hydrology

MDPI

Article

Groundwater Engineering in an Environmentally Sensitive Urban Area: Assessment, Landuse Change/Infrastructure Impacts and Mitigation Measures

Yohannes Yihdego *, Cara Danis and Andrew Paffard

Snowy Mountains Engineering Corporation (SMEC), Sydney, New South Wales 2060, Australia
* Correspondence: yohannesyihdego@gmail.com; Tel.: +61-413-539-214

Received: 14 June 2017; Accepted: 7 July 2017; Published: 12 July 2017

Abstract: A rise in the shallow unconfined groundwater at a site in Australia is causing water logging of the underground facility in the affected area. Realizing this problem, a study was conducted to identify the source of water that is causing the rise and to develop an implementation and operation plan of the mitigation (dewatering system). Modelling was undertaken using MODFLOW-SURFACT code, within the framework of Visual MODFLOW, to assess the spatial and temporal groundwater level at the site. The study undertaken incorporates compilation and assessment of available data, including a list of factual information reviewed, development of a conceptual groundwater model for the site and modelling of the pre and post development conditions. The outcomes of the assessment indicate water level rises due to the construction of the embankment are likely less than 0.12 m and changes in land, such as affected area burial, may change aquifer characteristics more significantly than the embankment. It is concluded that the elevated groundwater levels in the affected area are most likely a result of above average rainfall since 2007 and long term cumulative land use changes. The embankment construction is just one of many land use changes that have occurred both within and surrounding the affected area and likely only a minor contributor to the elevated water levels. Greater contribution may be attributed to re-direction of the natural flow paths the railway culvert weir reducing the overland flow gradient and ongoing changes (burial) within the affected area and including the embankment. The model findings gives answers on what factors may be/are causing/contributing to, the higher than usual groundwater levels in the study area. A combination of drainage and/or pumping (dewatering system) is suggested as a solution to overcome the problem of rising groundwater levels at the site. Further, the model output can aid in assessing mitigation options, including horizontal drainage networks and pumping to control for the rising water table conditions in the area, depending on the level of treatment and pathogenic criteria.

Keywords: numerical modeling; dewatering; pumping; drainage; environment; hydrogeology; geotechnique; engineering geology; flood; water; infrastructure

1. Introduction

Fresh groundwater is a valuable resource, while saline groundwater may be a threat to natural resources. In both cases, monitoring and interpreting changes in groundwater levels is essential for management. Hydrographs show changes in groundwater levels over time and are often the most important source of information about the hydrological and hydrogeological conditions of aquifers. The pattern of water-level change in a hydrograph is governed by physical characteristics of the groundwater flow system, the rainfall pattern and the interrelation between recharge to, and discharge from, an aquifer. Water level changes in a hydrograph can also be caused by other management options such as extraction, irrigation and land use change [1–4].

An ability to understand and interpret changes in groundwater levels is essential for sound management of groundwater resources. Water resources planners and managers assess the level of risk to aquifers, the environment, and the socio-economic development required for sustainable management of groundwater. Many areas are suffering from the groundwater level increase, especially in the coastal, urban and low land areas. It may be caused by climatic conditions (i.e., intensive precipitations, low evaporation) and/or local hydraulic conditions (i.e., low permeability of soil and or aquifer) [5]. The rising water table suggests that the unbalanced water system may be present. The increasing groundwater level can potentially cause, not only damages to the structures and properties due to water wetting and flooding in the close vicinity, but also major environmental adverse effects to the health of inhabitants. Assessment of groundwater level fluctuation has been used for range of tasks including recharge estimation, discrimination of climatic and landuse changes, system dynamic and monitoring of the resources or asset [6,7].

Variations in groundwater levels within unconfined and confined aquifers are often the result of numerous and interacting factors, such as land cover change, climate variability and groundwater pumping. Estimating the impact from pumping, in comparison with other drivers, is very valuable for resource management, but also very challenging. A variety of methods are used to model water-table dynamics, ranging from spatially explicit, deterministic, numerical physical-mechanistic models, such as MODFLOW, to stochastic approaches, such as Autoregressive Moving Average (ARMA). Numerical modeling is obviously the preferred choice for the spatial and temporal groundwater assessment role in investigating the effects of climate and human interventions in groundwater head fluctuations [8]. The model can predict the future behaviour of the phenomena and its uncertainty [9,10].

In the study area, the introduction of land use change and/or embankment fill system breaks the existing water balance and causes the water table to rise at the places where natural drainage cannot cope with the increase in groundwater recharge. The study area has experienced over the increases in level and extent of groundwater encountered when performing excavations to facilitate burials over the last few years. It has been acknowledged that even though burials have been delayed in the past (several times a year for decades preceding the commencement of works on the Bypass Project, the time taken for the water to reduce in level to the point which excavation can safely take place now, seems much longer than it did in years past). One of the major changes over that time is the construction of a large embankment for the Bypass adjacent to the north-western boundary of the site. This phenomenon has kept spreading in the last decade. The study area is nowadays experiencing a significant groundwater level increase (water-logging), resulting in large areas of site being almost flooded. Shallow water table, insufficient surface and/or sub-surface drainage and poor natural drainage system are some of the major adverse effects of land use systems. Thus, a proper assessment of these waterlogged areas is a necessary step to finding a solution for the problem. This requires the available data to be evaluated and an assessment of groundwater conditions at, and surrounding, the affected area.

The objective of this study is to assess whether the construction of the embankment (or other historical events) could have led to an increase in groundwater levels and a reduction in the rate of decline in said levels (Figure 1) using the available data. To help understand the hydrogeological conditions in the study area, a numerical model was developed to simulate the spatial and temporal conditions of the shallow aquifer for the assessment of the water table rise/water-logging problem. The numerical model output can be further used to evaluate the proposed solutions to lower and keep control of the groundwater levels through efficient water management plans.

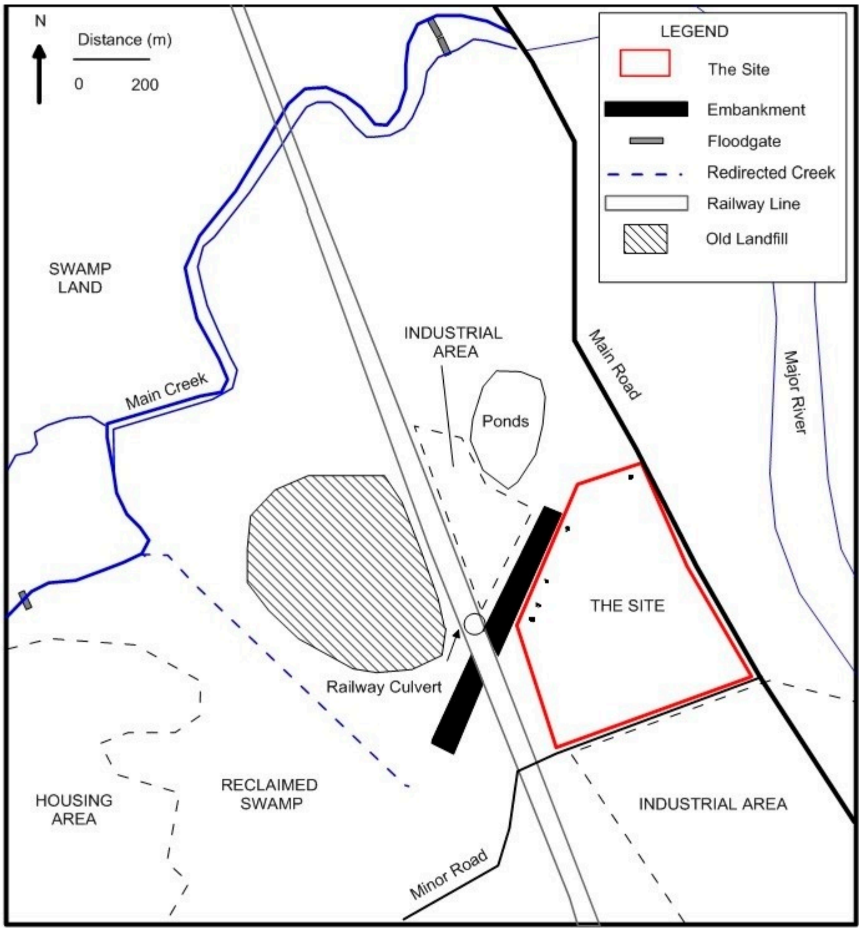

Figure 1. Study area and site showing the land use. Observation wells shown as black dot points inside the study area.

2. Description of the Site

The study site is in NSW, Australia but, due to legal constraints, no further information can be given on its exact location. All the data come from this actual site, which is located on an alluvial plain of the historically affected area.

There has been above average rainfall in the area over the period of time from 2010–2012. Overland flow from the affected area flows toward a creek (south and west) which is on the opposite side of the constructed embankment (Figure 1). To the west of the site, the first of 8 floodgates at the connection point between the creek and the river was opened in December 2008, two more in December 2009 and three more in December 2011. These were opened to allow full tidal flushing of the low-lying wetland areas adjacent to the creek to restore wetland health. The opening of these gates roughly coincides with the exacerbation of the drainage issues at the affected area, but this may be coincidental. The final 2 were scheduled to be opened sometime later in 2012, but casual inspection suggests all appeared to be open. Another creek has been noticeably tidal since the commencement of site development tasks in late 2009. It is also noted that the affected area on-site drainage system was damaged during the 1989 Earthquake. Since then, they have been using a system of lay-flat hoses and pumps to remove water from the site to adjacent areas. As part of the Inner City Bypass project, an approximately 1 m deep bridging layer/drainage blanket was constructed over the area adjacent to the affected area. The pre-loaded embankment was subsequently constructed over this layer to a maximum depth of 8 m. It was noted in February 2012 that water had ponded between the boundary fence to the affected area and the toe of the embankment. Survey indicated a difference in surface water level between the eastern and western sides of the embankment of approximately 0.4 m. An excavator was used to dig perpendicular trenches between the fence and the batter slope to expose the drainage layer. Surface water flowed immediately toward the trenches and under the embankment. Subsequent survey indicated an equalization of the water level on each side of the embankment.

3. Method

A conceptual model of the site was constructed and used as a basis for the construction of the numerical model. The development of the conceptual hydrogeological model for the area under investigation, construction and calibration of the groundwater level fluctuation were based on the following information and data:

1) Site setting of the affected area and its spatial and temporal relationship to analyse historical over a period of time. The procedure has improved the estimates, due to high correlation between the height of the pass by/railway/land fill/drainage diversion and high water level rise, and has added physical sense to predictions.
2) Records of rainfall and groundwater levels;
3) Time series, topographic/image data over a period of time;
4) Water level data from piezometer within approximately a range of the affected area. Five vibrating wire piezometers have been installed adjacent to the north-western boundary of the site to monitor groundwater levels. Some have been found to react very markedly to rainfall events and others do not. The original installation aim was to see if there was any correlation between the spikes in water level and high rainfall events and to assess dissipation; and
5) Drawdown in a series of monitoring wells during slug test that were conducted within the scope of the study to investigate the hydraulic characteristics of the area.

For the generation of temporal and spatial scenarios, historical aerial photo and images were used.

4. Conceptual Model

The affected area aquifer consists of aeolian sand and forms a small, localised, unconfined permeable aquifer. It inter-tongues with residual clay (south) and alluvial clays (west and north) and unconformably overlies clayey material, all of lower permeability (Figure 2). The affected area aquifer is elevated with respect to the surrounding land.

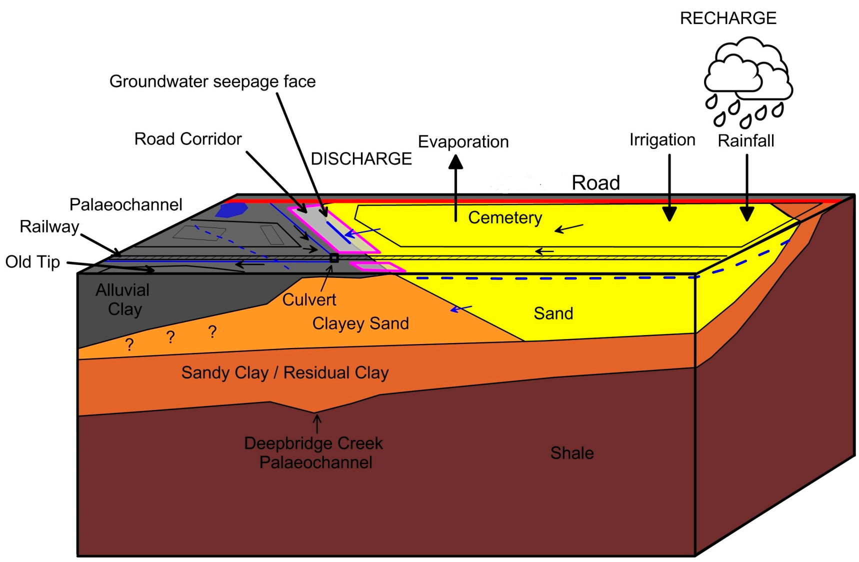

Figure 2. Conceptual model for the affected area aquifer.

The bypass embankment fill sits on sandy clays and clays just north-west of the toe of the affected area aquifer. There may be paleochannels of more permeable material underlying the embankment fill marking the original direction of drainage from the site or fingers of sand which spread out into the Swamp land.

Groundwater moves from the high point at the corner of the main road and minor road west and north-west towards the bypass corridor and rail line. The main road marks the ground water/surface water divide between the affected area aquifer and the major river. This divide continues north to just south of main creek (Figure 1).

Recharge is via rainfall and affected area irrigation, while discharge from the affected area aquifer is via evapotranspiration, lateral movement into the lower permeability sediments and discharge to the surface water environment. The largest discharge mechanism is surface discharge via a seepage face which occurs mainly along the north western boundary with the bypass corridor.

The groundwater gradient is considered dynamic and linked closely to rainfall. Unfortunately there are no current monitoring piezometers within the affected area.

5. Piezometric Surface and Groundwater Flow Direction

The initial pre-construction (embankment) water levels (prior to installation of the piezometers) were interpolated from 19 data points, as shown on Figure 3. The groundwater elevation was estimated from the two metre contour Digital Elevation Model (DEM) as surveyed water levels for data points were not available.

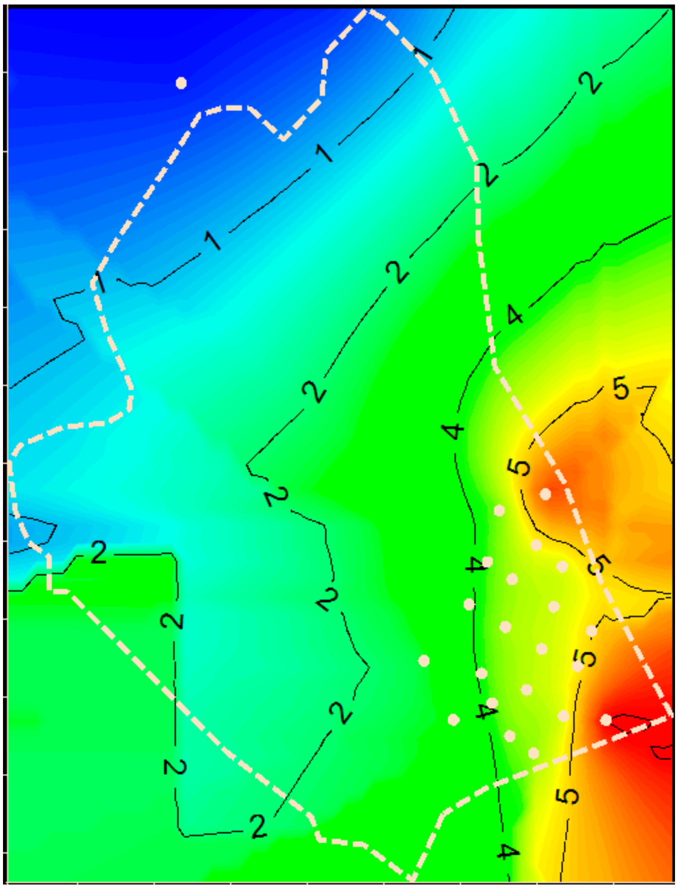

Figure 3. Groundwater contours in meter Australian Height Datum (AHD) (Year 1991; pre-construction). Water level data points shown as grey dots (circle); Dashed line represents model area and grey is bedrock.

Prior to major landfilling (former Astra Street Tip to the north west of the affected area), groundwater movement was in a west/north-west direction (Figure 3). The current groundwater flow direction is principally to the northwest, in subdued conformity to the current surface topography. The dashed line (Figure 3) marks the model area. Five piezometers have been installed along the western affected area boundary with the Bypass Corridor to monitor groundwater levels (Figure 4).

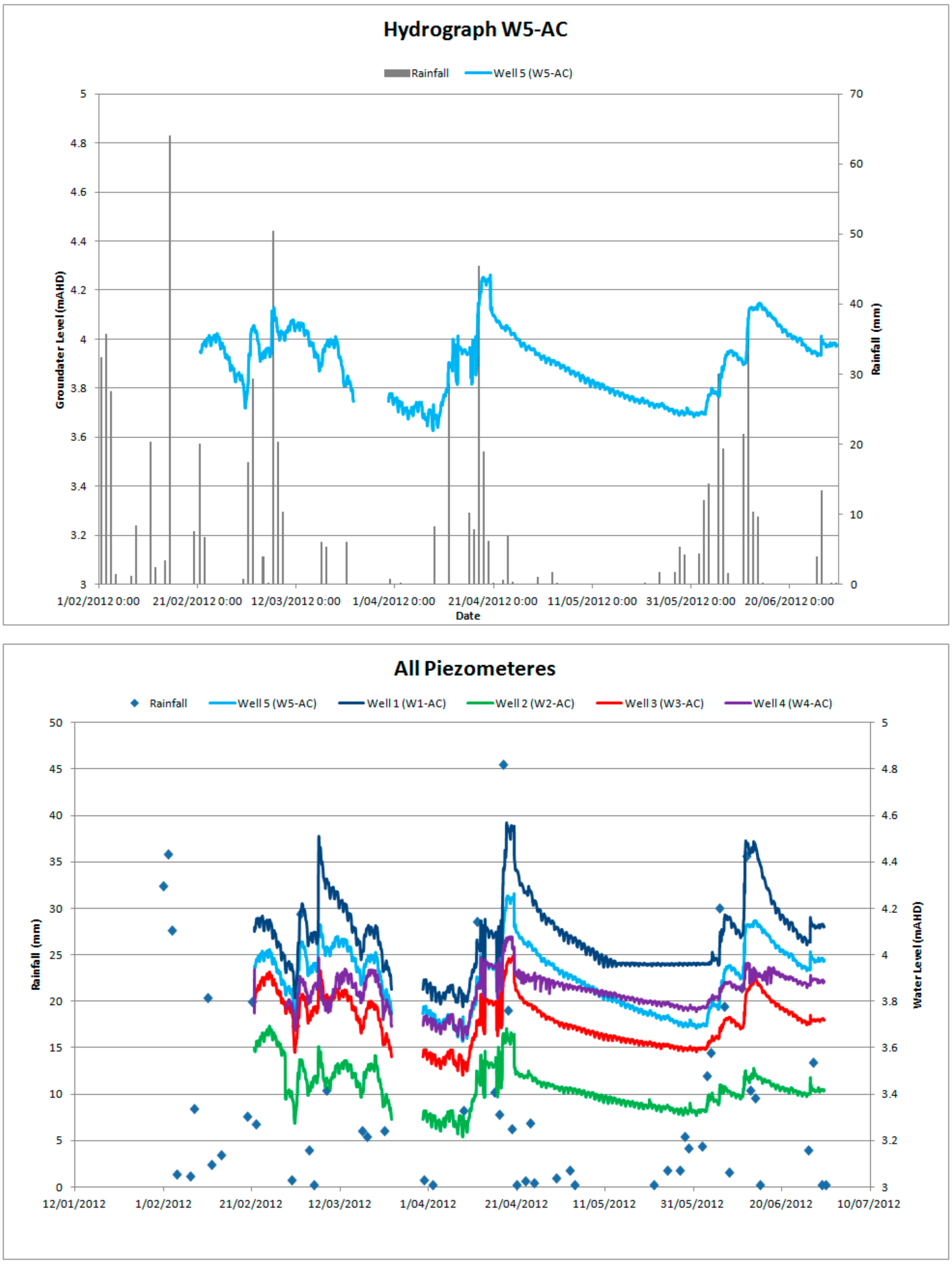

Figure 4. Groundwater level and rainfall versus time (piezometers).

Recharge to the groundwater flow system is mainly from rainfall (see piezometer hydrographs (Figure 4) with an unknown irrigation input. Rainfall infiltration rates in the order of 30 to 35 percent have been estimated for Layer 1 affected area aquifer, during the model calibration. Recharge zoning was made based on the geology, that is, high for the affected area aquifer and lower for clays.

The long-term annual precipitation was assumed to be 995 mm/year (data from nearby Rainfall Station data). For the transient state model, a time varying recharge was applied as a percentage (30 to 35 percent) of average monthly precipitation.

Evapotranspiration (ET) is the combined loss of water to the environment due to evaporation from the soil surface and transpiration through plants. Given the depth of groundwater is shallow in the model area, the ET is considered significant. Evaporation rate (70 percent of the pan evaporation value), with an extinction depth of 2.5 m has been estimated during the model calibration. For the transient state model, a time varying evaporation rate was applied as a percentage (70 percent) of average monthly evaporation.

6. Numerical Model

A numerical model was used to assess the impact of climate and human interference on the rise in water level at the site/affected area. This section presents the development and application of the numerical model.

Modeling was undertaken using MODFLOW-SURFACT code [11], an advanced MODFLOW-based code that handles complete de-saturation and re-saturation of grid cells), within the framework of Visual MODFLOW Version 4.6.

7. Model Design

The extent of the model domain is based on the appropriate site specific geological and hydrogeological boundaries. The initial model covered an area of approximately 2.32 km^2 (model area), with the site/affected area located in the south-east corner (Figure 5).

Subsequently the active model area was reduced to cover an area of 0.61 km^2 bounded by the main road, minor road and rail corridor to just north of the bypass corridor (Figure 6). The model was designed for steady state and transient state simulation of groundwater flow.

The model area (indicated with red line on Figure 5), is located between a series of general head and no flow boundaries:

- west and north—following Deep Bridge Creek and Iron Bark Creek; and
- east and south—coinciding with bedrock outcrop along main road and minor road which form the current surface/groundwater divide.

The active model area (0.61 km^2, Figure 6) is bounded by:

- the railway on the western boundary (simulated using drain package); and
- the northern boundary represented using a General Head Boundary (GHB).

The model is based on the conceptual model with four layers corresponding to the main geological units, as illustrated in Table 1 and on Figures 2 and 7. The layers are:

- Layer 1: Surface layer used to simulate the upper portion of the affected area aquifer and underdrainage layer. It ranges in depth from 1 m (drainage layer) to 1.9 m (the depth of burial);
- Layer 2: Transported material representing affected area aquifer grading to sandy clay and clay;
- Layer 3: Residual Clay over laying basement; and
- Layer 4: Basement (inactive). A non-uniform, 50 m thick basement bottom layer was assigned.

The model uses a 10 × 10 m grid with 236 rows and 186 columns which was applied across the active model area (Figure 6). The thickness of the layers was determined from assessment of borehole data in reports and from the project. In the vertical direction, deformed model layers were used to represent the hydrogeological framework in the model (Figure 7). Vertical discretisation using deformed model layers allows horizontal continuity to be maintained with fewer cells [12].

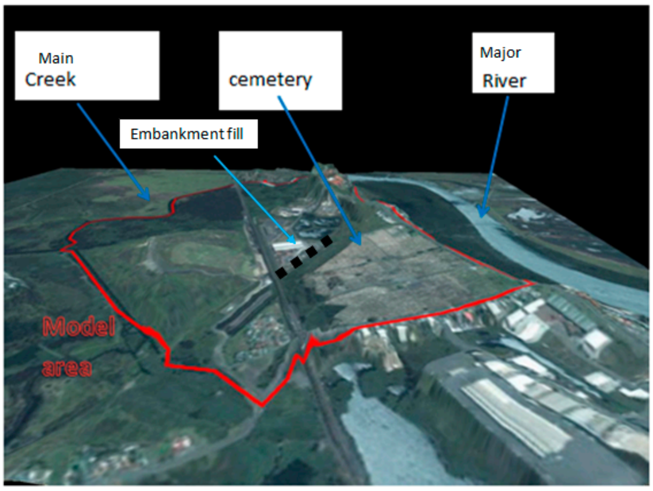

Figure 5. 3-D view of the original model area.

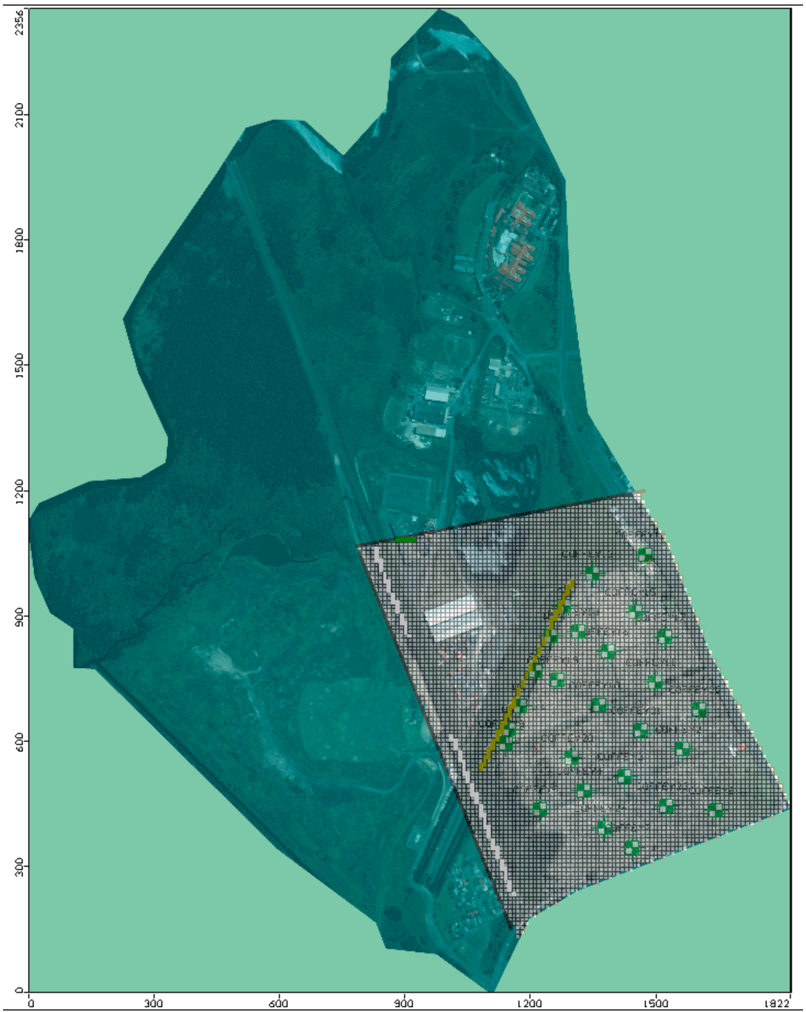

Figure 6. Groundwater Flow Model Grid. Embankment and railway lines represented as wall and drain packages respectively. The green cells represent General Head Boundary (GHB) in the northern part of the model. Bores are shown as green symbols.

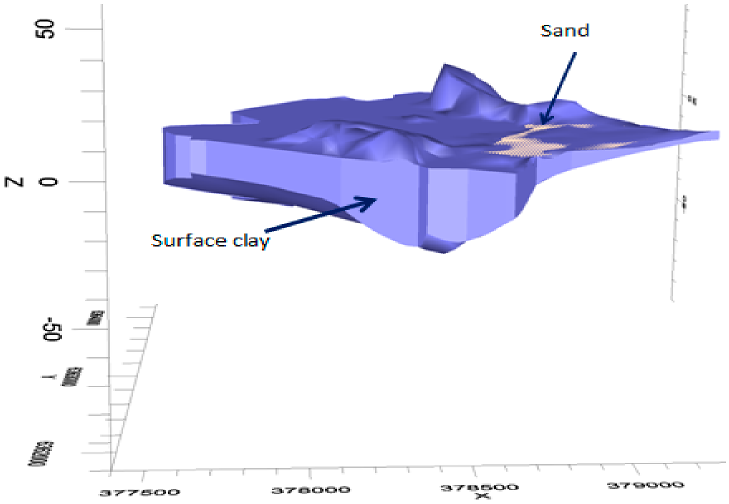

Figure 7. Hydro-stratigraphic units in the original groundwater model.

8. Aquifer Hydraulic Parameters

Initially, aquifer property estimates are based on previous works. Where no data is available literature values (for example; [13]) and professional judgement have been adopted. The calibrated aquifer parameters are summarized in Table 1.

Table 1. Calibrated Aquifer Properties for Modeling Purposes.

Layer	Description	Horizontal Hydraulic Conductivity (K) (m/day)	Specific Storage (m^{-1})	Specific Yield
1, 2, 3	Transported and residual clay	1×10^{-3}	2×10^{-5}	0.02
1, 2	Affected area sand	17	2×10^{-5}	0.15
4	Basement	1×10^{-5}	1×10^{-6}	0.0002

9. Modeling Approach

Modeling was undertaken in a staged approach to allow improved calibration and refinement of the adopted parameters in the Conceptual Hydrogeological Model (CHM).

The five modelled scenarios are:

1. Steady state, pre-project construction condition;
2. Steady state, post-project construction condition;
3. Transient, post-project construction condition;
4. Transient, pre-project construction condition (by removing the embankment); and;
5. Transient, post-project construction condition and assessment of grave impact on the water level.

The affected area aquifer was simulated initially using 3 layers (Layer 4 basement was made inactive). After calibration (for Scenario 5) Layer 1 was refined by making the upper 1.9 m another layer to allow assessment of the potential impact of burials. All layers have been assigned as confined/unconfined (that is, the transmissivity may vary). The effect of the embankment fill was modeled using the Horizontal-Flow-Barriers Package ("*Wall Package*") with a variable thickness representing the embankment fill (6 to 10 m) and a range of hydraulic conductivity values ranging from 0.01 to 1×10^{-5} m/day.

The steady and transient calibrated models were re-run to assess the impact of non-climatic variables (embankment placement and graves/changes to recharge) on the pre/post construction period by removing/adding the effect of embankment placement.

The first three scenarios were used to calibrate and verify the model, as well as to examine the general response of the groundwater water level and flow system due to the climatic variables and embankment placement (the consolidation effect). Scenario 4 is also used to assess the impact of embankment placement by comparing the residual heads at the piezometers in comparison with the residual head output from Scenario 3. Scenario 5 is designed specifically to assess the potential impact of burials in the affected area (land use changes) on the water level.

10. Model Calibration

Calibration was accomplished by applying a set of hydraulic parameters, boundary conditions and stresses that produce computer generated simulated pressure heads that match actual field measurement within an acceptable range of error. Model calibration was performed by manual (trial and error) and automatic (inverse model using the Parameter Estimation (PEST) package) [14] methods.

11. Steady State Calibration

The model was calibrated by matching observed groundwater heads against predicted heads in 17 bores (two bores are screened within residual clay) within the model domain (Figure 8). To improve calibration, the hydraulic conductivity, recharge and drain conductance of the multiple layers and zones were adjusted until the modeled head elevations were able to match observed head elevations to an acceptable level of accuracy.

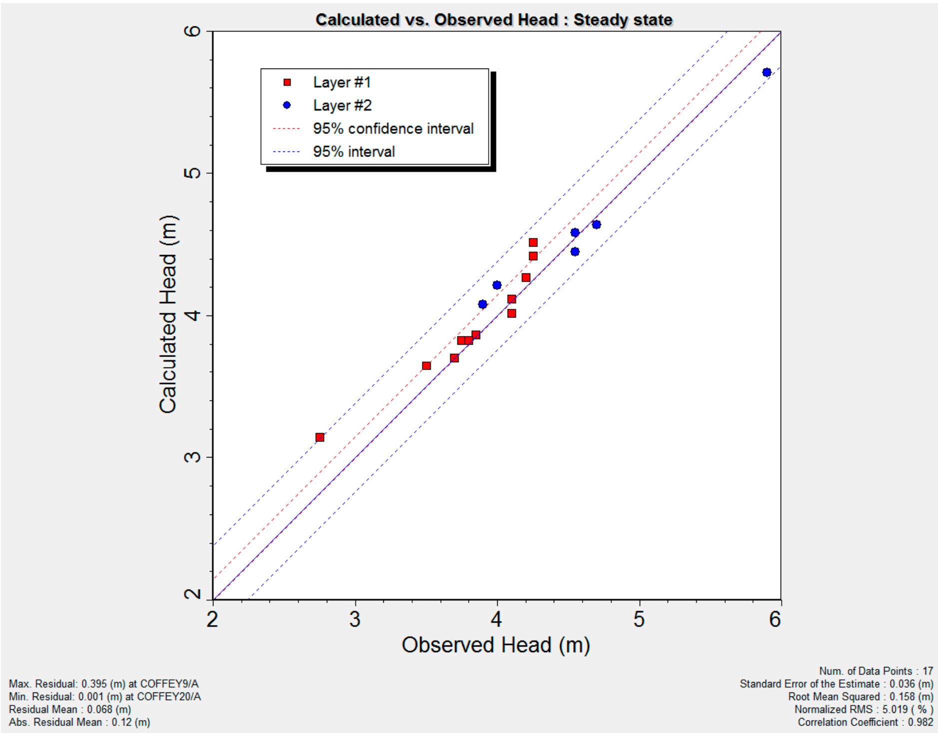

Figure 8. Comparison of observed head versus calculated head-scenario 1.

Figure 8 presents calibration results (that is, calibrated head versus observed head for Layer 1 and Layer 2), with a correlation coefficient of 0.98. The Root Mean Squared Error was 0.16 m. This indicates a good correlation between observed and calculated groundwater heads. The residual mean error is 0.068 m for model calibration. Analysis of the calibrated steady state model output indicates that the model simulates the groundwater elevation and flow direction (Figure 9) across the active model area to an acceptable level. The baseline water level gradient results in a default groundwater flow in a northern and north-westerly direction through the affected area aquifer.

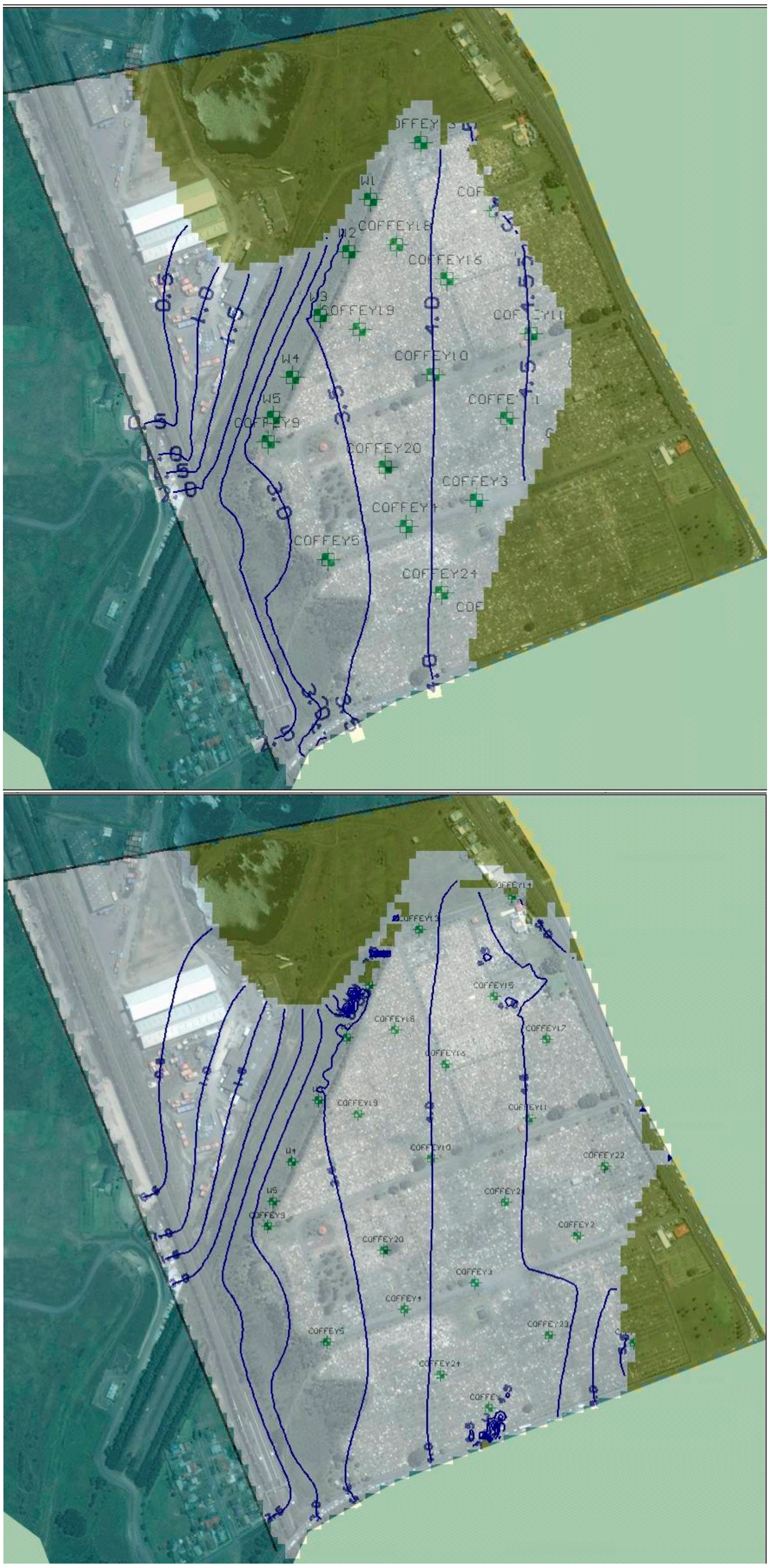

Figure 9. Scenario 1—Calibrated steady state potentiometric surface for Layer 1 and Layer 2. Observation Piezometer in green.

The model calibration is considered acceptable, considering the correlation coefficient, mass balance (−0.01 percent discrepancy) (Table 2) and spatially random residual error (Figure 10) [15,16]. Additional confidence in the calibration was obtained through a transient state history match to water level at monitoring piezometers W1 to W5 (Figure 11).

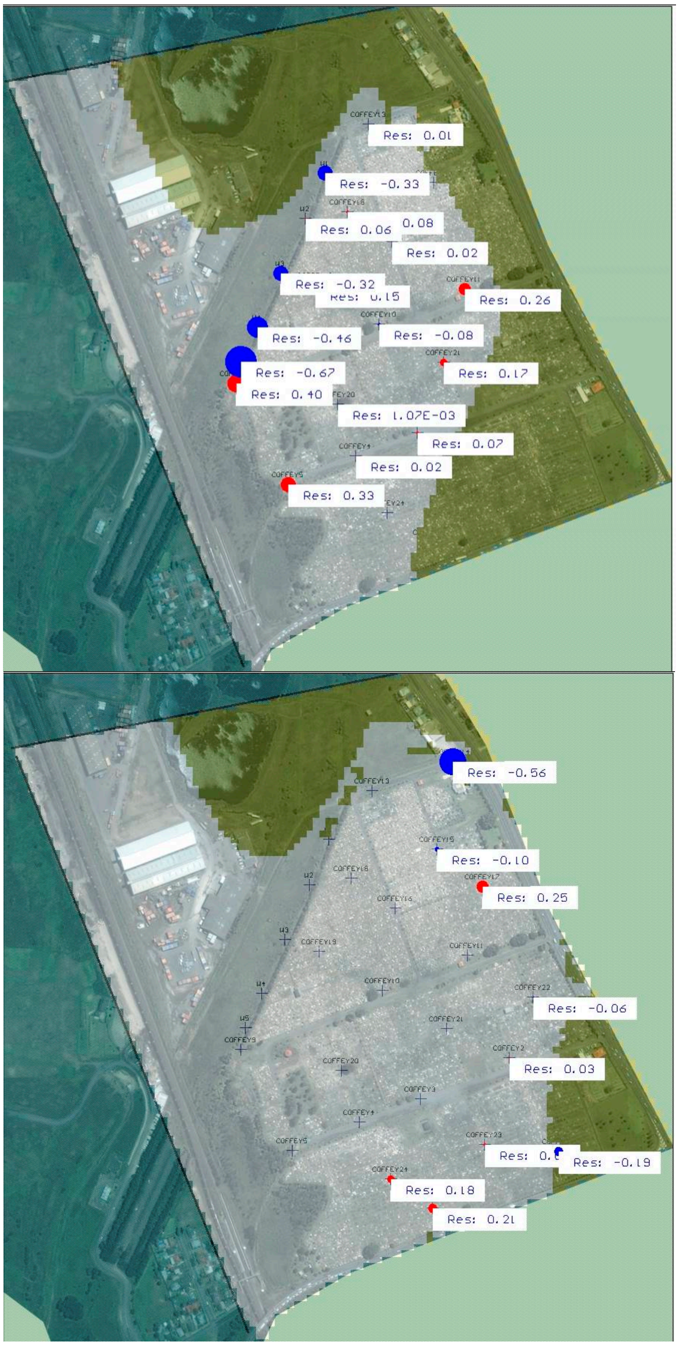

Figure 10. Scenario 1—Layer 1 and Layer 2 residual heads. Blue dots indicate positive (under estimation) and red dots indicate negative (over estimation) values. The size indicates the level of residual error.

12. Transient State Calibration

Aquifer parameters were adjusted in the model using manual and automatic methods to match the observed head at the five piezometers installed along the affected area western boundary within the bypass corridor. Adjustment to hydraulic conductivity and storage coefficient resulted in the match shown on Figure 11 and in Table 1.

The transient calibration used seven monthly stress periods over the duration of 212 days. This matched the period of monitoring data for the piezometers installed.

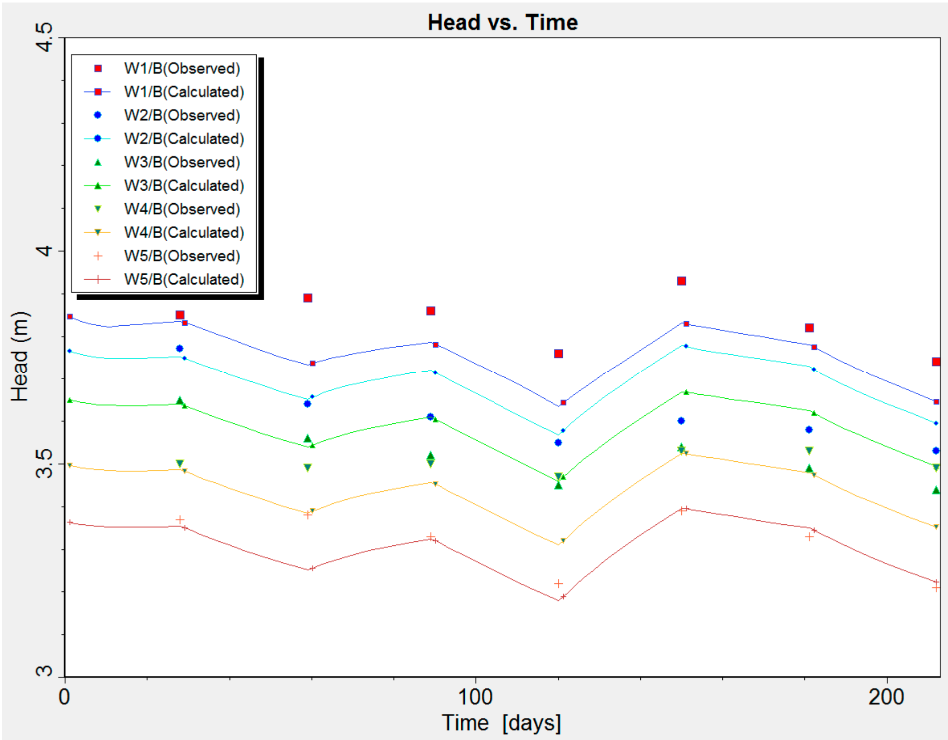

Figure 11. Calibrated head versus observed head for monitoring piezometers W1 to W5.

13. Model Results

13.1. Scenario 1: Steady State, Pre-Construction Condition

Table 2 provides a summary of the modeled water balance for steady state conditions. It shows that the model is balanced and that the flow system conserves mass and the water entering the model area is mainly through rainfall recharge. The volume of water entering the model through recharge equals the volume that leaves the model through evaporation (82 percent), drain (17 percent) and through flow (1 percent).

Table 2. Scenario 1 Steady State Modeled Mass Water Balance Summary.

Component	Inflow (m^3/day)	Outflow (m^3/day)
Recharge	384	0
Evapotranspiration	0	315
Through flow	0	4
Drain		65
IN-OUT	−0.02 m^3/day	
Discrepancy	−0.01 percent	

13.2. Scenario 2: Steady State, Post-Construction Condition

The change in groundwater level due to the embankment is compared with the pre-construction period (Scenario 1) using the residual head model output at the piezometers. The residual head (observed head minus calculated head) before and after placement of the embankment for piezometers W1 to W5 are provided in Table 3. To assess the impact of the embankment with respect to water level rise, the embankment was simulated using the wall package with a hydraulic conductivity of 1×10^{-5} m/day (worst case) and thickness of the embankment fill ranging from 6 to 10 m.

The model indicates that the change in the residual head between the pre and post-construction simulations at the installed piezometers (W1 to W5) is 0.12 m or less (post-construction minus pre-construction, last row Table 3). The change in head at the piezometers all have a positive value indicating the post construction simulated heads are higher than the pre-construction simulated heads and hence, the embankment fill may have attributed to the rise in water level irrespective of the values. The result indicates the observed water levels (at the piezometers) may be 0.12 m higher than expected if the embankment was not present. It should be noted that the expected rise within the affected area would be less than the 0.12 m at the piezometers.

The 0.12 m is within the range of water level measurement error and the error from the two metre DEM. The fact that all are positive and within a 0.03 m range lend weight to the assessment that the embankment has had a (small) impact on water levels.

Table 3. Change in head across the piezometers due to the embankment (pre and post-construction).

Piezometer ID	W1	W2	W3	W4	W5	Remark
Residual Head (m)	−0.31	0.06	−0.30	−0.45	−0.66	Pre-construction
Residual Head (m)	−0.22	0.18	−0.19	−0.35	−0.57	Post-construction (base line)
Change in head due to embankment (m)	0.09	0.12	0.11	0.10	0.09	Difference

13.3. Scenario 3: Transient State, Post-Construction Condition

Scenario 3 is designed to provide baseline groundwater levels for a pre-construction period simulation to assess the potential impact of the embankment on the groundwater system using a transient simulation calibrated to the observed time series heads. Figure 12 shows that the calculated head(s) match with the observed heads as shown for one of the monitoring piezometers (W5). The initial mismatch could be related to error associated with the water level measurement (early logger data was not atmospheric compensated) and/or issues with piezometer installation (poor surface sealing allowing ingress of surface water).

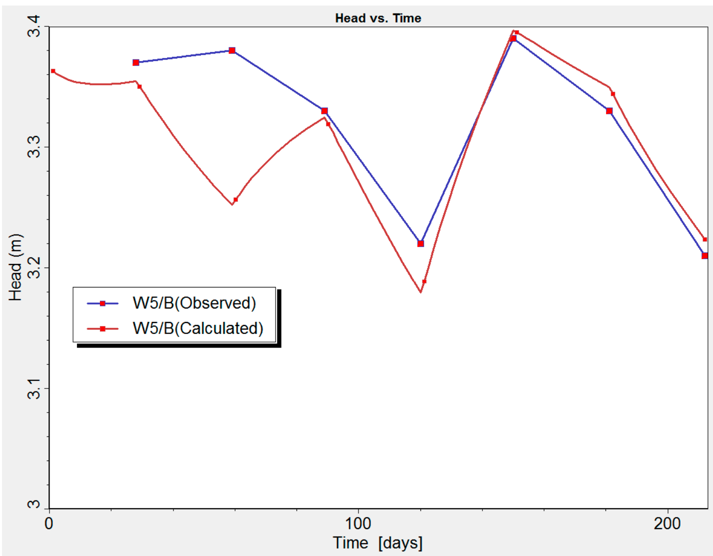

Figure 12. Head versus time at the monitoring piezometer-W5 (Scenario 3).

Transient simulations, Scenarios 4 and 5 were carried out to estimate the effects of landuse change on the groundwater system. The model scenarios are used to assess if there is an effect on water level rise, due to the embankment and or burials.

13.4. Scenario 4: Transient State, Pre-Construction Condition

A transient simulation to pre-construction was carried out to examine the effects of embankment fill at the piezometers located along the embankment fill. The model predicted that there will be less head change at the piezometers, as shown in W5 (pre-construction period) compared to the post-construction period. The small difference in the average change in water level between Scenarios 3 and 4 (Figures 12 and 13 respectively), indicates that the embankment is likely to contribute to the increase in water levels to some degree.

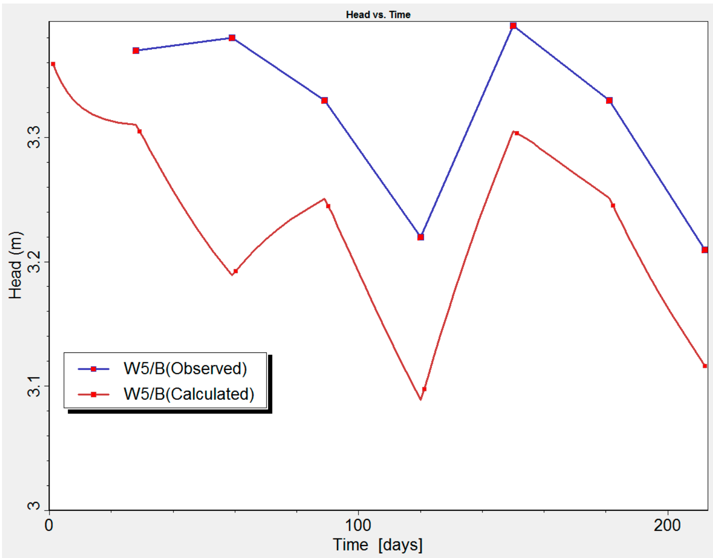

Figure 13. Head versus time at the monitoring piezometer-W5 (Scenario 4).

13.5. Scenario 5: Transient State, Impact of Burials on Water Levels

Scenario 5 was undertaken to simulate the effect of burials (land use changes) within the affected area on groundwater levels.

Layer 1 was refined to include an upper 1.9 m thick layer to represent the grave excavation depth and allow changes due to burial to be contained in this layer. Additional zones were also delineated within the refined upper layer that is zoning to storage and recharge was assigned to represent the change in hydraulic properties and infiltration rate due to grave excavations.

The simulation was carried out using the following assumptions:

- there are approximately 90,000 graves (assuming 1 m width and 2 m length, they cover an area of 0.18 km^2) which is about 56 percent of the site/affected area land area of 0.32 km^2;
- it is estimated that the 90,000 graves take up about 342,000 m^3, around 44 percent of the volume of the upper 1.9 m thick refined Layer 1;
- the grave excavations would normally increase the storage due to disturbance; however, it is assumed:
    - many coffins remain sealed (do not rot away),
    - the dirt is compacted during backfilling,
    - many graves contain two coffins; and
    - often concrete slabs are added between coffins to separate burials and stop the lower coffin floating during the second burial.

- the burials may have resulted in a change in the storage capacity of the upper 1.9 m which is modeled using the specific yield of Layer 1 by varying between 20 to 300 percent;
- rainfall infiltration rates (recharge) are likely to have changed and are, therefore, modeled as both increased and decreased.

Table 4 indicates that a reduction in recharge is more significant than an increase in inducing a change in the residual head. The change in head ranges up to ~0.6 m for a 20 percent reduction in recharge and only a ~0.38 m change for a 50 percent increase.

Table 4. Change in head at piezometers W1 to W5 due to change in recharge (Scenario 5) in comparison to the baseline calibrated model (recharge = 351 mm/year (35 percent)).

Change in Residual Head (m)						
W1	**W2**	**W3**	**W4**	**W5**	**Percent of Recharge**	**Recharge (mm/year)**
−0.38	−0.16	−0.15	−0.14	−0.13	50	502
−0.18	−0.16	−0.15	−0.14	−0.13	40	401
0.18	0.17	0.15	0.14	0.13	30	301
0.59	0.53	0.48	0.44	0.42	20	201

Table 5 indicates that a change (increase) in specific yield, while maintaining the calibrated recharge of 35 percent of rainfall, has limited impact on the head which ranges up to 0.06 m for a 300 percent increase in specific yield from the calibrated value.

Scenario 5 indicates that changes to recharge have a greater impact than changes in specific yield which have minimal or no impact. This may be explained as most burials remain above the water table and only a small portion along the north western boundary interact with the water table during wet periods, whereas changing the amount of water that enters the affected area aquifer is much more significant.

It should be noted that without substantial field investigations the actual impact of burials may not be fully understood.

The numerical model in this study includes many assumptions based on literature values and the experience of the modeller. Limitations exist with respect to error associated with project pre-construction water level observation data, hydrogeological properties for the aquifers (residual clays, transported sandy clays and clays and affected area aquifer) and spatial distribution of recharge areas. The model is sensitive to the recharge and horizontal hydraulic conductivity of the top layer. Effort was made to constrain the model using the historic and factual data, which is expected to minimize the degree of uncertainty [17].

Table 5. Change in head at piezometers W1 to W5 due to changing specific yield (Scenario 5) in comparison to the baseline calibrated specific yield of 0.12.

Change in Residual Head (m)					
W1	**W2**	**W3**	**W4**	**W5**	**Percent of Specific Yield Increase from the Calibrated Value**
0	0	0.01	0	0	20
0	0	0.01	−0.01	0	40
0	0.01	0.01	−0.01	0	60
0.01	0.01	0.02	−0.02	0.01	80
0.01	0.01	0.02	−0.02	0.01	100
0.03	0.04	0.06	−0.05	0.04	300

14. Discussion and Conclusions

Utilizing geological input from the field investigations and the available hydrogeologic data, a three dimensional numerical model that simulated the groundwater level dynamics was developed and calibrated.

The steady and transient calibrated models were run to assess the impact of non-climatic variables to pre/post embankment placement by removing and adding the effect of the embankment and burials within the affected area. A good calibration for the steady state model was achieved. Additional confidence in the calibration was obtained through a transient state history match to water level at the monitoring piezometers.

The groundwater flow model simulation results demonstrate that large areas in the northern part of the study area become wet at ground surface if there exist conditions such as the presence of clay unit at a shallow depth, an intensive cultivation, and surface water leakage to recharge the aquifer. The model result indicates water level rises due to the construction of the embankment are likely less than 0.12 m based on model results and changes in land use potentially related to burials in the affected area, resulting in changes to recharge may be more significant (up to 0.59 m) than the embankment (up to 0.12 m). It is concluded that the elevated groundwater levels in the affected area are most likely a result of above average rainfall since 2007 and long term cumulative land use changes surrounding and within the affected area aquifer. The embankment construction is just one of many land use changes that have occurred both within and surrounding the affected area, and likely only a minor contributor to the elevated water levels. Greater contribution may be attributed to re-direction of the natural flow paths, the railway culvert weir reducing the overland flow gradient and ongoing changes (burial, and surface activities) within the affected area, more than 90,000 grave manholes since the last 150 years (might result in change storage, rejection in recharge etc.), for the last 150 years (which might result in change storage and rejection in recharge). The railway culvert and weir installed in 2007 have effectively decreased the surface water drainage gradient along the bypass corridor by damming the water on the up gradient side. This has likely resulted in a reduction in the rate of drainage from this area slowing the rate of groundwater seepage out of the toe of the Affected area Aquifer.

The water level rise in the affected area has been noticed since the early 1980s. Indeed, it gets worsened since the last three years which coincides with the opening of the gates and above average rainfall (Figure 1; specifically since 1987). An ability to understand and interpret changes in groundwater levels is essential for sound management of groundwater resources. As the groundwater level changes, the area of groundwater discharge may change, dynamically feeding back and altering the trend rate of change.

The groundwater level, which in natural environments remains in equilibrium with forces of nature, responds to anthropological influences. The subsurface water rise, threatening the affected area, is of a concern. Effects of the ongoing burial within the affected area and construction for the bypass corridor and associated embankment have been assessed via the numerical model, including the sensitivity to changes in storage and recharge within the affected area aquifer. The scenarios modeled indicate that the change in the residual head between pre and post embankment placement is less than 0.12 m and this is within the range of water level measurement error and the 2 m contour DEM data and changes in the head within the affected area, due to the land use changes (burials) is more significant due to recharge than changes in specific yield. That is, burials (and other land uses) are more likely to impact recharge rates (infiltration) as opposed to change the affected area aquifer properties, as the graves are mainly above the water table.

The adverse impact of water rise are numerous and severe (El Sheikh et al., 2014) and this could be critical in the future due to climate change resulting extreme wet climate condition [18–20]. Some of these impacts are tangible and can be measured, while others are intangible and difficult to assess [9]. Planning and control policies, if effective and enforced, can be very influential in controlling the extent and rate of groundwater degradation. For example, since the road construction, landfill is a very important recharge source [21] or diverting flow system or operational measures [22–24]. The simulation of the surficial aquifer using a three-dimensional numerical modelling (MODFLOW-SURFACT code within the Visual MODFLOW environment), demonstrated that the majority areas of the study area become flooded if the current conditions persist, and that the implementation of the horizontal drainage network and/or pumping (dewatering within the affected area and discharge off site), will be able to control and mitigate the rising water table conditions in the area. The study suggested applying the horizontal drainage system and constructing a cut off wall parallel to embankment/culvert/rail to break the flow of groundwater from embankment/culvert/rail to this area to control the water-logging problem. Also, it is suggested to use the pathogenic constrained dewatering methods to minimize the recharge to the shallow groundwater aquifer and apply suitable biological drainage system in the logged areas by cultivating high water-consuming plants, such as acacias. Further pathological study can assist to constrain/update the calibrated model and improve our understanding of the current knowledge with respect to the design and installation of the proposed mitigation measures.

Acknowledgments: The manuscript has benefitted from reviewers' comments.

Author Contributions: Y.Y., C.D and A.P. conceived and designed the research; Y.Y., C.D and A.P. analyzed the data; Y.Y. performed the numerical simulation; Y.Y. wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Healy, R.W.; Cook, P.G. Using groundwater levels to estimate recharge. *Hydrogeol. J.* **2002**, *10*, 91–109. [CrossRef]
2. Yihdego, Y.; Webb, J.A. Modeling of bore hydrograph to determine the impact of climate and land use change in western Victoria, Australia. *Hydrogeol. J.* **2011**, *19*, 877–887. [CrossRef]
3. Yihdego, Y.; Khalil, A. Economic and Environmental Management of Water Resources: Perspective of Groundwater. *Glob. J. Hum. Soc. Sci. B* **2017**, *17*, 45–52.
4. Yihdego, Y.; Webb, J.A.; Vaheddoost, B. Highlighting the Role of Groundwater in Lake–Aquifer Interaction to Reduce Vulnerability and Enhance Resilience to Climate Change. *J. Hydrol.* **2017**, *4*, 10. [CrossRef]
5. El Sheikh, A.E.; El Osta, M.M.; El Sabri, M.A. Study of the Phenomenon of Groundwater Levels Rise in South El Qantara Shark Area, Ismailia, Egypt. *J. Hydrogeol. Hydrol. Eng.* **2013**, *2*. [CrossRef]
6. Al-Senafy, M.; Mukhopadhyay, A.; Azrag, E. Simulation of potential dewatering system for managing high water table. In *Groundwater Modeling and Management under Uncertainty*; Hadi, K., Copty, N.K., Eds.; Taylor and Francis Group: London, UK, 2013; ISBN 978-1-138-00012-4.
7. Yihdego, Y. Simulation of Groundwater Mounding Due to Irrigation Practice: Case of Wastewater Reuse Engineering Design. *Hydrol. J.* **2017**, *4*, 19. [CrossRef]
8. Mengistu, H.; Tessema, A.; Abiye, T.; Demlie, M.; Lin, H. Numerical modeling and environmental isotope methods in integrated mine-water management: a case study from the Witwatersrand basin, South Africa. *Hydrogeol. J.* **2015**, *23*, 533–550. [CrossRef]
9. Somaratne, N.; Zulfic, H.; Ashman, G.; Vial, H.; Swaffer, B.; Frizenschaf, J. Groundwater risk assessment model (GRAM): Groundwater risk assessment model for wellfield protection. *Water* **2013**, *5*, 1419–1439. [CrossRef]
10. Somaratne, N.; Smettem, K.; Frizenschaf, J. Three criteria reliability analyses for groundwater recharge estimations. *Environ. Earth Sci. J.* **2014**, *72*, 2141–2151. [CrossRef]
11. HydroGeoLogic Inc. *MODFLOW-SURFACT: A comprehensive MODFLOW-Based Hydrologic Modelling System: Code Documentation and User's Manual*; HydroGeoLogic, Inc.: Reston, VA, USA, 2002.
12. Reilly, T.E.; Harbaugh, A.W. *Guidelines for Evaluating Groundwater Flow Models*; U.S. Geological Survey Scientific Investigations Report 2004-5038, 2004; p. 30.
13. Kazemi, G.A. *Hydrogeology—A Global Perspective*; InTechpublishing Company: Rijeka, Croatia, 2012; ISBN 978-953-51-0048-5.
14. Doherty, J. *PEST—Model Independent Parameter Estimation*; Watermark Computing: Corinda, Australia, 1994; p. 122.

15. Middlemis, H. *Benchmarking Best Practice for Groundwater Flow Modelling*; The Winston Churchill Memorial Trust of Australia: Kent Town, Australia, 2004.
16. Barnett, B.; Townley, L.R.; Post, V.; Evans, R.E.; Hunt, R.J.; Peeters, L.; Richardson, S.; Werner, A.D.; Knapton, A.; Boronkay, A. *Australian Groundwater Modelling Guidelines*; Waterlines Report; National Water Commission: Canberra, Australia, 2012.
17. Wu, J.C.; Zeng, X.K. Review of the uncertainty analysis of groundwater numerical simulations. *China Sci. Bull.* **2013**, *58*, 3044–3052. [CrossRef]
18. Commonwealth Scientific and Industrial Research Organisation. *Groundwater Yields in South-Western Australia: A Report to the Australian Government from the CSIRO South-West Western Australia Sustainable Yields Project*; Technical Report; CSIRO: Canberra, Australia, 2009.
19. Suppiah, R.; Collins, D.; Della-Marta, P. *Observed Changes in Australian Climate*; CSIRO Report; CSIRO: Canberra, Australia, 2001.
20. Wu, Y.; Cheng, D.; Yan, W.; Liu, S.; Xiang, W.; Chen, J.; Hu, Y.; Wu, Q. Diagnosing Climate Change and Hydrological Responses in the Past Decades for a Minimally-disturbed Headwater Basin in South China. *Water Resour. Manag.* **2014**, *28*, 4385–4400. [CrossRef]
21. Ordens, C.M.; Werner, A.D.; Post, V.E.A.; Hutson, J.L.; Simmons, C.T.; Irvine, B.M. Groundwater recharge to a sedimentary aquifer in the topographically closed Uley South basin, South Australia. *Hydrogeol. J.* **2012**, *20*, 61–72. [CrossRef]
22. Yihdego, Y.; Danis, C.; Paffard, A. Why is the groundwater level rising? A case study using HARTT to simulate groundwater level dynamics. *J. Water Environ. Res.* **2017**. Available online: https://doi.org/10.2175/106143017X14839994523785 (accessed on 24 February 2017).
23. Pujades, E.; López, A.; Carrera, J.; Vázquez-Suñé, E.; Jurado, A. Barrier effect of underground structures on aquifers. *Eng. Geol.* **2012**, *145–156*, 41–49. [CrossRef]
24. Yihdego, Y. Evaluation of Flow Reduction due to Hydraulic Barrier Engineering Structure: Case of Urban Area Flood, Contamination and Pollution Risk Assessment. *J. Geotech. Geol. Eng.* **2016**, *34*, 1643–1654. [CrossRef]