Technical Report 21

Assessment of Groundwater Effects

NZ TRANSPORT AGENCY
WAKA KOTAHI

1 MacKays to Peka Peka Expressway

Revision History

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Approved by	Graham Spargo		20 March 2012
on behalf of	Beca Infrastructure Ltd		

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Executive summary

The proposed MacKays to Peka Peka Expressway route ("the Expressway") is one of eight sections within the Wellington Northern Corridor which is identified as a Road of National Significance. This report presents an assessment of the potential effects of the proposed Expressway on the existing groundwater regime. This report feeds into Technical Report 35, Volume 3 and Technical Report 26, Volume 3.

Construction and operation of the proposed Expressway will require construction of embankments with localised surcharge/preload or excavation/replacement of peat (peat treatment) that in places requires cuts below the groundwater table, construction of stormwater devices for treatment, conveyance and attenuation of run-off, and short term groundwater take for construction water supply. These activities have the potential to cause a change (lowering or rise) in groundwater level.

Fieldwork including investigation drilling, in-situ testing, piezometer installation and groundwater level monitoring has been used to develop a conceptual hydrogeological model. The groundwater regime in the area of the proposed Expressway route consists of a series of interbedded aquifers and aquitards creating a leaky, unconfined to semi-confined aquifer system. The near surface hydrogeology is dominated by Holocene dune sands, with areas of peat (that support wetlands of high ecological value) having developed in the lower lying areas between dunes. The construction of the proposed Expressway has the greatest potential to affect the shallow groundwater system (i.e. the Holocene sand and peat).

Two and three-dimensional groundwater modelling was undertaken to assess the effects of the short term construction and long term operation of the proposed Expressway on regional and local groundwater flows. The results of modelling suggest that the construction groundwater take is likely to result in small changes to groundwater levels, flow directions and aquifer through flow and such changes will be limited to the construction period (4 years).

In the longer term the proposed Expressway embankment (and associated peat treatment) will result in very small (typically <0.1 m within 50 m to 70 m of the proposed Expressway) long term changes to groundwater levels and flow directions, with no discernible changes in aquifer through flow.

Where storm water devices are constructed at the approximate groundwater level there will be no discernible changes to the existing groundwater regime. Where such devices are constructed above or below the existing groundwater level and modelling indicates a change in groundwater level might result that would be deleterious to the existing environment, they will be lined to limit interactions.

A monitoring programme will be established prior to construction to record natural variations in groundwater levels and surface water flows. This monitoring will allow appropriate responses to be triggered should actual effects differ from those predicted.

1. Introduction

Construction of the proposed Expressway will require forming embankments (in places over compressible peat), cuts below the groundwater table, construction of stormwater devices for treatment, conveyance and attenuation of run-off, and short term groundwater take for construction water supply. These activities have the potential to cause a change (lowering or rise) in groundwater level which in turn might result in ground settlement, or changes to water levels in existing wetlands, ecological systems or water supplies. A full Project description (Construction & Operation) is given in Part D, Chapters 7 and 8, Volume 2.

This assessment of effects considers what changes might occur to the existing groundwater regime as a result of the construction and operation of the proposed Expressway.

The soil profile and peat distribution are described in Technical Report 36, Volume 3. The planned stormwater devices are described in Technical Report 22, Volume 3. The potential effects resulting from local groundwater drawdown are described in Technical Report 35, Volume 3 and the potential effects resulting from changes to groundwater levels in the vicinity of wetlands are described in Technical Report 26, Volume 3.

The effects on groundwater have been assessed by the development of regional and area specific 2- and 3-dimensional computer groundwater models calibrated to water level monitoring data and taking into consideration the modelling work carried out by others addressing parts of the region.

In order to check that actual effects do not exceed the effects assessed in this report from data analysis, testing and computer modelling, a programme for groundwater monitoring has been set out in the Groundwater (Level) Management Plan (Appendix I of the CEMP, Volume 4). This Plan also sets out opportunities for mitigation, should this be needed.

2. Existing environment

2.1. Geological setting

2.2. Regional geology

The geology of the Waikanae area has been dominated by tectonic activity and glacial and fluvial processes in combination with changes in sea level. Tectonic activity in the area has resulted in vertical uplift of the greywacke basement rocks forming the hilly terrain of the Tararua Ranges in the east. Horizontal shifts of these hills have occurred along faults such as the Ohariu fault (which runs along the base of the greywacke hills to the east of the proposed Expressway) and associated splinter faults. The hill slopes have been dissected by glacial and fluvial processes that have eroded the greywacke and re-deposited it as sandy, gravely alluvial soils including channel deposits, overbank deposits and fans near the coast in the west. These processes, in combination with longshore drift, formed large coastal plains. With each large scale tectonic movement, the rivers altered course and slowly migrated north and south across the alluvial fans depositing gravels, sands and silts. Episodic flood events resulted in finer materials (silts and clays) being deposited further away from the river channels, and in between such events, areas of peat developed in low lying areas between dunes. Sand dunes inter-finger with the peat deposits and rise up to 20 m in elevation along the coast.

2.3. Local geology

A geological model, comprising long-sections and cross-sections of the subsurface geology, has been developed from existing water well data records, drilling records from geotechnical investigations undertaken as part of the proposed MacKays to Peka Peka Expressway Project and geomorphic interpretation of the surface distribution of sands and peat (as described in Technical Report 36, Volume 3). The computer software HydroGeoAnalyst (HGA), a data management and groundwater visualisation tool, was used to facilitate the development of a 3-dimensional ground model. This model comprises eight stratigraphic units of up to 20 m thick with a cyclic depositional sequence (Appendix 21.A).

The basal unit consists of a layer of terrestrial gravels, the Waimea Aquifer, which is overlain by sandy marine deposits, and in turn by alluvial peats, sandy gravels, or dune sands. These units underlie another terrestrial gravel aquifer, the Parata Aquifer, which underlies a further layer of sandy shelly marine deposits. Peat horizons and dune sands form the cover beds in the area.

Greywacke rock outcrops east of SH1 and is inferred to dip steeply beneath the Waimea Aquifer, as a result of tectonic activity along the NE-SW aligned Ohariu North fault which roughly follows the base of the foothills of the Tararua Ranges, east of SH1 (Hemi Matenga and Maungakotukutuku parks).

These eight stratigraphic units represent the key hydrogeological units (that is, units that have similar hydrogeological properties and behaviour) that occur in the vicinity of the proposed Expressway (Table 1).

2.4. Hydrogeological units and their properties

A series of 13 cross-sections showing the eight hydrogeological units were extracted from the HGA model (Appendix 21.A).

The key hydrogeological properties (hydraulic conductivity, storativity and specific yield), for each unit were assessed from in-situ field testing, pumping tests and review of published literature. A description of tests and test results is given in Appendix 21.C. A summary of the distribution of units and their adopted values is set out in Table 1.

Due to the nature of deposition, it is expected that parameters may vary spatially; variability in parameters is evaluated using sensitivity analyses.

Table 1: Key Hydrogeological Units and Their Properties

Hydrogeological Unit	Description	Thickness (m)	Depth (mRL)	Adopted Hydraulic Conductivity (m/s)	Adopted Storativity / Specific Yield
Holocene Alluvium	Alluvial gravel deposits in and around the present course of the Waikanae River and debris deposits (alluvium/colluvium) from the adjacent greywacke hills	0 to 20 (thickest at foothills and river bed)	Surface or beneath cover of peat/sand	$K_h = 3 \times 10^{-3}$ $K_v = 3 \times 10^{-5}$	Sy = 0.3
Holocene Peat	Fibrous woody material to amorphous, silty peat, organic silt, organic clay, organic sand	0 to 8 (typ. up to 4 at Alignment)	Surface	$K_h = 4 \times 10^{-6}$ $K_v = 1 \times 10^{-7}$	Sy = 0.5
Holocene Sand	Fine to medium dune sand; coastal and inland sand dunes	5 to 30	Surface to 8	$K_h = 5 \times 10^{-5}$ $K_v = 5 \times 10^{-5}$	Sy = 0.001
Pleistocene Sand	Sand deposits that lie below the Holocene sand boundary and include reworked dune, beach and estuarine sands	5 to 40	10 to -105	$K_h = 5 \times 10^{-5}$ $K_v = 1 \times 10^{-5}$	Sy= 0.05
Pleistocene Silt/Clay	Silt and clay at depth often packed with carbonaceous leaves and wood	0 to 30	0 to -60	$K_h = 1 \times 10^{-6}$ $K_v = 1 \times 10^{-7}$	$S = 3 \times 10^{-4}$
Parata Aquifer	Pleistocene sand/gravel and clay-bound gravel; thinning to the south and surfacing at the foothills in the north	10 to 40	-10 to -20	$K_h = 5 \times 10^{-4}$ $K_v = 2 \times 10^{-5}$	$S = 1 \times 10^{-4}$ to 4×10^{-4}
Waimea Aquifer	Terrestrial sand/gravel and clay-bound gravels	5 to 40*	-20 to -100	$K_h = 5 \times 10^{-4}$ $K_v = 1 \times 10^{-4}$	$S = 5 \times 10^{-5}$ to 4×10^{-4}
Greywacke		Basement rock	0 - > -100 m	Modelled as impermeable or inactive zone	

* Base of layer not encountered in all boreholes (therefore may be thicker in some areas)

The Alignment passes through the Waikanae Groundwater Zone (WGZ), one of six broad groundwater management zones on the Kāpiti Coast (WRC, 1994). The key aquifer horizons within the WGZ are the deep Waimea Aquifer and Parata Aquifers, from which the Kāpiti Coast District Council (KCDC) production wells abstract water for public water supply. Domestic wells generally abstract water from the shallow Pleistocene and Holocene Sands.

The construction of the proposed Expressway has the greatest potential to affect the shallow groundwater system i.e. the Holocene Sand, Peat and Alluvium because works will be largely carried out within these materials.

The Holocene Peat (Table 1) is variable in nature, ranging from amorphous organic silt and clay through to fibrous woody peat. Generally the peat is more fibrous towards the southern end of the Alignment, whilst amorphous peat is more dominant at the northern end of the Alignment, although both types are present in some areas. The hydraulic conductivity of this unit is typically of the order of 10^{-6} m/s to 10^{-7} m/s but ranges between 2×10^{-9} m/s and 1×10^{-5} m/s.

There is significant overlap in the hydraulic conductivity of the various dune, alluvial and marine sands (Holocene Sand, Pleistocene Sand and Parata and Waimea Aquifers, Table 1) with hydraulic conductivity tending to be of the order of 10^{-5} m/s, but ranging between 2×10^{-7} m/s and 4×10^{-4} m/s.

2.5. Groundwater levels, gradients and direction of flow

Interpolated regional groundwater levels are contoured in Figures B1 and B2, and tabulated in Appendix 21.B. The contours consider data from two key sources; Greater Wellington Regional Council (GWRC) monitoring stations within the WGZ and 54 No. piezometers installed historically and recently along the proposed Expressway Alignment.

The GWRC monitoring stations are spread throughout the Waikanae area and within the different aquifers (well depths ranging from 5 m to 122 m bgl). Water levels in all wells have been monitored since 2005, with some records starting as early as 1994, and so the well hydrographs provide a valuable record of long term trends in groundwater levels. A summary of available hydrograph data is given in Appendix 21.B.

The hydrographs show a seasonal variation with the lowest water levels typically recorded in April (end of summer) and the highest water levels recorded in October (end of winter). Water levels in the deeper bores (R26/6566, R26/6284 and R26/6378) appear to be rising slightly, while the water level trend in the shallow bores remains generally constant from year to year.

Comparison with rainfall records recorded at the Waikanae Treatment Plant indicates that changes in water level in the shallow unconfined aquifers have a strong correlation with rainfall events, suggesting that the shallow aquifer responds rapidly to rainfall recharge. This is supported by moisture balance modelling carried out by Gyopari, 2005.

A series of monitoring bores has been installed along the proposed Expressway Alignment targeting the shallow geological layers and a programme of regular water level monitoring has been established since October 2010 (tabulated in Appendix 21.B). Some irregular monitoring of older installations has occurred since 2007. These detailed short term records correlate well with the longer term records from GWRC.

The data indicate that the main groundwater flow direction is from the foothills in the east towards the coast in the west; this means that the groundwater flow direction is broadly perpendicular to the proposed Expressway (Figures B1 and B2). The groundwater gradient is approximately 1:500 along the southern and central sectors of the Alignment. Near the northern end of the Alignment a steeper gradient of 1:250 is inferred, and may be due to the higher level of the greywacke basement rock in this area.

2.6. Groundwater use

It is estimated that almost 3000 domestic garden irrigation wells are spread across the populated area of the model (Gyopari, 2005). The pumping schedules and as-built details for these wells are not known and the abstractions are not metered. The wells are generally thought to be between 3 m and 5 m deep and to each abstract 1 – 5 m^3/day. Although the individual take from wells is small, the cumulative volume (3,000 m^3/day to 15,000 m^3/day) is more substantial.

2.7. Groundwater/ surface water interaction

There are a large number of surface water features within the WGZ which interact with the shallow and deeper groundwater system.

The **Waikanae River** has a direct connection with the underlying gravel aquifer with large losses and gains to and from groundwater indicated by flow gauging. A flow loss of up to 300 l/s from the river to groundwater has been calculated between SH1 and Jim Cooke Memorial Park (Gyopari, 2005).

The **Waimeha and Wharemauku Streams** also have a direct connection to groundwater, being almost entirely spring-fed through shallow gravels and sands with flows of 100 l/s to 300 l/s, and 20 l/s to 50 l/s respectively.

A large number of **wetlands** occur within the WGZ. Wetlands and lagoons have typically formed in the low lying areas between dunes where peat has been deposited and where the groundwater level is very close to the surface. Wetlands are generally thought to be points of groundwater “discharge” with flows largely sustained by shallow groundwater (Gyopari, 2002). However there is also evidence that some wetlands within the Kāpiti Coast are “recharge” wetlands fed by rainfall and run-off perching on the low permeability peat (Allen, 2010). Data collected and modelling carried out as part of this Project confirms that both types of wetland occur depending on the particular conditions at each site.

In addition to these natural features there are also several large drains constructed historically to lower the water table in the area (described in more detail in Technical Report 22, Volume 3), the largest being the **Mazengarb drain** which is thought to discharge approximately 50 l/s of shallow groundwater (Gyopari, 2005).

2.8. Conceptual groundwater model

The conceptual groundwater model and water balance data are described in Appendix 21.D. The groundwater regime consists of a series of interbedded aquifers and aquitards creating a leaky, unconfined to semi-confined aquifer system (Figure 1). The predominant source of recharge is from rainfall, which slowly infiltrates down into the lower layers.

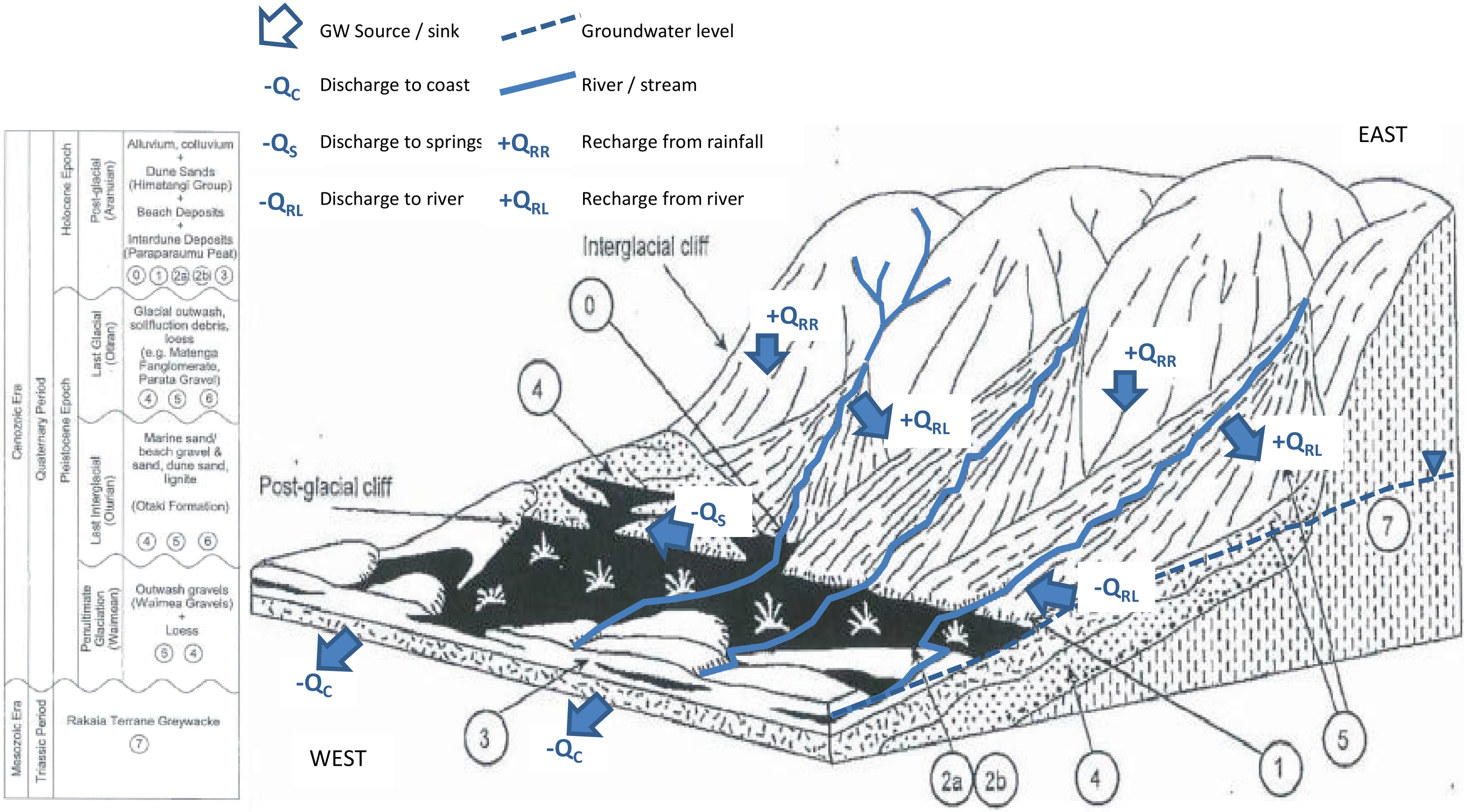
At depth, moderate to high transmissivity terrestrial gravels form the confined Waimea Aquifer and Parata Aquifer. Municipal water supply wells for KCDC abstract water for the most part from the Waimea Aquifer as its deep and confined nature gives greater security to the groundwater source and limits effects in overlying aquifers.

The deeper confined aquifers are overlain by a series of unconfined aquifers comprised of fluvial gravels, and marine sands with interbeds of regression alluvium. Private irrigation wells commonly abstract water from these upper marine sands. These units are in turn overlain by alluvium and Holocene dune sand, with areas of peat having developed in the lower lying areas between dunes.

The peat ranges from amorphous organic silt to fibrous woody peat of variable permeability and compressibility. The peat is significant in that it supports a series of recharge and discharge wetlands of high ecological value.

The construction of the proposed Expressway has the greatest potential to affect the shallow groundwater system (i.e. the Holocene sand, peat, and alluvium) because works will be largely carried out within these materials.

Figure 1: Conceptual Groundwater Model



Modified after Maclean, C & Maclean, J (2010)

3. Potential groundwater issues

Proposed Expressway construction includes the following elements that will have implications for groundwater:

- Embankment construction:
  - Cuts below the groundwater table, some requiring short term dewatering;
  - Excavation and replacement of peat with sand; and
  - Surcharging of peat to accelerate ground settlement.
- Stormwater treatment, storage and attenuation:
  - Construction of stormwater treatment/ attenuation wetlands;
  - Construction of swales for the treatment, attenuation and conveyance of surface run-off from the proposed Expressway; and
  - Earthworks to provide flood storage areas (cuts resulting in permanent lowering of the groundwater level and / or bunds).
- Installation and pumping of water supply wells to provide a short term source of construction water.

Construction of the embankments and stormwater devices, cuts and at-grade activities are limited to the upper, unconfined groundwater system (upper marine sands, alluvium, dune sands and peat) but may result in changes (lowering or rise) in groundwater levels that could result in:

- Consolidation settlement in the peat (addressed in Technical Report 35, Volume 3);
- Reduced groundwater through flow, and groundwater levels in surface water bodies (addressed in this report) that may change ecological habitats (addressed in Technical Report 26, Volume 3);
- Changes to direction and flow of groundwater, potentially altering contaminant migration paths (addressed in Technical Report 23, Volume 3); or
- Reduction of water levels in existing wells.

The majority of proposed stormwater devices would have water levels that are comparable to the surrounding local groundwater level and so noticeable changes in groundwater level in these areas are unlikely. The design of wetlands OA and 9 and off-set storage areas 2, 3A and wetland 3, requires water levels that are more than 0.5 m above or below the existing groundwater level and therefore there is the potential for a change in groundwater level in these areas. For this reason, the effect of the proposed stormwater designs on these wetland areas have been assessed in site specific 3D computer modelling. The significance of the wetlands is discussed in Technical Report 26, Volume 3.

Construction of the proposed Expressway in the vicinity of the Otaihanga Landfill has the potential to alter groundwater flow paths which might alter the distribution of any leachate currently discharging from the landfill and a site-specific 3D model was therefore also developed to consider this area.

It is currently assumed that the construction water supply wells will abstract water from the intermediate depth Parata Gravel aquifer so as to limit, as far as is practical, associated effects on the shallow, unconfined system (from which most local wells in the area abstract water) and avoid interference effects with the KCDC municipal supply wells (most of which abstract water from the deeper Waimea aquifer). It is noted that the construction water wells will be pumped for a short period of time to facilitate construction and dust suppression during construction of the proposed Expressway and so any effects associated with pumping will not be permanent.

Opportunities for sharing existing KCDC water supplies and developing fewer wells that might remain in supply to meet future KCDC needs are being explored.

3.1. Sector specific groundwater issues

3.2. Sector 1 Raumati South

In Sector 1 the proposed Expressway passes in close proximity to the Raumati Manuka wetland and over a significant surface drain (Drain 7).

To the east of Drain 7 the proposed Expressway will be constructed on an embankment and to the west of the drain the proposed Expressway is in cut along the western flank of a dune. Through this sector it is intended to surcharge the peat that is up to 3 m thick in some places (Technical Report 35, Volume 3).

Wetland OA is to be constructed between the proposed Expressway and Drain 7 for treatment and attenuation of stormwater prior to discharge to the drain (Technical Report 22, Volume 3). Areas OB and OC are constructed for offset flood storage only (i.e. no change in groundwater level).

Within this sector key groundwater issues considered are:

- The interaction between the stormwater wetland OA and the Raumati Manuka Wetland; and
- The potential for peat surcharge to reduce groundwater through flow to the Raumati Manuka Wetland and cause up-gradient ponding.

3.3. Sector 2 Raumati / Paraparaumu

In Sector 2 the proposed Expressway passes through the Kiwi Pond, Wharemauku and Mazengarb Streams (and their tributaries) and close to several other small wetland areas.

Through this sector the Alignment is constructed using both embankments and cut depending on existing ground level. South of Kāpiti Road the dominant peat treatment is surcharging. Where peat is encountered between Kāpiti and Mazengarb Roads it will be excavated and replaced by sand.

Flood offset storage areas 2 and 3A are to incorporate the Kiwi Pond. It is proposed to lower the groundwater level by up to 0.6 m in this area to allow for flood storage (refer to Technical Report 22, Volume 3 for constructed offset storage area and wetland detail). Two small treatment and attenuation wetlands (4 and 5) are also planned within this sector however these do not result in changes to the groundwater level.

In this sector the groundwater issues considered are:

- The interaction between the storage areas 2, 3A and wetland 3 and the Wharemauku Stream and the potential for groundwater lowering to reduce the groundwater flow to the stream;
- The effect of potential groundwater lowering on aquifer systems and yield from existing wells;
- The potential for groundwater lowering to result in consolidation settlement for neighbouring residential areas; and
- Effects of peat treatment methodologies.

3.4. Sector 3 Otaihanga / Waikanae

In Sector 3 the proposed Expressway passes close to several wetlands, most notably the El Rancho Wetlands, which have significant ecological and cultural value (Technical Report 26, Volume 3). The proposed Expressway also crosses two significant surface water bodies, the Waikanae River and the Waimeha Stream, and passes in proximity to the Otaihanga Landfill.

Through this sector the Alignment is generally in cut, with both surcharging and replacement of peat proposed in at-grade/ fill areas.

Several small treatment wetlands (7 to 9) are proposed in this sector. Groundwater lowering is proposed near Puriri and Kauri Roads, as a result of Wetland 9 (~200 mm) and proposed French drains (refer to Technical Report 22, Volume 3 for constructed wetland and drain operation and detail).

Groundwater issues considered in this area include:

- Potential changes in flow directions in the vicinity of Otaihanga Landfill that might result in changes to current leachate flow directions;
- Potential interactions with El Rancho wetland, in particular, whilst groundwater lowering may address surface flooding in the area there is potential for this lowering to reduce the water level in the El Rancho wetlands; and
- Peat treatment methodologies.

3.5. Sector 4 Waikanae North

In Sector 4 the proposed Expressway passes through the Te Harakiki Regen Wetlands and between the ecologically significant Nga Manu sanctuary and Te Harakiki/ Kawakahia wetland.

The Alignment is largely in cut or at grade. South of CH15000, peat is expected to be excavated and replaced with sand; north of CH15000 the peat will be surcharged.

Large flood offset storage areas are proposed near Kakariki Stream; however these will be above groundwater level and hence unlikely to affect groundwater recharge areas. During flood flows some minor seepage out of the base may occur resulting in localised mounding however this will be short term and unlikely to extend far enough to affect the adjacent wetlands. Three large flood offset areas are also proposed north of Ngarara Road which would require lowering of the groundwater level.

Key groundwater issues in this sector are:

- Peat treatment methodologies, in particular the interaction with natural wetlands; and
- The potential effects of groundwater lowering if required to facilitate flood offset storage.

3.6. Geotechnical issues arising from the existing groundwater system

3.7. Excavations in peat (construction phase)

Short term (less than a few days) excavation in the peat may require dewatering to allow the optimal placement and compaction of sand. The proposed construction methodology assumes that the excavation is limited to that volume which can be backfilled in one day; hence any related drawdown will be transient in nature and likely to be limited to within the Designation.

In areas where an upward groundwater gradient is present and where the full thickness of peat is removed, “boiling” may occur in the base of excavation, potentially resulting in increased groundwater flows and instability for the excavation sides.

Dewatering / groundwater inflows in the peat are unlikely to be uniform with greater inflows occurring in areas of more fibrous / woody peat and much smaller inflows occurring in amorphous peat / organic silt.

3.8. Construction on peat (operation phase)

Localised dewatering for excavation or surcharging of the peat may result in consolidation settlement; such settlement needs to be allowed for in design of the embankments.

The peat is not uniform in nature, vertical thickness or lateral extent, meaning that differential effects may occur in some areas.

Peat has very high natural water contents, generally greater than 150 % but in some cases as much as 900 % natural water content. Therefore some discharge of water may occur locally when areas of peat are surcharged.

3.9. Deep cuts (construction and operation phase)

Generally, where deep cuts are proposed the final road level is above the regional water table and hence drawdown is not likely. However it is possible that perched aquifers may be encountered and local discharge of these aquifers, resulting in drainage of small volumes of groundwater may occur. There would not be a noticeable effect except perhaps where a shallow privately owned bore was abstracting water from such a shallow perched zone. Known shallow wells in these areas (identified in GWRC records) are all located more than 250 m from the cuts; this is beyond the extent of effects on groundwater levels and hence no adverse effects are anticipated.

3.10. Consolidation of peat and sand

Opus (2008) undertook site-specific compaction trials which indicated that the sand could be expected to densify by less than 10 %; this degree of densification would not result in noticeable changes to hydraulic conductivity for in-situ sand.

Where peat is to be surcharged, compression of 20 % to 50 % is expected. This could reduce the hydraulic conductivity of the peat by a factor 1/10 to 1/1000 (Carlsten, 1988).

In areas where peat is excavated and replaced with sand (that has been densified by 10 %), the sand will nevertheless have a higher hydraulic conductivity than that of the in-situ peat that it replaces.

4. Methodology

4.1. Investigation and assessment process

4.2. Ground investigations

During the course of historical and recent site investigations, several phases of site investigation have been undertaken comprising in total:

- 102 No. boreholes;
- 48 No. test pits;
- 111 No. hand augers; and
- 146 No. cone penetration tests.

This site-specific investigation data has been combined with logs from the GWRC well database to develop the geological model (described in 2.1.2).

54 No. standpipe piezometers have been installed within the study corridor. Details of piezometer location and construction are given in Technical Report 36, Volume 3.

Piezometers were generally constructed so that only one geological unit is monitored in each, allowing variation in water levels in different units to be identified, with:

- 10 No. piezometers screened within the Holocene peat;
- 1 No. piezometer screened within the Holocene sand and gravels; and
- 43 No. piezometers screened within the Pleistocene sands and gravels.

4.3. Groundwater level monitoring

Piezometers installed as part of earlier investigations (and of earlier alignments) have been monitored periodically. Monthly monitoring of piezometers along the current Alignment was recommenced in November 2010 to extend the baseline data for Volume 2. Water levels are contoured in Figures B1 and B2, and tabulated in Appendix 21.B.

4.4. Peat excavation trials

Excavation and fill trials were carried out on an area of peat adjacent to the proposed Expressway at the end of Greenhill Road (near Peka Peka interchange). From a groundwater perspective the purpose of the tests was to:

- Determine the time taken to lower the groundwater level within the excavation and the extent of the drawdown effect beyond the excavation; and
- Determine the hydraulic conductivity of the peat by recording the drawdown effects in adjacent piezometers due to lowering of the groundwater level in the excavation.

The test methodology involved excavating an area of 20 m (W) x 10 m (L) x 2.5 m (D).

As the excavation proceeded, groundwater was pumped out of the pit using a surface pump achieving a drawdown of 0.02 m to 0.38 m (on average 0.22 m) in adjacent peat and shallow sand piezometers, with drawdown recorded to extend no further than 40 m from the excavation after two days of dewatering.

Upon completion of the excavation the pump was stopped and the groundwater allowed to flow into the excavation. After a period of 42 hours, groundwater levels in piezometers had on average recovered by 70 % (although water level recovery in individual piezometers varied between 10 % and 100 %). The main groundwater inflow to the excavation occurred through the excavation faces, primarily where pieces of wood were present. Some seepage through the sand base was also noted in isolated areas.

Records of groundwater levels in the adjacent piezometers (screened in peat and the underlying sand layer) were also used to assess hydraulic conductivity (Appendix 21.C). Hydraulic conductivities calculated in the sand ranged from 1 x 10^{-5} m/s to 4 x 10^{-5} m/s and a geometric mean of 3 x 10^{-5} m/s. Hydraulic conductivities calculated in the peat ranged over two orders of magnitude from 1 x 10^{-7} m/s to 1 x 10^{-5} m/s, with a geometric mean of 2 x 10^{-6} m/s.

4.5. Groundwater modelling

4.6. Regional model 3D model

Three dimensional groundwater flow modelling has been used to evaluate the aquifer budget (water flowing into and out of the model) and assess the likely regional effects of the construction of the proposed Expressway on groundwater, wetlands and river levels. This section sets out the methodology used in development of the model. Details of the model code, set-up, development and calibration are given in Appendix 21.F.

The regional model covers an area of 22.5 km by 11.0 km, and is comprised of 14 layers representing the eight hydrogeological units described in Table 1. The spatial distribution of the 14 layers is as mapped on the published geological maps for the area (Begg and Johnston, 2000 and Begg and Mazengarb, 1996), and supplemented with borehole data from the Greater Wellington Regional Council (GWRC) database and the site specific investigations.

The regional model has cell dimensions of 40 m x 40 m in the vicinity of the proposed Expressway, gradually widening to 400 m x 400 m at the outer bounds of the model. This cell size allows assessment of broad-scale changes in the areas where changes might take place, without making the model overly-complicated or numerically unstable.

Significant rivers, streams and drains that act as groundwater sources or groundwater sinks are considered in the model.

An average annual rainfall of 1311 mm/year (calculated from GWRC records over the period 2000 to 2010) was applied to the model area with individual recharge zones differentiated by soil type and land use (refer to Appendix 21.D for the assessment method).

The groundwater model was calibrated using known average static water levels for existing wells, slug test results from peat trials, rainfall and corresponding water level time series, and a conceptual water balance.

A series of sensitivity checks were undertaken in the regional model which identified that the model is relatively insensitive to changes in hydraulic conductivity in the upper three layers (alluvium, peat and sand) and to small changes in rainfall recharge. These results indicate that a satisfactory calibration has been achieved (Appendix 21.F, section F1.3).

The potential effects of the Project were modelled by:

- Simulating potential changes in peat hydraulic conductivity due to surcharging (decrease in hydraulic conductivity) or excavation and replacement of the peat with sand (increase in hydraulic conductivity);

- Removing rainfall from the area of the proposed Expressway (as all rainfall will go to swales and stormwater devices for controlled discharge to rivers);
- Simulating the introduction of man-made storage areas and wetlands; and
- Simulating abstraction from the construction water supply wells.

Both steady state and transient models were developed; the steady state to consider average long term effects and a transient model to consider the cumulative effect of the proposed Expressway and climate extremes such as high or low rainfall. The findings are described in Appendix 21.F and summarised in Section 5.

4.7. Detailed 3D groundwater/ stormwater interaction models

Three smaller, more detailed 3D flow models were developed to assess the interaction between some of the key stormwater devices and groundwater, specifically:

- Wetland OA/ OB (existing ecological area);
- Flood offset storage areas 2, 3A and wetland 3 (Wharemauku Stream and proposed flood offset area); and
- Wetland 9 (El Rancho ecological and cultural area).

A site specific model was also developed to consider the interactions of the Otaihanga Landfill and adjacent wetlands with proposed Expressway construction.

The models consider in more detail the interaction between constructed / man-made wetlands and ponds and the existing groundwater regime (changes in flow direction, gradient and water levels) and the effects of proposed peat treatment methodologies. Details of the model code, set-up, development and calibration are given in Appendix 21.F.

These smaller models have an area of 1 km^2 to 2.5 km^2 (i.e. 1 km by 1 km, or 1.5 km by 1.5 km for Wetland 9), and are comprised of the same 14 layers and unit distribution as the regional model.

Immediately adjacent to the proposed Expressway and stormwater devices, a cell size of 2.5 m x 2.5 m (or less) is used, gradually widening to 10 m x 5 m at the outer bounds of the models. This cell size allows for detailed consideration of changes in water level and flows.

Significant rivers, streams and drains that act as groundwater sources or groundwater sinks are considered in the model. Rainfall recharge is applied via individual recharge zones differentiated by soil type and land use as per the regional model.

Hydrogeological parameters are those calibrated for the regional model, with boundary conditions varied to achieve calibration. The groundwater models were calibrated to known average static water levels within existing wells (where available) and to simulate flooding / surface water bodies where they are known to occur.

The potential effects of the Project were modelled by:

- Simulating potential changes in peat hydraulic conductivity due to surcharging (decrease in hydraulic conductivity) or excavation and replacement of the peat with sand (increase in hydraulic conductivity);
- Removing rainfall from carriageway areas (as all rainfall will go to swales and stormwater devices for controlled discharge to watercourses); and
- Simulating the controlled water levels in man-made ponds and wetlands.

Both steady state and transient models were developed; a steady state model to consider average long term effects and a transient model to consider the cumulative effect of the proposed Expressway and climate variation such as high or low rainfall. An 8 year rainfall record available for the period 2003 – 2011 was used in transient analyses. This period includes a wet 2004 and a drought in 2005 which allowed comparison of effects at each of these time steps. The findings are described in Appendix 21.F and summarised in Section 5.

4.8. 2D Modelling of Expressway

A series of 2D flow models were developed perpendicular to the proposed Expressway to assess the potential effects of embankment construction on aquifer through flows and groundwater levels. The models specifically look at the potential effects resulting from peat excavation and replacement or peat surcharge, however where sections were located near stormwater devices these have also been considered.

In addition to these detailed 2D models, a series of generic 2D flow models were developed to assess how typical drawdown curves might change with variations in peat thickness.

Because the 2D sections can't consider 3D flow effects they tend to overestimate the magnitude and extent of drawdown; for this reasons it is important to consider the results of the 2D models and 3D models together.

For the detailed 2D models, the spatial distribution of the 14 layers is as mapped on the published geological maps for the area (Begg and Johnston, 2000 and Begg and Mazengarb, 1996), and supplemented with borehole data from the GWRC database and the site specific investigations. For the generic models a simple, uniformly layered profile of peat overlying sand was modelled with the thickness of the peat varied in 0.5 m increments. Hydrogeological parameters were those calibrated for the regional 3D model.

Immediately adjacent to the proposed Expressway, a cell width of less than 2.0 m is used, gradually widening to 30 m at the outer bounds of the models. This cell size allows for consideration of changes in water level and flows in close proximity to the Alignment.

The 2D models were calibrated to known water level information (where available) and checked to see that areas of known flooding were simulated. The generic models assume a flat groundwater table at the surface.

Rainfall recharge was applied as for the 3D regional model.

The potential effects of the Project were modelled by:

- Simulating potential changes in peat hydraulic conductivity due to surcharging (decrease in hydraulic conductivity) or excavation and replacement of the peat with sand (increase in hydraulic conductivity); and
- Removing rainfall from the area of the proposed Expressway (as all rainfall will go to swales and stormwater devices for controlled discharge to rivers).

The results of the modelling are described in Appendix 21.E and summarised in Section 5.

4.9. Model calibration and limitations

Details of model calibration, sensitivity and limitations are outlined in Appendix 21.E (2D modelling) and Appendix 21.F (3D modelling).

The models were calibrated to observed water levels and a conceptual water balance using known values of hydraulic conductivity and storativity (where available from site-specific investigations or previous modelling exercises, i.e. Gyopari, 2005 and Beca, 2011) and rainfall recharge (using the factors derived by Gyopari, 2005). Sensitivity checks indicate the model is suitably calibrated to the available data.

The 3D regional model was also calibrated to a transient series of seasonally varying water levels and corresponding rainfall. A reasonable calibration to observed water levels, conceptual water balance and general flow patterns was achieved (Figure F4).

Water levels have been obtained from several different sources recorded over differing time-frames and with varying degrees of reliability. During calibration greater weight was placed on water levels from longer term records.

Although the model domains cover significant areas, data calibration points tend to be located in proximity to the Alignment. Hence the model is best suited for assessment of effects within ± 200 m of the Alignment, where the greatest density of reliable calibration data (gathered as part of this Project) is located.

The wider area where less geological data and water level observations are available contains some interpolation, but is nevertheless suitable for a qualitative assessment of effects.

5. Effects assessment

5.1. Groundwater levels and flow directions

The results of numerical modelling suggest that overall the proposed Expressway will have a very small effect on existing groundwater levels and flow directions.

5.2. Expressway

Both 2D and 3D groundwater modelling suggest that peat treatment (surcharging or excavation and replacement) will alter groundwater levels by typically less than 0.3 m (but up to 0.5 m) immediately adjacent to the proposed Expressway, reducing to 0.1 m at a distance of 50 m to 70 m from the edge of the embankment in the upper layers of the profile only, with no discernible change in flow directions. In the case of surcharging, a small rise in groundwater levels up-gradient may occur (although the modelling suggests that reduced rainfall recharge to the proposed Expressway area counters any small rise in water level for no change overall); in the case of excavation and replacement, a small lowering of groundwater levels may occur.

5.3. Stormwater devices

Where construction of stormwater devices results in a lowering of groundwater levels (i.e. flood storage areas 2, 3A and wetland 3 at Wharemauku) a maximum drawdown of 0.5 m is likely immediately adjacent to the stormwater devices, with measurable drawdown (s = 0.1 m) extending for some 200 m to 300 m from the ponds depending on variations in ground conditions. Locally this has a small effect on groundwater flow directions, but overall, the effects on flow gradients and directions are not discernible. However the expected drawdown could result in ground settlements (discussed in the Technical Report 35, Volume 3).

Where the maintained water level in stormwater devices is more than 0.5 m above or below the existing groundwater level, modelling suggests constructing a low permeability lining in the ponds will be required to avoid lowering of the groundwater level beneath and adjacent to the ponds or raising the groundwater level beneath and adjacent to the ponds, respectively. This applies to wetland OA, wetland 4 and wetland 9 where a constructed lining of minimum thickness 0.5 m and maximum hydraulic conductivity 1 x 10^{-7} m/s (or other product to achieve a similar reduction in groundwater through-flow) is required.

All other stormwater wetlands are at the same level as the groundwater and no discernible effects are expected.

5.4. Construction water supply

The abstraction of groundwater for construction water supply progressively from a series of 9 bores constructed along the Alignment at up to 750 m^3/day from any single bore and a maximum of 1990 m^3/day in total from any group of bores pumping at any one time, will result in a short term (i.e. no longer than the 4 year length of the construction period) groundwater drawdown of up to 2 mat the bore within the Parata Aquifer with the cone of depression typically reducing to less than 0.1 m at less than1 km. Some minor drawdown (< 0.7 m) may also occur in the overlying and underlying aquifers in the vicinity of each well, however these effects would be limited to within the period of construction. Modelling indicates that groundwater levels are expected to recover to 80 % of pre-construction levels within 1 day of ceasing pumping. The drawdown estimates are based on continuous pumping and do not consider the significant recovery that will occur between periods of intermittent pumping.

5.5. Wetlands and surface waters

The results of numerical modelling suggest that overall changes to the groundwater budget are unlikely to be discernible. Groundwater contribution to rivers and streams may reduce by up to 1.5 % (peak) as a result of the construction water take over the limited period of that take (a number of months).

Modelling suggests that due to the relatively limited extent of drawdown resulting from proposed Expressway construction and the lining of stormwater wetlands that would require a reduction in water level of more than 0.5 m (for which modelling indicates a change in groundwater level that might be deleterious to the existing environment), there will be no discernible long term effects on groundwater contributions to rivers and streams.

The exception to this is the Wharemauku Stream where groundwater that would have directly discharged to the stream will instead be discharged to flood offset areas 2 and 3A before being directed to the stream (refer Section 5.5.2 for detail). This is a non-consumptive take; however groundwater base flow over a length of 600 m adjacent to the pond will be reduced by 17 %.

Modelling suggests there will be no discernible effect on water levels in natural wetlands in the long term, due to the relatively limited extent of drawdown resulting from the proposed Expressway and the lining of the stormwater wetlands in areas where long term effects might otherwise have occurred.

5.6. Contaminant migration

As changes in groundwater levels, gradients and flow are expected to be very small, the potential for changes in contaminant migration as a result of the Project is also very small.

Both regional and site-specific 3D groundwater modelling of the proposed Expressway in the vicinity of the Otaihanga Landfill indicate no noticeable change in groundwater levels, gradients and flow as a result of proposed Expressway construction (Appendix 21.F). Changes in contaminant migration from the landfill as a result of proposed Expressway construction are therefore considered negligible.

5.7. Groundwater users

The results of numerical modelling indicate maximum changes in water level of up to 0.2 m within 6 No. existing wells. This level of drawdown is unlikely to have an adverse impact on existing users, but if these wells are very shallow low yield wells the yield from them may be affected and a temporary replacement supply or longer term solution may be needed.

5.8. Sector-specific effects

5.9. Sector 1

The construction of the proposed Expressway and associated stormwater devices (assuming that wetland OA is lined) may draw down the water table by up to 0.5 m immediately adjacent to these features, however the effects generally extend less than 20 m to 40 m, such that drawdown of the water level in the Raumati Manuka wetland is not expected. Monitoring, as outlined in Section 6 and in CEMP Appendix I, Volume 4, will be used to confirm that effects are within the range modelled.

Some minor, localised seepage out of the base of wetland OA is likely and this will raise the water level immediately below the wetland (by up to 0.5 m), with no effects expected beyond the boundary of the wetland.

Lowering of the groundwater level around Wetland OA will reduce the amount of surface flooding west of the Alignment, reducing the volume of groundwater that will discharge to Drain 7 in this area.

5.10. Sector 2

Lowering of the groundwater level associated with flood offset storage areas 2, 3A and wetland 3 results in up to 0.5 m of drawdown immediately adjacent to the storage areas, with the drawdown extending for 200 m to 300 m radially out from the wetland. Whilst this may help alleviate surface flooding experienced in this area there is the potential for consolidation settlement of ground beneath the neighbouring residential areas (as discussed in Technical Report 35, Volume 3).

Because of the upward groundwater gradient in this area (as indicated by the spring fed Wharemauku Stream and artesian water levels in deep piezometers), when the peat is excavated from the pond footprint the confining head is removed and so some drawdown will also occur in the upper Marine Sand layer (up to 0.5 m directly beneath the storage area). In deeper layers drawdown of less than 0.2 m is predicted.

Lowering of the groundwater level around flood storage areas 2, 3A and wetland 3 reduces the amount of groundwater which naturally discharges to the Wharemauku Stream (a reduction of about 17 %) and Drain 7 (a reduction of about 13 %,) over a length of some 600 m. However, the groundwater which would have naturally discharged to the stream instead discharges to the flood offset area, and is then redirected to the stream further down gradient such that down gradient flows are not affected (i.e. the take is non-consumptive).

Monitoring, as outlined in Section 6 and in CEMP Appendix I, Volume 4, will be used to confirm that effects are within the range of that modelled.

5.11. Sector 3

The construction of the proposed Expressway (peat excavated and replaced with sand) may draw down the water table by up to 0.4 m immediately adjacent to the proposed Expressway with measurable drawdown (0.1 m) typically extending for less than 50 m (but up to 100 m). Drawdown of the water table beneath the adjacent natural wetlands is not expected.

Construction of storage area 6, located in proximity to the toe of the landfill may result in a lowering of the groundwater level by up to 0.1 m immediately adjacent to the storage area, with drawdown extending less than 100 m. Wetland 8 may cause a drawdown of 0.5 m immediately adjacent to the wetland, reducing to 0.1 m at 50 to 100 m distance.

Wetland 9 will be constructed with a low permeability liner in order to limit interactions between the wetland and groundwater level; however some very small changes in groundwater level can still be expected. Immediately adjacent to wetland 9, a maximum drawdown of 0.3 m is likely, reducing to less than 0.1 m at a distance of 20 m to 30 m.

As changes in groundwater level are of limited magnitude and extent there is no measureable change to the volume of groundwater which naturally discharges to the Waikanae River in this area.

Monitoring, as outlined in Section 6 and in CEMP Appendix I, Volume 4, will be used to confirm that effects are within the range of that modelled.

5.12. Sector 4

Within Sector 4, the Alignment is largely above the groundwater level and so effects on water levels in the adjacent Te Harakiki Regen Wetlands, Nga Manu sanctuary and Te Harakiki/ Kawakahia wetland are expected to be negligible.

Large flood offset storage areas are proposed near Kakariki Stream, however these are planned to be at or above groundwater level and would therefore have little effect on the groundwater system. A system of drains is proposed north of Ngarara Road which would result in local lowering of the groundwater level that could potentially result in consolidation settlement affecting the existing SH1 and railway embankment (as discussed in Technical Report 35, Volume 3).

6. Summary of Groundwater Level Effects

A summary of the modelled changes to groundwater levels (from both 2D and 3D modelling) for all sectors is given in Table 2.

Table 2: Summary of Drawdown Effects

Wetland/ Offset Storage Area/ Section	*Drawdown Up to (m)	Mounding Up to (m)	*Extent of Effect Up to (m)
Wetland OA	0.5	-	< 20 - 40
Offset storage area 2, 3A and wetland 3	0.5	-	200 - 300
Embankment construction between offset storage area 2 and 3 - Wetland 5	0.2	-	immediately adjacent
	< 0.05	-	down gradient
	-	0.2	immediately adjacent
	-	<0.05	10 – 20 up gradient
Embankment construction (general)	0.5		Immediately adjacent
	<0.1		50 – 70
Wetland 5	0.2	-	immediately adjacent
	0.1	-	25
Offset storage area 6	0.1	-	50 - 100
Wetland 8	0.5	-	immediately adjacent
	0.1	-	50 – 100
Offset storage area 9A	0.1	-	immediately adjacent
Wetland 9	0.3	-	immediately adjacent
	0.1	-	20 - 30
Wetland 10	0.2	-	immediately adjacent
	0.1	-	50 - 100
Offset storage area 13 and 13A	0.2	-	immediately adjacent
	0.15	-	up to 600
	< 0.05	-	up to 1,600

7. Monitoring and mitigation of effects

Monitoring of groundwater levels, ground surface elevations (settlement) and surface water flows will be undertaken to confirm the results of predictive modelling and to refine models if early monitoring indicates that actual behaviour is different to that predicted.

Monitoring will also serve as a trigger to initiate more comprehensive monitoring and / or implementation of mitigation measures if necessary. Potential mitigation options are described in Section 6.2.

The proposed monitoring and mitigation options are set out in CEMP Appendix I, Volume 4.

7.1. Monitoring

A monitoring programme will be required to record groundwater effects and trigger appropriate responses. A draft groundwater monitoring programme (GWMP) has been prepared as part of the CEMP, Volume 4 and will include a combination of the following:

- Standpipe piezometers (single and paired) in proximity and at distance from the proposed Expressway to monitor changes in groundwater levels as set out in Appendix A of the GWMP;
- Baseline monitoring data taken in advance of works to obtain seasonal and annual variations (this has been underway since November 2010 and it is recommended that this continue in the existing and new installations until construction begins);
- Flow meters or continuous flow monitoring of the Wharemauku Stream upgradient and down gradient of proposed storage areas 2 and 3A and wetland 3 to check modelled losses and gains and provide additional data for groundwater model calibration at detailed design;
- Monitoring of key indicators of mobile contaminants in selected bores down gradient and below landfills (as detailed in CEMP Appendix K, Volume 4);
- Monitoring of spring flows at Te Puna o Rongomai;
- Establishment of various trigger levels (Alert and Action) with appropriate remedial action plans; and
- A system of review to determine at what stage after construction monitoring can be reduced or cease.

7.2. Mitigation

The following strategies have been used in the proposed Expressway design to mitigate potential effects on groundwater:

- Lining and other refinements to the design of large storm water devices where they require a permanent lowering of the water level of more than 0.5 m below the existing water table and modelling indicates potentially deleterious effects on the environment;
- Optimisation of construction activities e.g.:
  - A larger number of construction water take wells, spread out along the Alignment each taking a small volume at different times depending on the construction programme, rather than fewer wells pumping continuously at a higher rate;
  - Limiting the open length of excavation to reduce the area and period of any dewatering; and
  - Use of the starter layer in embankment construction as a drainage blanket to limit damming effects up-gradient of surcharged peat.

The following strategies are commonly used during the construction phase of works, and one (or a combination) of these strategies could be considered to reduce the amount of drawdown and associated effects should maximum consented drawdowns be exceeded. The method selected will be dependent on the nature, extent and location of the exceedance.

i. Monitor groundwater elevation, flow and quality and respond appropriately;

ii. Alter the excavation methodology to reduce the period of time that excavations are drained;

iii. Alter the peat treatment methodology to balance drawdown / damming effects;

iv. Use active drainage measures beneath embankments (e.g. pipe) to facilitate flow through the embankment;

v. Redirection of treated surface water to wetlands or surface water bodies;

vi. Where private water supply wells are affected, water from the construction wells could be tankered to users, or it might be necessary to deepen the well to increase the available drawdown;

vii. Controlled recharge of groundwater to limit the amount of drawdown.

Appropriate mitigation method(s) would be selected by the Project Team[1] at the time that the need for mitigation was identified.

8. Summary and Conclusions

Numerical groundwater modelling has been undertaken in order to provide an assessment of effects on the existing groundwater regime associated with the short term construction and long term operation of the proposed Expressway.

The groundwater regime consists of a series of interbedded aquifers and aquitards creating a leaky, unconfined to semi-confined aquifer system. The near surface hydrogeology is dominated by Holocene dune sands, with areas of peat (which support wetlands of high ecological value) developed in the lower lying areas between dunes. The construction of the proposed Expressway has the greatest potential to affect the shallow groundwater system (i.e. the Holocene sand and peat).

Construction of the embankments, stormwater devices and cuts associated with the proposed Expressway is likely to result in changes (lowering or rise) to the existing groundwater level. The results of numerical modelling suggest that overall:

- The proposed Expressway embankment (and associated peat treatment) will result in small (generally 0.3 m but up to 0.5 m) long term changes to groundwater levels and flow directions immediately adjacent to the proposed Expressway, with no discernible change (< 0.1 m) in groundwater levels, flow directions or aquifer through flow at a distance of 50 m to 70 m;
- Where stormwater devices are constructed at the approximate groundwater level there will be no discernible changes to groundwater levels, flow directions or aquifer through flows; and
- Where stormwater devices are constructed below or above the existing groundwater level, and are lined to reduce seepage, they are likely to result in small (< 0.3 m) changes to groundwater levels and flow directions immediately adjacent to the devices, reducing to no discernible changes in groundwater levels, flow directions or aquifer through flow beyond a distance of 50 m;
- Construction in the vicinity of the Otaihanga Landfill will result in only small changes in groundwater level and have no noticeable effect on groundwater gradients and flows. Therefore changes in contaminant migration from the landfill as a result of proposed Expressway construction are considered negligible;

[1] This Technical Report refers to the Project team as carrying out works on behalf of and as contracted by the NZTA. The NZTA is the requiring authority and the consent holder.

- Abstraction of water from construction water supply wells is likely to result in changes in groundwater level of less than 0.7 m in the shallow groundwater system close to the wells, with very small associated changes in flow directions and aquifer through flow in the vicinity of the wells. Such changes will be limited to the construction period (4 years).

Given the small scale, magnitude and extent of changes identified it is considered unlikely that these would result in adverse environmental effects.

A monitoring programme will be established prior to construction to record natural variations in groundwater levels and surface water flows. This monitoring will allow appropriate responses to be triggered should actual effects differ from those predicted. Overall, the effects of the Project on groundwater are considered to be less than minor, with a number of readily available and widely used mitigation options available to manage unexpected effects, should they occur.

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10. Glossary

Where given *italic text* provides an example of the term in the context of the Project.

Anisotropy	Having variations in physical properties that differ dependent on the direction of measurement, i.e. *horizontal permeability being greater than vertical permeability*. Opposite of isotropy.
Aquifer	A geologic formation that contains sufficient saturated material to yield water *i.e. Waimeha Gravels*
Aquitard	A geologic formation that contains water (is saturated) but does not readily yield water. An aquitard may transmit appreciable water to or from adjacent aquifers i.e. *Regression Alluvium*
Interbedded	Describes a geological formation or unit that is comprised of multiple beds or layers
bgl	Abbreviation for below ground level.
Borehole	Hole (nominally 65 mm to 150 mm in diameter) drilled into the ground to allow assessment to be made of characteristics of the soil and rock encountered. Returns a cylindrical soil or rock sample (known as core) to the surface for examination. Typically vertical, but can be inclined or horizontal in order to target specific depths / units.
Calibration	A comparison between measurements or values. *For the context of this report describes the comparison between observed/ tested measurements/values and those predicted by the numerical modelling.*
Compressible	A geological unit whose volume and/or structure can change in response to changes in applied pressure (due to additional load at surface or reduction in groundwater level) *i.e. Holocene Peat.*
Dewatering	The removal of water from the soil / rock to reduce flow rate and diminish pressure in order to allow construction to proceed in the

	dry. *In the context of this report, refers to the allowance of water to seep in to the open face, be collected in a sump and pumped out of the excavation for disposal.*
Drawdown	The lowering of groundwater level due to pumping of a well *or in the context of this Project dewatering of an excavation.*
Flow gauging	The measurement of the total (from all sources) volume of water flowing in a river channel
GWL	Abbreviation for groundwater level.
Homogeneous	Of uniform structure or composition throughout *i.e. assumes that material properties such as hydraulic conductivity are constant throughout a unit*. Opposite of heterogeneous.
Hydraulic Conductivity	The measure of a soil or rocks ability to transmit a specific fluid. Unlike permeability this value **is dependent** on fluid viscosity and density. *For the context of this Project refers to a unit's ability to transmit water*. Given as the cubic metres of water per second, that will transmit through 1 m^2 (i.e. $m^3/s/m^2$ or m/s)
Hydraulic Conductivity test	refer to **slug test**
Hydrogeological	Relating to groundwater and the occurrence, movement and properties of water in the ground.
Hydrogeological unit	One (or many) geological formations with a distinct set of hydrogeological properties (i.e. hydraulic conductivity, storativity) which distinguish it from another formation.
In-situ	In natural or original position / place. *In the context of in-situ testing refers to testing of soil or rock as it is in the ground, as opposed to removing a sample and testing in the laboratory.*
Lining	A very low permeability layer used to limit groundwater seepage out of an excavation.

Long Term	Permanent condition (post construction)
Negligible	No discernable effect when compared to natural baselines.
Orders of magnitude	An estimate of a size or magnitude expressed as a power of 10, used to express the comparative scale between two parameters.
Perched water level	An unconfined ground water body sitting on top of an impermeable (unsaturated) or poorly permeable (partially to fully saturated) formation. *For the context of this Project used to describe elevated water levels in the peat*.
Permanently	*For this Project refers to the long term, final condition or structure, i.e. post construction, operational etc.*
Permeability	The intrinsic ability of a material (natural or man-made) to transmit fluid, usually a function of grain size and pore space between grains, independent of type of fluid *i.e. a coarse grained soil such as gravel will more readily transmit any type of fluid then a dense, compacted silt*
Piezometer	A permanent hole / installation in the ground designed to measure the groundwater level. Typically designed to allow the water to only enter from a particular depth or unit (not the full length of the hole).
Rising head test	A type of in-situ hydraulic conductivity test (or slug test) whereby water is removed from a borehole and the recovery of the water level back to static water level is observed allowing an assessment of the hydraulic conductivity of the soil / rock to be made.
Screened interval / unit	Refer to **standpipe piezometer**.
Small (effects)	Effects that could be discernable above day-to-day variations, but too small to adversely affect other persons or the environment.
Settlement	Gradual subsidence of the ground or a structure due to compression

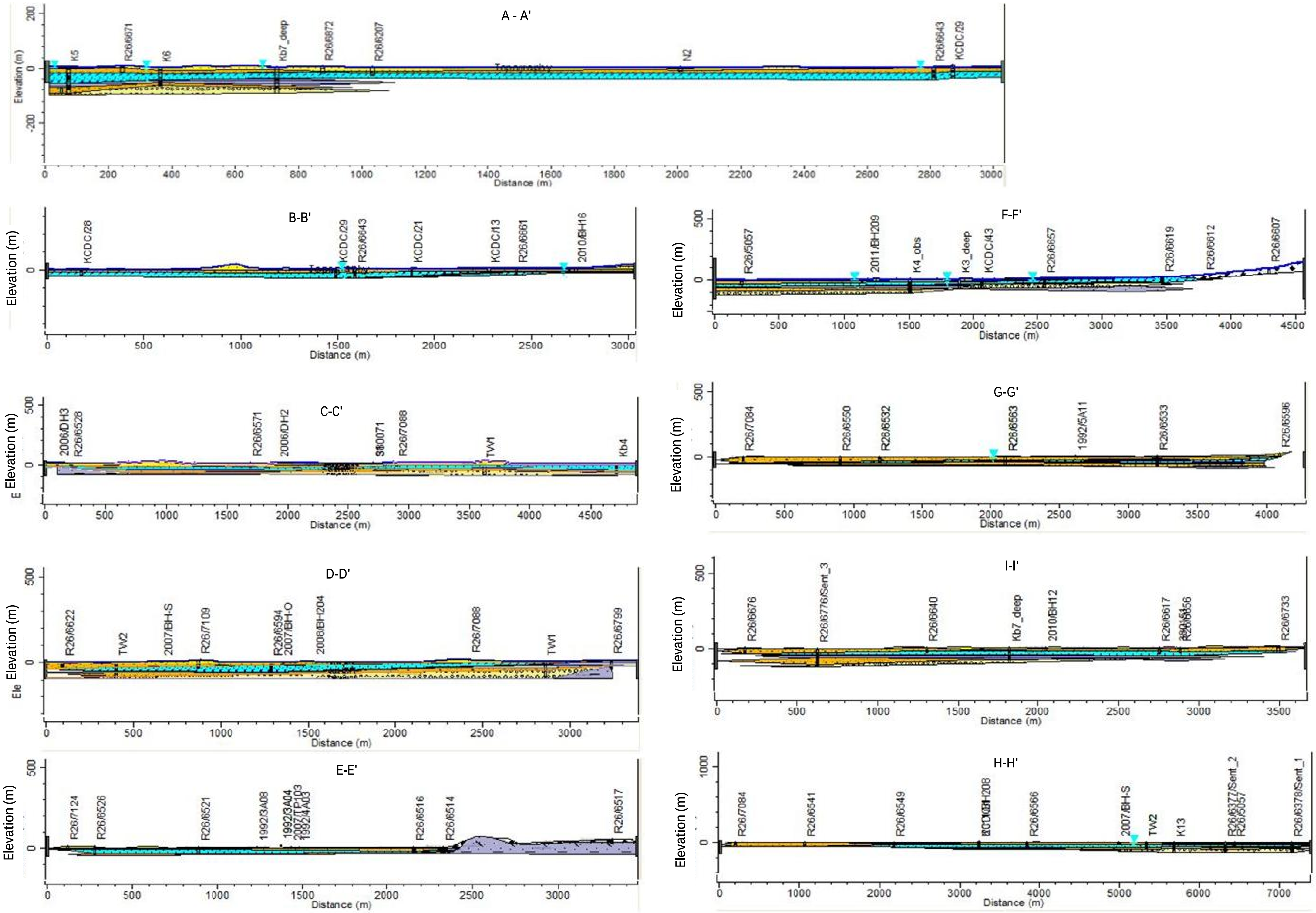
	of the soil.
Short Term	For this Project refers to the period of construction (4 years)
Slug test (hydraulic conductivity test)	A type of groundwater test undertaken "in-situ" i.e. in a borehole or piezometer. Involves the removal or addition of a "slug" (volume) of water. Observations of the recovery back to static water level allow an assessment of the hydraulic conductivity of the soil / rock exposed in the borehole or piezometer to be made.
Stand pipe piezometer	A type of piezometer comprising a length of (typically, and for the purposes of this Project) narrow diameter PVC pipe installed in a bore hole. Over a limited depth the PVC is slotted (i.e. has holes) so that water from the ground can enter into the pipe from that depth / unit; this is referred to as the screen / screened interval / screened depth.
Static water level	The naturally occurring level of groundwater within a borehole or piezometer.
Storativity	The volume of water an aquifer releases from (or takes into storage) for a particular area and change in water level i.e. a measure of how readily a formation will dewater. A dimensionless ratio, always less than 1.0.
Temporarily	*For this Project refers to the short term (< 5 year) construction condition.*
Transmissivity	The rate at which water is transmitted through a unit width of aquifer under a given hydraulic gradient. Given as cubic metres of water per day transmitted through a vertical section of aquifer 1 m wide (i.e. m^2/d). To convert to hydraulic conductivity, divide by the thickness of the aquifer.

Appendix 21.A

Ground Model

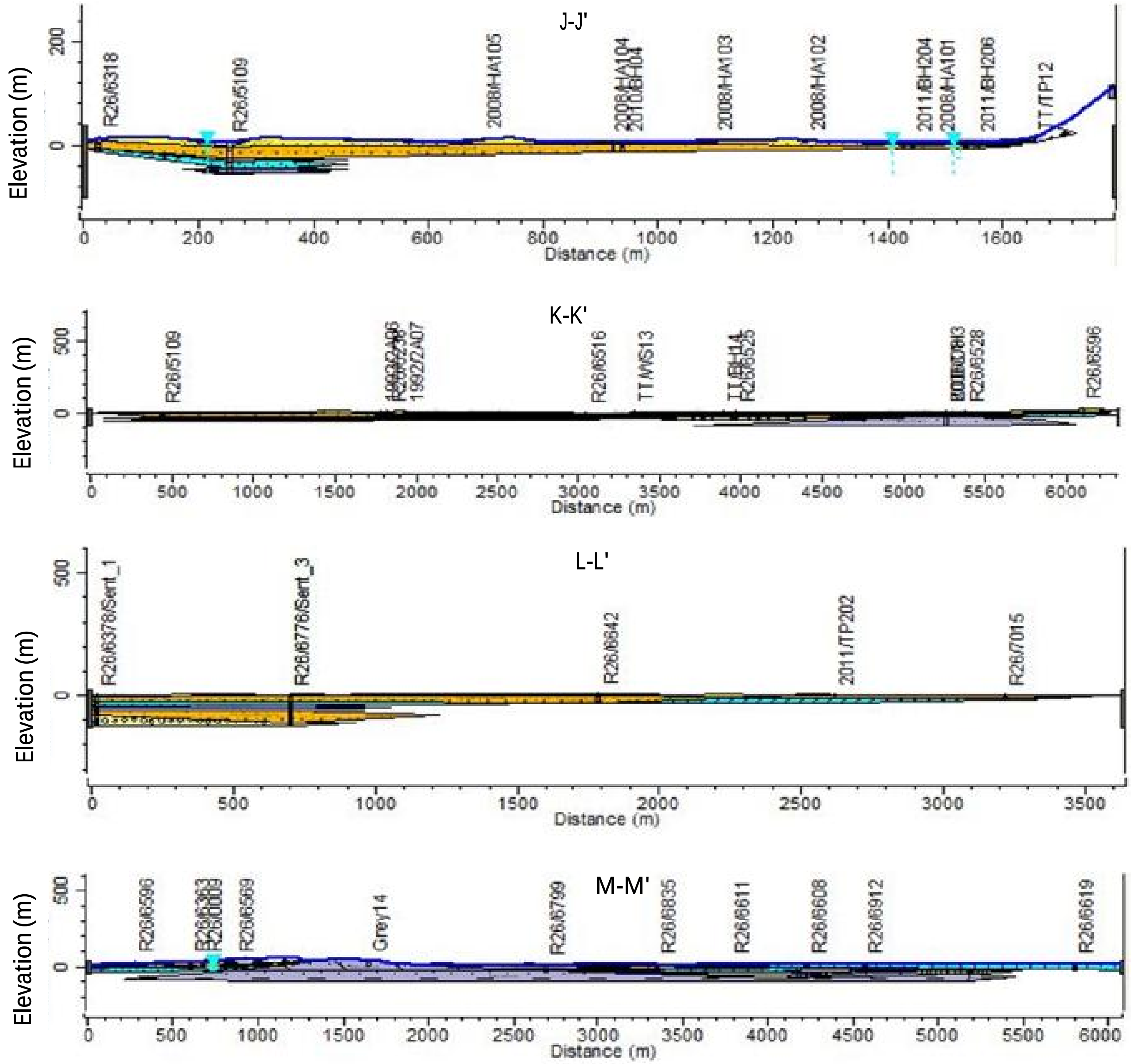
Cross Section Plan

Figure A1



Natural Scale

Figure A2



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3320901/500/010

Natural Scale

Figure A2

Appendix 21.B

Groundwater Level Data

Appendix B – Groundwater level data

B1. Groundwater Level Data

Interpolated regional groundwater levels are contoured in Figures B1 and B2. The contours consider data from two key sources; Greater Wellington Regional Council (GWRC) monitoring stations within the Waikanae Groundwater Zone and 54 No. piezometers installed historically and recently along the Expressway alignment.

B1.2 Greater Wellington Regional Council

The GWRC monitoring stations are spread throughout the Waikanae area and within the different aquifers (well depths ranging from 5 m to 122 m bgl). Water levels in all wells have been monitored since 2005, with some records starting as early as 1994, and so the well hydrographs provide a valuable record of long term trends in groundwater levels. A summary of available hydrograph data is given in Table B1.

Table B1 - Summary of Hydrograph Data

GWRC Bore No.	Depth [m BGL]	Recording start	Comments
R26/6831	9	March 2001	
R26/6833	9	April 2001	
R26/6916	21	August 1994	
R26/6566	79	February 2005	
R26/6284	90	July 2003	
R26/7025	5	November 2005	
R26/6886	6	November 2005	
R26/6287	6	December 2002	
R26/6673	38	February 2005	Recordings suggest regular pumping nearby
R26/6991	5	November 2005	
R26/6992	7	November 2005	
R26/6378	122	September 2006	General increase in water level since recording started

The hydrographs show a seasonal variation with the lowest water levels typically recorded in April (end of summer) and the highest water levels recorded in October (end of winter). Water levels in the shallow bores appear to remain generally constant from year to year.

Comparison with rainfall records recorded at the Waikanae Treatment Plant indicates that changes in water level in the shallow unconfined aquifers have a strong correlation with rainfall events, suggesting that the shallow aquifer responds rapidly to rainfall recharge. This is supported by moisture balance modelling carried out by Gyopari (2005).

B1.3 Site Specific Piezometers

54 No. piezometers have been installed as part of recent and historic investigations. These piezometers are located along the Expressway alignment and target the key shallow hydrogeological layers.

A programme of regular water level monitoring has been established since October 2010. Some irregular monitoring of older installations has occurred since 2007. These detailed short term records correlate well with the longer term records from GWRC and show the lowest water levels typically occurring between February and April (end of summer) and the highest water levels recorded in October (end of winter). Seasonal variations tend to range between 0.3 and 0.8 m.

B2. Groundwater Gradients and Levels

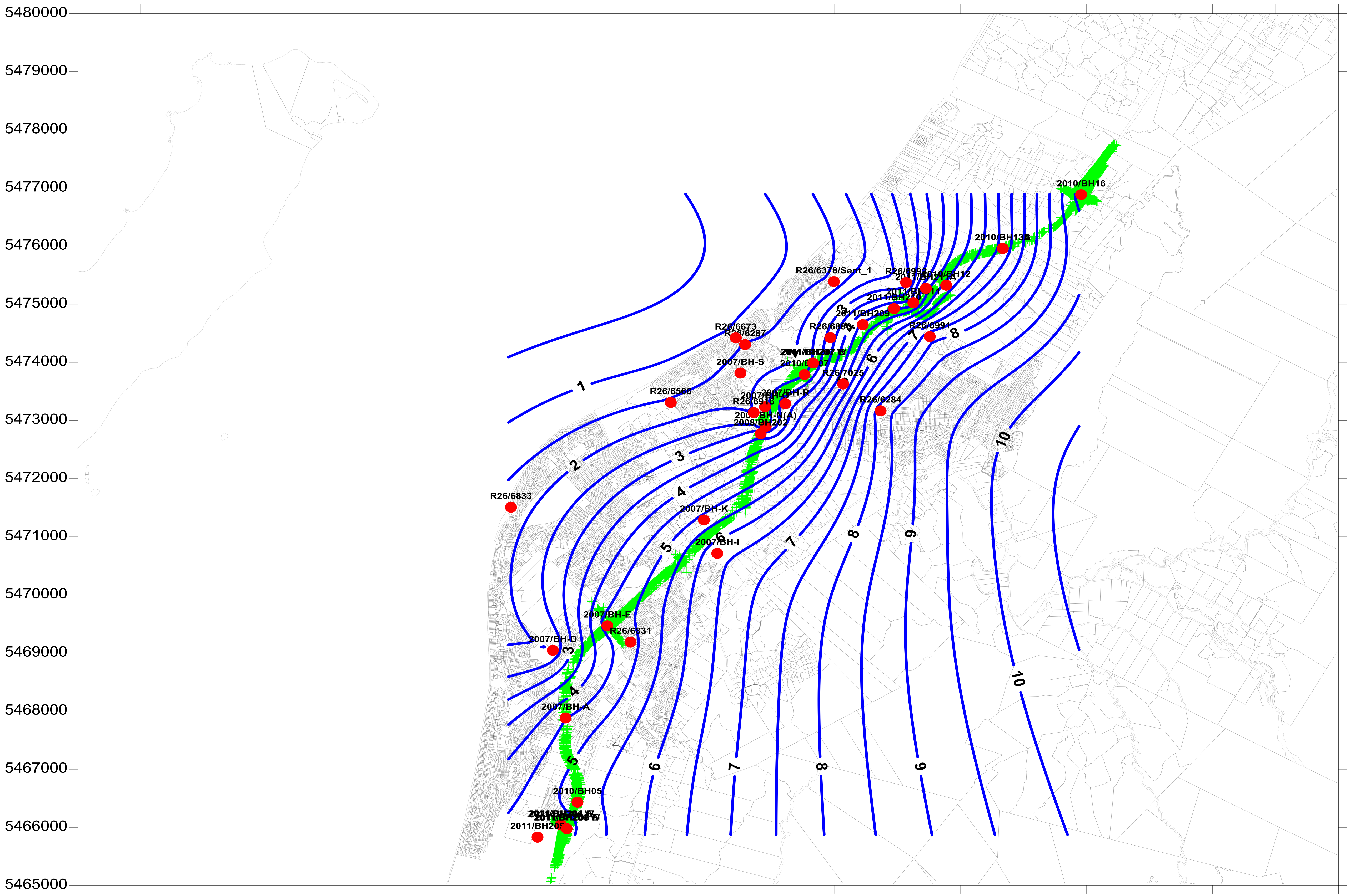
The data indicates that the main groundwater flow direction is from the foothills in the east towards the coast in the west. The groundwater flow direction is roughly WNW, approximately perpendicular to the Expressway (Figure B1 and B2).

The groundwater gradient is approximately 1:500 through sectors 1 to 3 of the alignment. Near the northern end of the alignment (sector 4) a steeper gradient of 1:250 is inferred, and may be due to the rise in the level of the greywacke basement in this area.

Under average conditions the groundwater level is very close to (< 0.3 m bgl) or at the surface in a number of areas resulting in natural wetlands. The interaction between groundwater and surface water in these wetlands is not well understood due to a paucity of longer term monitoring data within them. Where information is available (for Te Harakiki and Te Hapua wetlands) it appears that both recharge and discharge wetlands occur within this area (Allen, 2010 and Law, 2008).

High groundwater levels also result in areas of residential flooding. For some of these areas (for example Rata Rd, near Wharemauku Stream and Puriri Road, near El Rancho), there is anecdotal evidence and reports from land owners that the groundwater level (GWL) is at or near the surface year round.

Piezometer pairs have been installed in order to assess the potential for vertical (upward or downward) gradients. At CH16000 (near the Peka Peka interchange) a series of piezometer pairs installed as part of a peat excavation trial indicate that the GWL in the peat tends to be 0.05 m to 0.2 m higher than that in the underlying sand. GWLs in the sand are however also elevated being just 0.1 m to 0.3 m below the ground surface



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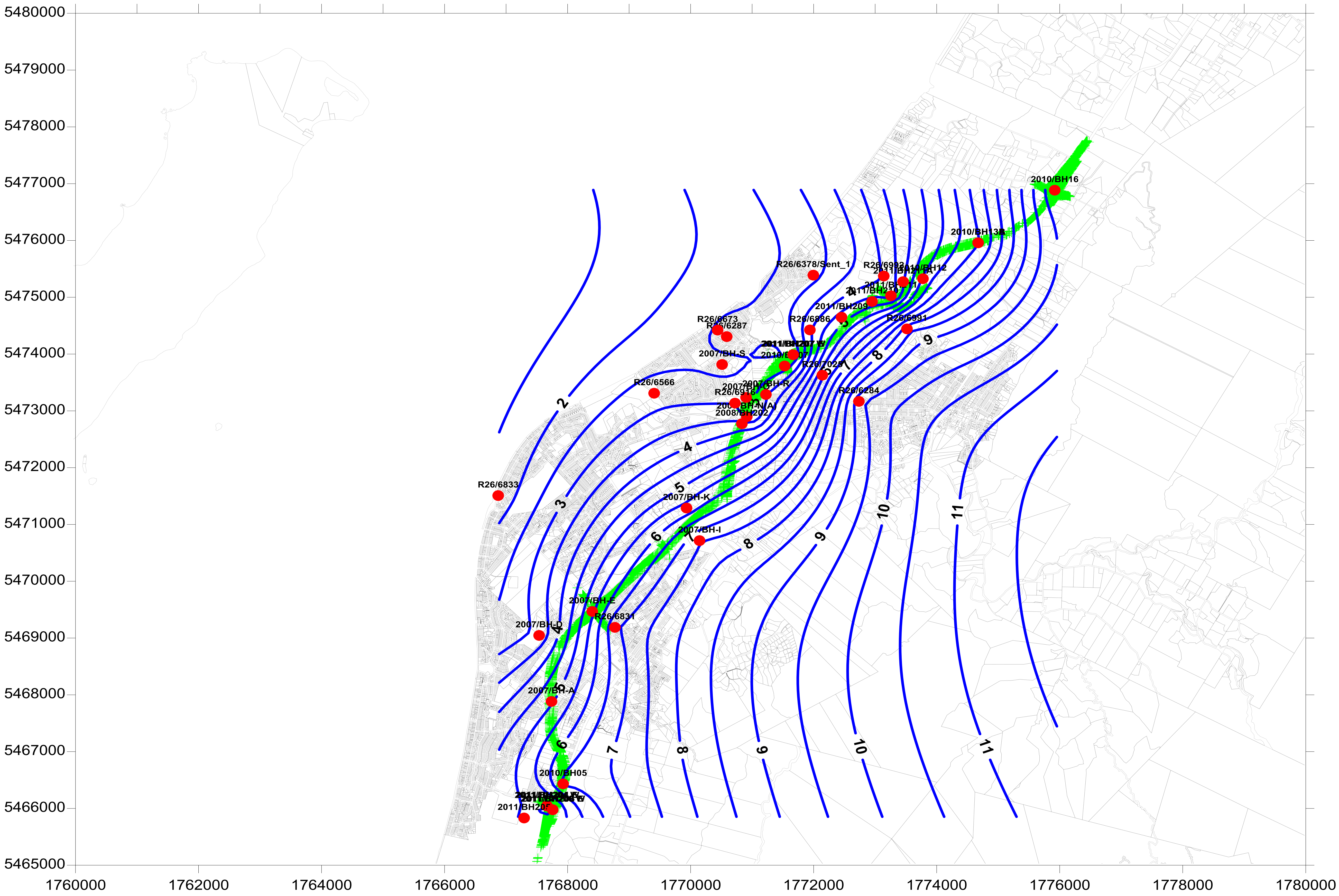
Minimum Interpolated Groundwater Levels

Figure B1

3320901/500/010



MacKays to Peka Peka

3320901/500/010

Maximum Interpolated Groundwater Levels

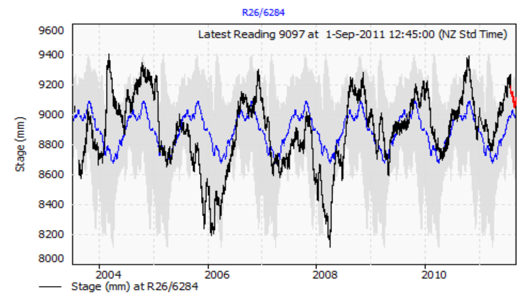
Figure B2

Taken directly from www.gw.govt.nz

R26/6284

Located in the Waikanae groundwater zone and is approximately 90m deep. This site has been operating since July 2003.

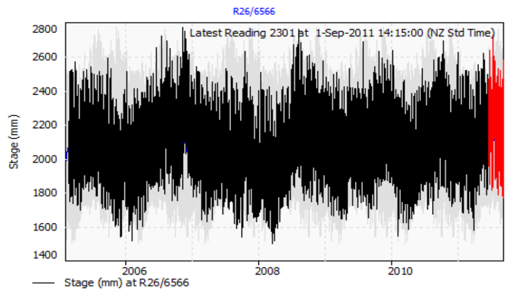
From 01/07/2003 15:57 To 01/09/2011 15:57 Go



R26/6566

Located in the Waikanae groundwater zone and is approximately 79m deep. This site has been operating since February 2005. The site is owned by Kapiti Coast District Council, groundwater temperature and conductivity are also measured at this site.

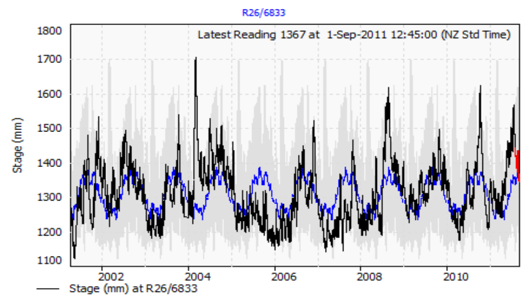
From 01/02/2005 16:00 To 01/09/2011 16:00 Go



R26/6833

Located in the Waikanae groundwater zone and is approximately9m deep. This site has been operating since April 2001.

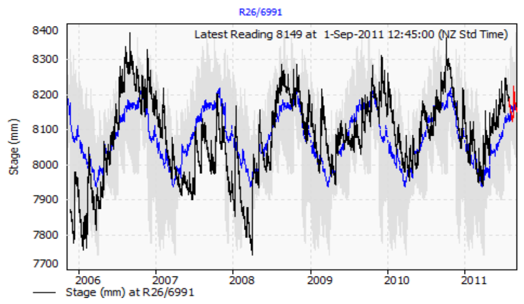
From 01/04/2001 15:51 To 01/09/2011 15:51 Go



R26/6991

Located in the Waikanae groundwater zone and is approximately 5m deep. This site has been operating since November 2005.

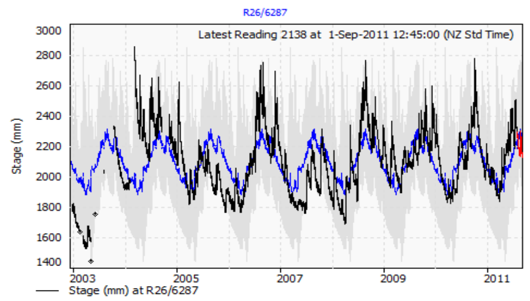
From 01/11/2005 15:53 To 01/09/2011 15:53 Go



R26/6287

Located in the Waikanae groundwater zone and is approximately 6m deep. This site has been operating since December 2002.

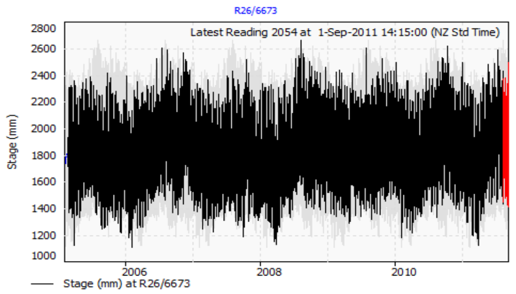
From 01/12/2002 15:57 To 01/09/2011 15:57 Go



R26/6673

Located in the Waikanae groundwater zone and is approximately 38m deep. This site has been operating since February 2005. The site is owned by Kapiti Coast District Council, ground water temperature and conductivity are also measured at this site.

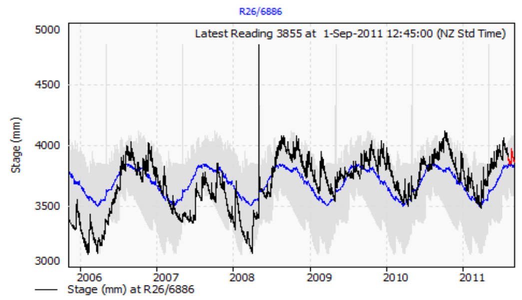
From 01/02/2005 16:01 To 01/09/2011 16:01 Go



R26/6886

Located in the Waikanae groundwater zone and is approximately 6m deep. This site has been operating since November 2005. The site is owned by the Kapiti Coast District Council.

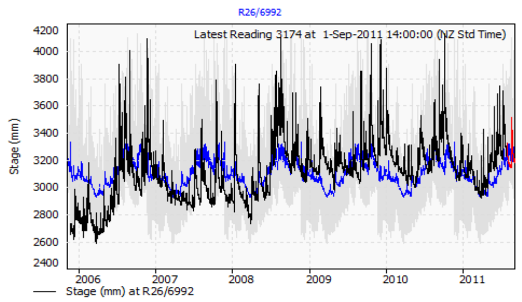
From 01/11/2005 15:51 To 01/09/2011 15:51 Go



R26/6992

Located in the Waikanae groundwater zone and is approximately 7m deep. This site has been operating since November 2005. The site is owned by Kapiti Coast District Council.

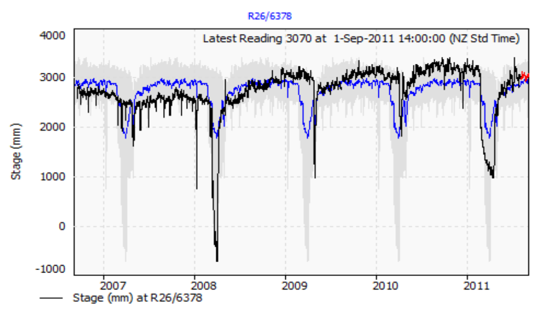
From 01/11/2005 15:53 To 01/09/2011 15:53 Go



R26/6378

Located in the Waikanae groundwater zone and is approximately 122m deep. This site has been operating since September 2006. This site is owned by Kapiti Coast District Council, ground water temperature and conductivity are also measured at this site.

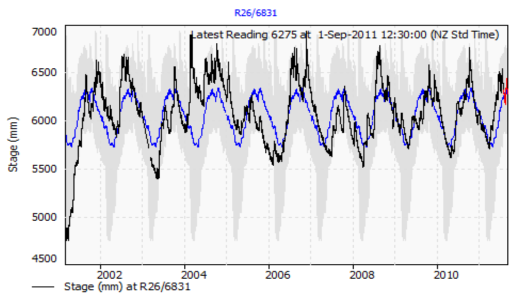
From 01/09/2006 15:58 To 01/09/2011 15:58 Go



R26/6831

Located in the Waikanae groundwater zone and is approximately 9m deep. This site has been operating since March 2001.

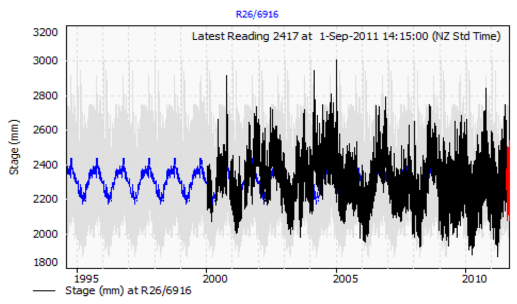
From 01/03/2001 15:42 To 01/09/2011 15:42 Go



R26/6916

Located in the Waikanae/Raumati groundwater zone and is approximately 21m deep. This site has been operating since August 1994.

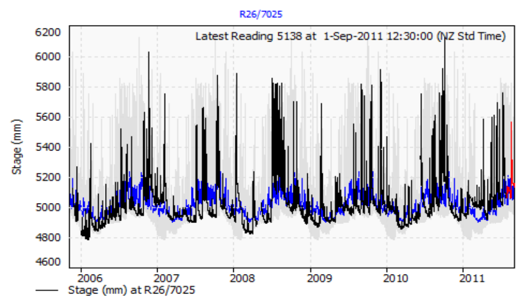
From 01/08/1994 15:52 To 01/09/2011 15:52 Go



R26/7025

Located in the Waikanae groundwater zone and is approximately 5m deep. This site has been operating since November 2005. The site is owned by the Kapiti Coast District Council.

From 01/11/2005 16:01 To 01/09/2011 16:01 Go



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MacKays to Peka Peka

GWRC Hydrographs

Bore ID				Depth to Screen		Screen RL	
Borehole no.	Borehole RL (m)	Comments	Material Type	Top of Screen (m)	Bottom of Screen (m)	Top of Screen (m)	Bottom of Screen (m)
BH-A	21.76		Sand/ Gravel	26	29	-4.24	-7.24
BH-B	5.06		Gravel	10	13	-4.94	-7.94
BH-C	4.84		Sand	12	15	-7.16	-10.16
BH-D	3.28		Sand	7	10	-3.72	-6.72
BH-E	11.11		Sand	7	10	4.11	1.11
BH-I	9.7		Sand/ Gravel	6	9	3.7	0.7
BH-J	6.29		Sand	4	7	2.29	-0.71
BH-K	6.2		Sand	7	10	-0.8	-3.8
BH-L	3.68		Sand	10	13	-6.32	-9.32
BH-M	3.64		Gravel	1.5	4.5	2.14	-0.86
BH-N	10.03		Sand	5	8	5.03	2.03
BH-N(A)	3.36		Sand	6	9	-2.64	-5.64
BH-O	2.91		Sand	10	13	-7.09	-10.09
BH-Q	25.73		Sand	27	30	-1.27	-4.27
BH-R	4.14		Sand	7	10	-2.86	-5.86
BH-S	4.62		Sand	7	10	-2.38	-5.38
BH-T	8.03		Sand	7	10	1.03	-1.97
BH-U	6.12						
BH-V	7.3		Sand	6	9	1.3	-1.7
BH202	13.5		Sand	9.5	12.5	4	1
BH204	13		Sand	18.8	21.8	-5.8	-8.8
BH205	3.3		Sand	6.4	9.4	-3.1	-6.1
BH04	8.166		Gravel/ Sand	5.5	15.5	2.666	-7.334
BH05	8.096		Gravel	3.5	12.15	4.596	-4.054
BH07	3.589		Gravel/ Sand	2.5	15	1.089	-11.411
BH12	8.557		Sand	1.8	15	6.757	-6.443
BH13A (s)	7.152		Sand	3	14.5	4.152	-7.348
BH13B (n)	7.152		Sand	0.3	1.4	6.852	5.752
BH16	11.307		Sand	5.5	15	5.807	-3.693
2010/CPT14							
2011/BH203							
2011/BH204 E	5.827		Gravel	6	9	-0.173	-3.173
2011/BH204 W	5.827		Peat	1	2.5	4.827	3.327
2011/BH205	8.453		Peat	2.5	5.5	5.953	2.953
2011/BH206 E	6.066		Gravel	6	9	0.066	-2.934
2011/BH206 W	6.066		Peat	1	3	5.066	3.066
2011/BH207 E	5.14		Gravel	20	23	-14.86	-17.86
2011/BH207 W	5.14		Gravel	5	8	0.14	-2.86
2011/BH208	21.65		Sand	19	21	2.65	0.65
2011/BH209	10.95		Sand	17	20	-6.05	-9.05
2011/BH210	8.59		Sand	17	20	-8.41	-11.41
2011/BH211	7.48		Sand	15	18	-7.52	-10.52
2011/BH211A	9.24		Sand	14	20	-4.76	-10.76
2011/BH213 S /2011/BH404 S	4.8	RL estimated from LiDAR	Sand	5	6	-0.2	-1.2
2011/BH213 N /2011/BH404 N	4.8	RL estimated from LiDAR	Gravels	9	10	-4.2	-5.2
2011/BH214 /2011/BH406		RL estimated from LiDAR	Sand	9.5	10.5	-9.5	-10.5
2011/BH215 /2011/BH702	4	RL estimated from LiDAR	Sand	9	10	-5	-6
2011/BH803	10	RL estimated from LiDAR	Gravel	16	17.5	-6	-7.5

2011/WM2			Peat				
2011/WM4			Peat				
2011/WM5			Peat				
2011/WM8			Sand				
2011/WM9			Sand				
2011/WM10							

Bore ID	Historic GW Level (m). (measured water depth below ground level)																		
Borehole no.	30/01/07	08/02/07	12/02/07	15/02/07	22/02/07	26/02/07	28/02/07	07/03/07	09/03/07	24/04/07	21/08/07	12/10/07	17/01/08	14/08/08	8/10/08	12/11/08	12/02/09	5/05/09	21/08/09
BH-A	18.9									17.3	17.3		17.5	16.9	16.8	16.8	17.9	17.3	17.4
BH-B		0.5								0.6			0.0						
BH-C		2.1								1.9	1.4		1.8	1.1	1.3	1.4	1.9	1.7	1.5
BH-D		1.3								1.7	1.3		1.4	0.8		1.2	1.8	1.3	1.3
BH-E		5.8								6.3	*6.3*		6.2	5.7		5.9	6.6	5.2	6.2
BH-I										3.2	*2.9*		3.6	3.1		3.2	4.0	3.4	3.3
BH-J			0.5							0.6	0.4		0.6	0.1		0.2	1.1	0.4	0.4
BH-K										1.2		0.8	1.0	0.4		0.6	0.9	1.1	0.9
BH-L					0.5					1.0	0.8		0.1	0.3		0.6	1.4	1.0	0.9
BH-M								1.5				1.7	2.1	0.9		1.9	1.7	2.0	2.2
BH-N							Dry	1.7		Dry		7.3	Dry	7.0	7.3	7.1	7.3	7.4	7.5
BH-N(A)										0.8		0.9	1.3	0.5	0.8	1.2	0.9	1.3	1.3
BH-O						0.3				0.6	0.2		0.4	0.1	0.2	-0.1		0.5	
BH-Q										23.5	23.4			23.2		23.1	23.9	23.9	23.6
BH-R				1.1						2.5		2.4	0.9	0.5		0.2	0.4	0.8	0.8
BH-S			0.9							1.0		0.7	2.6	2.3		2.4	2.5	2.5	2.5
BH-T							2.5				2.8		3.0	2.4		2.4		3.0	2.9
BH-U							1.9			1.9	1.8		1.9	1.5		1.0		1.9	1.9
BH-V									0.6		-0.1		1.0	0.6		0.7	1.3	1.0	0.8
BH202													10.3	9.7		9.9	10.1	10.2	10.2
BH204													8.9	8.9		8.9	8.9	9.0	8.9
BH205													0.4	0.0	0.1	0.2	0.8	0.3	0.3
BH04																			
BH05																			
BH07																			
BH12																			
BH13A (s)																			
BH13B (n)																			
BH16																			
2010/CPT14																			
2011/BH203																			
2011/BH204 E																			
2011/BH204 W																			
2011/BH205																			
2011/BH206 E																			
2011/BH206 W																			
2011/BH207 E																			
2011/BH207 W																			
2011/BH208																			
2011/BH209																			
2011/BH210																			
2011/BH211																			
2011/BH211A																			
2011/BH213 S /2011/BH404 S																			
2011/BH213 N /2011/BH404 N																			
2011/BH214 /2011/BH406																			
2011/BH215 /2011/BH702																			
2011/BH803																			

2011/WM2																			
2011/WM4																			
2011/WM5																			
2011/WM8																			
2011/WM9																			
2011/WM10																			

Bore ID	GW Level (m) (measured water depth below ground level)																		
Borehole no.	21/10/10	4/11/10	25/11/10	9/12/10	23/12/10	13/01/11	27/01/11	17/02/11	3/03/11	17/03/11	31/03/11	14/04/11	12/05/11	26/05/11	9/06/11	23/06/11	7/07/11	14/07/11	29/07/11
BH-A	16.8	16.8	16.9	17.0	17.0	17.2	17.2	17.2	17.3	17.3	17.3	17.3	17.3	17.3	17.2	17.1		17.0	
BH-B																			
BH-C																			
BH-D	1.0	1.0	1.3	1.3	0.1	1.2		1.2	1.2	1.3									
BH-E	5.7	5.7			6.0		6.1	6.1	6.1	6.2	6.2	6.2	6.2	6.1	6.0	6.4		6.3	
BH-I	2.9						2.2	3.3	3.3	3.4	3.4	3.4	3.3	3.3	3.2	3.1		2.9	
BH-J																			
BH-K	0.5	0.6	0.8	0.9	0.7	1.0	0.9	1.0	1.1	1.1	1.0	1.0	0.8	0.6	0.6	0.5		0.4	
BH-L																			
BH-M																			
BH-N																			
BH-N(A)		1.3	1.2	1.3	1.0	1.3	1.3	1.3	1.3	1.4	1.4			0.6		1.0		0.9	
BH-O		0.2	0.3			0.4		0.6	0.4	0.4	0.4			0.2		0.1		0.1	
BH-Q																			
BH-R		0.8	0.8	0.9	0.7	0.9	0.9	0.8	0.9	0.9	0.9	0.9		0.7	0.7	0.7		0.5	
BH-S		2.3	2.4	2.4	2.4	2.5	2.9	2.5	2.5	2.6	2.5	2.5		2.4	2.4	2.3		2.2	
BH-T																			
BH-U																			
BH-V																			
BH202			10.1	10.1	9.8				10.2										
BH204																			
BH205																			
BH04																			
BH05		2.4	2.5	2.8	2.5	2.5	2.4	2.4	2.5	2.5	2.5	2.5	2.5	2.3	2.0	1.5	1.3		
BH07		0.9	1.0	1.3	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.1	0.8	1.0	1.0	1.0		
BH12		2.6	2.8	2.9	2.7	2.9	2.9	3.0	3.0	3.0	2.9	2.8	2.7	2.6	2.6	2.4	2.4		
BH13A (s)	0.2		0.4	0.5	0.4	0.6	0.5	0.5	0.6	0.6	0.5			0.2		0.2	0.1		
BH13B (n)			0.5	0.6	0.3	0.6	0.5	0.5	0.6	0.6	0.5			0.1		0.1	0.1		
BH16		1.0	1.2	1.4	1.2	1.4	1.4	1.5	1.6	1.6	1.5			1.0		0.8	1.0		
2010/CPT14													1.3	0.3	1.2	1.2			
2011/BH203																			
2011/BH204 E													1.1	1.0	1.0	0.8	0.8		
2011/BH204 W													1.0	0.9	0.9	0.8	0.8		
2011/BH205													3.5	3.4	3.4	3.4	3.4		
2011/BH206 E													1.3	1.2	1.2	1.1	1.1		
2011/BH206 W													0.1	0.1	0.1	0.0	0.0		
2011/BH207 E													2.7		2.6	2.5	2.5		
2011/BH207 W													2.6		2.5	2.5	2.6		
2011/BH208													16.8		16.9	16.9	16.8		
2011/BH209													6.4		6.3	6.2	6.2		
2011/BH210													4.2	4.1	4.0	3.9	3.8		
2011/BH211													3.5	3.2	3.4	3.2	3.2		
2011/BH211A													4.5		4.4	4.2	4.2		
2011/BH213 S /2011/BH404 S																			
2011/BH213 N /2011/BH404 N																		0.9	
2011/BH214 /2011/BH406																		2.3	
2011/BH215 /2011/BH702																			0.8
2011/BH803																			

2011/WM2																			
2011/WM4																			
2011/WM5																			
2011/WM8																			
2011/WM9																			
2011/WM10																			

Bore ID	GW Level (m) (measured water depth below ground level)											
Borehole no.	4/08/11	15/09/11	20/09/11	29/09/11	11/10/11	13/10/11	2/11/11	9/11/11	30/11/11	1/12/11	11/01/12	18/01/12
BH-A	17.0	17.2		17.2			17.1		17.2		17.2	
BH-B												
BH-C												
BH-D												
BH-E	5.9	6.4		6.0			6.0		6.1		6.1	
BH-I	2.9			3.2	3.8		3.0		3.1		3.2	
BH-J					0.6		0.2					
BH-K	0.6	0.7		0.7			0.6		0.8		0.8	
BH-L												
BH-M												
BH-N												
BH-N(A)	1.2					0.6		1.1		1.2		1.2
BH-O	0.2					0.3		0.2		0.3		0.3
BH-Q												
BH-R	0.7	0.8				0.5		0.7		0.8		0.9
BH-S	2.3	2.4				2.4		2.4		2.4		2.5
BH-T												
BH-U												
BH-V					1.1							
BH202												
BH204												
BH205												
BH04												
BH05	1.3	1.4		1.5			1.2		1.7		1.7	
BH07	1.0	1.0				0.8		1.0		1.0		1.0
BH12	2.5					2.5		2.6		2.7		2.8
BH13A (s)	0.2					0.0		0.2		0.3		0.4
BH13B (n)	0.2					0.1		0.1		0.3		0.3
BH16	1.0	1.0				0.7	0.8			1.1		0.8
2010/CPT14				1.2			1.2		1.3			
2011/BH203												
2011/BH204 E	0.9			1.0			0.9		1.0		1.0	
2011/BH204 W	0.9			1.0			0.9		1.0		1.0	
2011/BH205	3.4			3.5			3.4		3.5		3.5	
2011/BH206 E	1.1			1.3			1.2		1.3		1.3	
2011/BH206 W	0.2			0.4			0.1		0.4		0.3	
2011/BH207 E												
2011/BH207 W												
2011/BH208												
2011/BH209												
2011/BH210												
2011/BH211												
2011/BH211A												
2011/BH213 S /2011/BH404 S	0.1			1.1			0.2		0.9		0.3	
2011/BH213 N /2011/BH404 N	0.9			0.3			0.8		0.3		1.1	
2011/BH214 /2011/BH406	2.2			2.4			2.4		2.5			
2011/BH215 /2011/BH702	0.9	0.9				0.7		0.8		0.9		0.8
2011/BH803												

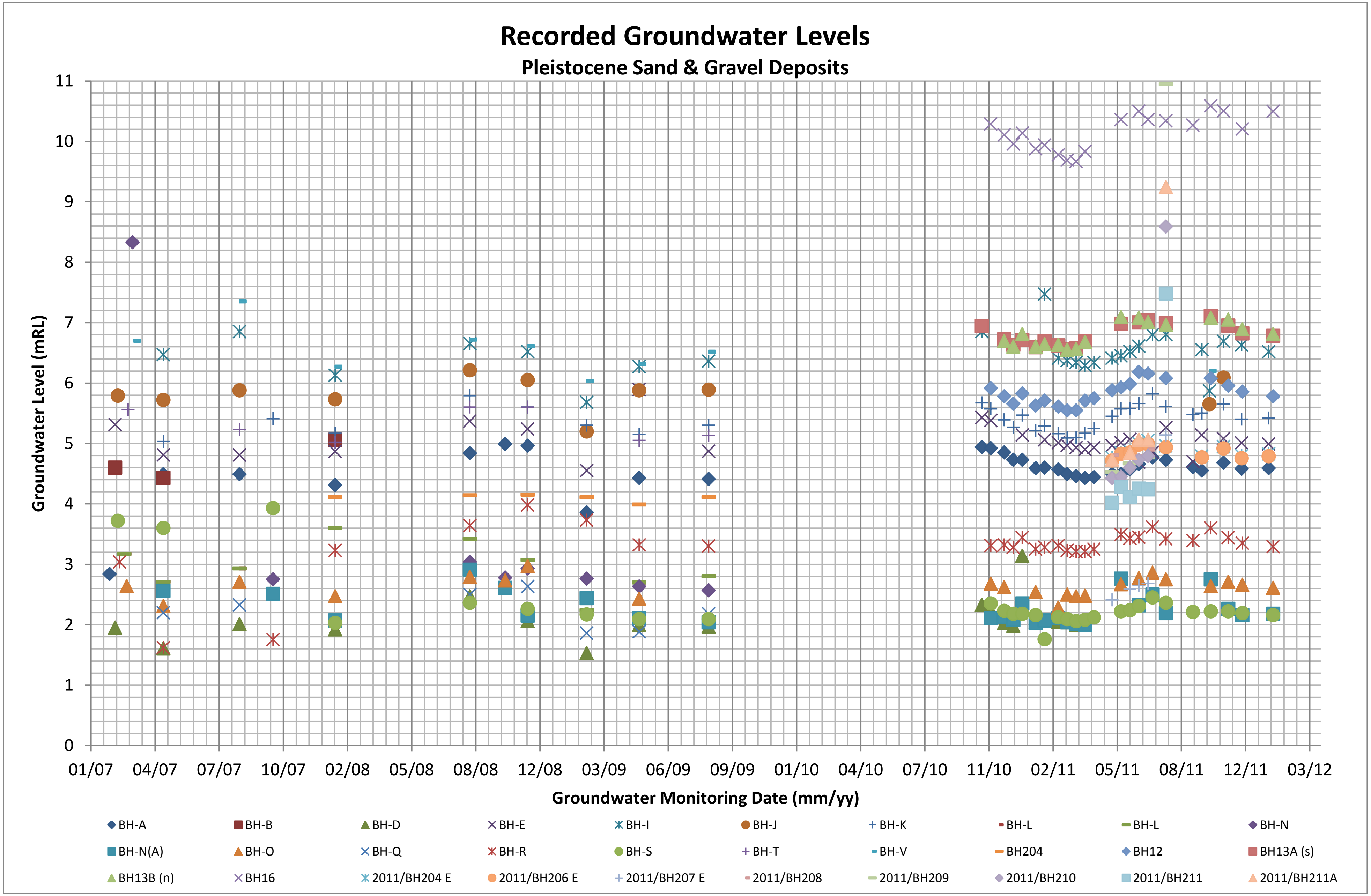
2011/WM2	0.2	0.2	0.2	0.3			0.0		0.1		0.1	
2011/WM4	0.1											
2011/WM5	0.3					0.5		0.0		0.1		0.6
2011/WM8												
2011/WM9	0.1			0.6								
2011/WM10				0.6			0.0		0.5		0.3	

Bore ID	Historic GW Reduced Level (mRL)																		
Borehole no.	30/01/07	08/02/07	12/02/07	15/02/07	22/02/07	26/02/07	28/02/07	07/03/07	09/03/07	24/04/07	21/08/07	12/10/07	17/01/08	14/08/08	8/10/08	12/11/08	12/02/09	5/05/09	21/08/09
BH-A	2.8									4.5	4.5		4.3	4.8	5.0	5.0	3.9	4.4	4.4
BH-B		4.6								4.4			5.1						
BH-C		2.7								2.9	3.4		3.1	3.7	3.5	3.5	3.0	3.1	3.3
BH-D		2.0								1.6	2.0		1.9	2.5		2.1	1.5	2.0	2.0
BH-E		5.3								4.8	4.8		4.9	5.4		5.2	4.6	5.9	4.9
BH-I										6.5	6.9		6.1	6.7		6.5	5.7	6.3	6.4
BH-J			5.8							5.7	5.9		5.7	6.2		6.1	5.2	5.9	5.9
BH-K										5.0		5.4	5.2	5.8		5.6	5.3	5.2	5.3
BH-L					3.2					2.7	2.9		3.6	3.4		3.1	2.2	2.7	2.8
BH-M								2.1				2.0	1.5	2.7		1.8	1.9	1.7	1.4
BH-N								8.3				2.8		3.0	2.8	2.9	2.8	2.6	2.6
BH-N(A)										2.6		2.5	2.1	2.9	2.6	2.2	2.4	2.1	2.0
BH-O						2.6				2.3	2.7		2.5	2.8	2.7	3.0		2.4	
BH-Q										2.2	2.3			2.5		2.6	1.9	1.9	2.2
BH-R				3.0						1.6		1.8	3.2	3.6		4.0	3.7	3.3	3.3
BH-S			3.7							3.6		3.9	2.0	2.4		2.3	2.2	2.1	2.1
BH-T							5.6				5.2		5.0	5.6		5.6		5.1	5.1
BH-U							4.3			4.3	4.3		4.2	4.7		5.2		4.2	4.2
BH-V									6.7		7.4		6.3	6.7		6.6	6.0	6.3	6.5
BH202													3.3	3.8		3.6	3.4	3.4	3.3
BH204													4.1	4.1		4.2	4.1	4.0	4.1
BH205													2.9	3.3	3.2	3.1	2.5	3.0	3.0
BH04																			
BH05																			
BH07																			
BH12																			
BH13A (s)																			
BH13B (n)																			
BH16																			
2010/CPT14																			
2011/BH203																			
2011/BH204 E																			
2011/BH204 W																			
2011/BH205																			
2011/BH206 E																			
2011/BH206 W																			
2011/BH207 E																			
2011/BH207 W																			
2011/BH208																			
2011/BH209																			
2011/BH210																			
2011/BH211																			
2011/BH211A																			
2011/BH213 S /2011/BH404 S																			
2011/BH213 N /2011/BH404 N																			
2011/BH214 /2011/BH406																			
2011/BH215 /2011/BH702																			
2011/BH803																			
2011/WM2																			
2011/WM4																			
2011/WM5																			
2011/WM8																			
2011/WM9																			
2011/WM10																			

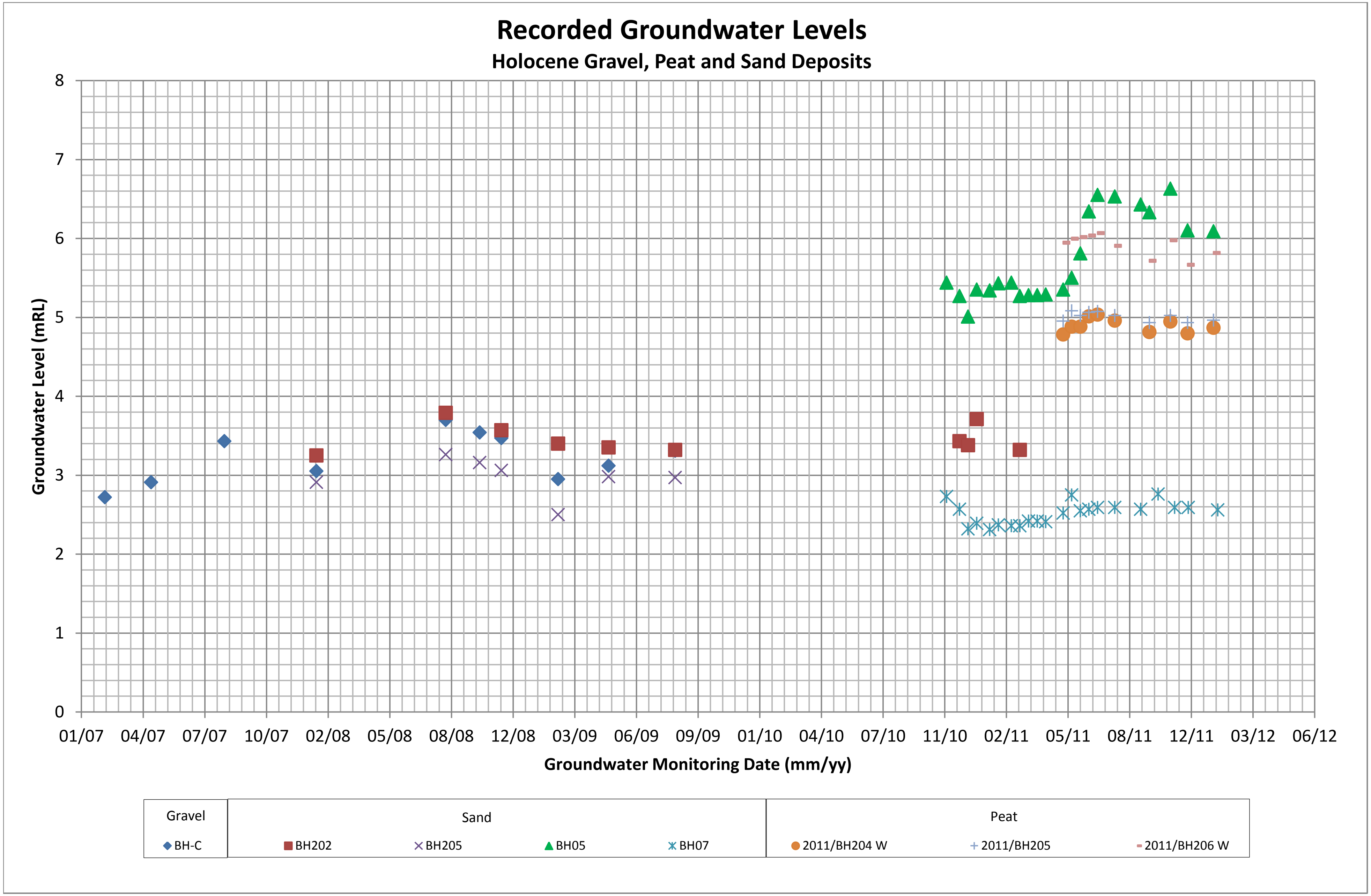
Bore ID	GW Reduced Level (mRL)																		
Borehole no.	21/10/10	4/11/10	25/11/10	9/12/10	23/12/10	13/01/11	27/01/11	17/02/11	3/03/11	17/03/11	31/03/11	14/04/11	12/05/11	26/05/11	9/06/11	23/06/11	7/07/11	14/07/11	29/07/11
BH-A	4.9	4.9	4.9	4.7	4.7	4.6	4.6	4.6	4.5	4.5	4.4	4.4	4.5	4.5	4.6	4.7		4.8	
BH-B																			
BH-C																			
BH-D	2.3	2.2	2.0	2.0	3.1	2.0		2.1	2.0	2.0									
BH-E	5.4	5.4			5.1		5.1	5.0	5.0	4.9	4.9	4.9	5.0	5.0	5.1	4.7		4.9	
BH-I	6.9						7.5	6.4	6.4	6.3	6.3	6.3	6.4	6.5	6.5	6.6		6.8	
BH-J																			
BH-K	5.7	5.6	5.4	5.3	5.5	5.2	5.3	5.2	5.1	5.1	5.2	5.3	5.5	5.6	5.6	5.7		5.8	
BH-L																			
BH-M																			
BH-N																			
BH-N(A)		2.1	2.1	2.1	2.4	2.0	2.1	2.1	2.0	2.0	2.0			2.8		2.3		2.5	
BH-O		2.7	2.6			2.5		2.3	2.5	2.5	2.5			2.7		2.8		2.9	
BH-Q																			
BH-R		3.3	3.3	3.3	3.4	3.3	3.3	3.3	3.2	3.2	3.2	3.3		3.5	3.4	3.5		3.6	
BH-S		2.4	2.2	2.2	2.2	2.2	1.8	2.1	2.1	2.1	2.1	2.1		2.2	2.2	2.3		2.5	
BH-T																			
BH-U																			
BH-V																			
BH202			3.4	3.4	3.7				3.3										
BH204																			
BH205																			
BH04																			
BH05		5.4	5.3	5.0	5.4	5.3	5.4	5.4	5.3	5.3	5.3	5.3	5.4	5.5	5.8	6.3	6.6		
BH07		2.7	2.6	2.3	2.4	2.3	2.4	2.4	2.4	2.4	2.4	2.4	2.5	2.7	2.5	2.6	2.6		
BH12		5.9	5.8	5.7	5.8	5.6	5.7	5.6	5.5	5.5	5.7	5.7	5.9	5.9	6.0	6.2	6.2		
BH13A (s)	6.9		6.7	6.6	6.7	6.6	6.7	6.6	6.6	6.6	6.7			7.0		7.0	7.0		
BH13B (n)			6.7	6.6	6.8	6.6	6.6	6.6	6.6	6.6	6.7			7.1		7.1	7.0		
BH16		10.3	10.1	10.0	10.1	9.9	9.9	9.8	9.7	9.7	9.8			10.4		10.5	10.4		
2010/CPT14													4.7	5.7	4.8	4.9			
2011/BH203																			
2011/BH204 E													4.8	4.8	4.9	5.0	5.1		
2011/BH204 W													4.8	4.9	4.9	5.0	5.0		
2011/BH205													5.0	5.1	5.0	5.1	5.1		
2011/BH206 E													4.7	4.8	4.8	5.0	5.0		
2011/BH206 W													5.9	6.0	6.0	6.0	6.1		
2011/BH207 E													2.4		2.6	2.7	2.7		
2011/BH207 W													2.5		2.6	2.7	2.5		
2011/BH208													4.8		4.8	4.8	4.9		
2011/BH209													6.1		6.2	6.3	6.3		
2011/BH210													4.4	4.5	4.6	4.7	4.8		
2011/BH211													4.0	4.3	4.1	4.3	4.2		
2011/BH211A													4.7		4.8	5.1	5.1		
2011/BH213 S /2011/BH404 S																			
2011/BH213 N /2011/BH404 N																		3.9	
2011/BH214 /2011/BH406																		4.8	
2011/BH215 /2011/BH702																			3.0
2011/BH803																			

2011/WM2																			
2011/WM4																			
2011/WM5																			
2011/WM8																			
2011/WM9																			
2011/WM10																			

Bore ID	GW Reduced Level (mRL)												Results				
Borehole no.	4/08/11	15/09/11	20/09/11	29/09/11	11/10/11	13/10/11	2/11/11	9/11/11	30/11/11	1/12/11	11/01/12	18/01/12	max mbgl	min mbgl	max mrl	min mrl	No of records
BH-A	4.7	4.6		4.6			4.7		4.6		4.6		18.9	16.8	5.0	2.8	33.0
BH-B													0.6	0.0	5.1	4.4	3.0
BH-C													2.1	1.1	3.7	2.7	10.0
BH-D													1.8	0.1	3.1	1.5	18.0
BH-E	5.3	4.7		5.1			5.1		5.0		5.0		6.6	5.2	5.9	4.6	29.0
BH-I	6.8			6.6	5.9		6.7		6.6		6.5		4.0	2.2	7.5	5.7	26.0
BH-J					5.7		6.1						1.1	0.1	6.2	5.2	11.0
BH-K	5.6	5.5		5.5			5.7		5.4		5.4		1.2	0.4	5.8	5.0	31.0
BH-L													1.4	0.1	3.6	2.2	9.0
BH-M													2.2	0.9	2.7	1.4	8.0
BH-N													7.5	1.7	8.3	2.6	8.0
BH-N(A)	2.2					2.8		2.3		2.2		2.2	1.4	0.5	2.9	2.0	27.0
BH-O	2.8					2.6		2.7		2.7		2.6	0.6	-0.1	3.0	2.3	23.0
BH-Q													23.9	23.1	2.6	1.9	7.0
BH-R	3.4	3.4				3.6		3.4		3.4		3.3	2.5	0.2	4.0	1.6	30.0
BH-S	2.4	2.2				2.2		2.2		2.2		2.2	2.9	0.7	3.9	1.8	30.0
BH-T													3.0	2.4	5.6	5.0	7.0
BH-U													1.9	1.0	5.2	4.2	8.0
BH-V					6.2								1.3	-0.1	7.4	6.0	9.0
BH202													10.3	9.7	3.8	3.3	10.0
BH204													9.0	8.9	4.2	4.0	6.0
BH205													0.8	0.0	3.3	2.5	7.0
BH04																	
BH05	6.5	6.4		6.3			6.6		6.1		6.1		2.8	1.2	6.6	5.0	22.0
BH07	2.6	2.6				2.8		2.6		2.6		2.6	1.3	0.8	2.8	2.3	22.0
BH12	6.1					6.1		6.0		5.9		5.8	3.0	2.4	6.2	5.5	21.0
BH13A (s)	7.0					7.1		7.0		6.8		6.8	0.6	0.0	7.1	6.6	18.0
BH13B (n)	7.0					7.1		7.1		6.9		6.8	0.6	0.1	7.1	6.6	17.0
BH16	10.3	10.3				10.6	10.5			10.2		10.5	1.6	0.7	10.6	9.7	19.0
2010/CPT14				4.8			4.8		4.7				1.3	0.3	5.7	4.7	7.0
2011/BH203																	
2011/BH204 E	5.0			4.8			4.9		4.8		4.8		1.1	0.8	5.1	4.8	10.0
2011/BH204 W	5.0			4.8			4.9		4.8		4.9		1.0	0.8	5.0	4.8	10.0
2011/BH205	5.0			4.9			5.0		4.9		5.0		3.5	3.4	5.1	4.9	10.0
2011/BH206 E	4.9			4.8			4.9		4.8		4.8		1.3	1.1	5.0	4.7	10.0
2011/BH206 W	5.9			5.7			6.0		5.7		5.8		0.4	0.0	6.1	5.7	10.0
2011/BH207 E													2.7	2.5	2.7	2.4	4.0
2011/BH207 W													2.6	2.5	2.7	2.5	4.0
2011/BH208													16.9	16.8	4.9	4.8	4.0
2011/BH209													6.4	6.2	6.3	6.1	4.0
2011/BH210													4.2	3.8	4.8	4.4	5.0
2011/BH211													3.5	3.2	4.3	4.0	5.0
2011/BH211A													4.5	4.2	5.1	4.7	4.0
2011/BH213 S /2011/BH404 S	4.7			3.7			4.6		3.9		4.5		1.1	0.1	4.7	3.7	5.0
2011/BH213 N /2011/BH404 N	3.9			4.5			4.0		4.5		3.7		1.1	0.3	4.5	3.7	6.0
2011/BH214 /2011/BH406	4.9			4.7			4.7		4.7				2.5	2.2	4.9	4.7	5.0
2011/BH215 /2011/BH702	2.9	3.0				3.1		3.0		2.9		3.0	0.9	0.7	3.1	2.9	7.0
2011/BH803																	
2011/WM2	7.0	7.0	7.0	7.0			7.2		7.1		7.2		0.3	0.0	7.2	7.0	7.0
2011/WM4	2.5												0.1	0.1	2.5	2.5	1.0
2011/WM5	2.6					2.4		2.9		2.8		2.3	0.6	0.0	2.9	2.3	5.0
2011/WM8																	
2011/WM9	4.9			4.4									0.6	0.1	4.9	4.4	2.0
2011/WM10				4.4			5.0		4.5		4.7		0.6	0.0	5.0	4.4	4.0



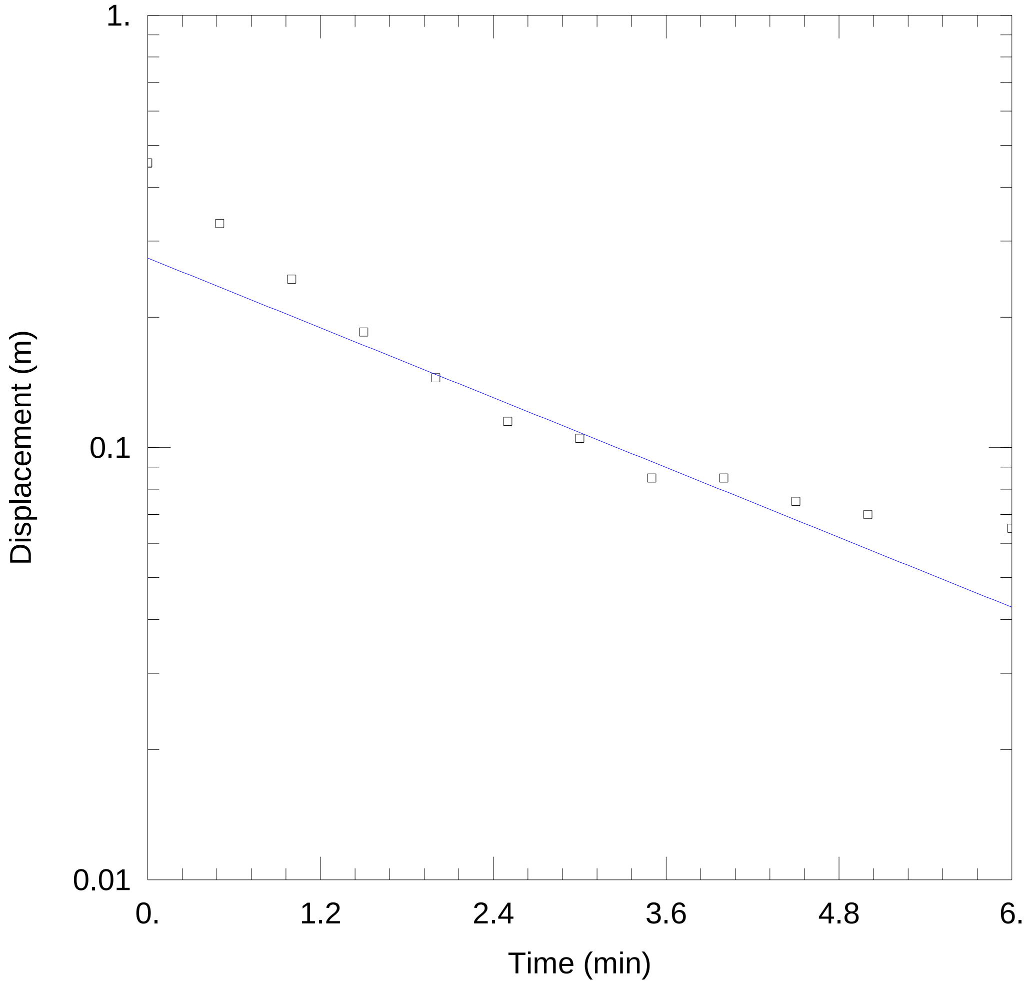
Recorded Groundwater Levels
Pleistocene Sand & Gravel Deposits
Groundwater Level (mRL)
0
1
2
3
4
5
6
7
8
9
10
11
01/07
04/07
07/07
10/07
02/08
05/08
08/08
12/08
03/09
06/09
09/09
01/10
04/10
07/10
11/10
02/11
05/11
08/11
12/11
03/12
Groundwater Monitoring Date (mm/yy)
BH-A
BH-B
BH-D
BH-E
BH-I
BH-J
BH-K
BH-L
BH-L
BH-N
BH-N(A)
BH-O
BH-Q
BH-R
BH-S
BH-T
BH-V
BH204
BH12
BH13A (s)
BH13B (n)
BH16
2011/BH204 E
2011/BH206 E
2011/BH207 E
2011/BH208
2011/BH209
2011/BH210
2011/BH211
2011/BH211A



Recorded Groundwater Levels
Holocene Gravel, Peat and Sand Deposits
Groundwater Level (mRL)
0
1
2
3
4
5
6
7
8
01/07
04/07
07/07
10/07
02/08
05/08
08/08
12/08
03/09
06/09
09/09
01/10
04/10
07/10
11/10
02/11
05/11
08/11
12/11
03/12
06/12
Groundwater Monitoring Date (mm/yy)
Gravel
BH-C
Sand
BH202
BH205
BH05
BH07
Peat
2011/BH204 W
2011/BH205
2011/BH206 W

Appendix 21.C

In-situ Hydraulic Conductivity Data



WELL TEST ANALYSIS

Data Set: P:\332\3320901\TGE\Groundwater\SlugTestsJuly2011\BH13.aqt
Date: 09/01/11 Time: 13:19:17

PROJECT INFORMATION

Company: M2PP Alliance
Client: NZTA
Project: 3320901
Location: Glenfield Road
Test Well: BH1 - Peat
Test Date: 29-06-2011

AQUIFER DATA

Saturated Thickness: 2. m
Anisotropy Ratio (Kz/Kr): 0.1

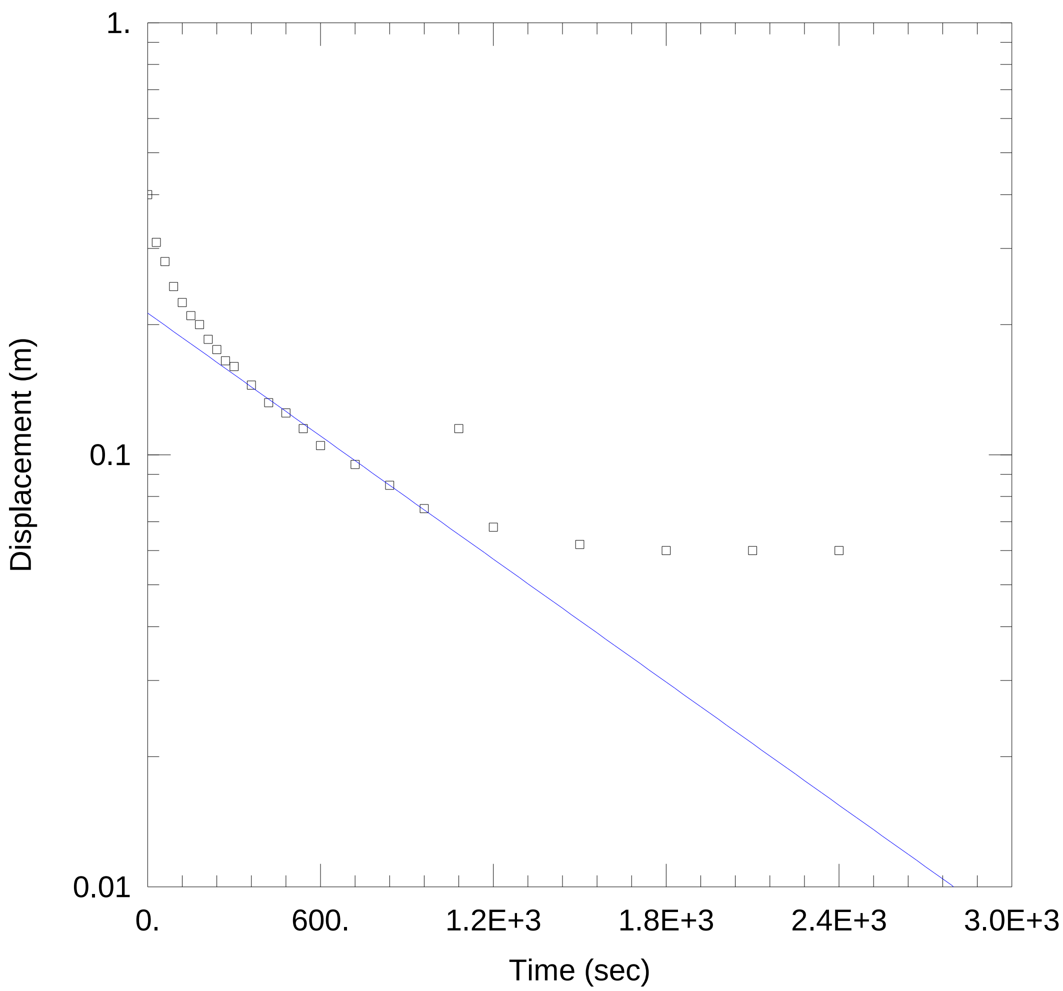
WELL DATA (BH13 - Sand)

Initial Displacement: 0.455 m
Static Water Column Height: 2. m
Total Well Penetration Depth: 2. m
Screen Length: 2. m
Casing Radius: 0.05 m
Well Radius: 0.09 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev

K = 1.478 m/day
y0 = 0.2743 m



WELL TEST ANALYSIS

Data Set: P:\332\3320901\TGE\Groundwater\SlugTestsJuly2011\BH204W.aqt
Date: 09/01/11 Time: 13:27:05

PROJECT INFORMATION

Company: M2PP Alliance
Client: NZTA
Project: 3320901
Test Well: BH204 - W
Test Date: 08/07/2011

AQUIFER DATA

Saturated Thickness: 20.5 m Anisotropy Ratio (Kz/Kr): 1.

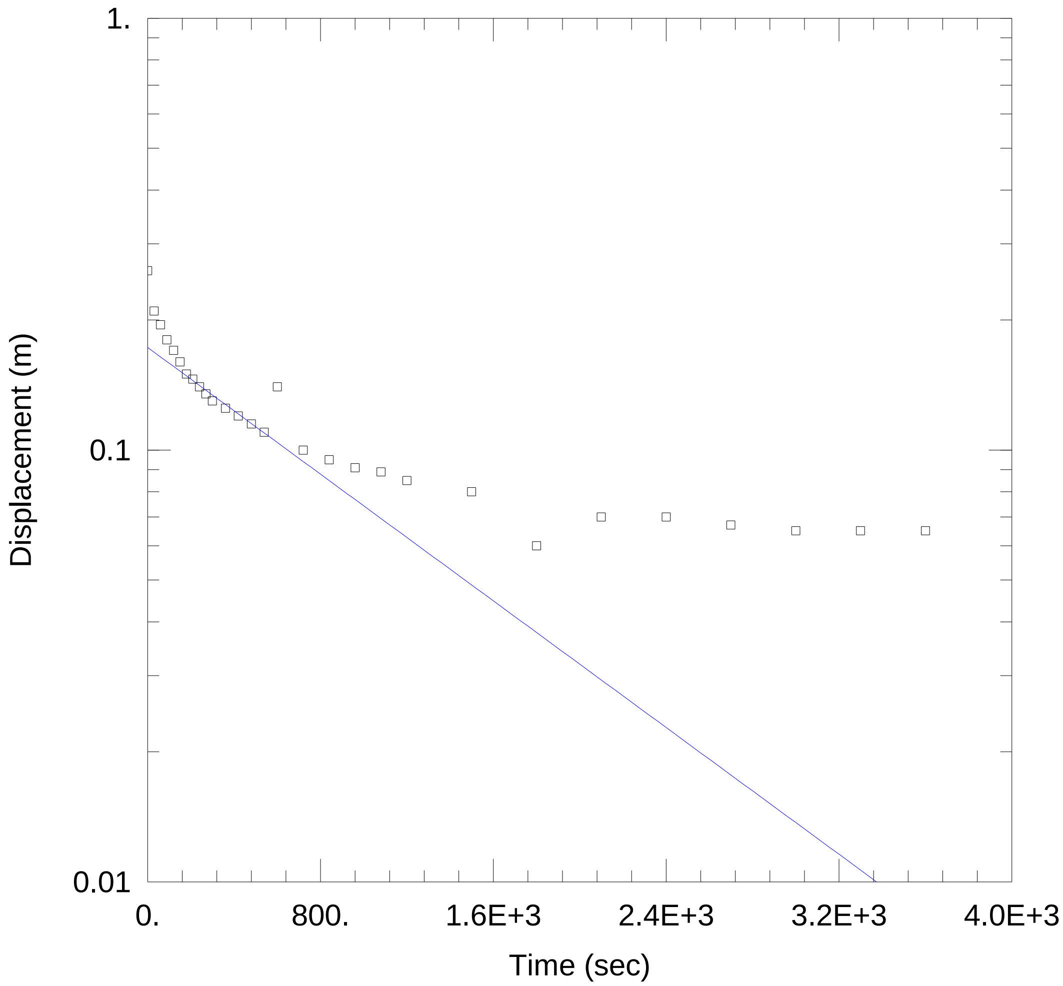
WELL DATA (BH204 W - Sand)

Initial Displacement: 0.4 m
Total Well Penetration Depth: 9. m
Casing Radius: 0.05 m
Static Water Column Height: 1.325 m
Screen Length: 3. m
Well Radius: 0.1 m
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined Solution Method: Hvorslev

K = 0.1338 m/day y0 = 0.2128 m



WELL TEST ANALYSIS

Data Set: P:\332\3320901\TGE\Groundwater\SlugTestsJuly2011\BH205.aqt
Date: 09/01/11 Time: 13:29:01

PROJECT INFORMATION

Company: M2PP Alliance
Client: NZTA
Project: 3320901
Test Well: BH205
Test Date: 06/07/2011

AQUIFER DATA

Saturated Thickness: 20. m Anisotropy Ratio (Kz/Kr): 1.

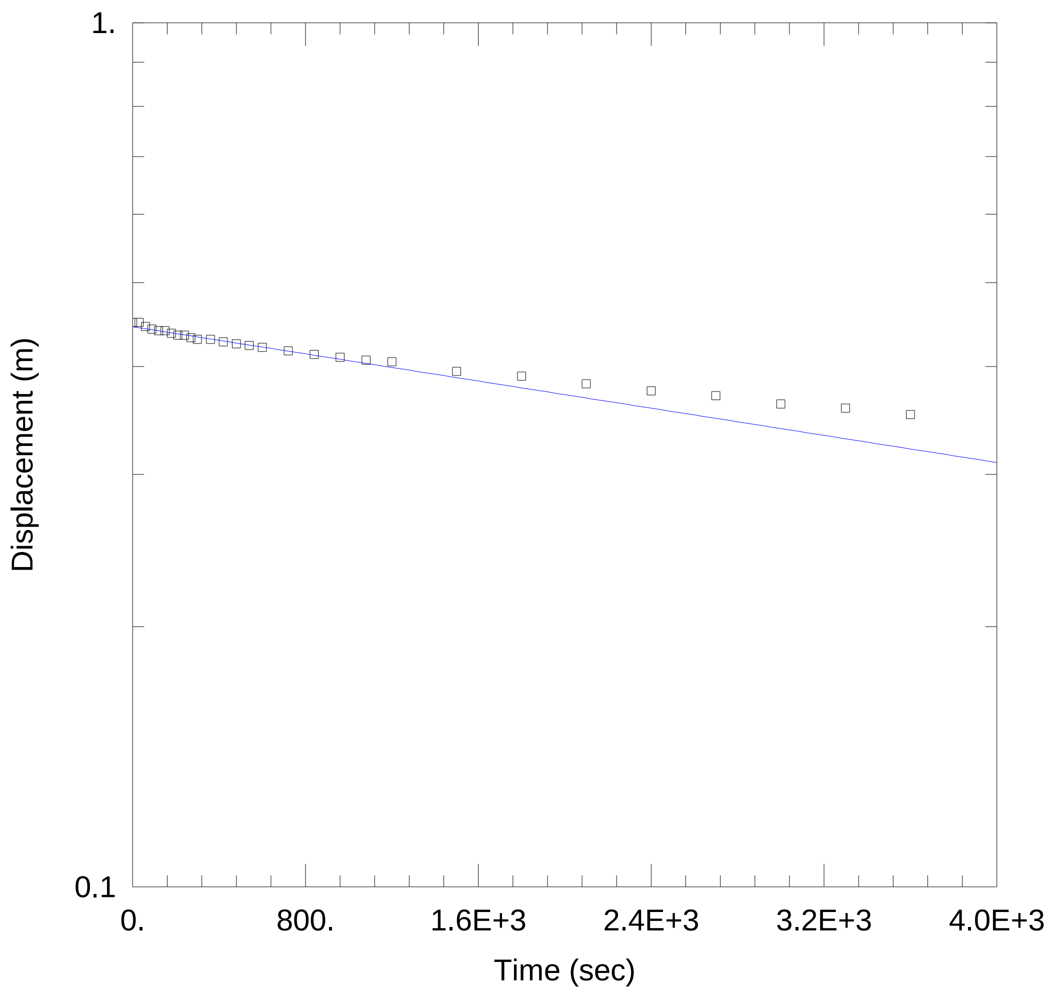
WELL DATA (BH205 - Sand)

Initial Displacement: 0.26 m
Total Well Penetration Depth: 5.4 m
Casing Radius: 0.05 m
Static Water Column Height: 4.19 m
Screen Length: 3. m
Well Radius: 0.1 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Hvorslev

K = 0.1034 m/day y0 = 0.1727 m



WELL TEST ANALYSIS

Data Set: P:\332\3320901\TGE\Groundwater\SlugTestsJuly2011\BH206A - peat.aqt
Date: 09/01/11 | Time: 13:30:47

PROJECT INFORMATION

Company: M2PP Alliance
Client: NZTA
Project: 3320901
Test Well: BH206A
Test Date: 08/07/2011

AQUIFER DATA

Saturated Thickness: 2.105 m | Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (BH206A - Peat)

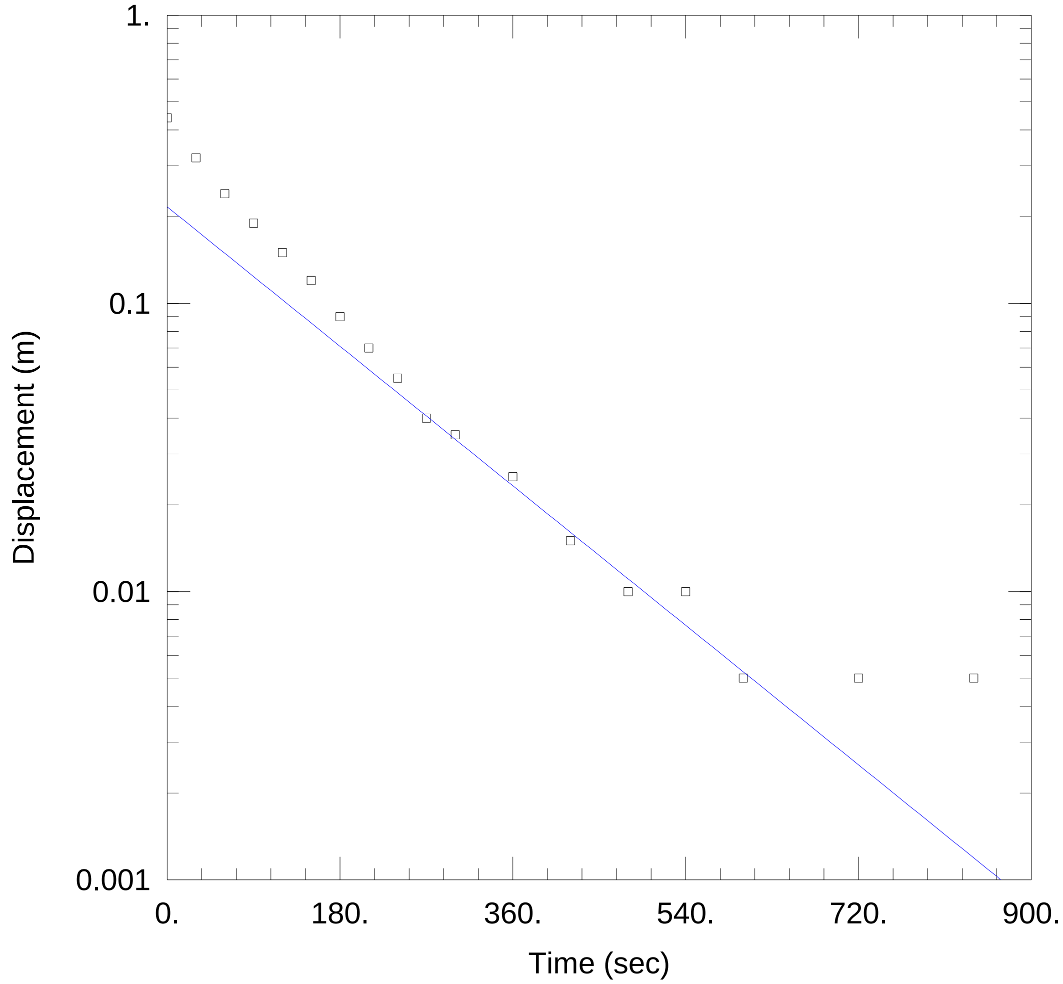
Initial Displacement: 0.45 m
Total Well Penetration Depth: 3. m
Casing Radius: 0.05 m

Static Water Column Height: 0.0495 m
Screen Length: 2. m
Well Radius: 0.1 m
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined | Solution Method: Hvorslev

K = 0.02365 m/day | y0 = 0.4447 m



WELL TEST ANALYSIS

Data Set: P:\332\3320901\TGE\Groundwater\SlugTestsJuly2011\BH207.aqt
Date: 09/01/11 Time: 13:34:11

PROJECT INFORMATION

Company: M2PP Alliance
Client: NZTA
Project: 3320901
Test Well: BH207
Test Date: 07/07/2011

AQUIFER DATA

Saturated Thickness: 14.4 m
Anisotropy Ratio (Kz/Kr): 1.

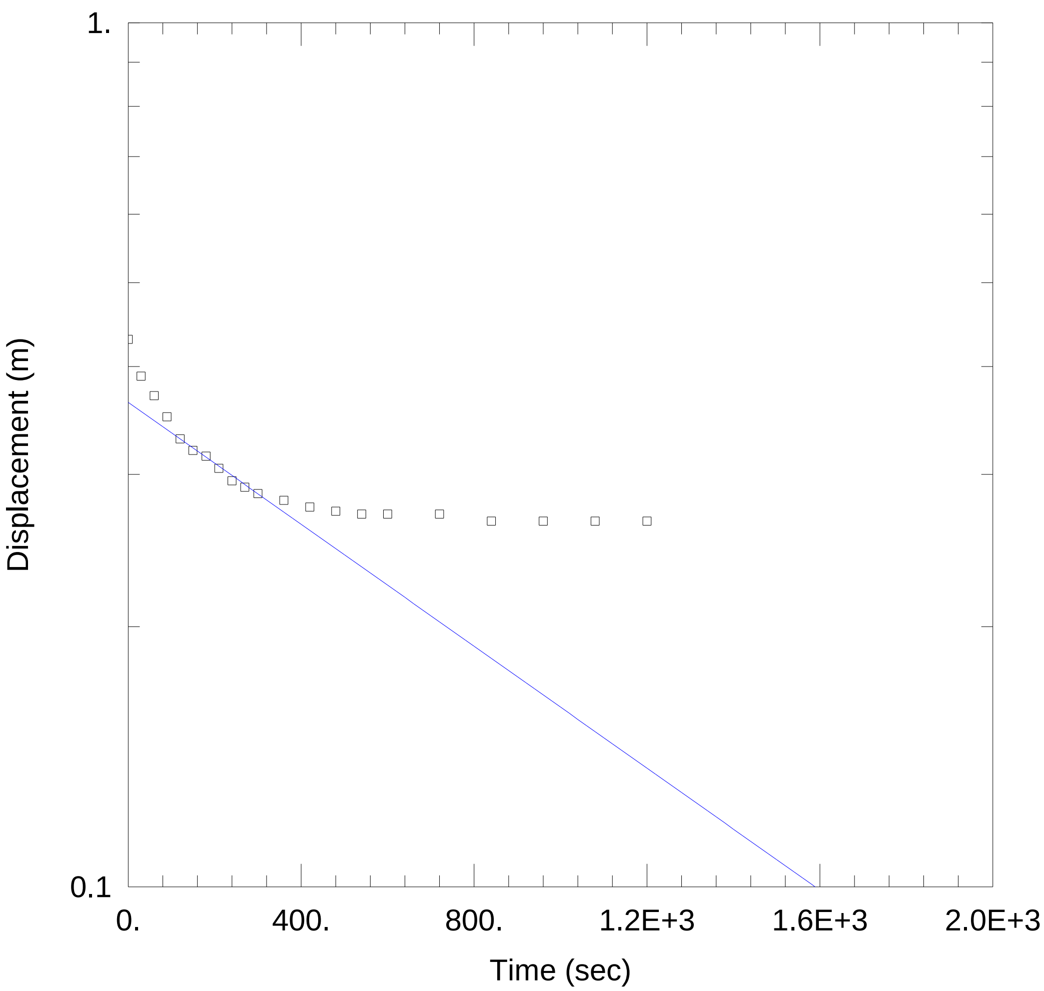
WELL DATA (BH207 - SAND trace organics)

Initial Displacement: 0.44 m
Total Well Penetration Depth: 8. m
Casing Radius: 0.05 m
Static Water Column Height: 2.6 m
Screen Length: 3. m
Well Radius: 0.1 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev

K = 0.7586 m/day
y0 = 0.2164 m



WELL TEST ANALYSIS

Data Set: P:\332\3320901\TGE\Groundwater\SlugTestsJuly2011\BH208.aqt
Date: 09/01/11 Time: 13:35:11

AQUIFER DATA

Saturated Thickness: 8.25 m Anisotropy Ratio (Kz/Kr): 1.

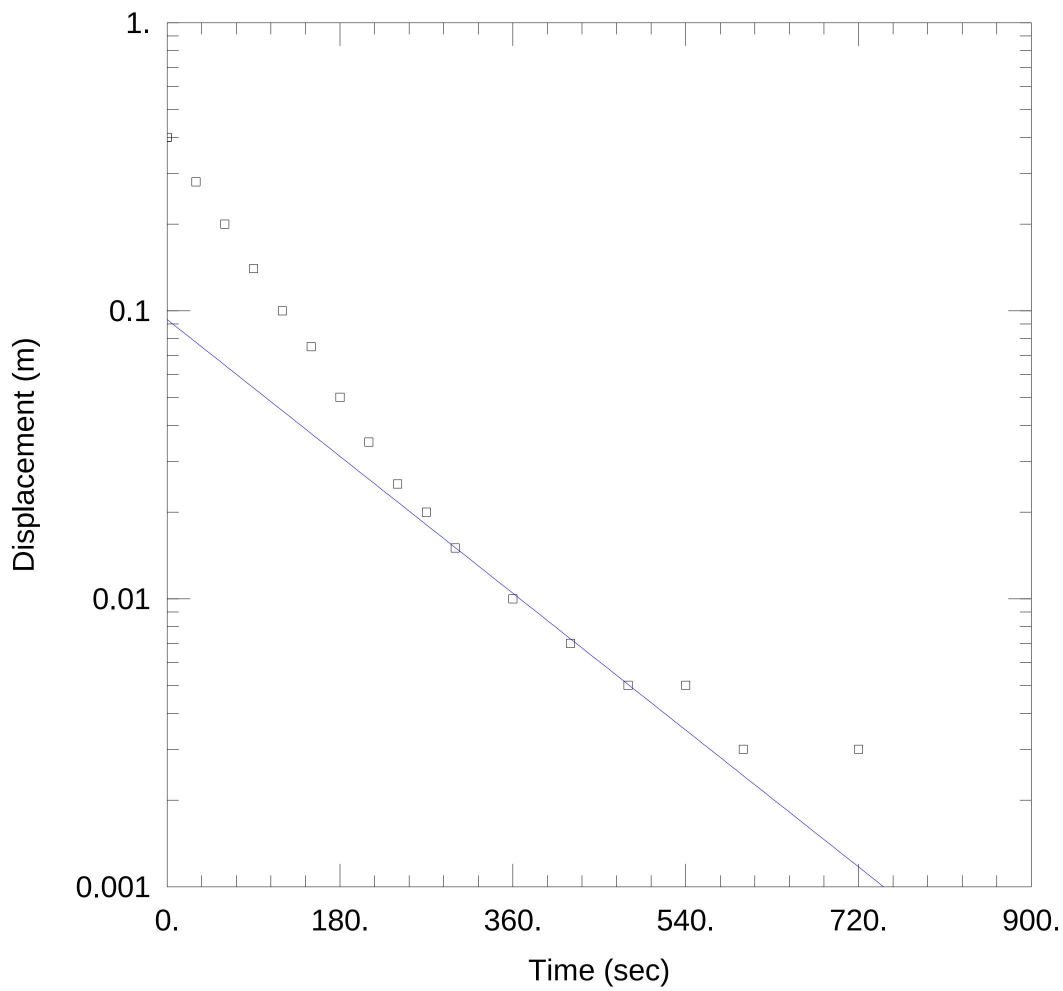
WELL DATA (BH208 - SAND)

Initial Displacement: 0.43 m
Total Well Penetration Depth: 21. m
Casing Radius: 0.05 m
Static Water Column Height: 16.75 m
Screen Length: 2. m
Well Radius: 0.1 m

SOLUTION

Aquifer Model: Unconfined Solution Method: Hvorslev

K = 0.1619 m/day y0 = 0.3636 m



WELL TEST ANALYSIS

Data Set: P:\332\3320901\TGE\Groundwater\SlugTestsJuly2011\BH209.aqt
Date: 09/01/11 Time: 13:37:48

PROJECT INFORMATION

Company: M2PP Alliance
Client: NZTA
Project: 3320901
Test Well: BH209
Test Date: 07/07/2011

AQUIFER DATA

Saturated Thickness: 13.82 m Anisotropy Ratio (Kz/Kr): 1.

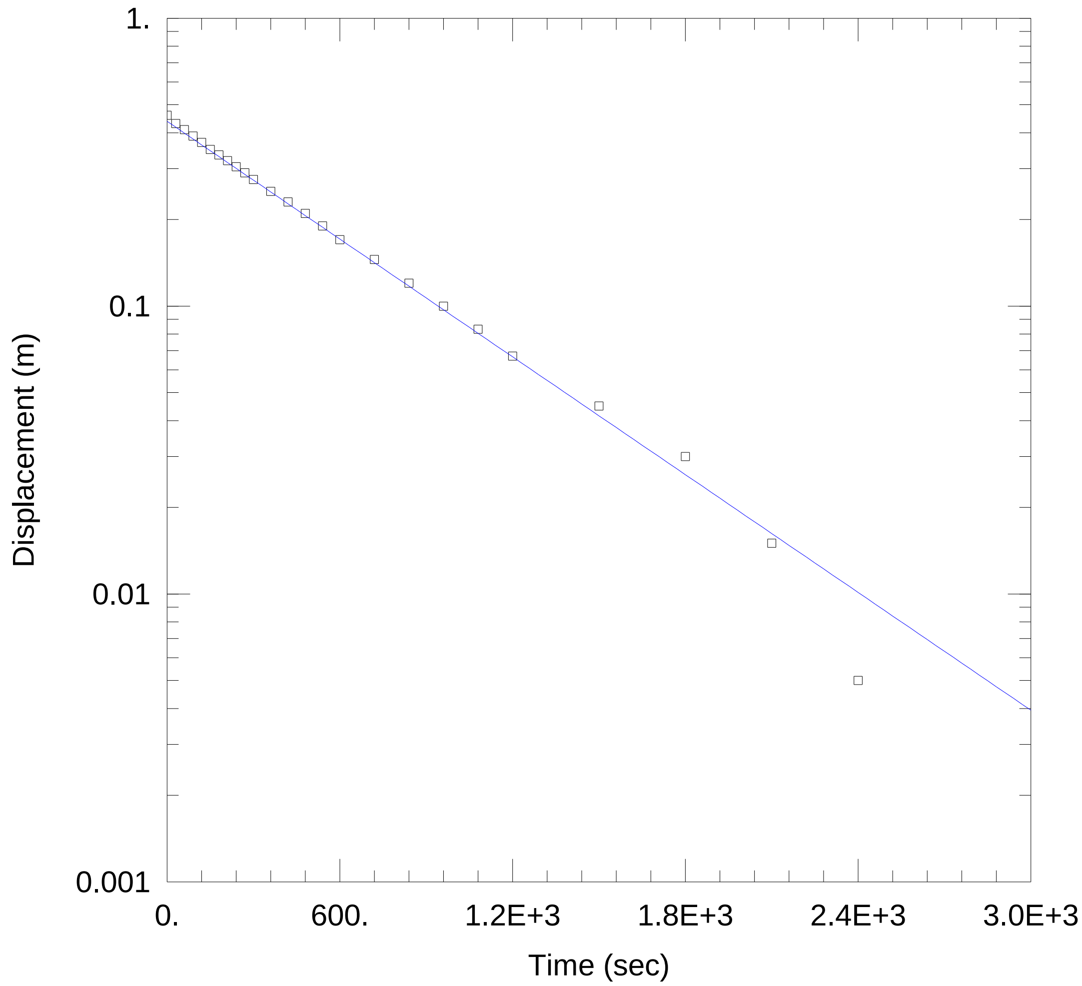
WELL DATA (BH209 - SAND)

Initial Displacement: 0.4 m
Total Well Penetration Depth: 20. m
Casing Radius: 0.05 m
Static Water Column Height: 6.18 m
Screen Length: 3. m
Well Radius: 0.1 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev

K = 0.8958 m/day
y0 = 0.09317 m



WELL TEST ANALYSIS

Data Set: P:\332\3320901\TGE\Groundwater\SlugTestsJuly2011\BH210.aqt
Date: 09/01/11 Time: 13:40:03

PROJECT INFORMATION

Company: M2PP Alliance
Client: NZTA
Project: 3320901
Test Well: BH210
Test Date: 06/07/2011

AQUIFER DATA

Saturated Thickness: 16.2 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH210 - SAND)

Initial Displacement: 0.46 m
Total Well Penetration Depth: 20. m
Casing Radius: 0.05 m
Static Water Column Height: 3.8 m
Screen Length: 3. m
Well Radius: 0.1 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.2315 m/day
y0 = 0.4383 m

Appendix 21.D

Conceptual Groundwater Model and Approach to Numerical Modelling

Appendix D – Conceptual groundwater model and approach to numerical modelling

D1. Conceptual Groundwater Model

The geological model was developed using the computer software Hydro GeoAnalyst (HGA) a data management, ground and groundwater visualisation tool which allows the development of a three-dimensional ground model.

This geological model (described in the main report body) comprises eight stratigraphic units of up to 20 m thick with a cyclic depositional sequence (Table 2, main report body). These stratigraphic units represent the key hydrogeological units (that is, units that have similar hydrogeological properties and behaviours).

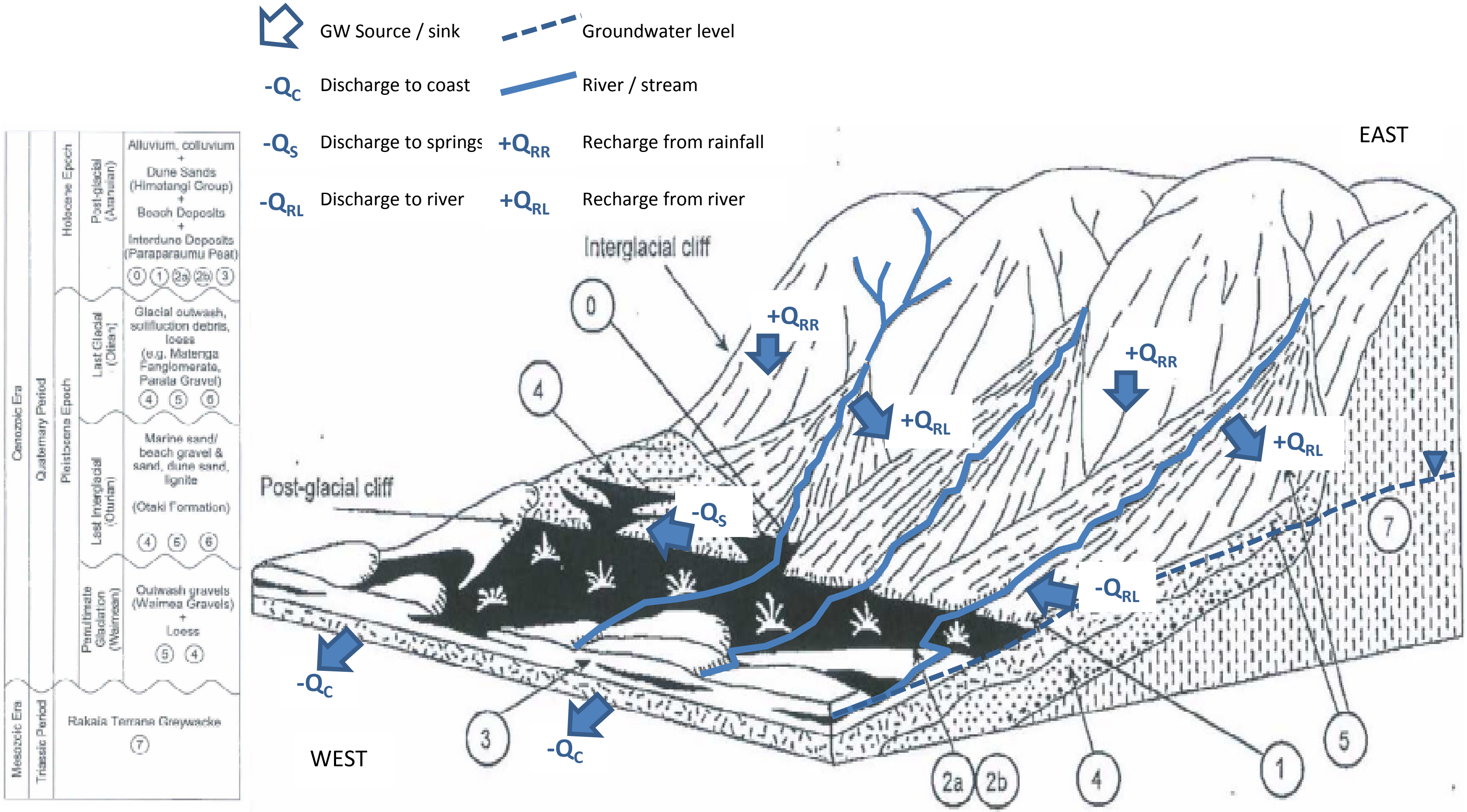
The conceptual groundwater model consists of a series of interbedded aquifers and aquitards creating a leaky, unconfined to semi-confined aquifer system (Figure D1). The predominant source of recharge is from rainfall, which slowly infiltrates down into the lower layers. Some recharge from rivers and up-gradient heads (in the greywacke) can also be expected.

At depth, moderate to high transmissivity terrestrial gravels form the confined Waimea Aquifer and Parata Aquifer. Municipal water supply wells for KCDC tend to target the Waimea Aquifer as the confined nature gives greater security to the groundwater source and limits effects in overlying aquifers.

The deeper confined aquifers are overlain by a series of unconfined aquifers comprised of fluvial gravels, and marine sands with interbeds of regressional alluvium. The upper marine sands are often targeted by private irrigation wells. These units are in turn overlain by alluvium and Holocene dune sand, with areas of peat having developed in the lower lying areas between dunes.

The peat ranges from amorphous organic silt to fibrous woody peat of variable permeability and compressibility. The peat is significant in that it supports a series of recharge and discharge wetlands of high ecological value. Recharge wetlands are fed predominantly by rainfall and run-off and because water is perched in the peat, the wetlands recharge the groundwater system. Discharge wetlands are fed dominantly by groundwater and springs.

Figure D1: Conceptual Groundwater Model

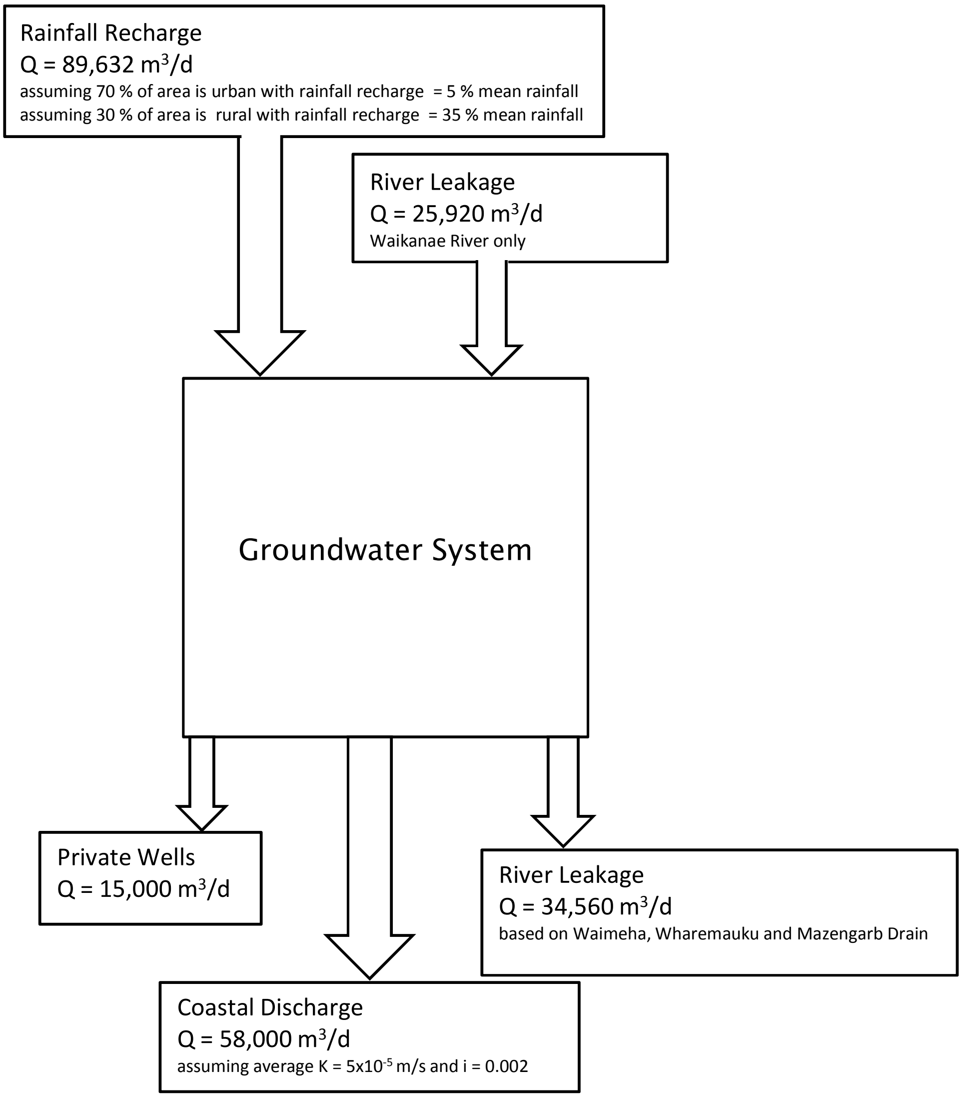


Modified after Maclean, C & Maclean, J (2010)

The construction of the Expressway has the greatest potential to affect the shallow groundwater system (i.e. the Holocene sand, peat, and alluvium) because works will be largely carried out within these materials.

A conceptual water balance, based on available data for key groundwater sources and sinks, is given in Figure D2.

Figure D2: Conceptual Water Balance



D2. Approach to Three-Dimensional Numerical Modelling

D2.1. Scope and Purpose

3D groundwater modelling has been undertaken in order to assess the likely effects of the Project on the existing groundwater regime.

A regional 3D groundwater model was developed to consider overall flow trends and broad scale effects resulting from the Project (Appendix E1). As such the model is large in scale with coarse cell dimensions and is not used for evaluation of changes in close proximity to the Expressway.

The regional model is used for assessment of:

- Effects on overall water balance and groundwater-surface water interactions;
- The potential magnitude and extent of changes in groundwater level;
- The potential magnitude and extent of drawdown from construction groundwater take; and
- For setting boundary conditions in a series of smaller, detailed 3D models.

In order to examine potential effects in sensitive areas, a series of smaller, detailed 3D models were developed. These models examine the interaction between the existing groundwater regime and natural wetlands, and the proposed Expressway and associated stormwater devices. Models were developed for:

- Wetland OA / OB (CH3250to CH4300);
- Offset storage areas 2, 3A and wetland 3 near Wharemauku Stream (CH4600 to CH5700); and
- Wetland 9 near El Rancho (CH10300 to CH11550).

A further model was developed for Otaihanga Landfill and adjacent wetlands to assess the potential for contaminant spread.

These detailed models are used for the assessment of:

- The magnitude and extent of changes in groundwater level (damming and / or drawdown) resulting from construction of the Expressway and stormwater devices with a particular focus on:
  - Changes in water levels in existing natural wetlands;
  - Changes in groundwater levels in residential and commercial areas (potential for drawdown and associated effects such as consolidation settlement , contaminant migration, effects on existing groundwater takes); and
- Effects on the overall water balance.

D2.2. Software

Three-dimensional groundwater modelling was undertaken using the computer software Visual MODFLOW Pro 2010.1 (Schlumberger). Visual MODFLOW is a user-interface for MODFLOW 2000 (Harbaugh et al, 2000) and ModPath developed by the United States Geological Survey.

MODFLOW 2000 is a three-dimensional finite-difference groundwater model. The groundwater flow equation is solved using the finite difference approximation. The flow region is subdivided into blocks in which the material properties are assumed to be uniform. In plan-view the blocks are made of mutually perpendicular lines that may be variably spaced, and the water level in each block is calculated. For the purposes of the Project the PCG2 solver was used.

D2.3. Calibration Targets

Model calibration has included both quantitative and qualitative measures and where possible has considered both groundwater levels and known interactions with surface water bodies.

The focus of calibration has been on groundwater levels recorded in standpipe piezometers or wells of known construction, with a reliable long term record of groundwater levels. There is limited reliable information for private wells in the model area in terms of construction details (casing depth, screened interval or aquifer) or groundwater records (static water levels, when recorded, seasonal variability) and so less weighting is placed on this data.

The steady state regional 3D model was calibrated to a target Normalised Root Mean Square (RMS) error of 10 % for average groundwater levels, and a residual mean error of +/- 1.0 m. Calibration to transient conditions was also undertaken with the emphasis on simulating the naturally occurring magnitude of groundwater level fluctuations.

Absence of accurate well data was particularly problematic for calibration of the smaller 3D models. The lack of long term, simultaneous groundwater records for evaluating observed steady state water levels (with which to calibrate to) meant that calibration was more qualitative with a focus on replicating general flow features i.e.:

- Matching the overall pattern of flow directions, gradients and temporal variations observed on site;
- Replicating areas of known wetlands and surface flooding; and
- Calculated steady state water levels matched to a residual mean error of +/- 1.0 m and within the expected range of groundwater levels based on limited records.

D2.4. Modelling of Constructed Expressway and Stormwater Devices

Expressway

Fills, embankments and bridges above the groundwater table have not been considered in modelling as they will have negligible effect on the groundwater system. Effects on surface water flows from these structures are considered in Technical Report 22, Volume 3.

Cuts below the groundwater table are simulated using the drain boundary package of MODFLOW. To simulate the condition of seepage at the cut face, the drain elevation is taken as equal to the base of the excavation and the amount of seepage into the drains is controlled by the modelled hydraulic conductance of the seepage face. Drain conductance is calculated from:

$$\text{Conductance} = \text{Cell Area } (m^2) * K \text{ (m/d)} / \text{Cell Thickness (m)}$$

Areas of peat excavation and replacement, and areas of peat surcharge beneath the Expressway are simulated by changing the relative hydraulic conductivities in the replaced or surcharged soils:

- Where peat is to be replaced by sand, it is assumed that the sand will be Holocene Dune sand mined from the Project area. Compaction trials (Opus, 2008) suggest that compacted sand hydraulic conductivity will be similar to that of its natural state (i.e. expected densification of less than 10 % which would not result in noticeable reduction in hydraulic conductivity); and
- Where peat is to be surcharged, compression of 20 % to 50 % is expected. This means that hydraulic conductivity could be reduced by a factor 1/10 to 1/1000 (Carlsten, 1988). A reduction in hydraulic conductivity a factor of 1000 has been modelled for the top half of the surcharged peat and a reduction factor of 100 for the bottom half.

Stormwater Devices

Rainfall recharge is removed from the constructed Expressway in all models, as all runoff is expected to go to stormwater devices (swales and constructed ponds and wetlands).

The potential infiltration from swales cannot be considered in the regional 3D model due to the coarse grid size; but it is expected that swales will rapidly “blind” (within one to two years) and lose little water to ground. Major wetlands and ponds are simulated using the RIVER Boundary Package of MODFLOW. This boundary simulates surface water/ groundwater interaction via a seepage layer separating the surface water body from the groundwater body. Depending on the hydraulic gradient between the two systems, the wetlands / ponds can act as recharge or discharge zones.

Within the smaller 3D models, the swales are simulated by increasing the rainfall recharge in these areas (to reflect the likely infiltration through the unlined swale sides and bottom (likely in the first one to two years)). Wetlands and other large stormwater devices are considered using the RIVER Boundary Package as outlined above.

D2.5. Model Limitations and Appropriate Use of Modelling Results

The models were calibrated to observed water levels from several different sources with varying degrees of reliability. During calibration greater weight was placed on water levels from longer term records. A reasonable calibration to observed water levels and general flow patterns was achieved (Figure F4) and is discussed in detail for each model in subsequent sections.

Although the model domains cover significant areas, data calibration points tend to be located in proximity to the alignment. Hence the model is best suited for assessment of effects within ± 200 m of the alignment, where the greatest density of reliable calibration data (gathered as part of this Project) is located.

The wider area where less geological data and water level observations are available contains some interpolation, but is nevertheless suitable for a qualitative assessment of effects and to provide boundary conditions to the more detailed models.

D3. Approach to Two-Dimensional Numerical Modelling

D3.1. Software

Two-dimensional groundwater modelling was undertaken using the computer software GeoStudio 2007 SEEP/W (Geo Slope International). SEEP/W is a finite element model formulated on the basis that flow of water through saturated soil follows Darcy's Law. For finite element calculation, the SEEP/W model is divided by nodes and the elevation of the water level at each node is calculated.

As a hydraulic conductivity function is defined (where hydraulic conductivity varies as a function of pore-pressure) SEEP/W can model both saturated and unsaturated flow.

D3.2. Scope and Purpose

2D groundwater modelling was undertaken to assess the likely effects of the Project on the existing groundwater regime in close proximity to the Expressway.

A series of simulations on three 2D cross-sections were developed for key sections of the alignment to assess potential changes in groundwater levels and aquifer through-flow for individual hydrogeological units, resulting from the differing peat treatments (excavate and replace or surcharge).

In addition a series of generic models were developed in order to assess how "typical" drawdown curves in the peat might change with variations in groundwater level and peat thickness.

These models also provide a further "check" to findings from 3D modelling.

D3.3. Calibration Targets

For 2D modelling, the focus of calibration has been on groundwater levels recorded in standpipe piezometers or wells of known construction with the model considered to be well calibrated where water levels in the majority of wells in close proximity to the alignment are replicated to within +/- 1 m.

D3.4. Modelling of Constructed Expressway and Stormwater Devices

Expressway

Fills, embankments and bridges above the groundwater table have not been considered in 3D modelling as they will have negligible effect on the groundwater system. Effects on surface water flows from these structures are considered in Technical Report 22, Volume 3.

Cuts below the groundwater table are simulated using a seepage face which allows water to freely drain out of the model at a rate proportional to the change in head and hydraulic conductivity of the relevant unit.

Areas of peat excavation and replacement, and areas of peat surcharge beneath the Expressway are simulated by changing the relative hydraulic conductivities in that area (as described in Section D2.4).

Stormwater Devices

Rainfall recharge is removed from the constructed Expressway in all models, as all runoff is expected to go to stormwater devices (swales and constructed ponds and wetlands).

The potential infiltration from swales was considered by increasing the recharge in the area of swales.

The flood offset area modelled in the section at CH5300 was simulated by maintaining a fixed groundwater level over the proposed area (reflecting the active drainage).

Appendix 21.E

2D Groundwater Models

Appendix E – 2D Groundwater Modelling

Typical cross-sections of the Expressway were selected to assess the average, long-term near-surface groundwater effects resulting from the constructed Expressway, as compared with the observed natural (existing) groundwater conditions.

The following sections were considered:

1. CH6140: Greatest thickness of peat excavation and replacement;
2. CH16000: Greatest embankment fill/ peat thickness (surcharge areas);
3. CH5300: Proposed offset flood storage wetland.

The models are constructed parallel to the main flow direction, however a minor component of flow / 3D effects can be expected locally that is not considered in the 2D models. Hence the models are conservative and the results should be considered in conjunction with those of the 3D models.

E1.1 Model Set Up

Model Set –Up

Geological sections for each of the detailed cross-sections were cut from the HGA ground model. Each section extends from the coastline in the west, to the foothills of the Tararua Ranges in the east. The topography and cut/ fill arrangements in the vicinity of the Expressway were input from the Project CAD model.

For the generic models, a simple uniform geological profile (no variation in layer thickness or surface topography) was adopted.

A coarse mesh of rectangles and triangles was generated for each model (both detailed and generic), with an element size of 30 m width for the broader model, and smaller elements (down to 2 m) then defined in the Expressway area.

The general model set ups are shown in Figure E1.

Distribution and Properties of Hydrogeological Units

Each hydrogeological unit was constructed as a separate region within the model. Post-import from HGA, the sections were checked to assess if the broad geological model was sufficiently detailed at the scale of the cross-section, in particular the extent and thickness of peat, with minor alterations made as necessary.

A hydraulic conductivity function was defined for each hydrogeological unit with the saturated conductivity as calibrated for the regional groundwater model. Sensitivity checks were carried out to check that the order of magnitude of hydraulic conductivity was reasonable.

Model Boundaries

Constant head boundaries were applied at either end of each model. A constant head of RL 0 m was applied at the western coastal margin to simulate mean sea level. At the eastern hill margin of each section, the constant head boundary was set in order to simulate (as close as possible) the observed water table from groundwater monitoring.

Recharge

Rainfall recharge was applied to the surface as a percentage of the average annual rainfall (as a unit flux in m/day), the percentage varying dependent on the assessed recharge factor (as per Section F1.1).

The recharge was removed from the constructed Expressway.

E1.2 Model Calibration

The models were calibrated to replicate observed groundwater levels, where such information was available on the cross-sections, and to simulate general flow conditions (such as replicating high GWLs, surface flooding etc).

E1.3 Model Sensitivity

As more detailed analyses were undertaken using the 3D modelling, sensitivity checks were primarily undertaken in the 3D models.

E1.4 Results of Numerical Modelling

The results are summarised in Table E1 however some general comments are provided below.

The proposed peat treatment methodologies result in small changes in groundwater level; this is confirmed by both the detailed and generic models.

Where the peat is to be excavated and replaced with higher permeability sand, some lowering of the groundwater level can be expected; this occurs as a result of locally reducing the rainfall infiltration (due to paved surfaces and capture by stormwater) and increasing the permeability. This lowering is indicated to be in the order of 100 mm to 200 mm immediately adjacent to the Expressway (based on the detailed models however the generic models suggest is could be much less). Where the peat is to be surcharged, a comparable amount of mounding may occur locally due to the reduction in peat permeability.

The through-flow of groundwater in the peat may also be reduced or increased locally (i.e. immediately adjacent to the Expressway) due to the change in permeability. Overall through-flow however is reduced by only a very small amount, as the underlying sand layers (which are of a much higher permeability) transmit the majority of groundwater and these layers are largely unaffected by changes to the surficial peat.

In general the detailed models indicate a greater extent and magnitude of changes in groundwater level, than do the generic models. This is likely because the detailed models incorporate surface topography (which affects recharge patterns near-surface) and variations in layer thickness. However it is noted that the 2D models have a tendency to overestimate effects because they do not consider 3D flow, hence it is important to consider the 2D results in conjunction with the 3D results.

E1.5 Predicted Drawdown for Settlement Analyses

A typical drawdown curve for the peat has been developed for the purpose of assessing consolidation settlement. The curve is based on the effects resulting from the embankments only. Where unlined wetlands are proposed below the current water table, drawdowns were assessed from the detailed 3D models.

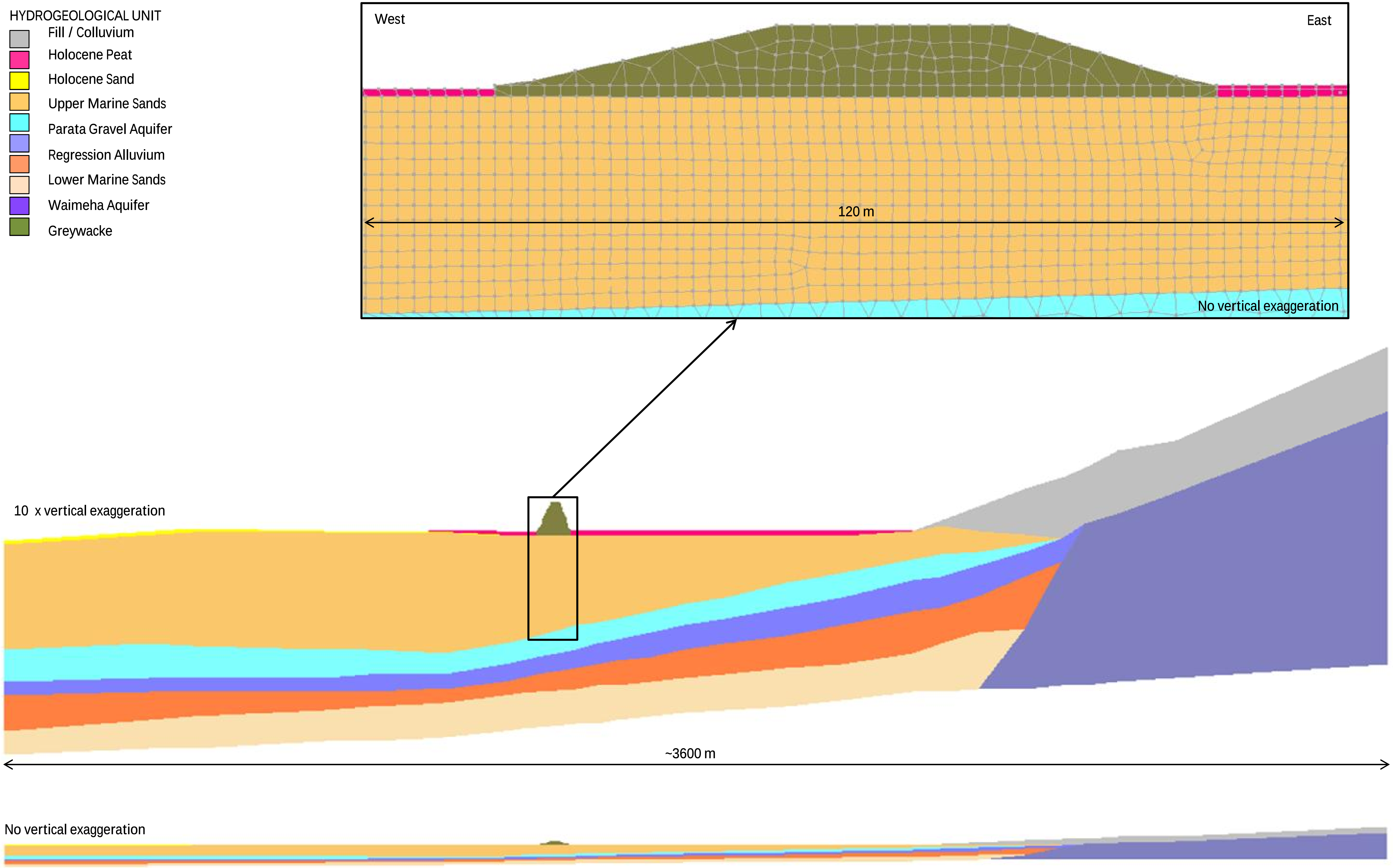
Figure E2 provides a summary of predicted drawdown in the peat from various methods, including observed drawdown resulting from a peat excavation trial where the GWL was pumped out of the excavation and held down for a period of 2 days. Figure E2 also shows a recommended drawdown profile for use in settlement calculations.

The measured drawdown during the peat trial was of a lesser magnitude and much lesser extent than the modelled drawdowns or recommended profile; it is likely that over a significant proportion of the alignment drawdown will be comparable to that recorded for the trial. However there will be areas where the peat is sandier or more fibrous and in those scenarios the drawdown may extend further; hence a wider cone of drawdown was selected for the consolidation analyses.

Some modelled drawdown values fall outside of this profile (e.g. Wetland 9 max) however these are the maximum values of drawdown calculated, applicable to local areas and are unlikely to be representative regionally.

Table E1: Summary of 2D Modelling Results

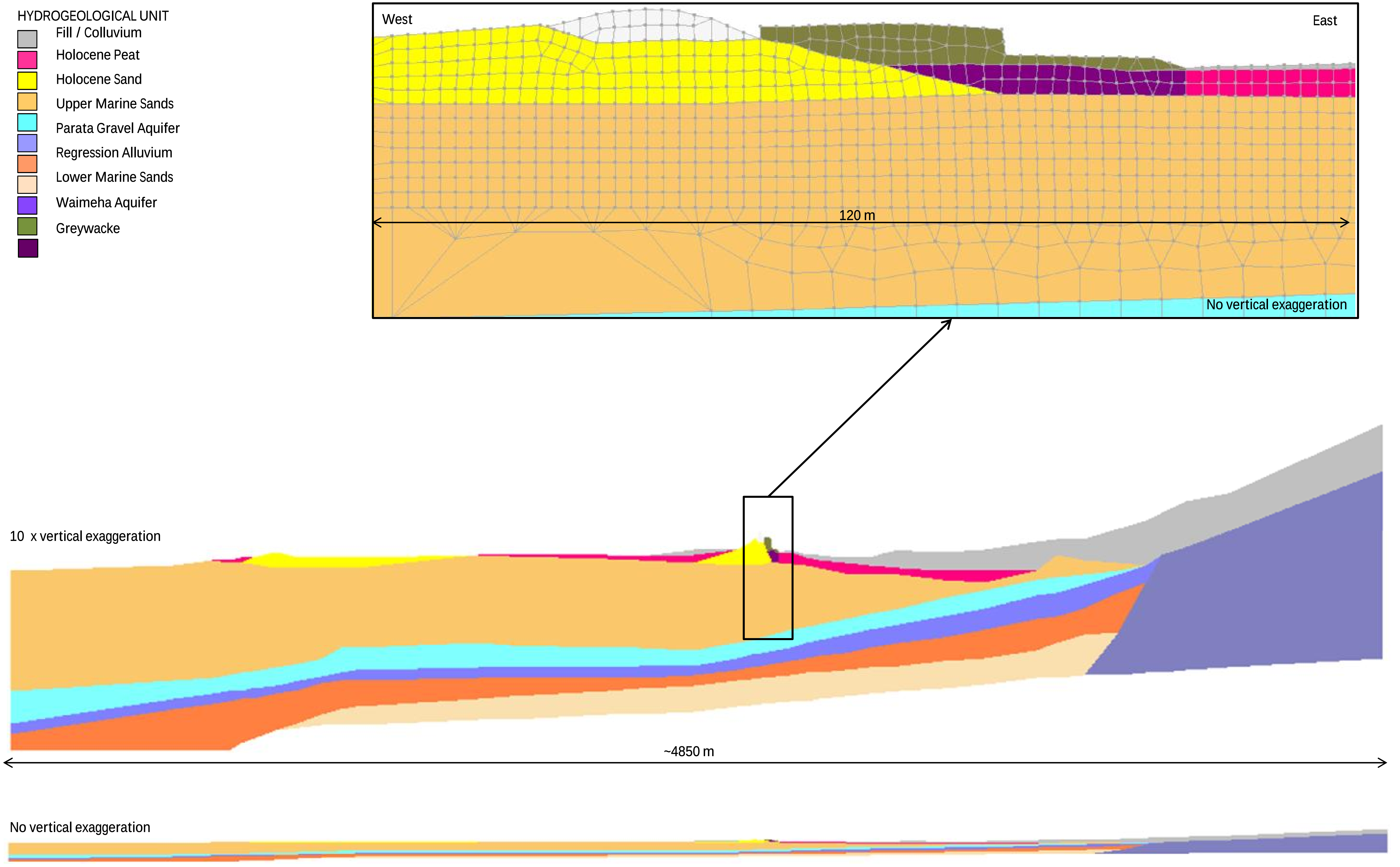
Section	Case	Change in Overall Groundwater Through Flow			Change in Water Level (m)
		Effect at Expressway	Effect @ 50 m-100 m	Effect at Coast	
CH6140 (detailed)	Excavate & replace peat	< -1%	< -2%	< -2 %	0.1 m to 0.2 m at Expressway, < 0.05 m in down-gradient peat
	Preload peat	< -1%	< -2%	< -2 %	- 0.1 m to -0.2 m at Expressway, < -0.05 within 10 – 20 m distance
CH16000 (detailed)	Excavate peat and replace with sand under Expressway	< -2%	<-5%	< -2 %	0.1 to 0.2 m at Expressway, 0.1 to 0.15 within 600 m, <0.05 m within 1600 m distance
	Preload peat under Expressway, with bedding layer	< -2%	<-5%	50 % – 100 % in peat < -2 % overall	0.1 to 0.2 m at Expressway, 0.1 to 0.15 within 600 m, <0.05 m within 1600 m
CH5300 (detailed)	1m excavation for flood storage	-20%	-20 to -30% in peat, -50% overall	-20 to -30% (due to drainage of storage area)	0.9 m at Expressway; 0.8 to 0.9m up-gradient decreasing toward SH1; 0.7 m in down gradient peat
	1m peat excavated for flood storage, clay bund up-gradient	No change from above – bund not effective as there is no low permeability horizon to key into			
	1m peat excavated for flood storage, slurry wall up-gradient				
Generic Model	Simple geology, peat excavation and replacement	Not assessed as change in level very small			< 0.1 m at Expressway and beyond
	Simple geology, peat surcharging	Not assessed as change in level very small			< 0.1 m at Expressway and beyond



MacKays to Peka Peka

CH5300 (detailed)

Figure E1



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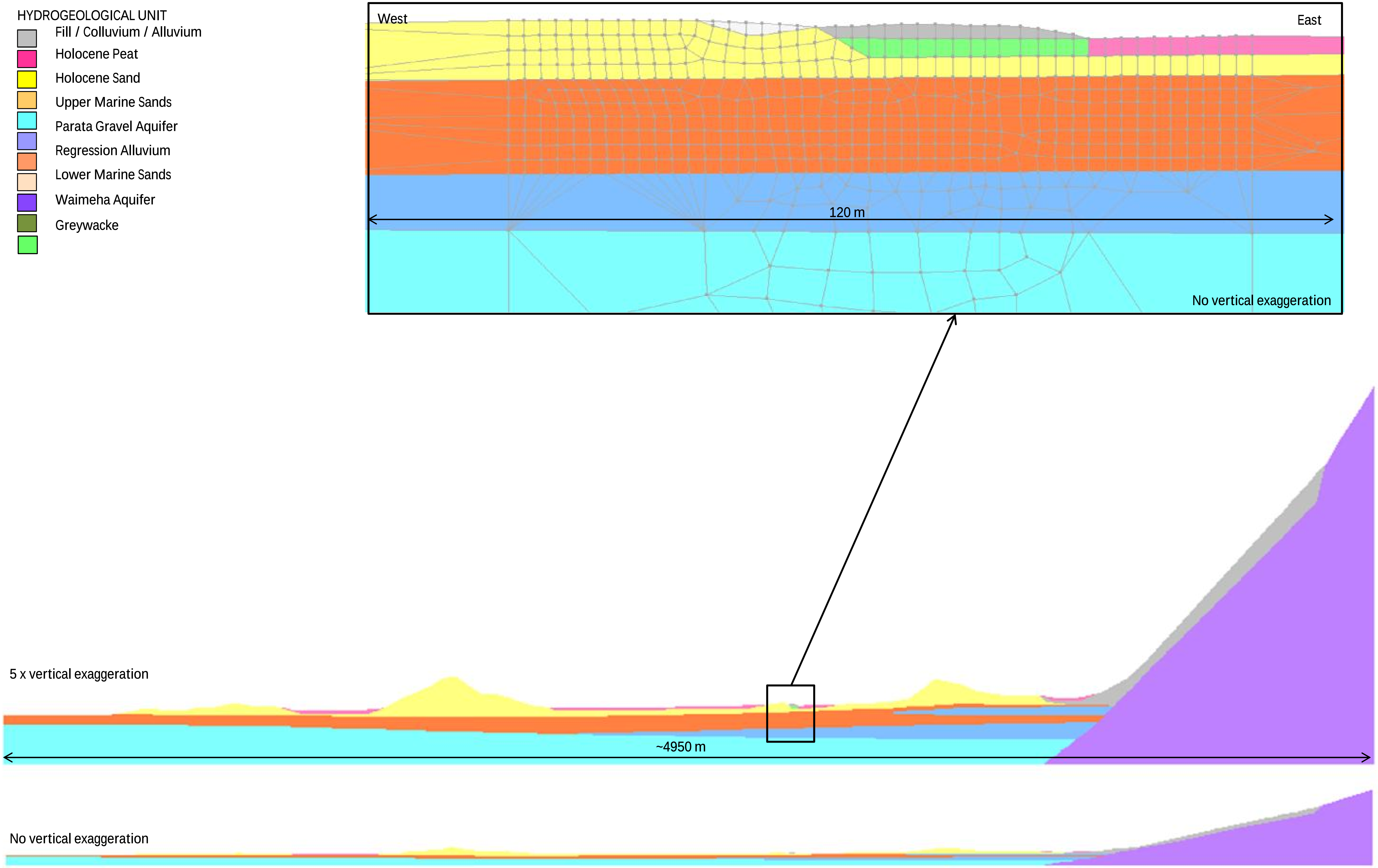
CH6140 (detailed)

Figure E1

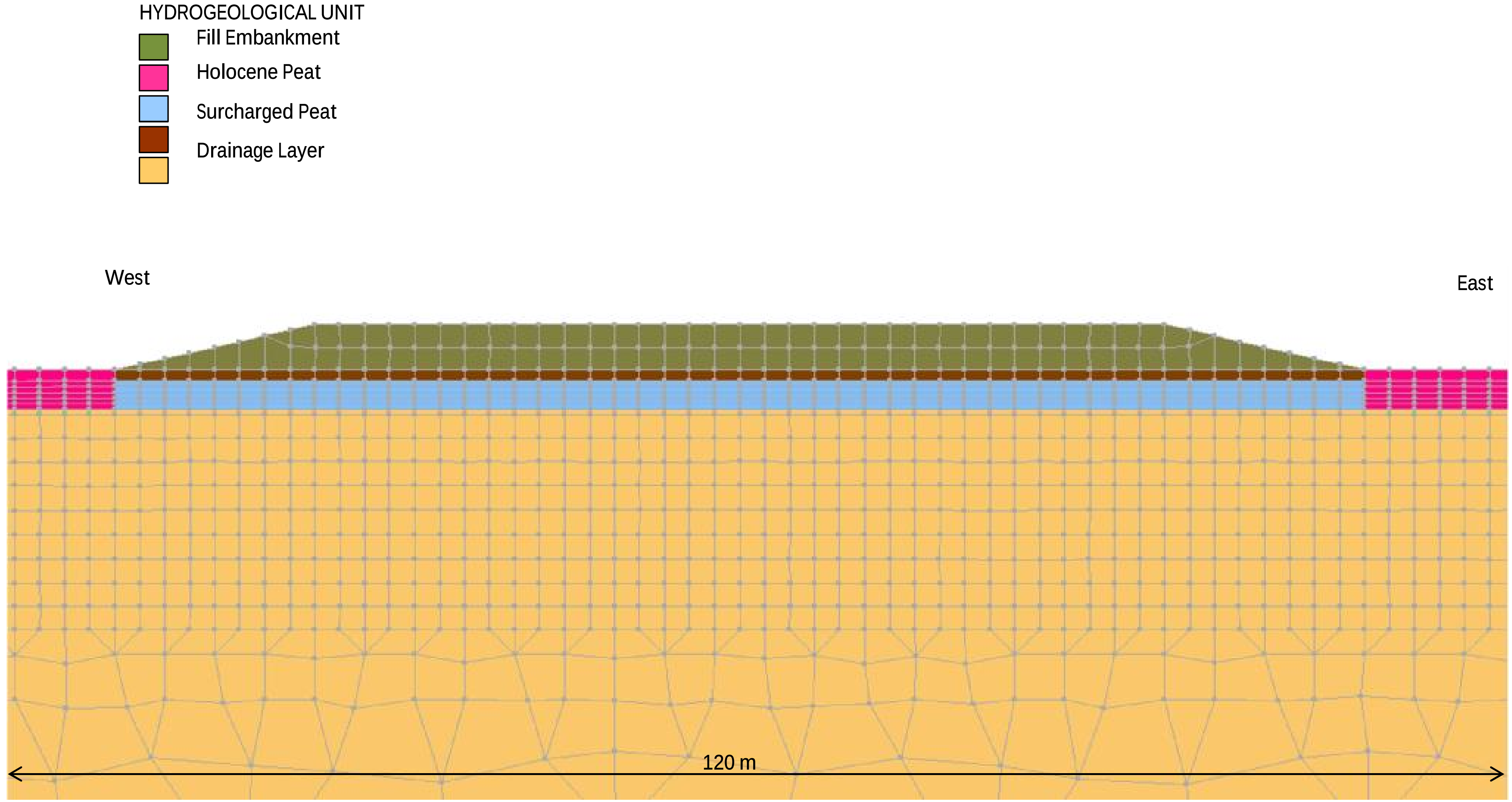


MacKays to Peka Peka

3320901/500/010

CH16000 (detailed)

Figure E1

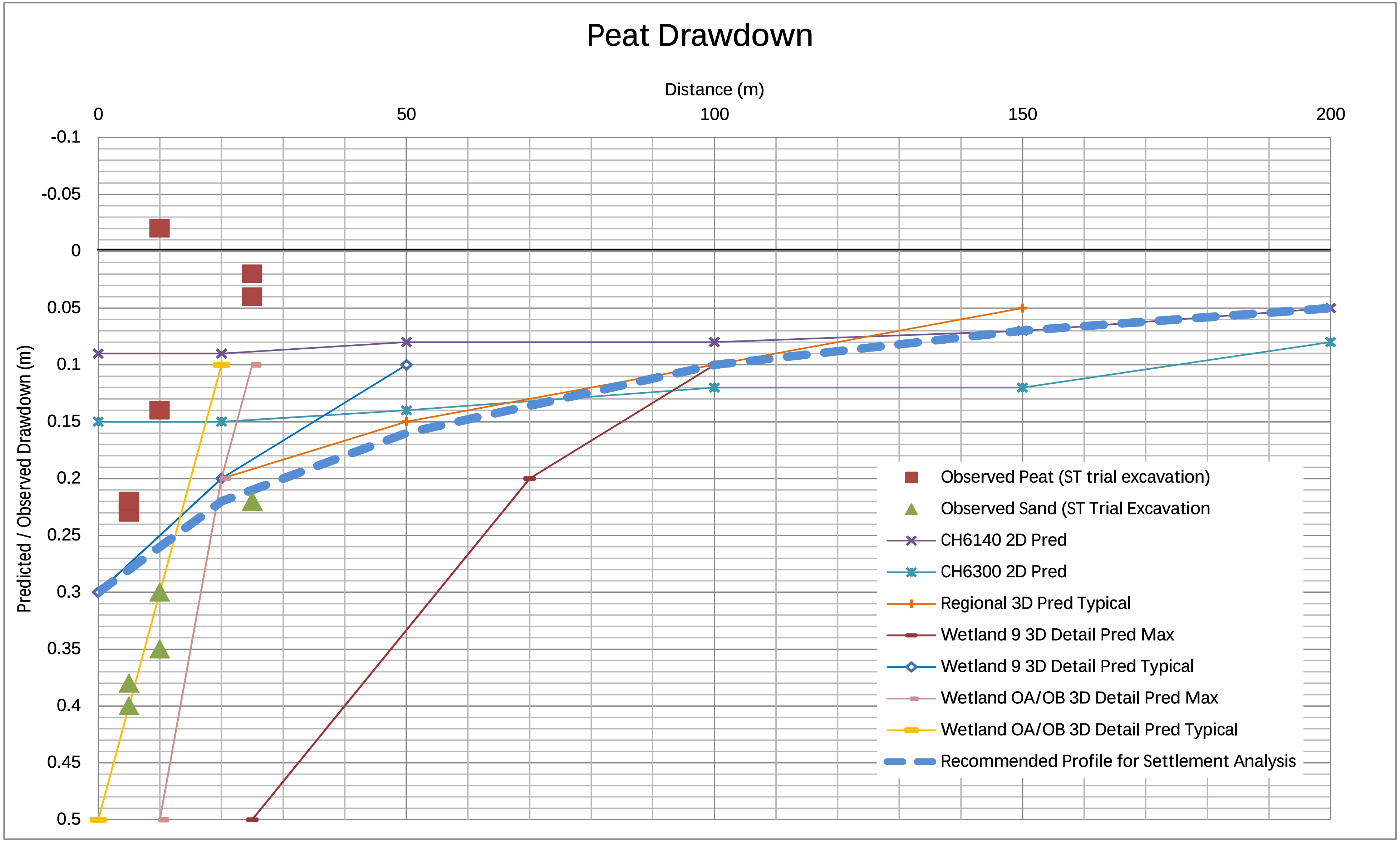


MacKays to Peka Peka

3320901/500/010

Generic Model

Figure E1



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3320901/500/010

Predicted and Observed Peat Drawdown Curves

Figure E2

Appendix 21.F

3D Groundwater Models

Appendix F – 3D Groundwater modelling

F1. Regional Model

F1.1. Model Set Up

Model Area, Extent and Grid Set –Up

In selecting a suitable model area the following was considered:

- Static water levels from long and short term piezometer records indicate a west-north-west flow direction from the Tararua Ranges towards the coastline;
- The model should incorporate the full extent of the Expressway, with the focus of the model (the Expressway) in the centre of the area to reduce the potential for "edge effects"; and
- Where possible the model boundaries should be known water levels.

The model domain covers an area of 15.5 km x 11.5 km (178 km^2), with the grid aligned orthogonal to the coastline in order to allow the general groundwater flow direction to be from right to left in the model (Figure F1). The eastern boundary of the model is the Tararua foothills (an "in-active" zone in the model). The northern boundary is located just north of Peka Peka Road and the southern boundary is located at Raumati South.

The grid resolution ranges between cell sizes of 400 m^2 and 40,000 m^2 with a cell size of 40 m by 40 m used in the area immediately surrounding the Expressway and gradually coarsening outwards to 200 m x 200 m at the edge of the model. Topographic data was sourced from LIDAR surveys (ALGGI Lidar Data, flown 2010), and imported into MODFLOW to define the ground surface. Vertically the model was divided into 11 hydrogeological layers to account for the differing hydrogeological units and hydraulic conductivities identified. The model comprises 176 rows and 284 columns for a total of 49,984 cells per model layer.

Both the regional steady state and regional transient models were set up with the same extents and grids.

Distribution of Hydrogeological Units

The 3-dimensional distribution of hydrogeological units was set up using data obtained from site specific investigations undertaken for the Project, existing well data records (GWRC), the computer programme Hydro GeoAnalyst (HGA) and the URS (2005) ground model. Model layers created in HGA were exported into text files, gridded in Surfer 9.0 and then imported into Visual Modflow as layer elevations.

Hydrogeological parameters were assigned according to the results of in-situ hydraulic conductivity testing (rising head slug tests) carried out in piezometers installed as part of this Project, laboratory gradings, pumping testing carried out as part of groundwater investigations for Kāpiti Coast District Council and previous groundwater models for this area. The parameters were then adjusted to achieve calibration.

Figure F2 shows the distribution of units. The hydrogeological parameters that allowed satisfactory calibration of the regional model are presented in Table F1.

Model Boundaries

There are a number of surface water bodies (streams, wetlands and the sea) which disect the model area. Because of the regional nature of the model and coarse cell size, only the main surface water bodies have been considered.

The Waikanae River and Waimeha Stream have been modelled using the River Package function that simulates surface water / groundwater interaction via a seepage layer which separates the surface water body from the groundwater body. Depending on the hydraulic gradient between the two systems, the rivers can act as recharge or discharge zones.

The Mazengarb Drain is modelled using the Drain Package Function.

The conductance values for the rivers and drains are as used in Gyopari (2005):

- Waimeha Stream conductance = 50,000 m/day;
- Waikanae River conductance = 5,000 m/day;
- Ngarara Stream conductance = 50,0000 m/day;
- Mazengarb Drain conductance = 8,000 m/day; and
- Local Agricultural Drains conductance = 50,000 m/day.

The coastal boundary has been modelled using the Constant Head Boundary (CHB) function that simulates sea level at 0 m head. A CHB is used to fix the head values in a cell; it therefore acts as an infinite groundwater source or sink.

Table F1: Hydrogeological Layers and Parameters

Hydrogeological Unit		Model Layers	Hydraulic Conductivity (m/s)		Storativity		Specific Yield	
			Observed	Calculated	Observed	Calculated	Observed	Calculated
1.	Holocene Alluvium	1 & 3	2×10^{-7} to 2×10^{-4}	$K_h = 3 \times 10^{-3}$ $K_v = 3 \times 10^{-5}$	n/a	0.3	n/a	0.3
2.	Holocene Peat	2	2×10^{-9} to 1×10^{-5}	$K_h = 4 \times 10^{-6}$ $K_v = 1 \times 10^{-7}$	n/a	0.5	n/a	0.5
3.	Holocene Sand	4	4×10^{-7} to 2×10^{-4}	$K_h = 5 \times 10^{-5}$ $K_v = 5 \times 10^{-5}$	0.005	0.001	n/a	0.001
4.	Pleistocene Sand	5, 7, 11 & 13	2×10^{-7} to 4×10^{-4}	$K_h = 5 \times 10^{-5}$ $K_v = 1 \times 10^{-5}$		0.05	n/a	0.05
5.	Pleistocene Silt/ Clay	6, 9 & 12		$K_h = 1 \times 10^{-6}$ $K_v = 1 \times 10^{-7}$	n/a	3×10^{-4}	n/a	
6.	Parata Aquifer	8, 10	5×10^{-4}	$K_h = 5 \times 10^{-4}$ $K_v = 2 \times 10^{-5}$	n/a	1×10^{-4} to 4×10^{-4}	n/a	
7.	Waimea Aquifer	14	*$T = 300\ m^2/d$*	$K_h = 5 \times 10^{-4}$ $K_v = 1 \times 10^{-4}$	4×10^{-4}	5×10^{-5} to 4×10^{-4}	n/a	

The eastern boundary has been assigned as a no flow boundary where the greywacke is outcropping at the foothills of the Tararua Ranges. Up-gradient flow from the greywacke is considered using a CHB, with the head set at ~RL 15 m according to nearby borehole data.

Both the regional steady state and regional transient model were set up with the same model boundaries.

Water Abstraction

In order to account for the likely groundwater take from the approximately 3,000 domestic water bores in the area ~5,000 m^3/day was removed from the water balance. As the exact details of how much water is taken from each well are unknown, we have assumed that every well takes about 1.5 m^3/day (when averaged out to continuous 24/7 pumping). The cumulative take is considered as an evapotranspiration with the ~5,000 m^3/day taken evenly over the model area.

The proposed construction water take was simulated in a transient model that includes the cumulative effects from the constructed Expressway and stormwater devices. Nine pumping wells are proposed along the alignment, to minimise water cartage, with a maximum proposed groundwater take of 750 m^3/day (9 l/s) from a single well and 1990 m^3/day (22 l/s) cumulatively. The proposed pumping schedule was applied in monthly time steps; conservatively this assumes continuous abstraction at the proposed rate 24 hours per day throughout the month and therefore does not take into account any recovery that will occur during rest periods or periods of lower abstraction. Details of the proposed abstraction schedule are given in Section 3.2 of Technical Report 4, Construction Methodology Report and shown on the M2PP-AEE-DWG-CV-CM-400 Plan series.

Recharge

Rainfall in the Kāpiti Coast area is on average 1311 mm/year. The proportion of that rainfall that recharges to groundwater varies with land use (urban vs. non-urban) and soil type (peat vs. sand vs. gravel) and this has been considered in the regional model through establishment of different recharge zones, as outlined in Table F2.   The distribution of these zones is show in Figure F3.

Table F2: Recharge Factors (modified from Gyopari, 2005)

Soil and Land Use Type	Soil Recharge Factor	Land Use Recharge Factor	Total Recharge Factor
Urban sand	0.4	0.15	0.06
Non-urban sand	0.4	1.0	0.40
Urban peat	0.35	0.15	0.05
Non-urban peat	0.35	1.0	0.35
Urban Parata Gravel	0.5	0.15	0.08
Non-urban Parata Gravel	0.5	1.0	0.50
Where a factor of 1.0 indicates that 100 % of rainfall is available for recharge e.g. 40 % of all rainfall that falls on sand is available for recharge however in the urban area, up to 70 % of that rainfall will be captured by drainage and stormwater so only 12 % of total rainfall is actually available for recharge			

Both the pre-construction and post-construction transient regional models were run for approximately 8 years and replicate the rainfall data from July 2003 to April 2011 recorded in fortnightly increments. This method allows for the direct comparison of pre-construction and post-construction water levels. The transient model was divided into 203 stress periods of approximately 14 days length (increasing to 250 stress periods when the pumping schedule is applied), with each stress period being divided into 10 incrementally increasing time steps.

F1.2. Model Calibration

Initially a steady state model for average long term conditions was developed, and this model was calibrated using the average static water levels, the average rainfall recharge from GWRC records and using the conceptual water budget.

The focus of calibration has been on groundwater levels recorded in standpipe piezometers or wells of known construction, with a reliable long term record of groundwater levels, though some consideration has also been given to the limited data provided from private wells in the area (refer section D2.2).

The steady state regional 3D model was calibrated to a target Normalised Root Mean Square (RMS) error of 10.8 %, and a residual mean error of +/- 0.4 m for average groundwater levels in all wells (Figure F4).

Qualitatively a check was made that the model also replicated general flow features such as overall direction and gradients of flows.

Under steady state conditions calculated inflows to the model are 113,420 m^3/day. Approximately 60 % of all inflow is sourced from rainfall recharge, with rivers and up-gradient flow contributing the remainder. This is comparable to analytically calculated outflow derived from Darcy's Law and the conceptual water balance outlined in Appendix D. A comparison of the modelled inflow and outflow, the conceptual water balance and analytically calculated outflow derived from Darcy's Law is provided in Table F3.

Table F3: Modelled Water Balance for Steady State (Natural) Model

Source / Sink	Flow Into Model (m^3/d)	Flow Out of Model (m^3/d)
Storage	0	0
Constant Head Boundaries	25,075	61,746
Rainfall Recharge	67,936	0
River Leakage	20,409	36,962
Drains	0	9,420
General Heads	0	0
Domestic Abstraction	0	4,919
TOTAL	113,420	113,047
Discrepancy (Outflow – Inflow)	-373 m^3/d	
	0.33%	
Conceptual Water Balance	116,000	108,000
Darcy	114,000 m^3/d	

A transient model considering variations in rainfall over the last 8 years (July 2003 to April 2011) was also developed to check that the model appropriately simulates the groundwater system under seasonal changes. A plot of selected piezometers showing the calibration of the transient model over time is provided in Figure F5. Calibration focused on replicating the approximate magnitude of seasonal variation.

F1.3. Model Sensitivity

Model sensitivity was assessed by comparing the calibrated RMS (a measure of calibration or fit of the data) with the RMS that results from changing individual parameters; a large change in the modelled heads result from minor changes in the parameter value and indicates that the model is sensitive to that parameter. Sensitivity analysis has been carried out by systematically changing the calibrated parameters in turn by factors of 0.1, 0.5, 0.75, 1.25, 1.5 and 10. The sensitivity of the model to these changes is shown in Figure F6.

Figure F6 shows that the model is relatively insensitive to changes in hydraulic conductivity in the upper three layers (alluvium, peat and sand) with even larger changes to the hydraulic conductivities of these units changing the RMS by less than 0.2 m. However a large change (an order of magnitude) to the horizontal hydraulic conductivity in layer 4 (Figure F6) does have a more noticeable effect, changing the RMS by 0.4 m.

Likewise small changes (x 0.1 to x 1.5) in rainfall recharge have only a very minor effect on the RMS, but a large change in rainfall recharge (increase by a factor or 10) has a large effect on RMS.

These results indicate that a satisfactory calibration has been achieved.

F1.4. Results of Numerical Modelling

Predicted Changes in Water Level Due to Expressway

Several long term steady state and transient scenarios and short term transient scenarios were considered in order to assess the potential effects of the Expressway and associated works:

Scenario			Rainfall		Expressway & Storm Water Devices	Construction Pumping Wells
No.	Duration	Type	Average	Variable		
1.	30 years	SS	✓		×	×
2.	30 years	SS	✓		✓	×
3.	8 years	Tr		✓	×	×
4.	8 years	Tr		✓	✓	✓
5.	8 years	Tr		✓	✓	×
Variable rainfall = 2003 to 2011 rainfall record						

The results of modelling suggest that the proposed peat treatment methodologies have a small effect on groundwater levels, with changes in level of less than 0.3 m immediately adjacent to the Expressway (and generally extending for no more than 20 m) resulting from either excavating and replacing, or surcharging the peat (Figure F7). This compares to seasonal variation in water levels of 0.3 m to 0.8 m. The limited extent of drawdown means that changes to water level in adjacent wetlands are not expected. As such, potential effects on groundwater through-flow and adjacent wetlands are judged to be undetectable.

As the predicted changes in water level in the Holocene Peat due to the Expressway are of limited extent they result in negligible changes in water levels within wetlands; an assessment of the effect of predicted water level changes on habitats and biodiversity is given in Technical Report 26, Volume 3.

Predicted Changes in Water Level Due to Stormwater Devices

Where groundwater lowering is proposed for flood offset storage (i.e. Wharemauku), average long term drawdown of up to 0.6 m is likely immediately adjacent to the area, with measurable drawdown extending for up to 300 m. In summer months, drawdown from natural levels of up to 1.0 m may occur immediately adjacent to the pond, with measurable drawdown extending for up to 600 m. Whilst this is likely to have some beneficial effects for adjacent residential areas currently affected by surface flooding, consolidation settlement is expected to occur. This effect is considered in Technical Report 35, Volume 3.

No significant drawdown is predicted resulting from wetland OA (and associated flood storage areas) or wetland 9 due to the lining of wetlands which limits interactions.

Water Supply

The construction water take wells will have a negligible effect on shallow groundwater levels, and are not expected to affect known private wells. Transient modelling indicates that if the construction water wells were to operate at their proposed schedules[1] they could cause a drawdown of up to 2 m (though typically less than 1 m) in the Parata Gravels (through which they are screened) at the well, with drawdown decreasing to less than 0.1 m at a 1 km radius. Drawdown of less than 0.7 m is predicted within the shallow Marine or Holocene sands at the location of the construction water well. The abstraction could temporarily result in less than 0.5 m drawdown in the much deeper Waimea Gravels from which the KCDC abstracts most of the water for public supply. This level of drawdown in the overlying and underlying aquifers is unlikely to result in adverse effects for most existing users.

Transient modelling indicates that pumping of the construction wells will not exacerbate any seasonal effects, with the range of predicted water levels (maximum minus minimum) being largely

[1] Expected peak takes are simulated as they vary with time but modelling limitations mean that pumping is assumed to occur 24 hours per day continuously and hence does not consider recovery that occurs during periods of lesser or no pumping.

unchanged. Transient modelling also confirms that water levels recover to within 80 % of pre-pumping levels within 1 day of pumping ceasing such that no long term effects are expected.

Predicted Changes in Water Balance

Modelling suggests that changes to the overall water budget due to the long term Expressway are small. Direct groundwater flow to the coastal zone would not be altered as a result of construction of the Expressway, its associated stormwater devices or short term pumping for construction water take. This is important as it is a KCDC objective that Projects do not interfere with flows from the hills to the coast and be hydraulically neutral.

Modelling suggests that the groundwater contribution to rivers and streams may reduce by up to 1.5 % (peak) as a result of the short term construction water take. For the longer term, a reduction of 2 % is predicted over the whole Project area, however this relates wholly to groundwater diverted away from Wharemauku Stream and into offset storage areas 2, 3A and wetland 3 and the model does not consider that the water will be discharged back to this stream a short distance down-gradient (i.e. the take is actually non-consumptive and only affects a 600 m length of stream).

In the short term, the construction water take could result in up to a 3 % reduction in the volume of groundwater discharging to major surface (man-made) drains.

Table F4: Regional - Modelled Water Balance

Source / Sink	Natural SS Model		Expressway SS Model		Construction Take Wells Tr Model		Expressway Tr Model (wet winter)		Expressway Tr Model (dry summer)	
	In (m^3/d)	Out (m^3/d)	In (m^3/d)	Out (m^3/d)	In (m^3/d)	Out (m^3/d)	In (m^3/d)	Out (m^3/d)	In (m^3/d)	Out (m^3/d)
Storage	0	0	0	0	39	50	20	81,755	25,656	114
Constant Head	25,929	60,720	25,689	40,408	29,023	54,494	22,055	64,264	31,763	50,951
Rainfall Recharge	67,807	0	66,690	0	49,692	0	164762	0	9048	0
River Leakage	19,372	38,288	19,701	38,060	24,157	32,241	19664	42,798	25973	29766
Drain Leakage	0	8,988.5	0	8,846.9	0	6,214	0	8,534	0	5,854
SW Wetlands			786	647	47	2,143	42	3,092	57	1,989
General Heads	0	0	0	0	0	0	0	0	0	0
Domestic Wells	0	4,668	0	4,943	0	5,021	0	4,690	0	4,644
Const. Water Take	0	0	0	0	0	1,930	0	0	0	0
TOTAL	113,110	112,660	112,870	112,910	102,958	102,093	206,543	205,133	92,497	93,318
Disc. (Out – In)	-450 m^3/d		40 m^3/d		865 m^3/d		-1410 m^3/d		821 m^3/d	
	0.39 %		-0.03%		-0.85 %		- 0.69 %		0.88 %	

F2. Wetland OA

F2.1. Purpose of Model

A detailed model of the area surrounding wetland and flood offset storage areas OA, OB and OC was developed in order to assess:

- the interaction between the stormwater wetland (and the naturally occurring Raumati Manuka Wetland; and
- the potential for peat surcharge associated with embankment construction to reduce groundwater through-flow to the Raumati Manuka Wetland and cause up-gradient ponding.

F2.2. Model Set Up

Model Area, Extent and Grid Set –Up

In selecting a suitable model area the following was considered:

- Static water levels from long and short term piezometer records indicate a west-north-west flow direction from the Tararua Ranges towards the Coastline; and
- The model should incorporate Wetland OA & OB, with the focus of the model (the Expressway and wetlands) in the centre of the area to reduce the potential for "edge effects".

The model domain covers an area of 1 km x 1 km (1 km^2), with the grid aligned orthogonal to the coastline in order to allow the general groundwater flow direction to be from right to left in the model (Figure F1 and F1a).

A maximum single grid / cell size of 5 m x 5 m was selected with progressive grid refinement to 2 m x 2 m in the vicinity of the wetlands and corridor. The model comprises 398 rows and 398 columns for a total of 158,404 cells per model layer.

Topographic data was sourced from LIDAR surveys (ALGGI Lidar Data, flown 2010), and imported into MODFLOW to define the ground surface. The highest elevation in the model domain is 84.7 mRL (Holocene Sand) with the model extending to a depth of -47.2 mRL. Vertically the model was divided into 6 hydrogeological layers to account for the differing hydrogeological units and hydraulic conductivities identified. The grid however comprises 7 layers representing the sequence of the geological processes that have occurred in the last 400,000 years.

Distribution of Hydrogeological Units

As for the regional model, the distribution of hydrogeological units was derived from the geological model developed in Hydro GeoAnalyst (HGA).

The hydrogeological parameters were imported directly from the calibrated regional 3D model (and are described in Table F1).

Figure F2a shows a slice through the model and the distribution of hydrogeological units.

Model Boundaries

Other than Drain 7 there are no surface water features present to use as boundaries to the model; these are therefore taken from the appropriate position in the 3D regional model.

General Head boundaries (GHB) have been used to represent heads outside the model domain (that contribute to up and down-gradient flow) on all sides of the model. Head levels were set from the calibrated regional steady state model and adapted to allow for satisfactory model calibration.

Drain 7 was modelled using the Drain function that simulates the effects of drainage features by removing water from the aquifer at a rate proportional to the difference between the head in the aquifer and some fixed head or elevation. If the head in the aquifer falls below the fixed head of the drain then the drain has no effect. Elevation data for Drain 7 was approximated from site observations and topographic survey data.

Recharge

Recharge zones (and rates) were imported directly from the regional model, and where necessary refined to meet the detail of the LIDAR, mapped geology and land-use (Figure F3).

F2.3. Model Calibration

The groundwater model was calibrated using known static water levels recorded in piezometers over the entire model domain. However absence of accurate well data was problematic for calibration, with many head observations obtained from hand auger hole records (i.e undeveloped hole records) or private wells (single GWL with no indication of whether it is a static water level or affected by local pumping). This meant that both quantitative and qualitative calibration techniques have been used.

The steady state model was calibrated to a residual mean of less than +/- 1.0 m and within the expected range of groundwater levels based on limited records. Private wells and piezometers with artesian pressures were not included in the calibration and no spatial trend is apparent in the observed residuals.

A qualitative check was made that general flow features were replicated with the overall pattern of flow directions and gradients simulated. The model was also calibrated to an average GWL close to the surface beneath wetlands or to reported surface flooding levels. Limited areas of surface flooding in non-wetland areas exist in the model. Anecdotal evidence suggests small scale local drainage in these areas feeding into Drain 7 is used to control this flooding.

Under steady state conditions calculated inflow to the model is 1,121 m³/day (Table F5).

Table F5: Modelled Water Balance for Steady State (Natural) Model

Source / Sink	Flow Into Model (m³/d)	Flow Out of Model (m³/d)
Storage	0.00	0.00
Domestic Abstraction	0.00	8.49
Rainfall Recharge	870.26	0.00
River Leakage	0.00	0.00
Drains	0.00	755.51
General Heads	250.88	349.30
TOTAL	1121.1	1113.3
Discrepancy (Outflow – Inflow)		-7.8 m³/d
		-0.7 %

F2.4. Results of Numerical Modelling

Several long term scenarios were evaluated before identifying the preferred design:

Scenario			Rainfall		Expressway	Wetland OA	
No.	Duration	Type	Average	Variable		Lined	Unlined
1.	30 years	SS	✓		×	×	×
2.	30 years	SS	✓		✓		✓
3.	30 years	SS	✓		✓	✓	
4.	8 years	Tr		✓	×	×	×
5.	8 years	Tr		✓	✓	✓	
Variable rainfall = 2003 to 2011 rainfall record							

Predicted Changes in Water Level

Within this area it is proposed to surcharge the peat in order to enable embankment construction. The two end members of peat compression (20 % and 50 %) were tested to assess the likely magnitude and extent of long term changes to average groundwater levels as a result of peat compression and GWL lowering around wetland OB. In addition peat excavation and replacement was also considered to assess if one methodology was more suitable than the other for this location. The results of steady state modelling suggest that there is negligible difference long term between the various peat treatment options (Figure 7a).

The majority of measurable, albeit still small, GWL changes result from the constructed stormwater wetland with only negligible changes due to the Expressway (and hence degree of peat consolidation does not have a significant impact on predicted results). For a lined pond (recommended design option), modelling suggests a maximum lowering of GWL in the peat of around 0.5 m immediately adjacent to wetland OA, reducing to less than 0.1 m within 20 m to 40 m of the Expressway (Figure F8a). Comparable levels of drawdown are predicted for the scenario where peat is excavated and replaced.

Modelling indicates no drawdown is expected in private wells in the vicinity.

The results of the transient models indicate that the maximum drawdown below naturally occurring low groundwater levels is 0.5 m as described above, i.e. the proposed works are not exacerbated by seasonal effects.

Predicted Changes in Water Balance

Modelling suggests that changes to the overall, long term water budget are unlikely to be discernible. The total aquifer budget is predicted to change by less than 1 % (Table F6) as a result of embankment and stormwater wetland construction (assuming the wetland is lined).

Some minor seepage through the base of the pond can be expected (~40 m^3/d), reducing in the long term as the base becomes blinded.

Table F6: Wetland 0A Modelled Water Balance (Steady State)

Source / Sink	Natural SS Model		Long Term Expressway with 50 % Peat Compression & Lined Wetland	
	In (m³/d)	Out(m³/d)	In (m³/d)	Out(m³/d)
Storage	0.00	0.00	0.00	0.00
Constant Head	0.00	0.00	0.00	0.00
Rainfall Recharge	870.26	0.00	792.63	0.00
River Leakage	0.00	0.00	0.00	0.00
Drains	0.00	755.51	0.00	720.15
Wetland Ponds	0.00	0.00	17.90	0.00
General Heads	250.88	349.3	260.50	331.95
Domestic Abstraction	0.00	8.49	0.00	11.19
TOTAL	1121.1	1113.3	1071.03	1063.29
Discrepancy (Outflow – Inflow)	-7.85 m³/d		-7.75 m³/d	
	-0.7 %		-0.73 %	

Table F7: Wetland 0A Modelled Water Balance (Transient)

Source / Sink	Transient Winter Conditions				Transient Summer Conditions			
	Natural		Constructed		Natural		Constructed	
	In (m³/d)	Out (m³/d)	In (m³/d)	Out (m³/d)	In (m³/d)	Out (m³/d)	In (m³/d)	Out (m³/d)
Storage	0.0	2.8	0.4	6.1	2.5	0.0	11.3	0.0
Constant Head	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rainfall Recharge	2140.2	0.0	2039.0	0.0	117.5	0.0	111.9	0.0
River Leakage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drains	0.0	754.8	0.0	728.5	0.0	745.4	0.0	700.2
Wetland Ponds	0.0	0	0.6	6.3	0.0	0.0	0.6	4.6
General Heads	252.0	341.8	256.7	365.9	254.9	331.0	273.2	307.4
Domestic Abstraction	0.0	70.6	0.00	70.6	0.0	62.6	0.00	62.6
TOTAL	2392.2	1170.0	2296.7	1177.4	374.9	1139.0	397.0	1074.8
Discrepancy (Outflow – Inflow)	-1222.2		-1119.3		764.1		677.8	
	105 %		95 %		67%		63 %	

F3. Offset Storage Areas 2, 3A and Wetland 3

F3.1. Purpose of Model

A detailed model in the vicinity of flood storage areas 2, 3A and wetland 3 was developed in order to assess:

- The effect of groundwater lowering associated with storage areas 2, 3A and wetland 3 and proposed flood offset storage measures, specifically the magnitude and extent of drawdown, and the potential for such drawdown to result in:
  - lowering of groundwater levels in private wells
  - reduction in groundwater levels or base flow contributions to Wharemauku Stream; and / or
  - consolidation settlement beneath residential dwellings; and
- The potential for peat surcharge or excavation associated with embankment construction to change groundwater levels.

F3.2. Model Set Up

Model Area, Extent and Grid Set –Up

In selecting a suitable model area the following was considered:

- Static water levels from long and short term piezometer records indicate a west-north-west flow direction from the Tararua Ranges towards the Coastline; and
- The model should incorporate storage areas 2, 3A and wetland 3, with the focus of the model (the Expressway and wetlands) in the centre of the area to reduce the potential for “edge effects”.

The model domain covers an area of 1 km x 1 km (1 km^2), with the grid aligned orthogonal to the coastline in order to allow the general groundwater flow direction to be from right to left in the model (Figure F1 and F1b).

A maximum single grid / cell size of 5 m x 10 m was selected with progressive grid refinement to 2 m x 2 m in the vicinity of the storage areas and Expressway corridor. The model comprises 176 rows and 284 columns for a total of 49,984 cells per model layer.

Topographic data was sourced from LIDAR surveys (ALGGI Lidar Data, flown 2010), and imported into MODFLOW to define the ground surface. The highest elevation in the model domain is 13.7 mRL (Holocene Sand) and the model extends to a depth of -48 mRL. Vertically the model is divided into 6 hydrogeological layers to account for the differing hydrogeological units and hydraulic conductivities identified. The grid however comprises 11 layers in accordance with the geological model.

Distribution of Hydrogeological Units

The distribution of hydrogeological units has been taken from the Hydro GeoAnalyst (HGA) ground model that was developed from site specific investigations undertaken for the Project and existing well data records (GWRC).

The hydrogeological parameters were imported directly from the calibrated regional 3D model (and are described in Table F1). Figure F2b shows the distribution of units.

Model Boundaries

General Head boundaries (GHB) have been used to represent heads outside the model domain (that contribute to up and down-gradient flow) on all sides of the model. Head levels were set from the calibrated regional steady state model.

Wharemauku Stream and Drain 5 were modelled using the River Recharge Package function that simulates surface water/ groundwater interaction via a seepage layer which separates the surface water body from the groundwater body. Depending on the hydraulic gradients between the two systems, the rivers can act as recharge or discharge zones. River stage and elevation data for Wharemauku Stream and Drain 5 were approximated from site observations, topographic survey data and stormwater modelling (KCDC and SKM).

Recharge

Recharge zones (and rates) were imported directly from the regional model, and where necessary refined to meet the detail of the LIDAR, mapped geology and land-use.

Model Calibration

The groundwater model was calibrated using known static water levels recorded in piezometers over the entire model domain. However absence of accurate well data was problematic for calibration, with the majority of head observations being from test pits and hand augers or private wells (single GWL with no indication of whether a static water level or affected by local pumping). For this reason calibration was both quantitative and qualitative.

The steady state model was calibrated to a residual mean of +/- 1.0 m and within the expected range of groundwater levels based on limited records (Figure F4).

A qualitative check was made that general flow features were replicated with the overall pattern of flow directions and gradients simulated. Also the model was calibrated to an average GWL close to the surface beneath Rata Rd (where anecdotal evidence suggests the GWL is close to the surface year round) and to surface flooding within the existing areas of wetland vegetation in winter and periods of high rainfall. Under steady state conditions calculated inflows to the model are 2,294 m^3/day (Table F8).

Table F8: Modelled Water Balance for Steady State (Natural) Model

Source / Sink	Flow Into Model (m^3/d)	Flow Out of Model (m^3/d)
Storage	0.00	0.00
Constant Head Boundaries	0.00	0.00
Rainfall Recharge	738.4	0.00
River Leakage	0.00	2,000.4
Drains	0.00	232.79
General Heads	1555.6	68.32
TOTAL	2,294.0	2301.5
Discrepancy (Outflow – Inflow)	7.55 m^3/d	
	0.33%	

F3.3. Results of Numerical Modelling

Several long term steady state (SS) and transient (Tr) scenarios for Expressway construction and stormwater devices have been evaluated:

Scenario			Rainfall		Expressway, SAs 2/3A and Wetland 3 Lowered 1.0 m	Expressway, SAs 2/3A and Wetland 3 Lowered 0.6 m
No.	Duration	Type	Average	Variable		
1.	30 years	SS	✓		×	×
2.	30 years	SS	✓		✓	×
3.	30 years	SS	✓		×	✓
3.	8 years	Tr		✓	×	×
4.	8 years	Tr		✓	×	✓
Variable rainfall = 2003 to 2011 rainfall record						

Predicted Changes in Water Level

Within this area it is proposed to surcharge the peat in order to enable embankment construction. The two end members of peat compression (20 % and 50 %) were initially tested to assess the likely magnitude and extent of long term changes to average groundwater levels, as a result of peat compression and GWL lowering in offset storage areas 2, 3A and wetland 3. The results of steady state modelling suggest there is no measurable drawdown resulting from the embankment construction for either scenario.

The majority of measurable GWL changes result from the proposed groundwater lowering associated with storage areas 2, 3A and wetland 3. Initially a lowering of ground (and groundwater) level of 1 m over a small surface area was trialled for storage areas 2, 3A and wetland 3, however this resulted in drawdown extending some distance beyond the wetlands; an alternative design with 0.6 m lowering over a wider surface area was trialled with more favourable results and this was adopted as the design for assessing transient effects.

Steady state modelling suggests a maximum lowering of GWL in the peat of around 0.5 m immediately adjacent to wetland 2, and at the front boundary of properties along Rata Road (Figure F7b). Measurable drawdown (0.1 m) is likely to extend for some 200 m to 300 m distance radially out from the wetland. Drawdown of up to 0.1 m is likely at the back of properties along Wedgewood and Konini Groves as a result of lowering the level of storage areas 2, 3A and wetland 3.

The results of transient modelling indicate that the maximum reduction in GWL below the naturally occurring lowest level is 0.5 m (as per the steady state model) and the maximum reduction below the naturally occurring highest level is 0.5 m (i.e. the proposed works do not exacerbate seasonal effects, and they may improve flooding in some areas) (Figure F8b).

Modelling indicates a maximum drawdown in 3 private wells (R26/7163, R26/5176 and R26/5555) of up to 0.2 m. This level of drawdown is unlikely to have adverse impacts though it is possible that if these wells are very shallow they may need to be deepened or an alternative water source identified.

Predicted Changes in Water Balance

Modelling suggests that overall, the long term water budget is likely to be reduced by less than 9 % as a result of embankment construction and groundwater lowering.

The lowering of groundwater for flood storage is likely to reduce the natural groundwater contribution to the Wharemauku Stream (a reduction of 17 %) and Drain 7 (a reduction of 13 %) over a length of approximately 600 m immediately adjacent to storage areas 2 and 3. This volume of groundwater which would previously have discharged directly to the stream and drain will instead be discharged to the offset flood area, where it will then be redirected in a controlled manner back to the stream. For this reason the overall take is non-consumptive and the effects on the stream are for the most part unlikely to be discernible, with the exception of the 600 m length adjacent to the flood offset storage areas.

Modelling suggests that up to 200 m^3/d of groundwater will need to be removed from flood storage areas 2, 3A and wetland 3.

Table F9: Flood Storage Areas 2, 3A and Wetland 3 - Modelled Water Balance (Steady State)

Source / Sink	Natural SS Model		Long Term Expressway with 50 % Peat Compression & SAs 2, 3A/Wetland 3	
	In (m^3/d)	Out (m^3/d)	In (m^3/d)	Out (m^3/d)
Storage	0.00	0.00	0.0	0.0
Constant Head	0.00	0.00	0.0	0.0
Rainfall Recharge	738.4	0.00	614.8	0.0
River Leakage	0.00	2,000.4	0.7	1669.9
Drains	0.00	232.8	0	160.6
Wetland Ponds	0.00	0.00	10.14	199.9
General Heads	1,555.6	68.3	1452.5	55.0
TOTAL	2,294.0	2,301.5	2078.1	2085.4
Discrepancy (Outflow – Inflow)	7.55 m^3/d		7.28 m^3/d	
	0.33 %		0.35 %	

Table F10: Flood Storage Areas 2/3A and Wetland 3 - Modelled Water Balance (Transient)

Source / Sink	Transient Winter Conditions				Transient Summer Conditions			
	Natural		Constructed		Natural		Constructed	
	In (m^3/d)	Out (m^3/d)	In (m^3/d)	Out (m^3/d)	In (m^3/d)	Out (m^3/d)	In (m^3/d)	Out (m^3/d)
Storage	0.0	1015.9	0.1	637.5	0.0	1.3	1.1	0.0
Constant Head	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rainfall Recharge	1814.4	0.0	1516.4	0.0	99.6	0.0	83.2	0.0
River Leakage	0.0	1783.9	0.7	1708.1	0.0	1647.2	1.7	1653.7
Drains	0.0	228.1	0.0	121.9	0.0	212.2	0.0	119.0
Wetland Ponds	0.0	0.0	0.9	369.0	0.0	0.0	1.0	207.0
General Heads	1298.6	80.7	1402.6	75.1	1417.7	45.4	1457.7	52.1
TOTAL	3113.0	3108.6	2920.7	2911.6	1517.3	1906.1	1544.7	2031.8
Discrepancy (Outflow – Inflow)	-4.4 m^3/d		-9.1 m^3/d		388.8 m^3/d		487.1 m^3/d	
	-0.1 %		-0.3 %		20.3 %		31.5 %	

F4. Wetland 9 (El Rancho) / Puriri Drive

F4.1. Purpose of Model

A detailed model was developed in the El Rancho area to assess:

- The interaction between the stormwater wetland 9 and the naturally occurring wetland to the west of the proposed Expressway; and
- The potential for peat excavation and replacement, associated with embankment construction, to change groundwater through flow or levels in the natural wetland.

F4.2. Model Set Up

Model Area, Extent and Grid Set –Up

In selecting a suitable model area the following was considered:

- Static water levels from long and short term piezometer records indicate a north-west flow direction from the Tararua Ranges towards the Coastline; and
- The model should incorporate Wetland 9, with the focus of the model (the Expressway and wetlands) in the centre of the area to reduce the potential for "edge effects".

The model domain covers an area of 1.5 km x 1.5 km (2.25 km^2), with the grid aligned orthogonal to the coastline in order to allow the general groundwater flow direction to be from bottom to top in the model (Figure F1 and F1c).

A maximum single grid / cell size of 5 m x 5 m was selected with progressive grid refinement to 2.5 m x 2.5 m in the vicinity of the wetlands and corridor. The model comprises 425 rows and 435 columns for a total of 184,875 cells per model layer.

Topographic data was sourced from LIDAR surveys (ALGGI Lidar Data, flown 2010), and imported into MODFLOW to define the ground surface. The highest elevation in the model domain is 14.7 mRL (Holocene Sand) with the model extending to a depth of -118.6 mRL. Vertically the model was divided into 6 hydrogeological layers to account for the differing hydrogeological units and hydraulic conductivities identified. The grid however comprises 12 layers in accordance with the geological model.

Distribution of Hydrogeological Units

The distribution of hydrogeological units was taken from the Hydro GeoAnalyst (HGA) ground model (Appendix A) developed from site specific investigations undertaken for the Project, existing well data records (GWRC) and the URS (2005) ground model.

The hydrogeological parameters were imported directly from the calibrated regional 3D model, with the exception of the alluvium. In order to achieve a satisfactory calibration the alluvium in this area was assigned a horizontal hydraulic conductivity of 1 x 10^{-6} m/s and a vertical hydraulic conductivity of 1 x 10^{-8} m/s, within the range of expected permeability, and consistent with site observations of a bedded sand, gravel and silt, and local springs.

Figure F2c shows a slice through the model and the distribution of the hydrogeological units.

Model Boundaries

General Head boundaries (GHB) have been used to represent heads outside the model domain that contribute to up and down-gradient flow at each edge of the model. Head levels were set from the calibrated regional steady state model and adapted to allow for satisfactory model calibration.

The Waikanae River and Waimeha Stream were modelled using the River Recharge Package function that simulates surface water/ groundwater interaction via a seepage layer which separates the surface water body from the groundwater body. Depending on the hydraulic gradients between the two systems, the rivers can act as recharge or discharge zones. River stage and elevation data for the Waikanae River and Waimeha Stream were approximated from site observations, topographic survey data and stormwater modelling (KCDC and SKM).

Recharge

Recharge zones (and rates) were imported directly from the regional model, and where necessary refined to meet the detail of the LIDAR, mapped geology and land-use (Figure 3).

F4.3. Model Calibration

The groundwater model was calibrated using known static water levels recorded in piezometers over the entire model domain. However absence of accurate well data was problematic for calibration, with the majority of head observations resulting from isolated handauger hole water levels. This meant that calibration needed to be both quantitative and qualitative.

The steady state model was calibrated to a residual mean of less than +/- 1 m and within the expected range of groundwater levels based on the limited records. A plot of observed vs calculated residuals is presented in Figure F4. Private wells and piezometers with artesian pressures were not included in the calibration and no spatial trend is apparent in the observed residuals.

A qualitative check was made that general flow features were replicated with the overall pattern of flow directions and gradients simulated. Also the model was calibrated to an average GWL close to the surface or with surface flooding within the existing areas of wetland vegetation.

Under steady state conditions calculated inflows to the model are 3,279 m^3/day (Table F11).

Table F11: Modelled Water Balance for Steady State (Natural) Model

Source / Sink	Flow Into Model (m^3/d)	Flow Out of Model (m^3/d)
Storage	0.00	0.00
Domestic Abstraction	0.00	34.8
Rainfall Recharge	2,342.1	0.00
River Leakage	375.99	2,960.9
Drains	0.00	0.00
General Heads	560.5	284.1
TOTAL	3,278.5	3,279.2
Discrepancy (Outflow – Inflow)		1.3 m^3/d
		0.04 %

F4.4. Results of Numerical Modelling

Several long term steady state (SS) and transient (Tr) scenarios have been evaluated:

Scenario			Rainfall		Expressway	Unlined Wetland 9	Lined Wetland 9
No.	Duration	Type	Average	Variable			
1.	30 years	SS	✓		×	×	×
2.	30 years	SS	✓		✓	✓	×
3.	30 years	SS	✓		✓	×	✓
4.	8 years	Tr		✓	×	×	×
5.	8 years	Tr		✓	✓	×	✓
Varied rainfall = 2003 to 2011 rainfall record							

Predicted Changes in Water Level

In this area it is proposed to excavate and replace the peat with sand to enable embankment construction.

Modelling suggests a maximum lowering of GWL in the peat / surficial alluvium (silt) of around 0.4 m immediately adjacent to the Expressway and wetland 9, with measurable drawdown (0.1 m) typically extending for less than 50 m distance, but up to 100 m in some areas (Figure F7c).

Because of the low permeability bund proposed around the wetland, drawdown of less than 0.1 m is predicted for properties on Puriri Road. Modelling suggests that drawdown will not extend to the urupa area or natural wetlands.

The results of transient modelling (Figure F8c) suggest that the maximum drawdown below the naturally occurring lowest GWL is 0.4 m, consistent with the steady state model of average conditions suggesting that the proposed works will not exacerbate or be exacerbated by seasonal effects. Modelling indicates a maximum drawdown in 3 private wells (R26/6811, R26/5147 and R26/7056) of up to 0.2 m. This level of drawdown is unlikely to have adverse effects though it is possible that some of the very shallow wells may need to be deepened.

Predicted Changes in Water Balance

Modelling suggests that changes to the overall, long term water budget are likely to be negligible as a result of embankment construction and groundwater lowering (Table F12). Changes to the inflows and outflows of the Waikanae River are expected to be less than 100 m^3/day and are therefore unlikely to be detectable above naturally occurring fluctuations.

Some long term seepage through the base of the wetlands can be expected.

Table F12: Wetland 9 - Modelled Water Balance (Steady State)

Source / Sink	Natural Steady State Model		Long Term Expressway with Peat Replacement & Lined Ponds	
	In (m^3/d)	Out (m^3/d)	In (m^3/d)	Out (m^3/d)
Storage	0.00	0.00	0.0	0.0
Constant Head	0.00	0.00	0.0	0.0
Rainfall Recharge	2,342.1	0.00	2183.6	0.0
River Leakage	376.0	2,960.9	377.9	2843.89
Drains	0.00	0.00	0.0	0.0
Wetland Ponds	0.00	0.00	8.1	3.4
General Heads	560.5	284.1	578.5	269.9
Domestic Abstraction	0.00	34.8	0.0	31.1
TOTAL	3,278.6	3,279.8	3148.1	3148.29
Discrepancy (Outflow – Inflow)	1.3 m^3/d		0.19 m^3/d	
	0.04 %		0.01 %	

Table F13: Wetland 9 - Modelled Water Balance (Transient)

Source / Sink	Transient Winter Conditions				Transient Summer Conditions			
	Natural		Constructed		Natural		Constructed	
	In (m³/d)	Out (m³/d)	In (m³/d)	Out (m³/d)	In (m³/d)	Out (m³/d)	In (m³/d)	Out (m³/d)
Storage	276	857.7	333.6	564.3	2392.9	207.6	2222.8	11
Constant Head	0	0	0	0	0	0	0	0
Rainfall Recharge	3143.2	0	2909	0	177.9	0	164.5	0
River Leakage	374.7	3113.3	374.1	3193	374.5	3116.2	374.6	3155.6
Drains	0	0	0	0	0	0	0	0
Wetland Ponds	0	0	1.6	35.2	0	0	1.6	99.5
Domestic Abstraction	544	299.6	529.8	322.3	540.2	301.7	534.6	319.8
General Heads	0	57.6	0	61.2	0	56	0	55.6
TOTAL	4337.9	4328.2	4148.1	4176	3485.5	3681.5	3298.1	3641.5
Discrepancy (Outflow – Inflow)	-9.7 m³/d		27.9 m³/d		196 m³/d		343.4 m³/d	
	-0.2 %		0.7 %		5.3 %		9.4 %	

F1. Otaihanga landfill

F3.1 Purpose of Model

A detailed model including the area of the Otaihanga Landfill was developed to assess:

- The interaction of water discharging from the vicinity of Otaihanga Landfill, which might contain contaminants, with groundwater;
- Changes in groundwater levels, gradients and flow paths that might result from peat excavation and replacement associated with embankment construction for the Expressway past the landfill; and
- The interaction between proposed Wetland 8 and the surrounding natural wetlands.

F3.2 Model Set Up

Model Area, Extent and Grid Set –Up

In selecting a suitable model area the following was considered:

- Static water levels from long and short term piezometer records indicate a regional north-westerly flow direction from the Tararua Ranges towards the Coastline; and
- The model should incorporate the Otaihanga Landfill, with the focus of the model (the Expressway and landfill) in the centre of the area to reduce the potential for "edge effects".

The model domain covers an area of 3.5 km x 2.0 km (7.0 km^2), with the grid aligned orthogonal to the coastline in order to allow the general groundwater flow direction to be from left to right in the model (Figure F1 and F1d).

A maximum single grid / cell size of 20 m x 5 m was selected with progressive grid refinement to 5 m x 5 m in the vicinity of the landfill and corridor. The model comprises 400 rows and 400 columns for a total of 160,000 cells per model layer.

Topographic data was sourced from LIDAR surveys (ALGGI Lidar Data, flown 2010), and imported into MODFLOW to define the ground surface. The highest elevation in the model domain is 39.5 mRL (Holocene Alluvium) with the model extending to a depth of -120.0 mRL. Vertically the model was divided into 6 hydrogeological layers to account for the differing hydrogeological units and hydraulic conductivities identified. The grid however comprises 13 layers in accordance with the geological model.

Distribution of Hydrogeological Units

The distribution of hydrogeological units was taken from the Hydro GeoAnalyst (HGA) ground model (Appendix A) developed from site specific investigations undertaken for the Project, existing well data records (GWRC) and the URS (2005) ground model. Stereo-pairs of aerial photographs flown in 1942, 1964, 1986 and 1998 that cover the landfill area were viewed to identify the likely ground conditions beneath the landfill. Work at the landfill site had just begun in the 1986 photos and appears to have comprised some cut of sand from the line of dunes in behind the current landfill and perhaps replacement with peat from the adjacent WWTP site which was being developed at the time. There is no evidence that the ground beneath the landfill (lower lying peaty soils) was excavated prior to placement of fill.

The hydrogeological parameters were imported directly from the calibrated regional 3D model, with the exception of the alluvium, Holocene Peat, Holocene Sand, Pleistocene Sand and Pleistocene Silt/Clay. In order to achieve a satisfactory calibration these units were assigned hydraulic conductivities within the range of expected permeability, and consistent with site observations of bedded sand, gravel and silt, fibrous peat and local springs. The hydrogeological parameters used are presented below in Table F14.

Table F14: Adopted Hydraulic Parameters

Hydrogeological Unit	Regional Adopted Hydraulic Conductivity (m/s)	Local Adopted Hydraulic Conductivity (m/s)
Holocene Alluvium	$K_h = 3 \times 10^{-3}$ $K_v = 3 \times 10^{-5}$	$K_h = 3 \times 10^{-3}$ $K_v = 6 \times 10^{-6}$
Holocene Peat	$K_h = 4 \times 10^{-6}$ $K_v = 1 \times 10^{-7}$	$K_h = 4 \times 10^{-6}$ $K_v = 9 \times 10^{-7}$
Holocene Sand	$K_h = 5 \times 10^{-5}$ $K_v = 5 \times 10^{-5}$	$K_h = 3 \times 10^{-5}$ $K_v = 3 \times 10^{-5}$
Pleistocene Sand	$K_h = 5 \times 10^{-3}$ $K_v = 1 \times 10^{-5}$	$K_h = 3 \times 10^{-3}$ $K_v = 8 \times 10^{-6}$
Pleistocene Silt/Clay	$K_h = 1 \times 10^{-6}$ $K_v = 1 \times 10^{-7}$	$K_h = 1 \times 10^{-6}$ $K_v = 3 \times 10^{-7}$

Figure F2d shows a slice through the model and the distribution of the hydrogeological units.

Model Boundaries

Constant Head Boundaries (CHBs) have been used to represent heads outside the model domain that contribute to up and down-gradient flow at each edge of the model. Head levels were set from the calibrated regional steady state model and adapted to allow for satisfactory model calibration.

The Waikanae River was modelled using the River Recharge Package function that simulates surface water/ groundwater interaction via a seepage layer which separates the surface water body from the groundwater body. Depending on the hydraulic gradients between the two systems, the rivers can act as recharge or discharge zones. River stage and elevation data for the Waikanae River was approximated from site observations, topographic survey data and stormwater modelling (KCDC and SKM).

The south-eastern boundary has been assigned as a no flow boundary where the greywacke is outcropping at the foothills of the Tararua Ranges. Up-gradient flow from the greywacke is considered using the CHB, with the head set at ~10.5 m according to the output of the calibrated regional model.

The northern boundary has been assigned as a no flow boundary, north of the Waikanae River. This is so that the Waikanae River is simulated as the northern boundary condition for the model.

Recharge

Recharge zones (and rates) were imported directly from the regional model, and where necessary refined to meet the detail of the LIDAR, mapped geology and land-use (Figure F3).

F3.3 Model Calibration

The groundwater model was calibrated using known static water levels recorded in piezometers over the entire model domain.

The steady state model was calibrated to a target Normalised Root Meat Square (RMS) error of 9.7 % and a residual mean error of +/- 0.1 m for average groundwater levels in all monitoring wells constructed in 2007 – 2011.

A plot of observed against calculated residuals is presented in Figure F4. The two Private wells identified in the model area were not included in the calibration. No spatial trend is apparent in the observed residuals.

A qualitative check was made that general flow features were replicated with the overall pattern of flow directions and gradients simulated. Also the model was calibrated to an average GWL close to the surface or with surface flooding within the existing areas of wetland vegetation.

Under steady state conditions calculated inflows to the model are 3,279 m^3/day (Table F15).

Table F15: Modelled Water Balance for Steady State (Natural) Model

Source / Sink	Flow Into Model (m³/d)	Flow Out of Model (m³/d)
Storage	0	0
Constant Head Boundaries	7,763	2,347
Rainfall Recharge	3,937	0
River Leakage	3,297	12,625
Drains	0.00	3,107
General Heads	3,477	658
TOTAL	18,474	18,737
Discrepancy (Outflow – Inflow)		261 m³/d
		1.4 %

F3.4 Results of Numerical Modelling

Long term steady state (SS) and transient (Tr) scenarios evaluated are summarised in Table F16.

Table F16. Scenarios Modelled

Scenario			Rainfall		Expressway	Landfill Particle Tracking	Unlined Wetland 8	Lined Wetland 8
No.	Duration	Type	Average	Varied				
1.	30 years	SS	✓		×	✓	×	×
2.	30 years	SS	✓		✓	✓	✓	×
3.	30 years	SS	✓		✓	×	×	✓
4.	8 years	Tr		✓	×	×	×	×
5.	8 years	Tr		✓	✓	×	×	✓
Varied rainfall = 2003 to 2011 rainfall record								

Predicted Changes in Water Level

It is proposed to use the peat surcharge method of embankment construction in this area. The two end members of peat compression (20 % and 50 %) were tested to assess the likely magnitude and extent of long term changes to average groundwater levels as a result of peat compression and GWL lowering around the landfill area.

Modelling suggests a maximum lowering of the GWL in the peat / surficial alluvium (silt) of around 0.1 m adjacent to the Expressway and Landfill, extending over a distance of less than 50 m in most areas, but up to 100 m in some areas (Figure F7d).

A maximum lowering of the groundwater level in the peat/surficial alluvium (silt) of around 0.2 m is indicated immediately adjacent to Wetland 8 and the Expressway in this section, with measurable drawdown (0.1 m) typically extending for less than 50 m distance, but up to 100 m in some areas (Figure F8d). Modelling indicates a drawdown of up to 0.5 m in the sand underlying the peat immediately adjacent to Wetland 8, reducing to 0.2 m within 20 m of Wetland 8. Measurable drawdown of 0.1 m could extend some 100 m from the wetland in the sand layer.

The results of transient modelling suggest that the maximum drawdown below the naturally occurring lowest level is 0.2 m (comparable to the steady state model of average conditions), suggesting that the proposed works will not exacerbate or be exacerbated by seasonal effects.

Modelling indicates a maximum drawdown in the shallow sands at two private wells (R26/6571, and R26/6569) of up to 0.2 m. As these wells are 65 m and 45 m deep respectively and screened at depth, the amount of drawdown recorded in the wells will be less than 0.2 m and will not be noticeable in the wells.

Predicted Changes in Groundwater Flow Rate

Modelling shows contaminant transport follows a north westerly direction (Figure F9). The advective transport rate equation (v = Ki/ne) was used to determine the travel time of the particles in the Holocene peat layer (Layer 2) and Holocene sand layer (Layer 3). A sensitivity check was undertaken using the highest observed hydraulic conductivity for both units. Results of calculations are given in Table F17.

Table F17. Estimated travel times of contaminants in water

Condition	Adopted K (Peat) 4×10^{-6} (Layer 2)	Highest K (Peat) 1×10^{-5} (Layer 2)	Adopted K (Sand) 1×10^{-5} (Layer 3)	Highest K (Sand) 2×10^{-4} (Layer 3)
Natural Condition	3 m/yr	5 m/yr	25 m/yr	100 m/yr
Constructed Condition	3 m/yr	6 m/yr	27 m/yr	108 m/yr

Modelling shows that the surcharge of the peat for construction of the Expressway does not change the local groundwater flow characteristics (direction and advective transport) for the adopted (calibrated parameters) and might be altered by a very small amount if the highest hydraulic conductivities identified occur everywhere. This coupled with the fact that drains are in place to capture leachate from the landfill indicates that the effects of expressway construction will be undetectable.

Predicted Changes in Water Balance

Modelling suggests that changes to the overall long term water budget are likely to be negligible as a result of embankment construction and groundwater lowering (Tables F18 and F19). Changes to the naturally occurring inflows to and outflows from the Waikanae River are expected to be less than 100 m^3/day and would not be detectable over naturally occurring fluctuations.

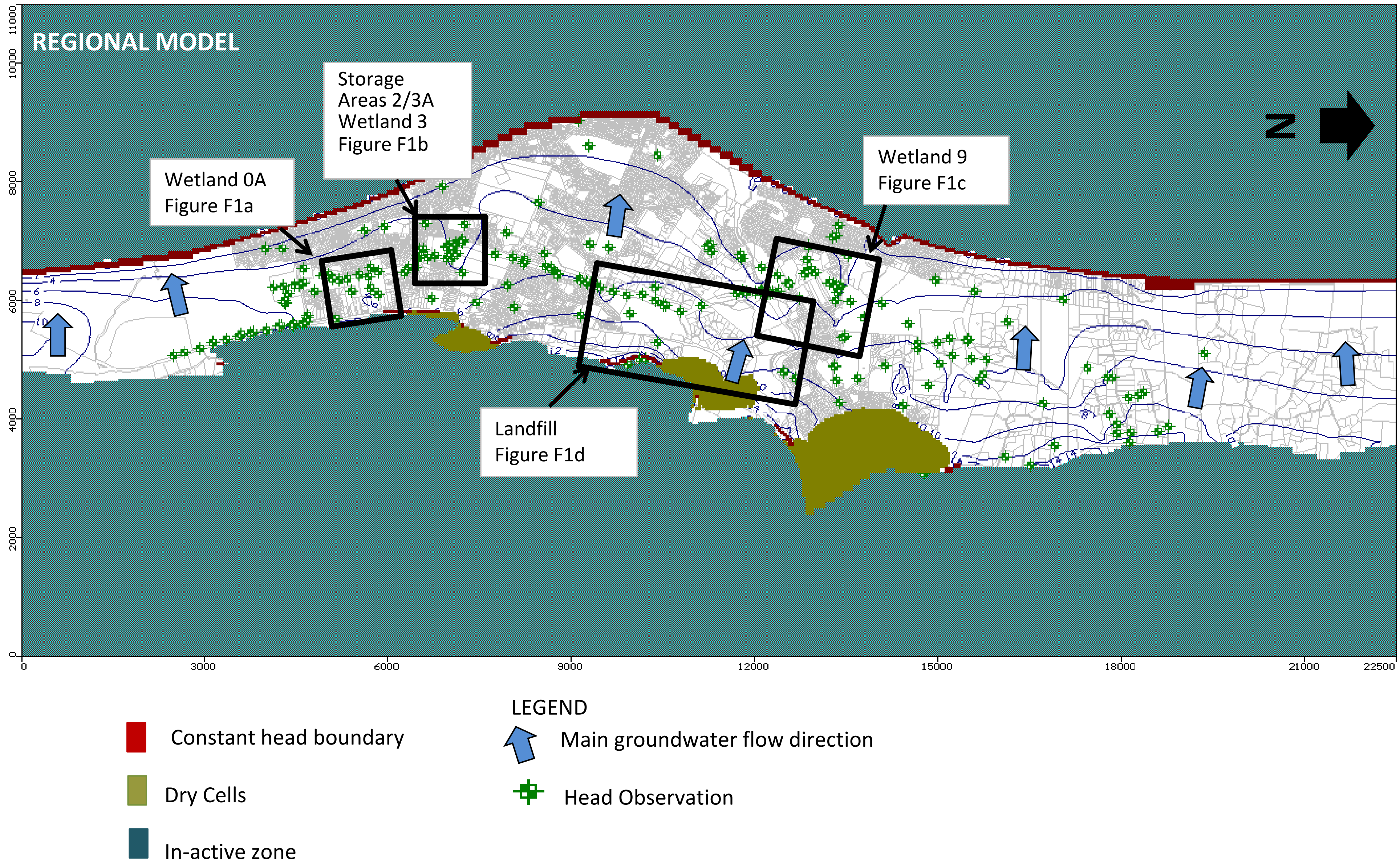
Some long term seepage through the base of the wetlands can be expected.

Table F18. Otaihanga Landfill and Wetland 8 - Modelled Water Balance (Steady State)

Source / Sink	Natural Steady State Model		Long Term Expressway with Peat Replacement & Wetland 8	
	In (m^3/d)	Out (m^3/d)	In (m^3/d)	Out (m^3/d)
Storage	0.00	0.00	0.00	0.00
Constant Head	7,763.3	2,347.4	7,778.0	2,311.7
Rainfall Recharge	3,937.1	0.00	3,863.4	0.00
River Leakage	3,297.9	12,625. 3	3,324.0	12,545.2
Drains	0.00	3,107. 1	0.00	2,878.4
Wetland Ponds	0.00	0.00	0.00	138.6
General Heads	3,477.6	658.0	3,514.6	647. 8
TOTAL	18,475.9	18,737.8	18,480.0	18,521.7
Discrepancy (Outflow – Inflow)	261.9 m^3/d		41.1 m^3/d	
	1.4 %		0.23 %	

Table F19: Otaihanga Landfill and Wetland 8 - Modelled Water Balance (Transient)

Source / Sink	Transient Winter Conditions				Transient Summer Conditions			
	Natural		Constructed		Natural		Constructed	
	In (m³/d)	Out (m³/d)	In (m³/d)	Out (m³/d)	In (m³/d)	Out (m³/d)	In (m³/d)	Out (m³/d)
Storage	1,957.6	2,776.6	40.4	45.3	5.4	0.8	34.3	0.8
Constant Head	7,402.6	3,037.7	7,685.0	3,025.5	8,384.6	2,327.1	7,961.2	2,951.2
Rainfall Recharge	10,819.6	0	10,442.0	0	2,887.2	0	1,408.9	0
River Leakage	2,920.1	13,795.3	2,913.7	13,689.8	3,322.1	12,596.9	3,004.3	13,395.4
Drains	0	4,103.7	0	4,918.4	0	1,804.9	0	3,440.3
Wetland Ponds	0	0	25.1	36.9	0	0	7.3	7.5
Domestic Abstraction	0	0	0	0	0	0	0	0
General Heads	0	0	0	0	0	0	0	0
TOTAL	23,100.0	23,713.2	21,106.2	21,715.9	14,599.3	16,729.8	12,416.1	19,795.2
Discrepancy (Outflow – Inflow)	-613.2 m³/d		-609.5 m³/d		-2130.5 m³/d		-7,379.1 m³/d	
	-2.6 %		-2.8 %		-12.7 %		-37.3 %	

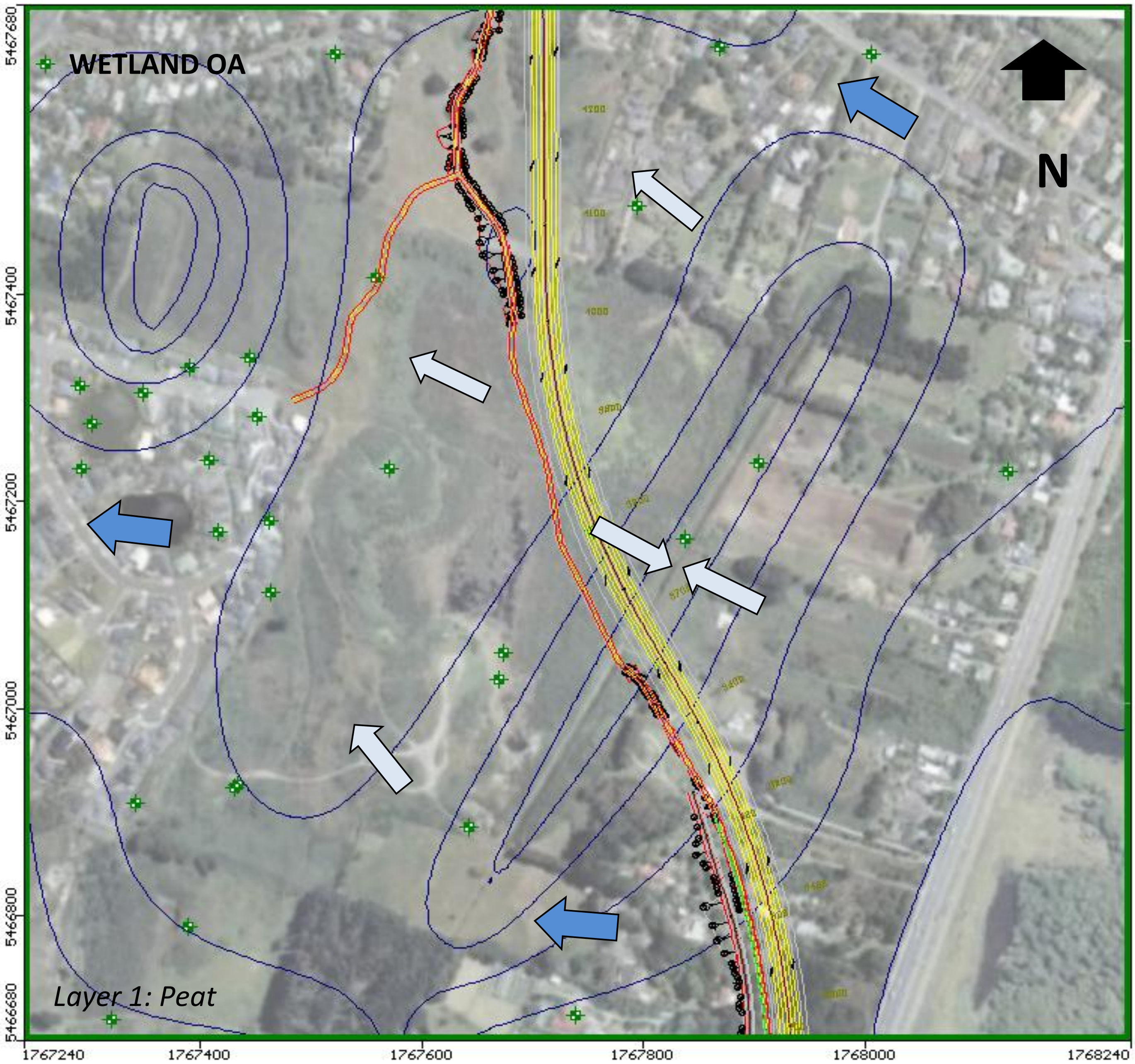


MacKays to Peka Peka

3D Model Pre Construction Steady State

NOTE: FIGURES AT DIFFERENT SCALES

Figure F1



LEGEND

General head boundary

Drain boundary
(Not displayed in this layer)

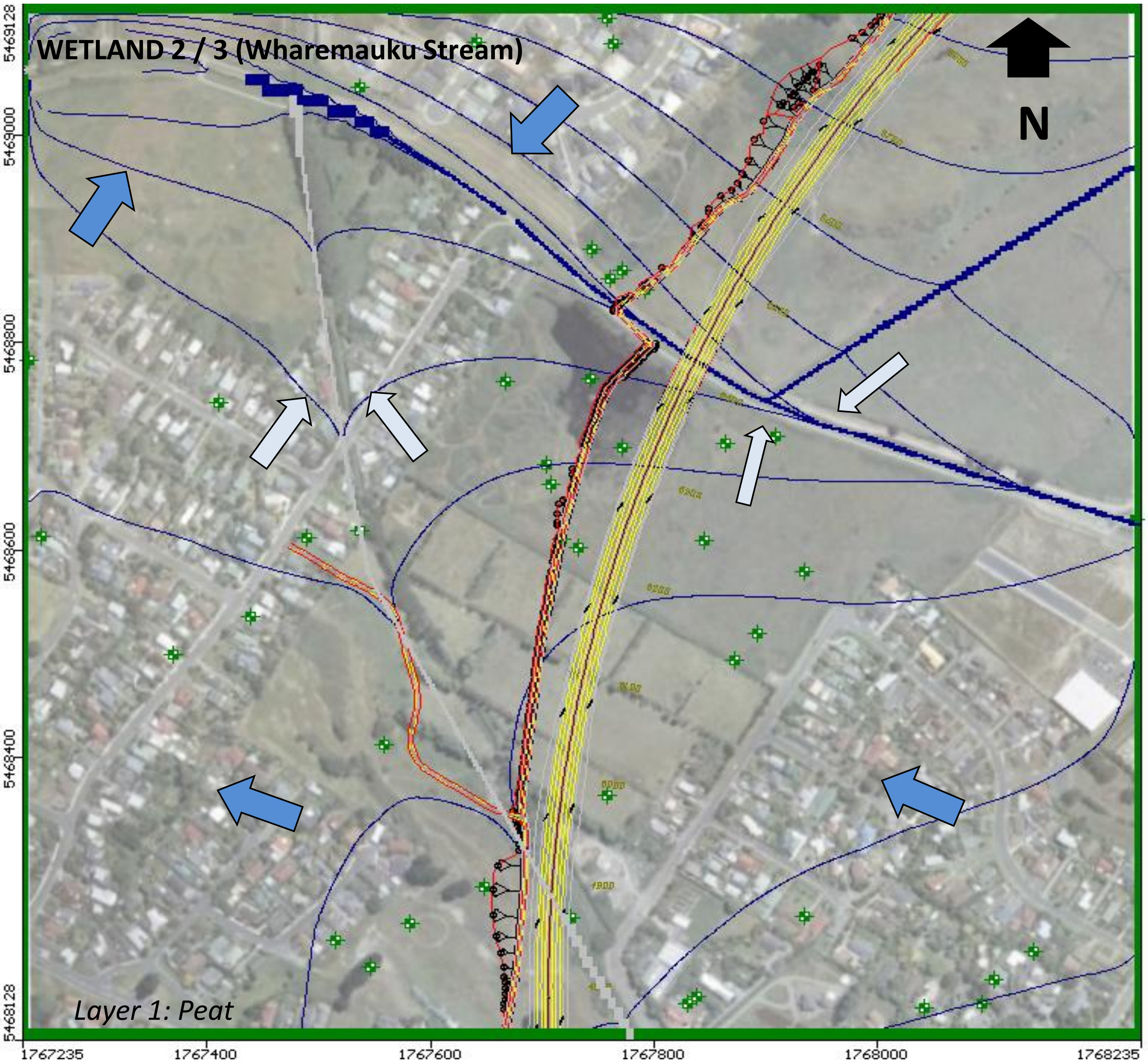
Main groundwater flow direction

Local groundwater flow direction

Head Observation

Pre Construction Steady State Wetland OA

Figure F1a



LEGEND

General head boundary

Drain boundary

Head Observation

Main groundwater flow direction

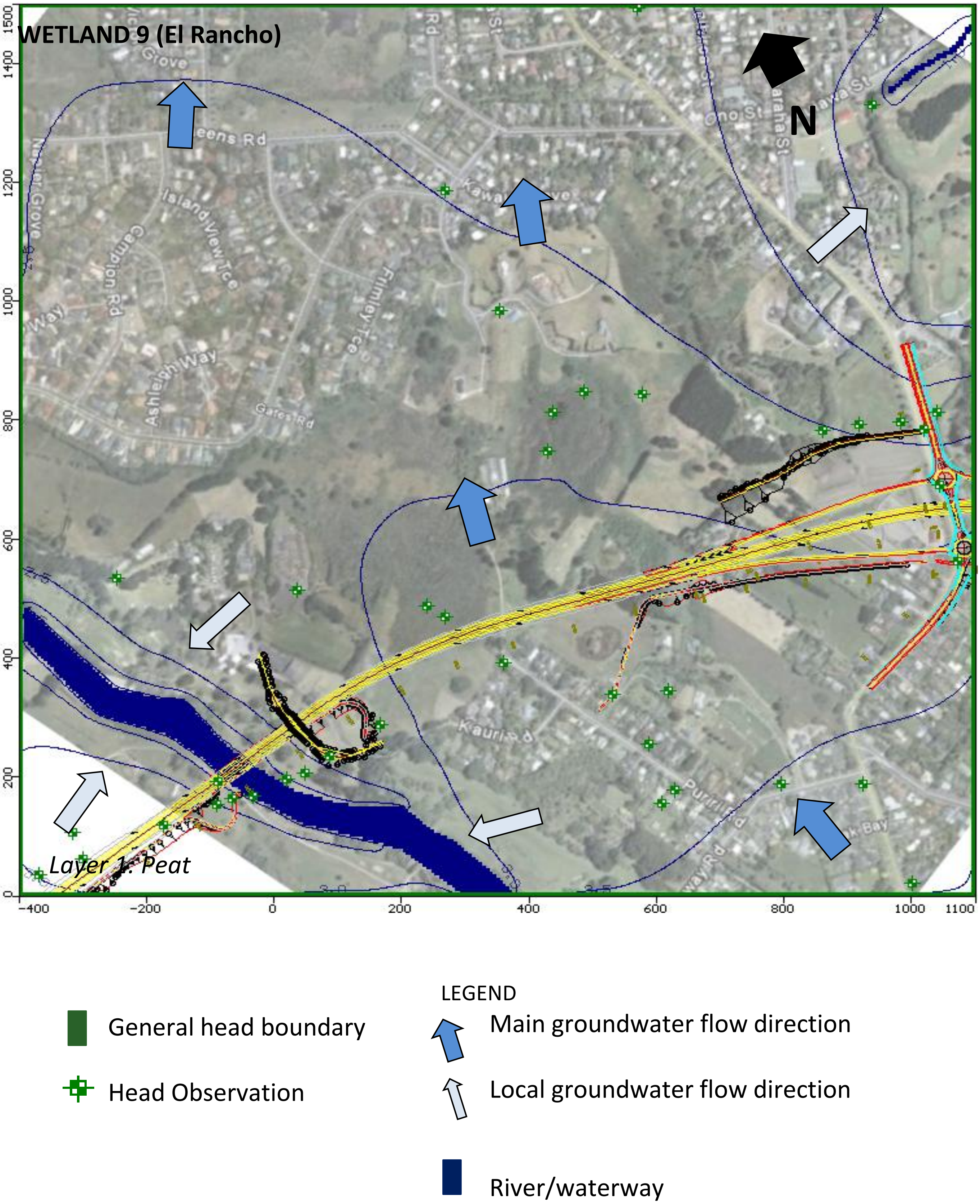
Local groundwater flow direction

River/waterway

Steady State Pre Construction Storage Areas 2/3A, Wetland 3

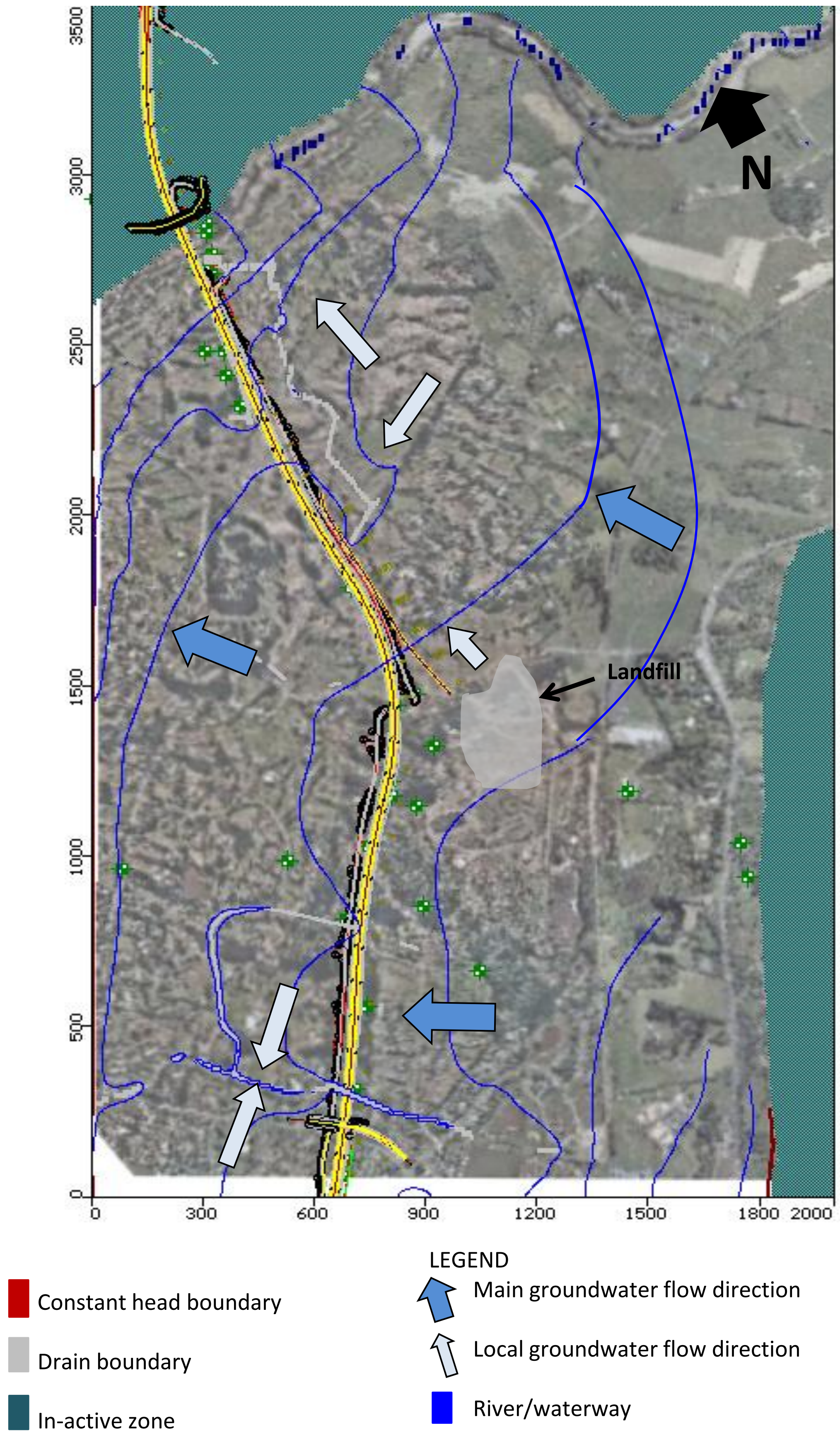
NZ Transport Agency — MacKays to Peka Peka

Figure F1b



Steady State Pre Construction Wetland 9

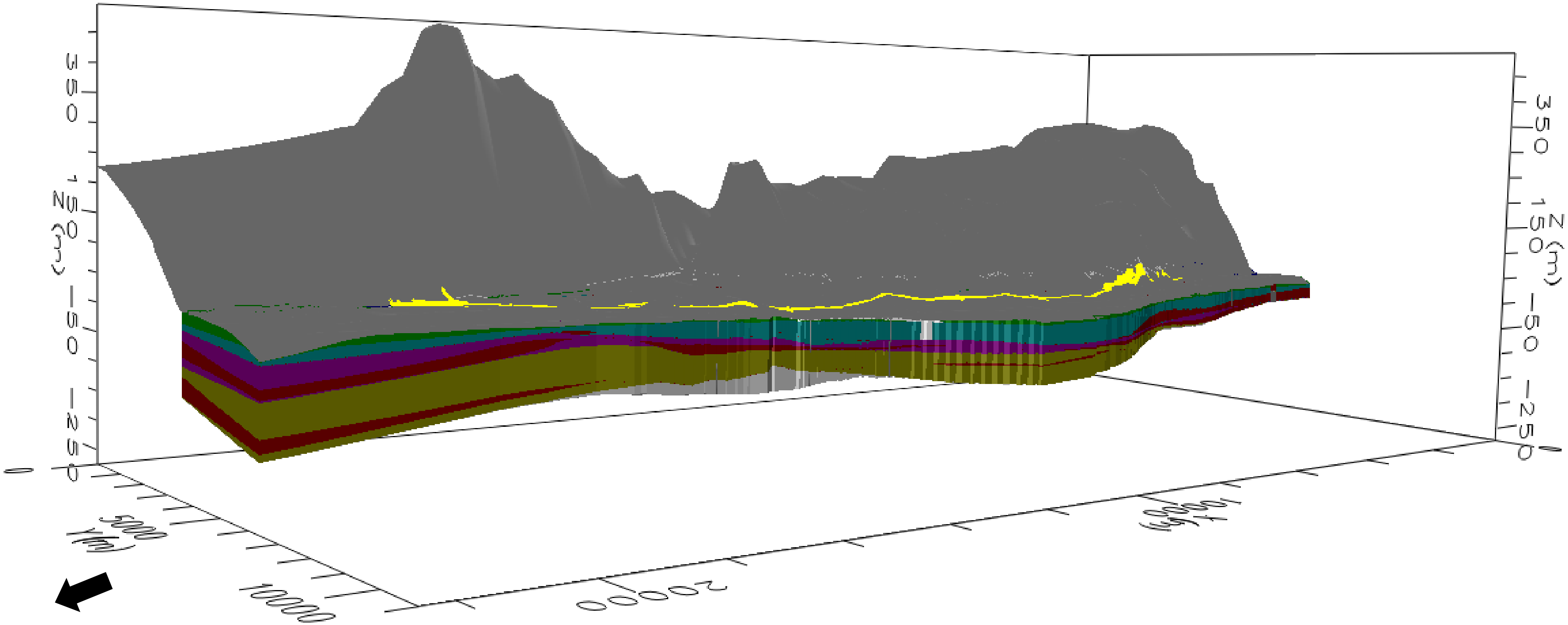
Figure F1c



MacKays to Peka Peka

Steady State Pre Construction Otaihanga Landfill

Figure F1d



LEGEND

Expressway Alignment

North

UNIT	Hydraulic Conductivity		Storage Coeff.	Specific Yield
	K_h (m/s)	K_v (m/s)		
Alluvium	3.00E-04	3.00E-05		0.3
Holocene Peat	4.20E-06	1.00E-07		0.25
Holocene Sand	5.00E-05	5.00E-05		0.001
Upper Marine Sand	5.00E-05	1.00E-05		0.05
Regression Alluvium	1.00E-06	1.00E-07	1.00E-04	
Lower Marine Sand	8.00E-05	1.00E-05	1.00E-04	
Parata Gravel	5.00E-04	2.00E-05	1.00E-04	
Waimea Gravel	5.00E-04	1.00E-04	1.00E-04	

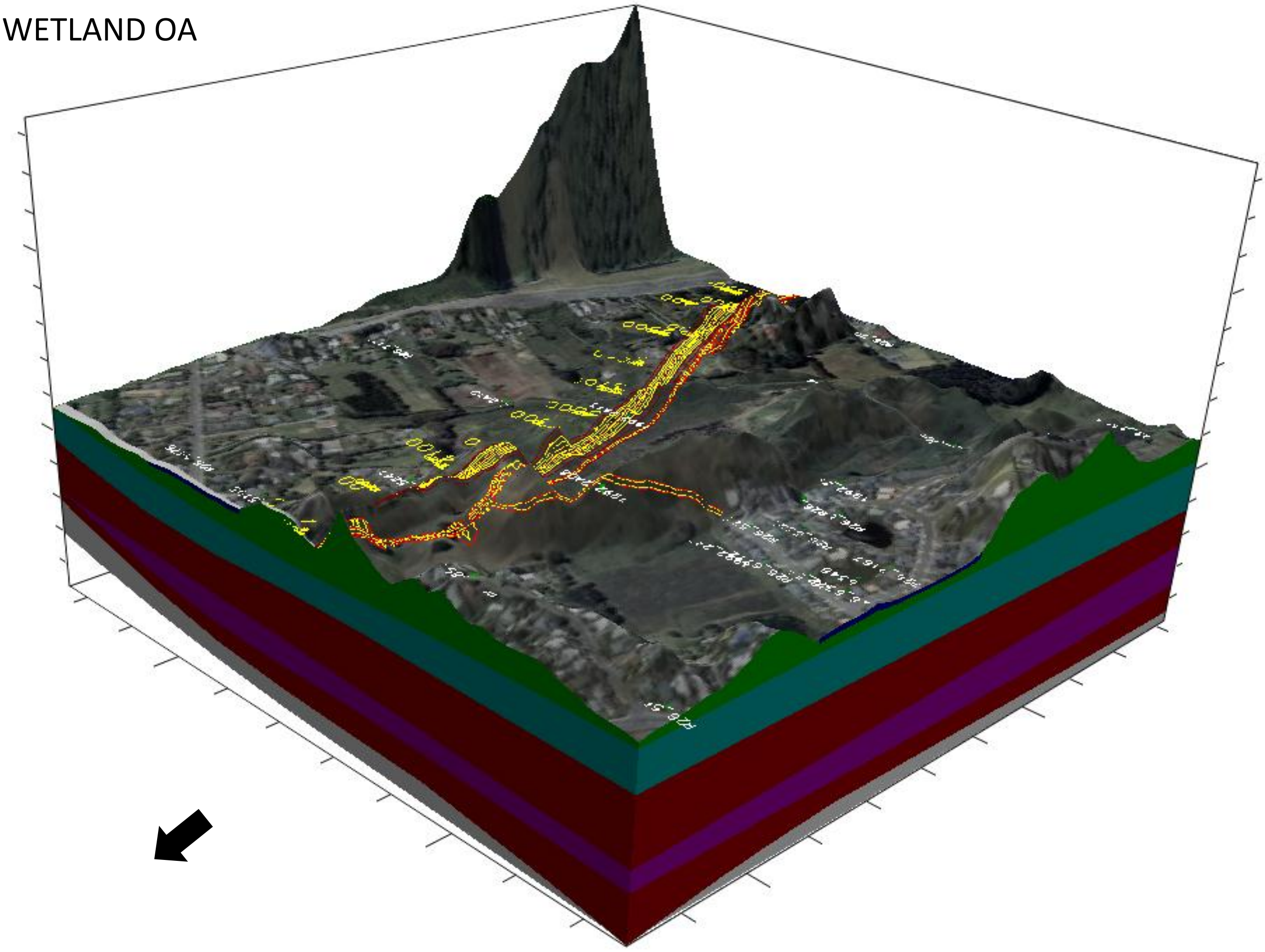
Distribution of Hydrogeological Units Along Alignment

MacKays to Peka Peka

NOTE: FIGURES AT DIFFERENT SCALES

Figure F2

WETLAND OA



LEGEND

Expressway Alignment

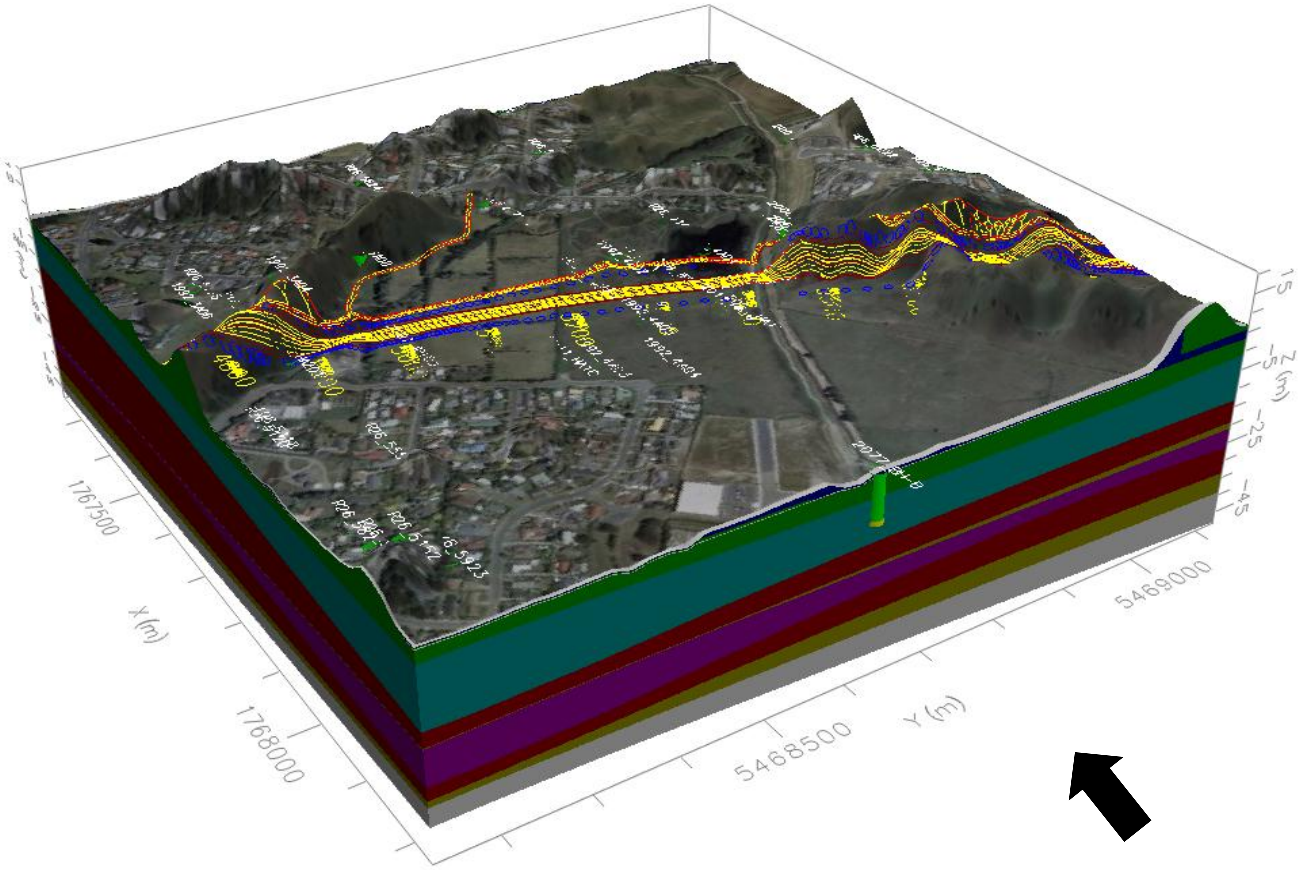
North

UNIT	Hydraulic Conductivity		Storage Coeff.	Specific Yield
	K_h (m/s)	K_v (m/s)		
Alluvium	3.00E-04	3.00E-05		0.3
Holocene Peat	4.20E-06	1.00E-07		0.25
Holocene Sand	5.00E-05	5.00E-05		0.001
Upper Marine Sand	5.00E-05	1.00E-05		0.05
Regression Alluvium	1.00E-06	1.00E-07	1.00E-04	
Lower Marine Sand	8.00E-05	1.00E-05	1.00E-04	
Parata Gravel	5.00E-04	2.00E-05	1.00E-04	
Waimea Gravel	5.00E-04	1.00E-04	1.00E-04	

Distribution of Hydrogeological Units - Wetland OA

Figure F2a

Offset Storage Area 2/3A, Wetland 3



LEGEND

Expressway Alignment

North

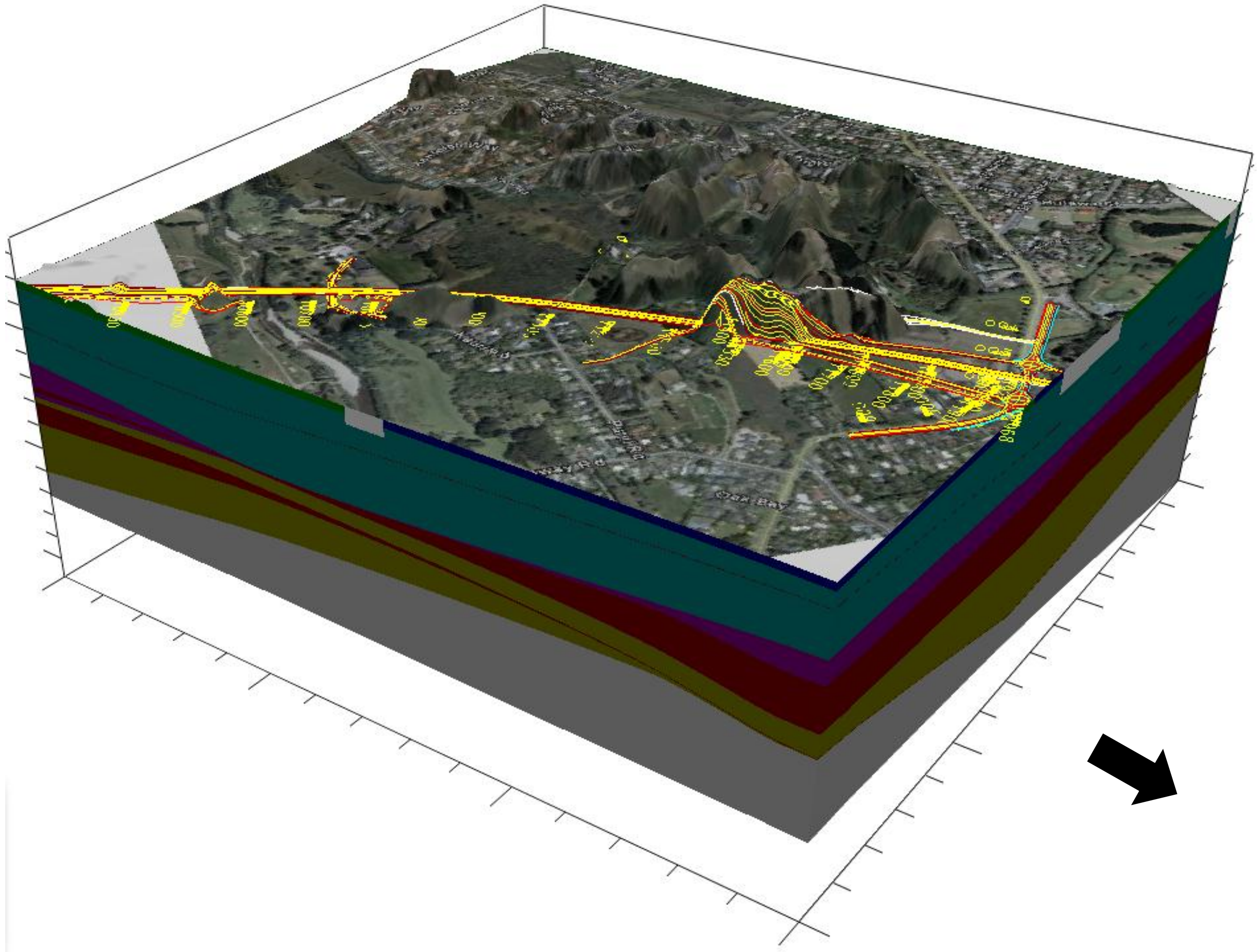
UNIT	Hydraulic Conductivity		Storage Coeff.	Specific Yield
	K_h (m/s)	K_v (m/s)		
Alluvium	3.00E-04	3.00E-05		0.3
Holocene Peat	4.20E-06	1.00E-07		0.25
Holocene Sand	5.00E-05	5.00E-05		0.001
Upper Marine Sand	5.00E-05	1.00E-05		0.05
Regression Alluvium	1.00E-06	1.00E-07	1.00E-04	
Lower Marine Sand	8.00E-05	1.00E-05	1.00E-04	
Parata Gravel	5.00E-04	2.00E-05	1.00E-04	
Waimea Gravel	5.00E-04	1.00E-04	1.00E-04	

Distribution of Hydrogeological Units
Offset Storage Area 2/3A, Wetland 3

MacKays to Peka Peka

Figure F2b

WETLAND 9 (El Rancho)



LEGEND

Expressway Alignment

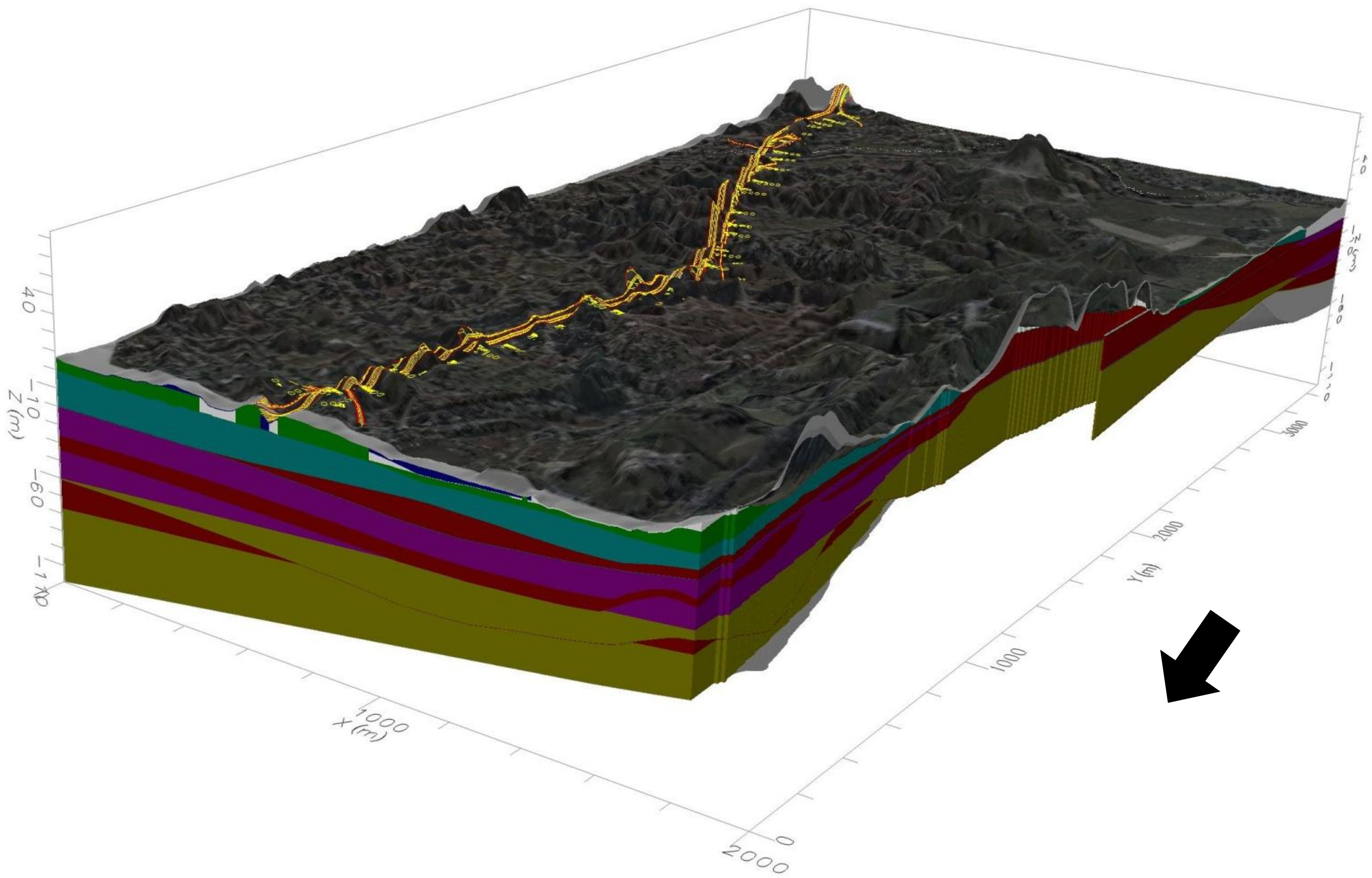
North

UNIT		Hydraulic Conductivity K_h (m/s)	K_v (m/s)	Storage Coeff.	Specific Yield
	Alluvium	3.00E-04	3.00E-05		0.3
	Holocene Peat	4.20E-06	1.00E-07		0.25
	Holocene Sand	5.00E-05	5.00E-05		0.001
	Upper Marine Sand	5.00E-05	1.00E-05		0.05
	Regression Alluvium	1.00E-06	1.00E-07	1.00E-04	
	Lower Marine Sand	8.00E-05	1.00E-05	1.00E-04	
	Parata Gravel	5.00E-04	2.00E-05	1.00E-04	
	Waimea Gravel	5.00E-04	1.00E-04	1.00E-04	

Distribution of Hydrogeological Units - Wetland 9

Figure F2c

OTAIHANGA LANDFILL



LEGEND

Expressway Alignment

North

UNIT		Hydraulic Conductivity		Storage Coeff.	Specific Yield
		K_h (m/s)	K_v (m/s)		
	Alluvium	3.00E-04	3.00E-05		0.3
	Holocene Peat	4.20E-06	1.00E-07		0.25
	Holocene Sand	5.00E-05	5.00E-05		0.001
	Upper Marine Sand	5.00E-05	1.00E-05		0.05
	Regression Alluvium	1.00E-06	1.00E-07	1.00E-04	
	Lower Marine Sand	8.00E-05	1.00E-05	1.00E-04	
	Parata Gravel	5.00E-04	2.00E-05	1.00E-04	
	Waimea Gravel	5.00E-04	1.00E-04	1.00E-04	

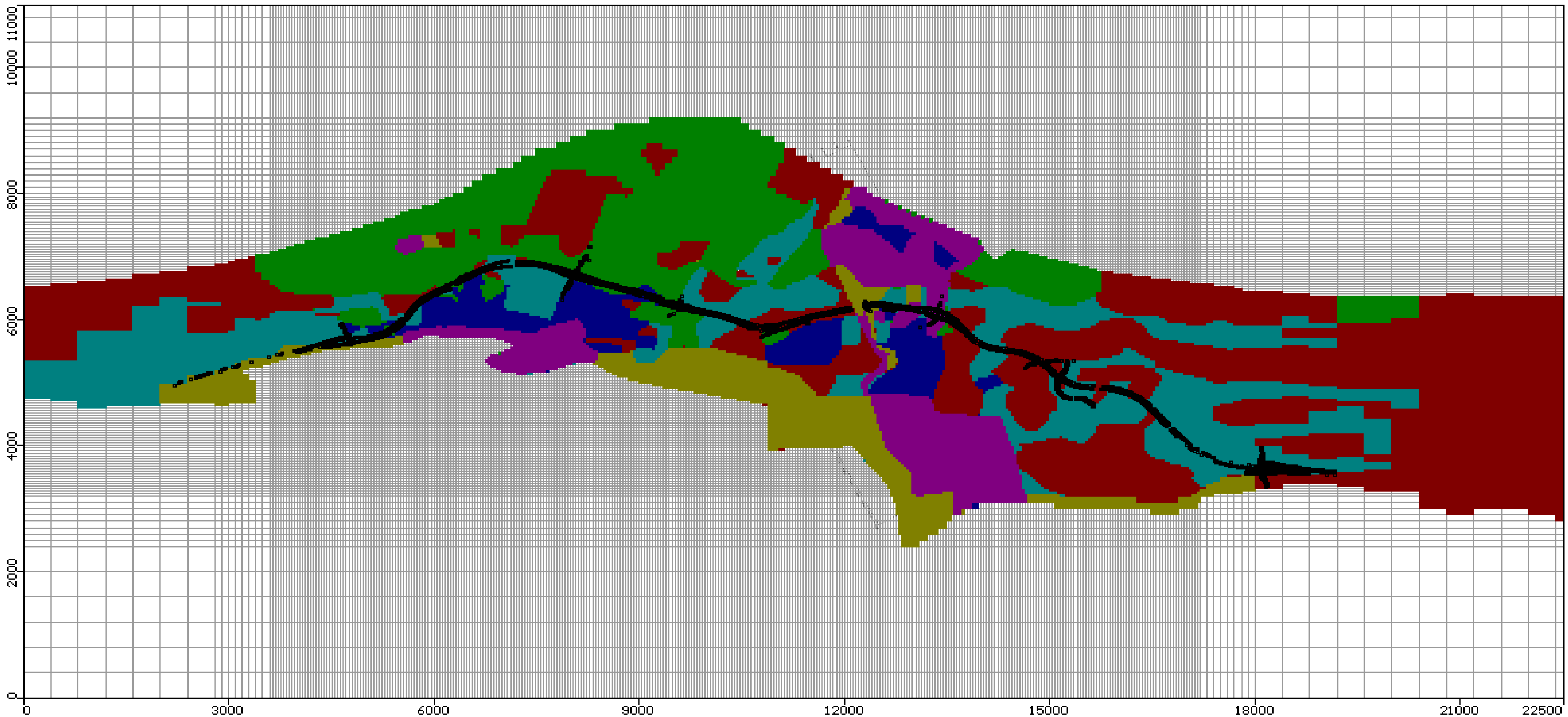
Distribution of Hydrogeological Units - Landfill

NZ Transport Agency MacKays to Peka Peka

Figure F2d

UNIT & LAND USE		RECHARGE FACTORS			RAINFALL RECHARGE (mm/yr)
		Soil	Land Use	Total	
PEAT	urban	0.35	0.3	0.11	66
	non-urban	0.35	1	0.35	220
SAND	urban	0.4	0.3	0.12	76
	non-urban	0.4	1	0.40	252
GRAVEL	urban	0.5	0.3	0.15	94
	non-urban	0.5	1	0.50	315

as per Gyopari, 2005

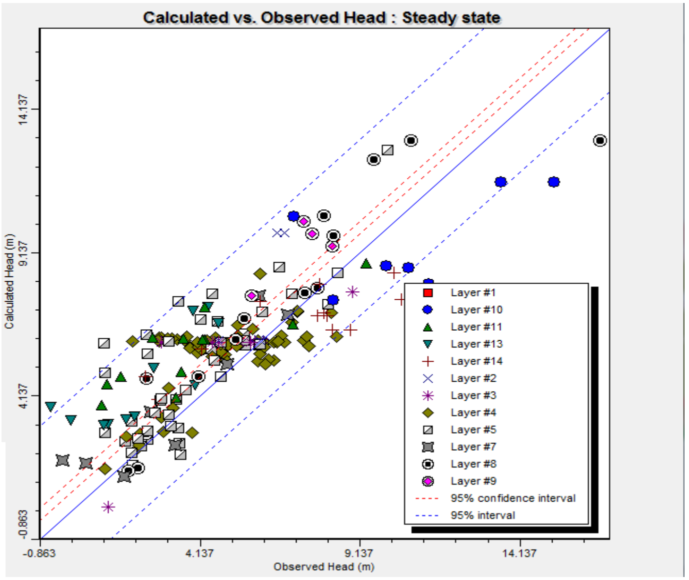


Recharge Zones

MacKays to Peka Peka

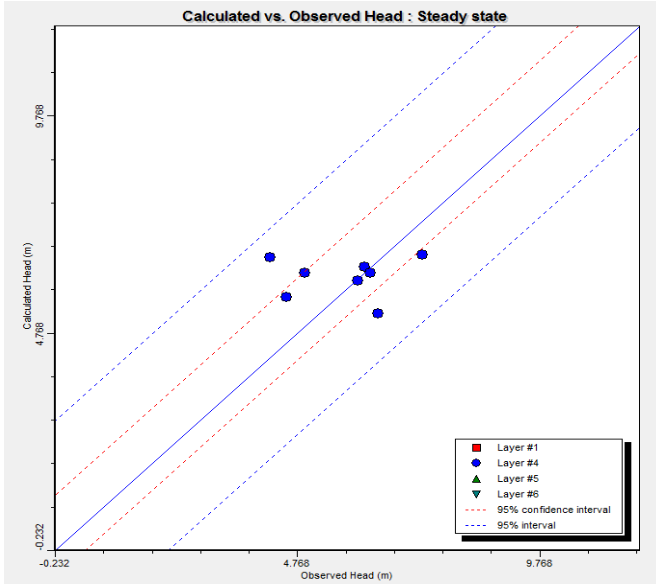
Figure F3

REGIONAL MODEL



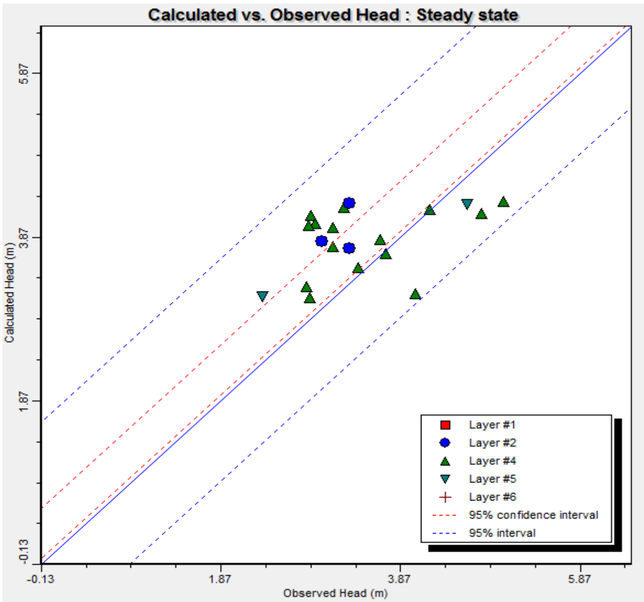
No. of data points = 207
Normalised RMS = 10.476 %
Residual Mean = 0.88 m
Max Residual = 4.87 m

WETLAND OA / OB



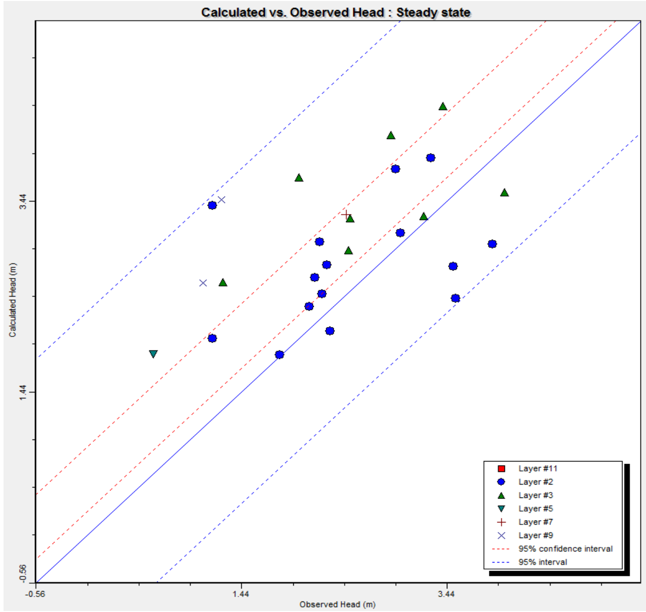
No. of data points = 10
Normalised RMS = > 10 %
Residual Mean = 0.329 m
Max Residual = 2.31 m

WETLAND 2 / 3A Storage Areas Wetland 3



No. of data points = 20
Normalised RMS = > 10 %
Residual Mean = 0.38 m
Max Residual = 1.27 m

WETLAND 9 (El Rancho)



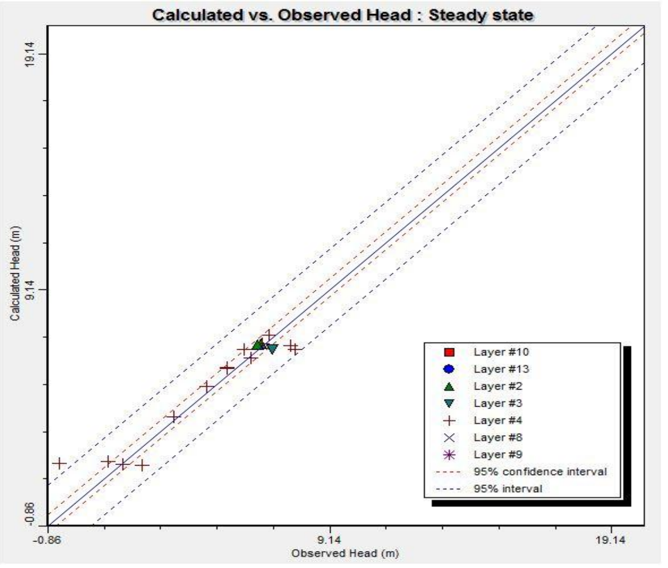
No. of data points = 27
Normalised RMS = > 10 %
Residual Mean = 0.588 m
Max Residual = 2.24 m

MacKays to Peka Peka

3D Model Calibration Statistics

Figure F4

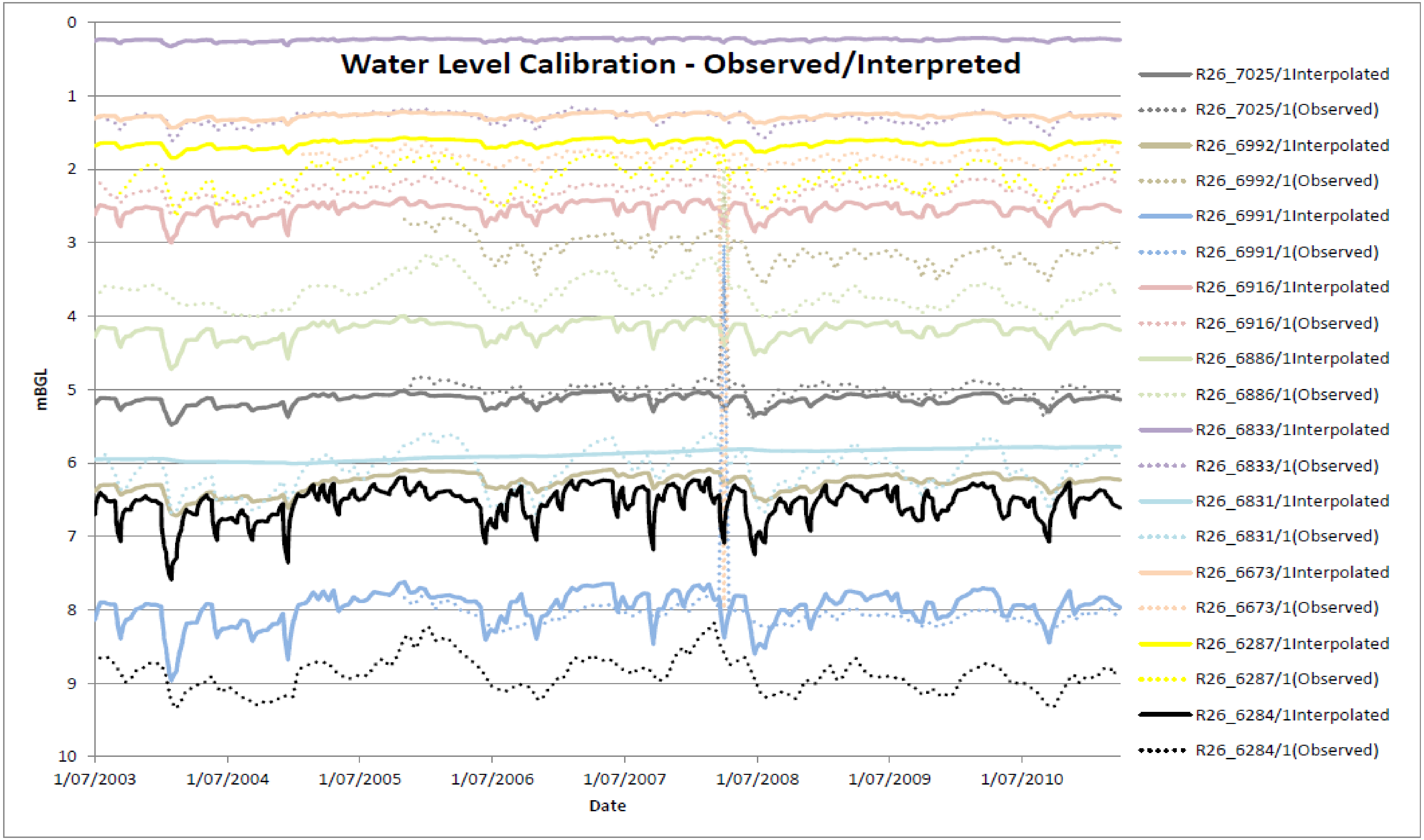
OTAIHANGA LANDFILL



No. of data points = 17
Normalised RMS = 8.994 %
Residual Mean = 0.09 m
Max Residual = 2.24 m

3D Model Calibration Statistics

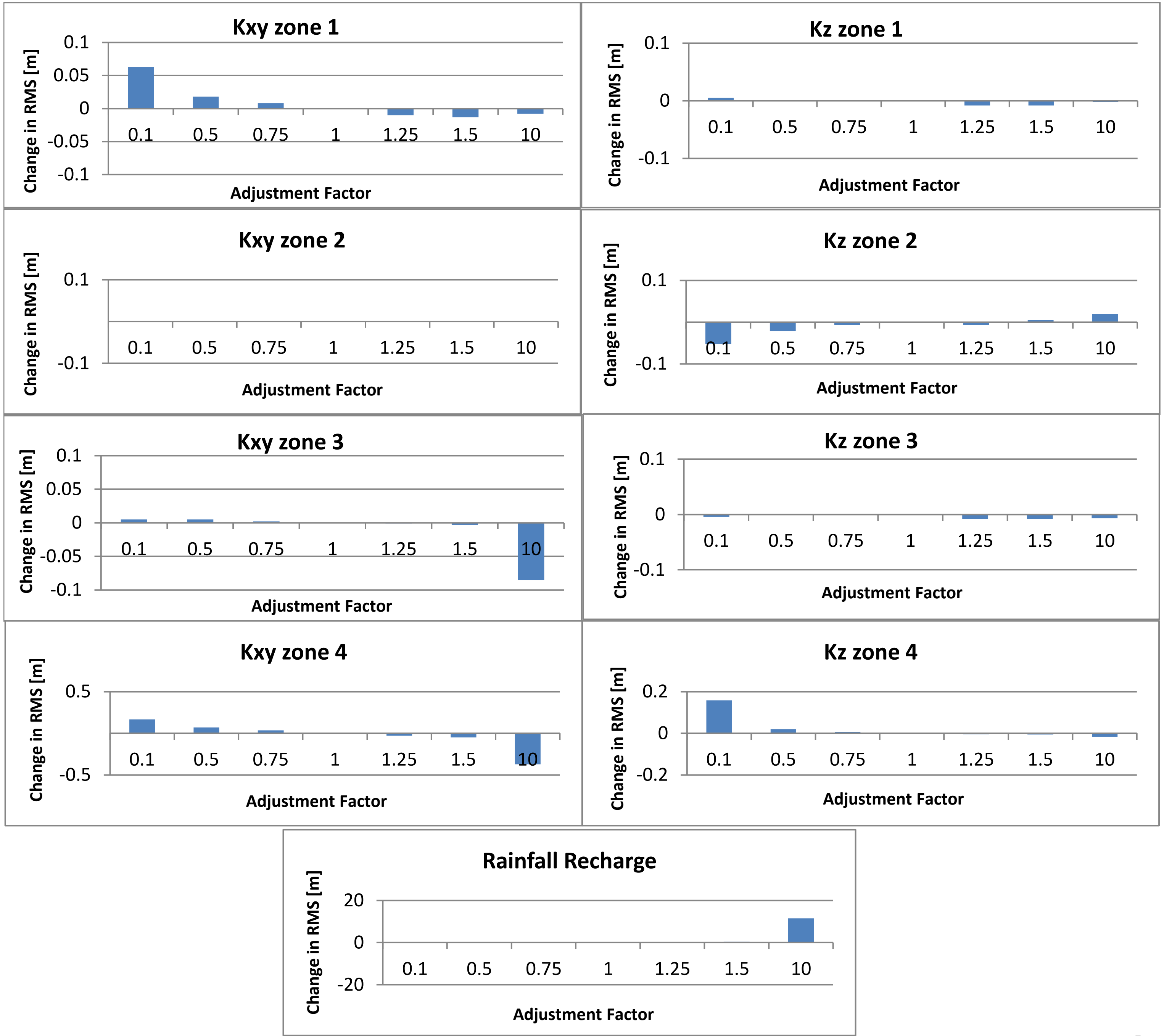
Figure F4b



3D Regional Transient Model Calibration

MacKays to Peka Peka

Figure F5



Hydraulic Conductivity Zone 1
Holocene Alluvium

Base Kx,y	3.00E-03	m/s
Base Kx	3.00E-05	m/s

Hydraulic Conductivity Zone 2
Holocene Peat

Base Kx,y	4.20E-06	m/s
Base Kx	1.00E-07	m/s

Hydraulic Conductivity Zone 3
Holocene Sand

Base Kx,y	5.00E-05	m/s
Base Kx	5.00E-05	m/s

Hydraulic Conductivity Zone 4
Holocene Sand

Base Kx,y	5.00E-05	m/s
Base Kx	1.00E-05	m/s

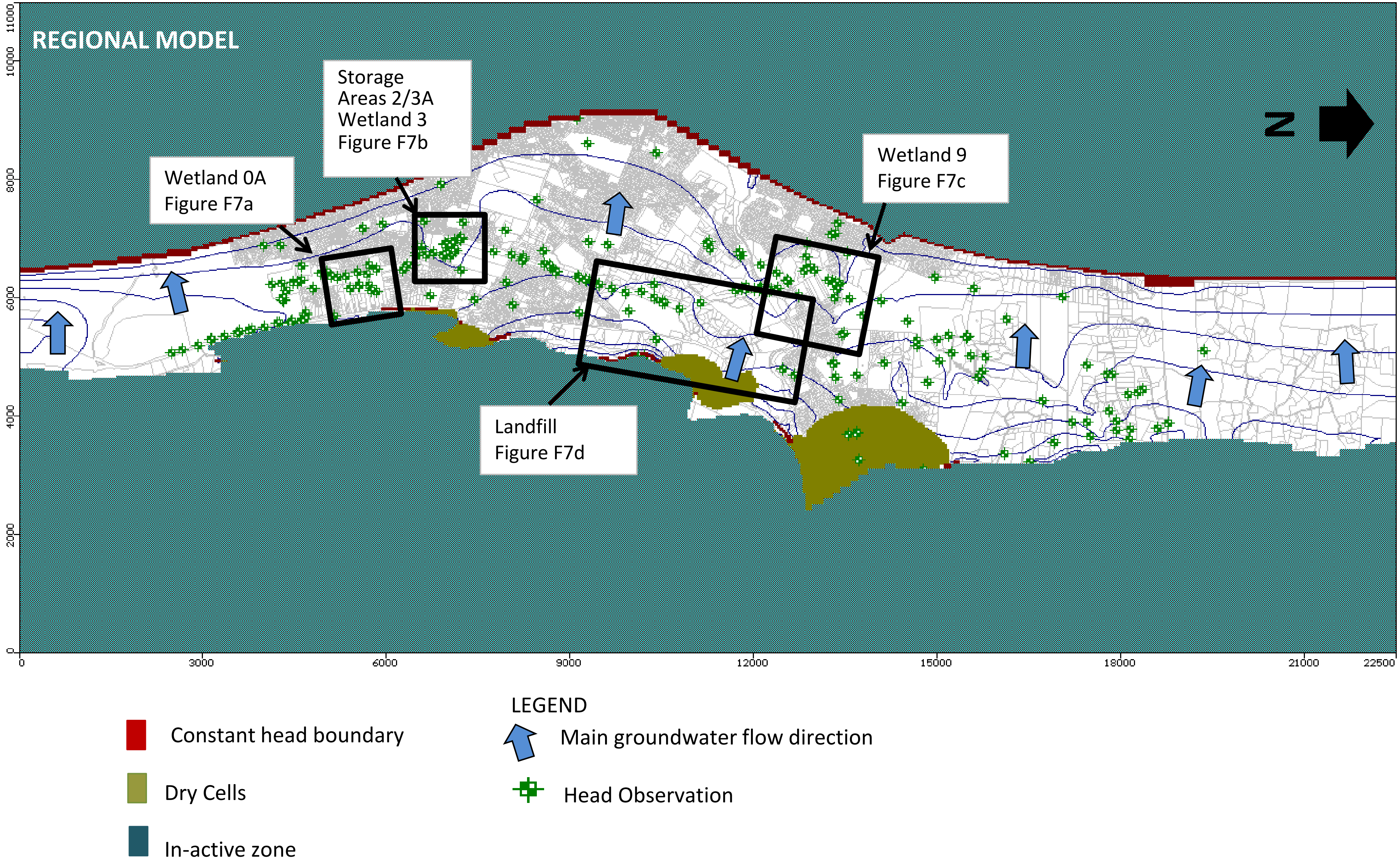
Rainfall Recharge (base values)

PEAT	urban	66	mm/yr
	non-urban	220	mm/yr
SAND	urban	76	mm/yr
	non-urban	252	mm/yr
GRAVEL	urban	94	mm/yr
	non-urban	315	mm/yr

MacKays to Peka Peka

Regional 3D Model Sensitivity

Figure F6

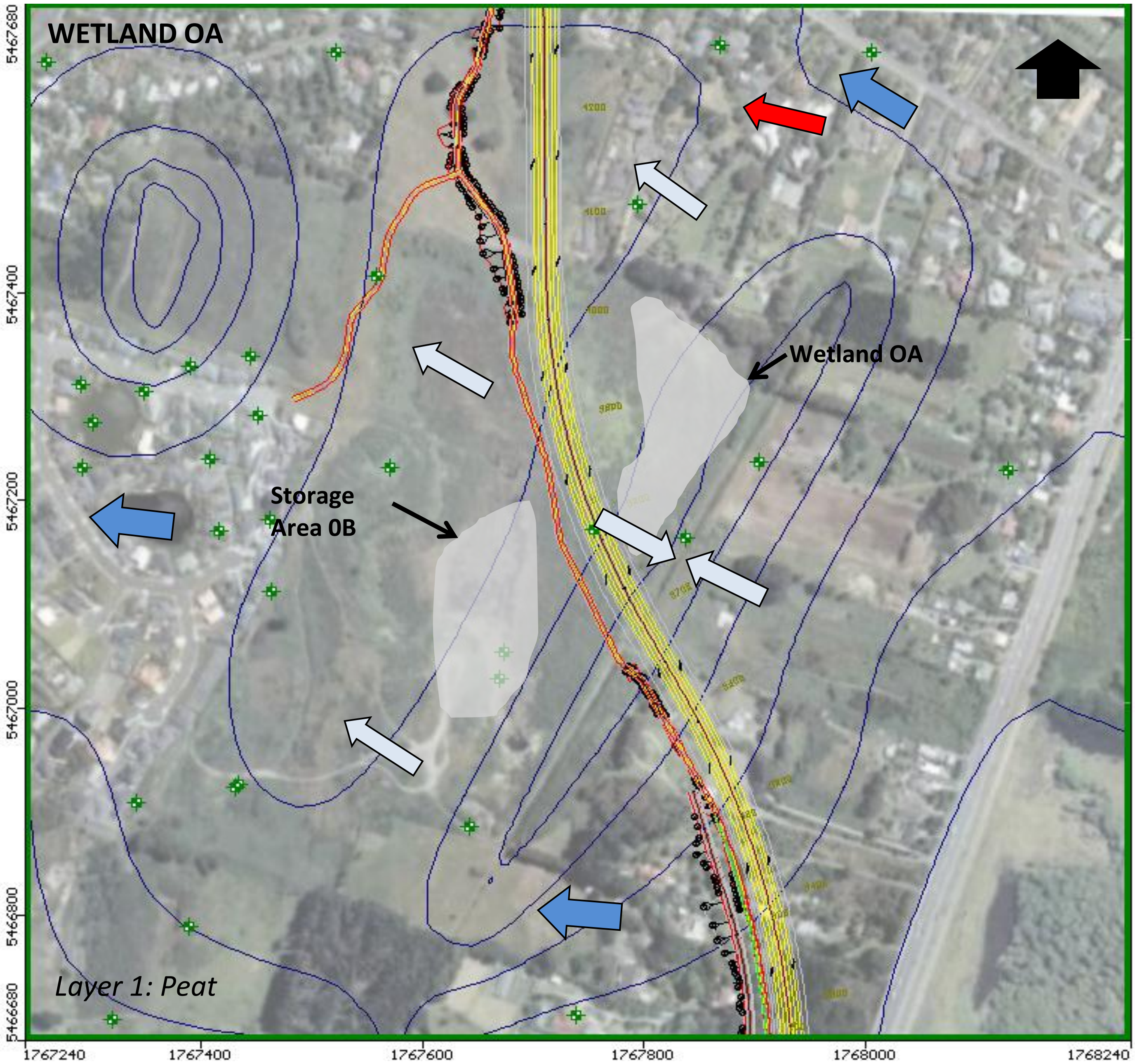


MacKays to Peka Peka

3D Model Post Expressway Construction Steady State - Flow Effects

NOTE: FIGURES AT DIFFERENT SCALES

Figure F7



LEGEND

General head boundary

Drain boundary

Head Observation

Main groundwater flow direction

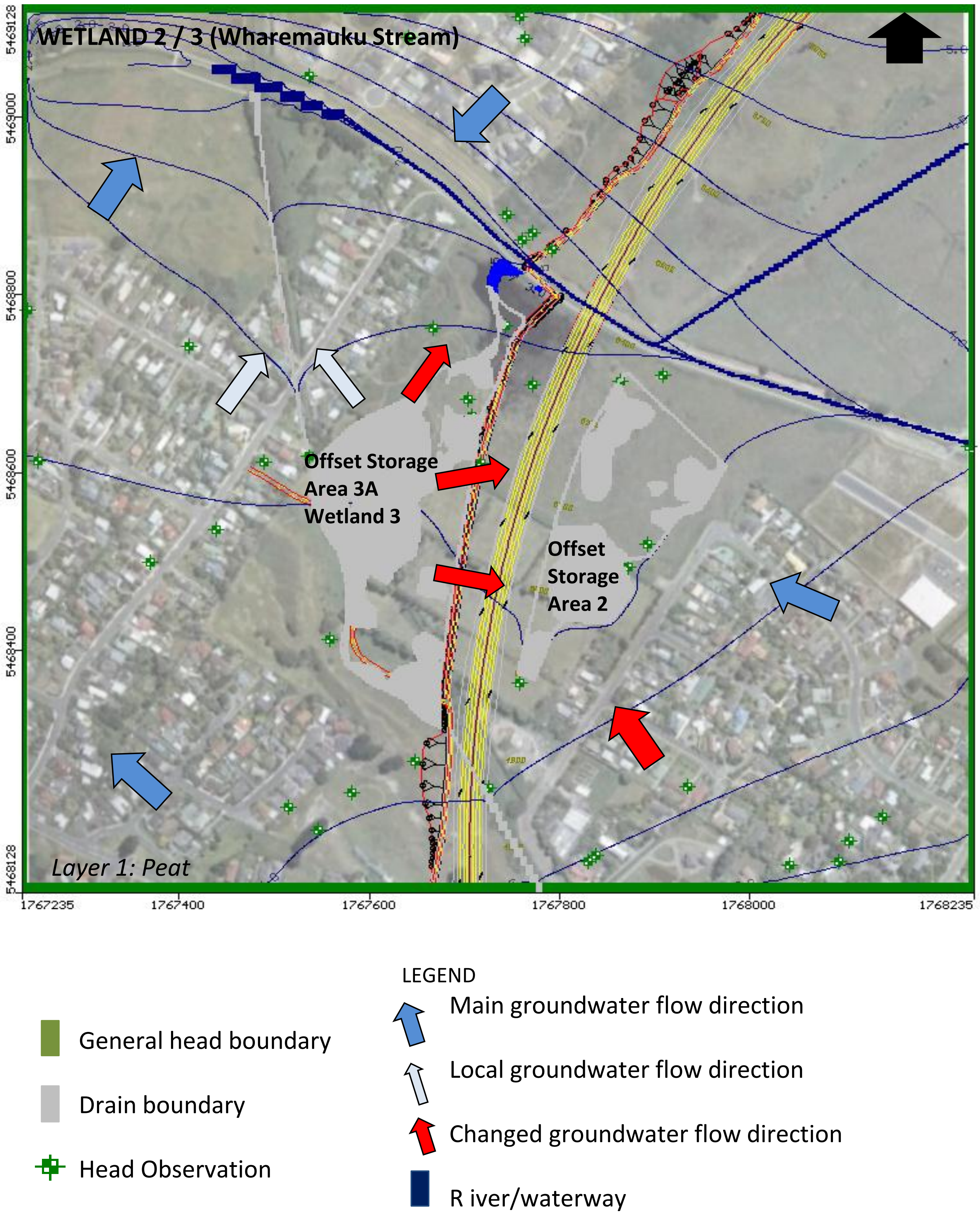
Local groundwater flow direction

Changed groundwater flow direction

Post Expressway Construction Steady State Flow Effects - Wetland OA

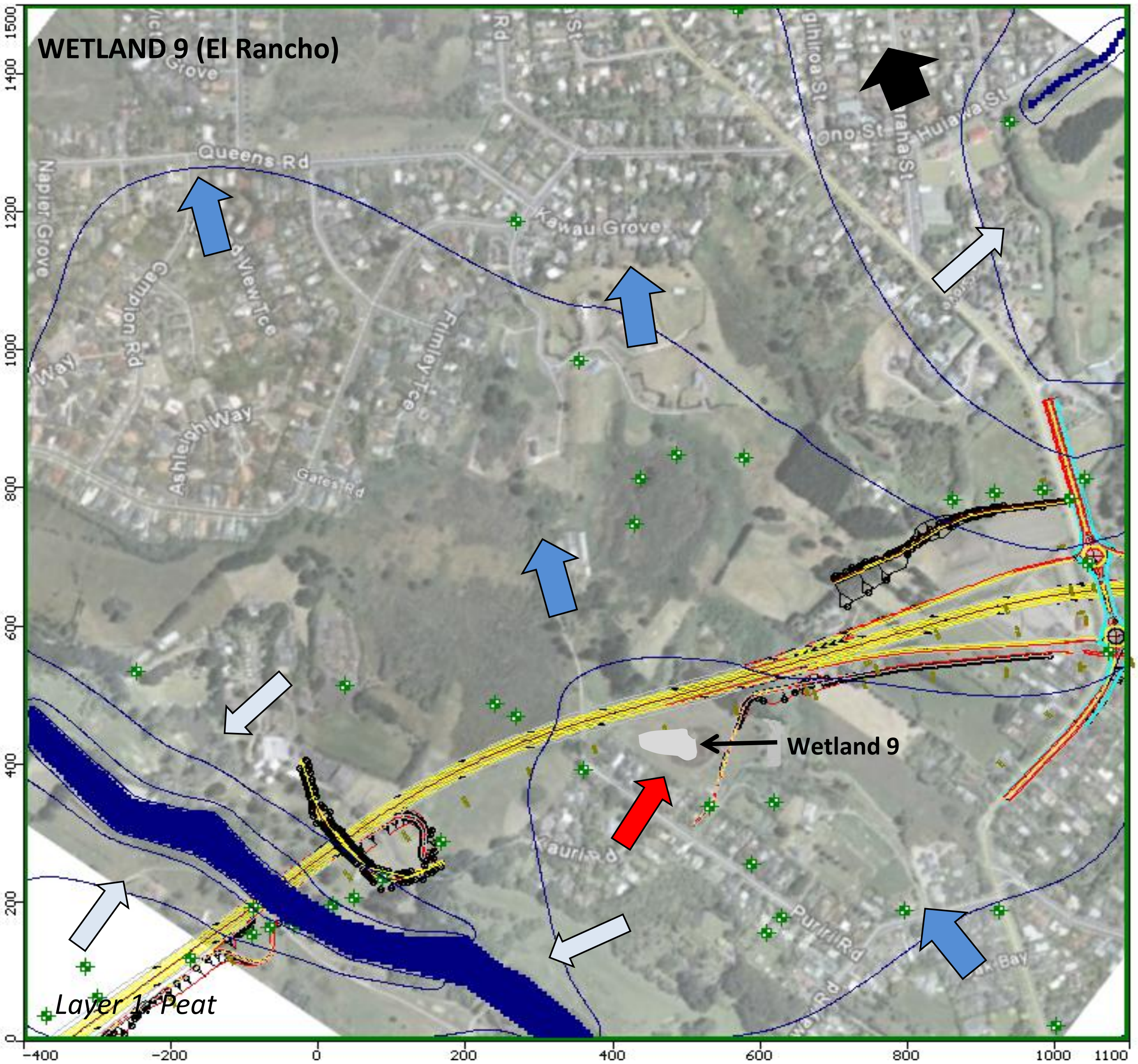
MacKays to Peka Peka

Figure F7a



Post Expressway Construction Steady State Flow Effects - Storage Areas 2/3A, Wetland 3

Figure F7b



Constant head boundary

General head boundary

River/Waterway

LEGEND

Main groundwater flow direction

Local groundwater flow direction

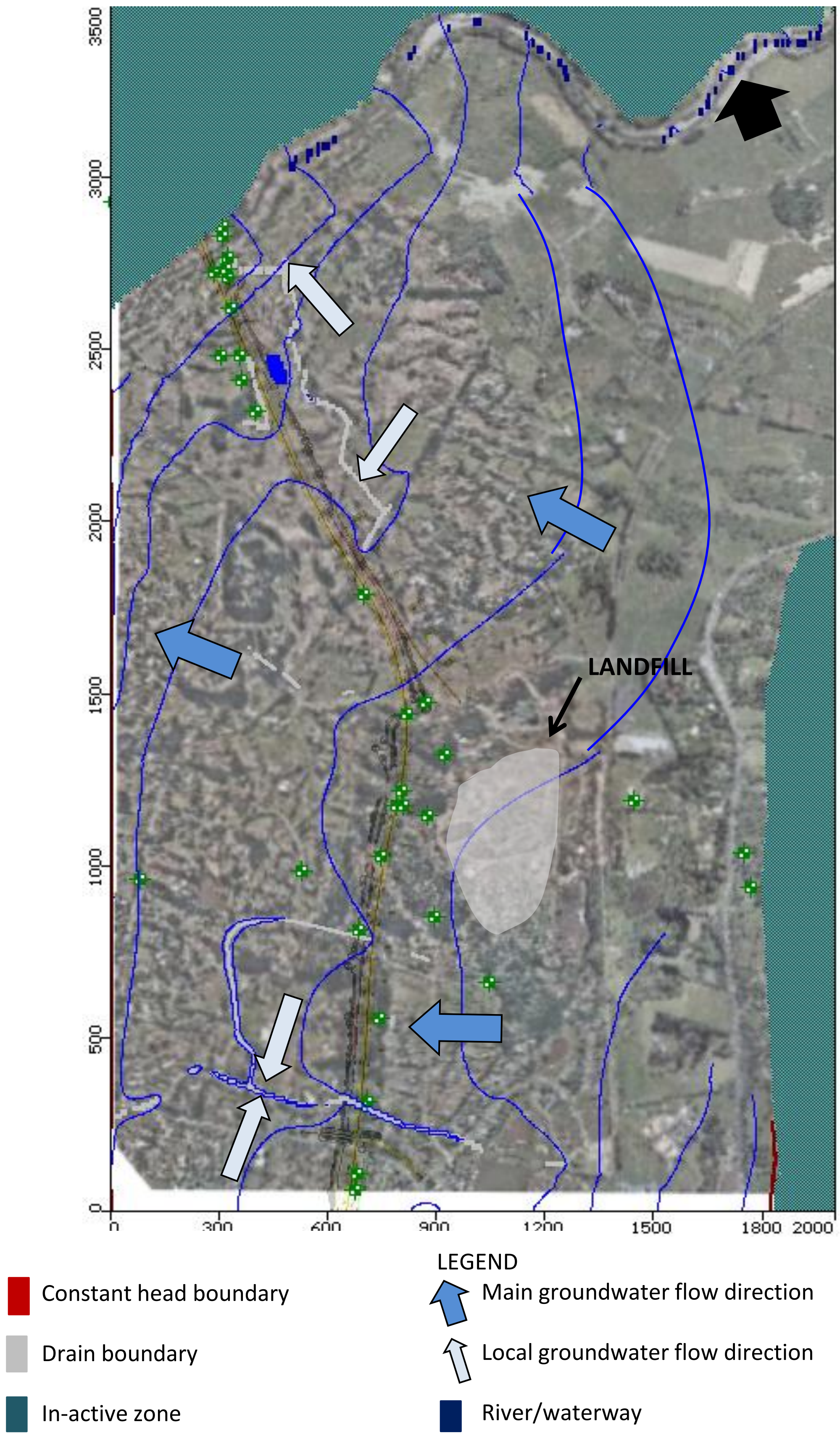
Changed groundwater flow direction

Head observation used in calibration

Post Expressway Construction Steady State Flow Effects - Wetland 9

MacKays to Peka Peka

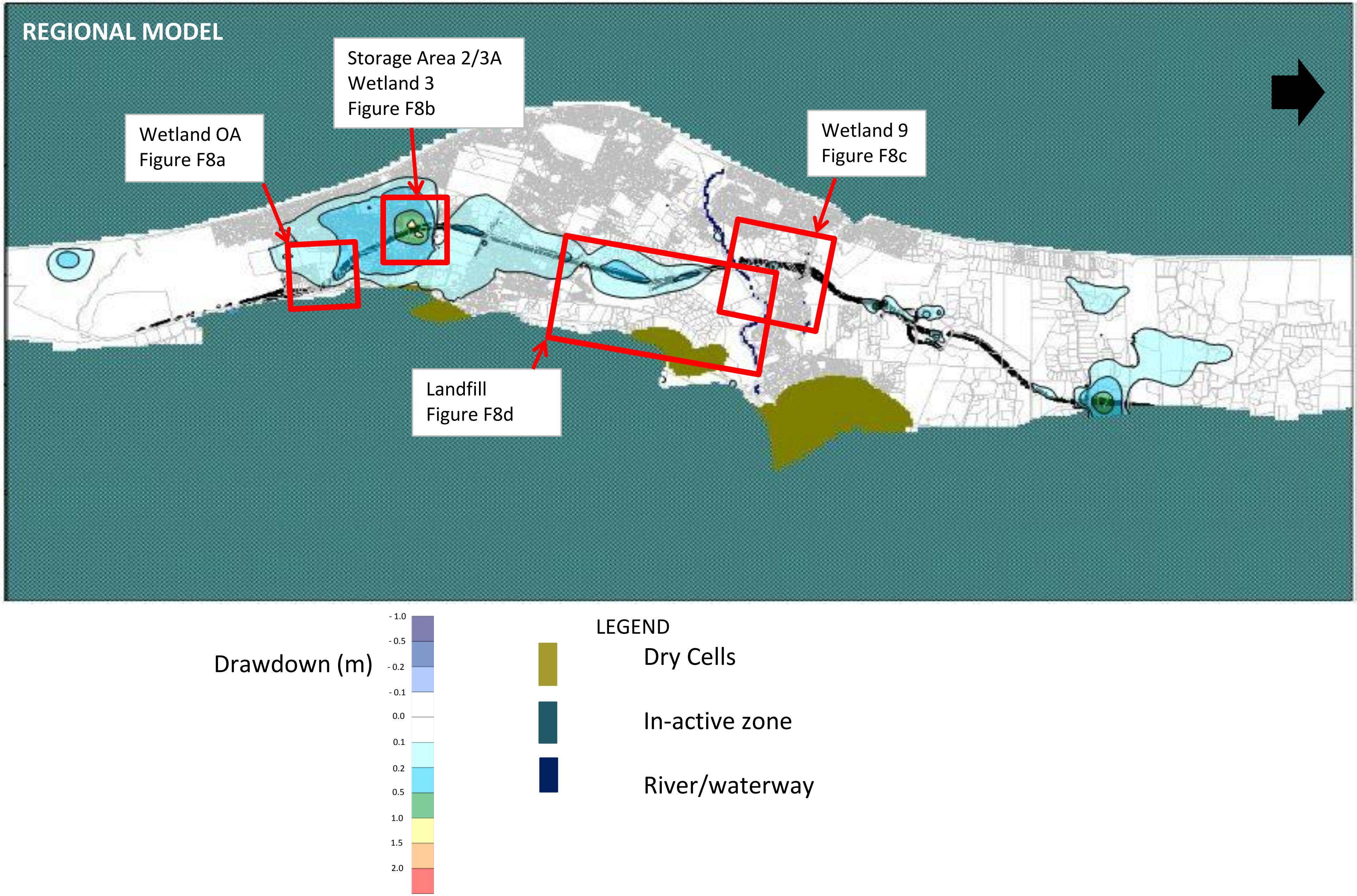
Figure F7c



Post Expressway Construction Steady State Flow Effects - Otaihanga Landfill

MacKays to Peka Peka

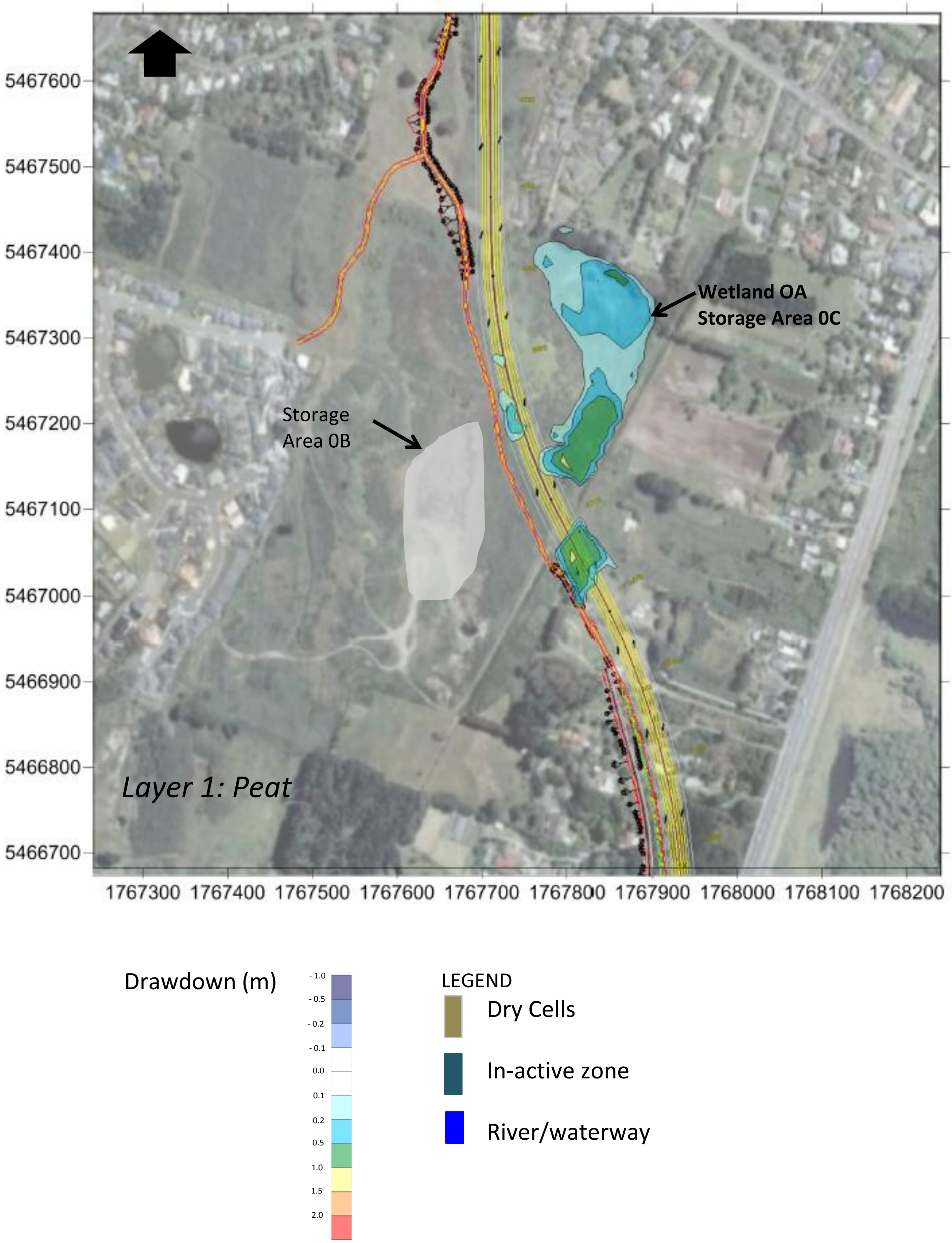
Figure F7d



3D Model - Post Expressway Construction - Steady State Drawdown Effects

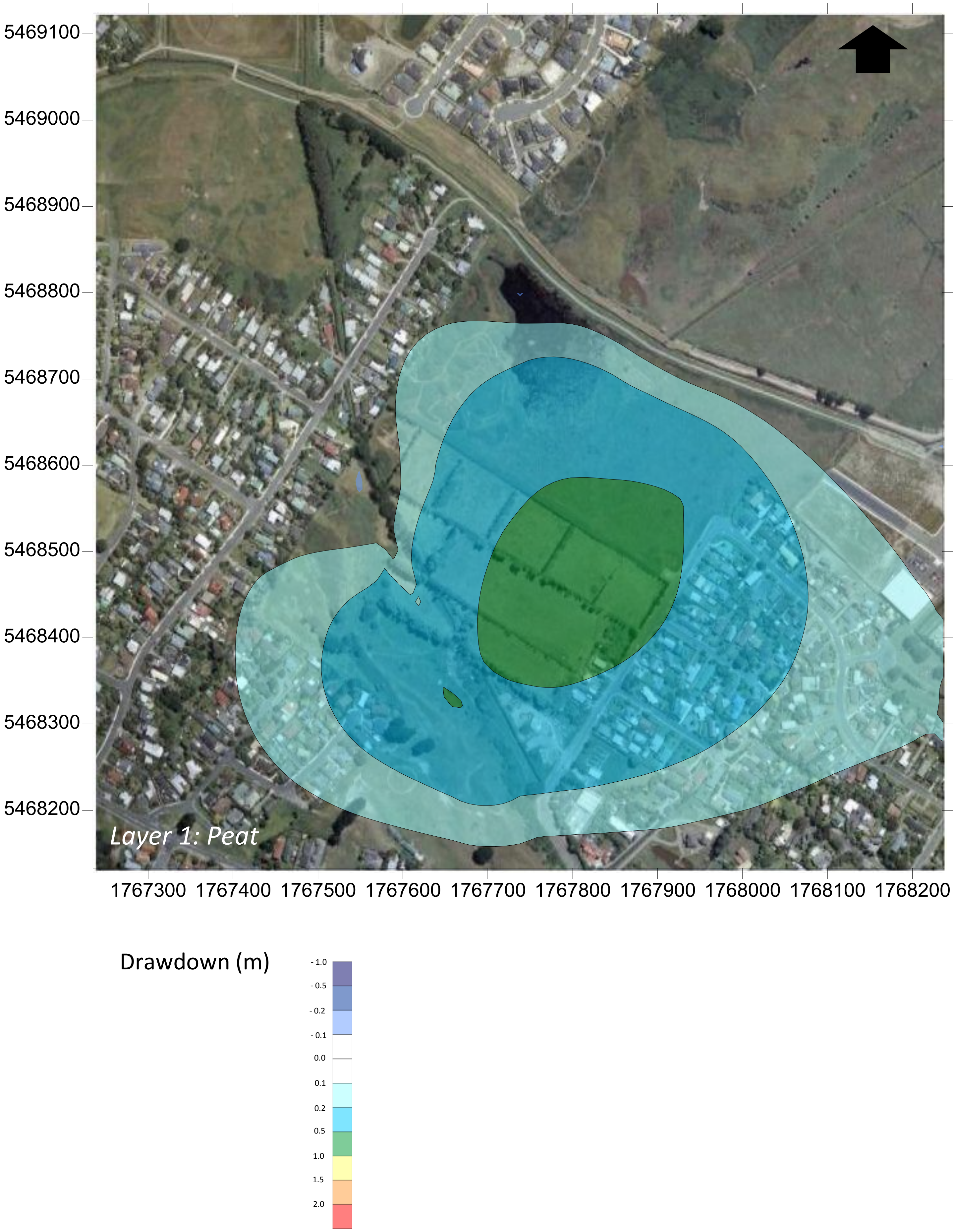
NOTE: FIGURES AT DIFFERENT SCALES

Figure F8



Wetland OA

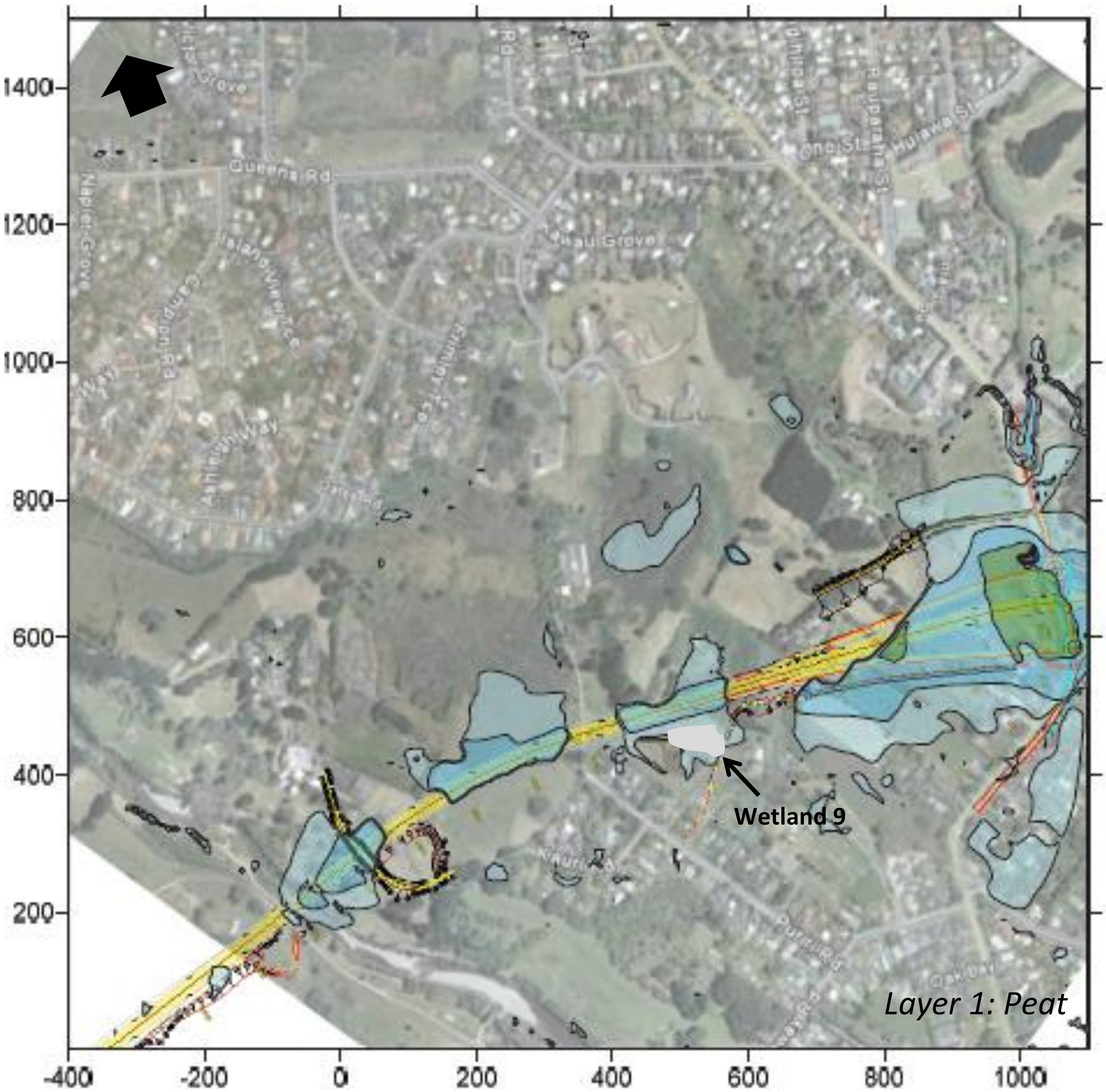
Figure F8a

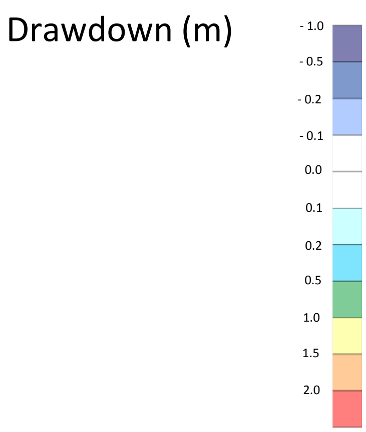


MacKays to Peka Peka

Storage Areas 2/3A, Wetland 3

Figure F8b

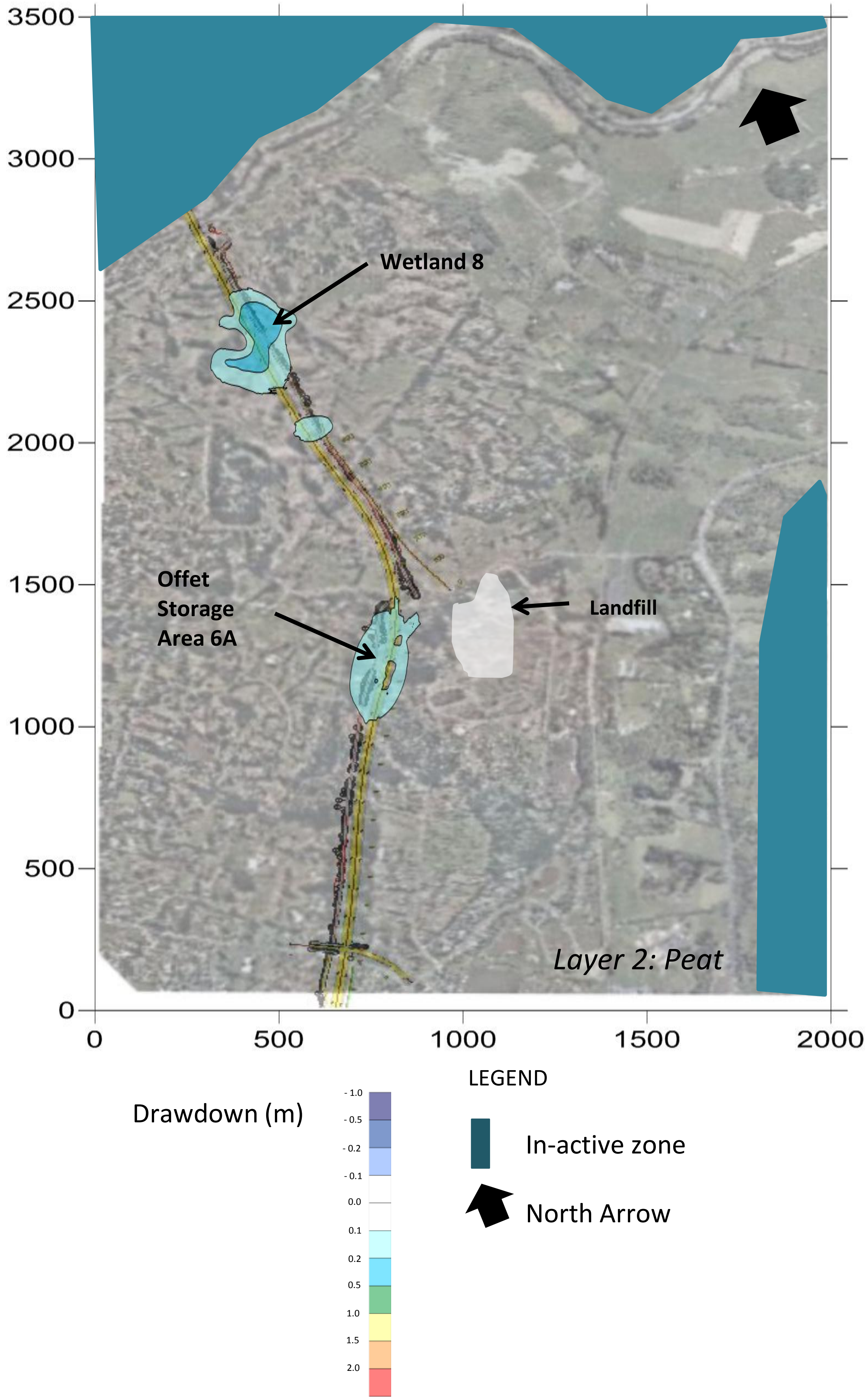




Wetland 9 El Rancho

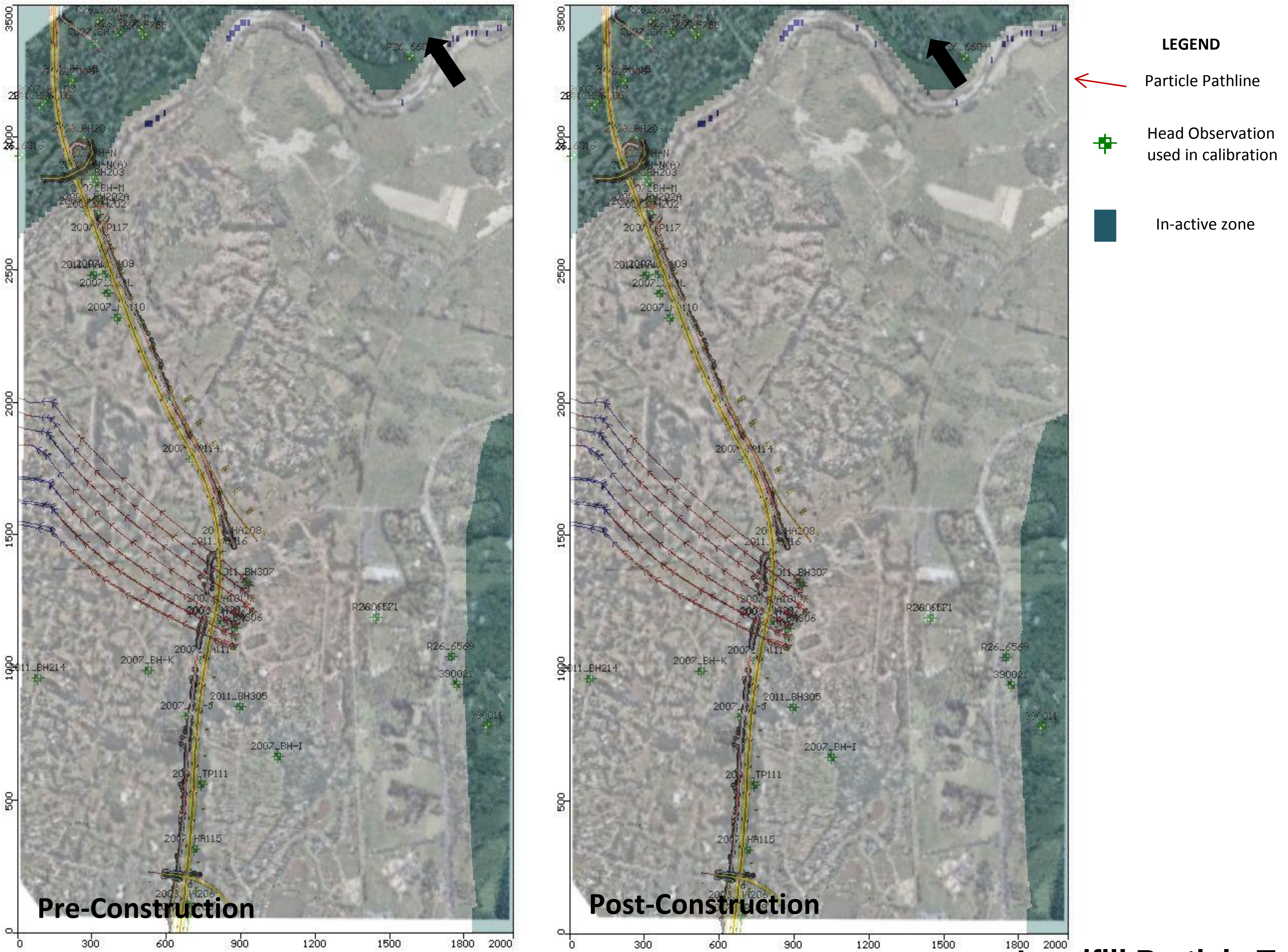
MacKays to Peka Peka

Figure F8c



Otaihanga Landfill

Figure F8d



Landfill Particle Tracking

Figure F9