FINAL DESIGN OF DRAINAGE SYSTEM REPORT

Client	NMDC DREDGING & MARINE
Project	HUDAYRIYAT EAST EXPANSION (CICPA HILL)
Reference	
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1 INTRODUCTION

1.1 General

Modon Properties (Employer) is developing Al Hudayriyat Island into a mix of residential, leisure and commercial land use including villas, townhouses and other leisure and entertainment facilities. Eastern Hudayriyat Island is currently being considered, Figure 1, for further expansion. A series of reclamation works are reclaimed CICPA Hill.

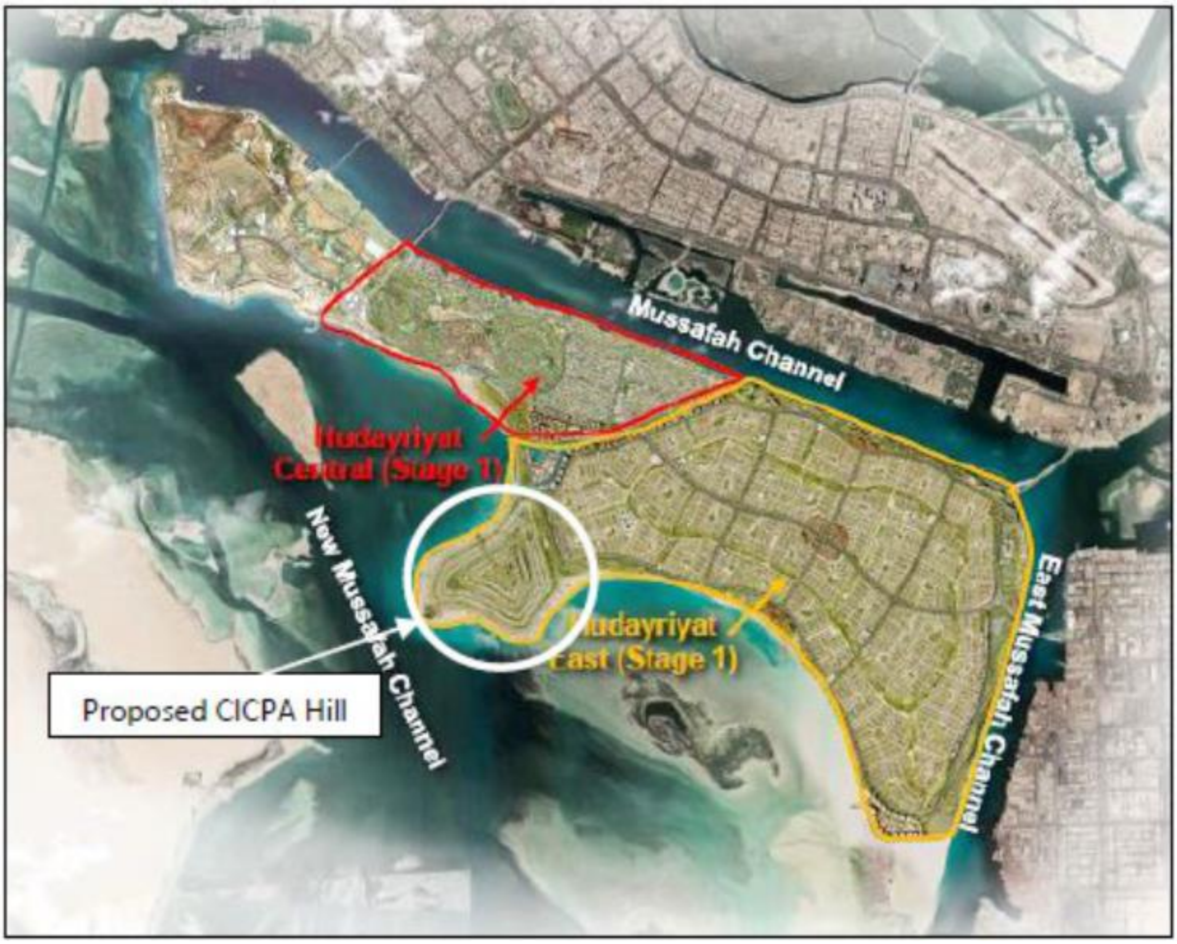

Figure 1: Proposed Hudayriyat Island Masterplan (Including the Hudayriyat East Development)

The footprint area of the CICPA Hill is in the order of 2,00,000 m2. Part of the Hill is expected to be resting on a reclaimed Island. The tentative height of the Hill is up to +55m NADD, while the existing ground level is at an approximate level of +2m NADD. The Hill's steep sides are provided with benches (or terraces) at approximately 10 m height intervals. The width of each terrace varies between 70m to 100m. These terraces provide a stable base for the construction of houses and infrastructure.

The general grading plan and layout of the hill are presented in Figure 2, Figure 3, and Figure 4 illustrate the hill cross-sectional view (B-B).

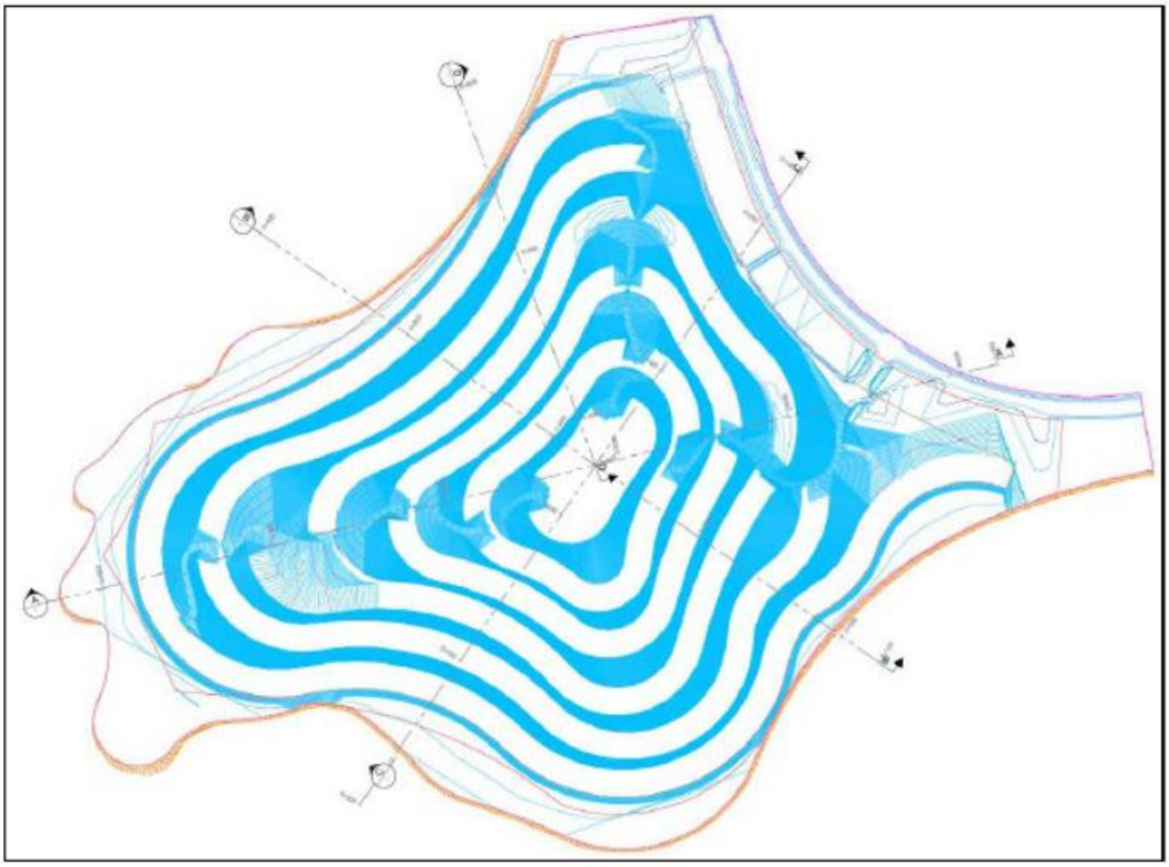

Figure 2: Grading layout of CICPA Hill

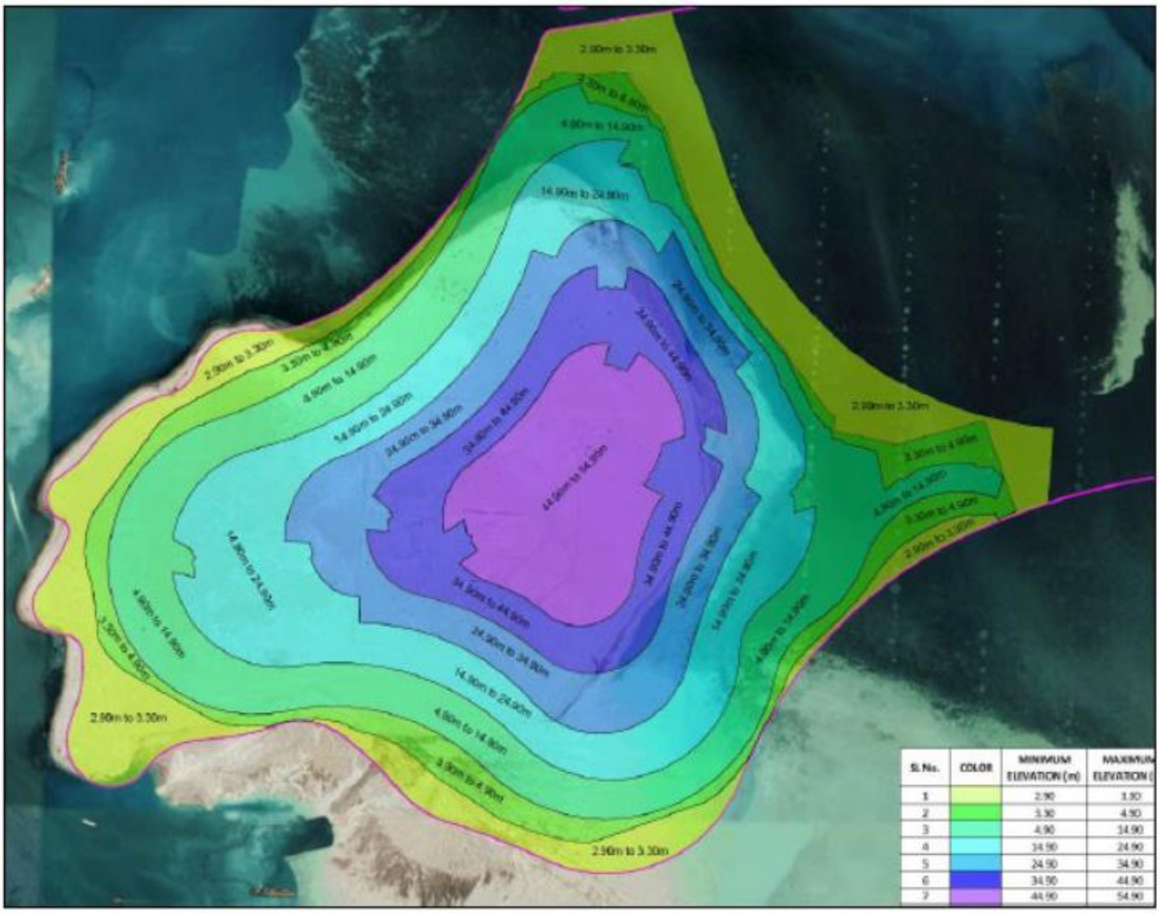

Figure 3: General Grading Plan of CICPA Hill

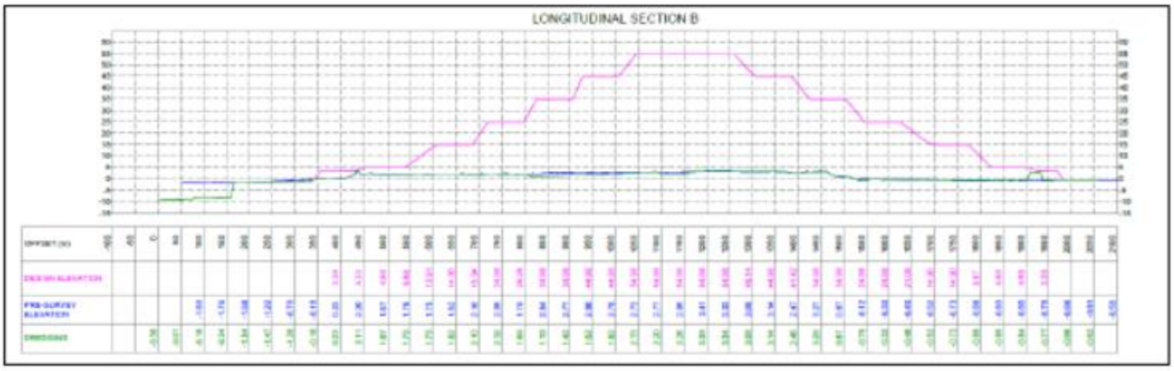

Figure 4: Cross-Sectional View (Section B-B)

As per requirements in project specifications [1][2] for the development of the CICPA hill, the presence of high-fine-content material in shallow layers, which exhibit low permeability/ conductivity properties might delay water drainage or trap water from different sources, i.e. precipitation, irrigation, hydraulic fill, …etc. Therefore, the application of many drainage systems such as drainage layer, vertical drains or a combination of both, was evaluated considering the actual thickness of drainage layer and the actual depth of vertical drains. Based on the prior study of the drainage systems, it was determined that a drainage system is required to drain hill's water. Following a thorough design study, the vertical drains system where we have recommended.

1.2 Objective of This Document

The objective of this report is to present the following:

* Description of CICPA Hill 3-D numerical model.

- Application results of the 3-D simulation of the drainage system (vertical drains).
- Assessment results of the effectiveness of the drainage system (vertical drains) in draining hill's water.
- The design drawings of the drainage system (vertical drains).
- The quantity of material that is used in constructing the drainage system (vertical drains).

Finally, the conclusion of the model results and recommendations for the drainage system have been presented, indicating that the expected drainage time for the seepage water inside the hill to reach +5.00 m NADD is within 6 months, as requested.

2 GEOTECHNICAL CONDITIONS

Table 1 shows the soil hydraulic parameters based on a review and interpretation of existing geotechnical information as well as borehole data. From the 25 boreholes drilled at the location, Figure 5, the groundwater was encountered between 1.50 m to 2.75 m below the existing ground, i.e. the groundwater level was between -0.68 m NADD to +0.91 m NADD. The ground water level considered for geotechnical design is at +0.5 m NADD, which also corresponds to the water between MHHW and MLHW level.

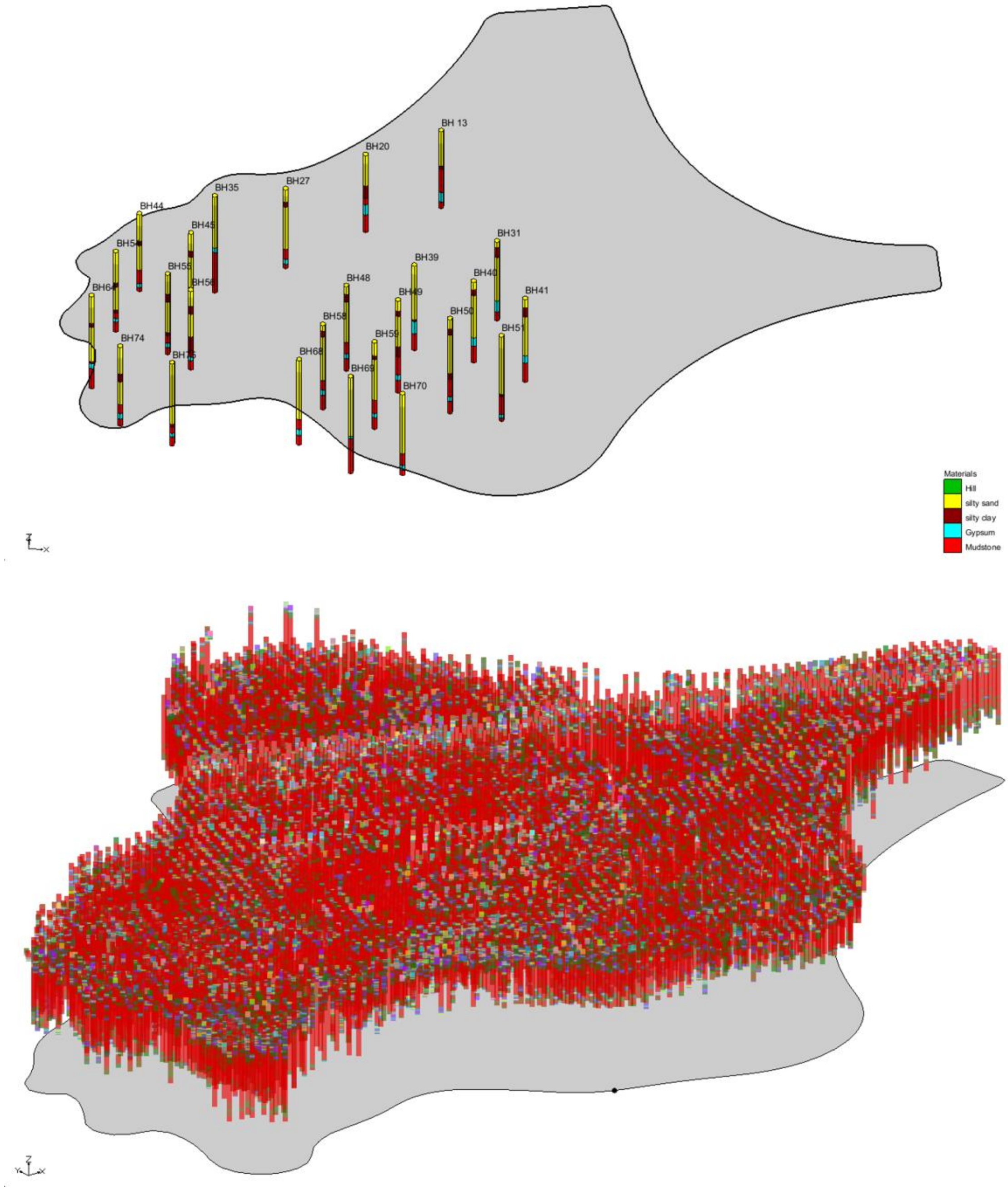

Figure 5: Executive Boreholes location and CPT data analysis in the project boundary.

Table 1: Native Ground Subsurface layers

Layer No.	Layer Description	Hydraulic conductivity (m/d)
1	Hill	0.33
2	Silty Sand	9.50
3	Silty Clay	0.08
4	Mudstone	8.64E-06
5	Gypsum	8.64E-06

Table 1 was derived from the geotechnical report provided by NMDC and the raw data provided by ADEC. This table reflects the hydraulic properties used in the model, with the majority of the available raw data falling within the Silty Sand layer (more than 80% of the data). Figure 6 shows that the median hydraulic conductivity value of the native soil has been chosen to be 9.50 m/d (the most critical layers for drainage).Therefore, the analysis of stratigraphy and parameters of hydraulic conductivity shall be explained in the following sections.

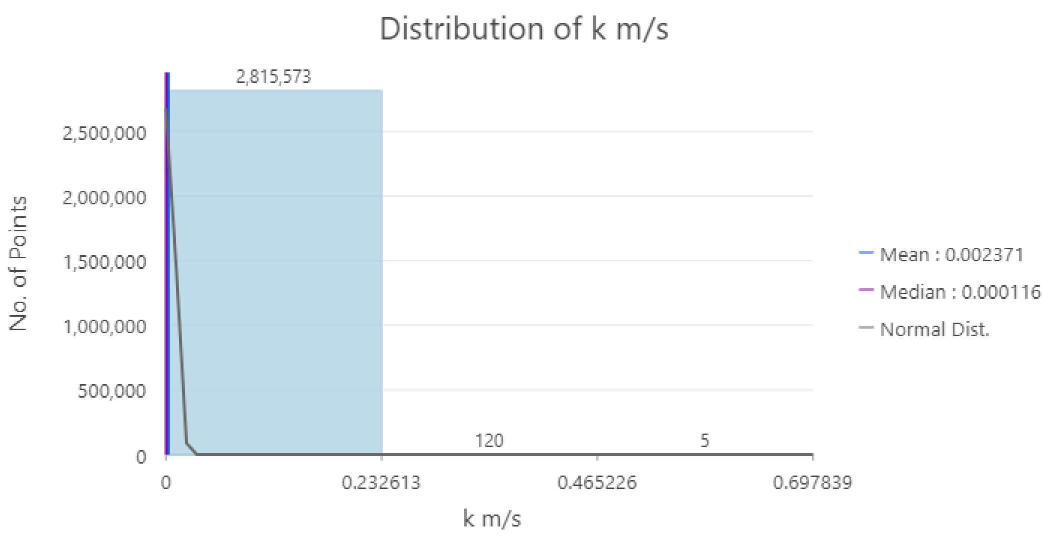

Figure 6: Raw data analysis for the Silty Sand Layer

For the Hill conductivity, a multi criteria evaluation has been conducted to choose the optimum and most effective value.

This criterion is based on the worst case scenario that the Hill is divided into 5 platforms, and the material does not conform to the best soil mixture, therefore, as illustrated in Table 2, different mixture of soils has been chosen, then taken the first quartile as highlighted.

Table 2: Hill Material Statistics

Platform No.	Percentage of Soil Hyd. Conductivity (k= 1E-5 m/s)	Percentage of Soil Hyd. Conductivity (k= 1E-6 m/s)	Resulted soil mixture Hyd. Conductivity (m/s)	Statistics	
1	80	20	2.80E-06	First quartile (m/s)	3.82E-06
2	64	42	4.84E-06	Median (m/s)	6.40E-06
3	40	60	6.40E-06	Third quartile (m/s)	7.75E-06
4	30	70	7.30E-06		
5	20	80	8.20E-06		

2.1 Post-improvement Conditions of Native Ground and Hill

The lateral extent of ground improvement (GI) requirements for the hills in order to meet the ground improvement criteria for global stability, bearing capacity, settlement, and liquefaction is presented in Figure 7. The treatment area is divided into two zones (Zone 1 and Zone 2), where the intermediate boundary is defined at +10.0m NADD hill contour grading.

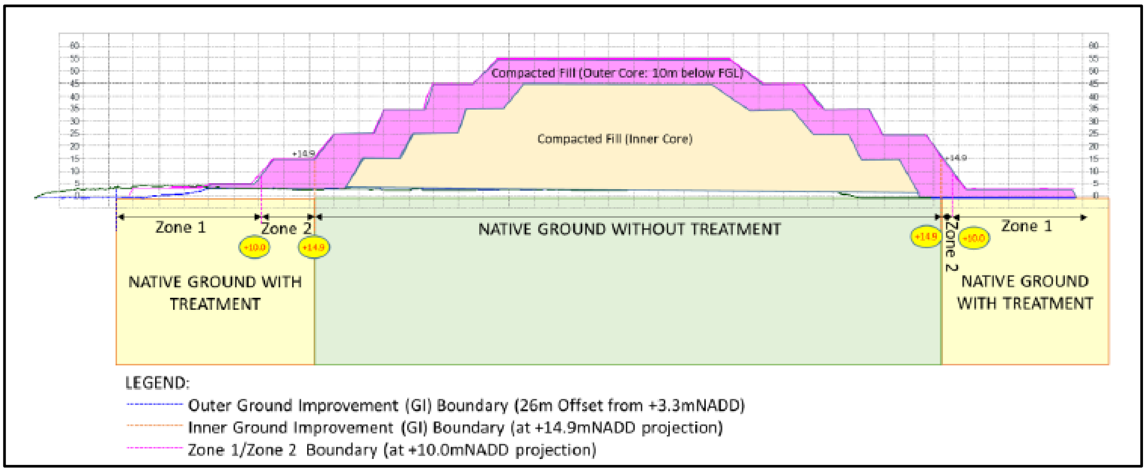

Figure 7: Typical Detail of Vertical and Lateral Extent of Ground Improvement for the Hill and Native Ground

2.2 Subsurface Soil Characterization

A thorough analysis of all drilled boreholes and CPT raw data across the project site was conducted to gain a comprehensive understanding of the subsurface soil conditions by interpolate and extrapolate all available data by natural neighbour method inside project boundary Figure 5. This detailed analysis resulted in the development of the cross-section presented in Figure 8. As shown in the cross-sections Figure 9 and horizontal sections for native soil at different levels in [Appendix B], the site primarily consists of three different main soil layers extending across most of the area with varying depths as follows:

Silty Sand: This surface layer, occasionally containing gravel in some locations, was encountered in all boreholes. Based on the analyzed data, the estimated hydraulic conductivity of the silty sand layer is 1.10 E-4 m/s (Figure 6).

Silty Clay: Underlying the silty sand layer in huge area across the entire site, a relatively impermeable silty clay layer was encountered. The coefficient of permeability values provided in the soil test results were analyzed to determine an estimated hydraulic conductivity of 9.26 × 10^-7 m/s for the silty clay layer (based on the geotechnical report).

Silty Sand: Located beneath the Silty clay layer, silty sand deposits were observed at varying depths across the site in specific boreholes. While hydraulic conductivity data were observed from the provided data with a value of about 1.10E-4 m/s.

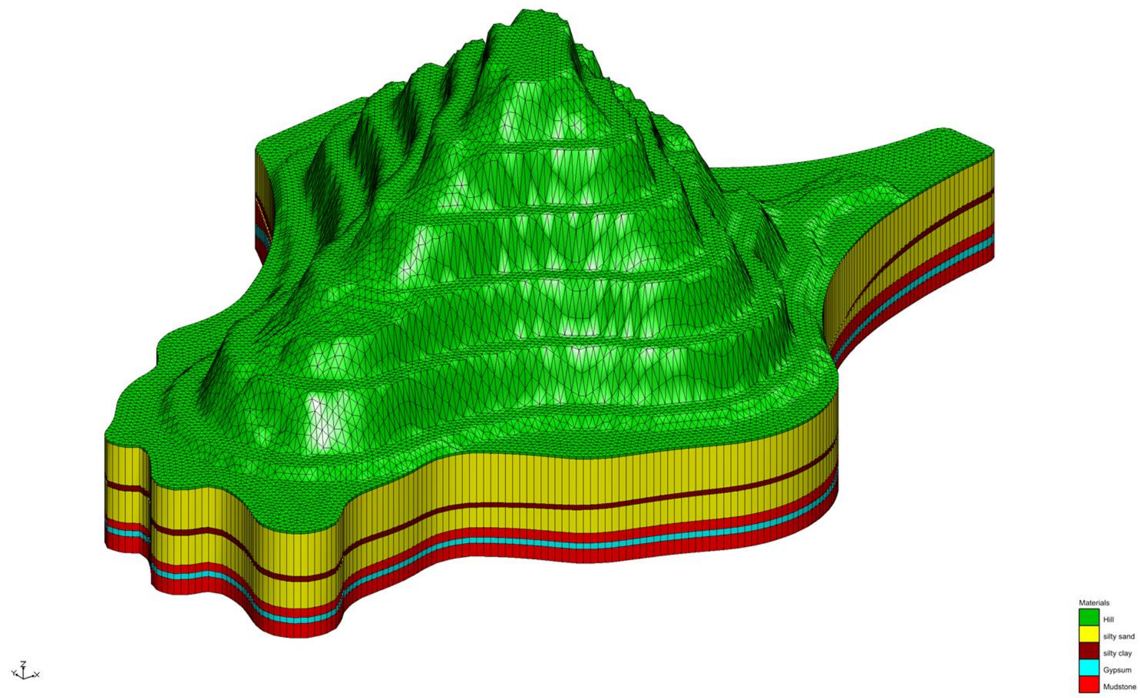

Figure 8: 3D Hydrogeological Model of the Study Area.

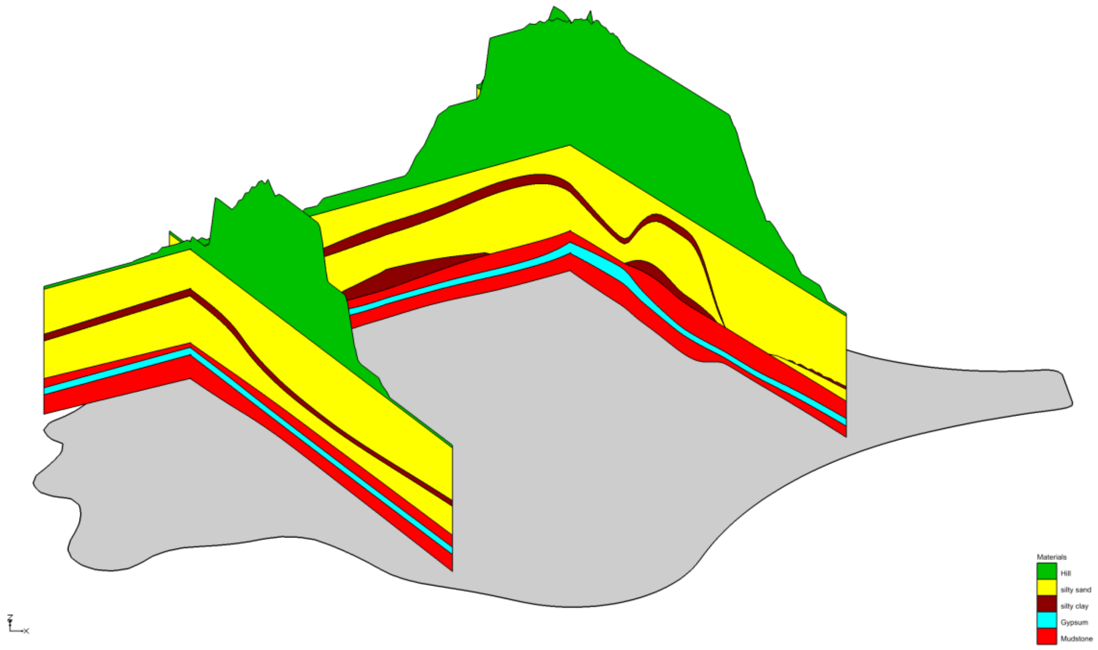

Figure 9: 3D Hydrogeological Model cross sections of the Study Area.

3 HYDROLOGICAL CONDITIONS

3.1 Groundwater Conditions

Based on the review and interpretation of available soil information, the groundwater was encountered between 1.5 m and 2.75 m below the existing ground surface in various boreholes, translating to a groundwater level ranging from -0.68 m NADD to +0.91 m NADD. For geotechnical design purposes, a groundwater level of +0.5 m NADD is considered, which also corresponds to the water level between the Mean Higher High Water (MHHW) and Mean Lower Low Water (MLHW) levels.

3.2 Rainfall Analysis

The initial water head resulting from the hydraulic fill equals the total height of the hill, although the water head measurements of the existing hills (east and west hills) indicated that this assumption is conservative. The available measurements from the east and west hills indicated that the initial water head after completion of the hills' construction was about +35.0 m NADD, whereas the top levels were about +45 and +55 m NADD in the east and west hills, respectively. The relatively low initial water head was attributed to the drainage rate during construction and ground improvement. Applying a heavy rainfall event to all the simulated scenarios will not change the results concerning the drainage performance since the CICPA hill was assumed to be in a fully saturated condition. The effects of different water sources, such as precipitation and irrigation, and the associated mitigation measures, have been added to the recharge that acts on the Hill.

Based on the Volume I- Design Manual of Storm water & Subsoil Drainage Systems 2022, the Arab United Emirates is divided into two zones. The first zone (Zone A) is devoted to Al Ain region while the second zone (Zone B) is devoted to the remaining part of the country, as shown in Figure 10.

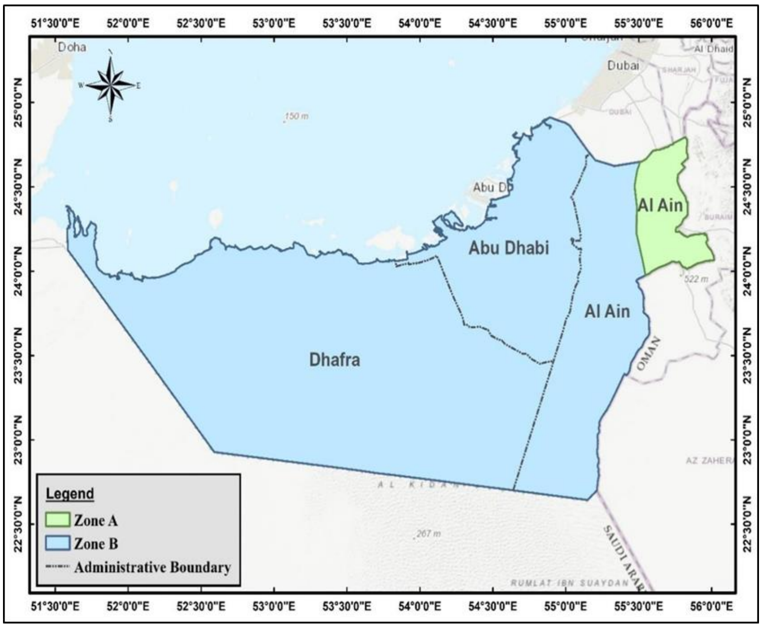

Figure 10: Hydrological Zones of UAE.

As Hudayriat Island is located in zone B, Figure 11 illustrates the Intensity-Duration-Frequency (IDF) approved for the region. Table 3 shows the values of the Intensity-Duration-Frequency curves as well as the values of Depth-Duration-Frequency relationship. Table 4 shows the equations of these relationships. The values of intensity and rainfall depth for the duration of 24-hours are shown in the last column of Table 3.

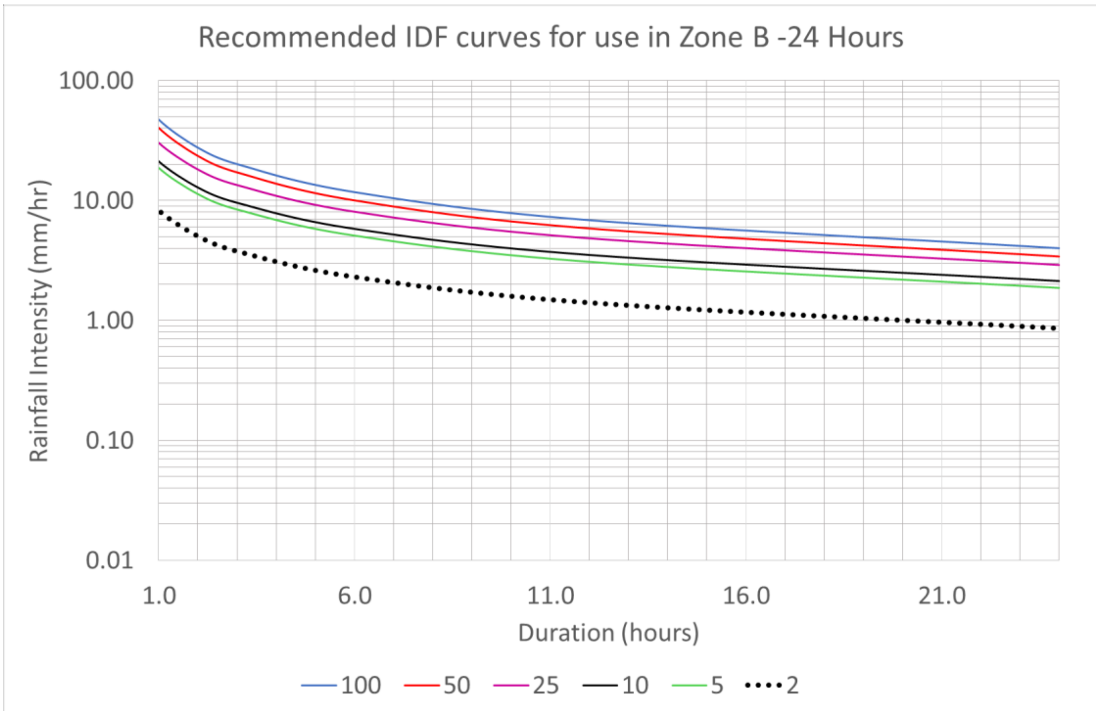

Figure 11: Recommended IDF Curves for Zone B – 24 Hours

Table 3: Recommended IDF and DDF tables for use in Zone B

Duration	5	10	15	30	60	120	180	360	720	1440
Duration (hrs)	0.083	0.167	0.25	0.5	1	2	3	6	12	24
Return period (yrs)	Rainfall Intensity (mm/h)									
100 yrs	444.46	259.45	189.39	110.55	64.53	37.67	27.49	16.05	9.36	5.47
50 yrs	378.00	220.66	161.08	94.03	54.87	32.03	23.38	13.65	7.97	4.65
25 yrs	248.94	149.27	110.72	66.40	39.82	23.88	17.71	10.61	6.37	3.82
10 yrs	163.61	99.20	74.01	44.83	27.16	16.46	12.27	7.44	4.51	2.73
5 yrs	115.52	69.95	52.12	31.53	19.07	11.54	8.61	5.21	3.15	1.91
2 yrs	46.28	28.21	21.14	12.92	7.88	4.82	3.60	2.20	1.35	0.82
Return period (yrs)	Rainfall Depth (mm)									
100	36.89	43.33	47.35	55.27	64.53	75.34	82.46	96.28	112.35	131.21
50	31.37	36.85	40.27	47.01	54.87	64.06	70.13	81.90	95.63	111.49
25	20.66	24.93	27.68	33.20	39.82	47.75	53.14	63.69	76.49	91.66
10	13.58	16.57	18.50	22.41	27.16	32.93	36.81	44.62	54.16	65.55
5	9.59	11.68	13.03	15.77	19.07	23.08	25.82	31.25	37.74	45.83
2	3.84	4.71	5.28	6.46	7.88	9.63	10.81	13.19	16.17	19.72

Table 4: Bell's Equations Recommended for use in Zone B

Return Period	α	β
100 years	47.206	0.777
50 year	40.284	0.777
25 year	30.237	0.738
15 year	22.327	0.695
10 year	21.183	0.723
5 year	18.685	0.725
2 year	8.248	0.712
t = storm duration in hours (tc) i = rainfall intensity in mm/hr M = multiplication factor	$i = \frac{\alpha}{(t * M)^B}$	

4 DRAINAGE SYSTEM

The drainage system includes vertical drains consisting of crushed stone columns enveloped with non-woven geotextile filter fabric to facilitate and improve the soil properties of the hill material and to drain water from the entire hill body to the sea. Figure 12 illustrates the cross section A-A passing by some of the vertical drains.

The efficiency and distribution of the vertical drains have been evaluated in the concept design stage and it was found the 368 drains with depths ranging from 15 m to 20 m are adequate to achieve the drainage of the hill within the appropriate time, referring to Appendix A. These columns have been chosen with a specific criterion (location and depth) to drain the water from the hill to the native soil inside the highest available permeable layer as shown in Figure 13.

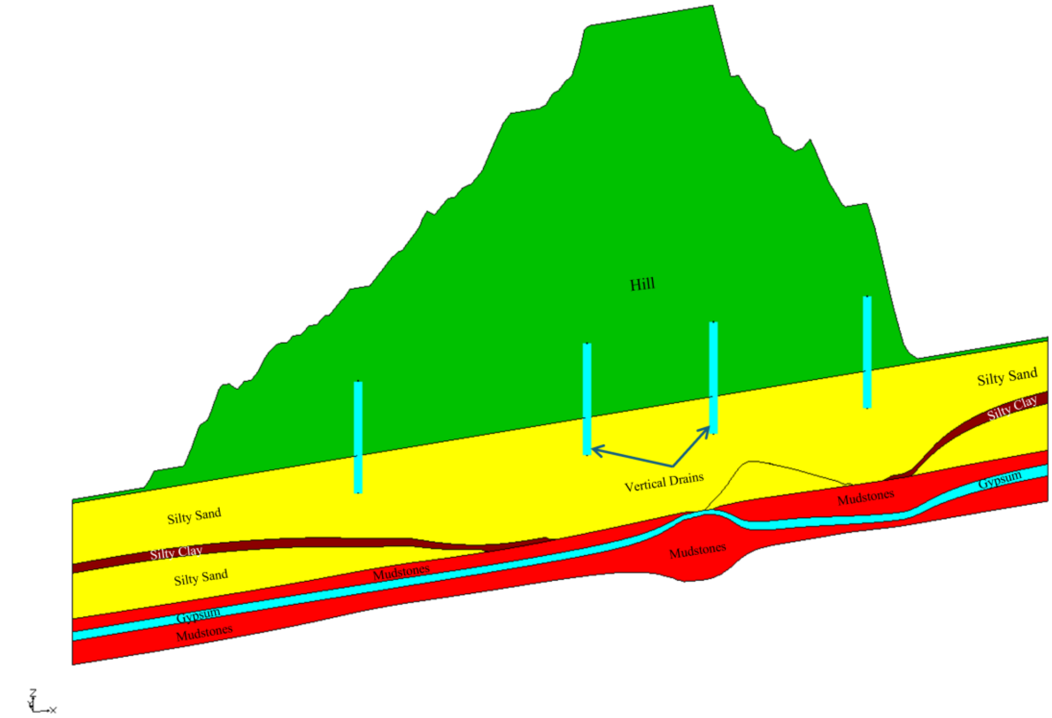

Figure 12: Drainage system (Vertical drains) along cross section A-A.

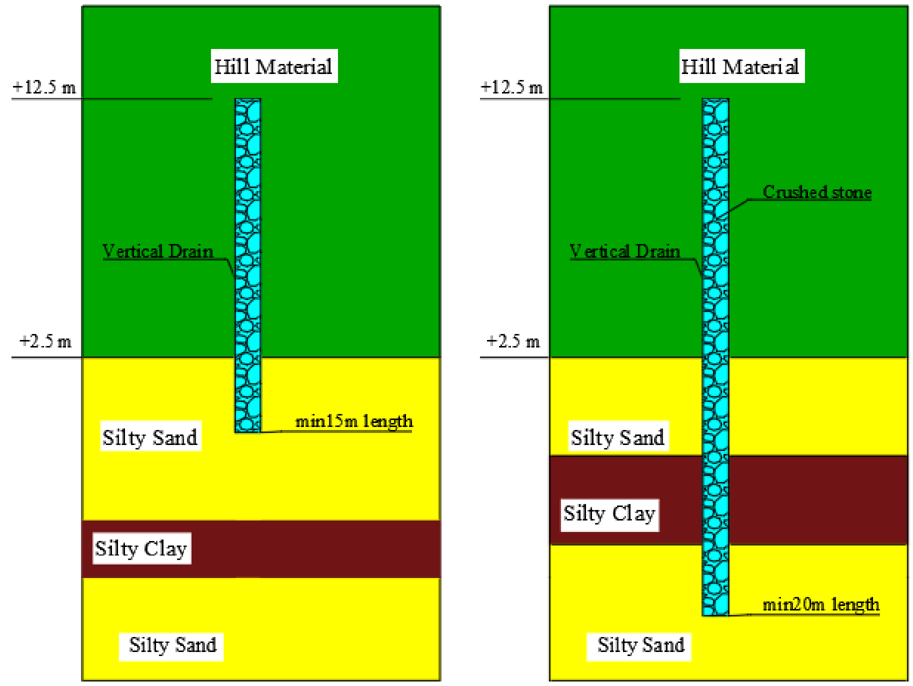

Figure 13: Schematic X-section in the Vertical Drain in 2 cases.

As a rule of thumb, and according to the geological cross section (Figure 14) , stone columns should penetrate the native soil and sea level (i.e. A minimum 3.0 m into the sand layer) (Case 1), however, in special cases if shallow clay layer in the native soil has been encountered at the end of the stone column depth, deeper stone column should be considered till penetration of the clay layer and reach the sand layer below, with minimum 2.0 m inside this deeper sand layer (Case 2).

According to the proposed system, and the generated 3-D hydrogeological model, the total volume of crushed stone is about 2870 m3 distributed in 331 vertical drains of 15 m- depth, and 37 vertical drains of 20 m depth.

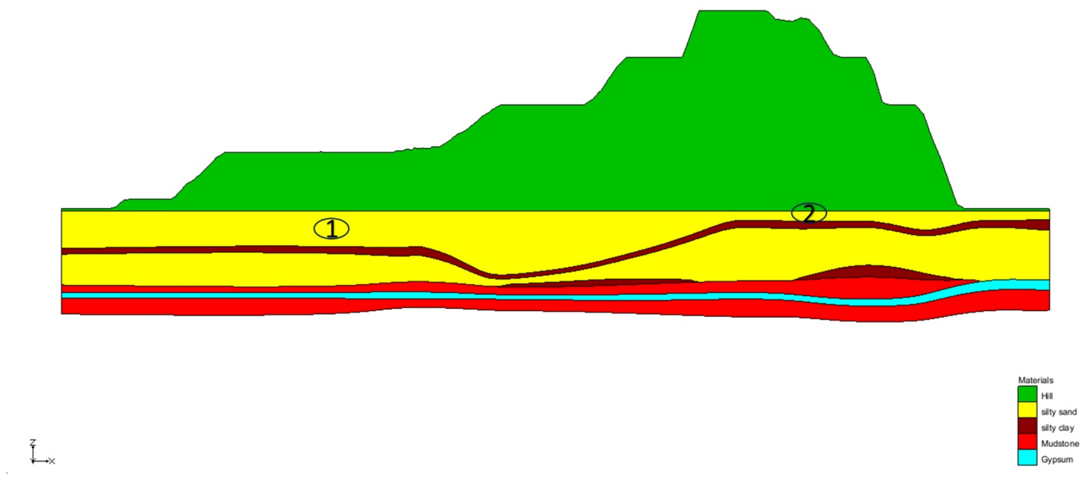

Figure 14: Geological Cross Section Inside the Study Area.

5 MODELING AND SIMULATION

5.1 Introduction

The simulation team of AIECON constructed and developed the simulation model of the hill and its basement native and improved layers considering the available data of the hill geometry as well as the hydraulic properties of the different layers. The following sections present the modelling steps and results.

5.1.1 Groundwater Modelling

In general, models are conceptual descriptions or approximations that describe physical systems using mathematical equations; they are not exact descriptions of physical systems or processes. The applicability, or usefulness, of a model depends on how closely the mathematical equations approximate the physical system being modelled. To evaluate a model's applicability or usefulness, a thorough understanding of the physical system and the assumptions embedded in the derivation of the mathematical equations will produce better predictions.

Groundwater models describe groundwater flow and fate-and-transport processes using mathematical equations that are based on certain simplifying assumptions. These assumptions typically involve the direction of flow, the geometry of the aquifer, the heterogeneity or anisotropy of sediments or bedrock comprising the aquifer, the contaminant transport mechanisms, and chemical reactions. Because of the simplifying assumptions embedded in the mathematical equations and the many uncertainties in the values of data required by the model, a model provides predictions as an approximation and not an exact duplication of field conditions.

Groundwater-flow models are used to calculate the rate and direction of movement of groundwater through aquifers and confining units in the subsurface, and the exchange of groundwater between aquifers and sources and sinks, where groundwater is added or removed from the aquifer. These calculations are referred to as “simulations.” The simulation of groundwater flow depends upon a thorough understanding of the hydrogeologic characteristics of the facility and the surrounding area.

A groundwater-flow model simulates the following processes:

- Movement of groundwater through aquifers and confining layers,
- Addition of groundwater by sources such as precipitation, leakage from surface water bodies, injection wells, infiltration galleries, etc.,
- Removal of groundwater by sinks such as pumping wells, drains, surface water bodies, interceptor trenches, etc., or
- The change in hydraulic head and hydraulic gradients as a result of the addition or removal of groundwater by sources and sinks.

The outputs from groundwater flow model simulations are the hydraulic heads and groundwater flow rates that are in equilibrium with the hydrogeologic conditions (hydrogeologic framework, hydrologic boundaries, initial and transient conditions, hydraulic properties, and sources or sinks) defined for the modelled area.

5.1.2 Mathematics of Three-Dimensional Groundwater Flow

A partial differential equation based on the principles of mass balance can be used to describe the groundwater flow system previously described in the conceptual model. The derivation of the generalized governing equation of groundwater flow in saturated media has been described in many references including those by Bear (1978), Anderson and Woessner (1992), Kresic (1997), and Schwartz and Zhang (2003). The partial differential equation can be written as:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t} \qquad \text{Equation 1.1}$$

Where

Kxx, Kyy, and Kzz equal horizontal hydraulic conductivity along the x, y, and z axes [LT –1];

h equals the potentiometric head [L];

W equals sources or sinks of water (volumetric rate per unit volume)

[L3 T–1 L–3];

Ss equals the specific storage of the porous media [L –1]; and

t equals time [T]6.

Predevelopment (or steady-state) conditions are represented by setting the right-hand side of Equation 1.1 to zero.

Equation 1.1 is subjected to the following boundary and initial conditions.

5.1.2.1 Boundary Conditions

Type 1. Specified head boundary (Dirichlet condition) in which the hydraulic head or potentiometric level is specified. When the hydraulic head is a constant value, such as a boundary representing sea level, this boundary is also referred to as a constant-head boundary condition.

Type 2. Specified flow boundary (Neumann condition) in which the gradient of the head (or flux) across a boundary is given. When the flux is specified as zero, this represents a no-flow boundary condition.

Type 3. Head-dependent flow boundary (Cauchy or mixed boundary) in which the flux over a boundary is calculated given a head value at the boundary. This boundary condition type is also known as a generalized-head boundary in model applications.

5.1.2.2 Initial Conditions

Under steady-state conditions (the right-hand side of Equation 1.1 is zero), initial conditions do not need to be specified. For transient or unsteady-state conditions, initial conditions supply the hydraulic head or potentiometric level everywhere within the domain of interest at some initial time such as steady-state (e.g., time = 0).

The system represented by Equation 1.1 and the respective boundary conditions can be solved using analytical and numerical methods. Analytical solutions are only available for simple systems, while complex systems require numerical methods (e.g., finite-difference or finite-element methods). The numerical code used in this study (e.g., MODFLOW-NWT) is one of the solvers available in MODFLOW-NWT. The NWT package is only used with the UPW Package. Using the NWT solver requires twice the memory of other MODFLOW solvers because using the Newton method results in an asymmetric matrix. MODFLOW-NWT includes two previously developed asymmetric matrix-solver options. The matrix-solver options include a generalized-minimum-residual (GMRES) Solver and an orthomin / stabilized conjugate-gradient (CGSTAB) Solver. Details of the solution methodology are described in Harbaugh (2005).

5.1.3 Numerical Models

The codes used for groundwater-flow simulation and model calibration included MODFLOW-2000, MODFLOW-2005, MODFLOW-ASP, MODFLOW-NWT and PEST 12. MODFLOW-2000, -ASP, and -2005 (Harbaugh et al. 2000; Harbaugh 2005; Doherty 2010) are based on the original modular finite-difference groundwater-flow model developed by McDonald and Harbaugh (1984).

These codes all simulate groundwater flow in a three-dimensional, heterogeneous, anisotropic porous media. MODFLOW-ASP and PEST 12 are computer codes used for parameter estimation and model calibration that were developed or modified by Doherty (2010, 2011). The model grid and arrays were constructed and manipulated using the graphical user interface software Groundwater Modeling System (GMS) version 10.8 (U.S. Army Engineer and Research Development Center 2008) and Model Muse version 2 (Winston 2009).

The used Newton package (NWT) is one of the solvers available in MODFLOW-NWT. The NWT package is only used with the UPW Package. Using the NWT solver requires twice the memory of other MODFLOW solvers because using the Newton method results in an asymmetric matrix. Because of the asymmetric matrix a different matrix solver must be used. The NWT package provides an option to use one of two matrix solvers: a generalized-minimum-residual (GMRES) solver and an Orthomin/stabilized conjugate-gradient solver called χMD (chi-MD).

Numerical models are capable of solving the more complex equations that describe groundwater flow and solute transport. These equations generally describe multi-dimensional groundwater flow, solute transport, and chemical reactions, although there are one-dimensional numerical models. Numerical models use approximations (e.g. finite differences, or finite elements) to solve the differential equations describing groundwater flow or solute transport. The approximations require that the model domain and time be discretized. In this discretization process, the model domain is represented by a network of grid cells or elements, and the duration of the simulation is represented by a series of time steps.

The accuracy of numerical models depends upon the accuracy of the model input data, the size of the space and time discretization (the greater the size of the discretization steps, the greater the possible error), and the numerical method used to solve the model equations.

Numerical models may be used to:

- Simulate very simple one- or two-dimensional flow and transport conditions, which may just as easily be simulated using an analytical model,
- Model more complex two- or three-dimensional groundwater flow and solute-transport problems,
- Simulate steady-state or transient groundwater flow or solute transport,
- Assess regional- or local-scale flow or transport,
- Estimate fluxes at simple or complex hydrogeologic boundaries.

The objective of constructing a numerical groundwater flow model of the CICPA Hill groundwater basin was to gain a better understanding of the aquifer lithology and evaluate the infiltration time for the hill's water with a drainage system alternative.

The numerical model used for this study is the USGS modular three-dimensional finite-difference groundwater flow model (MODFLOW) (McDonald and Harbaugh, 1988). Groundwater levels were calculated at discrete points by solving simultaneous equations that approximate the partial differential equation for groundwater flow. The discrete points are the result of the discretization of the model area into a series of layered square model cells with the points (or nodes) located at the center of the model cells.

6 CICPA 3-D NUMERICAL MODEL

This section describes the development of CICPA 3-D model.

The model constructed by translating the basic geometry and hydrologic information into numerical representation in the regional and local scales. The construction of the model comprises three steps:

- Model domain definition
- Model domain discretization; and
- Model boundary conditions specification

In the sections below, the construction of the model of CICPA Hill is presented.

6.1 Conceptual Model

The conceptual model is developed by determining the stratigraphy of the study area through the interpretation of the hydrogeologic settings as shown in Figure 8 and Figure 9. The geologic settings are correlated with the lithological logs of the boreholes and the layering system of the conceptual model is defined and visualized.

6.1.1 Model Layer Properties

The 3D geological model has been developed based on the borehole data as shown in Figure 8. The hydraulic properties of the different model layers are given in Table 5.

Table 5: Hydraulic Properties of Different Model Layers [1] [2] [3] [4] [5] [6] [7] [8]

Material	Hydraulic Conductivity (m/s)	Specific Yield	Specific Storage (1/m)	Porosity
Hill material	3.82E-06	0.2	0.0002	0.4
Silty Sand	1.10E-04	0.22	0.0002	0.25
Silty Clay	9.26E-07	0.02	0.00005	0.5
Gypsum	1E-10	0.05	0.00005	0.3
Mudstone	1E-10	0.05	0.00005	0.3

6.2 MODEL CONSTRUCTION

6.2.1 Model Domain and Discretization

The 3D model domain encompasses an entire area of around 8.00 km2 that extends approximately between longitudes 233,319.15 – 236,546.94 m East with total length of 3227 m in X-direction, and Latitudes of 2,697,062.72 – 2,699,653.30 m North with total length of 2590 m in y-direction (Dubai, UTM Zone 40 projection), Figure 15.

Accordingly, the model domain is discretized into a grid that consists of a finite difference mesh of eight layers to represent the aquifer system. The total number of rows and columns of the model grid are 260 and 323 respectively, number of active cells are 292224, and number of inactive cells are 379616 cells as shown in Figure 16. The model grid consists of regular cell sizes.

Figure 15: Model domain and discretization.

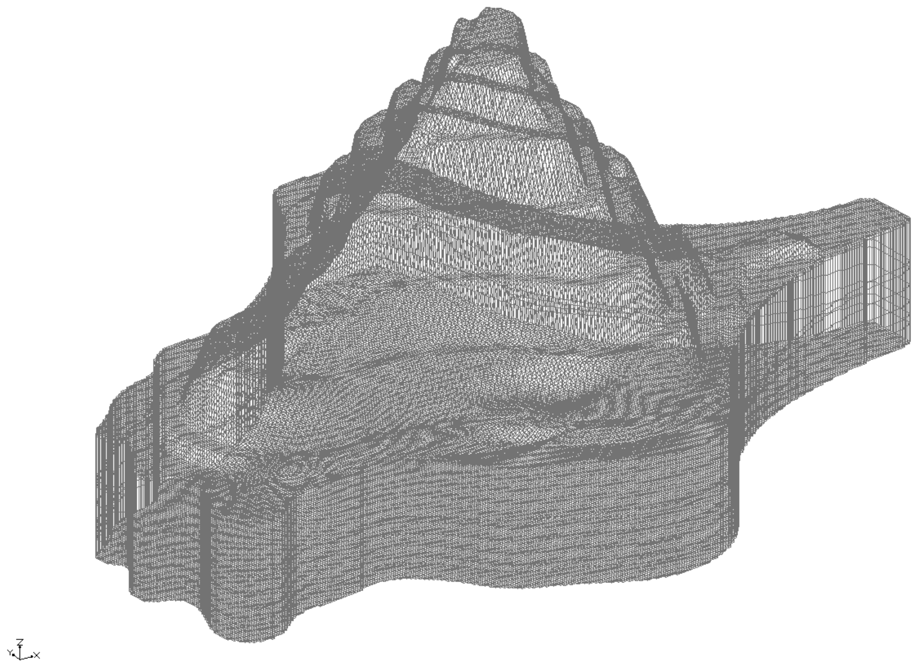

Figure 16: 3D active grid numerical model.

In order to reduce the numerical simulation time, the outer inactive cells of the domain are excluded from the model. Figure 16 shows the active model domain by GMS software.

6.2.2 Initial Conditions

The initial boundary condition is given to all the model domain as the water level at any point within the hill equals to its corresponding elevation (Fully Saturated Hill).

6.2.3 Boundary Conditions

The boundaries for the model domain are selected as follows:

- For the Hill: The Second type boundary (Recharge boundary) is assigned to allow water to flow through the Hill Surface.
- For the Native Soil: Constant head boundary that equals zero is assigned at the Sea Water Level around the whole base of the model and inside the aquifer system.
- Vertical drains have been assigned as drains as per drawings.

Boundary conditions are assigned for all simulations as follows:

Steady state:

The First type boundary (Constant head boundary) is assigned at the Sea Water Level around the whole base of the model and inside the aquifer system, in addition to, the Second type boundary (Recharge boundary) is assigned to allow water to flow through the Hill Surface.

Transient state:

The initial condition is taken as the results of the steady state conditions, with the same boundary conditions.

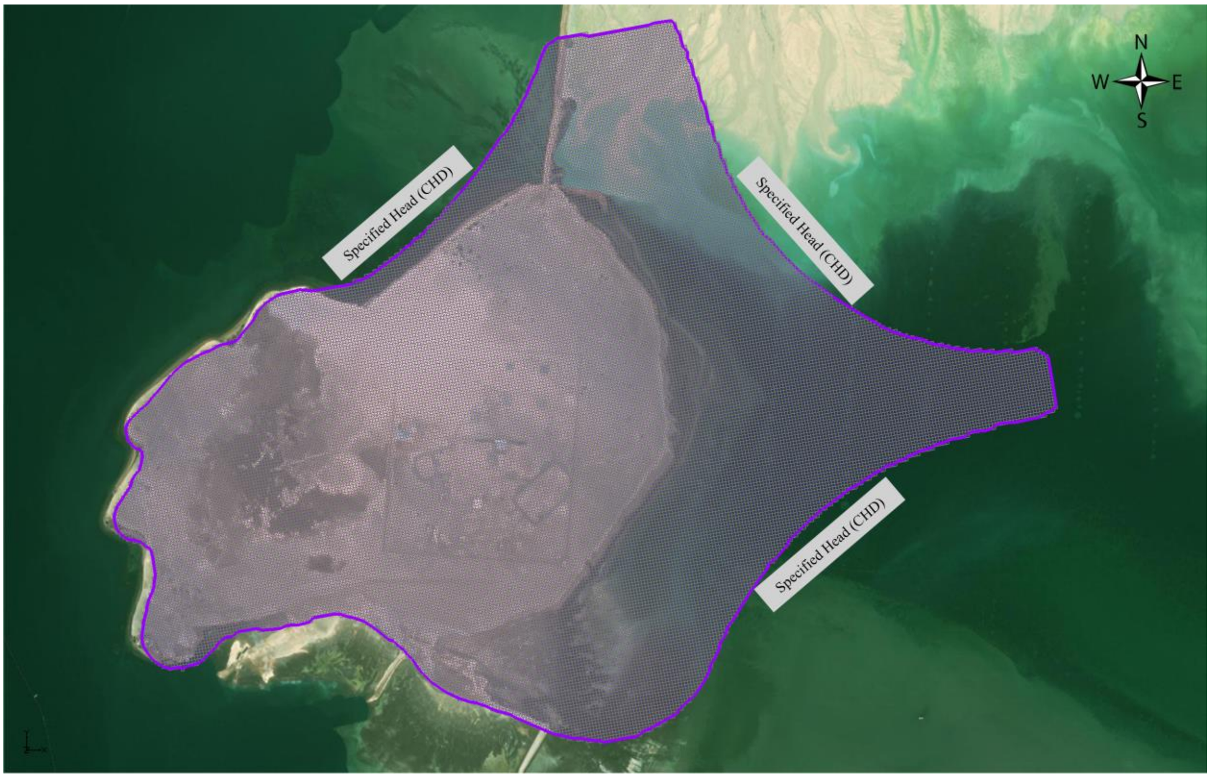

Figure 17: Model Domain and Boundary Conditions

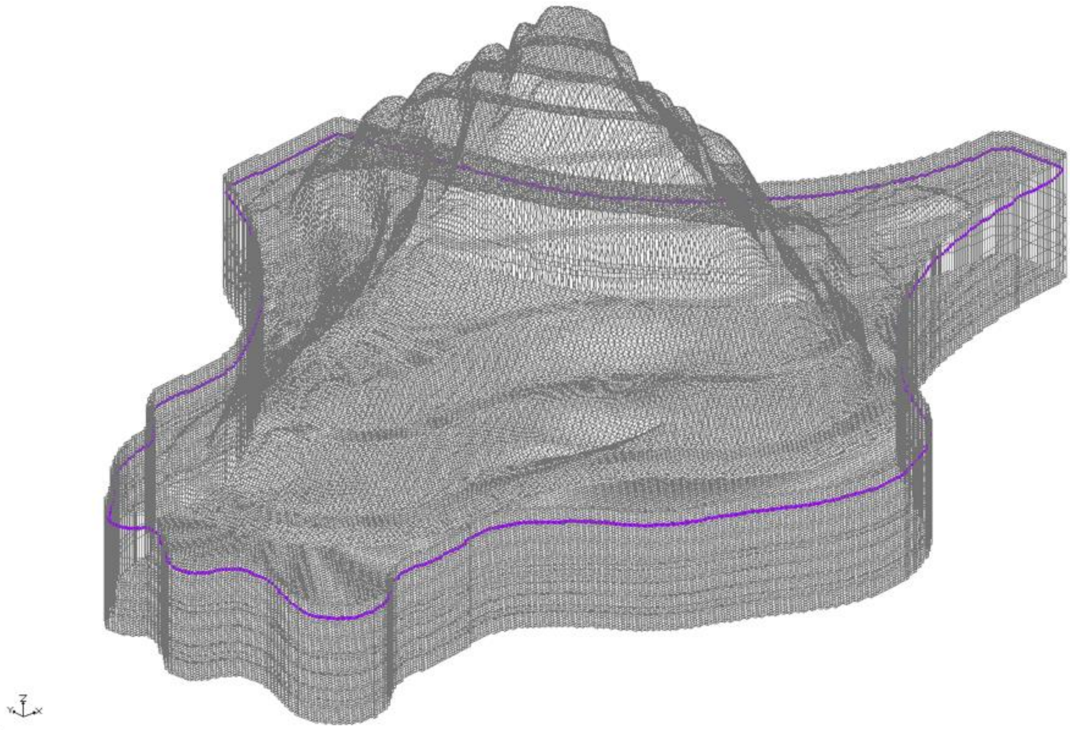

Figure 18: 3D Model Domain and Boundary Conditions

6.2.4 Model Topography

The topography of the Hill has been imported via the 3D surface provided by the Client, Figure 3. The maximum ground elevation in the domain reaches 55 m at the top of the Hill. The differences in the surface elevation control the flow direction of the surface water as well as the groundwater within the aquifer system.

6.2.5 Recharge Conditions

Based on the rainfall data explained in Section 3.2, and expected leakage from future wet utilities, the recharge value has been considered to take into account the recent high rainfall rate that happened in the early months of 2024, with a factor of 15%, 0.02 m/day. [9]

7 SIMULATION RESULTS

Based on the drainage system explained in Section 5, The Drainage system includes 368 Vertical drains consisting of crushed stone columns.

The column stone has been evaluated in the concept design with depths ranging from 15 m till 20 m and the distribution of these drains in the model as shown in Figure 19.

Figure 19: Vertical drain distribution in 3D grid model

The following figures from Figure 20 to Figure 37 is presented the numerical model results, where the hill's water level till the level (+5.00 NADD) at 6 months as requested.

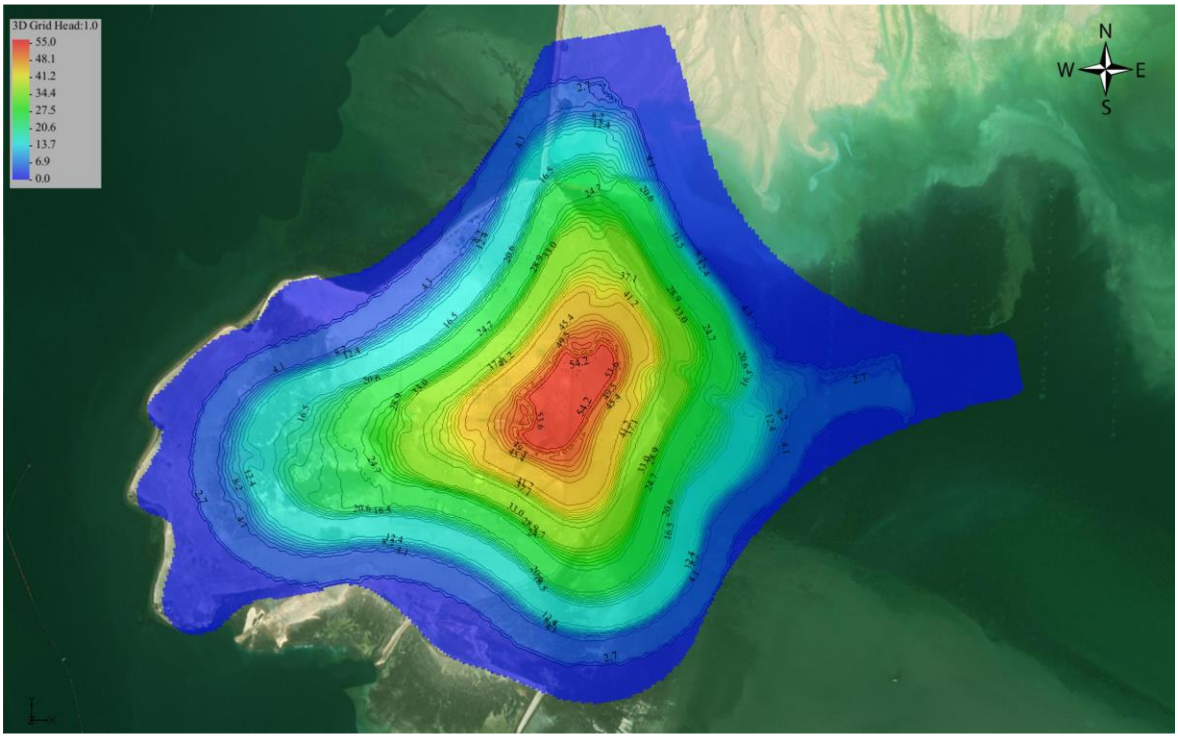

Figure 20: Water level contour map @ 1 day

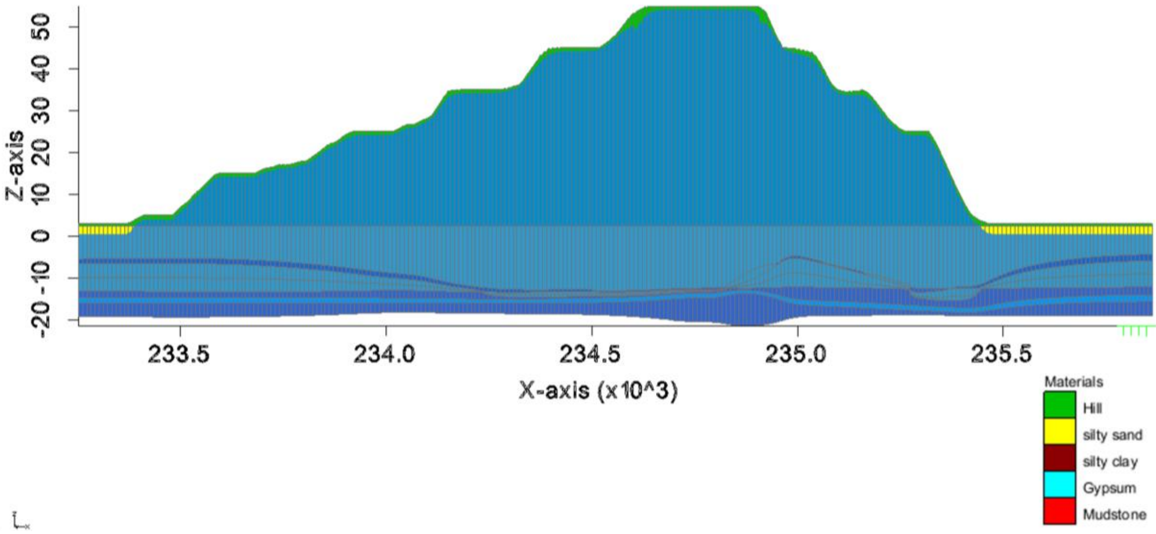

Figure 21: Water level cross-section @ 1 day

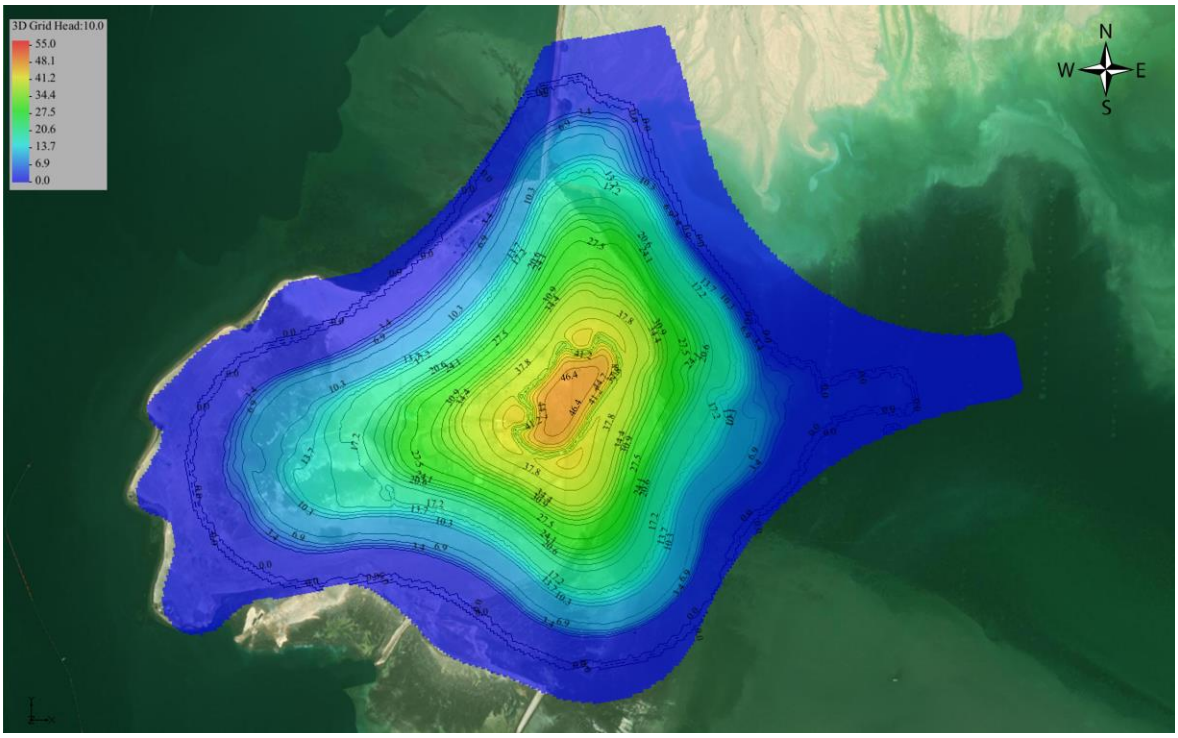

Figure 22: Water level contour map @ 10 day

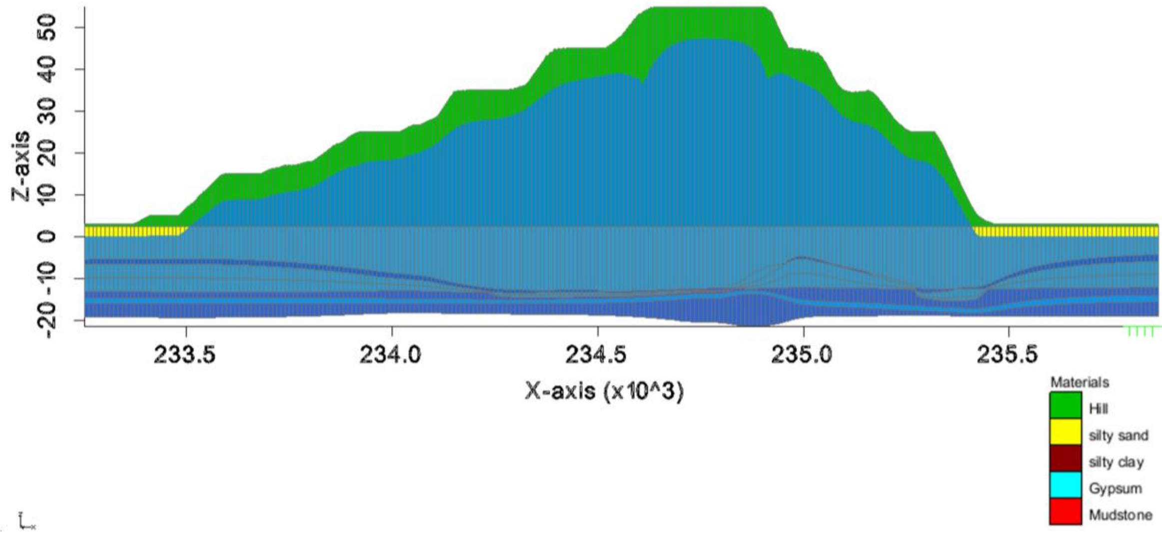

Figure 23: Water level cross-section @ 10 day.

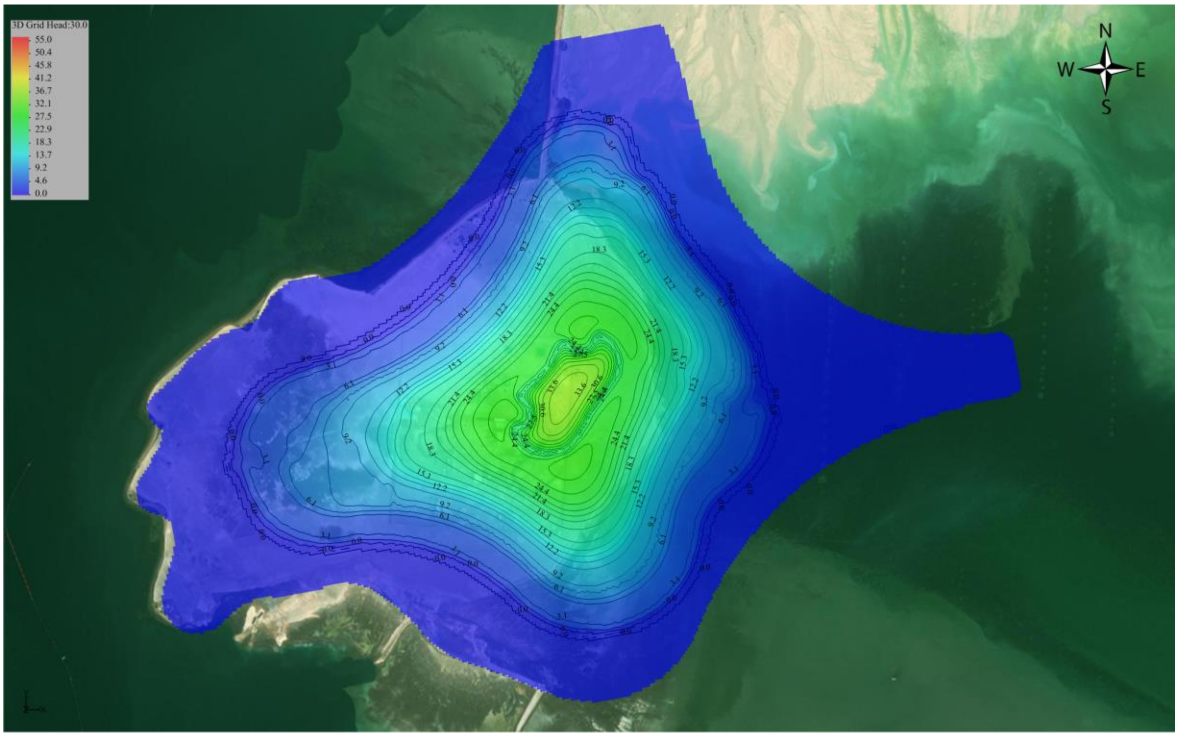

Figure 24: Water level contour map @ 1 month.

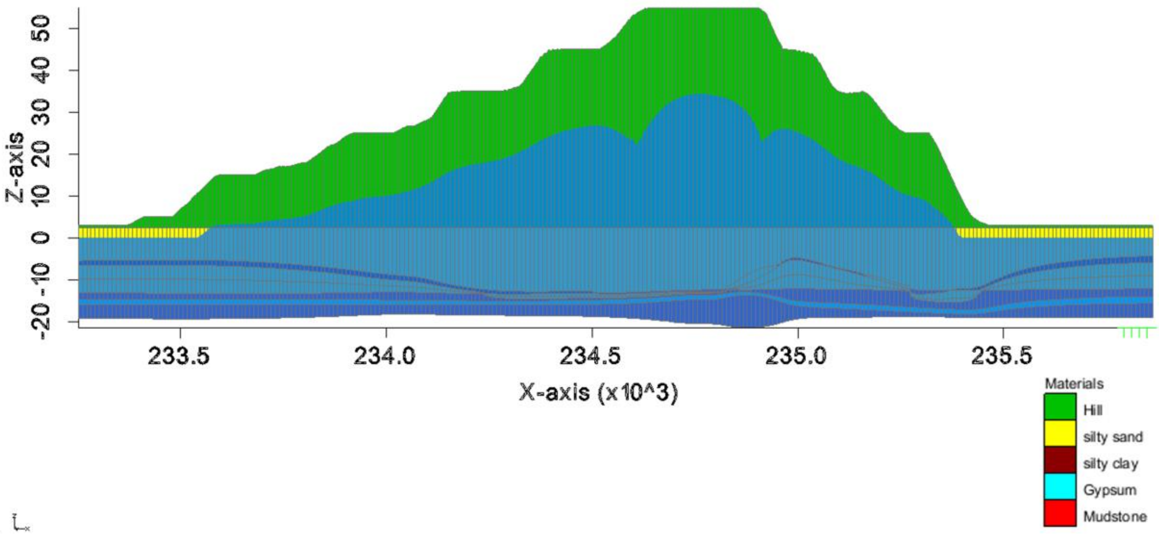

Figure 25: Water level cross-section @ 1 month.

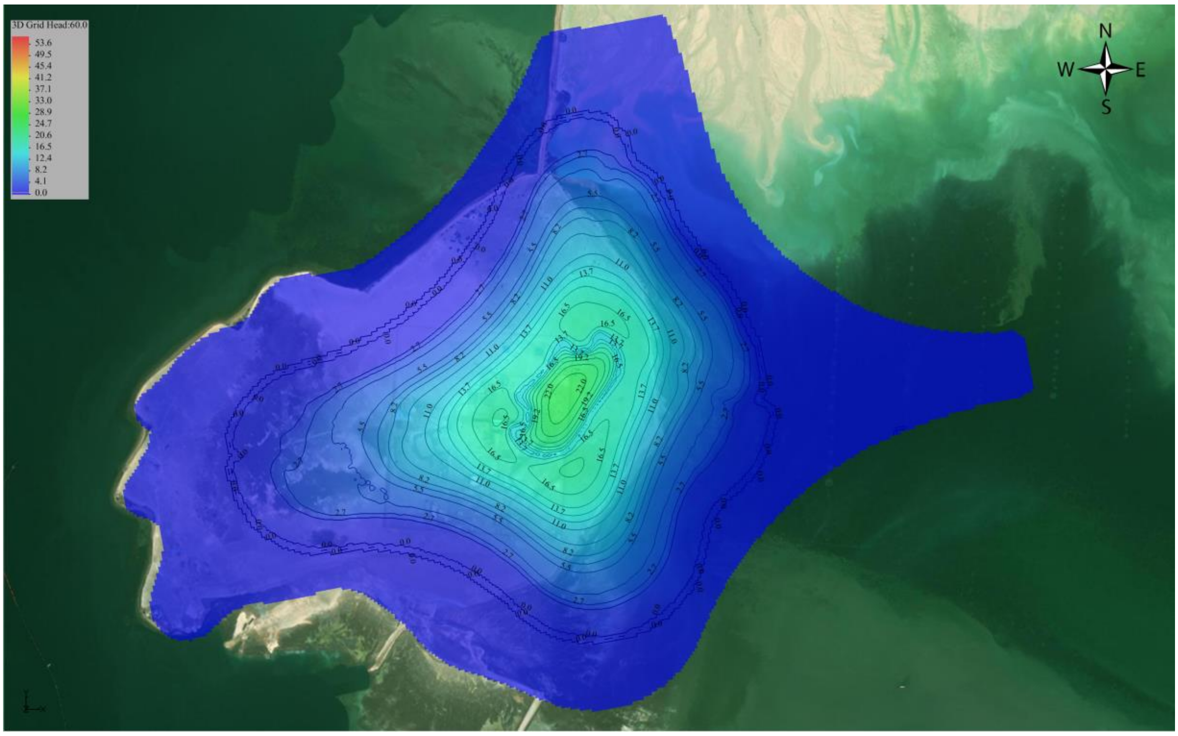

Figure 26: Water level contour map @ 2 month.

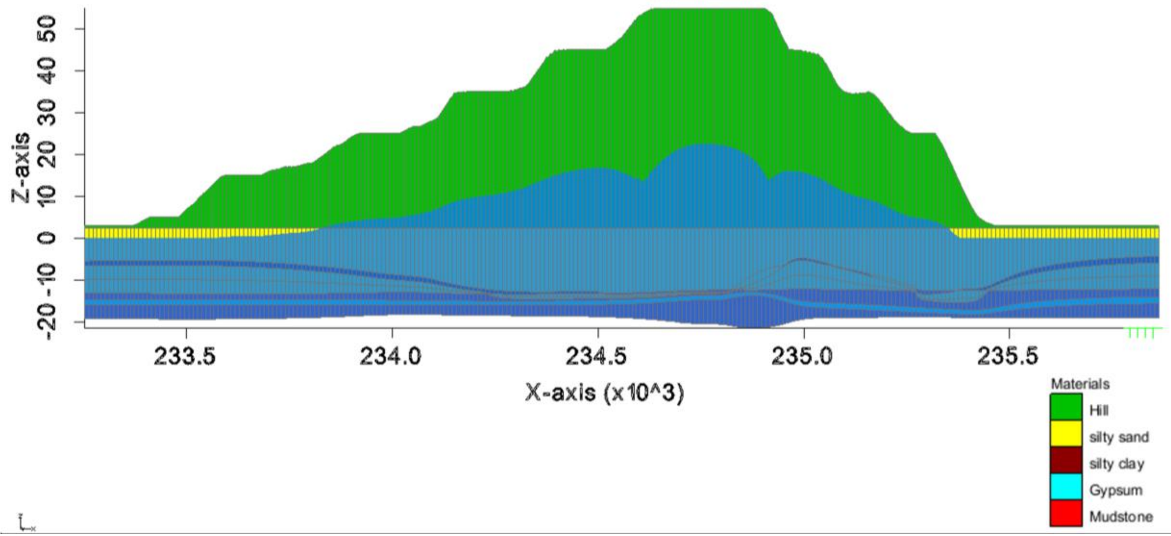

Figure 27: Water level cross-section @ 2 month.

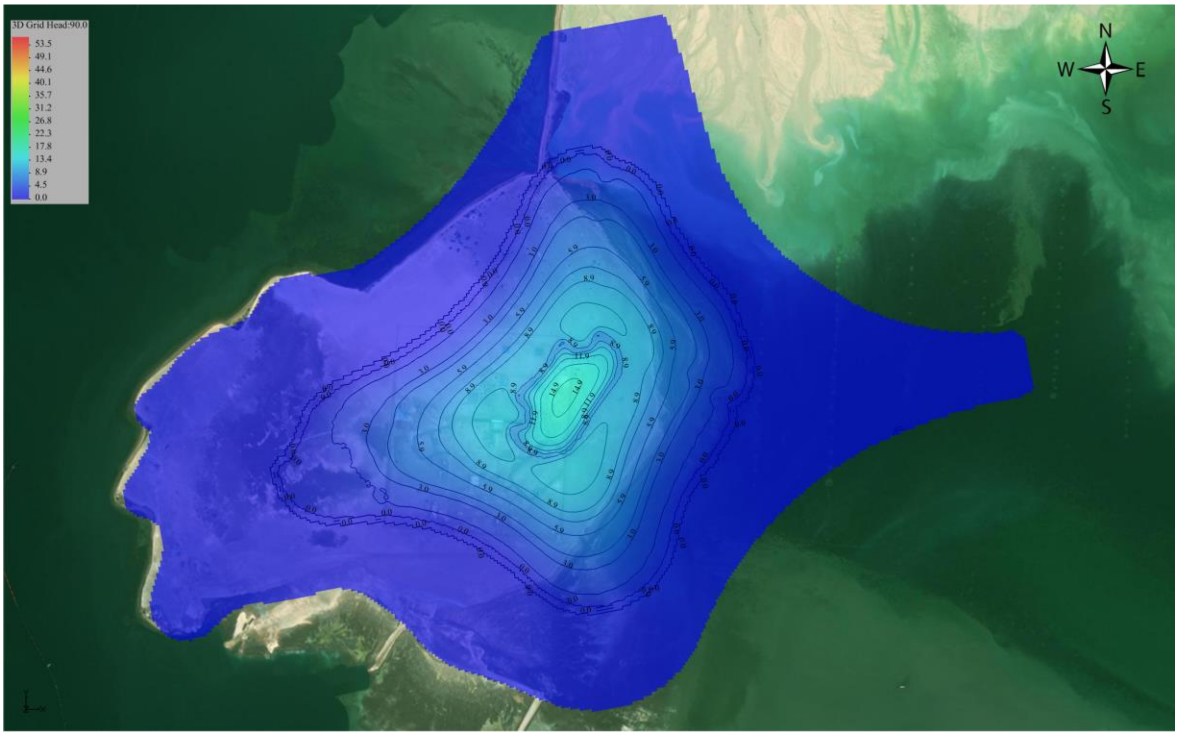

Figure 28: Water level contour map @ 3 month.

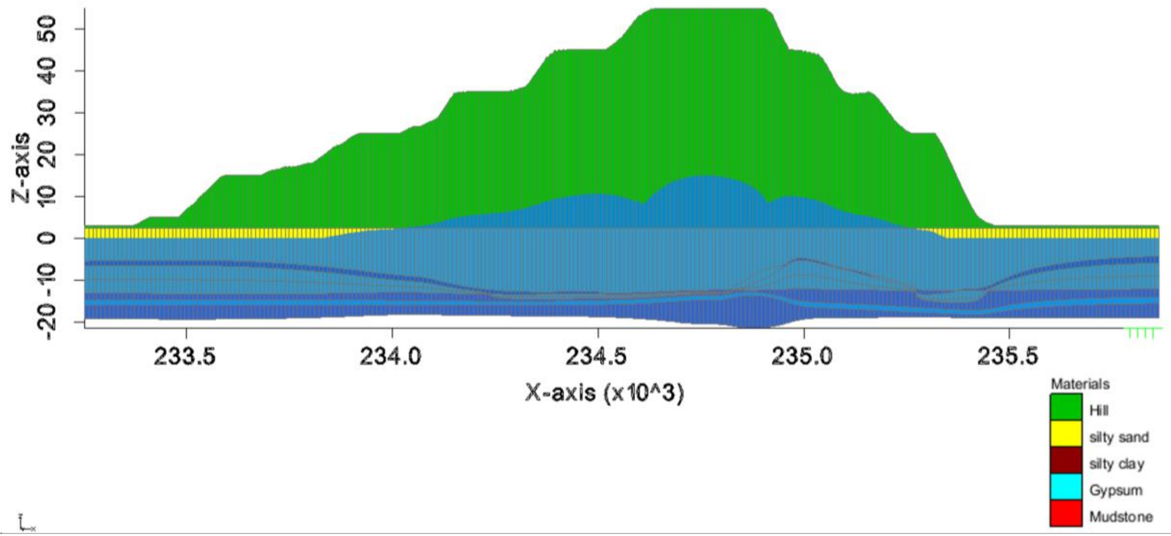

Figure 29: Water level cross-section @ 3 month.

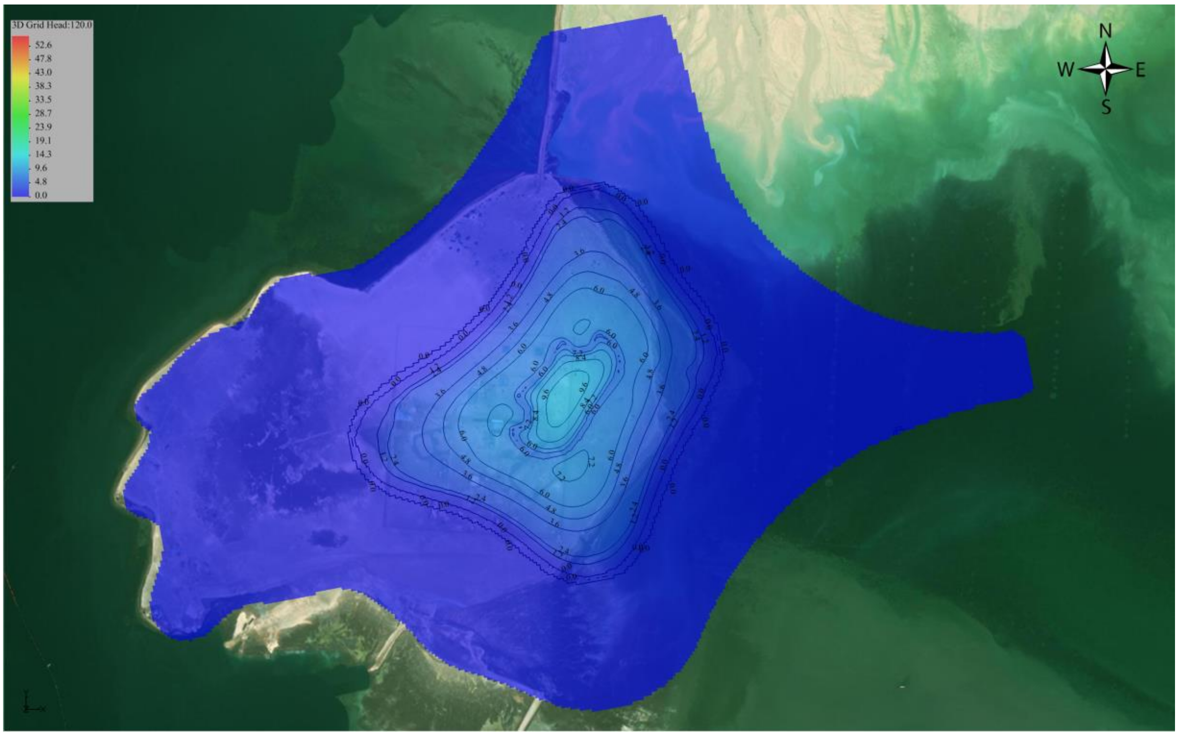

Figure 30: Water level contour map @ 4 month.

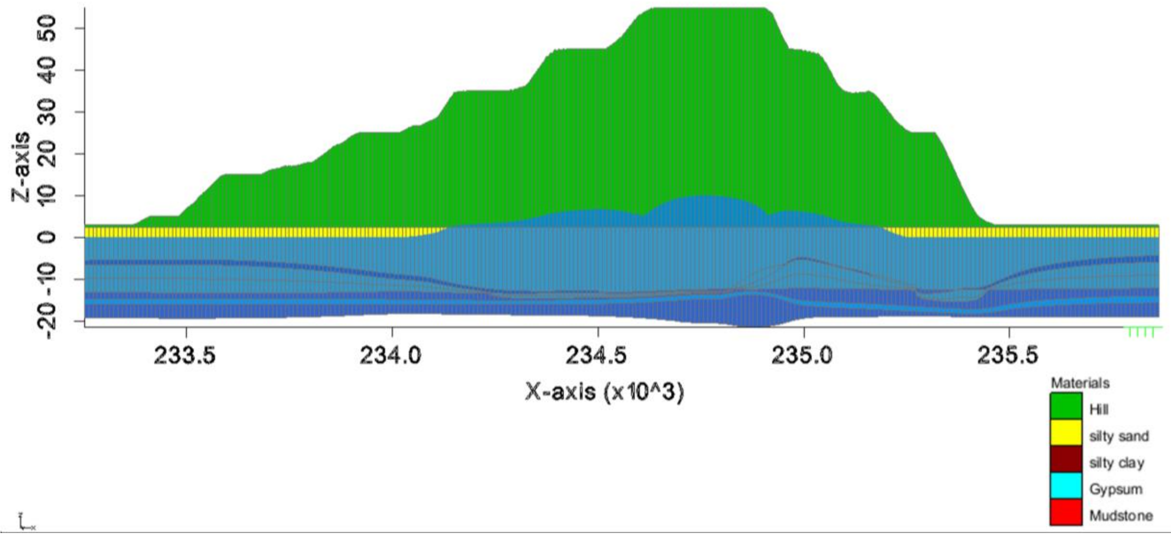

Figure 31: Water level cross-section @ 4 month.

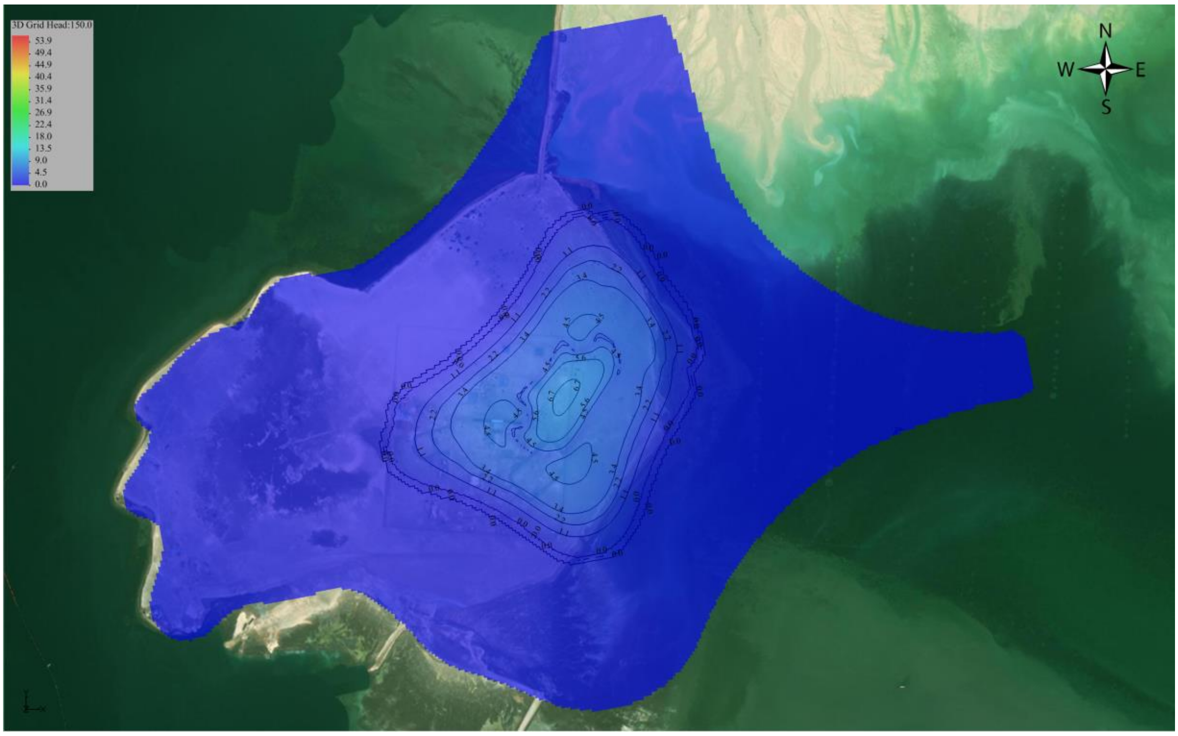

Figure 32: Water level contour map @ 5 month.

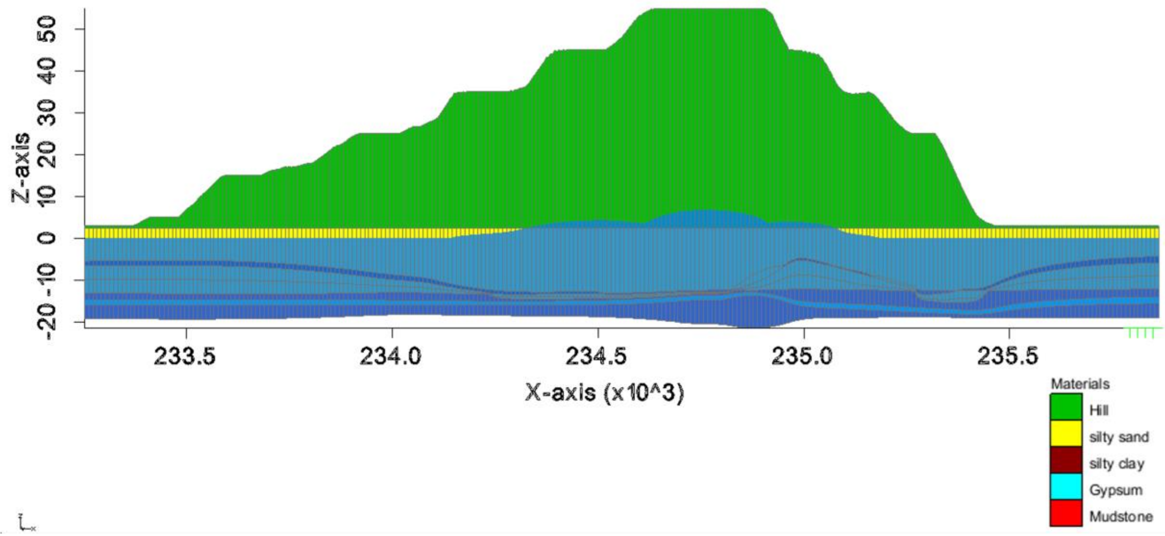

Figure 33: Water level cross-section @ 5 month.

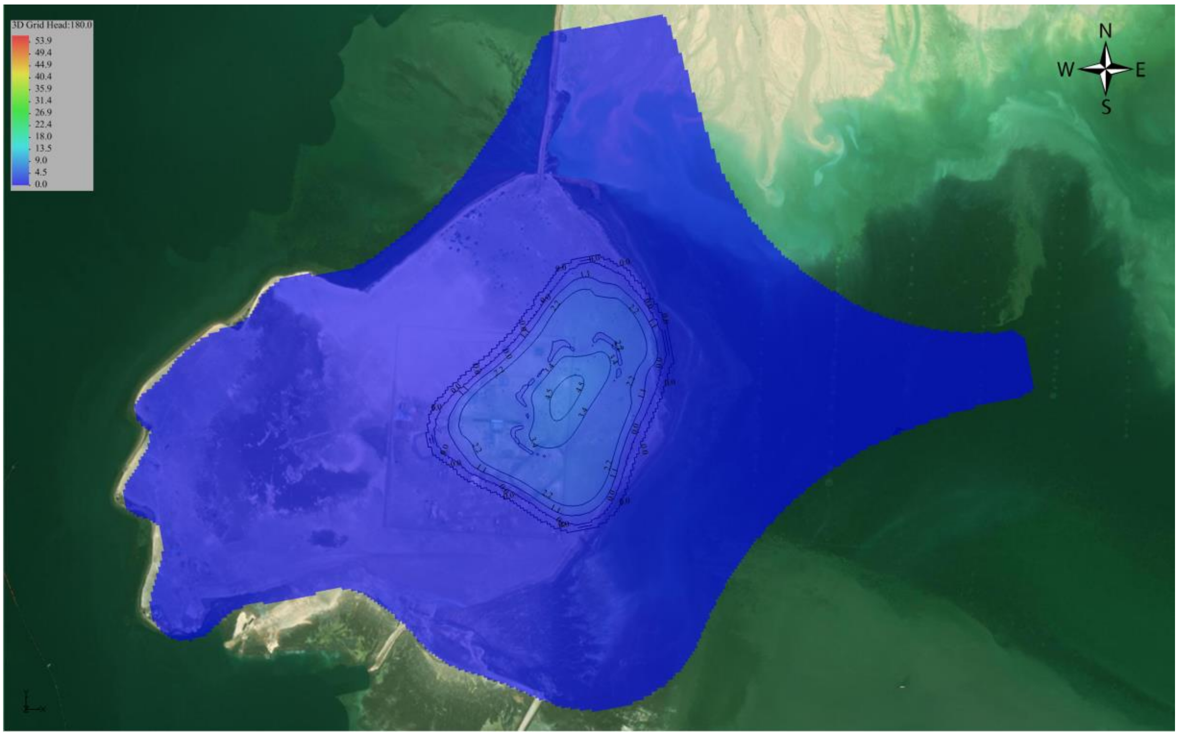

Figure 34: Water level contour map @ 6 month.

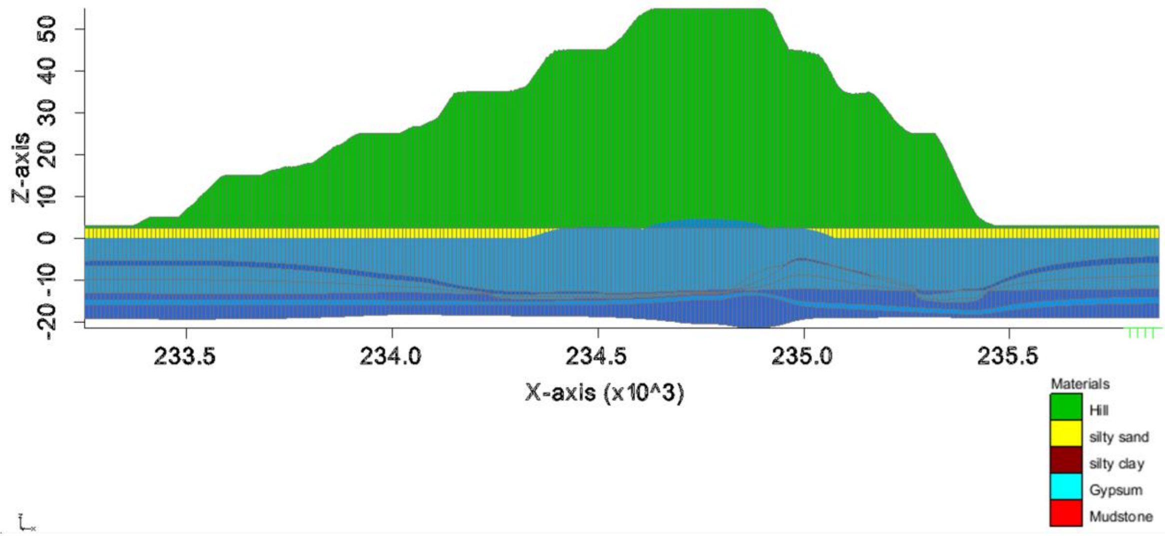

Figure 35: Water level cross-section @ 6 month.

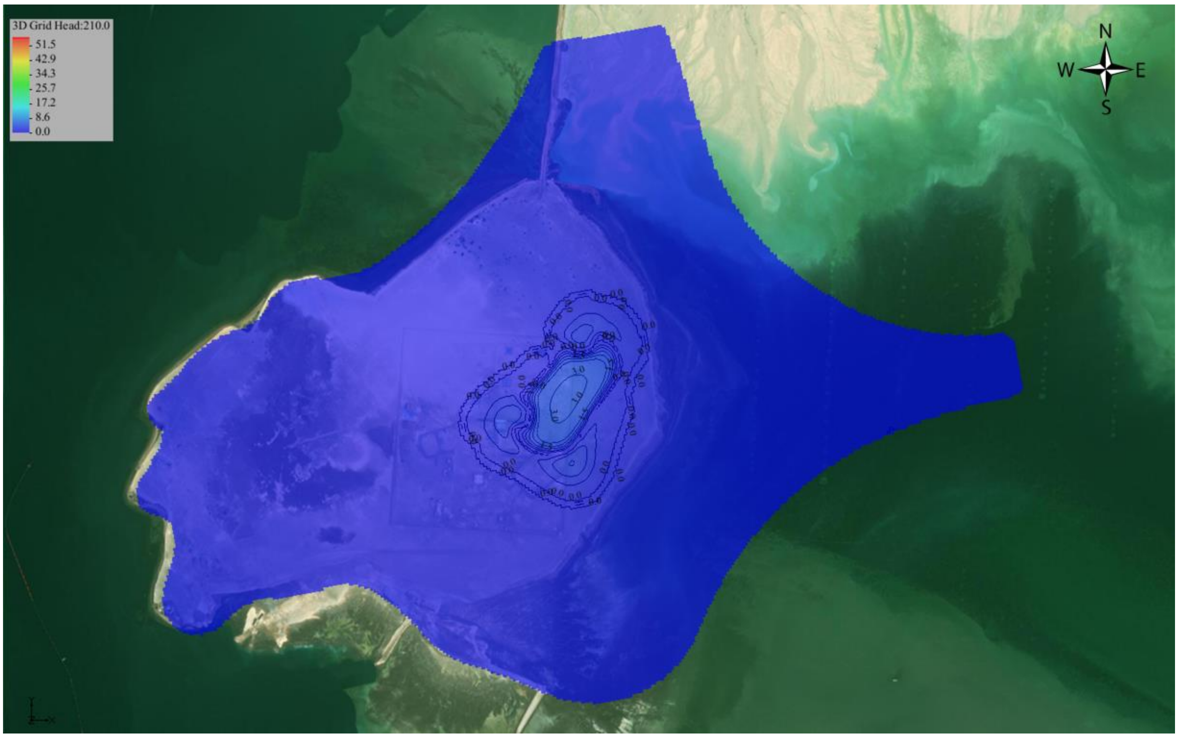

Figure 36: Water level contour map @ 7 month.

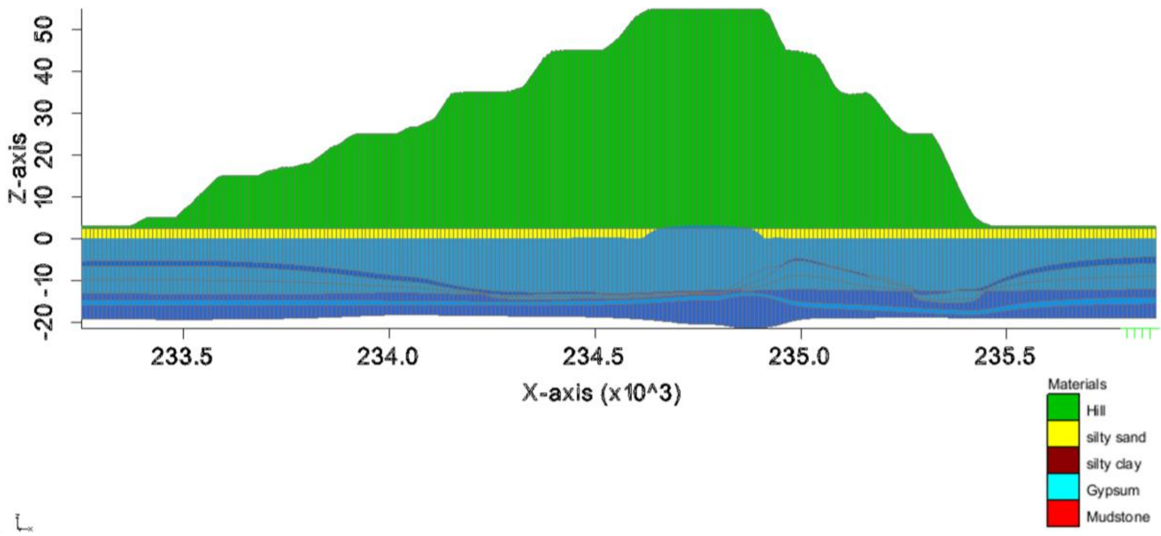

Figure 37: Water level cross-section @ 7 month.

The model was carried out for 480 days to observe the depletion of groundwater heads over time. Two piezometers were set up at the base of the hill (+2.5 m) with initial water levels set at +25 m and +55 m, respectively as shown in Figure 38.

Figure 39 and Figure 40 show the change of water level with time at the two monitoring piezometers.

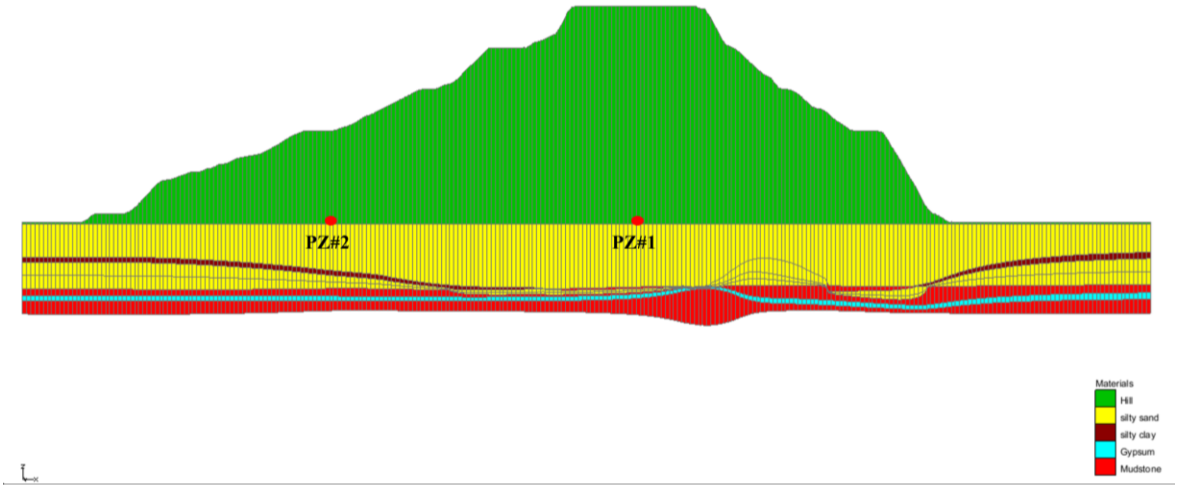

Figure 38: Piezometers location at cross-section.

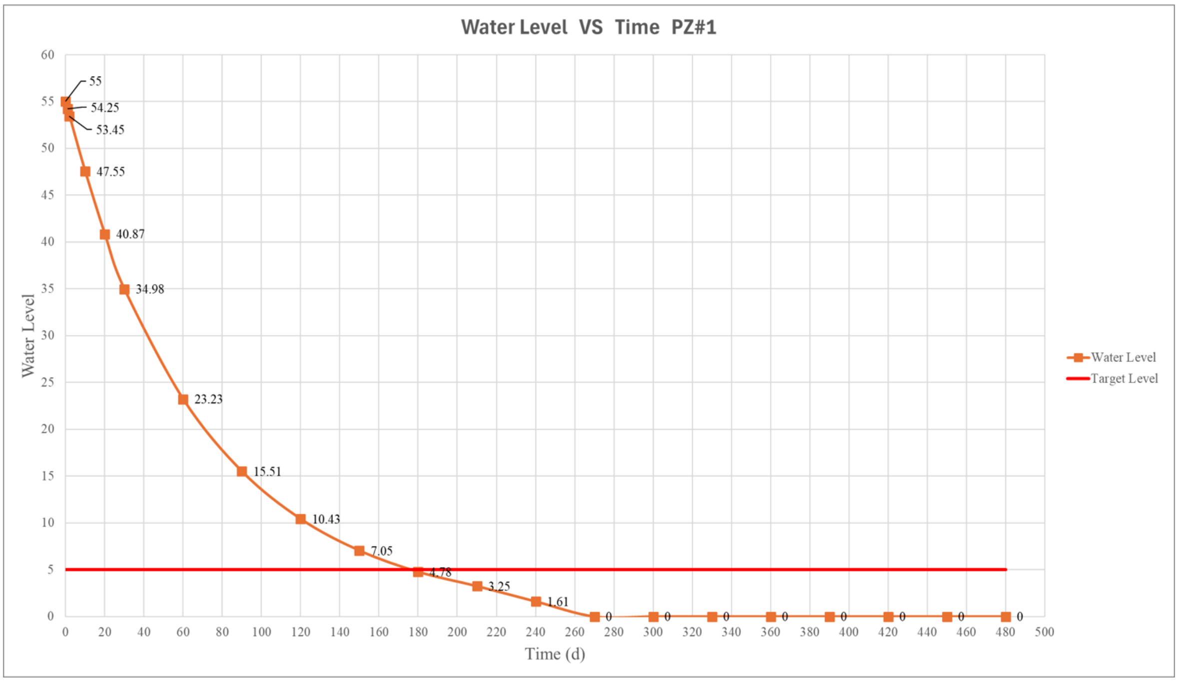

Figure 39: Water Level Changes at the Monitoring Piezometer 1.

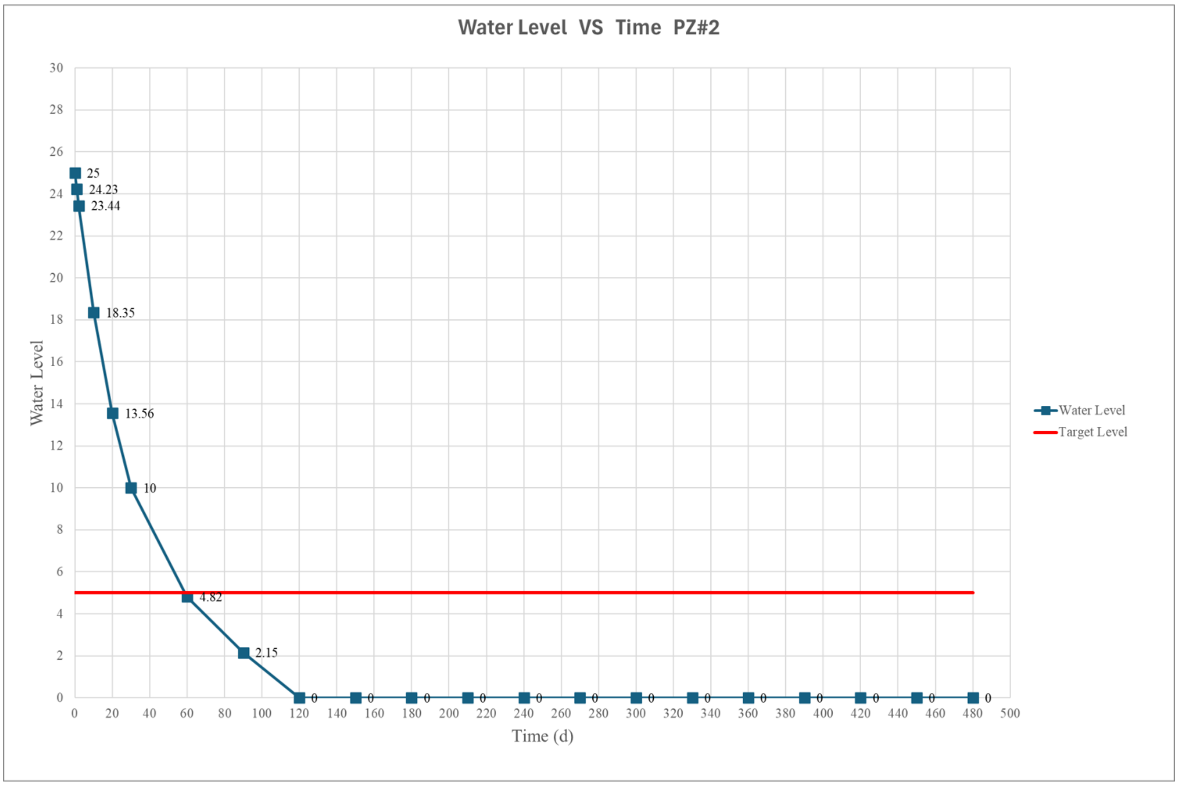

Figure 40: Water Level Changes at the Monitoring Piezometer 2.

8 CONCLUSIONS

The Drainage system of the hill that has been evaluated in the concept design stage includes 368 columns with depths ranges from 15 m till 20 m. The vertical drains are to be implemented from crushed stone as a rapid draining material with a high hydraulic conductivity (i.e. 300 to 1000 m/day) to facilitate and improve the soil drainage properties of the hill body in order to drain the hill's water into the sea in the appropriate time. The vertical drains penetrate the native soil with a minimum depth of 2.0 m in the sand layer.

A 3-d numerical model was developed to simulate the drainage system under the hydrologic conditions of a design storm of 0.02 m/day (the highest rainfall event occur in 2024). The simulation results showed propagation of the water levels within the hill's body until reaching +5.00 m NADD within 6 months as requested.

The simulation results showed the water levels at the different time steps till reaching the total drainage time of 6 months.

We recommend that the Contractor to consider precautions against erosion by the rainfall water running on the side slopes (out of scope).

9 REFERENCES

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APPENDIX A: VERTICAL DRAINS LOCATION AND DEPTHS

V.Drain No.	Easting	Northing	Depth (m)
1	234841.37	2699286.29	15
2	234818.33	2699292	15
3	234795.29	2699297.7	15
4	234772	2699300.79	15
5	234748.3	2699299.56	15
6	234725.01	2699295.5	20
7	234701.97	2699289.8	20
8	234680.27	2699280.31	20
9	234659	2699269.9	20
10	234639.75	2699256.01	20
11	234621.55	2699240.94	20
12	234605.3	2699223.65	20
13	234591.14	2699204.74	20
14	234578.47	2699184.67	20
15	234568.76	2699163.07	20
16	234559.96	2699141.03	20
17	234551.57	2699118.82	20
18	234543.17	2699096.62	20
19	234534.78	2699074.41	20
20	234524.68	2699052.95	20
21	234514.23	2699031.64	20
22	234503.79	2699010.32	20
23	234492.85	2698989.28	20
24	234480.45	2698969.04	20
25	234468.04	2698948.8	20
26	234455.64	2698928.56	20
27	234442	2698909.17	20
28	234427.74	2698890.19	20

V.Drain No.	Easting	Northing	Depth (m)
29	234413.49	2698871.2	20
30	234399.08	2698852.35	15
31	234383.11	2698834.79	15
32	234367.13	2698817.24	15
33	234351.16	2698799.68	15
34	234334.38	2698782.93	15
35	234316.82	2698766.96	15
36	234299.26	2698750.98	15
37	234281.71	2698735.01	15
38	234262.83	2698720.63	15
39	234243.85	2698706.38	15
40	234224.86	2698692.12	15
41	234205.45	2698678.51	15
42	234185.21	2698666.11	15
43	234164.97	2698653.71	15
44	234144.73	2698641.3	15
45	234123.65	2698630.44	15
46	234102.33	2698620	15
47	234081.01	2698609.55	15
48	234059.58	2698599.37	15
49	234037.61	2698590.39	15
50	234016.09	2698580.4	15
51	233994.83	2698569.86	15
52	233975.46	2698556.23	15
53	233956.4	2698542.13	15
54	233940.3	2698524.74	15
55	233924.93	2698506.74	15
56	233912.4	2698486.57	15

V.Drain No.	Easting	Northing	Depth (m)
57	233901	2698466.08	15
58	233892.39	2698443.96	15
59	233885.38	2698421.57	15
60	233880.99	2698398.25	15
61	233879.98	2698374.94	15
62	233883.55	2698353.64	15
63	233907.14	2698352.2	15
64	233930.86	2698351.34	15
65	233948.79	2698339.99	15
66	233951.34	2698317.11	15
67	233954.32	2698295.86	15
68	233964.22	2698274.31	15
69	233978.31	2698255.32	15
70	233994.96	2698238.75	15
71	234013.27	2698223.65	15
72	234033.57	2698211.51	15
73	234056.91	2698207.23	15
74	234075.1	2698198.72	15
75	234075.66	2698175.01	15
76	234075.56	2698151.27	15
77	234083.06	2698135.06	15
78	234106.76	2698133.64	15
79	234130.45	2698132.22	15
80	234154.15	2698130.8	15
81	234177.54	2698126.8	15
82	234200.93	2698122.77	15
83	234224.32	2698118.73	15
84	234247.16	2698112.29	15

V.Drain No.	Easting	Northing	Depth (m)
85	234269.96	2698105.69	15
86	234292.76	2698099.1	15
87	234314.78	2698090.26	15
88	234336.71	2698081.18	15
89	234358.65	2698072.11	15
90	234379.6	2698060.99	15
91	234400.39	2698049.54	15
92	234421.19	2698038.1	15
93	234440.84	2698024.83	15
94	234460.24	2698011.15	15
95	234479.64	2697997.47	15
96	234497.78	2697982.21	15
97	234515.55	2697966.47	15
98	234533.32	2697950.73	15
99	234550.05	2697933.91	15
100	234566.41	2697916.72	15
101	234583.72	2697900.48	15
102	234601.39	2697884.69	15
103	234621.32	2697871.8	15
104	234641.76	2697859.87	15
105	234663.67	2697850.74	15
106	234686.06	2697843.14	15
107	234709.25	2697838.06	15
108	234732.7	2697835.07	15
109	234756.42	2697834.21	15
110	234780	2697835.96	15
111	234803.5	2697839.34	15
112	234826.27	2697845.76	15

V.Drain No.	Easting	Northing	Depth (m)
113	234848.79	2697853.28	15
114	234869.85	2697864.12	15
115	234890.66	2697875.54	15
116	234909.17	2697890.38	15
117	234927.35	2697905.59	15
118	234942.83	2697923.58	15
119	234957.59	2697942.09	15
120	234969.62	2697962.56	15
121	234980.38	2697983.62	15
122	234988.56	2698005.91	15
123	234995.74	2698028.5	15
124	235002.24	2698051.33	15
125	235008.73	2698074.16	15
126	235015.22	2698096.99	15
127	235021.72	2698119.82	15
128	235029.64	2698142.18	15
129	235037.89	2698164.43	15
130	235046.14	2698186.69	15
131	235054.39	2698208.95	15
132	235063.7	2698230.75	15
133	235073.66	2698252.29	15
134	235083.61	2698273.84	15
135	235093.56	2698295.39	15
136	235104.18	2698316.52	15
137	235115.78	2698337.23	15
138	235127.38	2698357.94	15
139	235138.98	2698378.65	15
140	235150.58	2698399.36	15

V.Drain No.	Easting	Northing	Depth (m)
141	235163.41	2698419.3	15
142	235176.48	2698439.11	15
143	235189.55	2698458.93	15
144	235202.46	2698478.84	15
145	235214.57	2698499.25	15
146	235226.68	2698519.67	15
147	235237.93	2698540.49	15
148	235245.88	2698562.85	15
149	235253.21	2698585.35	15
150	235257.38	2698608.72	15
151	235261	2698632.12	15
152	235261.27	2698655.86	15
153	235260.82	2698679.41	15
154	235257.19	2698702.87	15
155	235253.57	2698726.33	15
156	235246.16	2698748.87	15
157	235238.73	2698771.41	15
158	235227.86	2698792.49	15
159	235216.83	2698813.51	15
160	235202.77	2698832.61	15
161	235188.44	2698851.53	15
162	235172.31	2698868.92	15
163	235156.18	2698886.33	15
164	235140.05	2698903.75	15
165	235123.92	2698921.16	15
166	235108.78	2698939.41	15
167	235094.38	2698958.28	15
168	235077.98	2698977.03	15

V.Drain No.	Easting	Northing	Depth (m)
169	235063.6	2698998.36	15
170	235053.12	2699016.22	15
171	235040.58	2699036.38	15
172	235028.04	2699056.53	15
173	235016.43	2699077.2	15
174	235005.87	2699098.45	15
175	234995.3	2699119.71	15
176	234984.74	2699140.97	15
177	234975.47	2699162.82	15
178	234964.59	2699183.91	15
179	234952.94	2699204.52	15
180	234938.15	2699223.09	15
181	234922.03	2699240.35	15
182	234903.98	2699255.77	15
183	234884.31	2699268.86	15
184	234844.1	2698692.15	15
185	234847.72	2698685.99	15
186	234851.34	2698679.83	15
187	234854.95	2698673.67	15
188	234857.09	2698666.89	15
189	234858.94	2698659.99	15
190	234860.78	2698653.09	15
191	234862.63	2698646.19	15
192	234863.16	2698639.12	15
193	234863.1	2698631.98	15
194	234863.03	2698624.84	15
195	234862.97	2698617.69	15
196	234861.97	2698610.69	15

V.Drain No.	Easting	Northing	Depth (m)
197	234860.01	2698603.82	15
198	234858.05	2698596.95	15
199	234856.08	2698590.08	15
200	234853.54	2698583.46	15
201	234849.82	2698577.37	15
202	234846.09	2698571.27	15
203	234842.37	2698565.17	15
204	234838.54	2698559.15	15
205	234834.14	2698553.52	15
206	234829.75	2698547.89	15
207	234825.35	2698542.26	15
208	234820.95	2698536.63	15
209	234816.64	2698530.94	15
210	234812.64	2698525.02	15
211	234808.63	2698519.11	15
212	234804.63	2698513.19	15
213	234800.62	2698507.28	15
214	234796.61	2698501.36	15
215	234792.61	2698495.45	15
216	234788.6	2698489.53	15
217	234784.6	2698483.62	15
218	234780.59	2698477.71	15
219	234776.58	2698471.79	15
220	234772.58	2698465.88	15
221	234768.83	2698459.81	15
222	234765.4	2698453.54	15
223	234761.97	2698447.28	15
224	234758.54	2698441.01	15

V.Drain No.	Easting	Northing	Depth (m)
225	234755.12	2698434.74	15
226	234751.69	2698428.47	15
227	234748.26	2698422.21	15
228	234744.83	2698415.94	15
229	234741.4	2698409.67	15
230	234737.98	2698403.4	15
231	234734.55	2698397.14	15
232	234731.12	2698390.87	15
233	234727.84	2698384.54	15
234	234724.43	2698378.26	15
235	234720.06	2698372.62	15
236	234715.63	2698367.01	15
237	234711.2	2698361.41	15
238	234706.77	2698355.8	15
239	234702.02	2698350.71	15
240	234696.32	2698346.4	15
241	234690.63	2698342.09	15
242	234684.93	2698337.77	15
243	234679.4	2698333.4	15
244	234672.79	2698331.08	15
245	234666.2	2698328.33	15
246	234659.6	2698325.59	15
247	234653	2698322.85	15
248	234646.19	2698321.24	15
249	234639.11	2698320.24	15
250	234632.04	2698319.25	15
251	234624.97	2698318.25	15
252	234617.99	2698317.84	15

V.Drain No.	Easting	Northing	Depth (m)
253	234610.89	2698318.66	15
254	234603.8	2698319.47	15
255	234596.7	2698320.29	15
256	234589.6	2698321.1	15
257	234582.82	2698323.2	15
258	234576.16	2698325.77	15
259	234569.49	2698328.35	15
260	234562.83	2698330.92	15
261	234556.44	2698334.01	15
262	234550.64	2698338.18	15
263	234544.83	2698342.35	15
264	234539.03	2698346.51	15
265	234533.23	2698350.68	15
266	234528.4	2698355.82	15
267	234523.83	2698361.31	15
268	234519.26	2698366.81	15
269	234514.69	2698372.3	15
270	234510.81	2698378.13	15
271	234507.77	2698384.6	15
272	234504.73	2698391.06	15
273	234501.69	2698397.53	15
274	234498.65	2698403.99	15
275	234504.68	2698407.08	15
276	234511.53	2698409.12	15
277	234518.37	2698411.16	15
278	234525.22	2698413.19	15
279	234532.07	2698415.23	15
280	234538.91	2698417.27	15

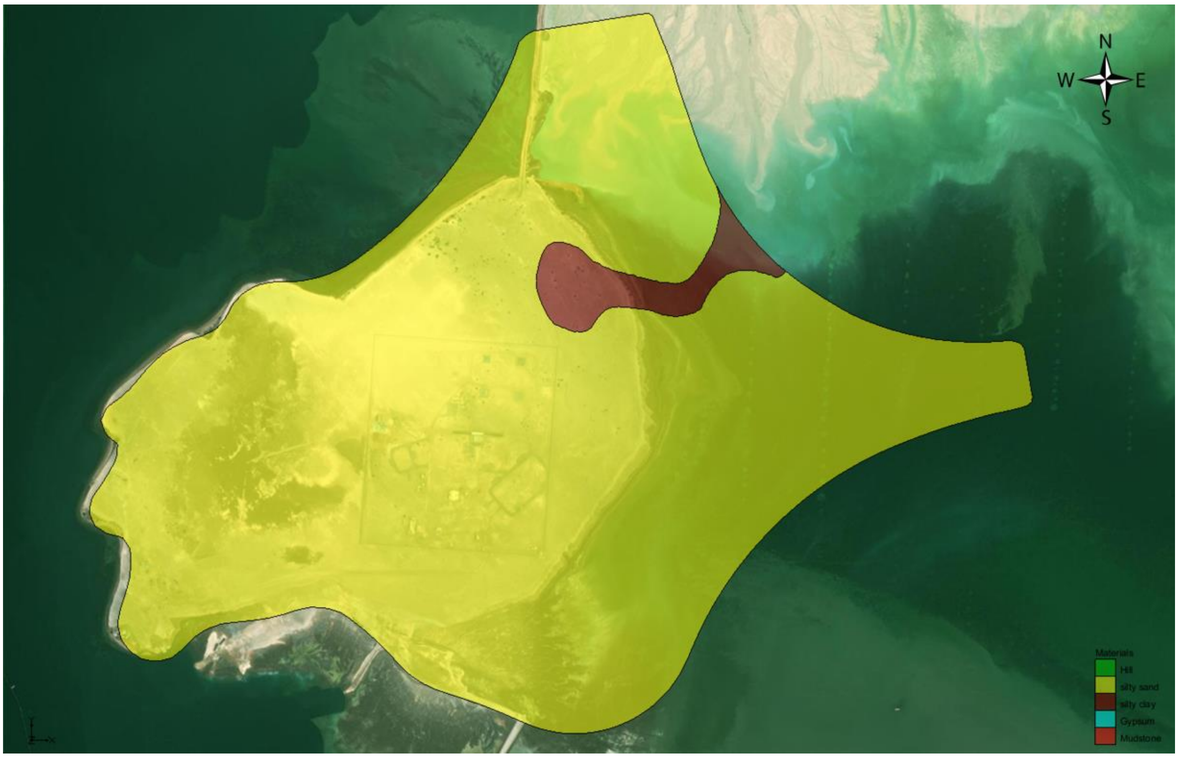
V.Drain No.	Easting	Northing	Depth (m)
281	234545.76	2698419.3	15
282	234552.61	2698421.34	15
283	234555.01	2698426.45	15
284	234553.89	2698433.5	15
285	234552.77	2698440.56	15
286	234554.9	2698446.25	15
287	234560.76	2698450.33	15
288	234557.53	2698456.37	15
289	234555.35	2698462.65	15
290	234558.4	2698469.12	15
291	234561.44	2698475.58	15
292	234557.03	2698480.43	15
293	234551.58	2698485.05	15
294	234546.14	2698489.68	15
295	234540.69	2698494.3	15
296	234535.25	2698498.92	15
297	234529.8	2698503.55	15
298	234524.36	2698508.17	15
299	234518.91	2698512.79	15
300	234519.26	2698518.68	15
301	234524.21	2698523.81	15
302	234529.35	2698528.77	15
303	234534.5	2698533.72	15
304	234539.65	2698538.67	15
305	234544.97	2698543.43	15
306	234550.61	2698547.81	15
307	234556.19	2698552.27	15
308	234561.39	2698557.17	15

V.Drain No.	Easting	Northing	Depth (m)
309	234566.59	2698562.07	15
310	234571.78	2698566.97	15
311	234576.98	2698571.87	15
312	234582.18	2698576.77	15
313	234587.37	2698581.67	15
314	234592.57	2698586.58	15
315	234597.27	2698591.93	15
316	234601.68	2698597.55	15
317	234606.1	2698603.17	15
318	234610.51	2698608.79	15
319	234614.92	2698614.41	15
320	234619.33	2698620.03	15
321	234623.74	2698625.65	15
322	234628	2698631.37	15
323	234631.53	2698637.58	15
324	234635.06	2698643.79	15
325	234638.59	2698650	15
326	234642.11	2698656.21	15
327	234645.64	2698662.43	15
328	234649.17	2698668.64	15
329	234652.7	2698674.85	15
330	234656.29	2698681	15
331	234660.34	2698686.88	15
332	234664.39	2698692.77	15
333	234668.44	2698698.65	15
334	234672.51	2698704.48	15
335	234678.33	2698700.98	15
336	234683.73	2698696.3	15

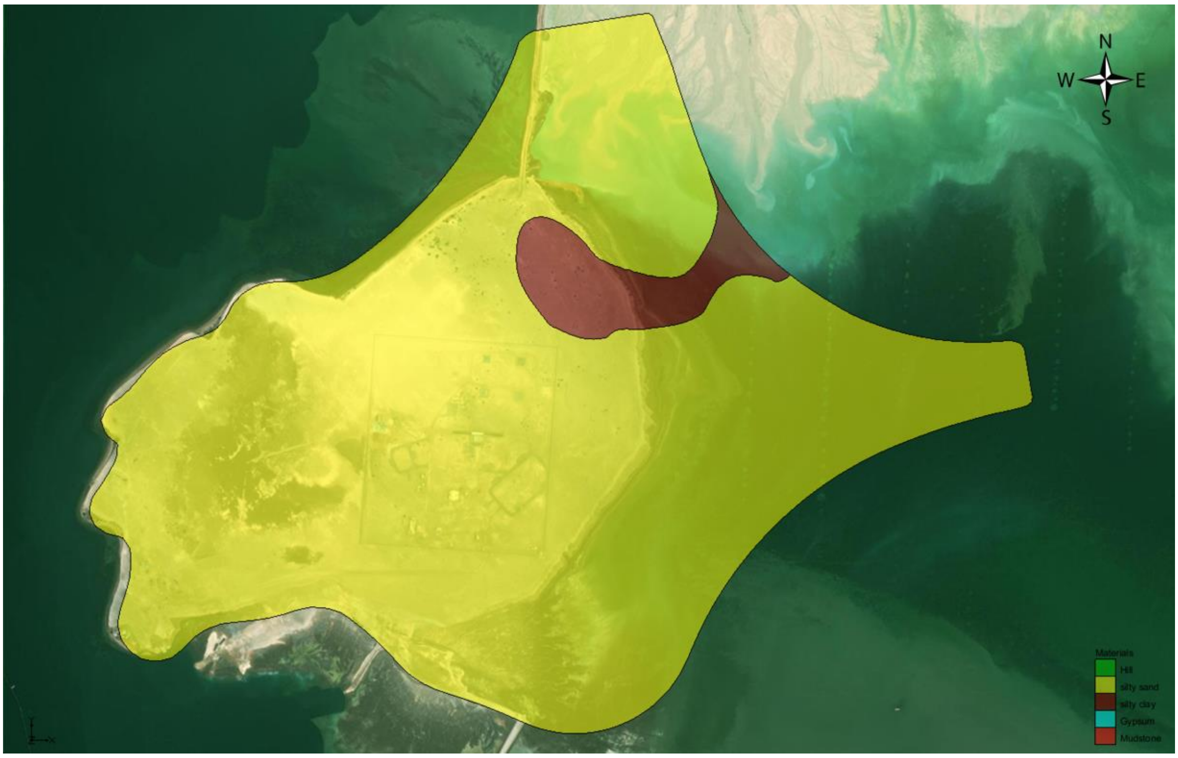
V.Drain No.	Easting	Northing	Depth (m)
337	234689.13	2698691.62	15
338	234694.52	2698686.94	15
339	234699.92	2698682.26	15
340	234705.32	2698677.58	15
341	234710.72	2698672.9	15
342	234716.11	2698668.21	15
343	234721.8	2698668.87	15
344	234727.68	2698672.93	15
345	234733.56	2698676.99	15
346	234739.92	2698674.15	15
347	234745.71	2698672.9	15
348	234749.59	2698678.9	15
349	234755.07	2698679.37	15
350	234762.18	2698678.62	15
351	234767.11	2698682.91	15
352	234770.51	2698689.19	15
353	234773.91	2698695.48	15
354	234777.32	2698701.76	15
355	234780.72	2698708.04	20
356	234784.12	2698714.32	20
357	234787.53	2698720.6	20
358	234790.93	2698726.88	20
359	234795.17	2698732.26	20
360	234801.45	2698728.92	20
361	234807.69	2698725.43	20
362	234813.92	2698721.94	20
363	234819.97	2698718.2	20
364	234825.1	2698713.23	20

V.Drain No.	Easting	Northing	Depth (m)
365	234830.23	2698708.26	20
366	234835.35	2698703.28	20
367	234840.48	2698698.31	20
368	234865.49	2699278.83	15

APPENDIX B: HORIZONTAL GEOLOGICAL CROSS-SECTIONS IN NATIVE SOIL

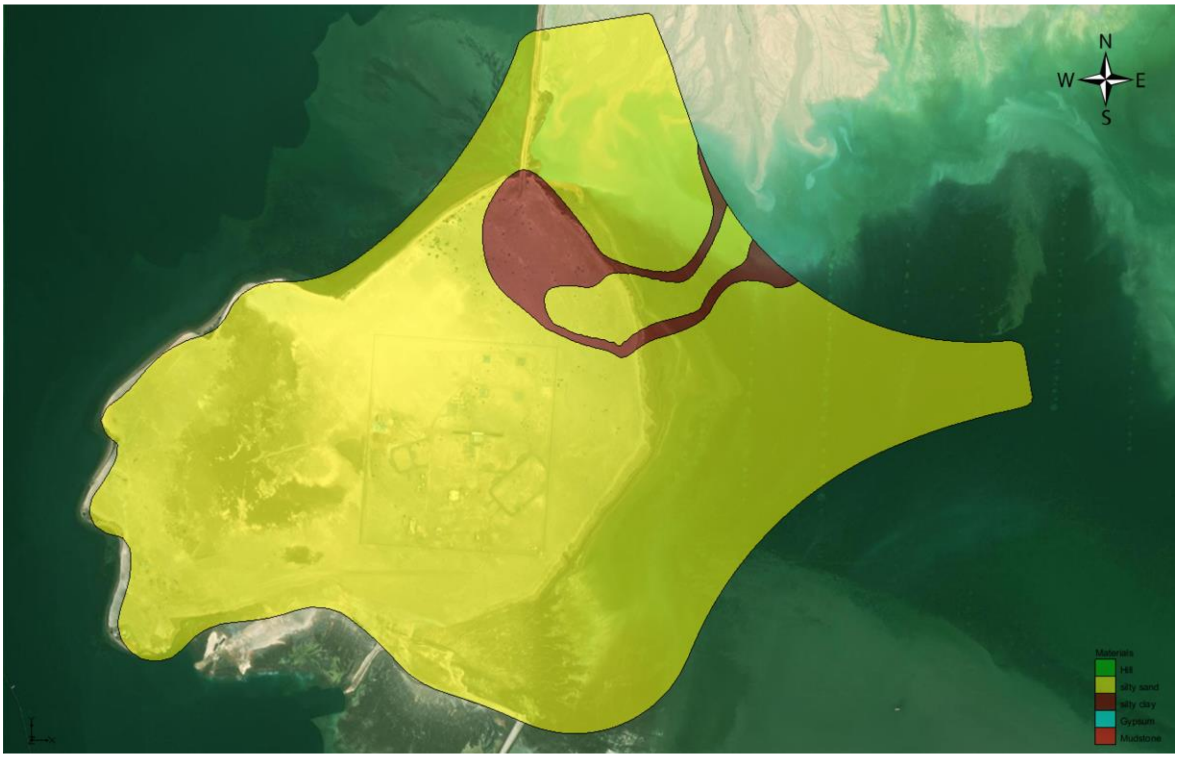


Horizontal Geological Cross-Section @ level (0.0 m NADD)

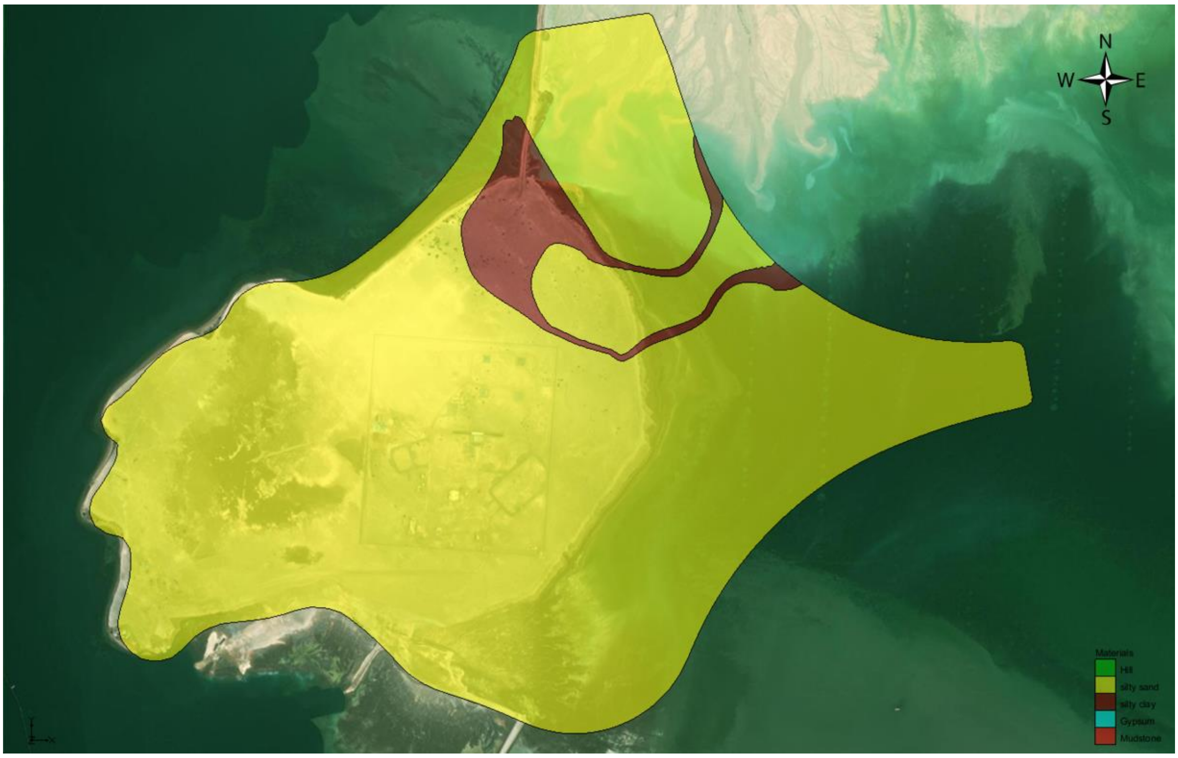


Horizontal Geological Cross-Section @ level (-0.5 m NADD)

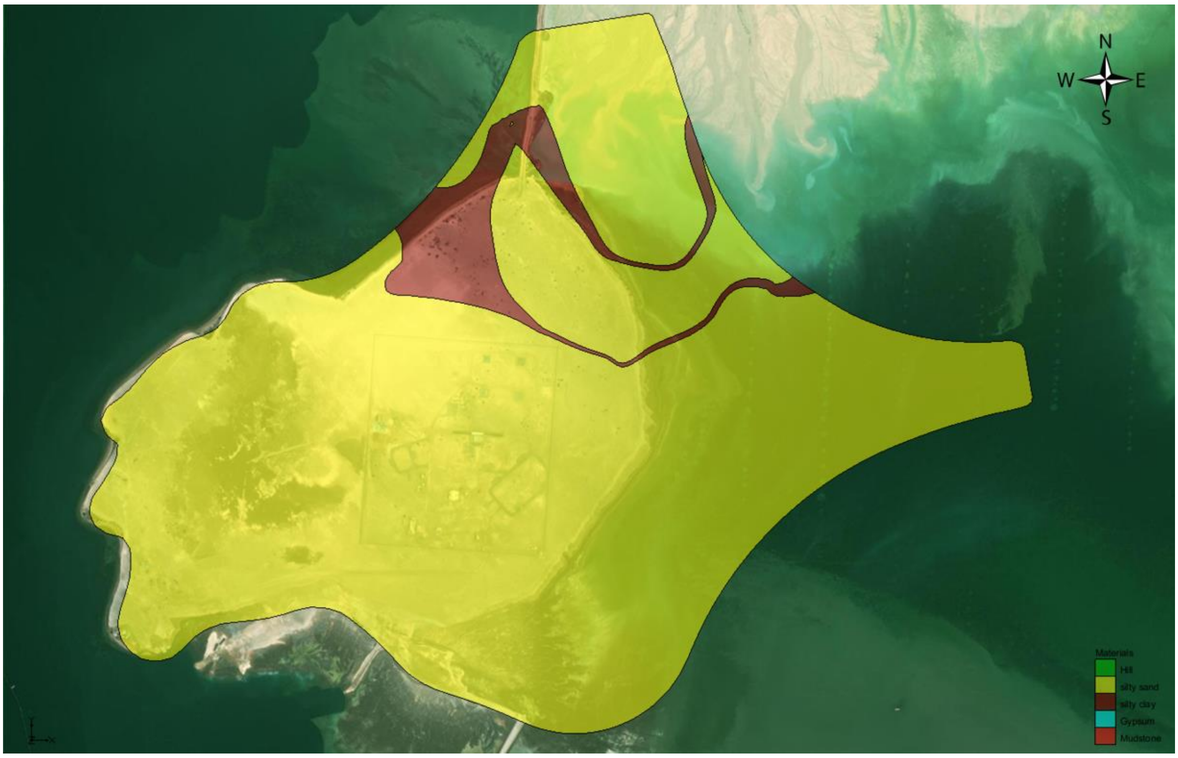
Horizontal Geological Cross-Section @ level (-1.0 m NADD)



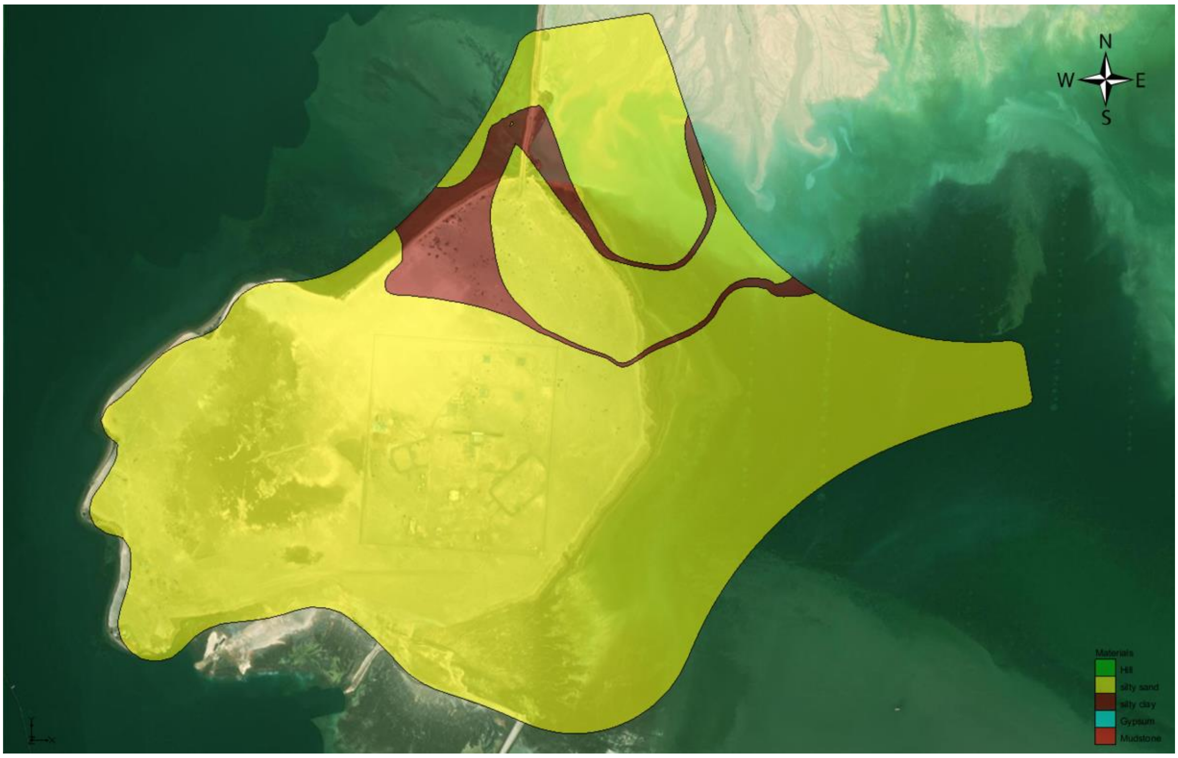
Horizontal Geological Cross-Section @ level (-1.5 m NADD)



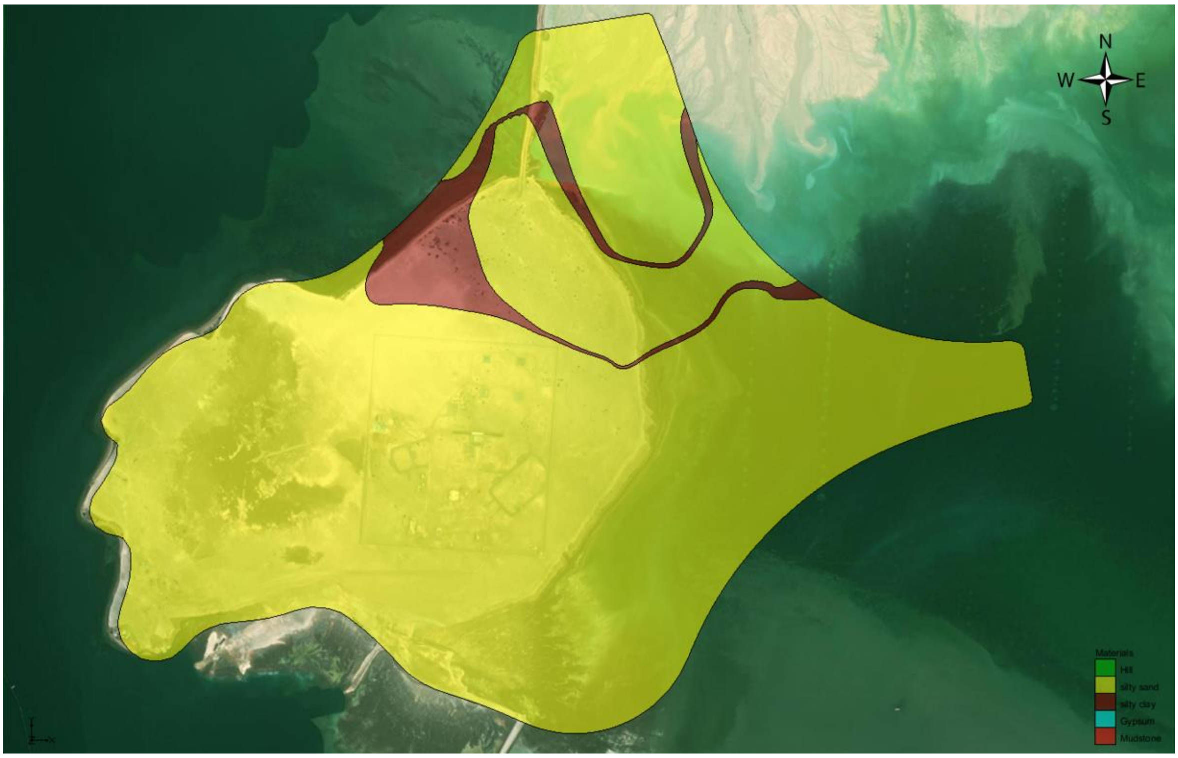
Horizontal Geological Cross-Section @ level (-2.0 m NADD)



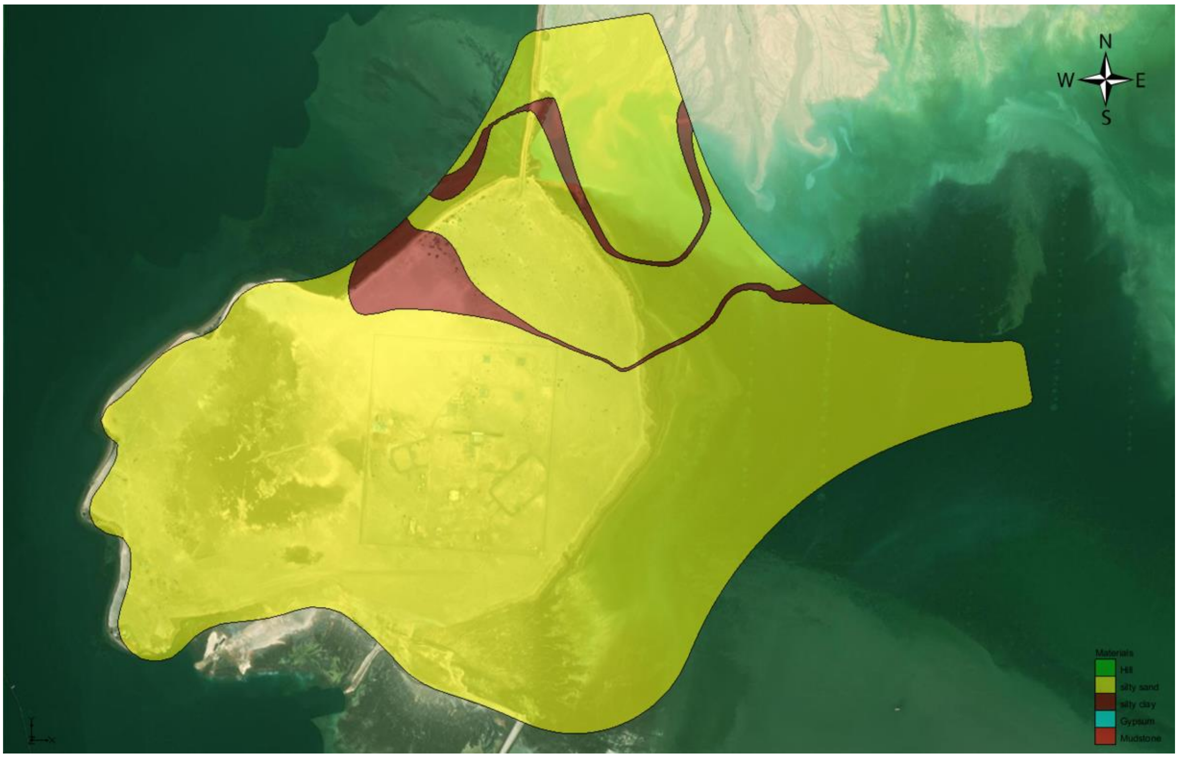
Horizontal Geological Cross-Section @ level (-2.5 m NADD)



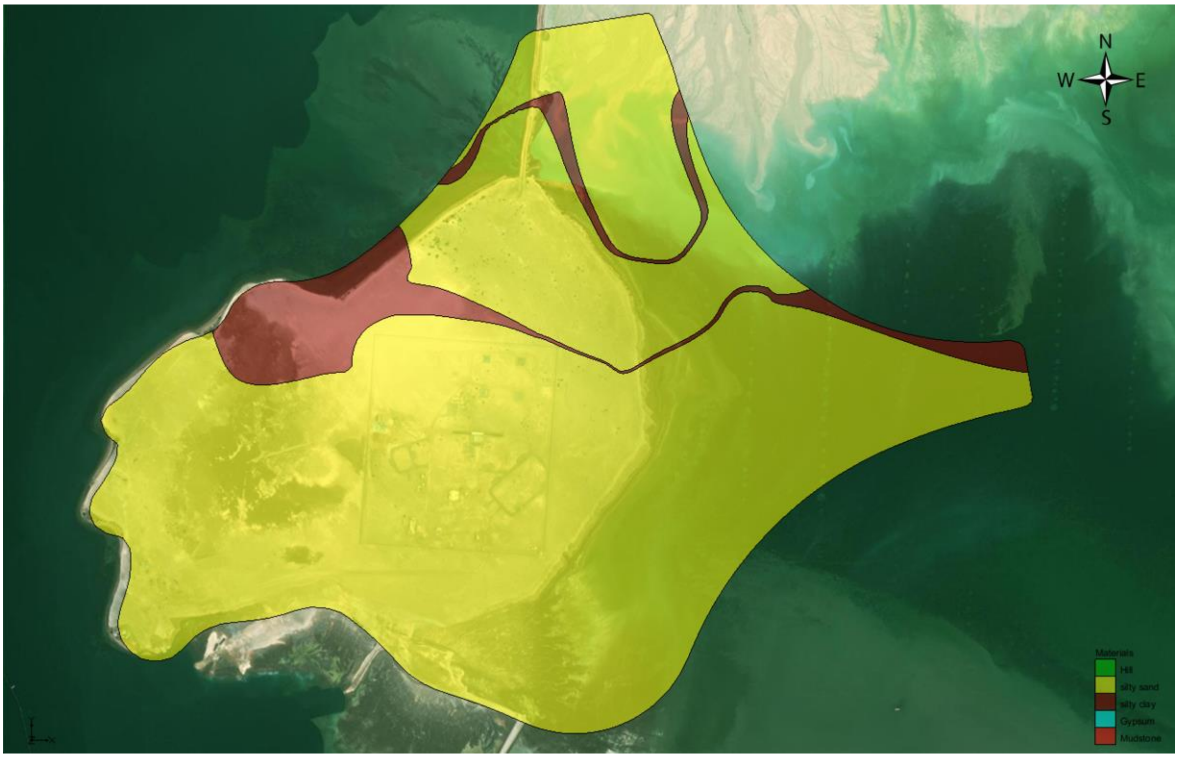
Horizontal Geological Cross-Section @ level (-3.0 m NADD)



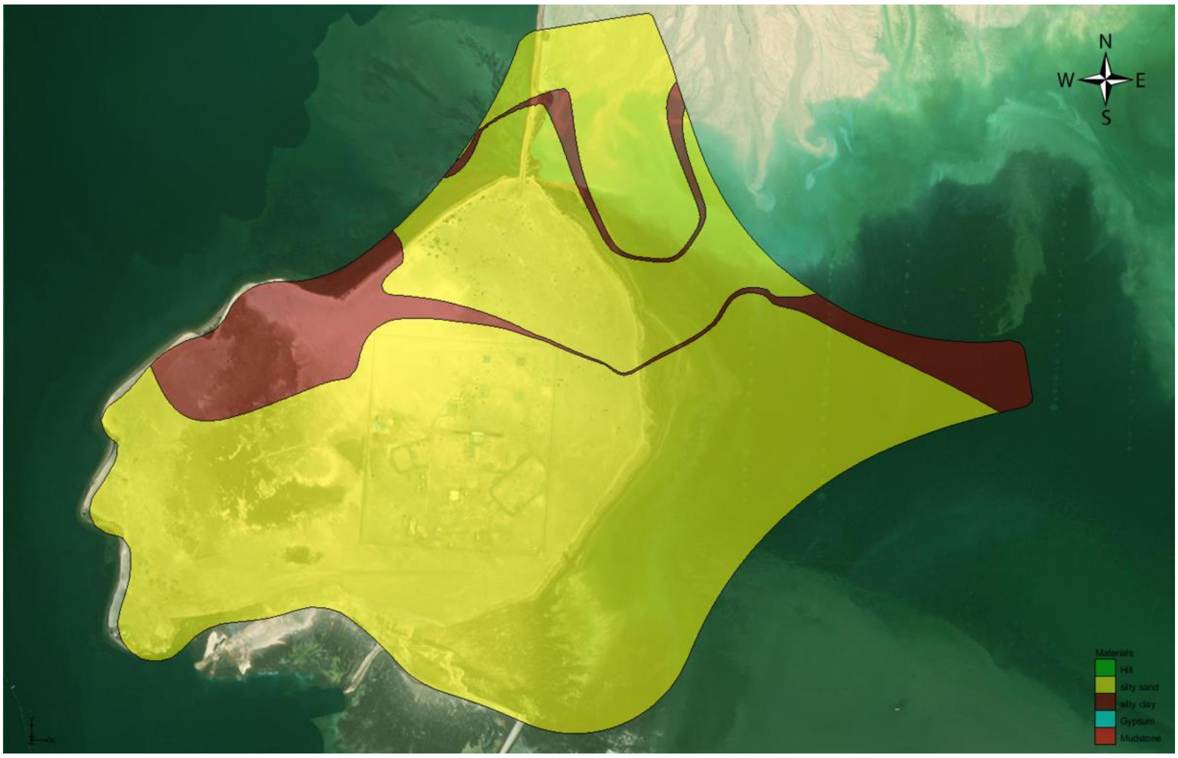
Horizontal Geological Cross-Section @ level (-3.5 m NADD)



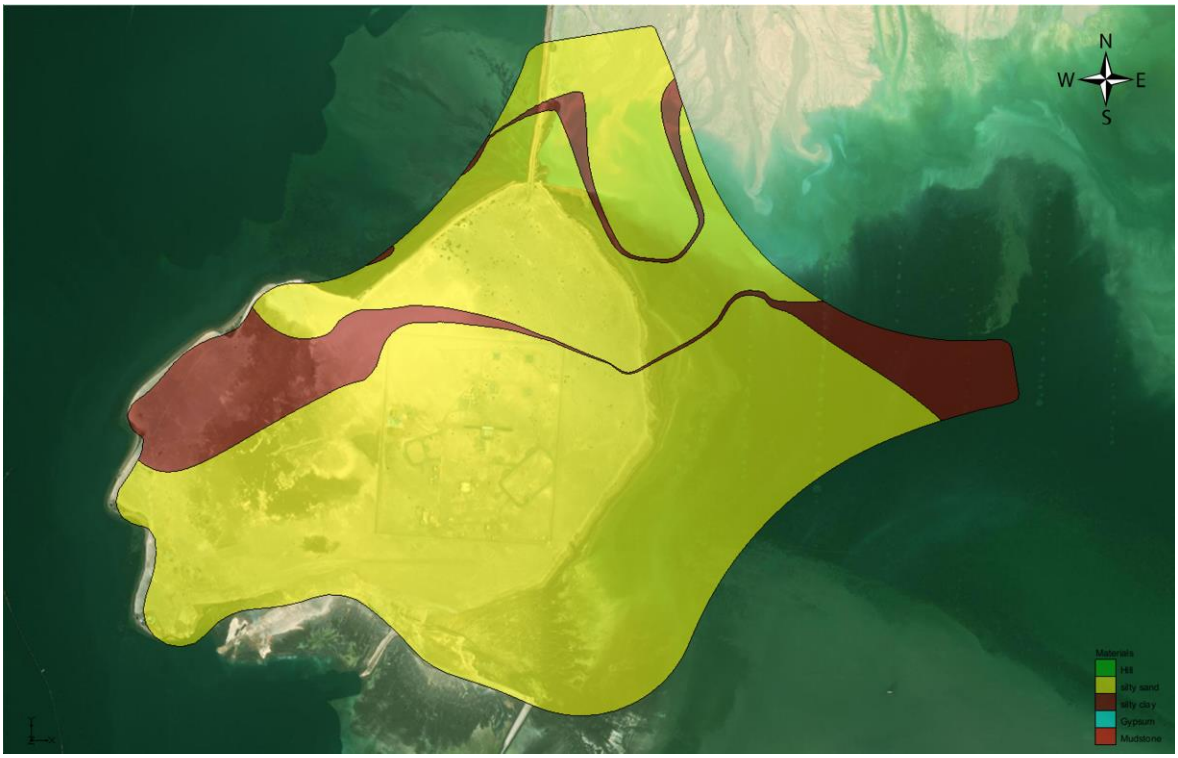
Horizontal Geological Cross-Section @ level (-4.0 m NADD)



Horizontal Geological Cross-Section @ level (-4.5 m NADD)



Horizontal Geological Cross-Section @ level (-5.0 m NADD)



Horizontal Geological Cross-Section @ level (-5.5 m NADD)

Horizontal Geological Cross-Section @ level (-6.0 m NADD)

Horizontal Geological Cross-Section @ level (-6.5 m NADD)

Horizontal Geological Cross-Section @ level (-7.0 m NADD)

Horizontal Geological Cross-Section @ level (-7.5 m NADD)

Horizontal Geological Cross-Section @ level (-8.0 m NADD)