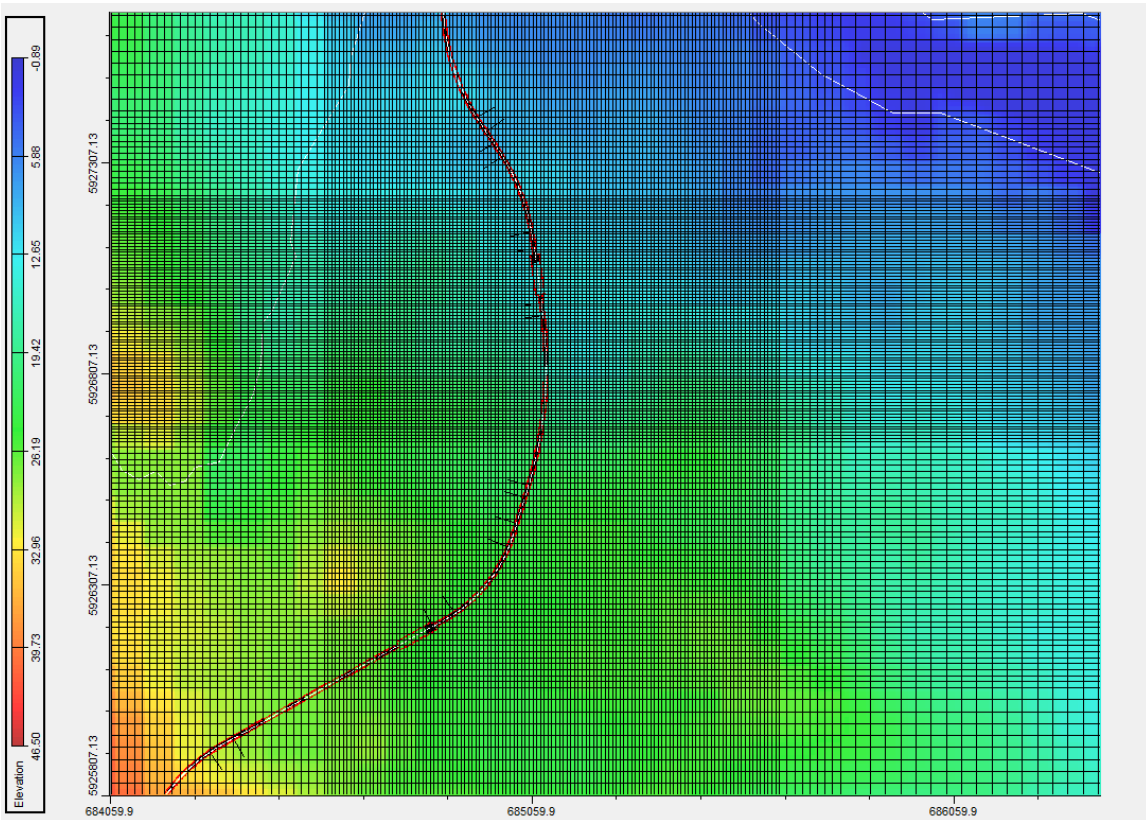

Figure 4-4. Topographic surface. Seatown-Fosterstown Sector

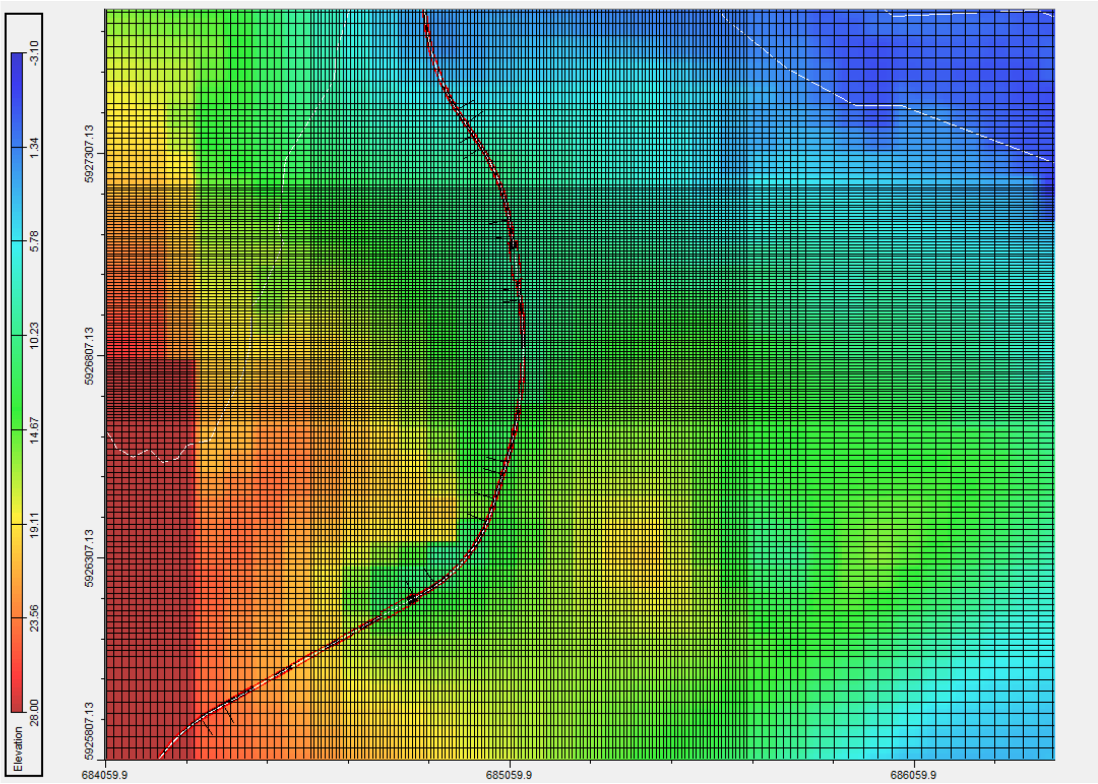

Figure 4-5. Upper surface level of the BoD. Seatown-Fosterstown Sector

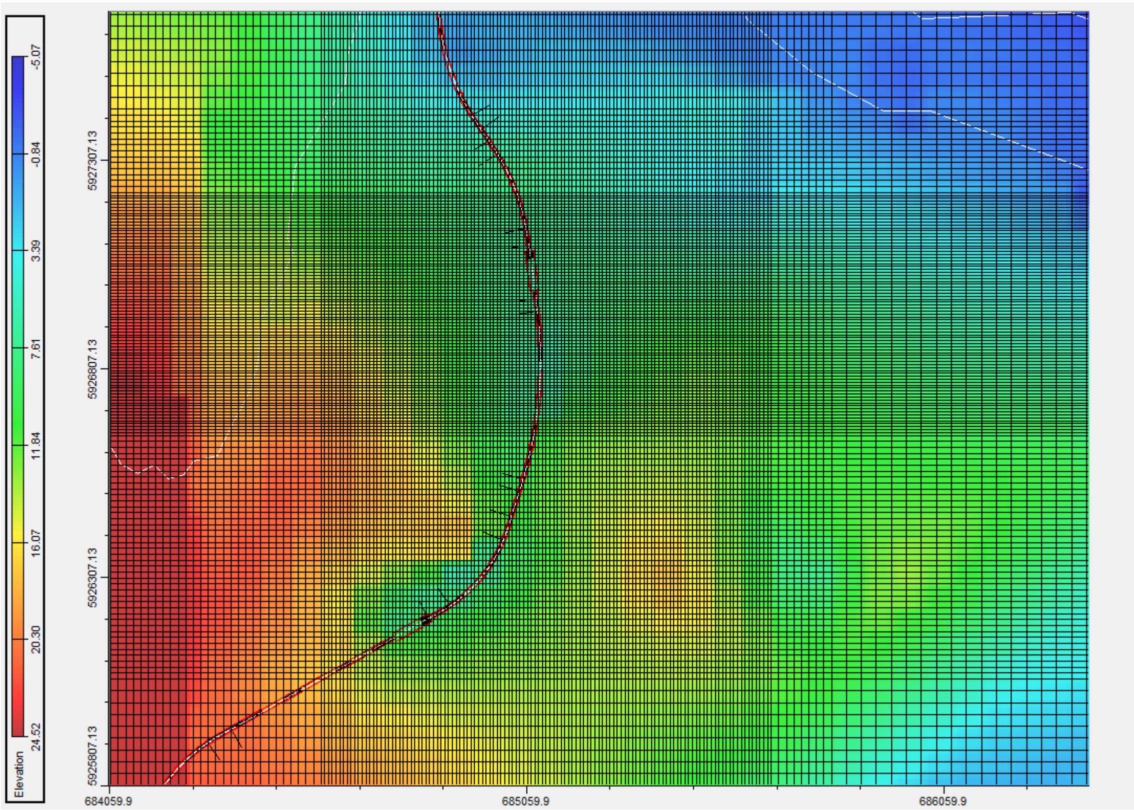

Figure 4-6. Upper surface level of the Bedrock. Seatown-Fosterstown Sector

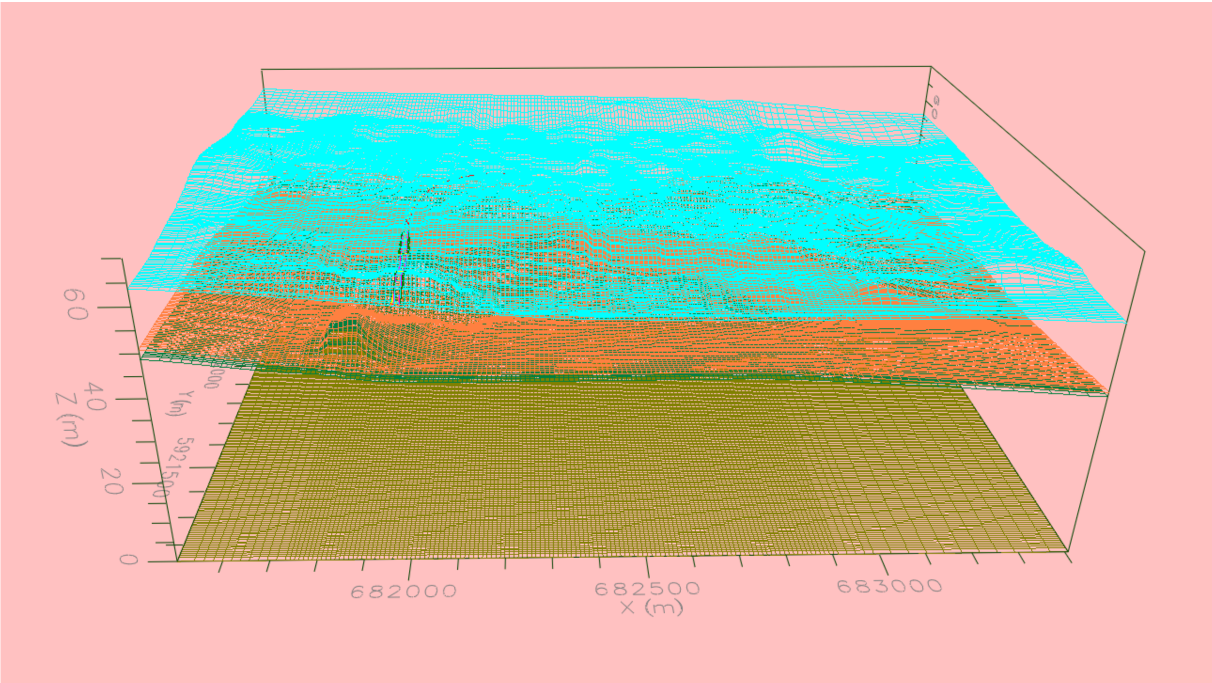

Figure 4-7. Stratigraphy: 3D Grid of the different levels. Dardistown Sector

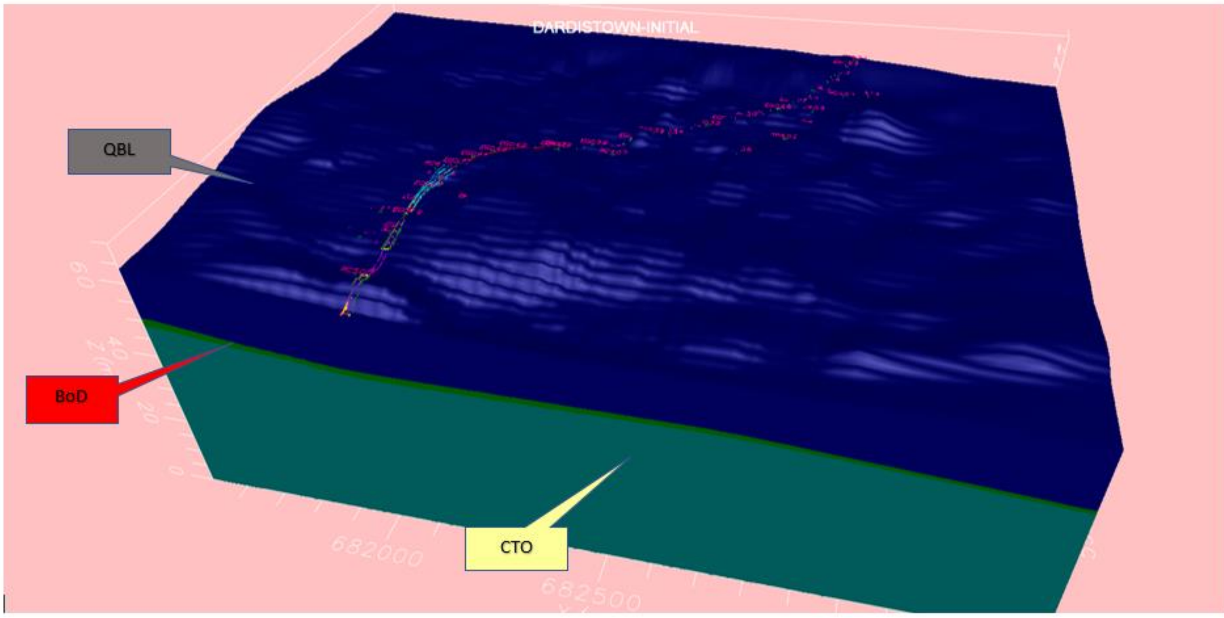

Figure 4-8. Stratigraphy: 3D view of the different levels and permeabilities. Dardistown Sector

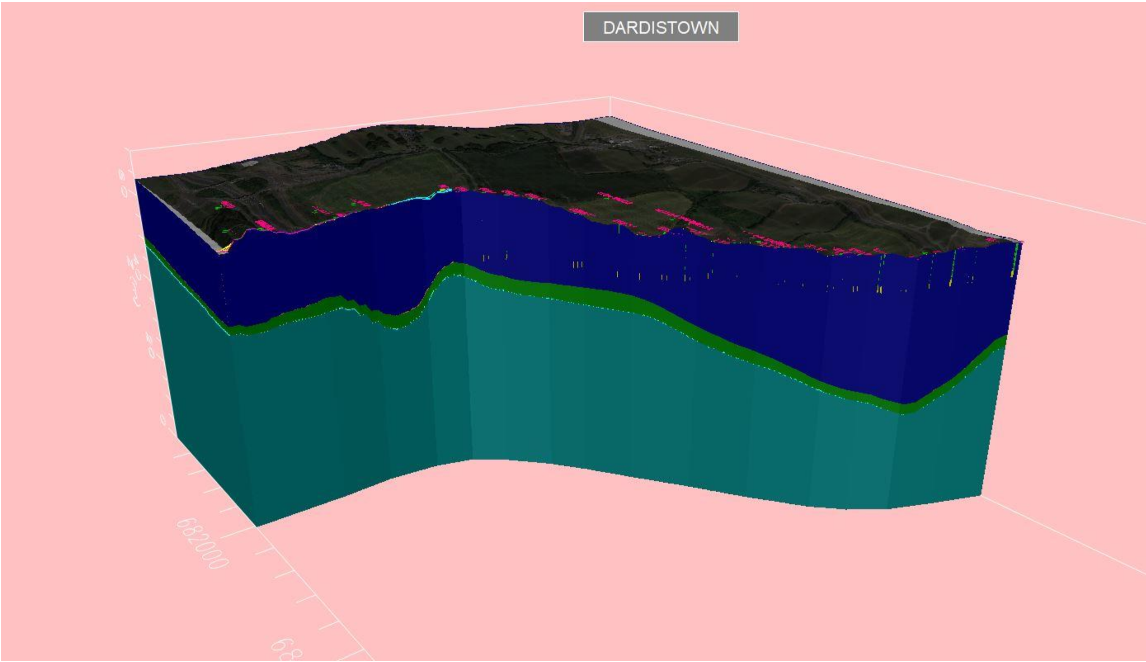

Figure 4-9. Cut by alignment: 3D view of the different levels and permeabilities. Dardistown Sector

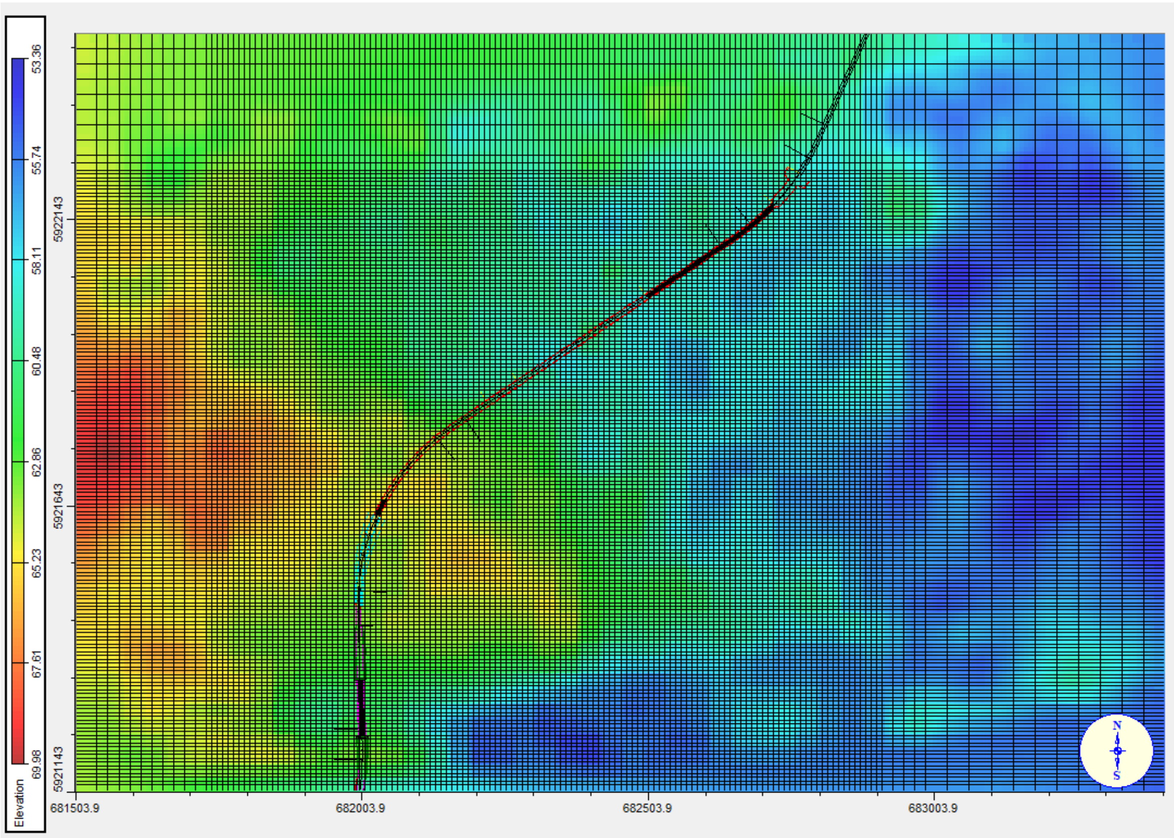

Figure 4-10. Topographic surface. Dardistown Sector

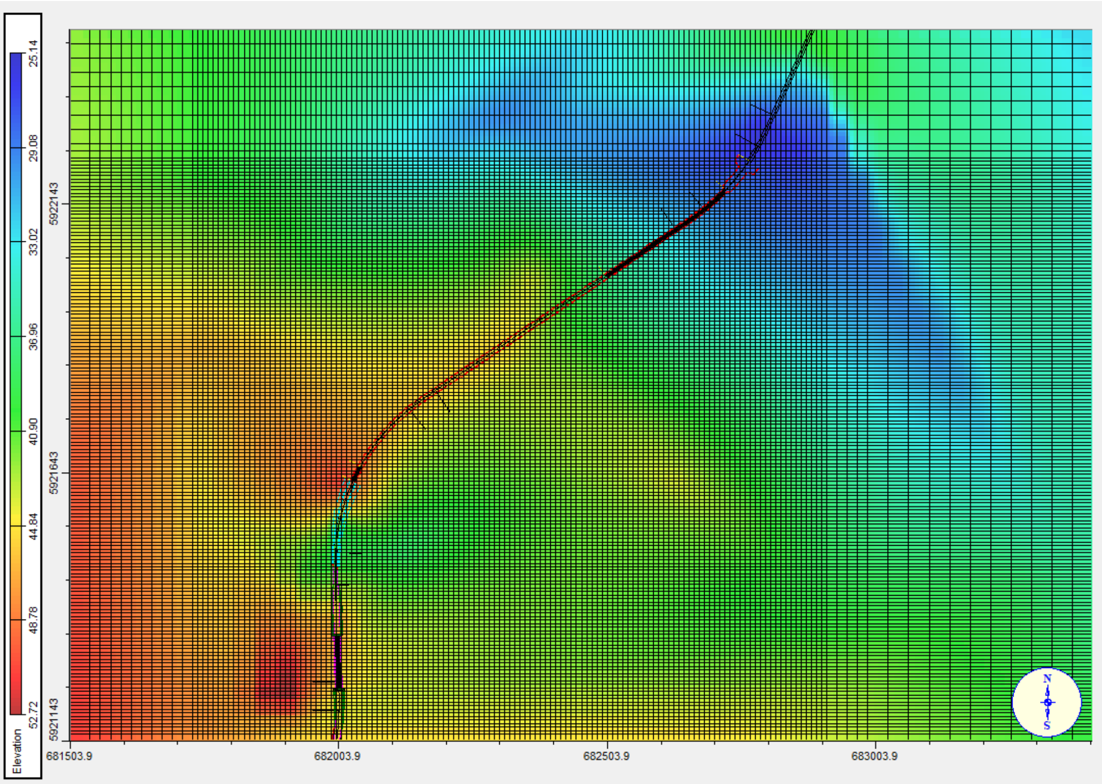

Figure 4-11. Upper surface level of the BoD. Dardistown Sector

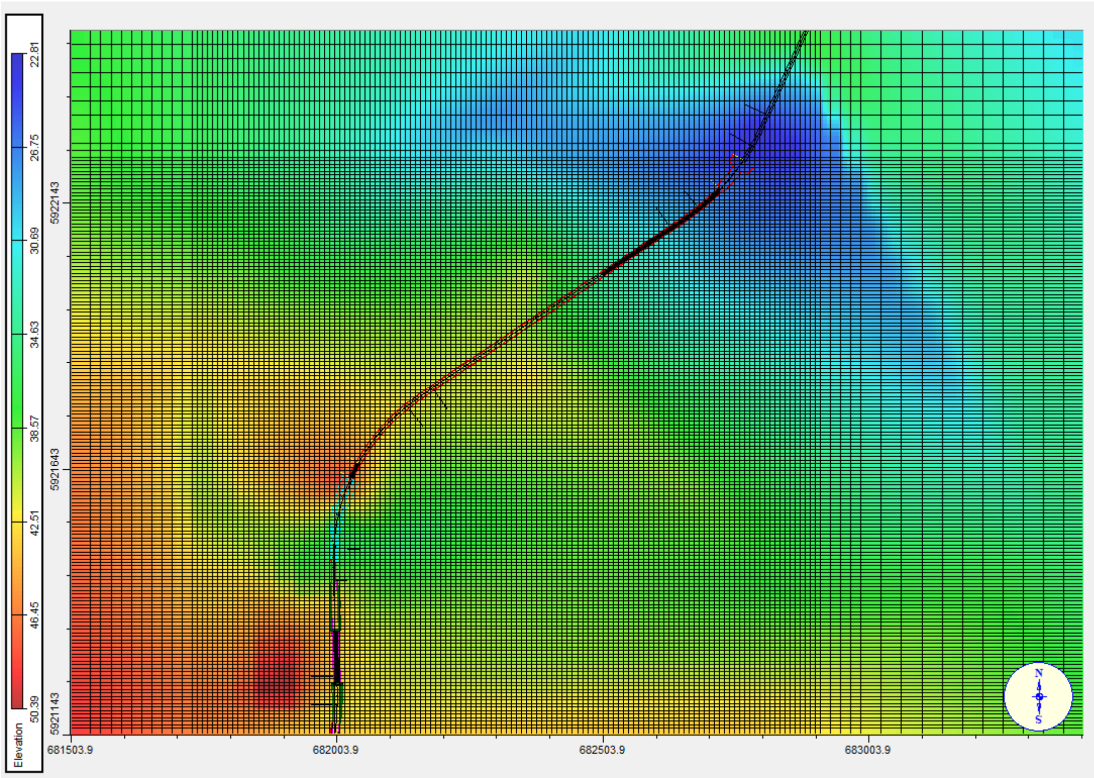

Figure 4-12. Upper surface level of the Bedrock. Dardistown Sector

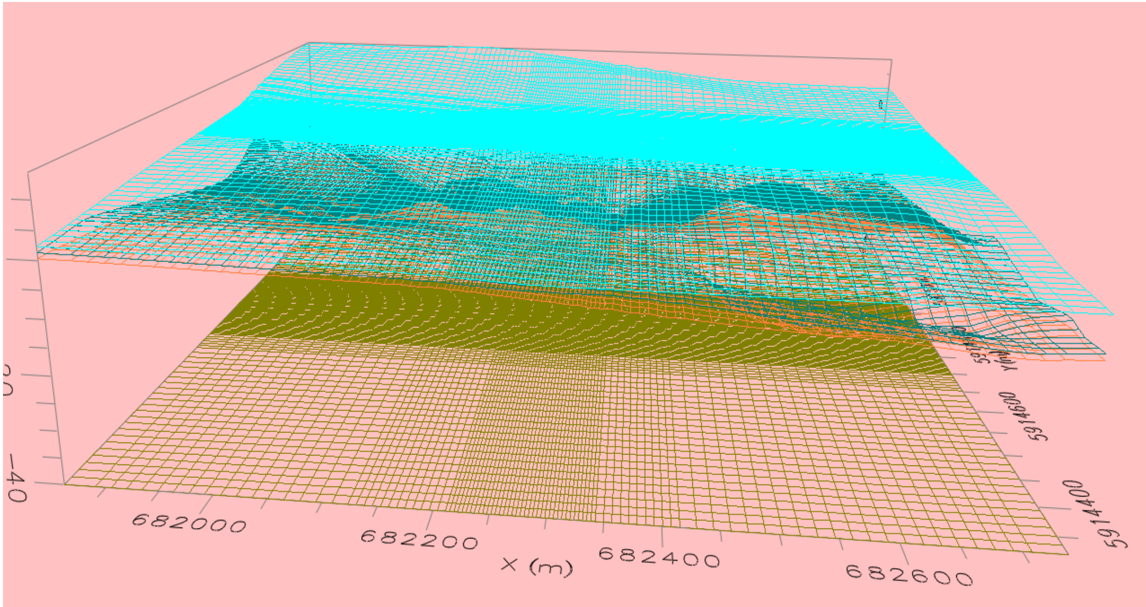

Figure 4-13. Stratigraphy: 3D Grid of the different levels. O'Conell Sector

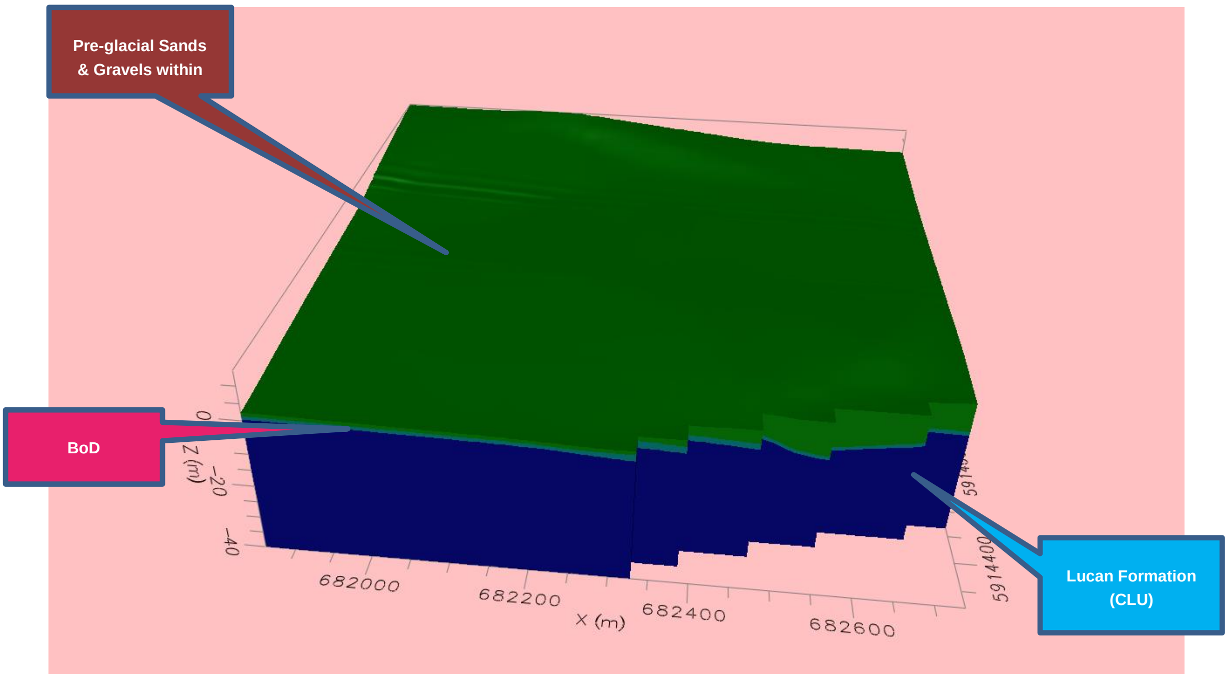

Figure 4-14. Stratigraphy: 3D view of the different levels and permeabilities. O'Conell Sector

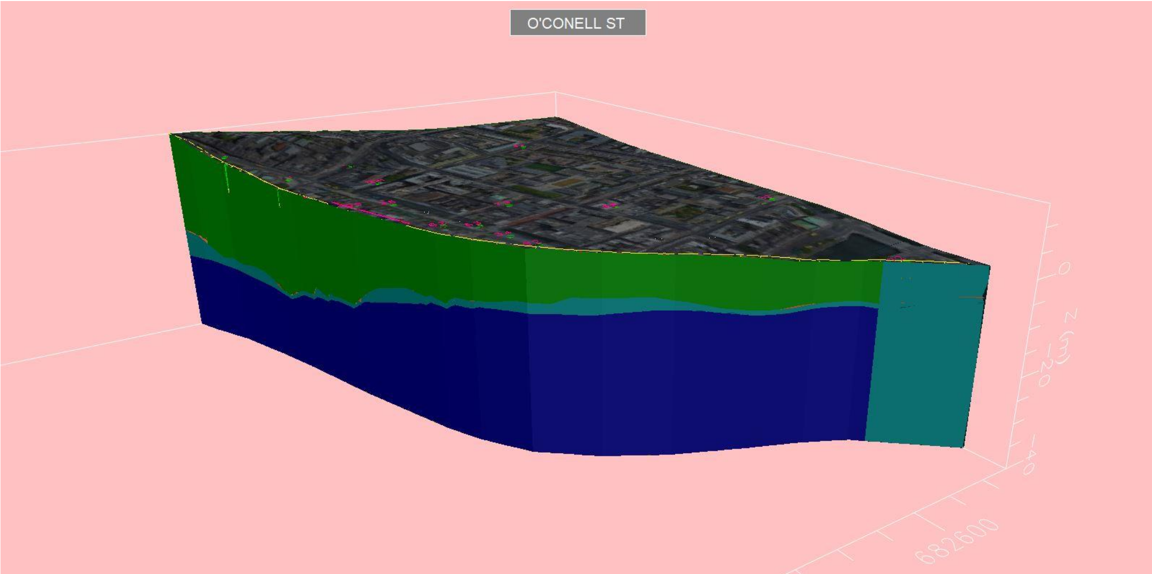

Figure 4-15. Cut by alignment: 3D view of the different levels and permeabilities. O'Conell

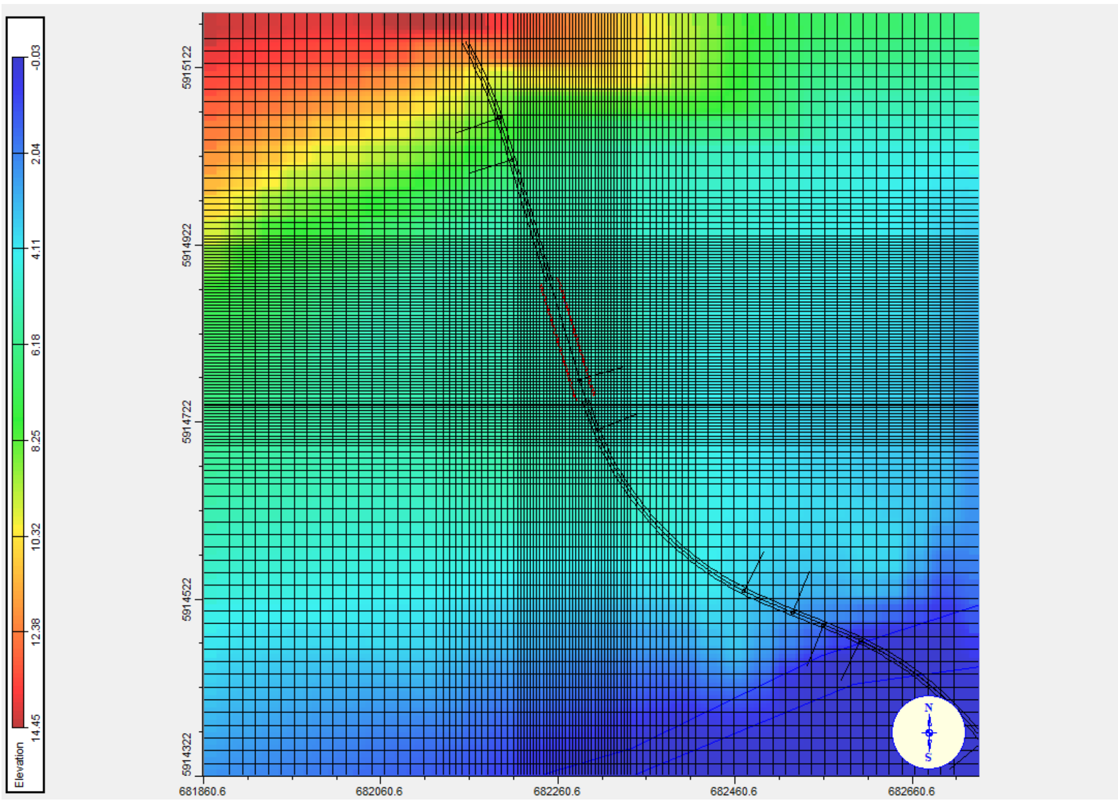

Figure 4-16. Topographic surface. O'Conell Sector

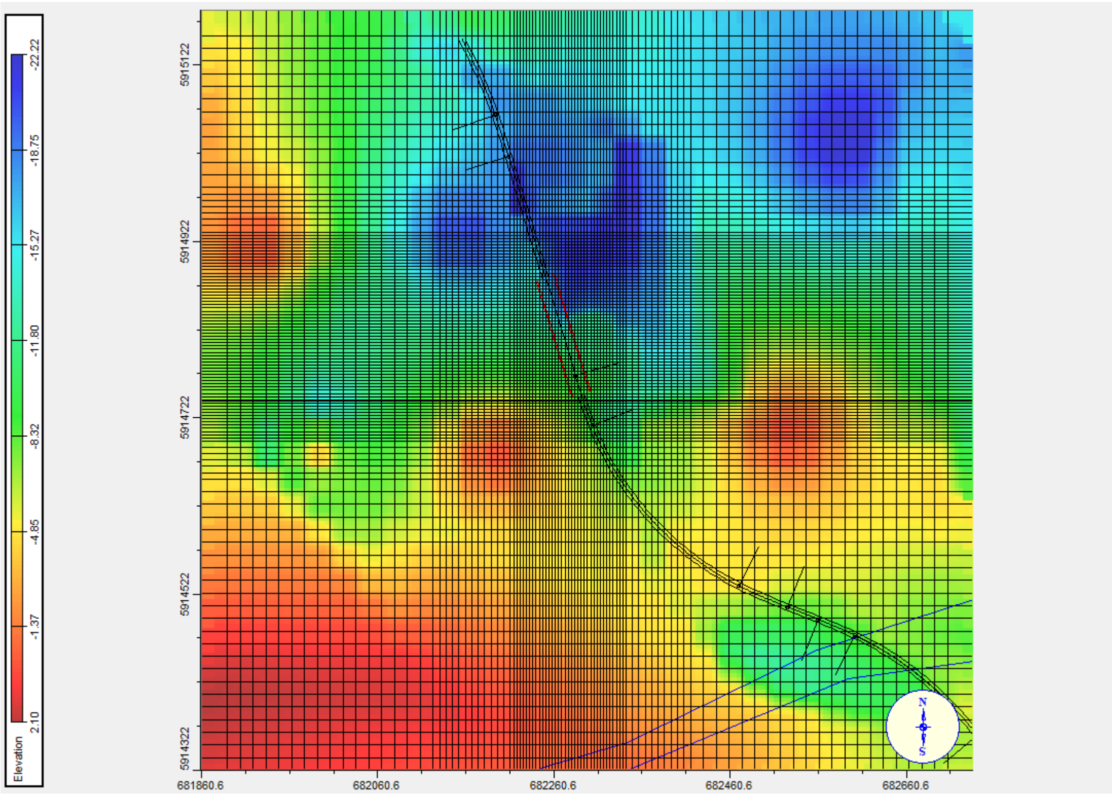

Figure 4-17. Upper surface level of the BoD. O'Conell Sector

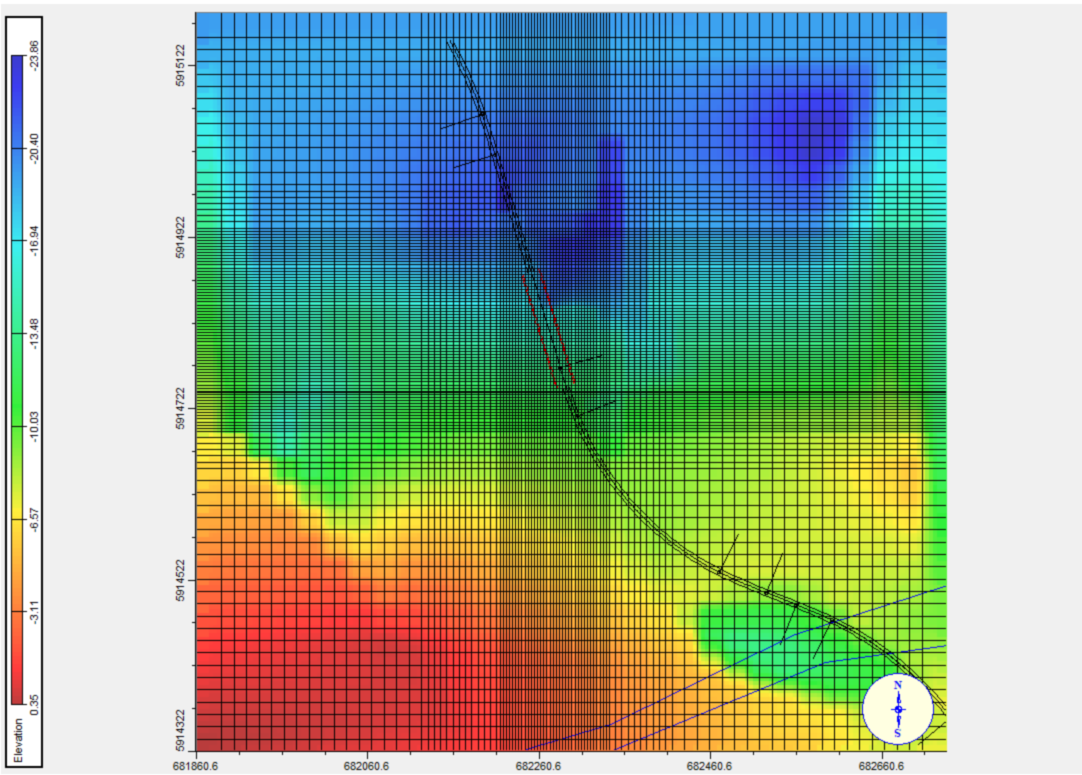

Figure 4-18. Upper surface level of the Bedrock. O'Conell Sector

The tables that collect the boreholes used in each model to generate the ground layers and the initial heads are included below (initial piezometry prior to the first calculation step)

Seatown-Fosterstown Sector

FID	Source	Register	UTM29N_Eas	UTM29N_Nor	Ground Level	BoD Level	Rock Level	Water Table
1	GSI	R5516/B134352	684,477.95	5,926,516.71	26.00	24.50	22.00	26.00
2	GSI	R4509/B126224	684,590.13	5,926,776.27	23.00	20.50	18.00	19.40
3	GSI	R90/B51059	684,408.54	5,927,101.76	18.00	16.50	14.00	18.00
4	GSI	R4188/B121314	684,467.03	5,927,281.61	15.00	12.50	10.00	15.00
5	GSI	R86/B51045	684,251.73	5,926,160.45	30.00	25.00	22.50	27.80
6	GSI	R5521/B134377	684,672.87	5,925,726.30	28.00	22.50	20.00	24.60
7	GSI	R3103/B100376	685,678.97	5,925,728.41	22.00	9.50	7.00	22.00
8	GSI	R3104/B100389	685,724.56	5,926,328.13	21.00	8.50	6.00	21.00
9	GSI	R3071/B95137	685,584.58	5,927,252.28	7.00	4.50	2.00	4.63
10	GSI	R3079/B95263	685,611.54	5,927,397.68	11.00	8.50	6.00	6.06
11	GSI	R371/B58222	685,310.15	5,927,565.47	7.00	4.50	2.00	4.50
12	GSI	R2917/B93226	685,208.80	5,927,018.98	13.00	10.50	8.00	11.80
13	GSI	R6184/B140251	686,601.18	5,926,862.50	10.00	7.50	5.00	10.00
14	GSI	R6494/B142847	683,983.68	5,925,662.62	45.00	42.50	40.00	42.40
15	GSI	R1044/B63601	684,295.90	5,927,574.24	18.00	16.00	13.50	18.00
16	GSI	R3610/B109266	684,306.48	5,927,390.37	15.00	12.70	10.20	15.00
17	GSI	R354/B55474	685,304.82	5,927,375.37	9.00	6.50	4.00	5.90
18	GSI	R1051/B63639	685,153.79	5,926,663.16	20.00	15.00	12.50	14.60
19	GSI	R3079/B95259	685,615.21	5,926,922.67	14.00	12.50	10.00	11.80
20	GSI	R3079/B95263	685,792.66	5,927,462.23	4.00	1.50	-1.00	3.44
21	GSI	R7593/B169388	685,920.17	5,925,644.79	21.00	2.50	0.00	21.00
22	GSI	R3079/B95246	685,950.91	5,926,305.30	18.00	16.30	13.80	18.00
23	GSI	R5108/B130779	685,386.95	5,926,297.39	26.00	20.50	18.00	23.60
24	GSI	R3417/B105862	685,521.95	5,926,583.32	23.00	15.50	13.00	23.00
25	GSI	R3158/B101469	685,500.11	5,926,786.04	18.00	15.50	13.00	18.00
26	GSI	R6184/B140239	686,654.48	5,927,055.27	6.00	3.50	1.00	6.00
27	GSI	R6184/B140254	686,710.19	5,926,720.01	14.00	12.00	9.50	14.00
28	GSI	R46/B50439	684,891.88	5,926,369.45	27.00	24.50	22.00	24.90
29	GSI	R3079/B95239	685,715.52	5,926,045.97	19	14	11.5	19
30	Project	BH204	684,052.83	5,925,581.05	44.989	27.879	25.269	35.104
31	Project	RC203	684,100.57	5,925,608.55	44.792	27.937	25.382	34.567
32	Project	RC202	684,054.91	5,925,695.46	45.176	27.766	24.651	41.961
33	Project	RC145	684,078.87	5,925,747.67	43.7064	26.6064	23.5064	40.2264
34	Project	RC201	684,146.12	5,925,728.40	43.087	26.322	23.262	39.112
35	Project	RC128	684,187.58	5,925,802.71	35.282	25.442	21.702	32.127

FID	Source	Register	UTM29N_Eas	UTM29N_Nor	Ground Level	BoD Level	Rock Level	Water Table
36	Project	BH66	684,260.63	5,925,913.70	30.682	25.282	20.437	27.827
37	Project	BH126	684,264.35	5,925,953.55	29.95	25.05	20.54	27.805
38	Project	BH125ACP	684,319.43	5,925,913.34	29.543	24.318	20.578	27.648
39	Project	BH125	684,326.63	5,925,917.39	29.739	24.589	20.834	27.844
40	Project	BH125A	684,326.70	5,925,918.65	29.742	24.692	20.772	27.757
41	Project	RC124	684,369.28	5,925,951.64	28.334	23.434	21.164	25.879
42	Project	BH123ACP	684,453.37	5,926,060.38	27.495	21.605	18.125	25.925
43	Project	BH139	684,625.57	5,926,156.49	26.933	19.478	16.338	25.423
44	Project	RC122	684,711.66	5,926,141.75	25.457	15.362	12.472	24.417
45	Project	RC121	684,739.69	5,926,220.30	25.571	9.521	5.726	23.581
46	Project	BH120	684,885.63	5,926,344.26	24.853	7.208	3.468	17.133
47	Project	BH119	684,926.72	5,926,346.86	24.389	7.634	3.694	16.134
48	Project	RC119	684,926.72	5,926,346.86	24.389	7.634	3.694	16.134
49	Project	RC67	684,950.07	5,926,388.71	24.301	7.546	3.606	17.416
50	Project	BH67	684,950.07	5,926,388.71	24.301	12.121	7.826	17.416
51	Project	RC118	684,974.58	5,926,435.40	23.421	15.136	11.346	18.256
52	Project	BH117	684,997.95	5,926,552.90	20.608	10.468	7.978	15.468
53	Project	BH129ACP	685,015.09	5,926,648.88	21.565	12.815	9.205	17.795
54	Project	RC127	685,082.42	5,926,717.14	18.213	9.208	5.263	13.138
55	Project	RC116	685,094.75	5,926,827.06	15.053	9.523	4.583	11.793
56	Project	RC114	685,085.56	5,926,935.33	13.211	9.026	7.241	12.461
57	Project	RC113	685,004.26	5,927,087.33	12.405	9.08	6.865	9.16
58	Project	RC113A	685,003.53	5,927,087.63	12.371	9.046	6.831	9.121
59	Project	RC68	685,034.55	5,927,115.35	11.644	9.094	7.244	8.644
60	Project	RC111	685,017.51	5,927,277.19	11.317	10.472	8.057	7.317
61	Project	BH109	684,897.66	5,927,578.33	8.008	0.938	-0.662	2.5
62	Project	RC69	684,887.11	5,927,624.55	7.961	2.311	0.761	2.961
63	Project	BH69	684,887.11	5,927,624.55	7.961	2.311	0.761	2.961
64	Project	RC108	684,837.22	5,927,670.47	7.964	2.164	1.114	3.1

Table 4-2. Boreholes. Seatown-Fosterstown Sector

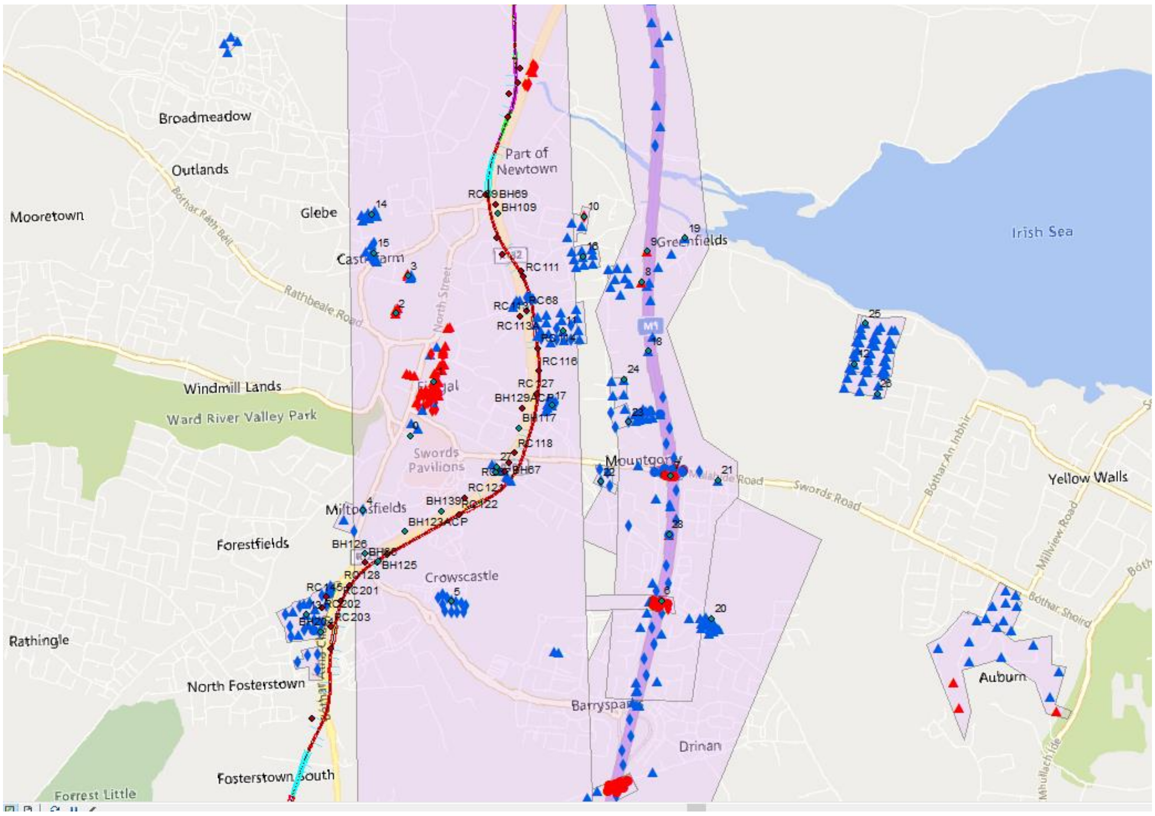

Figure 4-19. Data log available in the Seatown-Fosterstown Sector (Geological Survey Ireland Spatial Resources, Old Metro North and Project Log Data)

Dardistown Sector

FID	Source	Register	UTM29N_Eas	UTM29N_Nor	Ground Level	BoD Level	Rock Level	Water Table
1	GSI	B61147	679,352.32	5,920,514.06	73	-	3,5	-
2	GSI	B61150	680,040.44	5,920,653.72	75	-	-	73
3	GSI	B61151	680,554.92	5,920,552.92	75	-	-	73,7
4	GSI	B61152	680,760.82	5,920,775.83	73	-	-	71,7
5	METRONORTH	MN104/BH/001	682,106.58	5,922,017.06	61.52	-	-	-
6	METRONORTH	MN104/BH/002	682,313.28	5,922,037.49	60.26	-	-	-
7	METRONORTH	MN104/BH/002A	682,354.82	5,922,009.98	59.37	44,17	41,67	45,07
8	METRONORTH	MN104/BH/003	682,583.99	5,922,051.81	58.93	-	-	-
9	METRONORTH	MN104/BH/004	682,370.14	5,921,945.48	60.09	-	-	-
10	METRONORTH	MN104/IT/001	682,077.58	5,921,878.62	62.54	-	-	-
11	METRONORTH	MN104/IT/002	682,302.74	5,922,013.31	60.02	-	-	-
12	METRONORTH	MN104/IT/003	682,313.60	5,921,875.93	60.62	-	-	-

FID	Source	Register	UTM29N_Eas	UTM29N_Nor	Ground Level	BoD Level	Rock Level	Water Table
13	METRONORTH	MN104/IT/004	682,490.13	5,921,889.02	59.17	-	-	-
14	METRONORTH	MN104/TP/001	682,052.24	5,922,008.78	61.71	-	-	-
15	METRONORTH	MN104/TP/002	682,126.98	5,921,967.84	61.38	-	-	59,98
16	METRONORTH	MN104/TP/003	682,192.08	5,922,021.08	60.88	-	-	60,5
17	METRONORTH	MN104/TP/004	682,319.33	5,921,998.64	59.99	-	-	58,49
18	METRONORTH	MN104/TP/005	682,448.94	5,922,066.37	62.49	-	-	-
19	METRONORTH	MN104/TP/006	682,485.75	5,922,059.79	59.03	-	-	-
20	METRONORTH	MN104/TP/007	682,525.41	5,922,053.26	59.73	-	-	58,13
21	METRONORTH	MN104/TP/008	682,581.66	5,922,004.45	58.76	-	-	-
22	METRONORTH	MN104/TP/009	682,391.86	5,921,954.07	61.34	-	-	-
23	METRONORTH	MN104/TP/010	682,402.50	5,921,931.98	60.66	-	-	-
24	METRONORTH	RC407	682,357.99	5,921,827.45	60.81	43	42,2	52,51
25	METRONORTH	RC412	682,001.07	5,921,621.93	65.57	51,4	48,9	65,07
26	Project	RC29	681,848.07	5,921,204.98	64.82	46,92	46,32	-
27	Project	RC30	681,990.34	5,921,385.11	63.548	45	43,85	48
28	Project	RC302	683,555.19	5,923,893.63	65.681	51,8	45,5	55,8
29	Project	RC303A	683,473.09	5,923,679.38	65.862	53,1	49,6	48,4
30	Project	RC305	683,368.26	5,923,465.40	67.534	-	65,7	61,5
31	Project	RC306	683,251.78	5,923,444.28	67.768	63,1	60,5	62,9
32	Project	RC307	683,356.77	5,923,395.22	66.382	62,8	60,1	62,8
33	Project	RC308	683,334.65	5,923,291.16	65.053	57,2	54,85	60,9
34	Project	RC309	683,027.77	5,922,966.35	63.809	36,3	32,4	57
35	Project	RC311	683,164.70	5,923,162.91	65.854	44,5	42,35	57,6
36	Project	RC313	683,111.86	5,922,655.26	60.665	30,6	26,15	54,5
37	Project	RC314	682,925.63	5,922,316.66	59.645	29,4	27,2	53,6
38	Project	RC32	682,783.79	5,922,271.24	61.463	23,95	21,75	52,7
39	Project	RC33	682,984.55	5,922,783.81	62.253	31,7	27,8	55,4
40	Project	RC34	683,272.43	5,923,390.40	66.42	63,7	61,4	62
41	Project	RC35	683,301.00	5,923,543.37	67.275	58,9	55,8	56,67
42	Project	RC35	683,300.71	5,923,543.32	67.28	57,08	56,28	-
43	Project	RC401	682,863.11	5,922,250.49	59.351	26,05	23,45	52,8
44	Project	RC403	682,791.81	5,922,173.69	60.141	28,25	25,75	52,35
45	Project	RC408A	316,000.38	241,888.99	60.32	43,85	40,1	49,8
46	Project	RC409	315,725.32	241,712.76	65.55	45,83	42,5	47,96
47	Project	RC410	681,939.24	5,921,447.33	63.514	40,5	37,5	49,9
48	Project	RC501	681,928.47	5,921,367.54	64.084	47,15	44,2	48,3
49	Project	RC502	681,938.82	5,921,181.09	63.2327	44,3	42,4	47,12

FID	Source	Register	UTM29N_Eas	UTM29N_Nor	Ground Level	BoD Level	Rock Level	Water Table
50	Project	RC503	681,983.23	5,921,231.81	63.52	45,75	43,6	46,6
51	Project	RC505	681,839.04	5,920,914.95	59.648	45,85	43,35	58,57
52	Project	RC507	681,770.54	5,920,490.04	62.986	49,09	47,59	-
53	Project	RC56	678,934.84	5,920,985.17	76.73	75,53	74,73	-
54	Project	RC58	315,867.39	241,901.91	60.98	45	41,25	49
55	Project	RC61	683,729.11	5,923,105.17	59.93	40,43	39,31	-
56	Project	RC62	683,921.85	5,923,427.11	59.01	40,81	40,21	-
57	Project	TP402	682,743.47	5,922,016.19	58.862	-	-	57,06
58	Project	TP403	682626.43	5921883.93	58.773	-	-	-
59	Project	TP511	681897.76	5920906.06	58.677	-	-	57,08
60	Project	BH29	681,848.07	5,921,204.98	64.82	60,42	57,92	58,32
61	Project	BH30	681,990.34	5,921,385.11	63.548	45	43,85	48
62	Project	BH304	683,398.65	5,923,580.15	66.804	50,9	47,4	49,2
63	Project	BH307ACP	683,358.01	5,923,394.89	66.386	-	-	-
64	Project	BH31	682,125.56	5,921,503.31	65.659	37,4	34,9	49,25
65	Project	BH310	683,260.75	5,923,243.26	65.953	-	-	-
66	Project	BH32	682,783.79	5,922,271.24	61.463	23,95	21,75	52,7
67	Project	BH33	682,984.55	5,922,783.81	62.253	31,7	27,8	55,4
68	Project	BH35	683,301.00	5,923,543.37	67.275	58,9	55,8	56,67
69	Project	BH402	682,830.81	5,922,259.26	59.299	-	-	-
70	Project	BH404	682,769.20	5,922,107.04	59.138	29,1	26,75	52,5
71	Project	BH405	682,640.96	5,921,931.98	58.395	35,35	32,25	52,5
72	Project	BH503ACP	681,985.76	5,921,232.57	63.542	-	-	48,94
73	Project	BH504	681,939.88	5,920,957.07	57.306	-	-	50,806
74	Project	BH504A	681,929.28	5,920,961.93	57.44	-	-	54,74
75	Project	BH506	681,877.82	5,920,876.88	58.611	-	-	55,511
76	Project	BH506ACP	681,877.55	5,920,879.67	58.623	-	-	-
77	Project	BH56	678,934.84	5,920,985.17	76.73	75,53	-	-
78	Project	BH58	315,867.39	241,901.91	60.98	45	41,25	49

Table 4-3. Boreholes. Dardistown Sector

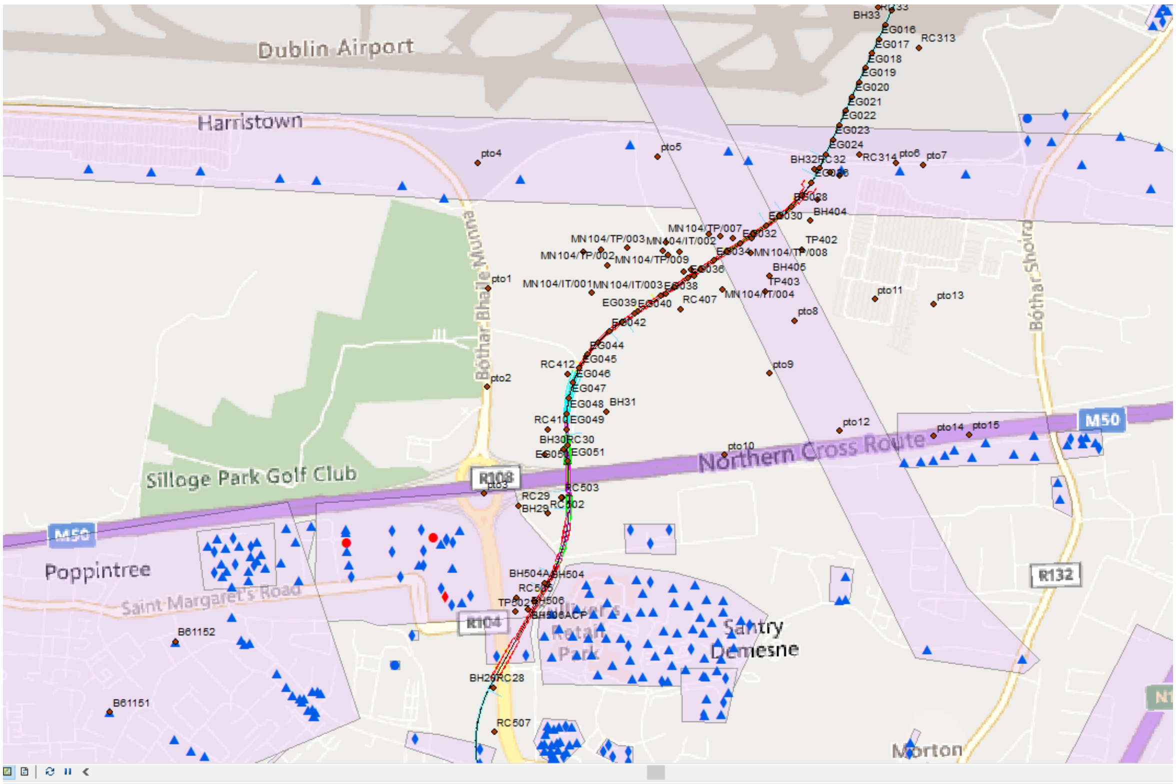

Figure 4-20. Data log available in the Dardistown Sector (Geological Survey Ireland Spatial Resources, Old Metro North and Project Log Data)

O'Conell Sector

FID	Source	Register	UTM29N_Eas	UTM29N_Nor	Ground Level	BoD Level	Rock Level	Water Table
1	GSI	B61584	681,837.22	5,914,691.19	6.1	-6.5	-6.8	5.5
2	GSI	B51660	683,048.12	5,914,566.14	4.49	-	-8.01	-0.5
3	GSI	B51664	683,152.29	5,914,626.61	4.43	-	-12.77	2.45
4	GSI	B57991	683,629.45	5,914,476.27	5.79	-13.44	-15.01	0
5	GSI	B57994	683,649.63	5,914,463.55	5.79	-9.75	-11.71	0
6	GSI	B51651	682,972.70	5,914,667.09	3.14	-	-10.26	-1
7	GSI	B51656	683,018.64	5,914,671.74	0.93	-7.77	-9.07	-0.5
8	GSI	B51659	683,054.25	5,914,628.23	4.58	-9.89	-11.24	-0.3
9	GSI	B51666	683,135.58	5,914,605.37	3.6	-2.35	-4.2	0
10	GSI	B51655	682,983.42	5,914,544.23	3.4	-5.6	-6.85	-1.6
11	GSI	B60398	681,997.52	5,914,742.44	-2.6	-15.7	-16	1.15
15	GSI	B81335	683,642.49	5,914,473.45	3.31	-	-15.49	1.41
16	GSI	B81337	683,635.46	5,914,475.36	3.34	-13.16	-15.66	0

FID	Source	Register	UTM29N_Eas	UTM29N_Nor	Ground Level	BoD Level	Rock Level	Water Table
17	GSI	B81343	683,623.12	5,914,428.18	-7.9	-12.4	-13.3	0
18	GSI	B81347	683,645.60	5,914,465.50	-6.9	-10.9	-12.25	0
19	GSI	B60396	681,953.21	5,914,692.82	-4	-16.3	-18	0.5
20	GSI	B81346	683,632.60	5,914,465.31	-6.6	-11.3	-12.2	1.14
21	GSI	B81349	683,630.90	5,914,444.29	-7.6	-12.4	-13.1	1.78
29	GSI	B61581	681,875.85	5,914,717.73	6.1	-6.9	-7.8	5.6
30	GSI	B51657	683,017.83	5,914,586.72	0.85	-7.6	-9.4	-0.55
31	GSI	B51661	683,069.41	5,914,545.43	0.89	-6.43	-7.78	-0.6
32	GSI	B60397	681,975.20	5,914,694.12	0.1	-	-12.5	-5.18
33	GSI	B81334	683,628.46	5,914,475.26	3.31	-	-17.89	0.001
34	GSI	B81345	683,620.56	5,914,468.15	-6.7	-10.7	-12.2	0
38	GSI	B51662	683,098.83	5,914,658.86	-3.61	-	-13.71	0
39	GSI	B51653	682,951.31	5,914,622.79	3.2	-7.56	-8.66	-0.2
40	GSI	B81344	683,638.16	5,914,425.39	-8	-12.9	-13.4	0
1	METRONORTH	RC07	682,437.47	5,914,198.80	4.5	-4.5	-6.5	2.4
5	METRONORTH	MGI/BH/708	682,359.40	5,914,707.38	4.63	-9.87	-11.57	2.42
6	METRONORTH	MGI/BH/709	682,407.67	5,914,303.04	-2.87	-	-6.77	-4.67
7	METRONORTH	MGI/BH/710	682,412.51	5,914,376.96	-2.39	-4.54	-6.64	-5.39
8	METRONORTH	MGI/BH/711	682,480.82	5,914,403.74	-3.7	-6.3	-7.15	-6.7
9	METRONORTH	MGI/BH/712	682,474.58	5,914,429.78	-4.29	-8.74	-9.89	-8.19
10	METRONORTH	MGI/BH/718	682,485.36	5,914,330.67	4.45	-3.05	0	-
11	METRONORTH	MGI/BH/719	682,393.69	5,914,425.24	3.34	-8.11	-10.31	1.2
12	METRONORTH	GL/BH13	682,762.72	5,914,806.17	3.25	-15.95	-17.75	1.4
13	METRONORTH	A1	681,980.31	5,915,806.86	14.81	-8.59	-11.14	14.11
13	METRONORTH	GL/BH18	682,592.48	5,915,035.81	4.6	-22.3	-24.9	-2.1
14	METRONORTH	B1	682,019.61	5,915,761.13	15.09	-9.33	-15.68	-
14	METRONORTH	GL/BH30	681,541.16	5,915,121.09	14.1	-	-11.9	4.1
15	METRONORTH	C	682,019.43	5,915,715.60	15.46	-6.65	-15	10.76
16	METRONORTH	D	681,995.81	5,915,671.54	16.91	-12.45	-14.61	15.77
17	METRONORTH	E1	682,022.38	5,915,653.90	16.29	-10.71	-16.77	15.88
18	METRONORTH	F	682,019.25	5,915,688.54	16.18	-9.32	-15	16.18
19	METRONORTH	AGI/RC/MP05	681,946.00	5,915,538.48	18.3	-9.8	-10.1	-
20	METRONORTH	AGI/RC/MP06	681,959.05	5,915,451.58	18.11	-8.19	-9.09	-
21	METRONORTH	AGI/RC/MP10	682,082.76	5,915,239.95	14.66	-6.04	-10.34	-
22	METRONORTH	GL/BH07	682,703.66	5,914,635.49	3.1	-4.55	-5.15	-7.4
22	METRONORTH	P005T1	681,945.18	5,915,536.94	18.35	-5.35	-9.65	-
23	METRONORTH	AGI/BH/MP001	682,006.51	5,915,650.62	17.27	-	-9.43	-

FID	Source	Register	UTM29N_Eas	UTM29N_Nor	Ground Level	BoD Level	Rock Level	Water Table
23	METRONORTH	GL/BH09	682,091.59	5,914,452.72	3.45	-4.85	-	-1.35
24	METRONORTH	AGI/BH/MP002	682,003.57	5,915,646.48	17.37	-	-9.48	-
24	METRONORTH	GL/BH15	681,727.61	5,915,518.75	21.4	-	-5.85	-0.05
25	METRONORTH	AGI/BH/MP003	682,001.63	5,915,641.76	17.56	-	-10.74	-
25	METRONORTH	GL/BH16	682,038.50	5,914,816.02	5.05	-12.45	-13.1	-0.45
26	METRONORTH	AGI/BH/MP004	681,991.46	5,915,611.32	17.62	-7.48	-10.53	-
26	METRONORTH	GL/BH17	682,153.96	5,914,926.66	5.25	-20.75	-21.75	-2.05
27	METRONORTH	AGI/BH/MP013	681,982.60	5,915,594.09	17.58	-8.72	-9.47	-
27	METRONORTH	GL/BH21	681,791.17	5,915,033.67	10.4	-16.8	-17.6	1.4
28	METRONORTH	GL/BH03	682,611.26	5,914,236.23	3.95	-	-2.1	-8.05
28	METRONORTH	GL/BH25	681,700.28	5,915,097.39	13.3	-9.7	-12.2	-2.7
29	METRONORTH	GL/BH04	682,472.77	5,914,343.28	4.55	-4.05	-4.45	-0.15
30	METRONORTH	GL/BH31	681,420.97	5,915,050.48	21.05	-	-10.45	-10.95
31	METRONORTH	GL/BH32	681,456.50	5,915,154.97	20.7	-4.7	-7.1	-5.8
32	METRONORTH	GL/BH33	681,467.29	5,915,241.11	17.45	-5.75	-8	-
33	METRONORTH	GL/BH34A	681,324.38	5,915,307.10	21.6	1.3	-4.4	-4.4
34	METRONORTH	GL/BH35	681,294.09	5,915,399.67	21.1	1	-5.7	0.8
35	METRONORTH	GL/BH14	682,190.14	5,914,676.29	5.6	-3.4	-9.4	-9.4
35	METRONORTH	GL/BH42	681,718.65	5,914,142.74	2.9	-5.75	-6.2	1.78
36	METRONORTH	GL/BH19	681,922.78	5,914,917.52	7.5	-18.2	-19.4	2.01
36	METRONORTH	GL/BH43	681,580.89	5,914,197.80	3.95	-1.15	-4.65	-1,15
37	METRONORTH	GL/BH37	682,525.24	5,914,695.83	3.65	-	-8.75	-1.15
37	METRONORTH	GL/BH44	681,537.35	5,914,308.18	3.8	-0.5	-3.2	1
38	METRONORTH	GL/BH45	681,488.60	5,914,719.46	7.8	-	-21.2	-4.2
2	Project	MGI/BH/637	681,959.43	5,915,609.07	17.31	-9.61	-10.2	0.51
3	Project	MGI/BH/639	682,024.19	5,915,806.18	14.39	-8.81	-9.45	-
4	Project	MGI/BH/641	681,966.07	5,915,779.35	14.94	-10.88	-12.56	0.84
12	Project	BX/BH02	682,564.59	5,914,410.15	-4.02	-8.02	-10.97	1.33
41	Project	BH.1 ISL	682,726.40	5,914,296.60	3.5	-4.9	-7.5	0
42	Project	UBN3	682,801.20	5,914,381.66	3.7	-5.1	-7.8	0
43	Project	BH.38 Luas	682,695.47	5,914,363.17	3.2	-3.75	-6.75	-0.3
44	Project	GQBH1	682,681.64	5,914,422.99	1.7	-7	-9.5	0.6
45	Project	BX/BH01	682,552.30	5,914,462.98	3.72	-8	-11	0
46	Project	BX/BH02	682,558.68	5,914,436.23	-0.5	-8.25	-11	1.33
47	Project	MGI/BH/715	682,530.94	5,914,410.13	3.72	-8.25	-11.25	0.75
48	Project	MGI/BH/716	682,463.46	5,914,456.67	3.5	-8.75	-12.85	-0.75
49	Project	MNEWSS01	682,390.20	5,914,572.33	4.47	-3.75	-6	0.66

FID	Source	Register	UTM29N_Eas	UTM29N_Nor	Ground Level	BoD Level	Rock Level	Water Table
50	Project	MNEWSS02	682,377.43	5,914,613.05	4.72	-4.25	-6.25	1.33
51	Project	BH.8 Luas	682,396.72	5,914,562.01	4.4	-4.25	-6.75	0
52	Project	BH.10 Luas	682,368.39	5,914,656.63	4.75	-7.5	-10	0.5
53	Project	MGI/BH/708	682,327.60	5,914,728.08	4.63	-10	-12.5	2.42
54	Project	BH.11 Luas	682,313.92	5,914,833.89	5.15	-12.5	-16.25	2.41
55	Project	RC10A	682,274.56	5,914,849.94	4.93	-15	-19.25	2.32
56	Project	RC09	682,426.44	5,914,769.12	4.18	-10	-13	2.01
57	Project	RC11	682,339.12	5,914,945.67	4.88	-19	-21.9	1.6
58	Project	BH12	682,190.11	5,915,086.24	8.83	-14	-18	0.5
59	Project	MGI/BH/706	682,219.82	5,914,974.67	5.54	-20.2	-23	0.63
60	Project	MGI/BH/707	682,337.12	5,915,041.21	5.51	-17.7	-21.1	-1.5
61	Project	MGI/BH/703	682,192.95	5,915,109.15	9.01	-13.4	-17.12	-1.75
62	Project	BH.12 Luas	682,245.49	5,915,007.95	5.9	-18.35	-22.35	-1.5
63	Project	MGI/BH/704	682,147.15	5,915,141.31	11.41	-12.5	-15.85	0.02
64	Project	MGI/BH/702	682,087.21	5,915,153.11	12.87	-10.6	-12.75	0.9
65	Project	BH.27 Luas	682,148.45	5,915,225.62	13.85	-8.15	-10.3	-0.75
66	Project	AGI/RC/MP11	682,098.58	5,915,218.28	14.01	-7.5	-11.5	0.7
67	Project	AGI/RC/MP12	682,112.39	5,915,177.50	15.5	-7.7	-10.8	0
68	Project	AGI/BH/MP09A	682,040.54	5,915,298.43	16.15	-8.15	-11.8	1
69	Project	BH14	682,018.36	5,915,416.33	17.13	-6.85	-13.7	1.7
70	Project	RC13	682,076.61	5,915,335.04	16.47	-7.5	-10.8	1.31
71	Project	BH.28 Luas	681,971.40	5,915,373.15	17.85	-7.3	-14.35	1.37
72	Project	AGI/RC/MP07	681,971.58	5,915,411.10	17.32	-5.5	-8.35	2.01
act	Project	NBH22 (shallow)	682,235.94	5,914,908.37				1
act	Project	NBH23A	682,254.89	5,914,830.18				1.35
act	Project	NBH23W	682,236.86	5,914,827.70				0.5
act	Project	NBH24 (deep)	682,269.82	5,914,737.71				4.93
act	Project	NBH24 (shallow)	682,269.82	5,914,737.71				4.71
act	Project	NBH63	682,426.44	5,914,769.12				1.7

Table 4-4. Boreholes. O'Conell Sector

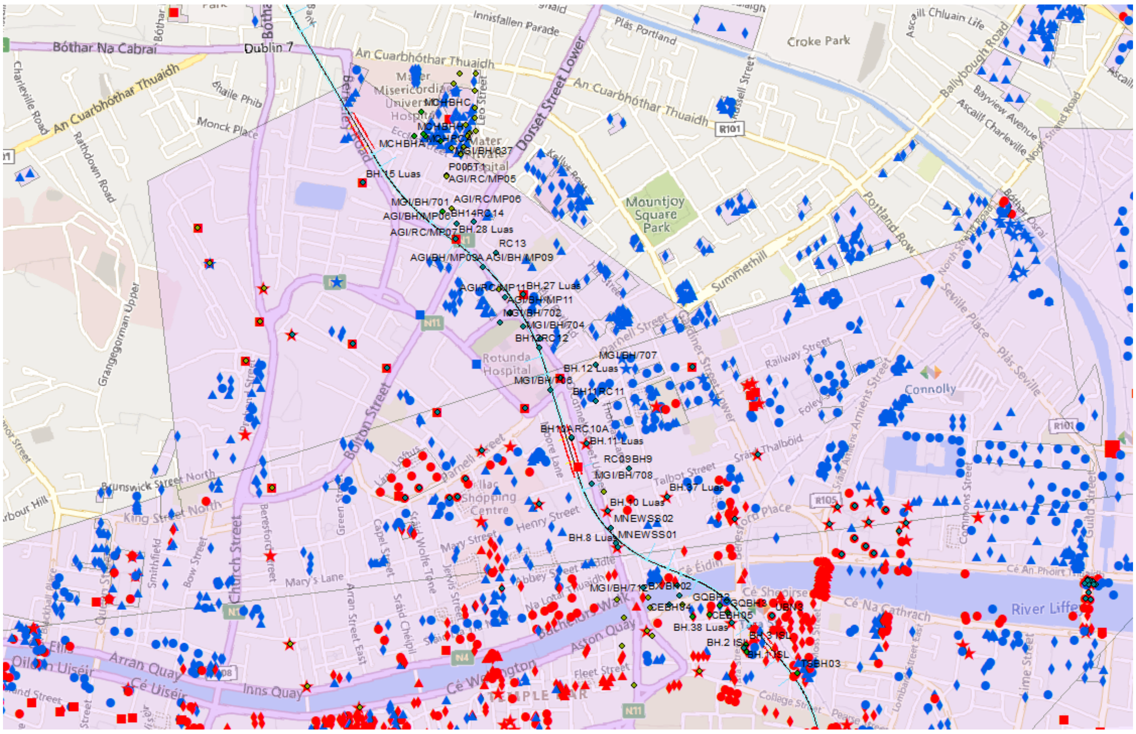

Figure 4-21. Data log available in the O'Conell (Geological Survey Ireland Spatial Resources, Old Metro North and Project Log Data)

4.3 PERMEABILITIES

In the groundwater flow study, it is essential to assign appropriate permeability values to the materials.

This property is directly related to granulometry. However, assigning a permeability value to a material is a complicated task due to its great variability in particle composition and orientation and compaction.

The main geotechnical characteristics of the different levels that will intervene in the calculation are summarized below.

4.3.1 <u>Made ground (QX)</u>

It includes heterogeneous materials selected to build embankments comprising sand, gravel or clay fill with many cobbles, boulders, brick, glass, ceramics and/or concrete. The thickness varies significantly, reaching up to 6 m, but a typical mean representative value would be around 2 m.

Fine content (%)	25.80
Limit Liquid (%)	34.90
Plasticity Index (%)	14.18
Moisture content (%)	14.5
Dry density (g/cm^3)	1.60
Permeability (m/s)	7.65E-7

4.3.2 Brown Boulder Clay (QBR)

The Dublin Boulder Clay (DBC) is the primary superficial deposit overlying bedrock in Dublin. DBC is characterised by a relatively simple microstructure with low water content, void ratio, permeability and high density.

Farrell et al. (1995a) made the differentiation between the Brown Boulder Clay and the Black Boulder Clay. Farrell and his co-authors stated that the (Upper) Brown Boulder Clay is a weathering product of the Black Boulder Clay but is broadly like it in terms of particle size distribution. These researchers also briefly note that there appears to be some local variation in the colour of the Black Boulder Clay, as it is locally brown.

The main properties of the Brown and Black Boulder Clay will be analysed separately.

QBR is the most common superficial strata present along the alignment. The thickness is quite variable. In addition, two geotechnical units exhibiting granular behaviour have been established (QBRs<10m and QBRs>10m)

BROWN BOULDER CLAY (QBR<10m)

This unit occurs from ground level to depths of up to 10 m, and is composed of brown, slightly sandy clay, with some gravel and cobbles. Locally, there are silt / gravel lenses and large boulders, sizes higher than 25,6 cm.

Fine content (%)	10.50
Limit Liquid (%)	29.05
Plasticity Index (%)	13.95

Moisture content (%)	10.00
Dry density (g/cm³)	0.05
Permeability (m/s)	7.62E-7

BROWN BOULDER CLAY (QBR>10m)

This unit is composed of a stiff to very stiff, brown, slightly sandy clay, with some gravel and cobbles. Locally, there are silt / gravel lenses and large boulders, up to 5 m thick. It exhibits significant variability in composition, with clay, sand, gravel and boulders in different proportions.

Fine content (%)	24.54
Limit Liquid (%)	29.55
Plasticity Index (%)	14.16
Moisture content (%)	9.61
Dry density (g/cm³)	2.07
Permeability (m/s)	6.64E-6

4.3.3 Black Boulder Clay

The QBL unit is the second most common drift deposit represented along the alignment. The thickness is quite variable.

This unit consists of a dark grey, slightly sandy clay, with some gravel and cobbles. Locally, there are silt / gravel lenses and large boulders up to 5 m thick. It is important to highlight the high compositional variability of this soil, with clay, sand, gravel and boulders in different proportions.

At this stage it has been considered appropriate to split this unit into two geotechnical units.

BLACK BOULDER CLAY (QBL<10m)

Fine content (%)	37.11
Limit Liquid (%)	30.04
Plasticity Index (%)	14.04
Moisture content (%)	10.26
Dry density (g/cm³)	2.09
Permeability (m/s)	7.21E-7

BLACK BOULDER CLAY (QBL>10m)

Fine content (%)	37.49
Limit Liquid (%)	30.13
Plasticity Index (%)	14.27
Moisture content (%)	9.36
Dry density (g/cm³)	2.14
Permeability (m/s)	7.15E-7

4.3.4 Base of drift deposits with top weathered rock

It is mainly composed of sand and gravel layers with erratic boulders of diameter more than 250 mm. The facies variability in glacial sediments is higher at the bottom of the sequence, with rapid changes over very short distances of a few centimeters.

The reason for treating this as a geotechnical unit is due to its geotechnical behaviour. This unit should have a mechanical behaviour intermediate between boulder clay and sound rock.

The contact between the glacial deposits and the underlying Carboniferous rocks shows very poor geotechnical properties. The geological-geotechnical-hydrogeological reasons for this are as follows:

- Within the basal glacial deposits there are many sand and gravel layers, which are cohesionless, along with the presence of large erratic boulders up to 5 m in diameter.
- The facies variability in the glacial sediments is greater at the base of the sequence, with rapid changes over very short distances.
- The glacial sediments were deposited over the topography which was developed thousands of years before the glacial age. For this reason, the carboniferous rocks are weathered in the first 2 m - 5 m, with the geotechnical characterisation of a soil.
- In many locations the contact between the glacial sediments and the original topography is inclined and may therefore be susceptible to landslides.
- During the glacial age there was a preferential water circulation within the Base of Drift (BoD) layer, where fine sediments were washed out from the basal glacial deposit and also the uppermost zone of the weathered rock.
- This layer includes material which has a very high porosity and permeability, forming one of the principal aquifers beneath Dublin.
- The groundwater flowing through this layer is an additional factor in the poor geotechnical behaviour of this soil.

Fine content (%)	22.53
Limit Liquid (%)	29.22
Plasticity Index (%)	13.54
Moisture content (%)	9.57
Dry density (g/cm^3)	2.08
Permeability (m/s)	2.90E-4

4.3.5 Lucan formation (CLU)

The Lucan or Calp Formation contains a dark grey to black, fine grained, graded limestone with interbedded calcareous shale, local cherts and fossiliferous beds.

As a result of the argillaceous nature of the Calp limestone, the formation is generally not susceptible to karstification and no major voids or cavities have been reported.

Dry unit Weight (g/cm^3)	2.64

E'rm (GPa)	23 GPa
v	0.25
|σ_ci| (MPa)	6 MPa
m_i	8
GSI	45
Permeability (m/s)	4.70E-6

4.3.6 Tober Colleen formation (CTO)

The Tober Colleen Formation is the lowest facies of the Calp Limestone and consists of dark grey interbedded calcareous mudstone or shale and thin layers of calcilutite, calcisiltite and very argillaceous micrite, which is usually burrowed.

Dry unit Weight (g/cm^3)	2.62 t/m3
E'_rm (GPa)	24 GPa
v	0.23
|σ_ci| (MPa)	6 MPa
m_i	8
GSI	45
Permeability (m/s)	1.40E-6 m/s

4.3.7 Lower part of Malahide formation (CMLO)

In its lower part the Malahide Formation contains calcareous shales, siltstones and sandstones with thin limestones (CMLO), whilst the uppermost part of the formation contains argillaceous limestones, nodular wackestones and shales (CMUP), forming an anticlinal structure. This layer is composed essentially of a light grey sound limestone of biologic origin, massive, and with frequent calcite veins.

Dry unit Weight (g/cm^3)	2.64 t/m3
E'_rm (GPa)	20 GPa
v	0.30
|σ_ci| (MPa)	4 MPa
m_i	8
GSI	45
Permeability (m/s)	1,38E-6 m/s

4.3.8 Upper part of the Malahide formation (CMUP)

The Malahide Formation stratigraphically underlies the Waulsortian Formation. In its lower part the Malahide Formation contains calcareous shales, siltstones and sandstones with thin limestones (CMLO), whilst the uppermost part of the formation contains argillaceous limestones, nodular wackestones and shales (CMUP), forming an anticlinal structure whose axis is located between the Fosterstown and Swords Central areas.

This lithological unit is the rock substrate expected to be encountered between Estuary Station and Dublin Airport.

This layer is composed essentially of a grey to black argillaceous limestone of bioclastic origin, massive, where it is difficult to recognize the bedding planes, as shown below.

Dry unit Weight (g/cm^3)	2.62 t/m3
E'_rm (GPa)	15 GPa
v	0.30
|σ_ci| (MPa)	3.5 MPa
m_i	8
GSI	45
Permeability (m/s)	5.79E-6

In all the study cases, and in view of the results obtained, it is observed that the groundwater flow circulates fundamentally and with greater intensity through the gravel levels.

4.4 HEAD OBSERVATION WELLS

The initial heads in the different available boreholes are also taken as input data. The data provided in the Phase 1-4 GI works, which included the monitoring of groundwater levels, have also been incorporated.

The generated surface with head isolines is used to calibrate the model and see the quality of the fit and represents the initial heads.

The tables that collect the point of initial head and observation wells in each sector are included below:

Seatown-Fosterstown Sector. Head Observation Wells

Well Name	X [m]	Y [m]	HEAD [m]
BH109	684897.66	5927578.33	2.5
BH117	684997.95	5926552.9	15.47
BH119	684926.72	5926346.86	16.13
BH120	684885.63	5926344.26	17.13
BH123ACP	684453.37	5926060.38	25.93
BH125	684326.63	5925917.39	27.84
BH125A	684326.7	5925918.65	27.76
BH125ACP	684319.43	5925913.34	27.65
BH126	684264.35	5925953.55	27.8
BH129ACP	685015.09	5926648.88	17.8
BH139	684625.57	5926156.49	25.42
BH204	684052.83	5925581.05	35.1
BH66	684260.63	5925913.7	27.83
BH67	684950.07	5926388.71	17.42
RC108	684837.22	5927670.47	3.1
RC111	685017.51	5927277.19	7.32
RC113	685004.26	5927087.33	9.16
RC113A	685003.53	5927087.63	9.12
RC114	685085.56	5926935.33	12.46
RC116	685094.75	5926827.06	11.79

Well Name	X [m]	Y [m]	HEAD [m]
RC118	684974.58	5926435.4	18.26
RC119	684926.72	5926346.86	16.13
RC121	684739.69	5926220.3	23.58
RC122	684711.66	5926141.75	24.42
RC124	684369.28	5925951.64	25.88
RC127	685082.42	5926717.14	13.14
RC128	684187.58	5925802.71	32.13
RC145	684078.87	5925747.67	40.23
RC201	684146.12	5925728.4	39.11
RC202	684054.91	5925695.46	41.96
RC203	684100.57	5925608.55	34.57
RC67	684950.07	5926388.71	17.42
RC68	685034.55	5927115.35	8.64
RC69	684887.11	5927624.55	2.96
NBH401	684843.66	5927717.19	3.7
NBH402	684838.3	5927712.44	3.79
NBH406	684894.77	5927454.54	7.22
NBH405 (shallow)	684899.55	5927705.9	3.82
NBH405 (deep)	684899.55	5927705.9	3.83
NBH407	684902.05	5927424.73	7.22
NBH408	684976.89	5927410.92	5.79
NBH403 (shallow)	684831.82	5927746.93	3.82
NBH403 (deep)	684831.82	5927746.93	4.29
NBH404 (shallow)	684831.69	5927681.46	3.898
NBH404 (deep)	684831.69	5927681.46	3.875
RC beside NBH404	684834.72	5927662.81	3.54

Table 4-5. Observation Wells. Seatown-Fosterstown Sector

Dardistown sector. Head Observation Wells

Well Name	X [m]	Y [m]	HEAD [m]
B61150	680040.44	5920653.72	73
B61151	680554.92	5920552.92	73.7
B61152	680760.82	5920775.83	71.7
BH29	681848.07	5921204.98	58.32
BH30	681990.34	5921385.11	48
BH304	683398.65	5923580.15	49.2
BH31	682125.56	5921503.31	49.25
BH32	682783.79	5922271.24	52.7
BH33	682984.55	5922783.81	55.4
BH35	683301	5923543.37	56.67
BH404	682769.2	5922107.04	52.5

Well Name	X [m]	Y [m]	HEAD [m]
BH405	682640.96	5921931.98	52.5
BH503ACP	681985.76	5921232.57	49.94
BH504	681939.88	5920957.07	50.8
BH504A	681929.28	5920961.93	54.74
BH506	681877.82	5920876.88	55.51
BH58	315867.39	241901.91	49
MN104BH002A	682354.82	5922009.98	52.07
MN104TP002	682126.98	5921967.84	59.98
MN104TP003	682192.08	5922021.08	60.5
MN104TP004	682319.33	5921998.64	58.49
MN104TP007	682525.41	5922053.26	58.13
NBH05s	682814.31	5922236.55	55.23
NBH07s	682683.7	5922132.25	54.97
RC30	681990.34	5921385.11	48
RC302	683555.19	5923893.63	55.8
RC303A	683473.09	5923679.38	48.4
RC305	683368.26	5923465.4	61.5
RC306	683251.78	5923444.28	62.9
RC307	683356.77	5923395.22	62.8
RC308	683334.65	5923291.16	60.9
RC309	683027.77	5922966.35	57
RC311	683164.7	5923162.91	57.6
RC313	683111.86	5922655.26	54.5
RC314	682925.63	5922316.66	53.6
RC32	682783.79	5922271.24	52.7
RC33	682984.55	5922783.81	55.4
RC34	683272.43	5923390.4	62
RC35	683301	5923543.37	56.67
RC401	682863.11	5922250.49	52.8
RC403	682791.81	5922173.69	52.35
RC407	682357.99	5921827.45	55.51
RC408A	316000.38	241888.99	49.8
RC409	315725.32	241712.76	47.96
RC410	681939.24	5921447.33	49.9
RC412	682001.07	5921621.93	65.07
RC501	681928.47	5921367.54	48.3
RC502	681938.82	5921181.09	47.12
RC503	681983.23	5921231.81	46.6
RC505	681839.04	5920914.95	58.57
RC58	315867.39	241901.91	49
TP402	682743.47	5922016.19	52.06
TP511	681897.76	5920906.06	57.08

Table 4-6. Observation Wells. Dardistown Sector

O'Conell. Head Observation Wells

Well Name	X [m]	Y [m]	HEAD [m]
B61584	681837.22	5914691.19	5.5
RC07	682437.47	5914198.8	2.4
B51660	683048.12	5914566.14	-0.5
MGI/BH/637	681959.43	5915609.07	0.5

Well Name	X [m]	Y [m]	HEAD [m]
B51664	683152.29	5914626.61	2.45
B57991	683629.45	5914476.27	0
MGI/BH/641	681966.07	5915779.35	0.84
B57994	683649.63	5914463.55	0
MGI/BH/708	682359.4	5914707.38	2.42
B51651	682972.7	5914667.09	-1
MGI/BH/709	682407.67	5914303.04	-4.67
B51656	683018.64	5914671.74	-0.5
MGI/BH/710	682412.51	5914376.96	-5.39
B51659	683054.25	5914628.23	-0.3
MGI/BH/711	682480.82	5914403.74	-6.7
B51666	683135.58	5914605.37	0
MGI/BH/712	682474.58	5914429.78	-8.19
B51655	682983.42	5914544.23	-1.6
B60398	681997.52	5914742.44	1.15
MGI/BH/719	682393.69	5914425.24	1.2
BX/BH02	682564.59	5914410.15	1.33
GL/BH13	682762.72	5914806.17	1.4
GL/BH18	682592.48	5915035.81	-2.1
GL/BH30	681541.16	5915121.09	4.1
B81335	683642.49	5914473.45	1.41
B81337	683635.46	5914475.36	0
B81343	683623.12	5914428.18	0
B81347	683645.6	5914465.5	0
B60396	681953.21	5914692.82	0.5
B81346	683632.6	5914465.31	1.14
B81349	683630.9	5914444.29	1.78
GL/BH07	682703.66	5914635.49	-7.4
GL/BH09	682091.59	5914452.72	-1.35
GL/BH15	681727.61	5915518.75	-0.05
GL/BH16	682038.5	5914816.02	0.61
GL/BH17	682153.96	5914926.66	2.32
GL/BH21	681791.17	5915033.67	1.4
GL/BH03	682611.26	5914236.23	-8.05
GL/BH25	681700.28	5915097.39	-2.7
B61581	681875.85	5914717.73	5.6
GL/BH04	682472.77	5914343.28	-0,15
B51657	683017.83	5914586.72	-0.55
GL/BH31	681420.97	5915050.48	-10.95
B51661	683069.41	5914545.43	-0.6
GL/BH32	681456.5	5915154.97	-5.8

Well Name	X [m]	Y [m]	HEAD [m]
B60397	681975.2	5914694.12	-5.18
B81334	683628.46	5914475.26	0.01
GL/BH34A	681324.38	5915307.1	0.55
B81345	683620.56	5914468.15	0
GL/BH35	681294.09	5915399.67	0.8
GL/BH14	682190.14	5914676.29	-9.4
GL/BH42	681718.65	5914142.74	1.78
GL/BH19	681922.78	5914917.52	2.01
GL/BH43	681580.89	5914197.8	0.92
GL/BH37	682525.24	5914695.83	2.5
B51662	683098.83	5914658.86	0
GL/BH45	681488.6	5914719.46	-4.2
B51653	682951.31	5914622.79	-0.2
B81344	683638.16	5914425.39	0
BH.1 ISL	682726.4	5914296.6	0
UBN3	682801.2	5914381.66	0
BH.38 Luas	682695.47	5914363.17	-0.3
GQBH1	682681.64	5914422.99	0.6
BX/BH01	682552.3	5914462.98	0
BX/BH02	682558.68	5914436.23	-3.75
MGI/BH/715	682530.94	5914410.13	0.75
MGI/BH/716	682463.46	5914456.67	-0.75
MNEWSS01	682390.2	5914572.33	0.66
MNEWSS02	682377.43	5914613.05	1.33
BH.8 Luas	682396.72	5914562.01	0
BH.10 Luas	682368.39	5914656.63	0.5
MGI/BH/708	682327.6	5914728.08	2.42
BH.11 Luas	682313.92	5914833.89	2.41
RC10A	682274.56	5914849.94	2.32
RC09	682426.44	5914769.12	2.01
RC11	682339.12	5914945.67	1.6
BH12	682190.11	5915086.24	0.5
MGI/BH/706	682219.82	5914974.67	0.63
MGI/BH/707	682337.12	5915041.21	-1.5
MGI/BH/703	682192.95	5915109.15	-1.75
BH.12 Luas	682245.49	5915007.95	-1.5
MGI/BH/704	682147.15	5915141.31	0.02
MGI/BH/702	682087.21	5915153.11	0.9
BH.27 Luas	682148.45	5915225.62	-0.75
AGI/RC/MP11	682098.58	5915218.28	-0.56
AGI/RC/MP12	682112.39	5915177.5	0

Well Name	X [m]	Y [m]	HEAD [m]
AGI/BH/MP09A	682040.54	5915298.43	1
BH14	682018.36	5915416.33	1.7
RC13	682076.61	5915335.04	1.31
BH.28 Luas	681971.4	5915373.15	1.37
AGI/RC/MP07	681971.58	5915411.1	2.01
NBH22 (shallow)	682235.94	5914908.37	1
NBH23A	682254.89	5914830.18	1.35
NBH23W	682236.86	5914827.7	0.5
NBH24 (deep)	682269.82	5914737.71	4.93
NBH24 (shallow)	682269.82	5914737.71	4.71

Table 4-7. Observation Wells. O'Conell

The following illustrations show the initial head layers generated in Visual Modflow by interpolation of the data provided by each borehole where a record of the water table is available. (data included in the previous tables)

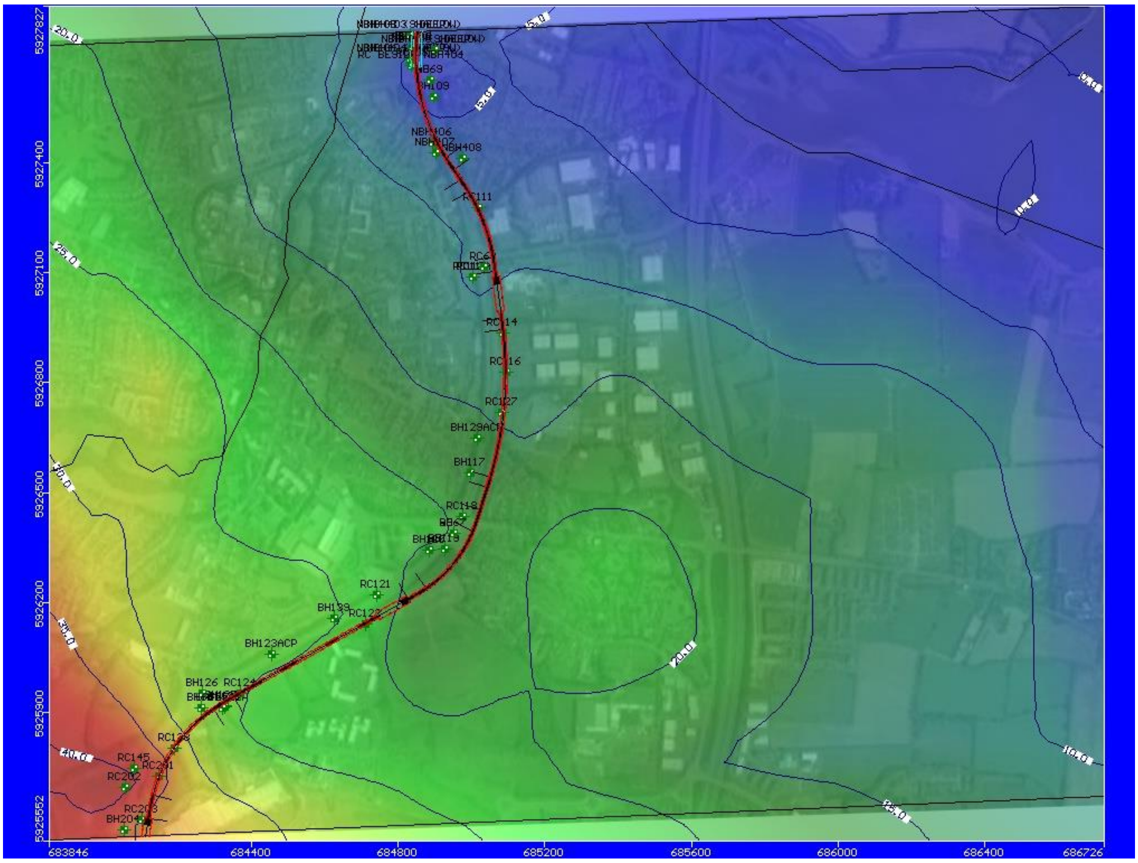

Figure 4-22. Initial Heads: Plant with contour lines. Seatown-Fosterstown Sector

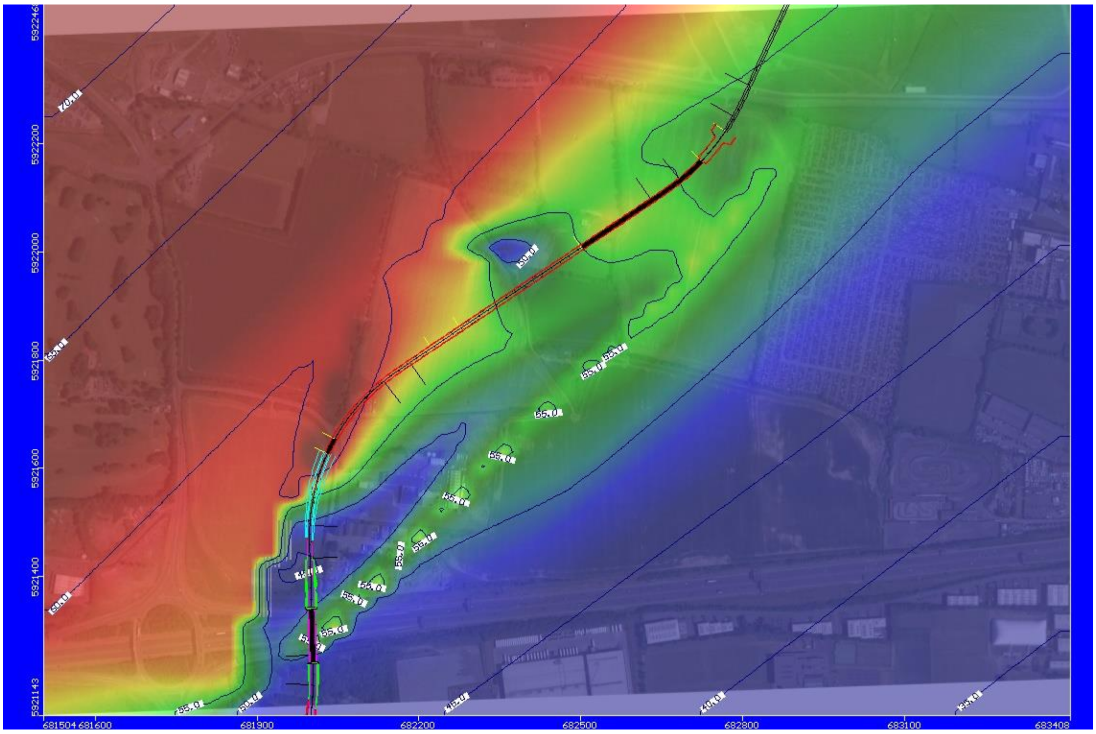

Figure 4-23. Initial Heads: Plant with contour lines. Dardistown Sector

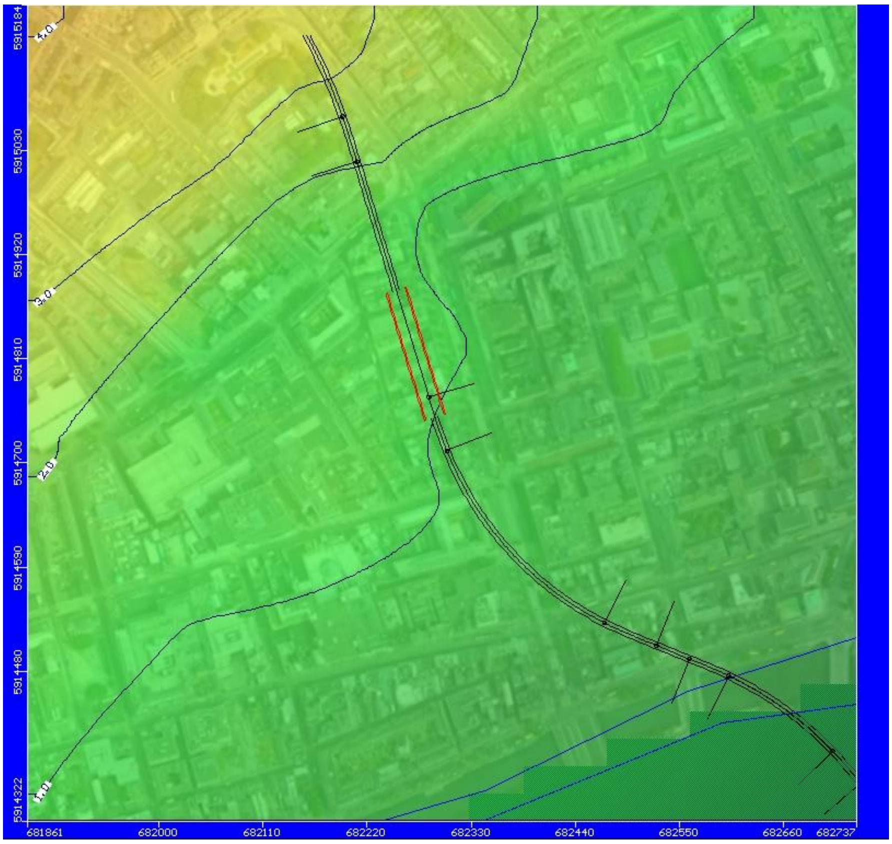

Figure 4-24. Initial Heads: Plant with contour lines. O'Conell Sector

4.5 CONSTANT HEAD BOUNDARY

The Constant Head boundary condition is used to fix the head value in selected grid cells regardless of the system conditions in the surrounding grid cells, thus acting as an infinite source of water entering the system, or as an infinite sink for water leaving the system. Therefore, Constant Head boundary conditions can have a significant influence on the results of a simulation, and may lead to unrealistic predictions, particularly when used in locations close to the area of interest.

For this study, the piezometric elevation at the edges has been calibrated in such a way as to provide a groundwater level elevation at the positions of the boreholes that coincides with the measurement. This condition has been assumed as a fixed piezometric bound.

It has been established at a mean distance from the alignments far enough away so as not to affect the study area.

4.6 RIVER BOUNDARY CONDITIONS

Visual MODFLOW supports the River Package included with MODFLOW. The Visual MODFLOW input data for River grid cells is stored in the projectname.VMB file (see Appendix A), while the MODFLOW input data for River grid cells is stored in the projectname.RIV file (see the MODFLOW-2000 Reference Manual .PDF file provided with the Visual MODFLOW installation media, in the Manual folder).

The River boundary condition is used to simulate the influence of a surface water body on the groundwater flow. Surface water bodies such as rivers, streams, lakes and swamps may either contribute water to the groundwater system, or act as groundwater discharge zones, depending on the hydraulic gradient between the surface water body and the groundwater system. The MODFLOW River Package simulates the surface water/groundwater interaction via a seepage layer separating the surface water body from the groundwater system (Figure 4-25)

The MODFLOW River Package input file requires the following information for each grid cell containing a River boundary;

- River Stage: The free water surface elevation of the surface water body. This elevation may change with time.
- Riverbed Bottom: The elevation of the bottom of the seepage layer (bedding material) of the surface water body.

- Conductance: A numerical parameter representing the resistance to flow between the surface water body and the groundwater caused by the seepage layer (riverbed). The Conductance value (C) may be calculated from the length of a reach (L) through a cell, the width of the river (W) in the cell, the thickness of the riverbed (M), and the vertical hydraulic conductivity of the riverbed material (K) using the following formula:

$$C = \frac{K \times L \times W}{M}$$

In the absence of precise data on the permeability of the river bed in this study, it has been considered equal to the permeability of the underlying level.

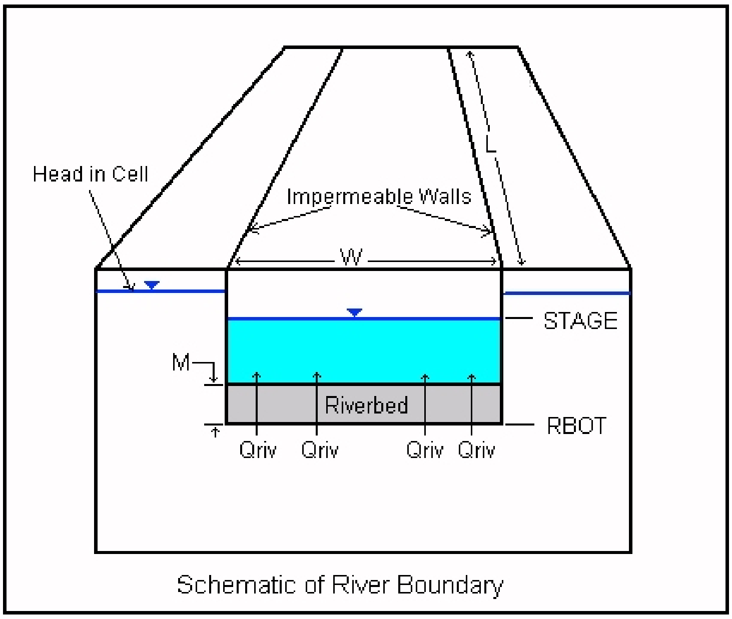

Figure 4-25. Schematic of River Boundary

4.7 RECHARGE TO THE GROUNDWATER SYTEM

Visual MODFLOW supports the Recharge Package (RCH) included with MODFLOW

The Recharge Package is typically used to simulate surficially distributed recharge to the groundwater system. Most commonly, recharge occurs as a result of precipitation percolating into the groundwater system.

For this study, the surface recharges for each sector have been taken from the mean data of the **Geological Survey Ireland Spatial Resources (www.gsi.ie)**

- Seatown-Fosterstown Sector = 67 mm/yr - recharge coefficient = 20% -effective rainfall = 300 mm/yr
- Dardistown Sector = 66 mm/yr - recharge coefficient = 20% -effective rainfall = 332 mm/yr
- O'Conell Sector = 60 mm/yr - recharge coefficient = 20% -effective rainfall = 302 mm/yr

5 DISCUSSION OF RESULTS

The analysis carried out under steady-state simulation includes two stages. First, the water table is calculated in the current situation, prior to the beginning of the projected works. In a second stage, the model is recalculated including the diaphragm walls. The Output section of Visual Modflow allows to visualize the groundwater flow, velocity vectors and pathlines.

In both stages, the hydraulic gradient is obtained, which allows obtaining the flow rates through the MetroLink alignments. This data is of special importance in this case, since it will allow sizing the transversal drainage systems that avoid the barrier effect. This does not always occur as it may be the case that there is no appreciable flow of water or that the entire work is above the water table, or that the natural flows run parallel and not transversal to the infrastructure and are not interrupted by the same.

It may also be the case that the flow of water infiltrating between the joints of the diaphragm walls below the level of floor or circulating at the ends of the tunnel, is sufficient to prevent significant changes in the phreatic level.

In these cases, it will not be necessary to install a system to allow the passage of groundwater from one side of the false tunnel to the other.

However, in those cases where an existing natural current of groundwater is interrupted by a tunnel, this will give rise to a barrier effect and, in this case, it shall be necessary to install a system to allow the passage of groundwater from one side to the other, as this would otherwise lead to various undesirable effects.

For this reason, in a second calculation step, the diaphragm walls are incorporated into the 3D models, checking their effect on the water table elevations and studying the raised elevations that occur.

5.1 INITIAL SITUATION

The first stage includes the construction of the terrain 3D model, the introduction of the transmissivity parameters, rivers, recharges, observation wells (in this case they are the soundings available with correct records of the water table), the adjustment of the boundary conditions.

The objective of the model calibration is to obtain the Initial Groundwater Levels that conforms to the available records from the observation wells.

In this first stage, the boundary conditions are adjusted to produce simulation results that better match the known or measured values. Specifically, the Constant Head Boundaries Conditions imposed for each layer have been modified in an iterative process in order to achieve a precise data fit.

Model calibration is the most critical process in groundwater flow construction, because the quality of the calibration inevitably determines the reliability of any conclusions and recommendations made using the simulation results.

The following sections show the initial groundwater levels obtained by reaching adequate correlation values that are obtained from the "Calculated vs. Observed Head" charts.

5.1.1 Initial Groundwater Levels

The following figure shows the contour lines of the initial groundwater levels obtained in the first step under steady-state simulation for each area studied:

Seatown-Fosterstown Sector

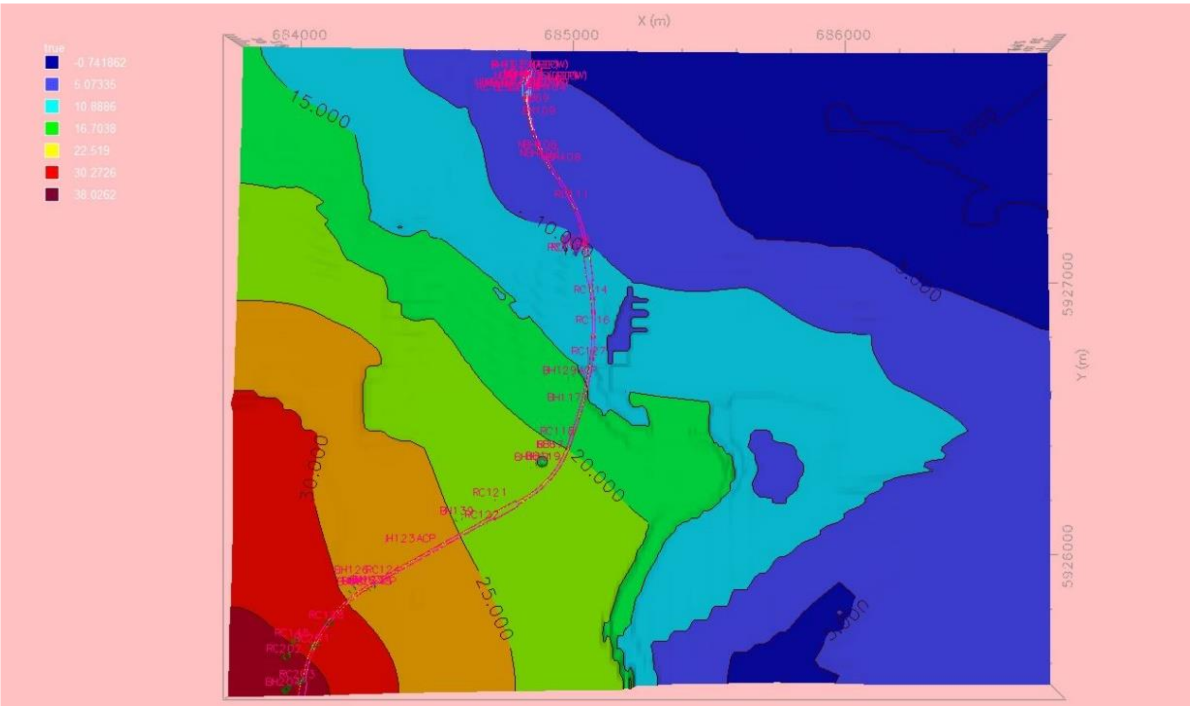

Figure 5-1. Calculated Water Table and Head Observation Wells – Without Diaphragm Walls. Seatown-Fosterstown Sector

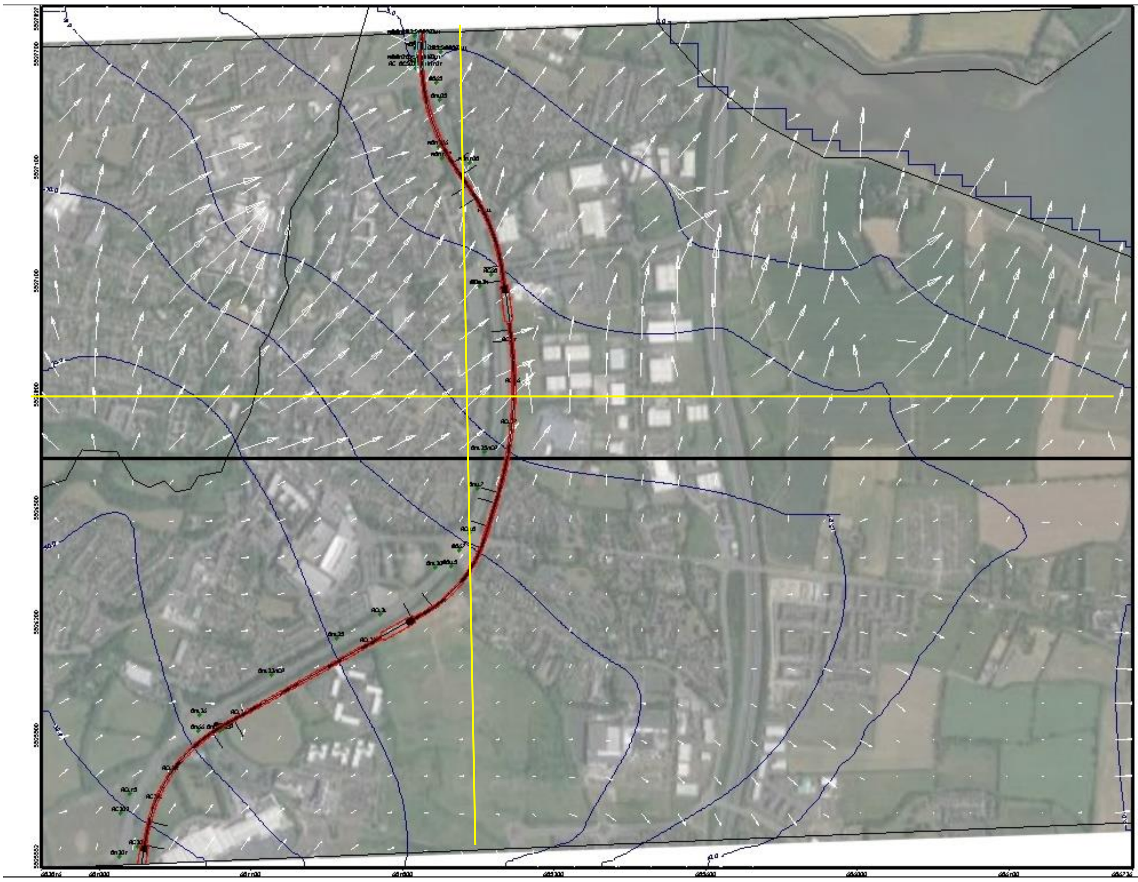

Figure 5-2. Velocity vector longitudinal profiles marks. Seatown-Fosterstown Sector

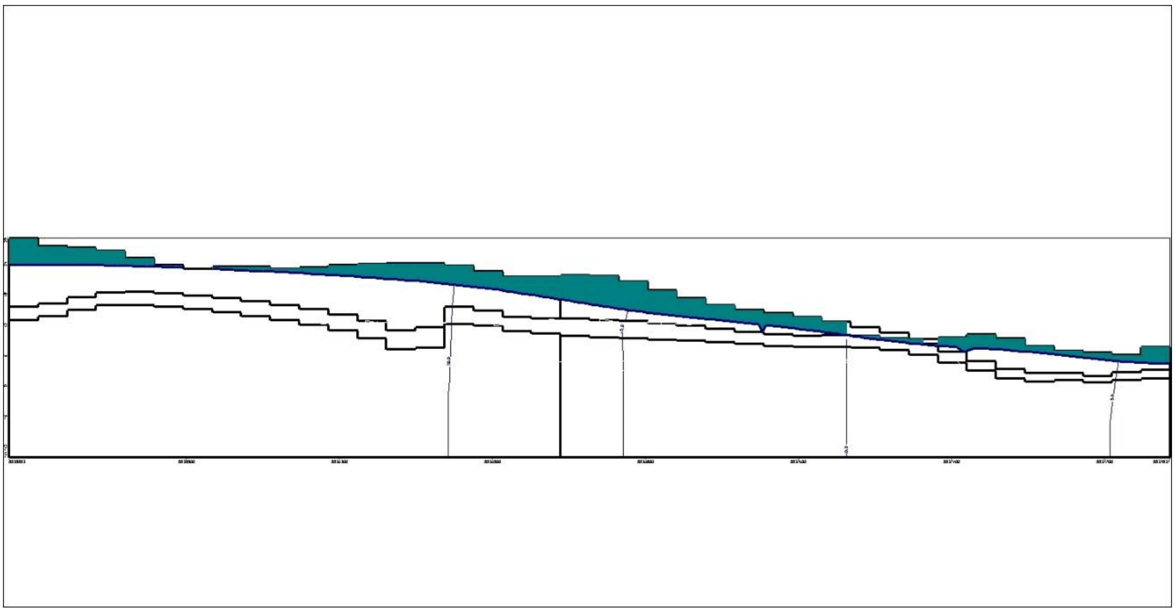

Figure 5-3. Longitudinal profile North-South (Column #83). Seatown-Fosterstown Sector

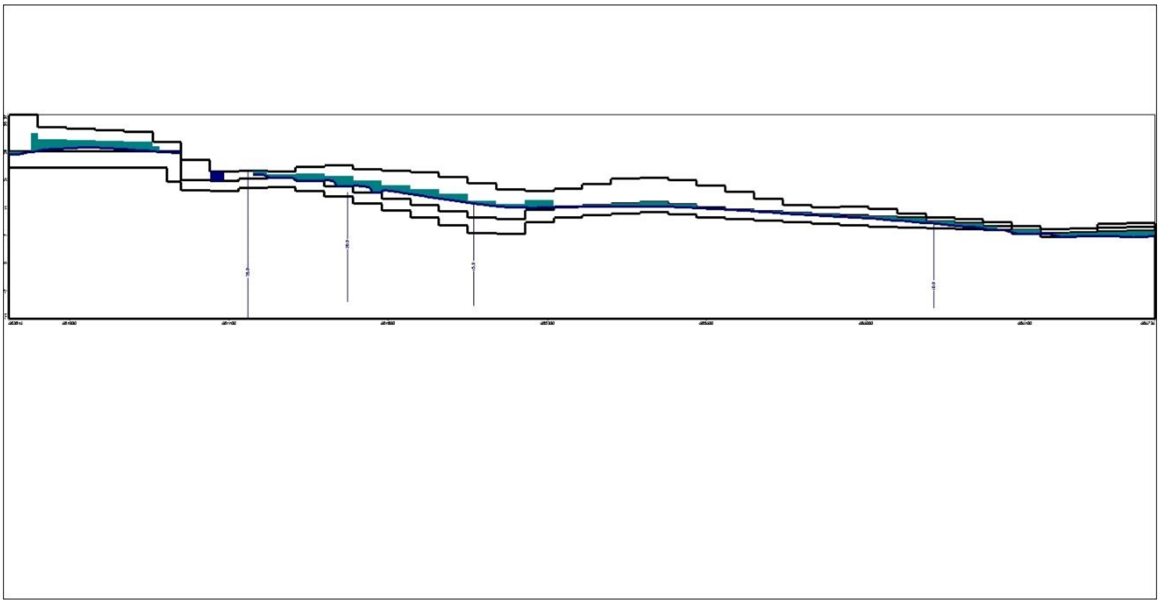

Figure 5-4. Longitudinal profile East- West (Row #93). Seatown-Fosterstown Sector

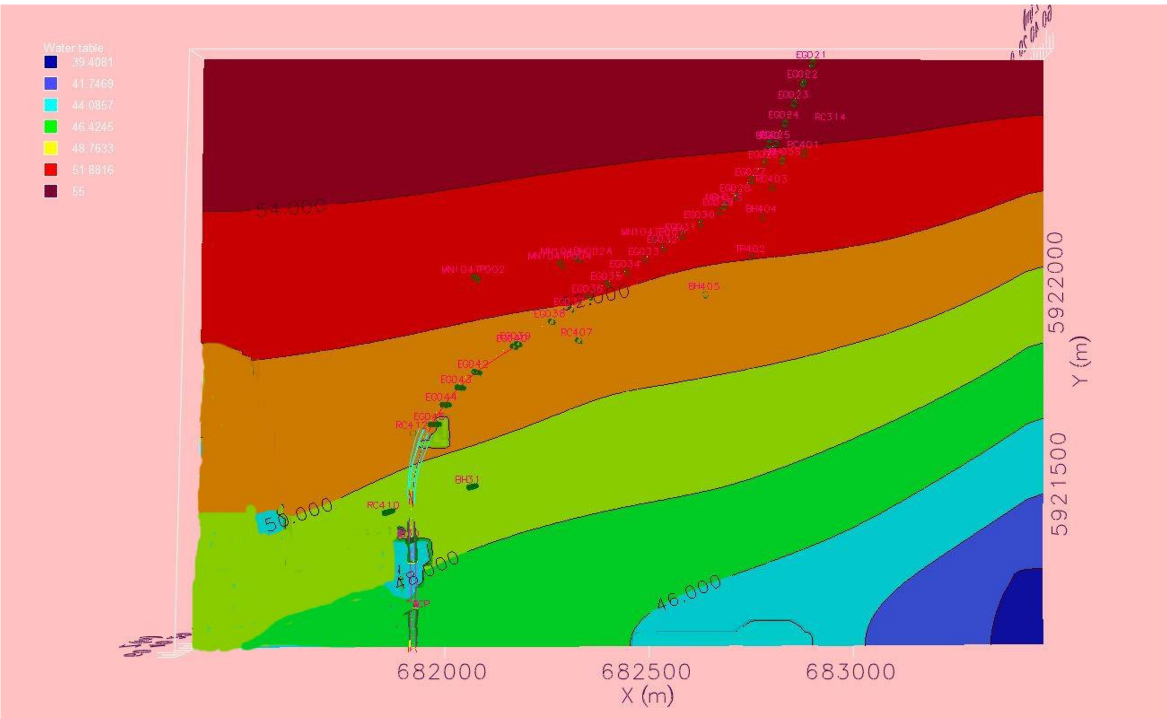

Figure 5-5. Calculated Water Table and Head Observation Wells – Without Diaphragm Walls. Dardistown Sector

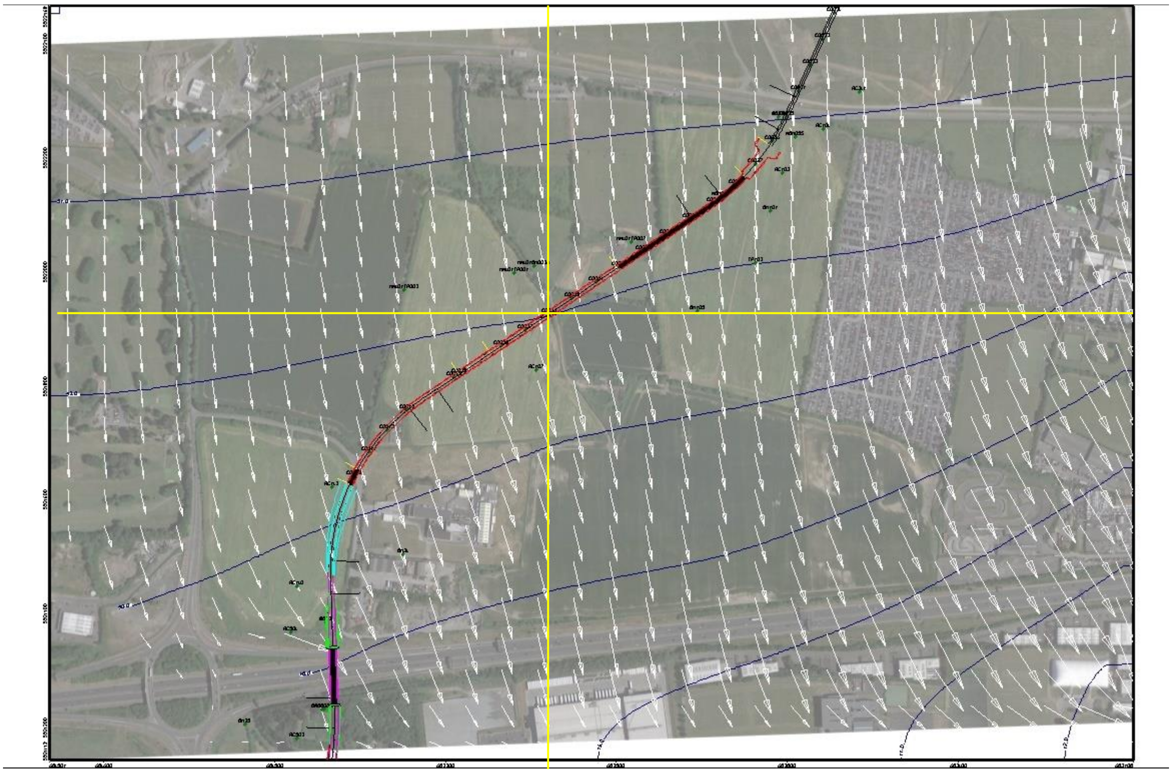

Figure 5-6. Velocity vectors longitudinal profiles marks. Dardistown Sector

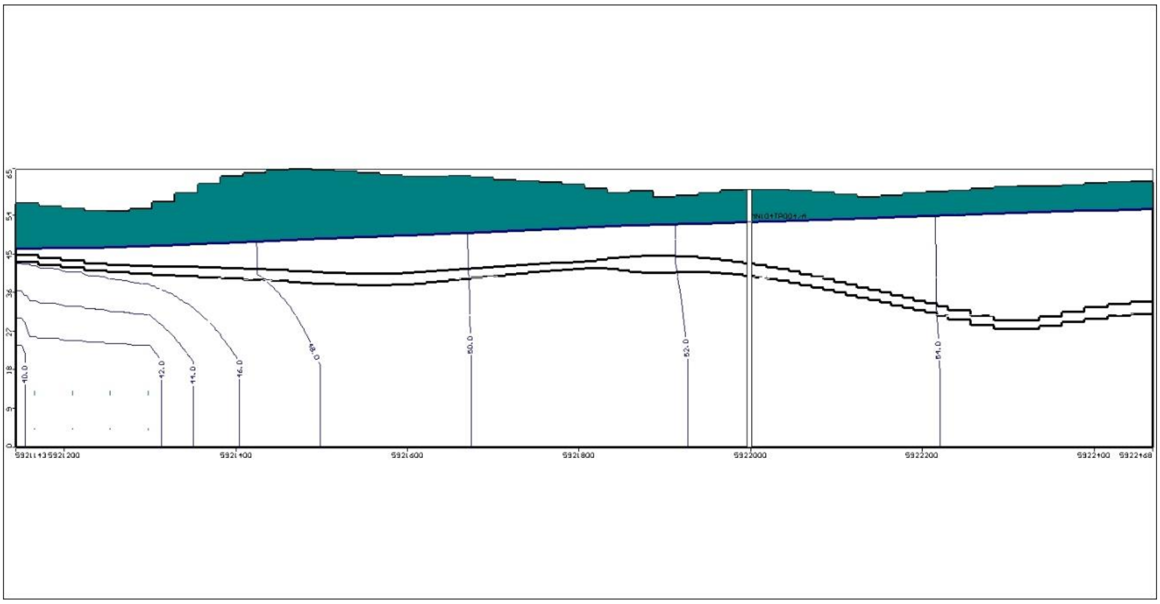

Figure 5-7. Longitudinal profile North-South (Column #73). Dardistown Sector

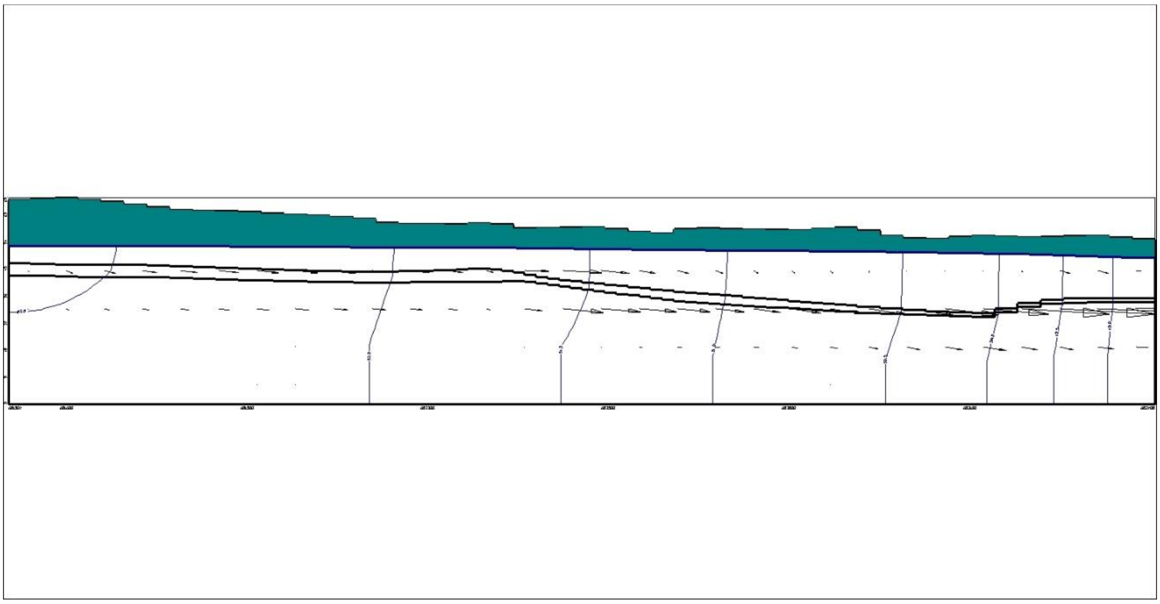

Figure 5-8. Longitudinal profile East- West (Row #63). Dardistown Sector

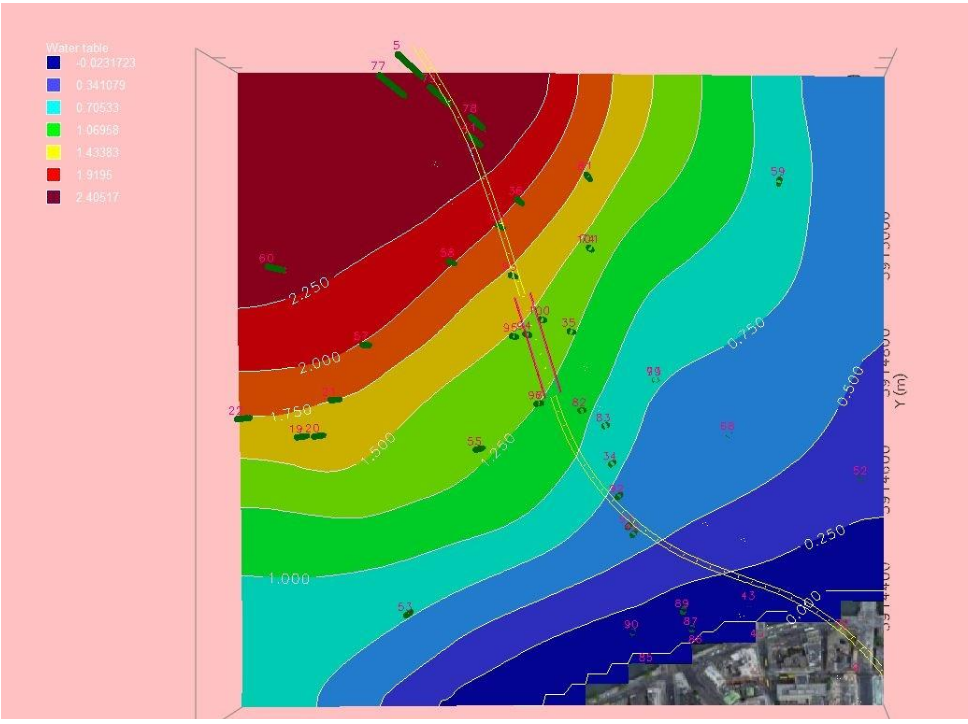

Figure 5-9. Calculated Water Table and Head Observation Wells – Without Diaphragm Walls. O'Conell Sector

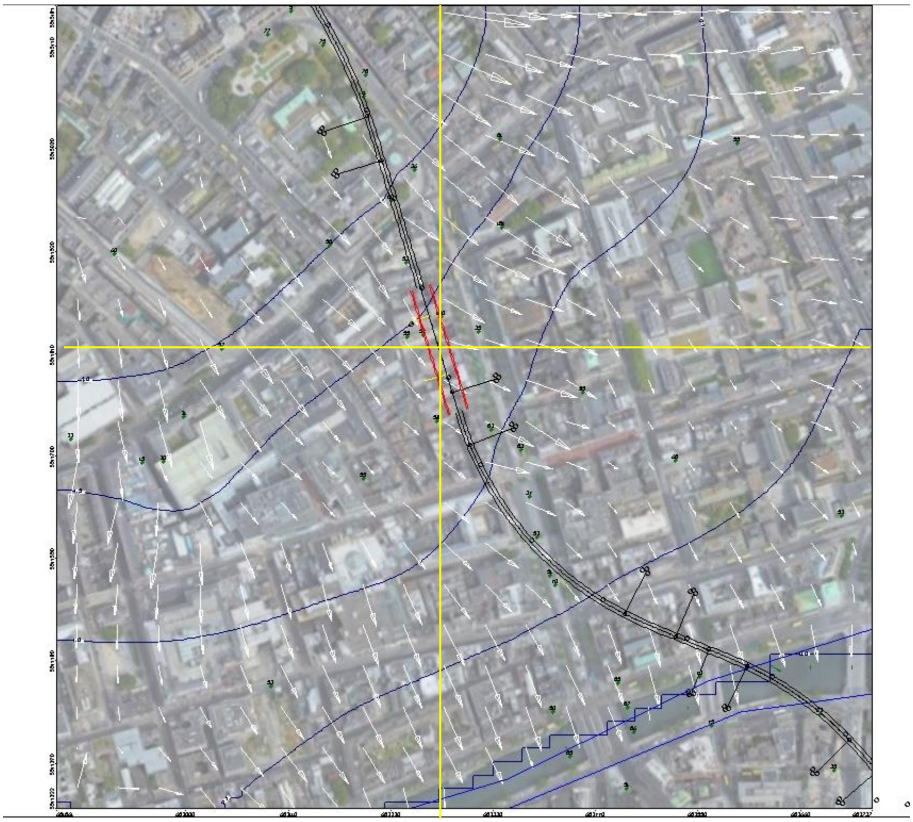

Figure 5-10. Velocity vectors and longitudinal profiles marks. O'Conell Sector

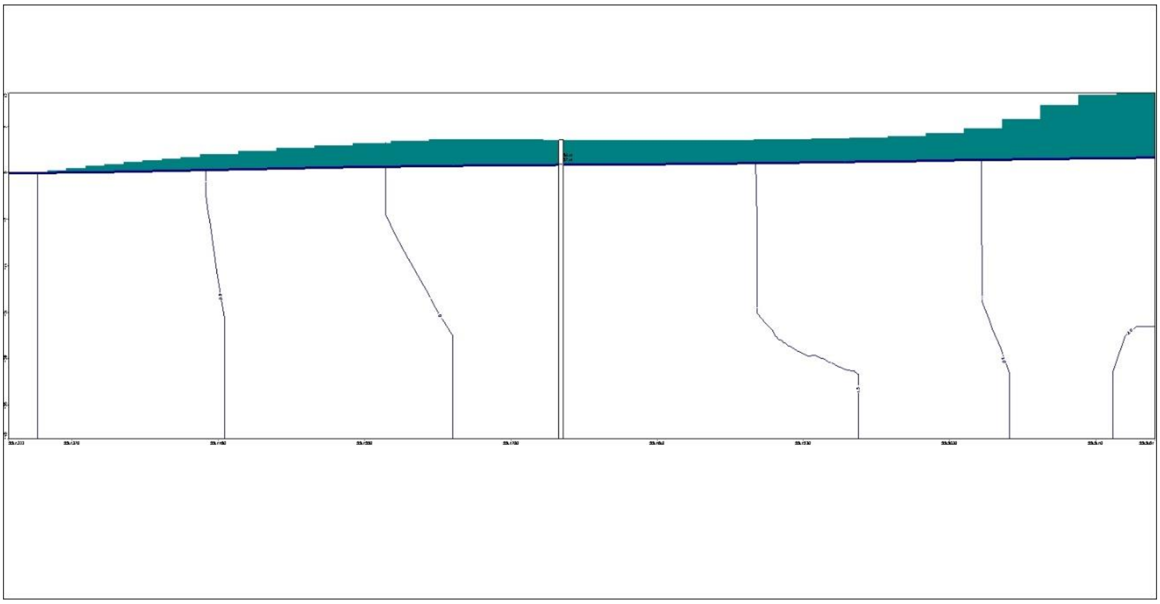

Figure 5-11. Longitudinal profile North-South crossing O'Conell (Column #46). O'Conell Sector

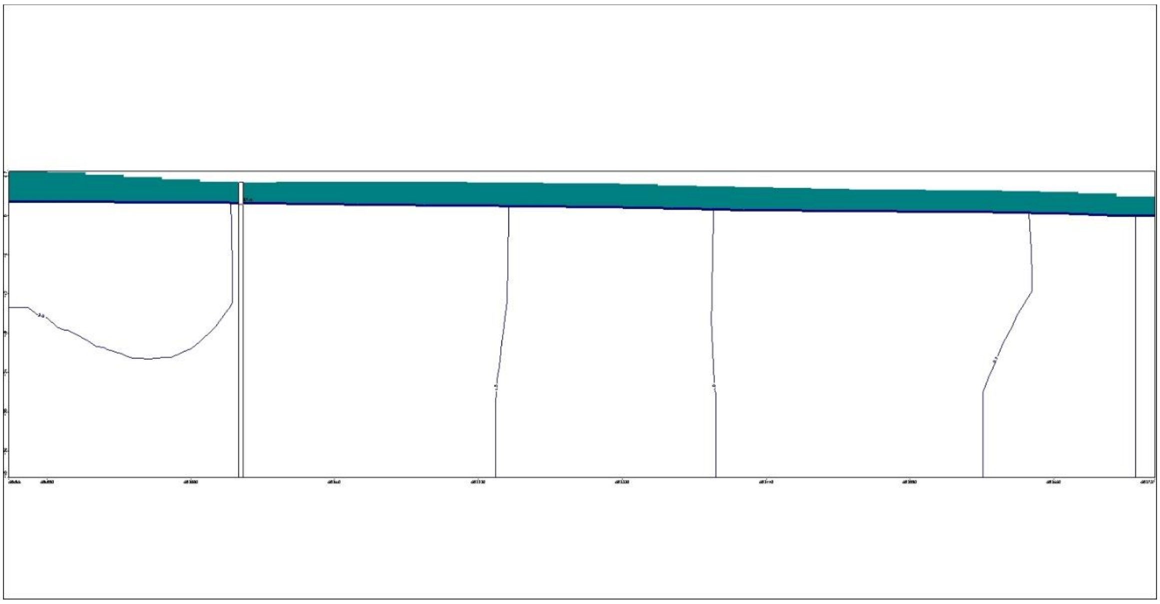

Figure 5-12. Longitudinal profile East- West crossing O'Conell (Row #53). O'Conell Sector

5.1.2 Calibration Graphs

The acceptability of a model's calibration is usually a subjective measure, as each model has different objectives, and must be calibrated to different conditions. However, there are some generally accepted methods of evaluating and interpreting the model calibration using both qualitative and quantitative measures.

Visual MODFLOW provides a comprehensive selection of model calibration analysis tools for evaluating, interpreting, and presenting the model calibration, including Calculated vs. Observed Heads Scatter Graphs.

These graphs represent a snap-shot in time of the comparison between the values calculated by the model (Y-axis), and the values observed or measured in the field (X-axis). When all of the data points intersect the 45-degree line on the graph where X=Y, this represents an ideal calibration scenario, but it is not likely to happen in many real-life situations.

The Calibration Residual (Ri) is defined as the difference between the calculated results (Xcal) and the observed results (Xobs) at selected data points vm_ch9_output66 (as shown in the following equation):

$$R_i = X_{cal} - X_{obs}$$

The Maximum and the Minimum residuals at the selected observation points are also reported.

The Root Mean Squared error (RMS) is defined by the following equation:

$$\bar{R} = \frac{1}{n} \sum_{i=1}^{n} R_i$$

The Normalized Root Mean Squared is the RMS divided by the maximum difference in the observed head values, and is expressed by the following equation:

$$NormalizedRMS = \frac{RMS}{(X_{obs})_{max} - (X_{obs})_{min}}$$

The Normalized RMS is expressed as a percentage, and is a more representative measure of the fit than the standard RMS, as it accounts for the scale of the potential range of data values. **An adjustment with a Normalized Root Mean Squared error (RMS) close to 10% is accepted (never higher than 15%) and the correlation coefficient (R) must be equal or great than 0.9**

The following Scatter Graphs shows the comparison between the mean groundwater level measured in the boreholes and level obtained in the model (Calculated vs. Observed)

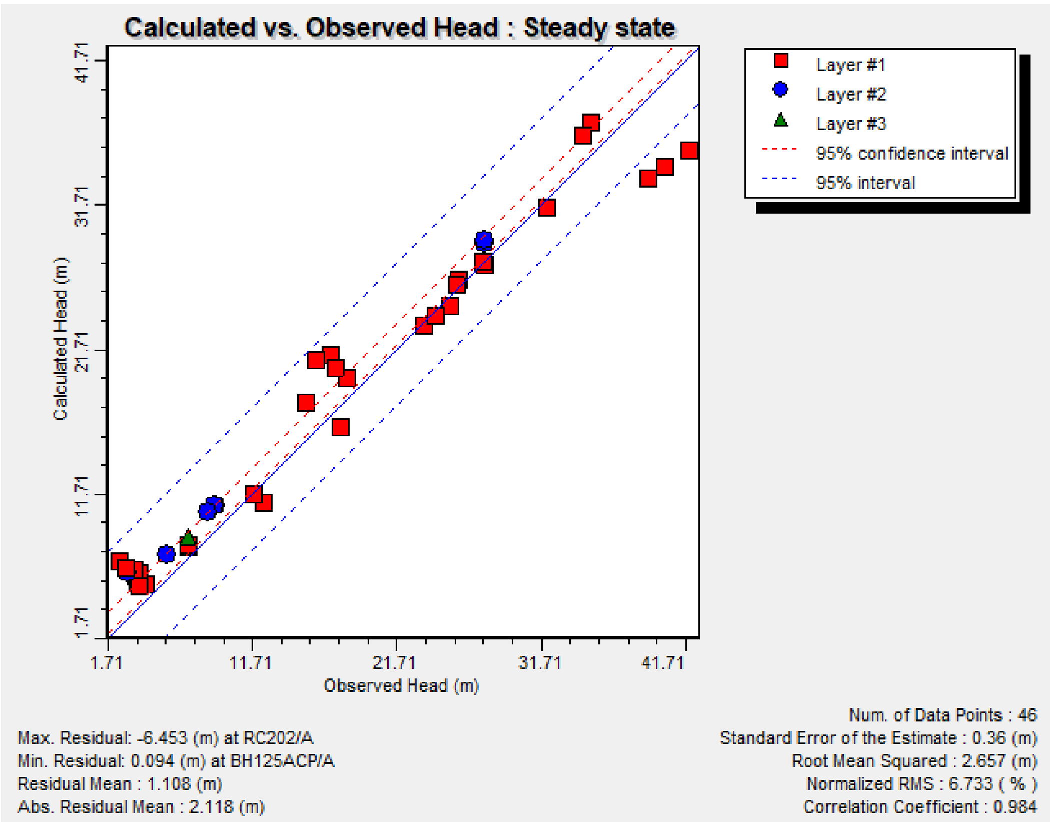

Figure 5-13. Calculated vs. Observed Head ***(Normalized RMS 6.733 %, CC=0.984)*** *– Head Observation Wells. Seatown-Fosterstown Sector*

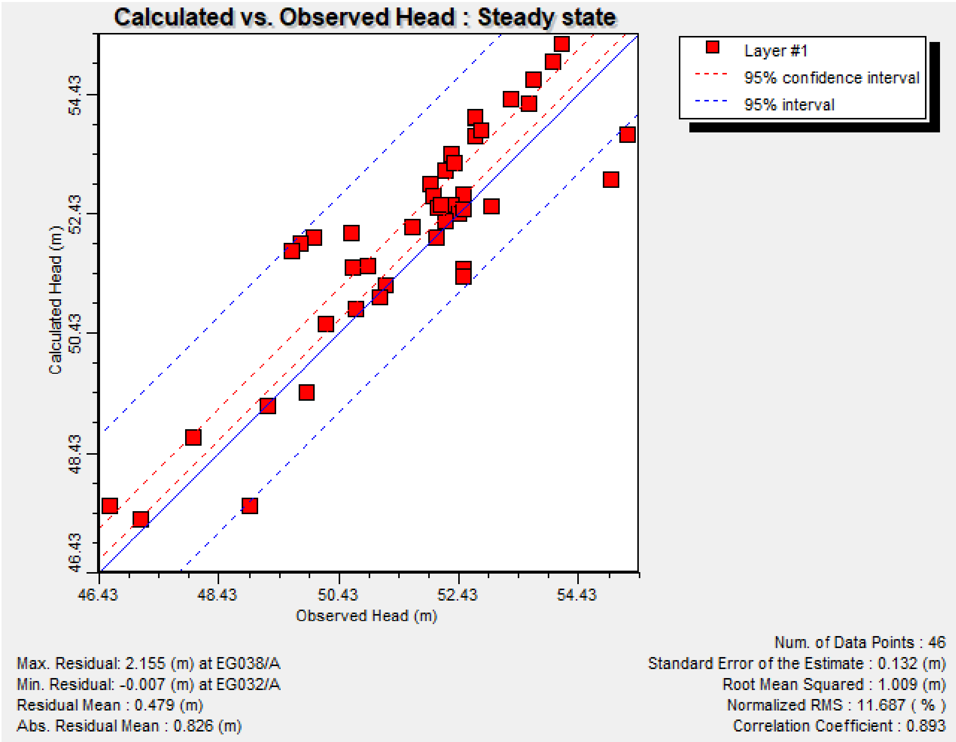

*Figure 5-14. Calculated vs. Observed Head **(RMS 11.68 %, CC=0.893)** –Head Observation Wells. Dardistown Sector*

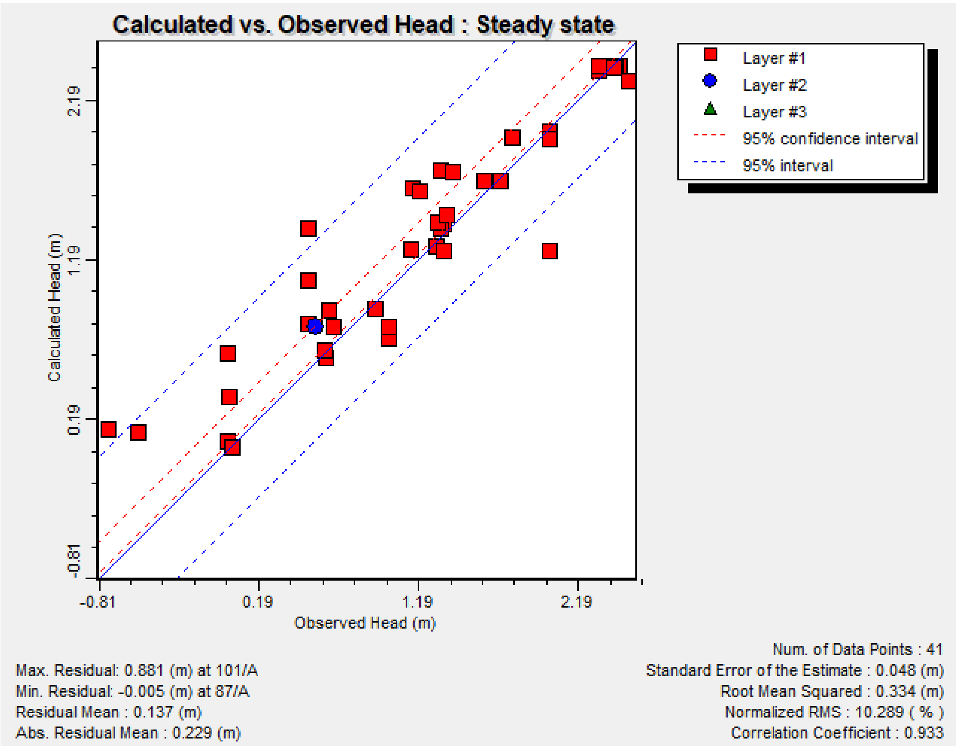

*Figure 5-15. Calculated vs. Observed Head **(RMS 10.289 %, CC=0.933)** – Head Observation Wells. O´Conell St*

The following tables show the differences obtained between the calculation and the recording of each observation well:

SEATOWN-FOSTERSTOWN SECTOR					
Well/Point Name	**X-Model**	**Y-Model**	**Obs.**	**Calc.**	**Calc.-Obs.**
BH117/A	684997.9	5926553	15.470	18.084	2.614
BH123ACP/A	684453.4	5926060	25.930	26.589	0.659
BH125/A	684326.6	5925917	27.840	27.553	-0.287
BH125A/A	684326.7	5925919	27.760	27.548	-0.212
BH125ACP/A	684319.4	5925913	27.650	27.744	0.094
BH126/A	684264.3	5925954	27.800	29.003	1.203
BH129ACP/A	685015.1	5926649	17.800	16.290	-1.510
BH139/A	684625.6	5926156	25.420	24.772	-0.648
BH204/A	684052.8	5925581	35.100	37.461	2.361
BH66/A	684260.6	5925914	27.830	29.269	1.439
BH67/A	684950.1	5926389	17.420	20.382	2.962
BH69/A	684887.1	5927625	2.960	6.570	3.610
NBH401/A	684843.7	5927717	3.700	5.474	1.774
NBH402/A	684838.3	5927712	3.790	5.658	1.868
NBH403 (DEEP)/A	684831.8	5927747	4.290	5.434	1.144
NBH403 (SHALLOW)/A	684831.8	5927747	3.820	5.396	1.576
NBH404 (DEEP)/A	684831.7	5927681	3.875	6.200	2.325
NBH404 (SHALLOW)/A	684831.7	5927681	3.898	6.200	2.302
NBH405 (DEEP)/A	684899.6	5927706	3.830	5.394	1.564
NBH405 (SHALLOW)/A	684899.6	5927706	3.820	5.394	1.574
NBH406/A	684894.8	5927455	7.220	8.075	0.855
NBH407/A	684902.1	5927425	7.220	8.185	0.965
NBH408/A	684976.9	5927411	5.790	7.534	1.744
RC BESIDE NBH404/A	684834.7	5927663	3.540	6.471	2.931
RC108/A	684837.2	5927670	3.100	6.228	3.128
RC111/A	685017.5	5927277	7.320	8.687	1.367
RC113/A	685004.3	5927087	9.160	10.932	1.772
RC113A/A	685003.5	5927088	9.120	10.935	1.815
RC114/A	685085.6	5926935	12.460	11.075	-1.385
RC116/A	685094.8	5926827	11.790	11.658	-0.132
RC118/A	684974.6	5926435	18.260	19.775	1.515
RC121/A	684739.7	5926220	23.580	23.391	-0.189
RC122/A	684711.7	5926142	24.420	24.038	-0.382
RC124/A	684369.3	5925952	25.880	26.216	0.336
RC128/A	684187.6	5925803	32.130	31.581	-0.549
RC203/A	684100.6	5925609	34.570	36.562	1.992
RC67/A	684950.1	5926389	17.420	20.382	2.962
RC68/A	685034.6	5927115	8.640	10.388	1.748

Table 5-1. Calculated & Observed Head. Seatown-Fosterstown Sector

DARDISTOWN SECTOR					
Well/Point Name	**X-Model**	**Y-Model**	**Obs.**	**Calc.**	**Calc.-Obs.**
BH30/A	681990.3	5921385	48	48.71	0.710
BH31/A	682125.6	5921503	49.25	49.22	-0.034
BH32/A	682783.8	5922271	52.7	54.04	1.335
BH404/A	682769.2	5922107	52.5	52.75	0.247
BH405/A	682641	5921932	52.5	51.50	-1.000
BH503ACP/A	681985.8	5921233	48.94	47.55	-1.392
EG021/A (*)	682882.1	5922454	54.15	54.27	0.120
EG022/A (*)	682861.3	5922409	54	54.97	0.974
EG023/A (*)	682840.4	5922363	53.68	54.67	0.985
EG024/A (*)	682819.6	5922318	53.3	54.35	1.051
EG025/A (*)	682798.6	5922273	52.7	53.03	0.330
EG026/A (*)	682774	5922229	52.7	53.72	1.025
EG027/A (*)	682744.2	5922189	52.3	52.43	0.130
EG028/A (*)	682709.9	5922153	52.2	52.16	-0.040
EG029/A (*)	682671.5	5922121	51.95	51.93	-0.020
EG030/A (*)	682630.1	5922093	52	52.74	0.742
EG031/A (*)	682588.6	5922065	52.31	52.57	0.263
EG032/A (*)	682547	5922037	52.43	52.43	-0.004
EG033/A (*)	682505.5	5922009	52.2	52.30	0.101
EG034/A (*)	682463.9	5921981	51.65	52.20	0.546
EG035/A (*)	682422.4	5921954	50.64	51.11	0.470
EG036/A (*)	682380.8	5921926	50	51.02	1.020
EG037/A (*)	682339.3	5921898	49.8	50.93	1.130
EG038/A (*)	682297.7	5921870	49.65	50.82	1.170
EG039/A (*)	682222.9	5921820	50.9	51.57	0.665
EG040/A (*)	682214.6	5921814	50.65	51.54	0.887
EG042/A (*)	682132.8	5921757	51.2	51.24	0.043
EG043/A (*)	682096.5	5921723	51.1	51.06	-0.043
EG044/A(*)	682065.1	5921684	50.7	50.84	0.140
EG045/A (*)	682039.5	5921641	50.2	50.58	0.383
MN104BH002A/A	682354.8	5922010	52.07	52.54	0.470
MN104TP002/A	682127	5921968	52.98	52.58	-0.405
MN104TP004/A	682319.3	5921999	52.49	52.52	0.027

DARDISTOWN SECTOR					
Well/Point Name	**X-Model**	**Y-Model**	**Obs.**	**Calc.**	**Calc.-Obs.**
MN104TP007/A	682525.4	5922053	52.13	52.57	0.444
NBH05S/A	682814.3	5922237	55.23	53.76	-1.475
NBH07S/A	682683.7	5922132	54.97	53.01	-1.958
RC30/A	681990.3	5921385	48	48.71	0.710
RC314/A	682925.6	5922317	53.6	54.28	0.679
RC32/A	682783.8	5922271	52.7	54.04	1.335
RC401/A	682863.1	5922250	52.8	53.83	1.029
RC403/A	682791.8	5922174	52.35	53.28	0.926
RC407/A	682358	5921827	52.51	51.39	-1.116
RC410/A	681939.2	5921447	49.9	49.45	-0.446
RC501/A	681928.5	5921368	48.3	48.93	0.633
RC503/A	681983.2	5921232	46.6	47.54	0.945
TP402/A	682743.5	5922016	52.06	52.03	-0.032

Table 5-2. Calculated & Observed Head. Dardistown Sector. EG===/A points are taken from the water table defined in the geotechnical profile of the project

O’CONELL					
Well/Point Name	**X-Model**	**Y-Model**	**Obs.**	**Calc.**	**Calc.-Obs.**
NBH23A	682274.6	5914850	1.350	1.409	0.059
NBH23W	682339.1	5914946	0.500	1.381	0.881
B60398	681953.2	5914693	1.150	1.636	0.486
MGI/BH/719	681975.2	5914694	1.200	1.622	0.422
BX/BH02	681997.5	5914742	1.330	1.745	0.415
GL/BH13	681875.8	5914718	1.400	1.740	0.340
B60396	682368.4	5914657	0.500	0.787	0.287
B81346	682313.9	5914834	1.140	1.258	0.118
B81349	682245.5	5915008	1.780	1.957	0.177
GL/BH16	682396.7	5914562	0.610	0.570	-0.040
GL/BH17	682190.1	5915086	2.320	2.370	0.050
GL/BH03	682552.3	5914463	0.000	0.052	0.052
B51664	682112.4	5915178	2.450	2.405	-0.045
B81334	682703.7	5914635	0.010	0.330	0.320
GL/BH34A	682091.6	5914453	0.550	0.771	0.221
GL/BH35	682190.1	5914676	1.300	1.277	-0.023
GL/BH42	682038.5	5914816	1.780	1.958	0.178
GL/BH19	682154	5914927	2.010	1.993	-0.017

O'CONELL					
Well/Point Name	**X-Model**	**Y-Model**	**Obs.**	**Calc.**	**Calc.-Obs.**
GL/BH43	682592.5	5915036	0.920	0.884	-0.036
GL/BH37	681922.8	5914918	2.500	2.308	-0.192
GQBH1	682525.2	5914696	0.600	0.620	0.020
MNEWSS01	682426.4	5914769	0.660	0.773	0.113
MNEWSS02	682339.1	5914946	1.330	1.381	0.051
MGI/BH/708	682087.2	5915153	2.420	2.405	-0.015
BH.11 Luas	682192.9	5915109	2.410	2.388	-0.022
RC10A	682147.2	5915141	2.320	2.404	0.084
RC09	682219.8	5914975	2.010	1.946	-0.064
RC11	682337.1	5915041	1.600	1.679	0.079
BH12	682327.6	5914728	0.500	1.056	0.556
MGI/BH/706	682359.4	5914707	0.630	0.870	0.240
MGI/BH/704	682474.6	5914430	0.020	0.015	-0.005
BH.27 Luas	682463.5	5914457	-0.750	0.127	0.877
AGI/RC/MP11	682393.7	5914425	-0.560	0.112	0.672
AGI/RC/MP12	682390.2	5914572	0.000	0.599	0.599
AGI/BH/MP09A	682377.4	5914613	1.000	0.700	-0.300
BH14	682235.9	5914908	1.700	1.686	-0.014
RC13	682254.9	5914830	1.310	1.427	0.117
BH.28 Luas	682236.9	5914828	1.370	1.469	0.099
AGI/RC/MP07	682269.8	5914738	2.010	1.242	-0.768
IGSL-BH09	682269.8	5914738	1.350	1.242	-0.108
NBH22 (shallow)	682426.4	5914769	1.000	0.773	-0.227

Table 5-3. Calculated & Observed Head. Seatown-Fosterstown Sector

5.1.3 Pathlines

The computer program MODPATH was developed by the USGS (Pollock, 1989) to calculate three-dimensional particle tracking pathlines from steady-state and transient flow simulation output obtained using Visual MODFLOW.

MODPATH uses a semi-analytical particle-tracking scheme. The method is based on the assumption that each directional velocity component varies linearly within a grid cell in its own co-ordinate direction. This assumption allows an analytical expression to be obtained describing the flow path within a grid cell. Given the initial position of a particle anywhere in a cell, the co-ordinates of any other point along its path line within the cell, and the time of travel between them, can be computed.

In each model, single particles have been added to obtain the flow path and thus check their incidence on the axis of the MetroLink alignment. If the trajectories are parallel, the barrier effect will be less significant than if the trajectories are perpendicular to the alignment. In addition, these trajectories show how the water flow is able to overcome the interference imposed by the diaphragm walls.

The following figures show the trajectories obtained through the permeable level BoD.

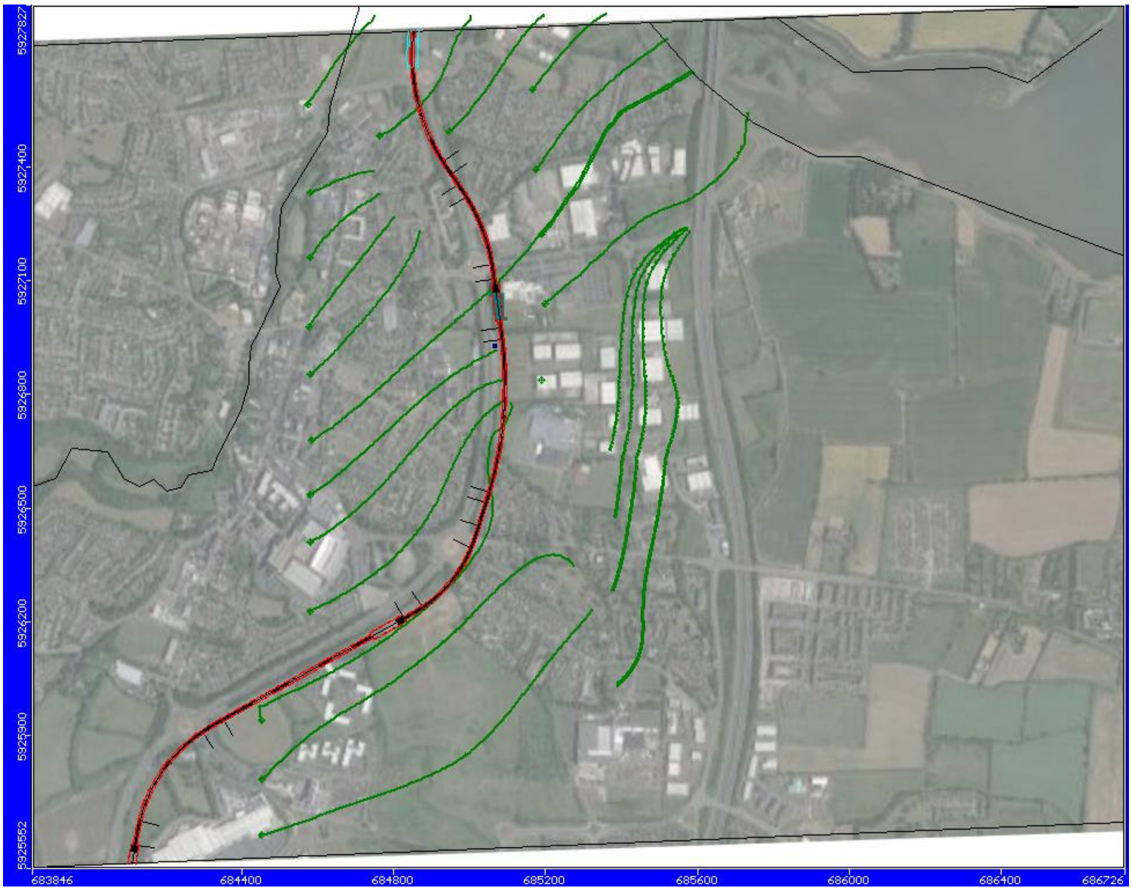

Figure 5-16. Pathlines through BOD level. Seatown-Fosterstown Sector

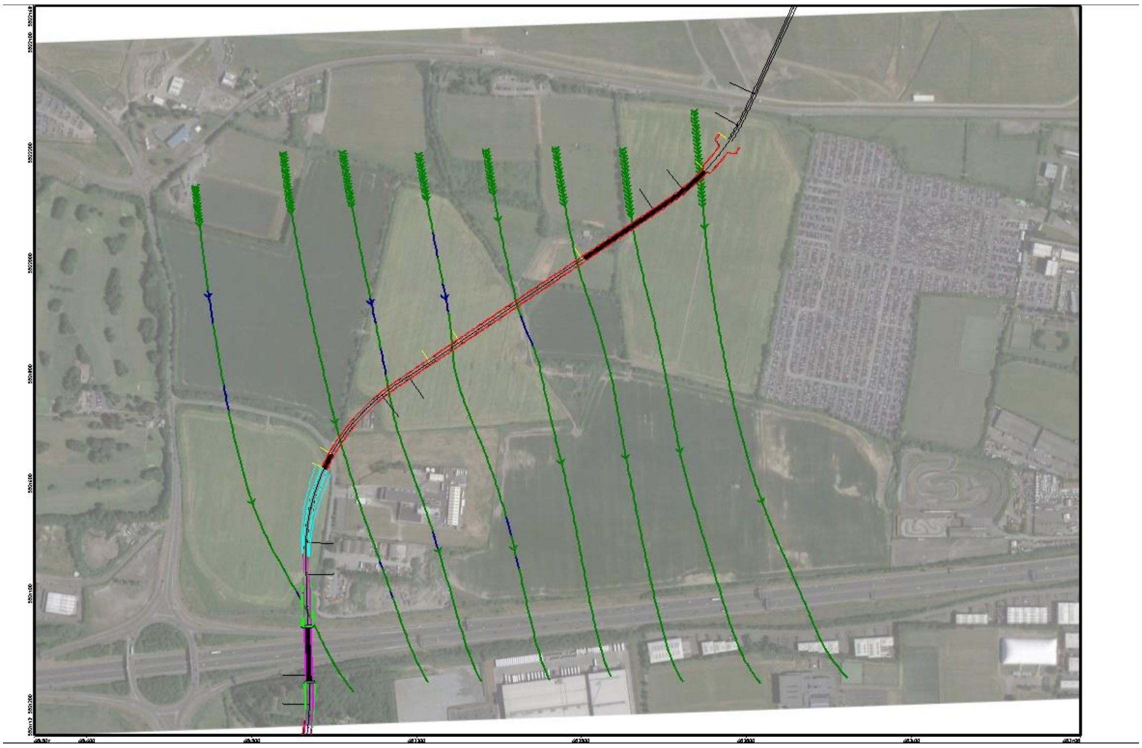

Figure 5-17. Pathlines through BoD level. Dardistown Sector

Figure 5-18. Pathlines through BoD level. O'Conell Sector

For the first sector (Seatown-Fosterstown Sector) it can be seen that there are some points of the alignment where the trajectories cut at approximately 45 degrees. Especially in the sector where the Seatown station is located. Between Swords Central and Fosterstown Station the paths are practically parallel to the line.

In the Dardistown sector the trajectories are almost perpendicular to the alignment, but in this case the diaphragm walls do not cut through the permeable level (Bod) and the barrier effect may not be significant.

At O'Conell station the flow lines cut the alignment with a more oblique path but in this case the diaphragm walls do cut the permeable level (BoD) However, in this sector the rest of the MetroLink line is executed by TBM and the flow lines can bypass the station without developing the barrier effect.

5.1.4 Hydraulic gradient

To determine the flow rates that cross the MetroLink alignment, the hydraulic gradients have been obtained. The following figures show the gradient of the permeable (BoD) layers in the predominant direction of flow.

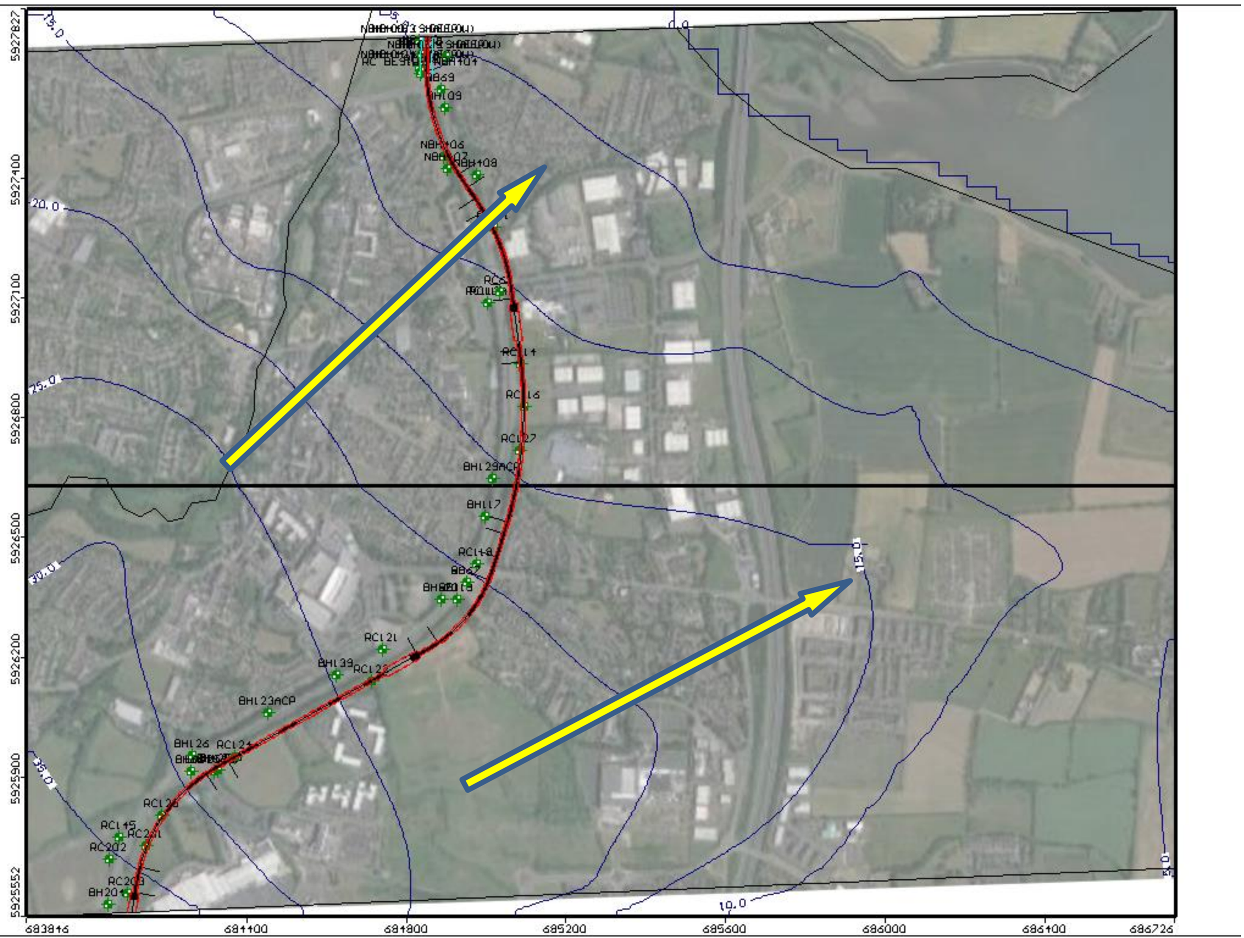

*Figure 5-19. Water table gradient, **i = 0.015**. Seatown-Fosterstown Sector*

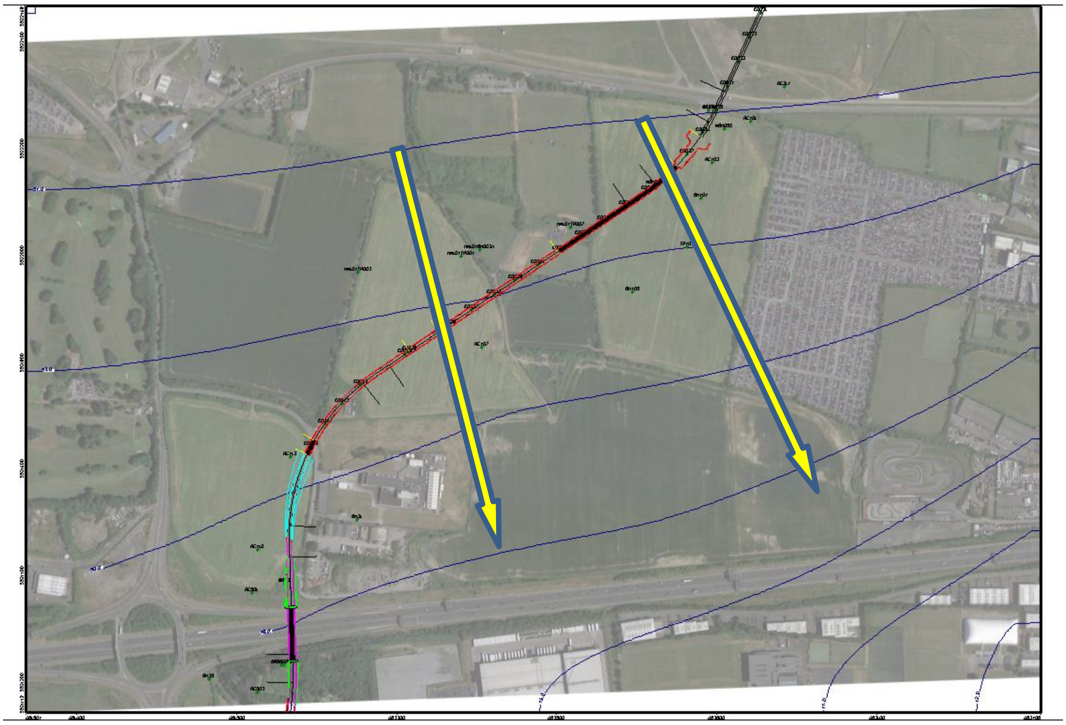

*Figure 5-20. Water table gradient, **i = 0.0086**. Dardistown Sector*

*Figure 5-21. Water table gradient, **i = 0.003**) O'Conell Sector*

5.2 INTERACTION WITH DIAPHRAGM WALLS

Once the models have been calibrated, the diaphragm walls are introduced to obtain the heads, the groundwater levels and the pathlines again. This second stage of calculation is also carried out under the consideration of steady state.

With the help of the longitudinal profiles provided by Modflow, the changes in heads and water table elevations that occur as a result of the inclusion of the diaphragm walls can be easily consulted.

The following sections show the results obtained for the water table and the flow conditions.

5.2.1 Seatown-Fosterstown Sector

In this sector, the diaphragm walls cut the permeable level BoD, increasing the possibility of producing the barrier effect.

The Figure 5-22 below shows the 3D representation of the diaphragm walls.

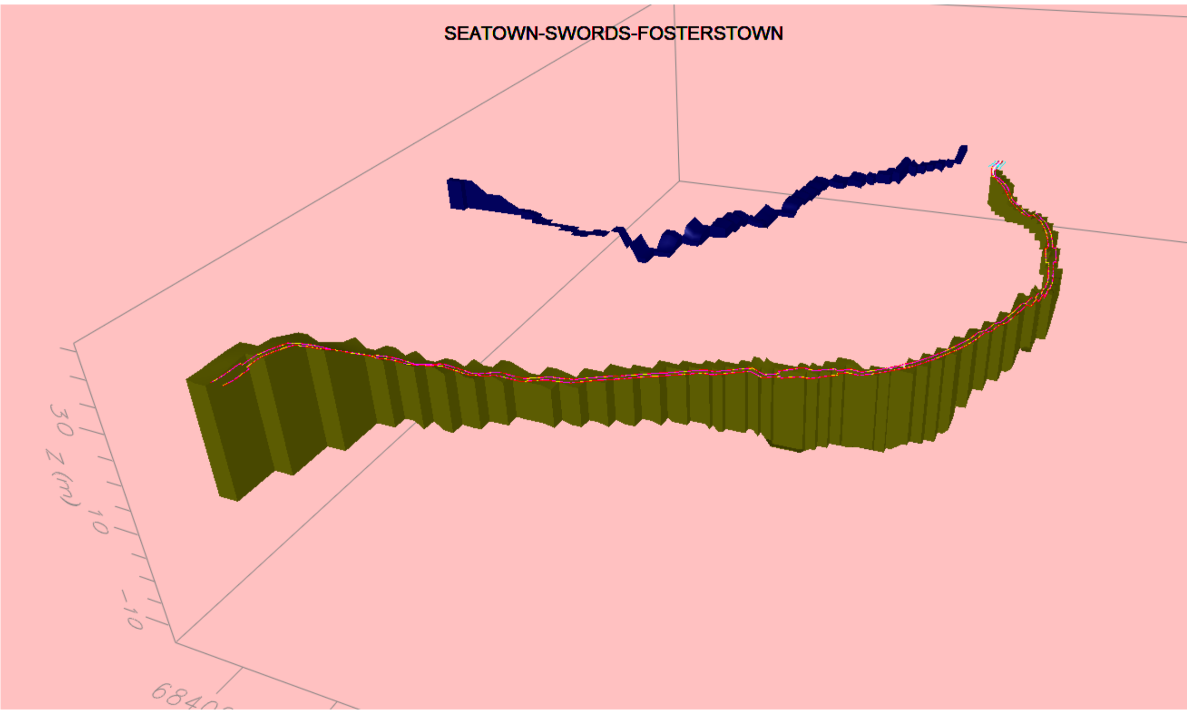

Figure 5-22. 3D view of the diaphragm walls. Seatown-Fosterstown Sector

The results obtained for this scenario with Visual MODFLOW are shown in the following figures:

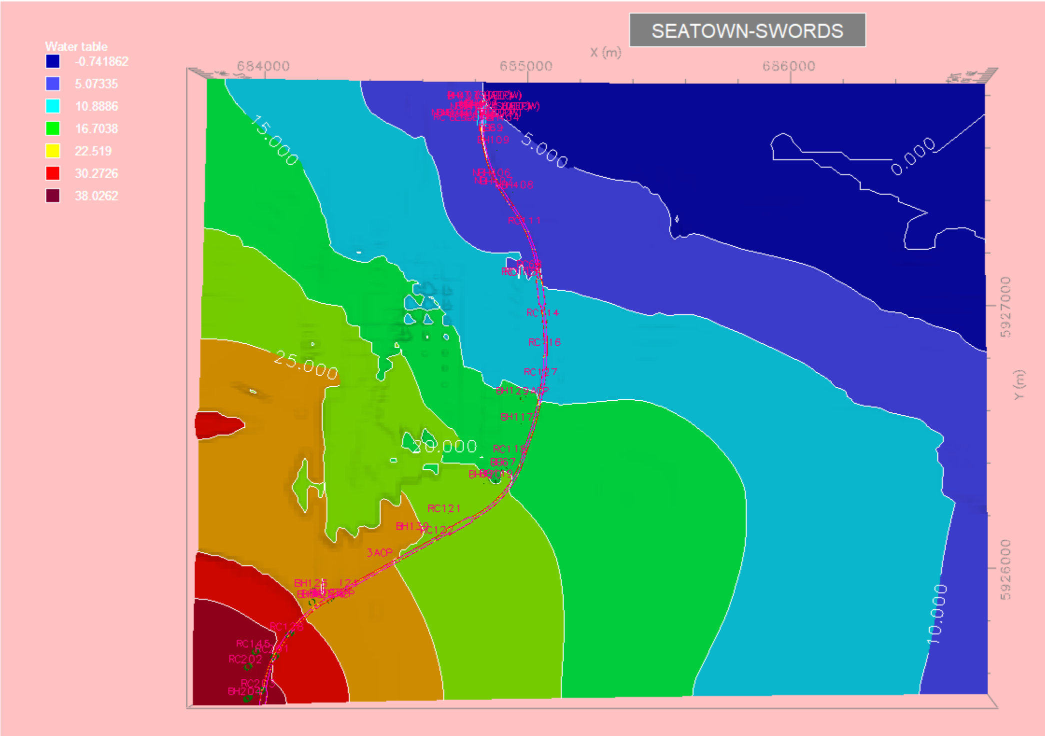

Figure 5-23. Calculated Water Table and Head Observation Wells – With Diaphragm Walls. Seatown-Fosterstown Sector

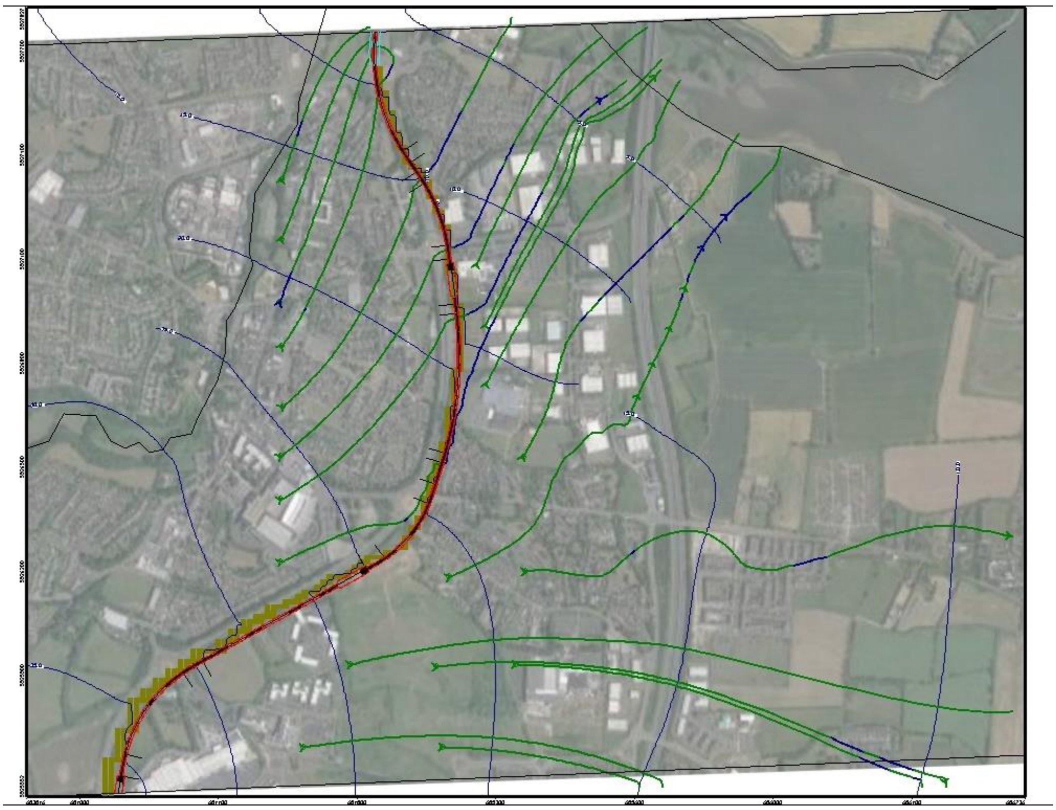

Figure 5-24. Pathlines through BOD level- With Diaphragm Wall. Seatown-Fosterstown Sector

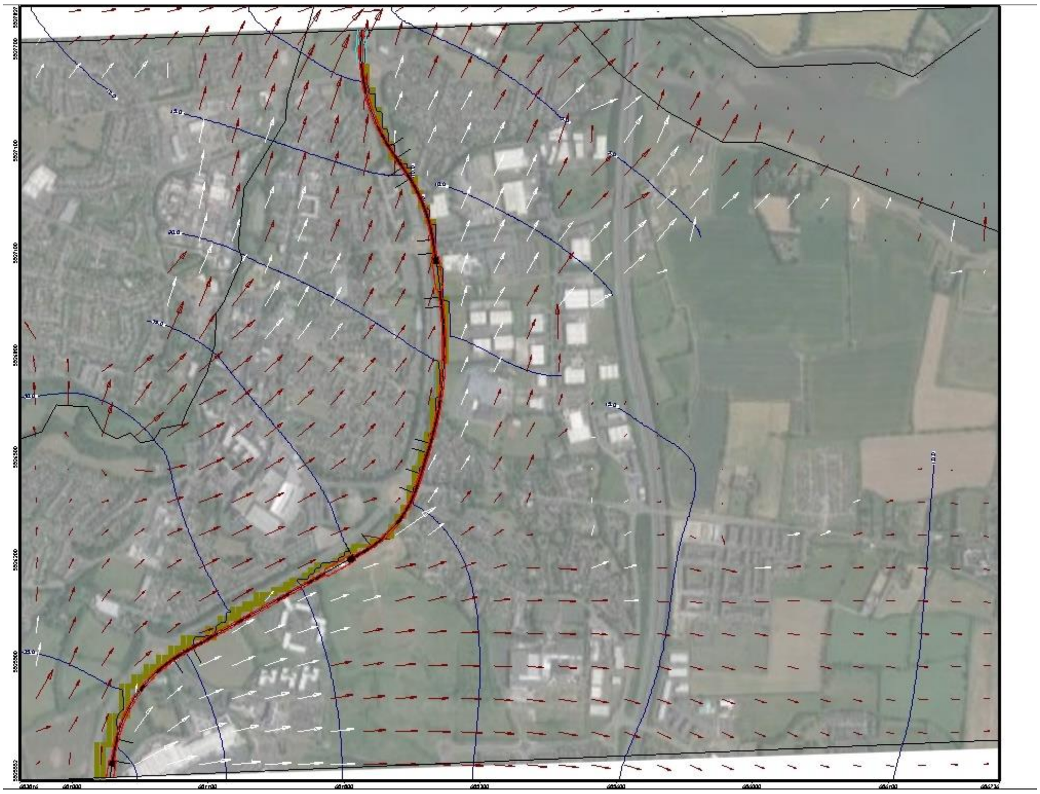

Figure 5-25. Velocity vector longitudinal profiles marks- With Diaphragm Wall. Seatown-Fosterstown Sector

The Figure 5-26 and Figure 5-27 below shows a cross section of the water table at Seatown Station.

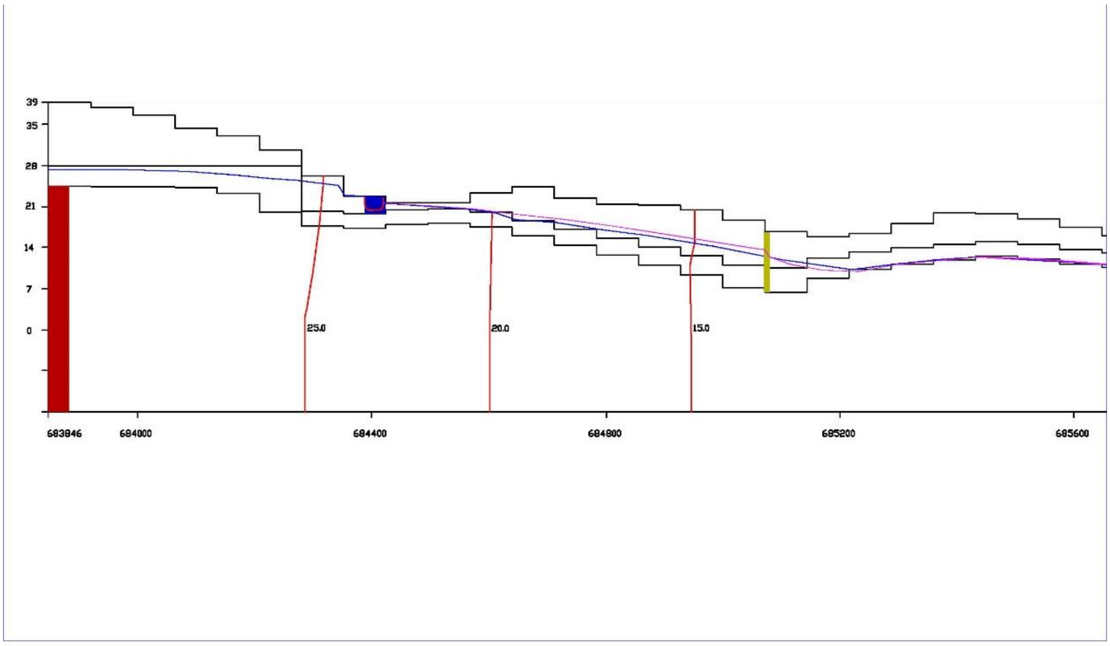

Figure 5-26. Longitudinal profile East- West (Row #93). Seatown-Fosterstown Sector

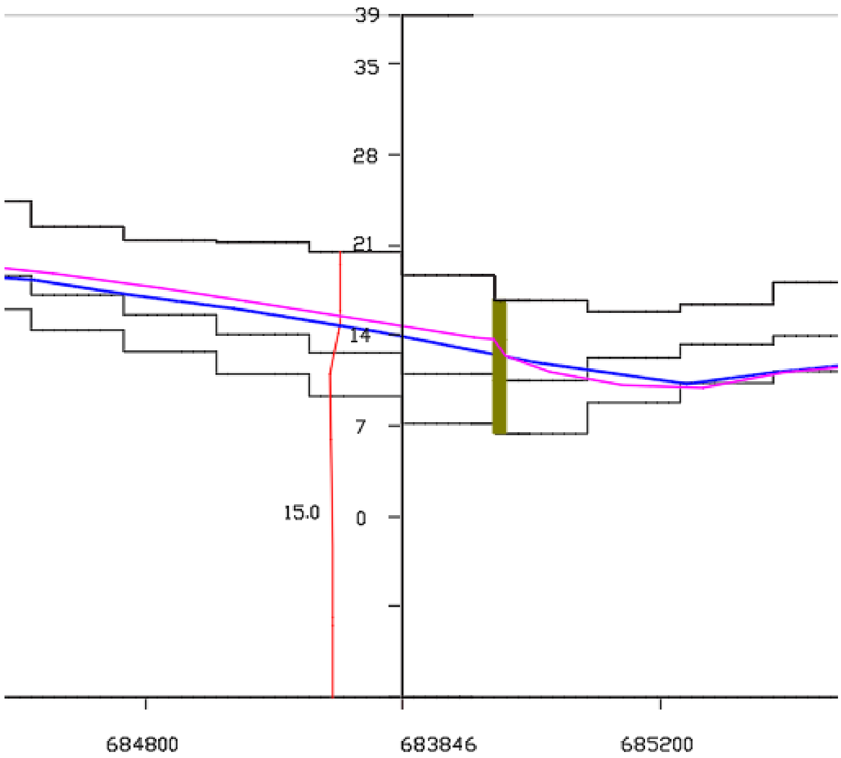

Figure 5-27. Longitudinal profile East- West (Row #93) detail. Measurement of the elevation of the water table upstream diaphragm wall: ***Elevation = 1.20 m****. Seatown-Fosterstown Sector*

In the Figure 5-27 it can be seen in more detail the elevation in Model Row #93 that is produced as a result of the incorporation of the diaphragm wall. The over-elevation is **1.20 m**, higher than the recommended value of 1.00 m, beyond which it may be considered necessary to use flow by-pass systems to mitigate the barrier effect.

SEATOWN-FOSTERSTOWN SECTOR							
Well/Point Name	X-Model	Y-Model	Obs.	Calc. Without D. Walls	Calc. With D. Walls	Differences	Position
BH117/A	684,998	5,926,553	15.47	18.08	19.22	1.135	upstream
BH123ACP/A	684,453	5,926,060	25.93	26.59	27.92	1.329	upstream
BH126/A	684,264	5,925,954	27.80	29.00	29.58	0.581	upstream
BH129ACP/A	685,015	5,926,649	17.80	16.29	16.93	0.635	upstream
BH139/A	684,626	5,926,156	25.42	24.77	25.58	0.809	upstream
BH66/A	684,261	5,925,914	27.83	29.27	30.30	1.034	upstream
NBH403 (DEEP)/A	684,832	5,927,747	4.29	5.43	5.34	-0.094	upstream
NBH403 (SHALLOW)/A	684,832	5,927,747	3.82	5.40	5.30	-0.094	upstream
NBH406/A	684,895	5,927,455	7.22	8.07	8.63	0.557	upstream
NBH407/A	684,902	5,927,425	7.22	8.19	8.69	0.507	upstream
RC BESIDE NBH404/A	684,835	5,927,663	3.54	6.47	6.50	0.028	upstream

SEATOWN-FOSTERSTOWN SECTOR							
Well/Point Name	X-Model	Y-Model	Obs.	Calc. Without D. Walls	Calc. With D. Walls	Differences	Position
RC108/A	684,837	5,927,670	3.10	6.23	6.20	-0.032	upstream
RC113/A	685,004	5,927,087	9.16	10.93	12.16	1.225	upstream
RC113A/A	685,004	5,927,088	9.12	10.94	12.16	1.221	upstream
RC118/A	684,975	5,926,435	18.26	19.78	20.23	0.459	upstream
RC121/A	684,740	5,926,220	23.58	23.39	23.48	0.092	upstream
RC122/A	684,712	5,926,142	24.42	24.04	23.87	-0.165	upstream
RC203/A	684,101	5,925,609	34.57	36.56	36.54	-0.024	upstream
RC67/A	684,950	5,926,389	17.42	20.38	20.94	0.554	upstream
RC68/A	685,035	5,927,115	8.64	10.39	10.80	0.410	upstream
BH125/A	684,327	5,925,917	27.84	27.55	27.48	-0.075	downstream
BH125A/A	684,327	5,925,919	27.76	27.55	27.47	-0.076	downstream
BH125ACP/A	684,319	5,925,913	27.65	27.74	27.82	0.077	downstream
BH204/A	684,053	5,925,581	35.10	37.46	37.85	0.393	downstream
BH67/A	684,950	5,926,389	17.42	20.38	19.94	-0.446	downstream
BH69/A	684,887	5,927,625	2.96	6.57	5.53	-1.043	downstream
NBH401/A	684,844	5,927,717	3.70	5.47	5.36	-0.117	downstream
NBH402/A	684,838	5,927,712	3.79	5.66	5.56	-0.102	downstream
NBH404 (DEEP)/A	684,832	5,927,681	3.88	6.20	6.16	-0.037	downstream
NBH404 (SHALLOW)/A	684,832	5,927,681	3.90	6.20	6.16	-0.037	downstream
NBH405 (DEEP)/A	684,900	5,927,706	3.83	5.39	5.05	-0.343	downstream
NBH405 (SHALLOW)/A	684,900	5,927,706	3.82	5.39	5.05	-0.343	downstream
NBH408/A	684,977	5,927,411	5.79	7.53	5.87	-1.663	downstream
RC111/A	685,018	5,927,277	7.32	8.69	8.59	-0.097	downstream
RC114/A	685,086	5,926,935	12.46	11.08	11.07	-0.003	downstream
RC116/A	685,095	5,926,827	11.79	11.66	11.67	0.013	downstream
RC124/A	684,369	5,925,952	25.88	26.22	26.11	-0.106	downstream
RC128/A	684,188	5,925,803	32.13	31.58	31.37	-0.215	downstream

Table 5-4. Over-elevations calculated in the observation wells upstream and downstream of the diaphragm walls. Seatown-Fosterstown Sector

Upstream a mean over-elevation is obtained equal to **0.62 m** and downstream a mean depression of **0.24 m** is obtained (for the head observation wells)

5.2.2 Dardistown Sector

In this sector the diaphragm walls do not cut the permeable level BoD, therefore, the barrier effect could be irrelevant. However, and adopting a conservative point of view, it has been considered that the diaphragm walls in this sector cut all levels above the BoD level.

The Figure 5-28 shows the 3D representation of the diaphragm walls.

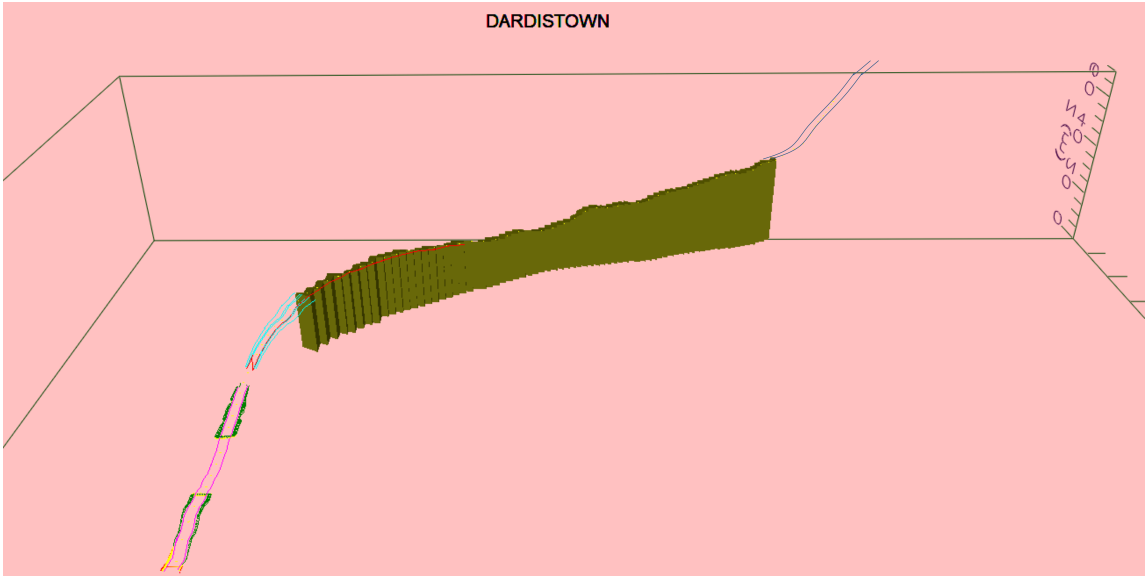

Figure 5-28. 3D view of the diaphragm walls. Dardistown Sector

The results obtained for this scenario with Visual MODFLOW are shown in the following figures:

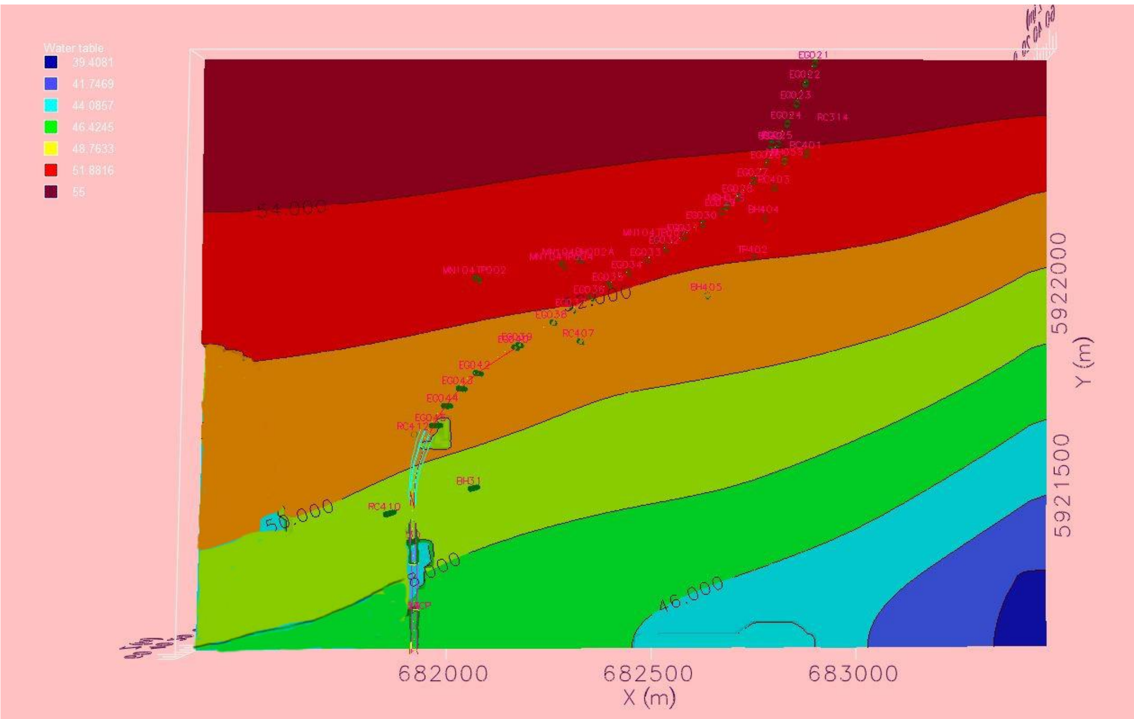

Figure 5-29. Calculated Water Table and Head Observation Wells – With Diaphragm Walls. Dardistown Sector

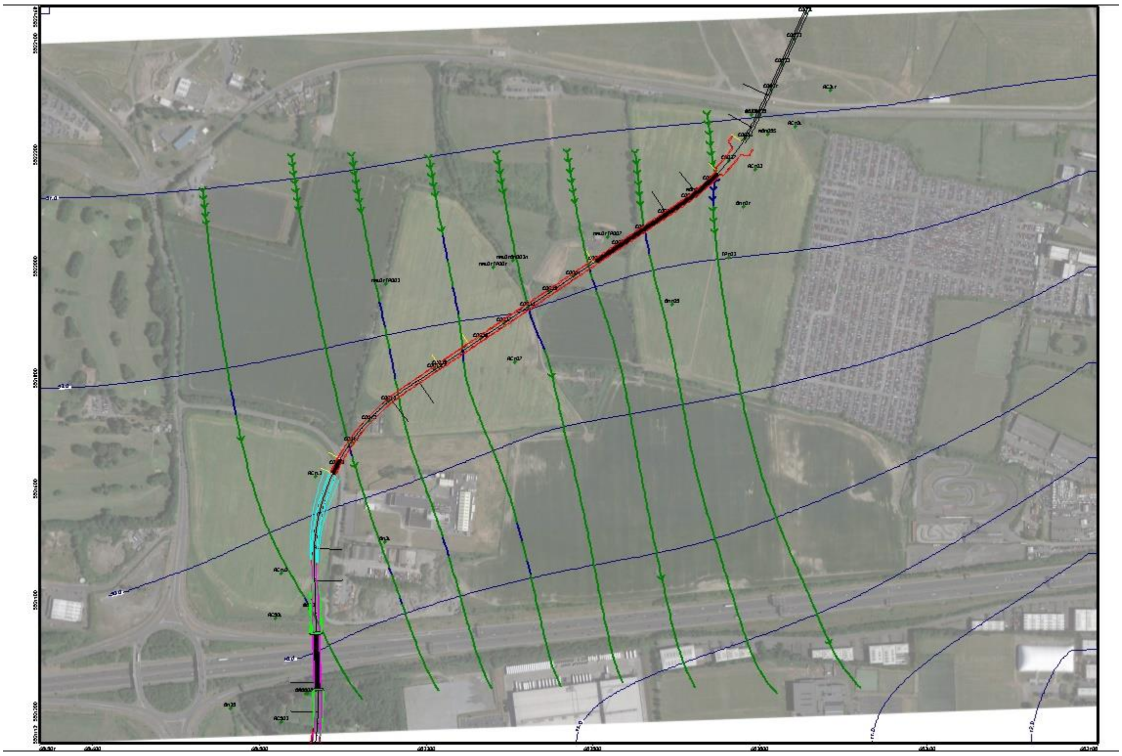

Figure 5-30. Pathlines through BOD level- With Diaphragm Wall. Dardistown Sector

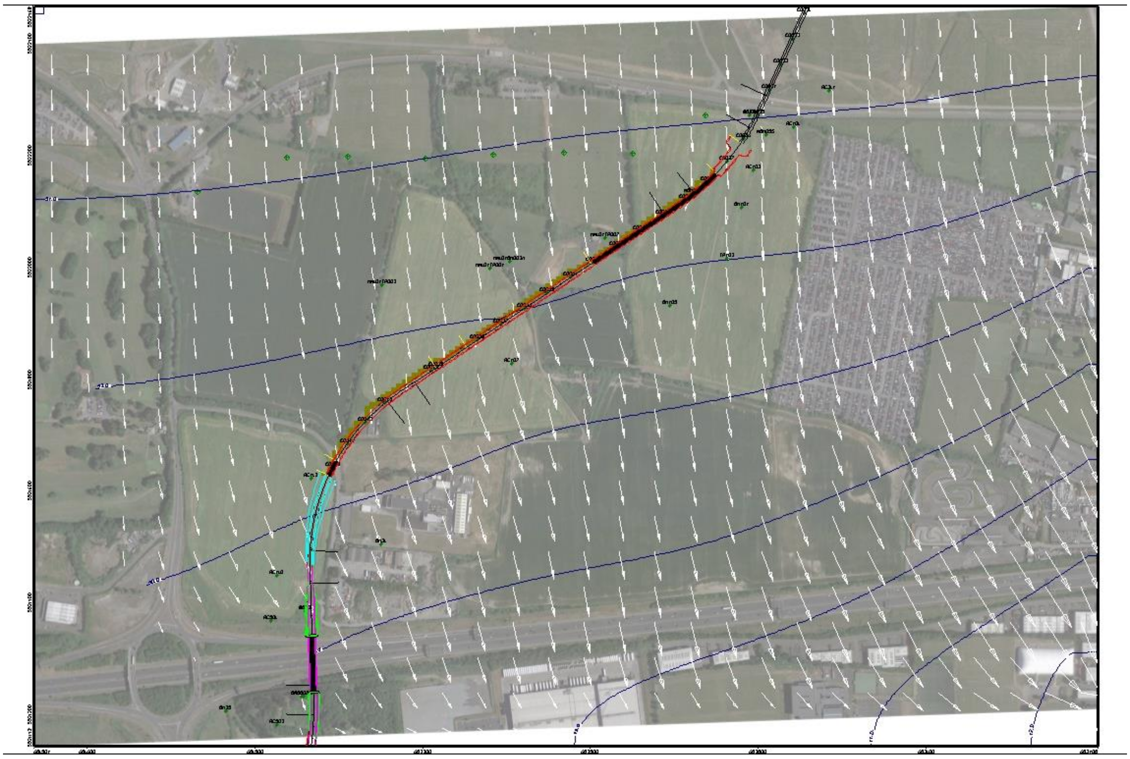

Figure 5-31. Velocity vector longitudinal profiles marks- With Diaphragm Wall. Dardistown Sector

The Figure 5-32 and Figure 5-33 below shows a cross section of the water table in Dardistown sector (Column #73)

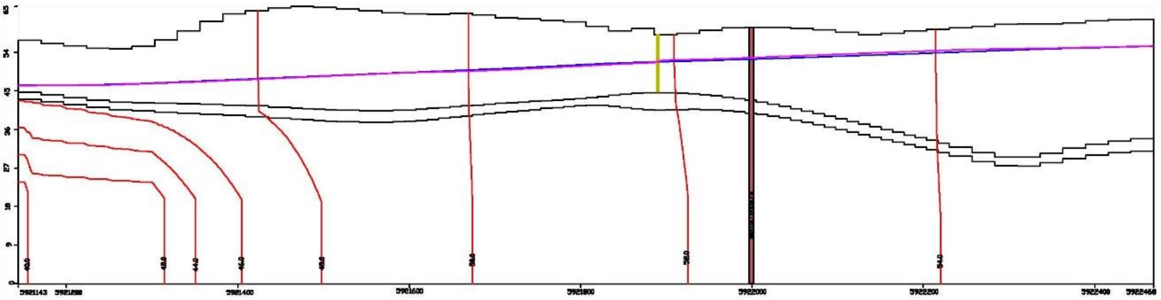

Figure 5-32. Longitudinal profile North-South (Column #73). Dardistown Sector

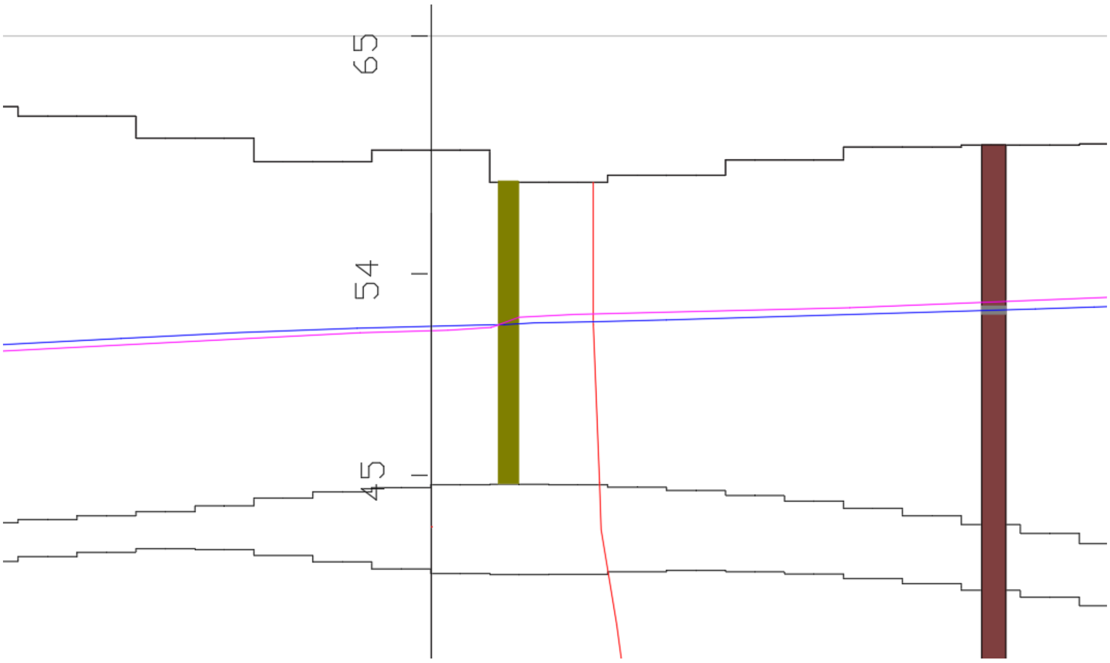

Figure 5-33. Longitudinal profile North-South (Column #73) detail. Measurement of the elevation of the water table upstream diaphragm wall: Elevation = 0.37 m. Dardistown Sector

In the Figure 5-33 it can be seen in more detail the elevation in Model Column #73 that is produced as a result of the incorporation of the diaphragm wall. The over-elevation is **0.37 m**, lower than the recommended value of 1.00 m, beyond which it may be considered necessary to use flow by-pass systems to mitigate the barrier effect.

DARDISTOWN SECTOR							
Well/Point Name	**X-Model**	**Y-Model**	**Obs.**	**Calc. Without D. Walls**	**Calc. With D. Walls**	**Differences**	**Position**
BH30/A	681990.3	5921385	48.00	48.71	48.711	0.001	upstream
BH32/A	682783.8	5922271	52.70	54.04	54.037	0.002	upstream
BH503ACP/A	681985.8	5921233	48.94	47.55	47.554	0.006	upstream
MN104BH002A/A	682354.8	5922010	52.07	52.54	52.935	0.395	upstream
MN104TP002/A	682127	5921968	52.98	52.58	52.977	0.401	upstream
MN104TP004/A	682319.3	5921999	52.49	52.52	52.823	0.306	upstream
MN104TP007/A	682525.4	5922053	52.13	52.57	52.814	0.240	upstream
NBH07S/A	682683.7	5922132	54.97	53.01	53.635	0.624	upstream
RC30/A	681990.3	5921385	48.00	48.71	49.334	0.624	upstream
RC32/A	682783.8	5922271	52.70	54.04	54.037	0.002	upstream
RC410/A	681939.2	5921447	49.90	49.45	49.457	0.003	upstream
RC501/A	681928.5	5921368	48.30	48.93	48.935	0.001	upstream
RC503/A	681983.2	5921232	46.60	47.54	47.551	0.006	upstream
BH31/A	682125.6	5921503	49.25	49.22	49.220	0.004	downstream
BH404/A	682769.2	5922107	52.50	52.75	52.741	-0.006	downstream
BH405/A	682641	5921932	52.50	51.50	51.185	-0.315	downstream
NBH05S/A	682814.3	5922237	55.23	53.76	53.756	0.001	downstream
RC314/A	682925.6	5922317	53.60	54.28	54.279	0.000	downstream
RC401/A	682863.1	5922250	52.80	53.83	53.829	0.000	downstream
RC403/A	682791.8	5922174	52.35	53.28	53.274	-0.002	downstream
RC407/A	682358	5921827	52.51	51.39	51.272	-0.122	downstream
TP402/A	682743.5	5922016	52.06	52.03	51.980	-0.048	downstream

Table 5-5. Over-elevations calculated in the observation wells upstream and downstream of the diaphragm walls. Dardistown Sector

Upstream a mean over-elevation is obtained equal to **0.20 m** and downstream a mean depression of **0.054 m** is obtained (for the head observation wells)

5.2.3 O'Conell Sector

O'Conell Station is executed with diaphragm walls that cut the permeable level BoD but the rest of the line is executed with a TBM. For calculation purposes, only the screens have been introduced in the model to evaluate the possible development of the barrier effect.

Figure 5-34. 3D view of the diaphragm walls. O'Conell

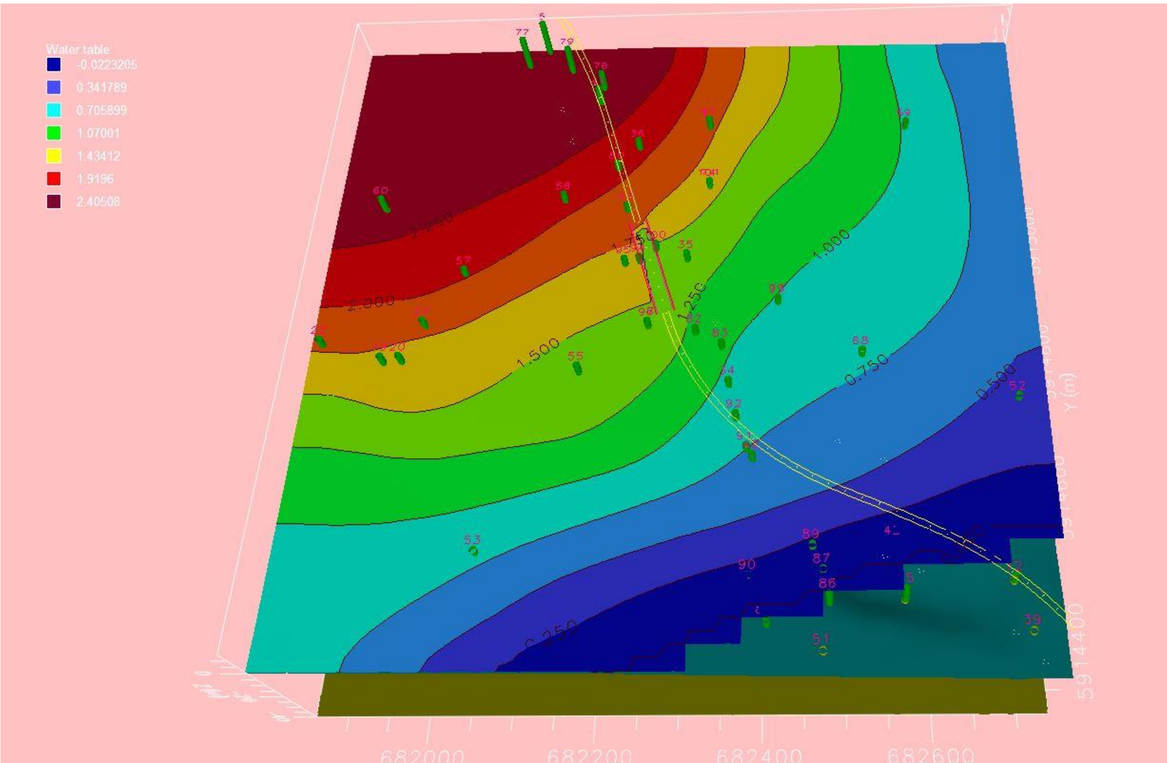

Figure 5-35. Calculated Water Table and Head Observation Wells – With Diaphragm Walls. O'Conell

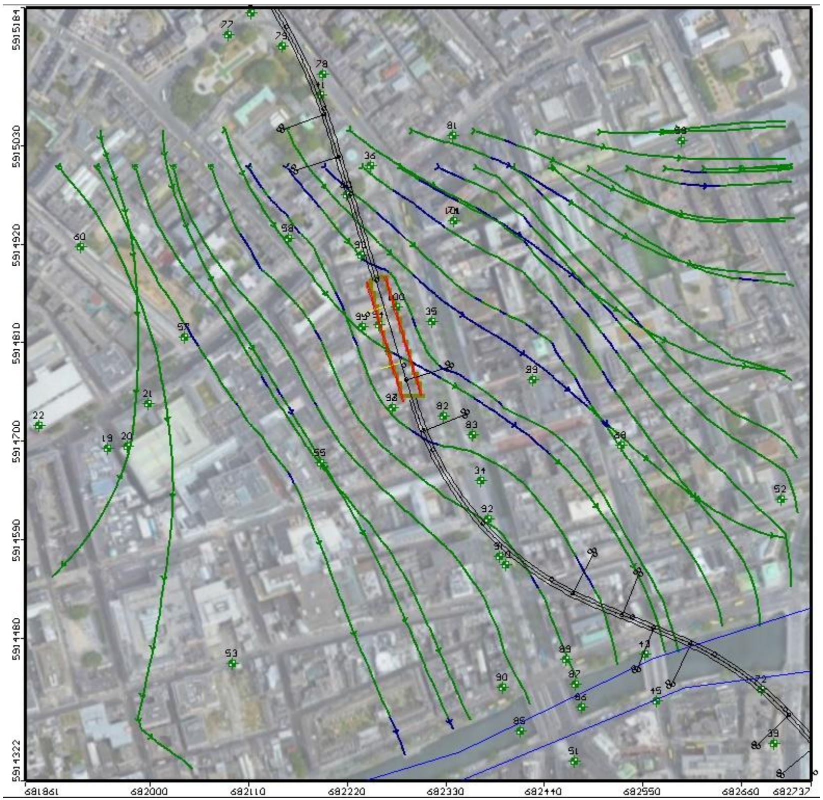

Figure 5-36. Pathlines through BOD level- With Diaphragm Wall. O'Conell

Figure 5-37. Velocity vector longitudinal profiles marks- With Diaphragm Wall. O'Conell

The Figure 5-38 and Figure 5-39 below shows a cross section of the water table at O'Conell Station (Row #53)

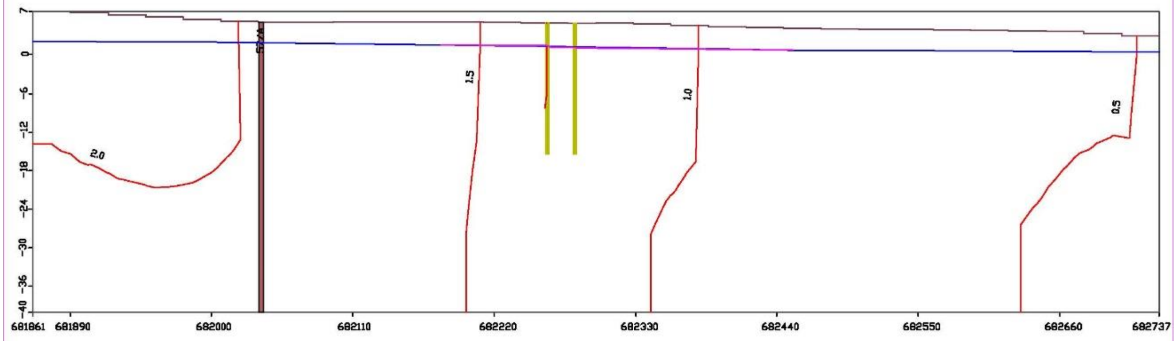

Figure 5-38. Longitudinal profile East- West crossing O'Conell (Row #53). O'Conell Sector

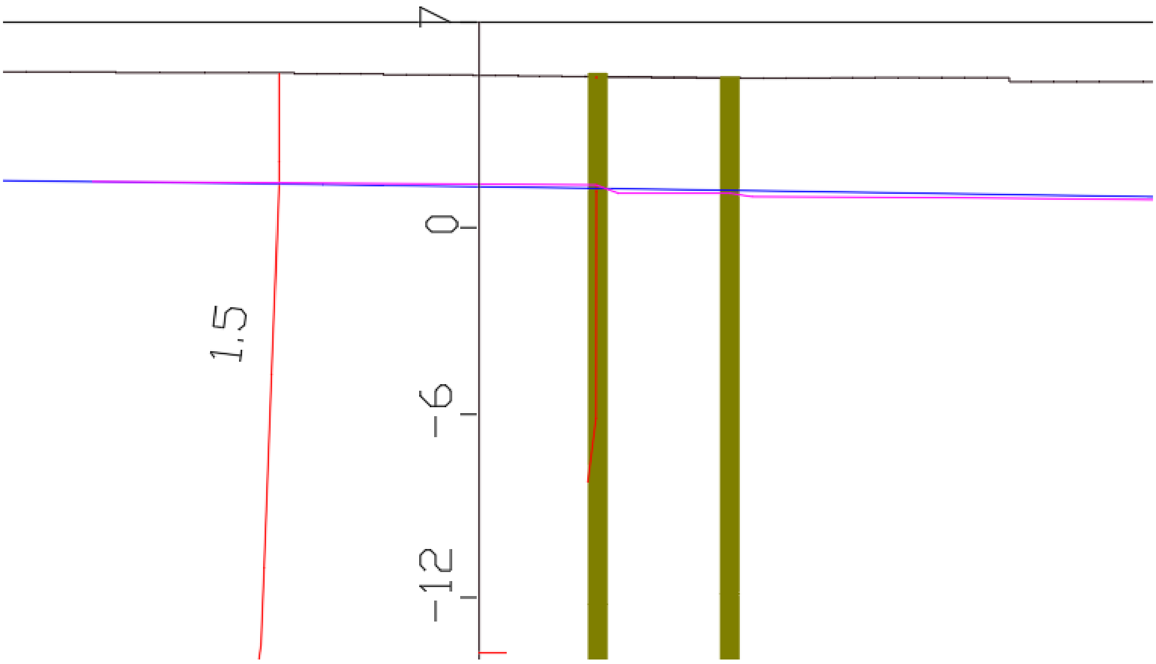

Figure 5-39. Longitudinal profile East- West crossing O'Conell (Row #53) detail. Measurement of the elevation of the water table upstream diaphragm wall: Elevation = 0.18 m. O'Conell Sector

In the Figure 5-39Figure 5-33 it can be seen in more detail the elevation in Model Row #53 that is produced as a result of the incorporation of the diaphragm wall. The over-elevation is **0.18 m**, lower than the recommended value of 1.00 m, beyond which it may be considered necessary to use flow by-pass systems to mitigate the barrier effect.

Well/Point Name	X-Model	Y-Model	Obs.	Calc. Without D. Walls	Calc. With D. Walls	Differences	Position
GL/BH17	682190.1	5915086	2.320	2.370	2.370	0.000	upstream
MGI/BH/708	682087.2	5915153	2.420	2.405	2.405	0.000	upstream
B51664	682112.4	5915178	2.450	2.405	2.405	0.000	upstream
RC10A	682147.2	5915141	2.320	2.404	2.404	0.000	upstream
GL/BH37	681922.8	5914918	2.500	2.308	2.309	0.002	upstream
GL/BH34A	682091.6	5914453	0.550	0.771	0.773	0.002	upstream
RC09	682219.8	5914975	2.010	1.946	1.950	0.004	upstream
GL/BH13	681875.8	5914718	1.400	1.740	1.747	0.007	upstream
B60398	681953.2	5914693	1.150	1.636	1.647	0.011	upstream
GL/BH42	682038.5	5914816	1.780	1.958	1.979	0.021	upstream
BX/BH02	681997.5	5914742	1.330	1.745	1.756	0.011	upstream
MGI/BH/719	681975.2	5914694	1.200	1.622	1.633	0.011	upstream
GL/BH19	682154	5914927	2.010	1.993	2.108	0.115	upstream
BH14	682235.9	5914908	1.700	1.686	1.806	0.120	upstream
GL/BH35	682190.1	5914676	1.300	1.277	1.300	0.023	upstream
AGI/RC/MP07	682269.8	5914738	2.010	1.242	1.269	0.026	upstream
IGSL-BH09	682269.8	5914738	1.350	1.242	1.269	0.026	upstream
BH.28 Luas	682236.9	5914828	1.370	1.469	1.656	0.188	upstream
RC13	682254.9	5914830	1.310	1.427	1.647	0.220	upstream
RC11	682337.1	5915041	1.600	1.679	1.671	-0.008	upstream
BH.11 Luas	682192.9	5915109	2.410	2.388	2.388	0.000	upstream
NBH23A	682274.6	5914850	1.350	1.409	1.248	-0.162	downstream
B81346	682313.9	5914834	1.140	1.258	1.121	-0.137	downstream
BH12	682327.6	5914728	0.500	1.056	1.016	-0.040	downstream
MNEWSS01	682426.4	5914769	0.660	0.773	0.746	-0.027	downstream
NBH22 (shallow)	682426.4	5914769	1.000	0.773	0.746	-0.027	downstream
MNEWSS02	682339.1	5914946	1.330	1.381	1.356	-0.025	downstream
NBH23W	682339.1	5914946	0.500	1.381	1.356	-0.025	downstream
MGI/BH/706	682359.4	5914707	0.630	0.870	0.847	-0.023	downstream
GQBH1	682525.2	5914696	0.600	0.620	0.606	-0.013	downstream
GL/BH43	682592.5	5915036	0.920	0.884	0.874	-0.010	downstream
B60396	682368.4	5914657	0.500	0.787	0.778	-0.009	downstream
B81334	682703.7	5914635	0.010	0.330	0.324	-0.006	downstream

Well/Point Name	X-Model	Y-Model	Obs.	Calc. Without D. Walls	Calc. With D. Walls	Differences	Position
AGI/BH/MP09A	682377.4	5914613	1.000	0.700	0.696	-0.004	downstream
GL/BH16	682396.7	5914562	0.610	0.570	0.566	-0.004	downstream
AGI/RC/MP12	682390.2	5914572	0.000	0.599	0.595	-0.004	downstream
B81349	682245.5	5915008	1.780	1.957	1.955	-0.002	downstream
BH.27 Luas	682463.5	5914457	-0.750	0.127	0.126	-0.001	downstream
GL/BH03	682552.3	5914463	0.000	0.052	0.051	-0.001	downstream
AGI/RC/MP11	682393.7	5914425	-0.560	0.112	0.111	0.000	downstream
MGI/BH/704	682474.6	5914430	0.020	0.015	0.015	0.000	downstream

Table 5-6. Over-elevations calculated in the observation wells upstream and downstream of the diaphragm walls. O'Conell

Upstream a mean over-elevation is obtained equal to **0.041 m** and downstream a mean depression of **0.024 m** is obtained (for the head observation wells)

6 CONCLUSIONS

The analysis of the barrier effect starts from the development of three hydrogeological models using the MODFLOW software, each of which includes the Cut & Cover sectors: Seatown - Swords Central- Fosterstown, Dardistown and O'Conell.

The work procedure performed under steady state simulation includes two stages. First, the head values and the water table are calculated for the current state. Secondly, the models are processed again, incorporating the diaphragm walls in the alignments to observe the variation of the water table and the possible barrier effect.

At the first stage, the boundary conditions are adjusted to produce simulation results that better match the known or measured values. Specifically, the Constant Head Boundaries Conditions imposed for each layer have been modified in an iterative process in order to achieve a precise data fit. Visual MODFLOW provides a comprehensive selection of model calibration analysis tools for evaluating, interpreting, and presenting the model calibration, including Calculated vs. Observed Heads Scatter Graphs

The configuration achieved is measured by the Normalized Root Mean Squared (NormalizedRMS) expressed as a percentage, and is a more representative measure of fit than the standard RMS, as it represents the scale of the potential range of data values. An adjustment with a Normalized Root Mean Squared error (RMS) close to 10% is accepted (never higher than 15%) and the correlation coefficient (R) must be equal or great than 0.9

The normalized values of the RMS obtained for each model have been the following:

- Seatown-Fosterstown Sector: Normalized RMS 6.733 %, CC=0.984.
- Dardistown Sector: RMS 11.68 %, CC=0.893
- O´Conell: RMS 10.289 %, CC=0.933

For each stage the hydraulic gradient is obtained, which allows obtaining the flow rates through the MetroLink alignments. This data is of special importance in this case, since it will allow sizing the transversal drainage systems that avoid the barrier effect.

In addition, single particles have been added to obtain the flow path and thus check their incidence on the axis of the MetroLink alignment. If the trajectories are parallel, the barrier effect will be less significant than if the trajectories are perpendicular to the alignment. In addition, these trajectories show how the water flow is able to overcome the interference imposed by the diaphragm walls.

The results obtained for each sector are summarized below:

Seatown-Fosterstown Sector

In this sector, the diaphragm walls cut the permeable level BoD, increasing the possibility of producing the barrier effect.

The elevation of the water table reaches 1.20 m in some sections as can be seen in the ***Figure 5-27. Longitudinal profile East- West (Row #93) detail. Measurement of the elevation of the water table upstream diaphragm wall: Elevation = 1.20 m. Seatown-Fosterstown Sector.***

Upstream a mean over-elevation in Head Observation Wells is obtained equal to 0.62 m and downstream a mean depression of 0.24 m is obtained.

With these data it is concluded that potentially the effect could occur in this sector, approximately between the **chainage references 2 + 800 - 4 + 800**

Dardistown Sector

In this sector the diaphragm walls do not cut the permeable level BoD, therefore, the barrier effect could be irrelevant.

In the Figure 5-33 it can be seen in more detail the elevation in Model Column #73 that is produced as a result of the incorporation of the diaphragm wall. The mean over-elevation in Head Observation Wells is 0.37 m, lower than the recommended value of 1.00 m, beyond which it may be considered necessary to use flow by-pass systems to mitigate the barrier effect.

Upstream a mean over-elevation is obtained equal to 0.20 m and downstream a mean depression of 0.054 m is obtained (for the head observation wells)

O'Conell

O'Conell Station is executed with diaphragm walls that cut the permeable level but the rest of the line is executed with a TBM. For calculation purposes, only the screens have been introduced in the model to evaluate the possible development of the barrier effect.

In the Figure 5-39 it can be seen in more detail the elevation in Model Row #53 that is produced as a result of the incorporation of the diaphragm wall. The mean over-elevation in Head Observation Wells is 0.18 m, lower than the recommended value of 1.00 m, beyond which it may be considered necessary to use flow by-pass systems to mitigate the barrier effect.

Upstream a mean over-elevation is obtained equal to 0.041 m and downstream a mean depression of 0.024 m is obtained (for the head observation wells)

7 RECOMMENDATIONS

As indicated in the previous conclusions chapter, in the Seatown-Fosterstown sector an upstream mean elevation in the head observation wells of 0.60 m has been obtained, reaching in some points an elevation equal to 1.20 m.

For this reason, it may be necessary in this sector to incorporate a by-pass system approximately between the chainage references 2 + 800 - 4 + 800

The flow rate must first be obtained by knowing the hydraulic gradient and considering that the area of passage is set at the most permeable level BoD.

The mean gradient for the Seatown-Fosterstown sector is taken equal to:

$$i = \frac{\Delta H}{L} = \frac{15}{1.000} = 0.015 = 1{,}5\%$$

To calculate the through section, it is observed how the BoD has a thickness that varies between 1.00 and 5.00 m in this section, taking a mean value of 3.00 m.

The flow rate calculation is carried out by applying Darcy's law:

$$Q = k.i.A = 2.9 \times 10^{-4} \times 0.015 \times 3.00 = 1.31 \times 10^{-5}\ m^3/s/m = 1.13\ m^3/d/m$$

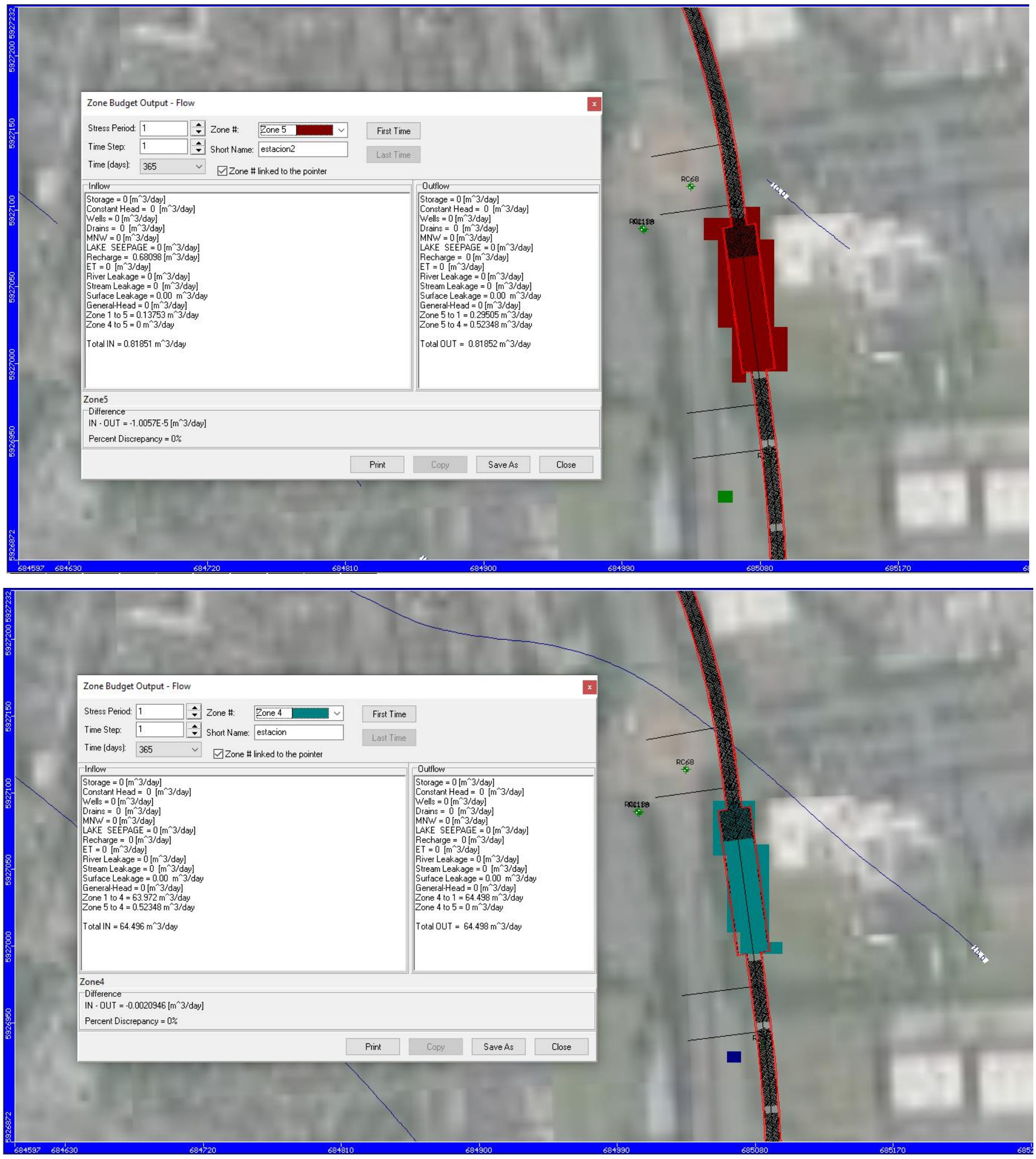

Figure 7-1. Balance of inlet and outlet flows at Seatown station. Visual MODFLOW model, Seatown-Fosterstown sector.

In Figure 7-1 the flow inlet balance is shown at the Seatown station, which is 95 m long. For the upper level (Boulder Clay) the flow rate is equal to 0.81 m^3/d and for the BoD level the flow rate is equal to 64.49 m^3/d. This is equivalent to specific flow rates of $8.53x10^{-3}$ m^3/d /m and 0.68 $m^3/d/m$ respectively. Therefore, adopting a flow rate equal to 1.13 m^3 /d/m is conservative.

To incorporate a By-Pass, it can be chosen to use a collection and diffusion system based on pairs of drainage wells located every 100 m along the alignments and connected to each other by means of a pipe through the cross-section of the tunnel (Figure 7-2)

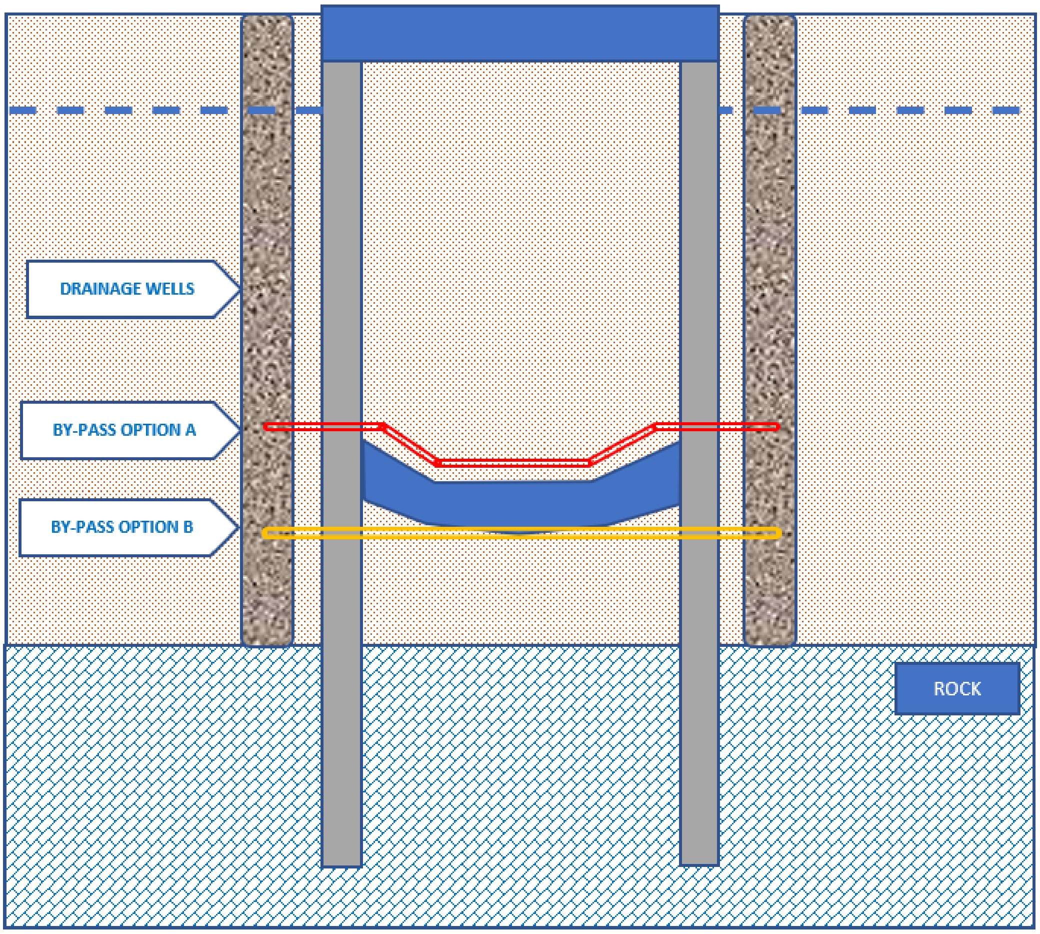

Figure 7-2. Cross-section of a water passage by pressure siphon

Each drainage well must have a minimum diameter of 850 mm and a length that reaches the rock level. It is recommended that these wells be filled with gravel (e.g. stone columns) and to avoid contamination of the drain hole, it could be lined with precast concrete perforated pipe or rings. As an alternative to this protection system, the encasement of stone columns with geotextile. may be used.

Each pair will be connected to each other through the tunnel by a pipe line with a minimum diameter of 200 mm to facilitate its disassembly by sections for cleaning and periodic maintenance. These bypass pipes may be plastic (PVC or HDPE) in order to facilitate their disassembly by sections for cleaning and periodic maintenance. For this purpose, shut-off valves with flanged connections must be installed at the inlet made in the diaphragm walls.

The pipe will rest on the intermediate slab (option a) or into the bottom slab. The passage will be drilled once it has been excavated up to this point, by means of a system called “preventer” that allows, thanks to a shutter system, to contain the thrust of the water table during the execution of the drillings.

Assuming the placement of a by-pass through a 200 mm diameter pipe placed every 100 m, then a pipe flow equal to $1.13x10^{-3}$ m^3/s can be considered for the section calculation.

The over-elevation that occurs will be due to head losses in the pipes.

There are two types of pressure drops:

- Localized pressure drops

$$\Delta h = K\frac{v^2}{2g}$$

Taking K equal to 0.50 for the outlet of the pipe and 1.00 for the outlet of the pipe, applying the continuity equation we have:

$\Delta h = 77.54 \times Q^2$

- Continuous pressure drops

Applying the Hazen-Williams equation and considering a value of the coefficient C =150 for a 200 mm diameter PVC pipe, we have:

$$\Delta h = 10{,}674 \cdot \frac{Q^{1{,}852}}{C^{1{,}852} \cdot D^{4{,}871}} \cdot L$$

$\Delta h = 45.52 \times Q^{1.852}$

Applying these head losses to the estimated flow, there is a rise of less than 5 cm. Therefore, and as a first approximation, it can be concluded that it may be sufficient to incorporate a 200 mm diameter pipe every 100 meters.

This siphon system has been introduced into the Seatown-Fosterstown sector model by means of pumping wells and recharge wells for both sides of the tunnel, extracting and introducing a flow equal to that which the drainage pipes can transfer. This simplified model allows, as a first approximation to the problem, to check whether the barrier effect can be controlled with the siphon system.

The Figure 7-3 and Figure 7-4 show the position of the By-Pass points represented by extraction and recharge wells arranged on both sides of the diaphragm walls every 100 m.

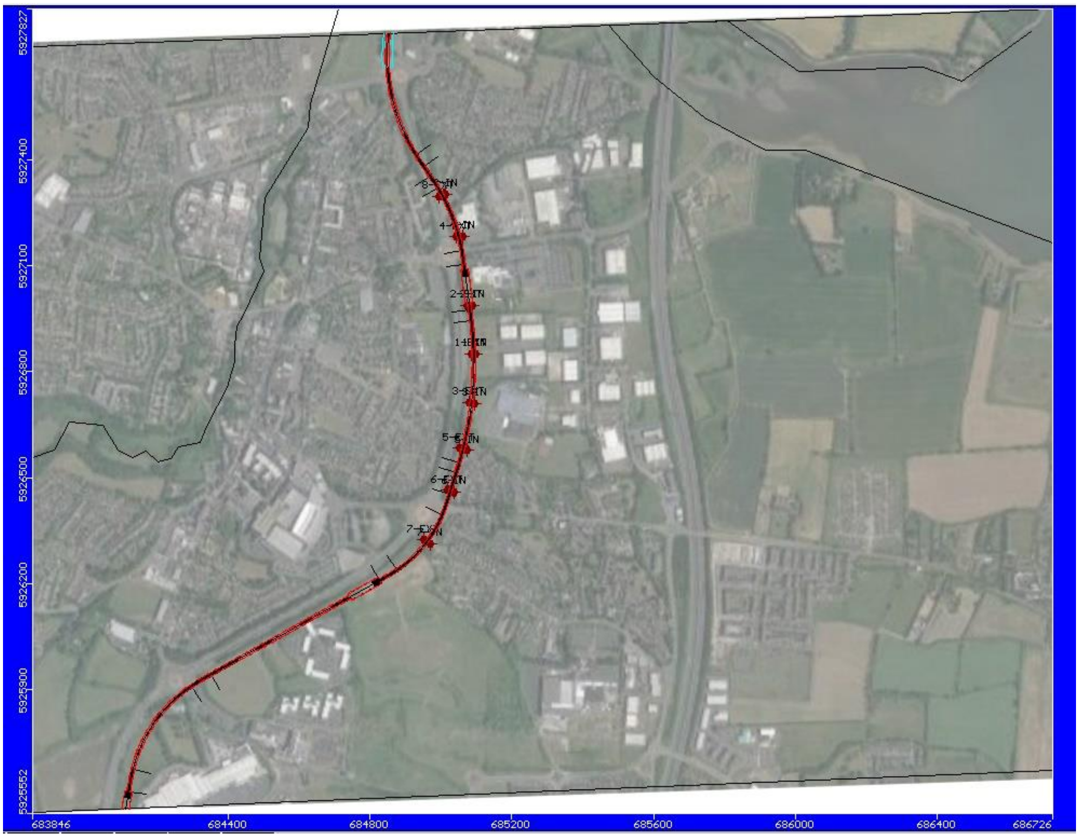

Figure 7-3. Plan position of the extraction and recharge wells on both sides of the diaphragm walls

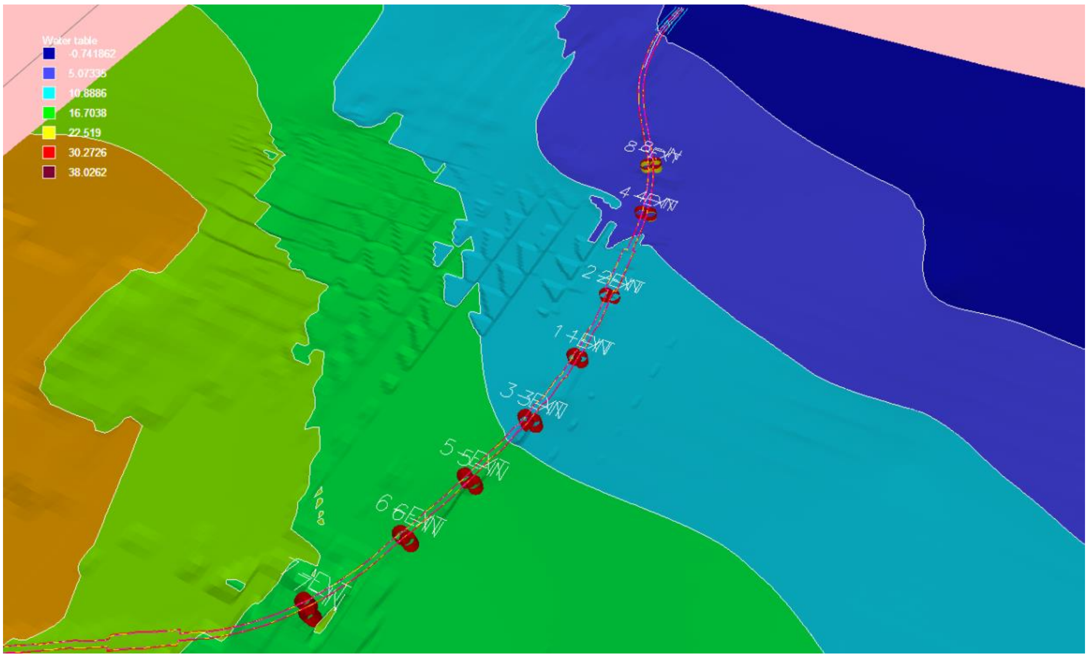

Figure 7-4. 3D view of the position of the extraction and recharge wells on both sides of the diaphragm walls

In the Figure 7-5Figure 5-27 it can be seen in more detail the water in Model Row #93 that is produced as a result of the incorporation of the siphon (represented by pumping wells and extraction wells) It can be seen in the figure that the 1.20 m elevation is not generated by the effect of the diaphragm walls.

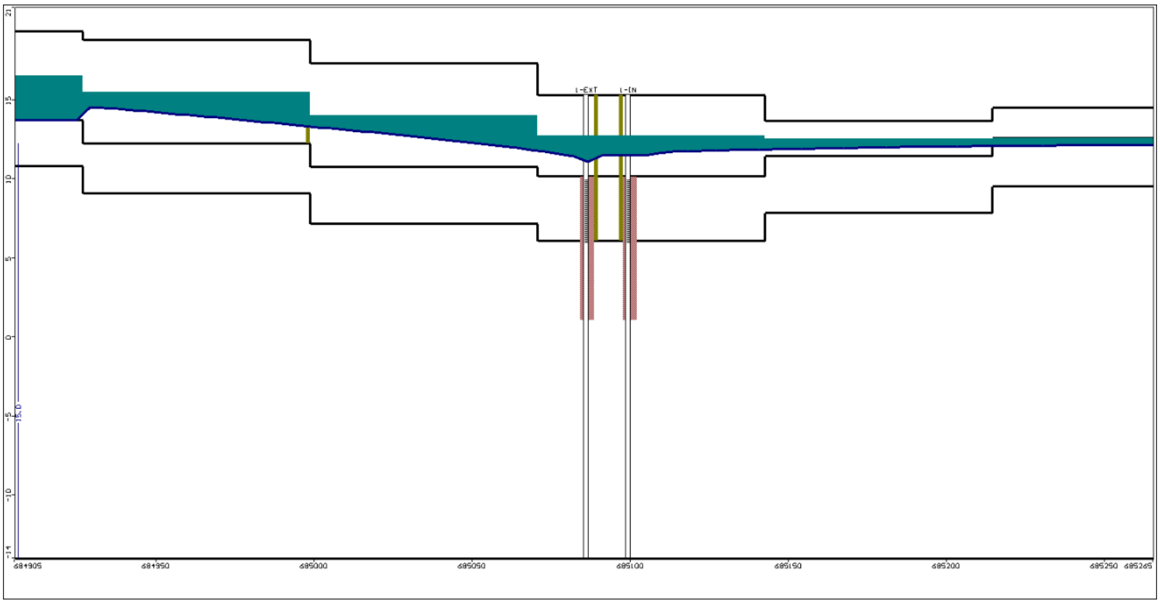

Figure 7-5. Longitudinal profile East- West crossing O'Conell (Row #93) with By-Pass. O'Conell Sector