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Poverty Bay Flats Groundwater Model Development
- *Assessment of Available Data and Information*

Prepared for Gisborne District Council

Report No H12004/1

December 2011

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Quality Control				
Client:	Gisborne District Council			
Report reference:	Title: Poverty Bay Flats Groundwater Model Development - Assessment of Available Data and Information		No:	H12004/1
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Reviewed by:	Greg Barkle	Approved for issue by:	Greg Barkle	
Date issued:	December 2011	Project No:	H12004	

Document History							
Version:	1	Status:	Final	Author:	CR	Reviewer:	GB
Date:	18-11-11	Doc ID:	Poverty Bay Flats GW info assessment.doc	Typist:	CR	Approver:	GB
Version:	2	Status:	Final	Author:	CR	Reviewer:	GB
Date:	14-12-11	Doc ID:	Poverty Bay Flats GW info assessment Final revised.doc	Typist:	CR	Approver:	GB

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1   INTRODUCTION

Gisborne District Council (GDC) is investigating the development of a groundwater modelling tool for the sustainable management of the Poverty Bay Flats (PBF) aquifer system. The model will be used to determine the sustainable allocable yield from the main aquifers and to understand and manage the interactions between the Waipaoa River and groundwater systems on the PBF.

The allocation limits from an aquifer system under the proposed National Environmental Standard (NES) for Ecological Flows are not more than 15% and 35% of the average annual recharge for shallow and coastal aquifers, and all other aquifers, respectively (MfE, 2008). GDC aims to assess existing groundwater allocation against the annual recharge from rainfall and river discharge to develop the necessary understanding of water allocation from both the mass balance and effects based approaches.

GDC's predecessor East Cape Catchment Board (ECCB) developed a groundwater model for the PBF aquifers in the late 1980s. This project was undertaken primarily using an external consultant, Mr. Grant Roberts from Ground Search Ltd. As an initial step towards developing an up-to-date groundwater model, GDC obtained an Envirolink grant from the Ministry for Science and Innovation (MSI 1026-GSDC96 Waipaoa catchment groundwater model). This grant was to examine the available resources from the previous ECCB's groundwater modelling project and obtain an understanding of the process that should now be followed to develop the required tool based on the existing data and information. GDC commissioned Aqualinc Research Ltd (Aqualinc) to assist them in this investigation.

Aqualinc contacted the developer of the previous model, Mr. Grant Roberts, and obtained all the available resources and data related to the 1980s model development. Unfortunately despite initial indications, a digital data of the model was not available. Only hard copies of reports which describe the model development and data reports were available for this review.

The purpose of this report is to outline the results of the examination of available resources of the previous PBF groundwater model, and provide recommendations on how to utilise the available information to develop a groundwater model for the PBF aquifer system.

2   AVAILABLE RESOURCE OF PREVIOUS MODEL

The developer of the previous PBF groundwater model in late 1980s, Mr. Roberts, has supplied all the available resources related to the initial model development. Mr. Roberts initially indicated that the digital data of the model was available and believed this was stored on "old" floppy discs. However, the relevant floppy discs could not be located and have not been supplied to Aqualinc for this review.

Mr. Roberts has supplied seven folders to Aqualinc. A summary of the content in these seven folders is listed below:

1. Geophysical (resistivity) survey, May 1986
   - The final report on the resistivity survey is available
   - Outcome/Conclusions are:
     a. The survey identified two higher resistivity areas within the PB flats with some uncertainty
     b. One of the survey's initial objectives to map basement structures has not been successful. Therefore, they recommended further investigations using exploration drilling.

2. Geophysical (resistivity) survey graphs for PBF area.

3. Computer printout data of the geophysical (resistivity) survey.

4. Pump test graphs for the Cemetery Bore at Cameron Road.

5. Pump test report for the Cemetery Bore at Cameron Road - July 1987. The findings of the report were:

   - Test was firstly conducted for variable rates over unspecified number of hours.
   - Secondly, a constant rate test for 26 days at a rate of 5,184 m^3/day.
   - Drawdowns had been recorded in the production bore and nearby observation bores.
   - Estimated aquifer parameters:
     Transmissivity, $T = 500$ m^2/day
     Storativity, $S = 0.0001$ to 0.003.

6. Pump test data for the Cemetery Bore at Cameron Road.

7. Two unfinished initial stage drafts of the Groundwater Model User Manual, and paper records of water levels for a few wells.

3 REVIEW OF DRAFT GROUNDWATER USER MANUALS

As discussed in Section 2 of this report, neither the final report nor the digital model of the PBF groundwater model is available. There is however relevant information that can be gathered from the unfinished drafts of the Groundwater Model User Manual. The summary of key information from the user manual is:

Model aim
The study objective was to produce a water management model or forecasting tool for the Poverty Bay groundwater system.

Water Age
The manual indicates that groundwater age based on Tritium analysis (details of the analysis are not given) can be more than 30 years.

Physiography

Standstone formations can be found in the upstream of the Waipaoa River catchment. Higher yielding bores are in the coarser deposits of gravels and sands, such as the Wapaoa river gravels, the Makauri and Matokitoki gravels.

Aquifers

The aquifer system is leaky. No information is available on exact descriptions of aquifers and aquitards.

Recharge

This section is incomplete. It appears that a percentage of the rainfall has been used as the aquifer recharge; however, the percentage value is not specified.

River Flows

River gauging work by ECCB shows that under low flow conditions (less than 3,500 l/s), the river gains about 300 l/s of flow over the reach from Kaiteratahi to Ormond. No details are given of the source of these gains. It was not practical to gauge the river at higher flows.

Conceptual Geological Model

The main geologic features are:

- The shallow alluvial deposits including the Te Hapara sands in the seawards part of the flats and the shallow fluvial deposits inland. There is exchange of water from this layer into deeper layers. This layer acts as a source of recharge (by leakage) for deeper aquifer layers.
- The Waipaoa gravel layer represents recent prior courses of the Waipaoa River.
- The Makauri gravel forms from prior course of the Waipaoa River but seems discontinuous and isolated from layers above and below.
- The Matokitoki gravel forms the deepest known aquifer in the system. It outcrops at the surface near the town, on the hills above the Matokitoki stream and then dives to depth below Kings Road.
- No details are given about the thickness of the aquifers.

Model grid

No grid sizes are given.

Boundary conditions

No details are available.

Parameters

River and drains – no information available
Transmissivity and Storativity – no information available on what was used in the model.
Estimated values from the Cemetery Bore (at Cameron Road) pump test reported are $T = 500$ m^2/day and $S = 0.0001$ to 0.003.

Simulation Period

No information is available.

Software

No information cannot be found in the draft manuals, however, Mr. Roberts indicated that MODFLOW was used (per. comm.).

Parameterisation

No information is available to determine whether the entire model domain was modelled using a single parameter category for each category (i.e., hydraulic conductivity, storage parameters etc) or another parameterisation method (e.g., zoning) was adopted.

Wells

No information is available on whether water abstractions from wells have been modelled.

Calibration

Although no detailed information is available, the manual indicates that steady state calibration was undertaken using average water levels. The transient model calibration was carried out using pump test data and water levels.

4   OTHER PREVIOUS RELEVANT STUDIES

A brief summary of other relevant studies undertaken in the PBF area is given in the following sections.

4.1   Hydrology of the Poverty Bay Flats aquifers by Taylor (1993)

Taylor (1993) investigated the PBF aquifer system using isotopic measurements. A cross-section of the PBF aquifer system along a central line from Kaiteratahi to the coast is shown Figure 4-1.
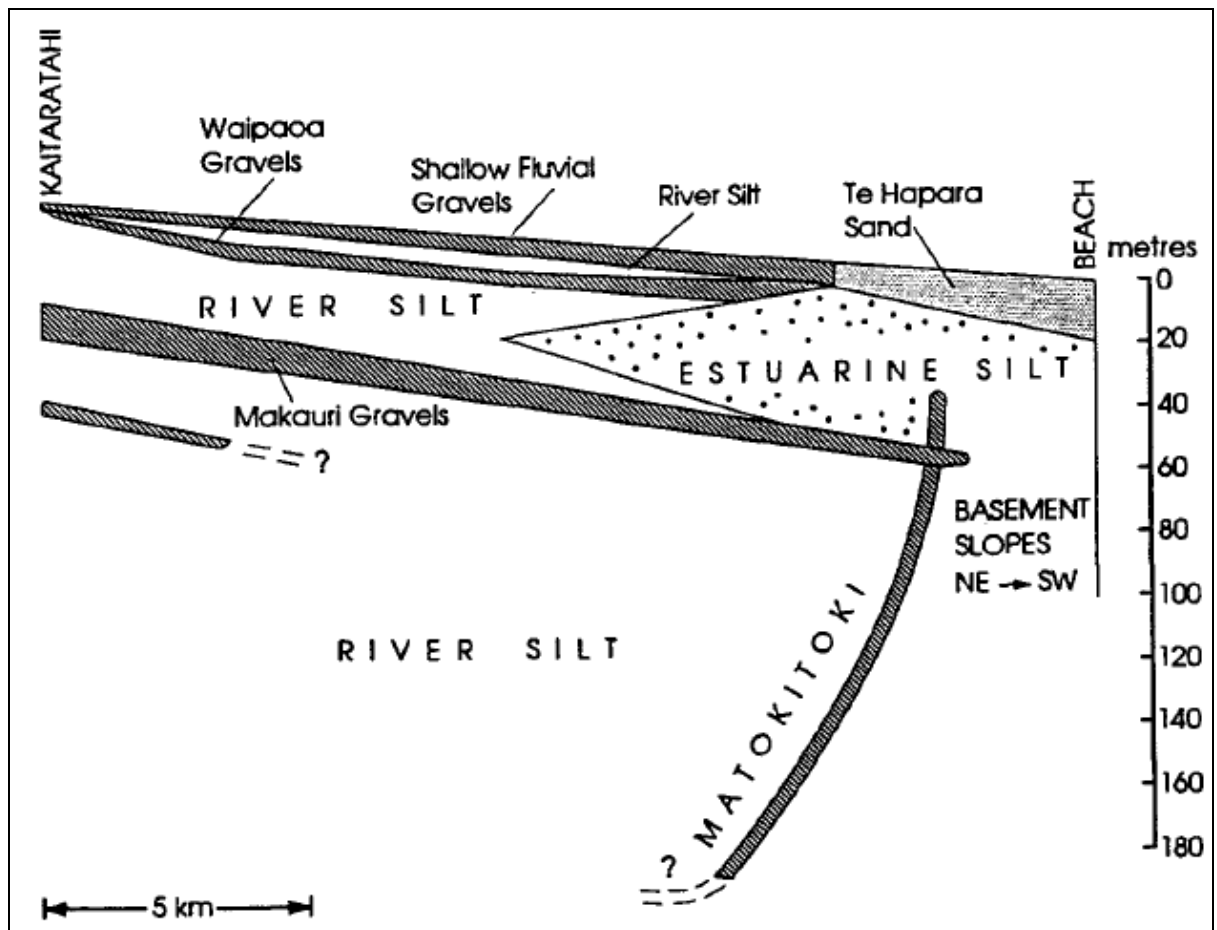
Figure 4-1: Cross-section of the PBF aquifer system along a central line from Kaitaratahi to the coast (taken from Taylor, 1993)

The study reveals:

- There are a number of gravel aquifers in the PBF area. These aquifers are separated by poorly permeable silt layers. The depths to the basement vary between 50 and 200 m.

- The aquifers that lie between Kaiteratahi to the coast are predominately recharged from the Waipaoa River. However, recharge mechanism of other aquifers that are around the outskirts of the PBF are not well established.

- The Waipaoa gravels aquifer connects to the Waipaoa River downstream of the narrow river valley north of Kaiteratahi.

- Permeability of the Te Hapara sands aquifer near the coast is higher compared to clay/loam soils in other areas of the Flats.

- Recharge to the Makauri aquifer may occurs from the direct recharge under the Waipaoa River near (closed system behaviour) and migrating river water at shallow levels (open system behaviour) before seeping into deeper aquifers.

- The Matokitoki aquifer, at the southern toe of the PBF, yields water recharged under similar conditions to the open system of the Makauri aquifer.

4.2   Groundwater of the Poverty Bay Flats by Barber (1993)

Barber (1993) has described the PBF aquifer system based on a pump test programme. In addition the monitoring of the aquifer system undertaken in previous research has been summarised in the report. The locations of the aquifers identified in the study are given in Figure 4-2. The key findings are:

- The underlying sediment layer of the PBF can be up to 250 m thick dominated by silts.
- Water bearing layers of sand and gravel are a small fraction of the total stratigraphy, the aquifer system is leaky.
- The Te Hapara shallow water table aquifer is up to 20 m thick, and consists of both unconfined and confined formations.
- Shallow fluvial deposits can be seen from Kaiteratahi down coast. These water bearing deposits are pumice sand and once occupied by the Waipaoa River.
- The Matokitoki narrow gravel aquifer extends from Gisborne City to Kings Road area. The thickness the aquifer varies from 4 to 28 m.
- The Makauri gravel aquifer lies underneath the Waipaoa River silt layers. It was estimated that transmissivity of the aquifer can be in the range of 1,000 to 2,000 m^2/day.
- There are a number of localised aquifers consist of gravel, pumice sand and sand deposits.
- There are three mechanisms of recharge: the Waipaoa River, rainfall and run-off from the hills to the north-east of the flats.
- Low flow surveys carried out north of Kaiteratahi and Te Karaka in the 1970s shows that Waipaoa River loss is 150 – 400 l/s.

FIGURE 2.1.

Present accepted extent of the main Poverty Bay aquifers

Te Hapara Sand Aquifer — – – – –
Waipaoa Gravel Aquifer — ·– ·– ·–
Makauri Gravel Aquifer ———
Matokitoki Gravel Aquifer ◆——◆

Scale 1:70,000

N ▲

Figure 4-2: Groundwater aquifers in the PBF (taken from Barber, 1993)

4.3 Review of groundwater information for the Poverty Bay Aquifers by NIWA (2010)

The aims of this project were to identify groundwater information available within PBF and review the current state of knowledge to develop an understanding of aquifer

recharge. Six previous studies, including Taylor (1993) and Barber (1993) have been reviewed. The summary of this review is:

- A brief description of aquifer system similar to the findings of Taylor (1993) and Barber (1993) is presented.
- PBF's primary groundwater source is the Makauri Gravel Aquifer that supplies approximately 52% of the total consented groundwater allocation (60,980 m^3/day) in the flats.
- The recharge to the Makauri Gravel Aquifer from the Waipaoa River accounts for about 90% of total river recharge. It has been estimated from Barber (1993) that losses from the river can be 150 – 400 l/s (i.e., 13,000 - 35,000 m^3/day or 4.7 – 12.7 million m^3/year)
- The average annual recharge for the whole aquifer system estimated using a simple soil moisture balance method was 37.8 million m^3/year. Allocation for the whole aquifer is 22.3 million m^3/year. Therefore, allocation is approximately 58% of the estimated annual recharge.

5 GROUNDWATER AND WAIPAOA RIVER INTERACTION

The previous studies show that the interactions between the Waipaoa River and the PBF aquifers are significant (Taylor, 1993; Barber, 1993; NIWA, 2010). The estimated average annual river losses are in the range of 4.7 – 12.7 million m^3/year (Barber, 1993). These recharge estimates are for low flows only (< 3,500 l/s) and recharges for high flows are unknown. However, NIWA (2010) estimated that the average annual recharge for the PBF aquifers is 37.8 million m^3/year.

Proposed interim limits for groundwater under the proposed NES (MfE, 2008) states that

> *For shallow, coastal aquifers (predominantly sand)*
> *An allocation limit of, whichever is the greater of:*
> - *15% of the average annual recharge as calculated by the regional council*
> - *the total allocation from the groundwater resource on the date that the standard comes into force less any resource consents surrendered, lapsed, cancelled or not replaced.*

NIWA (2010) estimates that average annual allocation is approximately 58% of the estimated annual recharge. This estimated annual allocation is significantly higher than the proposed interim limits under the proposed NES (i.e. 15%). However, NIWA estimated the annual recharge using a simple soil moisture balance method and may not be accurate.

The river recharge to the aquifer system will be influenced by groundwater abstractions. Since the river and groundwater interaction is high, the river contribution to the aquifer system will increase with greater groundwater abstractions. This occurs when groundwater levels drop with pumping and hence create a higher hydraulic gradient between the river level and the groundwater levels. The interaction of groundwater abstraction inducing higher river leakage reinforces the need for the PBF

water management plan to consider surface and groundwater systems together. Sustainable water management on the PBF needs to quantify and understand this co-dependence of both surface and subsurface resources. A well calibrated groundwater model that simulates the aquifer system including the river recharge interaction can be used to address management problems related to both aquifer and river flow as an integrated system rather than looking at one component in isolation.

6 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

All the available information from the previous PBF groundwater model development programme was collected and examined. Neither a digital model nor a final report of the model development were available. However useful geological information for the area and a long term pump test data were supplied. Both of these data can be used for the future groundwater model development programme.

As no digital model is available from this previous work it is recommended that GDC will need to develop a new groundwater flow model. The suggested pathway for the implementation of the desired model fit for purpose is described below.

6.1 Suggested Road Map for Future Work

The steps to develop a management tool to sustainably manage both the ground and surface water resources in the PBF area are outlined below. The required information needs at each step have also been identified. The available data and information from previous studies are described in Section 3 and 4. It is likely that GDC holds most of the other required data (per. comm.). However, a detailed assessment should be undertaken before development of the groundwater model programme to ascertain the actual availability of the data needs.

Objective

GDC's primary goal in considering the development of a groundwater model is to sustainably manage the groundwater abstraction of the PBF aquifers. As the aquifers and the surface water bodies are hydraulically connected, it is important that objectives are broadened to manage both surface water and groundwater as a whole. Clearly defined objectives will assist in developing an accurate conceptual model and assessing information needs and data gaps, and also determining the legal and regulatory framework applying to the project, as required.

Development of the Conceptual Model

There is a reasonable amount of good information available to develop the paper based conceptual model. This information includes the physiography data available from the previous model development project. Additional results from other aquifer studies (Taylor, 1993; Barber, 1993; NIWA, 2010) can also be used to help build up the conceptual model.

- The geometry, formation, and extent of the aquifers and aquitards can be developed using the available data from the previous studies. The borelogs for the area available from GDC can also be utilised to enhance and verify the understanding of the geological data.
- Boundary conditions can be developed based on the previous studies and borelogs. The lower boundary of the model is likely to be head-dependent boundary at the coast. The bottom boundary of the model can be modelled as no-flow boundary as a basement structure is present underneath the aquifers. Aquifer parameters can be obtained from existing aquifers test reports.
- Locations of the sources and sinks of water including river, streams, drain and wells can be included in the conceptual model using GDC's available data and information.
- Aquifer recharge occurs from three mechanisms: the Waipaoa River, rainfall and irrigation, and run-off from the hills to the north-east of the flats.

Data and Information Gathering Phase

The data and information required for the development of a groundwater model would depend on the outcomes of the conceptual model. However, it is likely that the following data and information would be required to develop a numerical model.

Digital maps of the area – this includes an accurate digital elevation map of the area at a high resolution (typically 20 m), locations of the rivers, streams, drains and build-up areas such as town.

Borelogs – the geological information available from the previous model development and other studies (e.g. Taylor, 1993; Barber, 1993) can be improved and updated with accurate borelog information held at GDC. This is valuable ground truthing as borelogs represents the accurate geology around the wells that are being used for groundwater abstractions.

Pump test data – it is possible that other pump tests have been undertaken within the model area over the last 20 years. The results from the tests can be utilised to define and improve the model parameters such as transmissivity, storage coefficients and leakage for different areas of the aquifer with a better degree of confidence.

River/stream cross-sections – data on river cross-sections (i.e. bed elevation and width) of the river, preferably variable-shaped cross-sections, at a reasonable resolution are important to confidentially describe the interaction of the fluxes from the river to the groundwater system.

Drains depth – similar to river/stream, flows in drains are an important aspect with regard to possible aquifer recharge. Therefore, accurate cross-section information can significantly improve the models predictions.

Land use of the model area - The land use over the PBF has varied over the years and therefore the amount of recharge into the aquifer system has also changed. It is important to collect accurate data over the period that the model will be tested against and calibrated. Recharge from the town or built up areas can be low due to high stormwater run-off. Whereas recharge through the bare

lands is higher, and this can further be elevated in irrigated areas. As rooting depths of different crops varies and evapotranspiration for different crops is a function of the rooting depth, it will also be valuable to identify the crop types for different areas of the model domain.

Groundwater levels – although some water level data is available in paper format prior to 1988, it is important to develop a digital dataset for well water level data for the whole model period including recent years. The water level data is very important for the model calibration and can be useful for setting up the model boundaries dependent on the aquifer formation.

Water use records – groundwater abstractions affect the aquifer water dynamics. Therefore, reliable water use data (i.e., pumping records) are important to develop and test the groundwater model against.

Surface water flows – as described above, surface and groundwater interactions are critical. Thus availability of accurate flow data for rivers and streams, especially at the upper boundary of the model area, is essential.

Drain flows – similar to river and stream flows, availability of the drain flow data can significantly improve the model accuracy during the calibration.

Selection of appropriate Software

The software platform for the groundwater model development can be chosen after completion of the construction of the conceptual model so that an appropriate tool is available to address the objectives. However, Aqualinc recommends using MODFLOW 2005 model (Harbaugh, 2005) using a graphical interface such as Groundwater Vistas or Visual MODFLW. The main reason for this recommendation is that as interactions between surface water and groundwater are highly important for the model area, a MODFLOW compatible flow package such as Stream Flow Routing (SFR2) Package (Niswonger and Prudic, 2005) can be utilised to model the interactions. In addition MODFLOW models can be calibrated using PEST (Dougherty, 2011), which is the industry standard calibration tool.

If GDC requires the use of the groundwater model for managing groundwater quality in the future, a MODFLOW compatible software package such as MT3DMS (Zheng, 2006) can be build into the MODFLOW model.

Development of the Numerical Model

After completion of the development of the conceptual model and gathering of required data and information, the numerical groundwater model could be constructed. The grid sizes of the model will be depended on the available data (i.e. resolution of digital elevation map etc.).

Initial Testing

The numerical model would be tested in the initial calibration phase. Available data such as well water levels, river flow and drain flow, and water balances for different parts of the model domain are tested at a coarse level to ensure the model is sound and responding in the expected way. A rather rudimentary sensitivity analysis may be

completed to understand the parameters which are the most sensitive in changing the outputs from the model. These parameters are the critical parameters which most attention needs to be paid to ensure their accuracy during the model development phase.

Assessment of Data and Information Gaps from Initial Testing

The initial calibration phase would enable the identification of gaps in data and information that are required to develop a well calibrated groundwater model. Thus data and information can be gathered and incorporated into the model.

Full Model Calibration Phase

Model calibration can be undertaken using a method such as PEST (Dougherty, 2011). The aquifer parameters such as hydraulic conductivity, storage parameter, river and drain bed conductance, and boundary cell conductance can simultaneously be estimated by comparison against measured groundwater levels using PEST. The model should be calibrated to meet the acceptable industry standards (Donnell et al., 2004; MDBC, 2001).

Use as a Management Tool

The calibrated model could be used to run different model scenarios to identify effects of different abstraction on the water resources of the PBF as a whole system. These scenarios can include:
- Change in river leakage due to increased groundwater abstractions at different locations of the aquifer.
- Effect of drain flows due to change in groundwater abstractions.
- Groundwater level change of the aquifer due to change in groundwater abstractions.
- Sea water intrusion potential due to lowered groundwater levels with increased abstractions.

Model Documentation

Excellent model documentation is required; this includes the detail description of the process that involved in developing the numerical model. The key points that should include are:
- Model's purpose
- Data and information used
- Assumptions used
- Uncertainties (i.e. data and sensitivities)
- Description of the model area and geology
- Boundary conditions
- Conceptual model development
- Code selection (software)
- Model construction (i.e., layering, gridding, boundary and initial conditions, model parameterisation)
- Model calibration
- Sensitivity analyses
- Description of scenario runs and results
- Recommendations.

Ongoing Maintenance

It is recommended that more than one GDC staff member is knowledgeable and familiar with using the model so that GDC is not at risk of losing all retained knowledge due to possible staff changes. It is highly likely that the model development process will identify the areas that the model accuracy can be improved by measuring dynamics in different parts of the aquifer system to reduce the uncertainty, bias and improve the accuracy of modelling decisions. It is important that GDC invest resources for data collection to improve the quality of the model in future enhancements. This process can be most effectively achieved with staff members who are familiar with the model.

Recommended Pathway for GDC Development of a Model

Whilst it is recommended that GDC commissions an external groundwater modeller to help with development of the model, the development process needs to be undertaken as a joint effort between GDC and any external consultants used. This arrangement will ensure that specialist expertise of a model developer is being used while still utilising the local knowledge in terms of data (i.e., supplying data and information, quality of data, uncertainties) and issues. It is believed that the close involvement of the GDC staff in the model development, maintenance and use would enable the best use of the investment by GDC and produce the best outcome for water management of the PBF resources.

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