Melbourne Groundwater Directory

METHODS REPORT

Final

4 September 2009
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1. Introduction

The Melbourne Groundwater Directory addresses the recognised need of user-friendly groundwater information covering the Greater Melbourne area. The Directory provides a centralised, consistent source of data and information to support water resource managers, environmental managers and the general public.

The project involved the following key tasks:

- **Stakeholder Consultation** - to clearly identify the requirements, content and format to best present the groundwater data to both technical and community user groups
- **Data Acquisition** - collection of groundwater data from three main sources: bore data; spatial data; and reference material
- **Database Development** – development of a database to consolidate each of the separate datasets into a unified groundwater dataset
- **Data Interpretation and Layer Generation** – generation of a series of groundwater layers, constructed from the interpreted bore data, existing GIS layers and reference material
- **Product Development** – development of products to meet the requirements of both the water industry (resource managers, consultants and research) and the broader community, including:
  - **Community Groundwater Map** - focusing on information relevant to the community and small scale groundwater users. Map includes information and simple explanations on aquifer extent and depths, potentiometry, yield and salinity.
  - **Technical Hydrogeology Atlas** - key technical groundwater layers, including information on aquifer extent and depths, potentiometry, yield, salinity and Managed Aquifer Recharge (MAR) potential
- **Product Lodgement** - integration of the products as web content to provide a user-friendly means of accessing the information

The purpose of this methods report is to provide documentation of the data compilation process so that users can understand the inherent strengths and limitations of the mapping products. This report documents the data sources, interpretation methods, assumptions and limitations associated with the generation of the hydrogeological mapping products. The report also includes identification of critical data gaps that limit the existing understanding of Melbourne’s hydrogeology, highlights geographic areas and aquifers that require further investigation and provide a procedure for updating the groundwater directory.
2. Stakeholder Consultation

There are a broad range of stakeholders with an interest in the products of the Melbourne Groundwater Directory. These stakeholders can be broadly grouped into resource managers, regulators, retailers, consultants, academics, students and the general public. In order to clearly identify the requirements of the different user groups Sinclair Knight Merz (SKM) engaged in a consultation process with the key stakeholders in the Groundwater Directory. The consultation took the form of two workshops: the first involving government agencies and the second involving industry professionals and academics.

The objectives of the consultation process were as follows:

- to establish stakeholder requirements for the Melbourne Groundwater Directory;
- to explore deliverables and formats which best meet these requirements; and
- to identify additional data sources that should be considered in the mapping process.

2.1. Stakeholder Organisations

The stakeholder groups invited to attend the respective workshops were identified in consultation with the Department of Sustainability and Environment (DSE), and the project steering committee. Rather than directly engage the general public it was decided that their needs and requirements would be addressed by the government agency representatives. The rationale being that these organisations have direct contact with the community regarding groundwater information and consequently have a strong understanding of community requirements.

Stakeholders represented in Workshop 1 (targeted at government agencies) were:

- Melbourne Water Corporation;
- City West Water;
- South East Water;
- Yarra Valley Water;
- Barwon Water;
- Western Water;
- Western Port Water;
- Southern Rural Water;
- The Environmental Protection Authority;
- The Department of Sustainability and Environment; and
- The Port Phillip and Western Port Catchment Management Authority.
Stakeholders represented in Workshop 2 (targeted at industry professionals and academics) were:

- The Australian Contaminated Land Consultants Association (ACLCA);
- The International Association of Hydrogeologists;
- RMIT University;
- La Trobe University;
- The Department of Primary Industries Research (PIRVIC);
- The Environmental Protection Authority; and
- The Department of Sustainability and Environment.

2.2. Workshop Structure

The workshops were loosely structured into the three sessions. Session 1 involved a discussion of user requirements for the Groundwater Directory products, Session 2 involved discussion of the strengths, weaknesses and suitability of existing hydrogeological mapping products, and Session 3 involved a discussion of potential mapping products and formats.

Session 1 – Discussion of User Requirements

In session 1, workshop attendees were asked to fill out a survey which listed a number of potential user requirements for the groundwater directory, as identified by SKM (refer Table 1). Stakeholders were requested to prioritise the identified requirements, ranking them from 1 (indicating a high priority) to 5 (indicating a low priority). The survey also allowed stakeholders to identify any additional requirements that were not covered in the original list.

Table 1 User requirements for Groundwater Directory products (as identified by SKM)

<table>
<thead>
<tr>
<th>Audience</th>
<th>User Requirement</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>Improve knowledge of groundwater resource</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Provide access to specific groundwater information (e.g. characteristics of explicit aquifers)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Identify groundwater resource opportunities including:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- physical properties (yield, salinity, depth); and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- policy development constraints (existing users, allocation limits, environmental constraints)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Provide information regarding groundwater constraints (watertable depth, salinity)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Understand Data Gaps</td>
<td>Describe our current level of knowledge with respect to the groundwater resource and where additional information is required</td>
</tr>
<tr>
<td></td>
<td>Understand methods and limitations</td>
<td>This relates to the interpretation, assumptions and processes used to</td>
</tr>
</tbody>
</table>
## Session 2 – Discussion of Existing Hydrogeological Mapping Options

The second session involved discussion of a selection of hydrogeological maps published in Australia over the last two decades. Key maps involved in the discussion were:

- **Bendigo 1:250,000 Hydrogeological Map** – produced as part of the Murray Darling Basin Hydrogeological Map Series. This map applies the BMR (1988) mapping standards. Key focus for the mapping is on yield and salinity class in the watertable aquifer.

- **Albany-Mt Barker 1:250,000 Hydrogeological Map** – produced as part of a series of hydrogeological maps by the Western Australian Government in the 1990s. The key mapping divisions are based on aquifer type/geology and resource size but not salinity (Anonymous, 1983).

- **The Hydrogeology of the Great Artesian Basin 1:2,500,000** – produced in 1997, the main map focus is groundwater flow paths within the major artesian aquifers (Habermehl and Lau, 1997).
Shallow Groundwater Salinity of the Murray Basin – compiled by BMR in association with a number of state agencies in 1988. The key mapping division in the main inset is groundwater salinity in the shallow aquifers.

Session 3 – Discussion of Potential Products

The final session involved a discussion of the mapping products proposed by SKM. The aim of this discussion was to test the relevance of each of the proposed products and to identify key content and format requirements. Products discussed in the session included:

- Technical Hydrogeological Map;
- Community Hydrogeological Map;
- Community Brochure;
- Web Content;
- Database of borehole data used in compilation of layers; and

2.3. User Requirements

The user requirement surveys from the two workshops were combined and the scores assigned to each requirement aggregated. The requirements were broken into two categories; those relevant to a technically minded audience (i.e. resource managers, industry professionals etc) and those needs relevant to the broader community (refer Table 2). The stakeholders were not asked to prioritise the requirements against each other, so it is not an absolute indication of their relative importance. There is also some disparity between the number of workshop participants present for the different stakeholder groups. For instance in the first workshop there were seven participants representing the water retailers but only one participant representing the groundwater regulator. As a result they do not provide an absolute indication of the value of each requirement, however the ranking does identify some general themes.

<table>
<thead>
<tr>
<th>Priority</th>
<th>Audience</th>
<th>User Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Technical</td>
<td>Aid in the identification of groundwater resource opportunities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mapping products are accessible online</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Products improve knowledge of groundwater resource and system (aquifer extents, resource potential, environmental constraints, resource sustainability)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Access to specific groundwater information (e.g. characteristics of specific aquifers)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Products are dynamic (capable of growing/changing as new information becomes available)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Access/presentation of all generated layers (as opposed to a compiled mapsheet)</td>
</tr>
</tbody>
</table>
## Priority | Audience | User Requirement
--- | --- | ---
Community | Simple communication method/format | Products are accessible online
| | | Provide information on resource availability (groundwater quality, depth to groundwater, yield)
Medium Priority | Technical | Provide information regarding groundwater constraints (watertable depth, salinity)
| | | Access to underlying data (i.e. interpreted bore data)
| | | Products should contain a high level of technical detail
| | | There should be an explicit description or representation of data gaps.
| | | Provide groundwater knowledge around asset sites (e.g. treatment plants)
| | | Groundwater related constraints
| | | Simple and accessible format (i.e. no additional interpretation required)
| | | Tangible/presentable format (tangible refers to hard copy format)
| | | Explicit identification of potential MAR opportunities
Technical | Low Priority | Integration of products with existing systems and frameworks (e.g. existing Hydro Mapsheet series, Mapshare)
| | | Understand methods and limitations
| | | Single mapping product (e.g. A0 Map)
Community | Education tool on groundwater processes and concepts

### Notes:
1. For the technical requirements a High Priority was given when the average score was < 1.5, a Medium Priority was allocated when the score was >1.5 and <2.5, a low priority was assigned to those requirements with a score >2.5
2. For the community requirements the average score for the use of mapping products as an education tool was notably lower than the other three requirements so this was allocated a low priority.

### 2.3.1. Identification of Additional User Requirements

In addition to providing feedback on the user requirements identified by SKM stakeholders were asked to identify any additional requirements that were not represented in the workshop list. These additional requirements are presented in Table 3 and have been categorised into higher and lower priorities according to the number of different workshop participants that separately identified the requirement. Those requirements identified by three or more individual participants have been classed as high priority while those identified by less than three participants have been attributed as lower priority requirements. The number in brackets following each requirement indicates the number of participants who identified it as a key requirement of the groundwater directory.
Table 3 Additional user requirements

<table>
<thead>
<tr>
<th>Priority</th>
<th>Audience</th>
<th>User Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher</td>
<td>Technical</td>
<td>Representation of groundwater quality information other than salinity (i.e. groundwater chemistry and contamination related data) (7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Representation of Groundwater/Surface water interactions (5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inclusion of contamination overlays (e.g. Groundwater Restricted Use Zones) (4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Representation of Groundwater Dependant Ecosystems (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inclusion and access to a detailed reference list used in the project (3)</td>
</tr>
<tr>
<td>Lower</td>
<td>Technical</td>
<td>Environmental Audit Overlays (from planning scheme) (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Recharge Areas (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Link between map and underlying data/database (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Beneficial Use Data (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Landfill locations (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Land use (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Communication tool for EPA data (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variability in watertable elevations and conditions (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Data Reliability (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Access to groundwater management information (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Access to layers for importation to GIS (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Geothermal Energy potential (1)</td>
</tr>
<tr>
<td>Community</td>
<td></td>
<td>Whole of water cycle, recharge potential and land use</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impact on environment and other stakeholders</td>
</tr>
</tbody>
</table>

A number of aspects were identified in this list of additional requirements that are beyond the scope of this project. Although these datasets may be useful in assisting in resource management, environmental assessment and land development across the region, they are subject to a range of processes and inter-organisational issues that are beyond the scope of this project to solve. Identifying the requirements however, may enable them to be addressed in future programs.
3. Data Acquisition

A wealth of hydrogeological information exists for the Greater Melbourne region, however much of its value is limited by the inability to identify and access the information. Groundwater data is spread across a number of government agencies and is captured in a range of different information systems and format types. The data acquisition phase for this project involved liaising with the custodians of groundwater data sets, identifying any constraints which would inhibit the acquisition of data sets and arranging for access to the data. Three key data sets were obtained throughout the data acquisition phase - bore data; report or reference material; and spatial data.

3.1. Bore data

The process of acquiring bore data commenced with an internal SKM workshop focussing on the identification of potential sources of groundwater data for the study area. This internal workshop was followed by the external stakeholder workshops (as discussed in Section 2) to provide government agencies and industry professionals an opportunity to transfer additional information and knowledge on data sources. Following the external stakeholder workshops, additional consultation was undertaken with the Environmental Protection Authority (EPA), VicRoads, Melbourne Water and Southern Rural Water (SRW) to identify the format and availability of groundwater data within each organisation.

Bore data was obtained for the Melbourne and Queenscliff 1:250,000 mapsheet area, plus an additional 20 km buffer zone (refer Figure 1). The Victorian Groundwater Management System (GMS), managed by SKM on behalf of DSE, was the primary bore dataset for the development of the hydrogeological mapping layers. Additional bore data was also obtained from Melbourne Water, SRW and the Department of Primary Industries (DPI). Bore data was not available in a readily useable format from VicRoads or the EPA, as the majority of the information was available in hard copy format only and did not contain consistent bore identifiers. Table 4 summarises the bore data sources and information obtained during the acquisition process. Sources of bore data that were not obtained and a discussion of the issues associated with these data sources is provided in Section 3.4.
Table 4 Description of data sets obtained in the data acquisition process

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Content</th>
<th>Number of records</th>
<th>Information provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSE (GMS)</td>
<td>Bore data</td>
<td>37,683</td>
<td>Waterlevel and groundwater salinity information (time of drilling and time series), driller’s logs and geologist logs</td>
</tr>
<tr>
<td>GEDIS Database (DPI Minerals and Mining Database)</td>
<td>Bore data</td>
<td>14,058</td>
<td>Drillers and geologist logs</td>
</tr>
<tr>
<td>PIRVic (DPI Groundwater Database)</td>
<td>Bore data</td>
<td>531</td>
<td>Time series waterlevel and groundwater salinity information as well as limited information on drillers and geologists logs</td>
</tr>
<tr>
<td>Melbourne Water (Geotechnical Access Database)</td>
<td>Bore data</td>
<td>13,283</td>
<td>Single date information on groundwater levels and groundwater salinity (from bores drilled for Melbourne Water geotechnical works)</td>
</tr>
<tr>
<td>Melbourne Water (Geotechnical Report Index)</td>
<td>Bore Log References</td>
<td>12,564</td>
<td>Limited information on groundwater levels and salinity readings. The primary function of this dataset is to indicate the existence of geologist logs. Each bore within this set possesses a hard copy log which is kept in either PDF or microfiche format by Melbourne Water. Used to provide a secondary source of data for areas where other bore data sources are limited</td>
</tr>
<tr>
<td>SRW</td>
<td>Bore data</td>
<td>1,513</td>
<td>Information on bores that have predominantly been drilled in the last 12 months. These represent a back log of bores and will eventually be entered into the GMS. This data set contains driller's logs and time of drilling standing waterlevel and groundwater salinity information</td>
</tr>
<tr>
<td>EPA</td>
<td>Site information only (no bore data)</td>
<td>209</td>
<td>Site summary information from a selection of Clean up to Extent Practicable (CUTEP) and EPA audit sites. This source contains general information on watertable depth, groundwater salinity (as Beneficial Use Class) and groundwater flow direction</td>
</tr>
</tbody>
</table>
Figure 1 Spatial distribution of bore data collected (red dashed line depicts ‘Port Phillip Special’ map boundary)
3.2. Spatial Data
A number of spatial datasets were acquired and processed as inputs for the generation of the mapping layers (refer Table 5). The complexity of this process varied depending on the data source. In some instances, significant processing was required to ensure the layers were consistent and appropriate for the project (e.g. Digital Elevation Model (DEM) and surface geology).

Table 5 Spatial data sets and layers acquired for the mapping process

<table>
<thead>
<tr>
<th>Theme</th>
<th>Source</th>
<th>Notes</th>
<th>Year data supplied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rivers (perennial)</td>
<td>Geoscience Australia(^1)</td>
<td>1:250,000 Geodata V3</td>
<td>2008</td>
</tr>
<tr>
<td>Water bodies</td>
<td>Geoscience Australia</td>
<td>1:250,000 Geodata V3</td>
<td>2008</td>
</tr>
<tr>
<td>Locations</td>
<td>Geoscience Australia</td>
<td>1:250,000 Geodata V3</td>
<td>2008</td>
</tr>
<tr>
<td>State borders</td>
<td>Geoscience Australia</td>
<td>1:250,000 Geodata V3</td>
<td>2008</td>
</tr>
<tr>
<td>Coastline</td>
<td>Geoscience Australia</td>
<td>1:250,000 Geodata V3</td>
<td>2008</td>
</tr>
<tr>
<td>DEM</td>
<td>DSE(^2) – 25 m DEM</td>
<td>The statewide DEM was re-sampled to 50m grid cells for this project</td>
<td>2008</td>
</tr>
<tr>
<td>Beneficial use</td>
<td>DSE</td>
<td>Four layers (Watertable, Upper Tertiary Unit, Middle Tertiary Unit, and Lower Tertiary Unit)</td>
<td>2007</td>
</tr>
<tr>
<td>Geology</td>
<td>DPI</td>
<td>Compiled to a single layer from 1:250,000 mapsheets. Simplified into 18 common map units which will be consistent with the bore interpretation</td>
<td>2007</td>
</tr>
<tr>
<td>Land use</td>
<td>Bureau of Rural Sciences (BRS) / DPI</td>
<td>Land parcel based</td>
<td>2007</td>
</tr>
<tr>
<td>Groundwater Management Units</td>
<td>DSE</td>
<td>Includes Groundwater Management Area (GMAs) and Water Supply Protection Areas (WSPAs)</td>
<td>2008</td>
</tr>
</tbody>
</table>

Notes:
1. © Commonwealth of Australia (Geoscience Australia) 2007. Topographic data was used in this project with the permission of Geoscience Australia.
2. The stated sourced data is copyright by the State of Victoria and licensed from DSE.

3.3. Reference Material
An extensive literature review of previous groundwater investigations and reports was undertaken, from which a comprehensive list of reference material was developed (refer to Appendix A). The reference list draws on a number of sources including Geological Survey reports (both published and unpublished), major hydrogeological studies and key infrastructure projects in the region (in particular road and tunnel developments) and Rural Water Commission reports. Each reference was...
flagged in accordance to its relevance and area of coverage and copies of those references with a high level of relevance to the mapping process were acquired (if available). A particular emphasis was given to locating any references with pumping test results or aquifer parameters as these were critical to the yield and MAR potential mapping.

3.4. Data Sources Identified but not Acquired

Several data sets were identified, but not readily accessible for this project. A discussion of these data sources and the custodian organisations is provided below.

EPA – The EPA is a custodian of a significant amount of groundwater data, supplied to the EPA in contaminated site audit reports or licence reports (e.g. landfill operators, wastewater treatment plant operators). There is substantial detail on groundwater level and groundwater quality (both salinity and other parameters) that is detailed in the audit reports, but not available on the GMS. This information is highly relevant to mapping the watertable and the groundwater salinity in the Greater Melbourne area.

The EPA was approached with regard to obtaining access to this information, however it is currently available in hard copy format only and the EPA was unable to provide the resources to access this information. The EPA is currently in the process of converting all hard copy reports to PDF format documents, however this process did not occur within the timeframe of this project. The EPA was however able to provide some general site summary data for their CUTEPE and selected audit sites (refer Table 4). This information covers general groundwater quality (Beneficial Use), watertable depth and groundwater flow direction.

The external workshop process also revealed a requirement amongst stakeholder groups to see some representation of Groundwater Restricted Use Zones (GRUZ) in the mapping product. The EPA was not prepared to provide this information as the location of these zones is not spatially rectified and the extent of the zones is dynamic and may change over time.

VicRoads – VicRoads is the custodian of a significant body of groundwater data associated with major road projects. The majority of this information is related to geotechnical investigations. Geopave, who manage this information on behalf of VicRoads, were contacted in order to identify the availability and format of this data. The data is currently stored in hard copy format and there is no comprehensive reference or index system. Reports are gathered and scanned manually on a site to site basis. Taking into consideration the scale of the mapping area and time constraints, a decision was made not to pursue the collection of bore data directly from VicRoads. It should be noted however that some of the VicRoads data is captured within the GMS and the Melbourne Water datasets.
Melbourne Water – Melbourne Water was able to provide a considerable amount of data on geotechnical bores that have been installed during major infrastructure projects (refer Table 4). There is however an enormous number of shallow geotechnical bores that were not able to be captured in the data acquisition process. The vast majority of these bores have basic lithological data only (i.e. driller’s logs), which is available in PDF or microfiche format. The shallow depth, limited use (i.e. the bores do not contain quality, level or yield information) and hard copy format were key factors in the decision not to pursue this data source.
4. Project Database Development

A project database was designed in Microsoft Access to consolidate all of the bore datasets which underpin the construction of the hydrogeological mapping layers. The project database serves the following functions:

- consolidates bore data from a number of sources into a central location and format;
- allows a forum for the interpretation and recording of bore logs and the production of stratigraphic logs;
- filters and disseminates bore datasets to allow for the stratigraphic, potentiometric, salinity and aquifer yield maps to be developed;
- provides a link between the bore dataset and the GIS system in which the mapping was undertaken;
- provides a dated log to store comments relating to the decisions made during the bore interpretation;
- enables data used in the mapping process to be isolated, formatted and exported for inclusion in other existing information management systems (e.g. Mapshare, GMS).

The following section outlines the development of the project database and provides information on the input data sets, pre-processing of bore data, and project database structure and functionality. The project database was filtered and summarised to form the basis of the borehole database that is a project deliverable.

4.1. Input Data Sets
The inputs datasets have been described in detail in Section 3. A brief summary of the bore data sources and the key information provided from each is shown in Table 6.
Table 6 Summary of input bore data

<table>
<thead>
<tr>
<th>Source</th>
<th>No. of Records</th>
<th>Driller’s Logs</th>
<th>Geologist’s Logs</th>
<th>Waterlevels</th>
<th>Time of Drilling</th>
<th>Water Quality</th>
<th>Time Series</th>
<th>Water Quality</th>
<th>Time Series</th>
<th>Water Quality</th>
<th>Time Series</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSE (GMS)</td>
<td>37,683</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>GEDIS Database (DPI Minerals and Mining Database)</td>
<td>14,058</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PIRVIC (DPI Groundwater Database)</td>
<td>531</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Melbourne Water (Geotechnical Access Database)</td>
<td>13,283</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SRW</td>
<td>1,513</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>EPA</td>
<td>209</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Notes:

1. The Melbourne Water dataset contains bore data with geo-referenced coordinates which are linked to bore logs that are only available in microfiche and pdf formats. These differ from the GMS, GEDIS and PIRVIC logs which are in a format amenable for input into the database and GIS system.

2. The EPA dataset contains generalised site information detailing the Beneficial Use segment, groundwater depth and flow direction at sites.

4.2. Pre-processing

A consolidated bore list containing bore identification numbers and coordinates was generated and processed in the GIS environment to provide a series of spatial attributes or fields for each bore. The following fields were generated through this process:

- **RLNS (Relative Level Natural Surface)** – Each bore was assigned a natural surface elevation relative to the project DEM;
- **Database Id** – A unique database record number was assigned to each bore to act as an identifier as some duplication was encountered in the bore id numbers between the different datasets;
- **GMA/WSPA** – Bores were flagged to track whether they are located in a Groundwater Management Unit. This process draws a distinction between groundwater management areas (GMAs) and Water Supply Protection Areas (WSPAs);
- **River Basin/Catchment** – Assignment of a river basin/catchment for each bore on the basis of DSE spatial layers;
- **CMA** – Assignment of a Catchment Management Authority for each bore on the basis of DSE spatial layers;
- **Hydrogeological Basin** – Assignment of a groundwater basin to each bore. This was done using the groundwater province overlay sourced from the National Land and Water Audit site.
- **1:100K Map Sheet Index** - Each bore was annotated to indicate the 1:100K mapsheet in which it is located.
- **Surface Geology Tag** – Each bore was assigned with a surface geology tag, based on a classified version of the 1:250K geological map layers.
- **Bedrock Filters** – A filtering process was undertaken to identify those bores with a surface geology tag corresponding to the bedrock geology.
- **Parish** – Each bore was assigned a Parish based on the Parish boundaries. This flag was useful to link older record information with more recent bore numbering systems.

### 4.3. Database Structure

The Access database was designed with a “back-end” consisting of a series of tables containing bore data and a “front-end” which provides the user interface.

#### 4.3.1. Database Table Structure

Bore data within the database was structured into the following five main tables:

- Location table;
- Construction detail table;
- Stratigraphy table;
- Water quality table; and
- Waterlevel table.

The tables in the database were linked through the bore id field, which served as the common identifier. A relational diagram showing the structure of the database and the fields contained within each table is presented in Figure 2. Additional tables were also created to store reference and EPA data that was not bore specific.
A summary of each of the main tables is provided below. A full description of the fields in each table is provided in Appendix B.

**Location Table**

The bore location table contains coordinate information on each of the bores, as well as detail on spatial characteristics (e.g. WSPA, Parish, River Basin etc.), bore depth and elevation. The table also contains a series of flags that track the use of bores in the generation of the different mapping layers.

**Construction Detail Table**

The construction detail table contains information on bore construction, including the depth of the completed well, screened interval and lithology of the screened interval. The construction details are combined with the bore location details in the user interface and are contained in the bore details tab (refer section 2.3.2)
Stratigraphy Table
The stratigraphy table contains information from driller’s logs and geologist logs recorded during the drilling of groundwater bores. This table also records the stratigraphic breakdown of interpreted bores.

Water Quality Table
The water quality table contains information on bores with both single and time series salinity measurements. Individual bores may contain salinity measurements in EC (Electrical Conductivity) units, TDS (Total Dissolved Solids) units or both. In order to maintain consistency with the State Environment Protection Policy (SEPP) – Groundwaters of Victoria Beneficial Use classes, TDS was selected as the mapping measurement for the water quality layers. If a TDS measurement was not available in the database, a conversion factor of 0.6 was applied to the recorded EC measurement to convert it to TDS (e.g. 1000 EC x 0.6 = 600 mg/L TDS).

A data currency code was automatically assigned to each of the water quality readings, on the basis of the measurement date. The data currency code allowed the distribution and reliability of the salinity reading to be mapped and assessed during the generation of the mapping layers. The data currency code was assigned according to the following rules:

- Water quality reading within 1 year of September 2006 = 1
- Water quality reading within 5 years of September 2006 = 2
- Water quality reading within 10 years of September 2006 = 3
- Water quality reading > 10 years of September 2006 = 4

The mapping of water quality was originally going to be based on spring 2006 data, however restricting the salinity readings to this time frame was found to result in a sparse data set that was not likely to produce a meaningful surface. As it was assumed that the groundwater salinity would not change significantly over time (i.e. the water quality would not shift Beneficial Use segment), it was subsequently decided that the salinity mapping would be undertaken using the latest reading from all bores with a salinity measurement (TDS or converted EC).

Waterlevel Table
The waterlevel table contains information on bores with single measurement waterlevel readings and time series waterlevel measurements. As with the water quality data, a currency code was assigned to each bore on the basis of the proximity of its nearest reading date to September 2006. The data currency codes were assigned according to the following rules:

- Time series waterlevel reading in Aug, Sep, Oct 2006 = 1
- Time series waterlevel reading within 2 years of Sept 2006 = 2
- Time series waterlevel reading >2 years of Sep 2006 = 3
- Time of drilling reading within 2 years of Sep 2006 = 4
- Time of drilling reading within 10 years of Sep 2006 = 5
- Time of drilling reading >10 years from Sept 2006 = 6

The data currency code allowed the source of the waterlevel reading and the reliability of the measurement to be mapped and analysed during the generation of the potentiometric layers. In order to maintain a consistency across the bore data set, all waterlevels are referenced to the project DEM.

4.3.2. Database User Interface Application

The initial function of the database was the collation and unification of a number of different groundwater data sets. As discussed above, the vast majority of data in the database came either directly from the source data or was generated through GIS analysis. Some functionality needed to be built in to the database however to allow for hydrogeological interpretation. In particular, the interpretation of stratigraphy, screened aquifers and the selection of waterlevel and water quality data to be used in the final mapping products.

To facilitate and standardise the manual interpretation process, a user interface was developed within the database. The user interface was designed for internal project use only, and provided unification of information from the different tables that form the database table structure (refer Section 2.3.1) allowing all data for a given bore to be reviewed in a quick and systematic manner. Undertaking the interpretation by using a designed user interface also allows quality control and standards to be built into the interpretation process.

The user interface consists of seven separate pages navigated through the use of tabs within the Access environment. The pages include bore details, stratigraphy, waterlevel, water quality, comments, reference list and a filtering page. Each of the seven pages are summarised below.

**Bore Details Page**

The bore details page displays unified data from the location and construction tables. Key features of this page include the ability to manually flag bores used in the generation of the individual mapping layers (e.g. stratigraphy, waterlevel, water quality), document pumping test data and aquifer parameters associated with individual bores and flag bores which contain unreliable information so that they can be excluded from the mapping process.

**Stratigraphy Page**

This tab allows for the drillers and geologist logs to be reviewed and a stratigraphic interpretation to be generated and saved in the database. The stratigraphic interpretations are then imported into
the GIS system and used in conjunction with the surface geology map to generate the aquifer extent and top of unit layers.

Over 170 geological units are described in the 1:250K geology overlay within the study area. In order to standardise the interpretation process these were rationalised into 33 geological units and then further grouped into 4 major aquifer / aquitard units (refer Table 7). Units highlighted in bold font were considered to be the most relevant to the mapping in the Greater Melbourne area.

- **Table 7 Stratigraphic groupings used in the interpretation of bore logs**

<table>
<thead>
<tr>
<th>Database Code</th>
<th>Stratigraphic Grouping</th>
<th>Comment</th>
<th>Groundwater Mapping Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Quaternary Alluvial</td>
<td>Contains all unnamed Quaternary Alluvial deposits</td>
<td>Watertable</td>
</tr>
<tr>
<td>11</td>
<td>Shepparton Formation</td>
<td></td>
<td>Watertable</td>
</tr>
<tr>
<td>20</td>
<td>Werribee Delta Sediments</td>
<td></td>
<td>Watertable</td>
</tr>
<tr>
<td>30</td>
<td>Port Melbourne Sand</td>
<td></td>
<td>Watertable</td>
</tr>
<tr>
<td>40</td>
<td>Yarra Delta Group</td>
<td>Includes the Coode Island Silt, Moray Street Gravel and the Fishermans Bend Silt</td>
<td>Watertable</td>
</tr>
<tr>
<td>50</td>
<td>Bridgewater Formation</td>
<td></td>
<td>Watertable</td>
</tr>
<tr>
<td>60</td>
<td>Newer Volcanics Group</td>
<td></td>
<td>Watertable</td>
</tr>
<tr>
<td>70</td>
<td>Brighton Group</td>
<td>Includes the Moorabool Viaduct Sands, the Baxter Sandstone, the Black Rock Sandstone and Red Bluff Sands</td>
<td>Upper Tertiary Unit</td>
</tr>
<tr>
<td>71</td>
<td>Parilla Sand</td>
<td></td>
<td>Upper Tertiary Unit</td>
</tr>
<tr>
<td>80</td>
<td>Fyansford Formation</td>
<td></td>
<td>Middle Tertiary Unit</td>
</tr>
<tr>
<td>81</td>
<td>Port Campbell Limestone</td>
<td></td>
<td>Middle Tertiary Unit</td>
</tr>
<tr>
<td>82</td>
<td>Gellibrand Marl</td>
<td></td>
<td>Middle Tertiary Unit</td>
</tr>
<tr>
<td>83</td>
<td>Heytesbury Group</td>
<td></td>
<td>Middle Tertiary Unit</td>
</tr>
<tr>
<td>85</td>
<td>Sale Group</td>
<td></td>
<td>Upper Tertiary Unit</td>
</tr>
<tr>
<td>86</td>
<td>Haunted Hills Gravel</td>
<td></td>
<td>Upper Tertiary Unit</td>
</tr>
<tr>
<td>87</td>
<td>Calivil Formation</td>
<td></td>
<td>Upper Tertiary Unit</td>
</tr>
<tr>
<td>90</td>
<td>Batesford Limestone</td>
<td>Includes the Lara Limestone</td>
<td>Middle Tertiary Unit</td>
</tr>
<tr>
<td>100</td>
<td>Pintadeen Basalt</td>
<td></td>
<td>Middle Tertiary Unit</td>
</tr>
<tr>
<td>110</td>
<td>Maude Formation</td>
<td></td>
<td>Middle Tertiary Unit</td>
</tr>
<tr>
<td>120</td>
<td>Jan Juc Formation</td>
<td></td>
<td>Middle Tertiary Unit</td>
</tr>
<tr>
<td>121</td>
<td>Clifton Formation</td>
<td></td>
<td>Middle Tertiary Unit</td>
</tr>
<tr>
<td>122</td>
<td>Narrawaturk Marl</td>
<td></td>
<td>Lower Tertiary Unit</td>
</tr>
<tr>
<td>123</td>
<td>Mepunga Formation</td>
<td></td>
<td>Lower Tertiary Unit</td>
</tr>
<tr>
<td>130</td>
<td>Maddingley Coal Seam</td>
<td></td>
<td>Lower Tertiary Unit</td>
</tr>
<tr>
<td>140</td>
<td>Demons Bluff Formation</td>
<td></td>
<td>Lower Tertiary Unit</td>
</tr>
<tr>
<td>141</td>
<td>Unnamed alluvium</td>
<td></td>
<td>Lower Tertiary Unit</td>
</tr>
<tr>
<td>142</td>
<td>Childers Formation</td>
<td></td>
<td>Lower Tertiary Unit</td>
</tr>
<tr>
<td>143</td>
<td>White Hills Gravel</td>
<td></td>
<td>Lower Tertiary Unit</td>
</tr>
<tr>
<td>150</td>
<td>Werribee Formation</td>
<td></td>
<td>Lower Tertiary Unit</td>
</tr>
</tbody>
</table>
Database Code | Stratigraphic Grouping | Comment | Groundwater Mapping Unit
--- | --- | --- | ---
160 | Older Volcanic Group | Lower Tertiary Unit | Lower Tertiary Unit
170 | Eastern View Formation | Lower Tertiary Unit | Lower Tertiary Unit
171 | Dilwyn Formation | Lower Tertiary Unit | Lower Tertiary Unit
172 | Pember Mudstone Member | Lower Tertiary Unit | Lower Tertiary Unit
180 | Bedrock | Includes all Pre-Cainozoic units | Bedrock

**Water Quality Page**
The water quality page presents all water quality measurements for each bore, as well as the selected water quality measurement (i.e. the water quality reading that is closest in observation date to Sept 2006) and the data quality code associated with this reading. A facility was also built into the user interface to manually reselect a different water quality reading to address those bores where there is error or uncertainty associated with the automatically selected reading.

**Waterlevel Page**
The waterlevel page presents all waterlevel measurements for each bore. As with the water quality page, the closest waterlevel measurement to September 2006 was automatically selected and displayed on the page, however facility existed in the database to manually reassign this value where it is unreliable.

**Interpretation/Comments Log**
A separate page was included in the user interface to allow comments to be recorded during the interpretation of bores and the generation of the mapping layers. This log was used to record all observations, decisions and assumptions made during the generation of the mapping process, to note key references for bores and areas, and to identify bores with unreliable/dubious logs.

**Reference List**
A bibliography of key references was generated for the project (refer Appendix A). This list was incorporated as a table in the database and a separate page included in the user interface to allow the reference list to be viewed for each 1:100K map sheet. A screen capture of the selected reference list for the Bacchus Marsh map sheet is displayed in Figure 3.
4.4. Advanced Filtering Features

Approximately 53,000 bores were imported into the project database. To assist in reviewing these bores in a systematic and efficient manner, a multi-criteria filter page was developed. This feature allowed bore lists to be generated on the basis of single or multiple criteria. The interface incorporates all major fields in the database and allows specific bore lists to be created and exported into the GIS system with ease (see Figure 4).
## Figure 4 Screen Capture of the Filter Function within the database

### 4.5. Borehole Database

A key project deliverable was the borehole database, which contains records of approximately 5,000 bores used in the compilation of the aquifer extent and top of unit, potentiometry, salinity and watertable depth layers. Approximately 1,000 bores contain stratigraphic interpretations. This subset of information has also been extracted from the project database and is available for general usage. Details of the borehole database structure are shown in Figure 5. A full description of the fields in each table is provided in Appendix C.
Figure 5 Relational data structure for the borehole database
5. Layer Generation - Methodology

5.1. Mapping Layers

The building blocks of all the mapped products was a series of groundwater layers, constructed from the interpreted bore data, existing GIS layers and reference material. The layers represent a combination of aquifer units and hydrogeological parameters. There are also additional layers (e.g. DEM) that are stand alone layers and not directly related to a single aquifer unit.

During the mapping process the approach was modified slightly from the product specification, to ensure better consistency with existing and currently underway mapping programs. The number of mapping outputs did not change, however it was more consistent to revise some of the naming conventions used in the mapping process.

Table 8 summarises the base layers for the Melbourne Groundwater Directory.

Table 8 Summary of mapping layers

<table>
<thead>
<tr>
<th>Layer</th>
<th>Extent and Top of Unit</th>
<th>Potentiometry</th>
<th>Salinity</th>
<th>Yield or Similar</th>
<th>Watertable Depth</th>
<th>MAR Potential</th>
<th>DEM</th>
<th>Cross Sections</th>
<th>GMU Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary Alluvial Formations</td>
<td>Watertable¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newer Volcanics</td>
<td>Watertable²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brighton Group and Equivalents</td>
<td>Upper Tertiary Unit</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Torquay Group</td>
<td>Middle Tertiary Unit</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Werribee Formation/Lower Tertiary</td>
<td>Lower Tertiary Unit</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bedrock</td>
<td>Bedrock</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Watertable</td>
<td>Watertable</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>Other</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Where the Quaternary Alluvial Formations comprise the watertable
2. Where the Newer Volcanics comprise the watertable

Some units such as the Quaternary Alluvium and Newer Volcanics were not be mapped in their own right, however were represented in the watertable overlay which forms a combination of
various aquifer units (refer to Table 7 for the full list of stratigraphic groupings within each groundwater mapping unit). Potentiometry, salinity and yield were not mapped for the Middle Tertiary Unit as it is predominantly an aquitard and the resource potential of this unit generally low, as is the amount of bore data available. Parts of the Middle Tertiary Unit do however provide an accessible source of groundwater (e.g. Fyansford Formation in the south eastern suburbs of Melbourne). This has been accounted for by incorporating the Middle Tertiary Unit as part of the Upper Tertiary Unit where relevant.

5.1.1. Extent and Top of Unit

Bores were interpreted using a combination of geologist logs, driller’s logs and other information from a range of data sources. In many instances hard copy and microfiche records were relied on to aid with the stratigraphic interpretation.

Bores were interpreted to define the following stratigraphic breaks:

- Top of the pre-Tertiary bedrock surface;
- Top of the Lower Tertiary Unit;
- Top of the Middle Tertiary Unit; and
- Top of the Upper Tertiary Unit.

Each stratigraphic break was assigned a height relative to the Australian Height Datum (AHD) from the project DEM. Surface geology was also cross referenced with the DEM to allocate elevation values to outcropping geology. The bore data and outcropping geology were then imported into a surfacing software package, to generate contours for the top of each of the modelled geological surfaces. The contours were then reviewed by a hydrogeologist on a 1:100K basis and hand drawn corrections were made to create a more realistic surface. The corrected contours were then digitised and used as additional input to the modelling process. Several iterations of this process (modelling, hand contouring, digitising and re-running the model) were undertaken. The final step in the modelling process was to compare the modelled surfaces with the bore data to identify where the unit was absent or was below the base of the borehole. Faults were included in the modelling analysis in two instances - where there was a significant and referenced displacement; or where the bore data/outcrop supported the inclusion of a fault. With one exception (fault to the east of the You Yangs) the location/presence of faults was taken from the DPI 1:250K geological mapping GIS layer.

One advantage of the technique adopted is the ability to model geological surfaces as a single system. For this project, the top of the Pre-tertiary bedrock was completed first and was then used as an input to define the location, extent and structure of the Lower Tertiary Unit. Similarly, once this was completed both the Lower Tertiary and bedrock surfaces were used as an input in the modelling of the Middle Tertiary Unit, and finally all three were used to help define the structure of
the Upper Tertiary Unit. This resulted in the surfaces being entirely consistent and not contradicting each other.

In the outcrop areas, the confidence in the mapped surface elevation is a direct relationship of the accuracy of the surface geology and the digital terrain model. In subsurface areas, the confidence relates to the proximity to stratigraphic bore data (or aquifer outcrop) and the density of that data. Interpretation of the lithological data into stratigraphic units was highly dependent on the quality of the stratigraphic log.

5.1.2. Watertable Elevation and Potentiometry

Watertable

The watertable elevation was compiled to represent the watertable surface as at Spring 2006 (or as close to this date as the data would allow). The watertable elevation layer was modelled using a geostatistical method called Sequential Gaussian Simulations (SGS). The key advantage of SGS is that it allows the incorporation of other information, such as surface water hydrology and it is possible to place bounds on the modelled watertable surface to prevent it from becoming artesian, or unusually deep in areas of sparse data.

Watertable bores were selected for modelling based on the following rules:

- bores less than 30m in depth;
- bores located within outcropping bedrock; and
- selected SOBN bores where they were considered to be monitoring the watertable aquifer (this was made on a case by case basis).

Only bores with a waterlevel reading in 2006 or 2007 (and as close to Spring 2006 as possible) were used in the input data set for the modelling. Within this timeframe however, both bores with time series data and single estimate time of drilling data were considered. The final modelled surface was correlated with the bore data to ensure that the actual readings were honoured.

Confidence in the watertable elevation layer is directly related to the availability and distribution of data representative of the 2006 – 2007 period. In addition, the analysis technique used to compile the watertable surface may not correctly represent the impact of significant groundwater extraction. This should be taken into account when using this data in areas where extraction is known to occur.

Upper Tertiary and Lower Tertiary Units

Potentiometric surfaces for the Upper Tertiary and Lower Tertiary Units were hand contoured using SOBN bore data with 2006 to 2007 waterlevel readings. In areas where the aquifers outcrop, the watertable elevation was used as an input in the hand contouring process.
As with the watertable elevation, confidence in these surfaces is directly related to the availability and distribution of data representative of the 2006 – 2007 period.

5.1.3. Salinity

Salinity modelling was undertaken using a custom geostatistical modelling program (GSLIB). A method called Ordinary Kriging was implemented, which involves the development of a spatial interpolation model (called a variogram) that is explicitly based on the modelling data (GSLIB, 1992). The modelling technique was undertaken on a 50m² grid cell basis.

Watertable bores were selected for salinity modelling based on the following rules:

- bores less than 30m in depth;
- bores located within outcropping bedrock; and
- selected SOBN bores where they were considered to be monitoring the watertable aquifer (this was made on a case by case basis).

In contrast to the potentiometric surface mapping however, the salinity mapping was undertaken using the latest reading from all bores with a salinity recorded. It was assumed that the groundwater salinity would not change significantly over time (i.e. the water quality would not shift Beneficial Use segment) and to restrict the mapping to a 2006 or 2007 salinity reading would result in a sparse data set that would not produce a meaningful surface.

Bores used in the salinity modelling of the Upper Tertiary and Lower Tertiary Unit layers came from two sources. The first data set was SOBN or other monitoring bores where the monitored aquifer is identified. The second data set was obtained by intersecting the screened interval of the bore with the derived aquifer surfaces in order to maximise the amount of groundwater salinity data available. Where there was no screened interval, the bottom six metres of the bore was assumed to be the screened interval (this was the average screened interval for all bores that possessed this information). The above process was cross checked by reviewing bore logs, chemistry reports and construction reports. Where bores were identified as not monitoring the target aquifer, they were removed from the modelling process.

The aim of the salinity modelling was to produce a generalised surface that reflects and displays large scale trends in salinity. To achieve this result, outlying data points were excluded, however the removal of these points was preserved in the modelling input files and can be identified in the accompanying data for each layer. Multiple iterations of each layer were run through the model to obtain an acceptable surface. The surface was then run through an averaging process to smooth the edges of each category and remove any artefacts. Small additions were also made by hand and the results of the watertable salinity surface was synthesised with the Upper Tertiary and Lower Tertiary Unit surfaces where the aquifers outcrop.
The groundwater salinity was mapped as milligrams per litre (mg/L) Total dissolved Solids (TDS). Confidence in the groundwater salinity layers is directly related to the availability and distribution of bore data. In areas of data complexity, values that significantly differ from the dominant trend in that area were omitted from the mapping.

5.1.4. Yield

Hydraulic Conductivity and Transmissivity

Hydraulic characteristics (i.e. hydraulic conductivity and transmissivity) of an aquifer vary in different parts of the study area, due to changes in aquifer thickness and lithological characteristics. To account for this, a mapping technique was employed to assign aquifer parameters to sub-regions or provinces that comprise similar characteristics.

Leonard (1979) divided Melbourne’s aquifers into six hydrogeological provinces, five for the Cainozoic Aquifers (i.e. the unconsolidated sediments and basalt) and one for the bedrock (Northern Province). For the purposes of this project, five additional provinces were added to enable the inclusion of the Western Port, Otway, Anglesea-Torquay, Silvan-Wandin and Werribee Delta areas.

For the Upper Tertiary and Lower Tertiary Units, a hydraulic conductivity value was defined for each of the aquifer units, within each of the provinces. The selection of hydraulic conductivity values were informed by a number of different sources (with references). Due to the complexity of the watertable aquifer system, hydraulic characteristics were assigned according to surface geology, rather than by province.

The eleven hydrogeological provinces and the assigned hydraulic conductivity values for the Upper Tertiary and Lower Tertiary Units are provided in Table 9

<table>
<thead>
<tr>
<th>Hydrogeological province</th>
<th>Upper Tertiary Unit</th>
<th>Lower Tertiary Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western</td>
<td>0.30</td>
<td>1.50</td>
</tr>
<tr>
<td>Werribee Delta</td>
<td>0.30</td>
<td>1.50</td>
</tr>
<tr>
<td>South Eastern</td>
<td>1.90</td>
<td>1.00</td>
</tr>
<tr>
<td>Mornington</td>
<td>0.40</td>
<td>1.00</td>
</tr>
<tr>
<td>Western Port</td>
<td>2.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Nepean</td>
<td>0.40</td>
<td>1.50</td>
</tr>
<tr>
<td>Bellarine</td>
<td>0.30</td>
<td>1.25</td>
</tr>
<tr>
<td>Otway</td>
<td>0.30</td>
<td>1.25</td>
</tr>
<tr>
<td>Anglesea-Torquay</td>
<td>0.30</td>
<td>2.00</td>
</tr>
<tr>
<td>North Eastern</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Table 9 Hydrogeological provinces and assigned hydraulic conductivity values
Hydrogeological province  | Hydraulic conductivity (m/day)  
--- | ---  
| Upper Tertiary Unit | Lower Tertiary Unit  
Silvan-Wandin | n/a | 1.00  

To obtain a transmissivity value for each of the aquifers, within each of the provinces, the assigned hydraulic conductivity values were subsequently input into the GIS, and multiplied by the saturated thickness of the aquifer, using the following equation:

\[ T = K b \]

Where:
- \( T \) = Transmissivity
- \( K \) = Hydraulic Conductivity
- \( b \) = Aquifer thickness

**Yield Potential**

The groundwater yield potential represents the volume of water that could be extracted through a single (hypothetical) bore that fully penetrates the aquifer and is operated continuously for 180 days. The yield volume was calculated using the Theis (1935) solution to transient groundwater flow. Aquifer properties (e.g. hydraulic conductivity, aquifer thickness, specific yield, storage coefficient) in conjunction with operational constraints (e.g. maximum allowable drawdown, period of operation) were used to determine the extraction rate per bore, in the following five categories (refer Table 10). The analysis was conducted for the Upper Tertiary and Lower Tertiary Units and the Watertable.

**Table 10 Estimated Yield Volume**

<table>
<thead>
<tr>
<th>Annual Volume (ML/yr)</th>
<th>Average Pump Rate (L/sec)</th>
<th>Potential Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>&lt;1</td>
<td>Suitable for stock and domestic use only</td>
</tr>
<tr>
<td>20 - 100</td>
<td>1 – 5</td>
<td>Suitable for stock and domestic use and small scale irrigation and industrial use</td>
</tr>
<tr>
<td>100 - 150</td>
<td>5 – 10</td>
<td>Suitable for irrigation and industrial use</td>
</tr>
<tr>
<td>150 - 800</td>
<td>10 – 50</td>
<td>Suitable for irrigation and industrial use</td>
</tr>
<tr>
<td>&gt;800</td>
<td>&gt;50</td>
<td>Suitable for irrigation and industrial use</td>
</tr>
</tbody>
</table>

The maximum allowable drawdown of the hypothetical bore was assumed to be 50% of the available pumping head (i.e. thickness from the watertable / potentiometric surface to the base of the aquifer) to an upper limit of 50 m of available head. For the purposes of this project, a
continuous operational period of 180 days was adopted. The 180 day period was assumed to be the upper estimate of the number of days in which extraction would occur over a 12 month period. It also allows for non-extraction periods to enable recovery of the waterlevel in the aquifer and for maintenance of the bore and/or pump.

The hypothetical bore was used to provide an objective assessment of the potential availability of groundwater, based on the aquifer properties. It should be noted that the yield of a groundwater bore is likely to be lower than that mapped if the bore screen does not fully penetrate the aquifer; there is bore interference; or the bore has not fully recovered between pumping events. Conversely, higher yields than those mapped could be expected for shorter periods of pumping (e.g. hours or days). It should also be noted that the yield mapping does not include consideration of groundwater management issues, such as existing groundwater allocations, impacts on neighbouring bores, or protection of groundwater dependent ecosystems.

5.1.5. Watertable Depth

The depth to watertable layer was modelled as a subtraction of the watertable elevation from the DEM surface. The resultant surface was quality checked to ensure that any small errors in either surface did not magnify to become bigger issues (e.g. to ensure that the depth to watertable in a coastal area did not imply the watertable was below sea level). Confidence in this layer is a direct relationship with the accuracy of the watertable elevation and DEM.

5.1.6. MAR Potential

The technique referred to as MAR is the process of intentionally injecting or infiltrating water into an aquifer and then extracting the water for use at a later date. There are many different types of MAR, however the storage potential for this map was calculated based on a specific type of MAR known as Aquifer Storage and Recovery (ASR). This type of MAR involves collection or harvesting of surplus supplies of water (e.g. stormwater or recycled water), treatment, and then pumping of this water via one or more wells into an aquifer, with subsequent extraction for reuse via the same wells.

The method for determining the MAR potential was adopted having considered previous efforts in Melbourne (Dudding et al, 2006), Adelaide (Pavelic, Gerges, Dillon and Armstrong, 1992; Hodgkin, 2004) and Perth (Scatena and Williamson, 1999). The MAR potential represents the volume of water that could be injected through a single bore that fully penetrates the aquifer and is operated continuously for 180 days. It was assumed that suitable treatment methods would be applied so that clogging would not be a constraint on the recharge potential. It was also assumed the volume of water available for recharge would be sufficient so that an adequate proportion of the injected water could be recovered at a quality fit for use.
The volume that could be injected into a bore was calculated using the Theis (1935) solution to transient groundwater flow. Aquifer properties in conjunction with the operational constraints (e.g. maximum allowable impressed head, well efficiency, period of operation, and velocity across the well screen) were used to determine the annual injection rate per bore, in four categories ranging from very low to high (refer Table 11). The analysis was conducted for Upper Tertiary, Lower Tertiary Units and the Watertable.

Table 11 Estimated MAR capacity

<table>
<thead>
<tr>
<th>Annual Injection Volume (ML/yr)</th>
<th>Category</th>
<th>Average Injection Rate</th>
<th>Potential Water Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>Very Low</td>
<td>&lt;0.1 ML/day (&lt;1.2 L/sec)</td>
<td>Rain water from individual houses or cluster developments</td>
</tr>
<tr>
<td>20 – 100</td>
<td>Low</td>
<td>0.1 - 0.5 ML/day (1.2 - 5.8 L/sec)</td>
<td>Rain water or stormwater from small housing, commercial or industrial developments with detention storage and treatment</td>
</tr>
<tr>
<td>100 – 200</td>
<td>Moderate</td>
<td>0.5 - 1 ML/day (5.8 - 11.6 L/sec)</td>
<td>Small size stormwater catchments, detention pond and treatment plant or sewer main and treatment plant</td>
</tr>
<tr>
<td>&gt;200</td>
<td>High</td>
<td>&gt;1 ML/day (&gt;11.6 L/sec)</td>
<td>Moderate size stormwater catchments, detention pond and treatment plant or sewer trunk main and treatment plant</td>
</tr>
</tbody>
</table>

Operational Limitations

Maximum Allowable Impressed Head and Well Efficiency
For unconfined aquifers the maximum allowable impressed head was considered to be the distance between the ground surface and the watertable. The maximum allowable impressed head was further reduced by assuming that the injection bore would operate with a well efficiency of 80% (refer Table 12). The maximum allowable impressed head for the confined aquifers was assumed to be 1.5 times the depth from the ground surface to the top of the confined aquifer (to an upper limit of 50 m of available head).

Table 12 Maximum allowable impressed head for unconfined aquifers

<table>
<thead>
<tr>
<th>Water Table Depth (m)</th>
<th>Max Allowable Impressed Head (m) – 100% Well Efficiency</th>
<th>Impressed Head (m) Used to Calculate Storage Potential – 80% Well Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5</td>
<td>Water table too shallow for injection</td>
<td>Water table too shallow for injection</td>
</tr>
<tr>
<td>5 to 10</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>10 to 20</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>&gt;20</td>
<td>20</td>
<td>16</td>
</tr>
</tbody>
</table>
Period of Operation
For the purposes of this assessment, a continuous operational period of 180 days was adopted. The 180 day period was assumed to be the upper estimate of the number of days in which source water would be available for injection over a 12 month period. This also allows for non-injection periods to enable pumping and maintenance of the injection bore and/or pump.

Velocity Across the Well Screen
For water supply bores the upper limit for the entry velocity is usually restricted to 0.03 m/sec in order to minimise well losses, corrosion, and abrasion. However, a factor of safety is normally applied which reduces the design entry velocity to 0.015m/sec (Driscoll, 1986). With a typical injection bore diameter of 200 mm and a screen open area of 35%, the aquifer would need to be less than 10 m thick and the injection rate greater than 1.5 ML/day before the entry velocity would exceed 0.015 m/sec. With most aquifers having a thickness significantly greater than 10 m it is highly unlikely that the entry velocity across the injection bore screen would be a constraint to the MAR potential.

5.1.7. Digital Elevation Model
The project used the Victorian state wide DEM (Vicmap Elevation Digital Terrain Model (DTM) 20m) which was re-sampled by our spatial team to meet the project requirements. Vicmap Elevation DTM 20 m has a spatial resolution of 20 m and has a positional of 12.5 m horizontally and 5 m vertically or better. It was constructed using source data of various resolutions, accuracies and ages to produce an improved statewide DTM containing increased detail in localised areas. The DTM is hydrologically enforced and correctly defines the natural surface drainage and hydrological flow. The methodology developed by SKM for DSE utilised a combination of ArcInfo TIN and ANUDEM processes to ensure that stream enforcement is achieved while maintaining a DTM which closely conforms to the original input data. More information on the methodology can be found in the product metadata description (www.land.vic.gov.au/vicmap).

The re-sampling for this project has altered this accuracy to suit the required project mapping scale of 1:250,000 and 50m grid cell sizes.
6. Data Gaps and Limitations

6.1. Key Data Gaps / Areas of Uncertainty

Bore data used in the generation of the structural, potentiometry and salinity layers has been posted onto maps of each aquifer system, to highlight the key areas of uncertainty for each layer. A discussion of the key data gaps and recommended priority areas for future groundwater investigation is provided below. The yield, watertable depth and MAR potential layers are not included in the discussion below as these were derived layers (i.e. were not generated from bore data).

6.1.1. Extent and Top of Unit

![Figure 6 Distribution of bore data used in compilation of the Bedrock structural surface](image)

Figure 6 Distribution of bore data used in compilation of the Bedrock structural surface
Figure 7 Distribution of bore data used in compilation of the Lower Tertiary Unit structural surface

Figure 8 Distribution of bore data used in compilation of the Middle Tertiary Unit structural surface
Figure 9 Distribution of bore data used in compilation of the Upper Tertiary Unit structural surface

Figures 6 to 9 illustrate the distribution of bore data used in the compilation of the structural surfaces. As can be seen, there is a relatively good coverage of bore data for each of the layers generated. Key areas of data uncertainty for the bedrock structural surface include to the west of Melbourne, between Bacchus Marsh and Werribee, west of Geelong and on the Bellarine Peninsula. For the Lower, Middle and Upper Tertiary Units the main areas of data uncertainty are in the vicinity of Werribee, Ocean Grove and Torquay.
6.1.2. Potentiometry

Figure 10 Distribution of bore data used in compilation of the Lower Tertiary Unit potentiometry

Figure 11 Distribution of bore data used in compilation of the Upper Tertiary Unit potentiometry

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Figure 12 Distribution of bore data used in compilation of the Watertable elevation

The distribution of bore data used in the compilation of the watertable elevation and potentiometric surfaces is illustrated in Figures 10 to 12. As can be seen, the main areas of uncertainty for the Lower Tertiary Unit include west of Melbourne, west of Geelong and on the Bellarine Peninsula. For the Upper Tertiary Unit the main data gaps include west of Melbourne, around Werribee, and the Bellarine and Nepean Peninsulas. These data gaps are more significant for aquifer potentiometry than for the aquifer extents and top of units (comparing Figures 7 and 10, Figures 9 and 11). This demonstrates a lack of active groundwater level monitoring for the Lower Tertiary and Upper Tertiary Units. As can be seen in Figure 12, the watertable elevation layer has a relatively good coverage of bore data. The main areas of uncertainty for this layer include west of Geelong and the Bellarine Peninsula, extending down to Ocean Grove and Torquay.
6.1.3. Salinity

Figure 13 Distribution of bore data used in compilation of the Lower Tertiary Unit salinity

Figure 14 Distribution of bore data used in compilation of the Upper Tertiary Unit salinity
Figure 15 Distribution of bore data used in compilation of the Watertable salinity

Figures 13 to 15 illustrate the distribution of bore data used in the compilation of the salinity surfaces. Key areas of uncertainty for the Lower Tertiary and Upper Tertiary Units include west of Melbourne, Geelong, Ocean Grove, Torquay and the Nepean Peninsula. There is a relatively good coverage of bore data for the watertable salinity layer.

6.1.4. Scale

The scarcity of bore data for many areas meant that it was not always possible to capture the fine detail within each of the layers. This is particularly relevant for the structural unit surfaces, where a thorough understanding of the stratigraphy and groundwater processes was required to interpret between areas where there was limited input data (i.e. geologist / driller’s logs).

With this limitation in mind, the mapping layers were compiled the aim of producing a generalised surface that reflects and displays large scale trends. As such, the appropriate viewing scale for each of the maps is 1:250,000 or smaller.

6.2. Recommended Product Uses

The mapping products have been complied to convey the general status and condition of the groundwater around Melbourne. The section below briefly describes the recommended product uses for each of the mapped layers.
Extent and Top of Unit - The aquifer extent and top of unit surfaces were mapped for the Upper Tertiary Unit, Middle Tertiary Unit and Lower Tertiary Unit and the Bedrock. These surfaces form key pieces of information allowing for targeted development of groundwater resources and assist in identifying the drilling depth required to develop the groundwater resource.

Potentiometry and Groundwater Flow Directions - The potentiometry map depicts the surface representative of the level to which water will rise in a bore screened within that aquifer and provides an indication of the direction of groundwater flow within that aquifer. These maps can be used as a planning tool to assisting resource managers and the community to make better resource allocation and management decisions, thus leading to better environmental condition.

Salinity - Groundwater salinity was mapped for the Upper Tertiary and Lower Tertiary Units and the Watertable, with the dataset contoured and presented according to SEPP Beneficial Use categories. Groundwater salinity is a limiting factor in any assessment of the groundwater resource potential and the salinity maps assist in identifying areas that contain viable, useable groundwater resources.

Yield - Bore yield is a limiting factor for the large scale (irrigation, commercial use) development of the groundwater resource. The bore yield maps produced for the Upper Tertiary and Lower Tertiary Units and the Watertable enable preliminary assessment and comparison of areas of potential groundwater resource development and allow for targeted development of groundwater resources and to minimise the extent of exploratory drilling that is required in the investigation phase.

Watertable Depth - This map shows the depth to watertable, measured in metres below ground surface. This layer is an important component in assessing development constraints and identifying areas of groundwater/surface water interaction and areas that contain valuable groundwater resources.

MAR Potential – Managed Aquifer Recharge (MAR) has great potential across Australia in both urban and rural environments. However, the relatively high cost of investigating MAR schemes, relative to other options, is often a significant impediment to their establishment. MAR potential maps provide a means for giving a strategic appraisal for MAR schemes and to reduce some of the initial uncertainty associated with MAR investigations.
7. Recommendations for Update of Mapping Products

7.1. Mapping Techniques and Future Updates

The framework used in the development of the Melbourne Groundwater Directory is shown in Figure 16. A summary of the suitability of the mapping techniques used for each of the layers generated and the recommended timeframe for updates to mapping layers is provided below.

**Figure 16 Framework for the Melbourne Groundwater Directory**

**DEM** - The project used the Victorian state wide DEM (10 m grid size) which was re-sampled by the spatial team to meet the project requirements. Within the project area, the only region likely to see significant improvement in the available terrain data is the coastal fringe. This area is currently being compiled by DSE as part of the Victorian Coastal Digital Elevation Model. The subsequent re-sampling of the data to meet the project requirements mean there would be little if any benefit in recompiling the project terrain model.

**Extent and Top of Unit** – Extents for each of the main aquifer units (Lower, Middle and Upper Tertiary and Bedrock) were derived from surface geology layers, reference material and interpreted bore data. A surface was then generated for each of these systems defining the top of the aquifers.
The development of these surfaces required a thorough understanding of the stratigraphy and groundwater processes. As such, input data was first run through the surfacing software package. This was followed by hand contouring of the surfaces to fully capture the “soft knowledge” and provide a more realistic surface.

The availability of data for structural mapping (e.g. geologist / driller’s logs) is not likely to change significantly from year to year. As such, it is recommended that the aquifer extent and top of unit layer be updated using a similar technique every 5 years, or upon completion of large projects where a significant amount of bore data for newly investigated areas has become available.

The 1:250,000 surface geology mapping used for the project was supplied by DPI (2007). DPI currently has a program to review and update this mapping. This program should be monitored, and the potential impact of changes to the mapped geological units in the project area assessed.

**Potentiometry** – A potentiometric surface was developed for the Upper Tertiary and Lower Tertiary Units and the Watertable. The watertable elevation was generated using a geostatistical method called Sequential Gaussian Simulations (SGS), then smoothed and cross checked with actual bore data to ensure that the waterlevels readings were honoured. SGS was selected as the optimum method to map the watertable elevation as a significant amount of bore data was available and it would allow the surface to be objectively updated in the future. Due to the limited amount of bore data for the Upper Tertiary and Lower Tertiary Units however, a hand contouring step was also used to create the potentiometric surfaces and ensure that the maximum amount of information was extracted from the data set.

It is recommended that future updates to the surfaces be undertaken on a yearly (if feasible) or two-yearly basis using SGS (or similar method) where the data permits and manual review and interpretation where there is limited data available.

**Salinity** – Salinity modelling was undertaken using Ordinary Kriging in a custom geostatistical modelling program (GSLIB), followed by smoothing of the surfaces and removal of outlying data points. It is recommended that future updates be undertaken every 2 to 5 years, using GSLIB or a similar Kriging method.

**Yield** – The groundwater yield potential was calculated using the Theis solution to transient groundwater flow. Aquifer properties (e.g. hydraulic conductivity, aquifer thickness, specific yield, storage co-efficient) in conjunction with operational constraints (e.g. maximum allowable drawdown, period of operation) were used to produce the surface.

It is recommended that groundwater yield layers be updated every 5 years, following the updating of the aquifer extent and top of unit layers and obtaining updated information on aquifer properties (e.g. hydraulic conductivity, specific yield and storage co-efficient).
**Watertable Depth** – The depth to watertable was generated by subtracting the watertable elevation from the project DEM. Depending on the level of usage and demand for this information, this layer could be updated on a yearly (if feasible) or two-yearly basis, following the updating of the watertable elevation layer.

**MAR Potential** – The MAR potential was calculated using the Theis solution to transient groundwater flow. It is recommended that this layer be updated every 5 years, following the updating of the aquifer extent and top of unit layers and obtaining updated information on aquifer properties (e.g. hydraulic conductivity, specific yield, storage co-efficient).

Table 13 summarises the techniques used to create each of the mapping layers and the recommended timeframe for future updates.

**Table 13 Mapping techniques and recommended updates**

<table>
<thead>
<tr>
<th>Current Mapping Technique</th>
<th>Recommended Future Mapping Technique</th>
<th>Recommended Timeframe for Updates</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM</td>
<td>Produced from the recently completed high resolution DEM for Victoria</td>
<td>Not envisaged</td>
</tr>
<tr>
<td>Extent and Top of Unit</td>
<td>Surface modelling plus hand contouring</td>
<td>5 yearly, or upon completion of large projects or changes to surface geology mapping.</td>
</tr>
<tr>
<td>Potentiometry</td>
<td>Watertable – SGS and hand contouring</td>
<td>SGS (or similar method) where the data permits and hand contouring / interpretation where there is limited data available</td>
</tr>
<tr>
<td>Salinity</td>
<td>Ordinary Kriging (GSLIB), followed by smoothing</td>
<td>GSLIB or a similar Kriging method, followed by smoothing</td>
</tr>
<tr>
<td>Yield</td>
<td>Theis solution</td>
<td>Theis solution</td>
</tr>
<tr>
<td>Watertable Depth</td>
<td>Watertable elevation subtracted from the project DEM</td>
<td>Watertable elevation subtracted from the project DEM</td>
</tr>
<tr>
<td>MAR Potential</td>
<td>Theis solution</td>
<td>Theis solution</td>
</tr>
</tbody>
</table>
7.2. Recommendations for future work

Data to GMS
It is recommended that data used in the interpretation and development of the mapping layers, in particular bore information that was captured from sources other than the GMS, is formatted and provided to DSE to import into the GMS (or its successor currently in development).

Product Review
After 4 to 5 years it is recommended that a review of each of the products be undertaken to access their accuracy, usability and currency. If required, the mapped layers should be updated to reflect any recommendations made as a result of the review process. As part of the mapping update, an attempt should be made to obtain those additional data sources identified but not acquired in the current project (refer Section 3.4).
8. References


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Appendix A – Bibliography

The following is a list of articles and reports identified as having some relevance to the hydrogeological mapping process. Only those references with a high level of relevance to the mapping process were acquired (if available). This bibliography is also available as a standalone Excel spreadsheet.


Anon., undated. () Cherry Brick Works, Hawthorn, parish of Boroondara. 40 chains to 1 inch, geological map 2539/M/1. Plan No 2539. Department of Energy and Minerals, Victoria, Mining plans & sections open file.

Anon., undated. () City Brickworks pit, Hawthorn, parish of Boroondara. 40 chains to 1 inch, geological map 2539/M/1. Plan No 2539. Department of Energy and Minerals, Victoria, Mining plans & sections open file.


Anon., undated. () MMBW SE trunk sewer, Dromana tunnel, parish of Prahan. 40 chains to 1 inch, geological map 74/G/4. Plan No 74. Department of Energy and Minerals, Victoria, Mining plans & sections open file.

Anon., undated. () MMBW SE trunk sewer, parish of Prahan. 40 chains to 1 inch, geological map 74/S/5. Plan No 74. Department of Energy and Minerals, Victoria, Mining plans & sections open file.

Anon., undated. () MMBW SE trunk sewer, parish of Prahan. 40 chains to 1 inch, geological map 74/S/5. Plan No 74. Department of Energy and Minerals, Victoria, Mining plans & sections open file.

Anon., undated. () MMBW SE trunk sewer, parish of Prahan. 40 chains to 1 inch, geological map 74/S/5. Plan No 74. Department of Energy and Minerals, Victoria, Mining plans & sections open file.

Anon., undated. () MMBW SE trunk sewer, parish of Prahan. 40 chains to 1 inch, geological map 74/S/5. Plan No 74. Department of Energy and Minerals, Victoria, Mining plans & sections open file.

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Anon., undated. () MMBW SE trunk sewer, parish of Prahan. 40 chains to 1 inch, geological map 74/S/5. Plan No 74. Department of Energy and Minerals, Victoria, Mining plans & sections open file.

Anon., undated. () Parish of Tuliamarine. 40 chains to 1 inch, geological map 2625/G/1. Plan No 2644. Department of Energy and Minerals, Victoria, Mining plans & sections open file.


Anon., undated. () Quarries, Brooklyn, parish of Cut Paw Paw. 40 chains to 1 inch, geological map 1600/M/4. Plan No 1600. Department of Energy and Minerals, Victoria, Mining plans & sections open file.

Anon., undated. () Quarries, Shire of Ferntree Gully, parish of Scoresby. 40 chains to 1 inch, geological map 2599/F/1. Plan No 2599. Department of Energy and Minerals, Victoria, Mining plans & sections open file.

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Anon., undated. () Tertiary beds, St Kilda Junction, parish of Prahan. 40 chains to 1 inch, geological map 74/G/3. Plan No 74. Department of Energy and Minerals, Victoria, Mining plans & sections open file.


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Sinclair Knight Merz (1994) Geelong - Corio Bore Completion Report. For the Department of Natural Resources and Environment. MC/44049.0.


Sinclair Knight Merz (1996) Geelong - Corio Groundwater Sampling. For the Department of Natural Resources and Environment. Jun-96..


SINCLAIR KNIGHT MERZ


Taylor, J. (1991) An assessment of the City of Camberwell's application to establish and develop a municipal waste disposal facility at a sand extraction site near Clayton Road, South Clayton - a groundwater perspective. Dr Jeff Taylor - Petrogenesis Pty. Ltd., for the City of Oakleigh February 1991.


Appendix B – Project Database Table Fields

Location Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RECNO</td>
<td>Unique database record number – generated for all bores and site details (e.g. EPA sites)</td>
</tr>
<tr>
<td>BOREID</td>
<td>Bore identification number.</td>
</tr>
<tr>
<td>EASTING</td>
<td>All data has been projected to GDA 94</td>
</tr>
<tr>
<td>NORTHING</td>
<td>All data has been projected to GDA 94</td>
</tr>
<tr>
<td>USES</td>
<td>Provides description of the bore use. Only available for the GMS and GEDIS bores</td>
</tr>
<tr>
<td>MGAZONE</td>
<td>All bores have been projected to MGA zone 55</td>
</tr>
<tr>
<td>RLNS</td>
<td>Surface elevation from survey data where available</td>
</tr>
<tr>
<td>RLNSDEM</td>
<td>Surface elevation assigned from the project Digital Terrain Model (DTM)</td>
</tr>
<tr>
<td>PARISHNO</td>
<td>Attributed through querying the bore coordinates against GIS overlay</td>
</tr>
<tr>
<td>PARISH</td>
<td>Attributed through querying the bore coordinates against GIS overlay</td>
</tr>
<tr>
<td>DATASOURCE</td>
<td>Source of the data (e.g. GMS, GEDIS, EPA)</td>
</tr>
<tr>
<td>GMA</td>
<td>Flag to indicate if the bore is located in a Groundwater Management Area</td>
</tr>
<tr>
<td>WSPA</td>
<td>Flag to indicate if the bore is located in a Water Supply Protection Area</td>
</tr>
<tr>
<td>RIVERBASIN</td>
<td>Attribution on the basis of river basin</td>
</tr>
<tr>
<td>CMA</td>
<td>Attribution on the basis of catchment management authority area.</td>
</tr>
<tr>
<td>HYDROBASIN</td>
<td>Flag to attribute each bore to a hydrogeological basin. This is based on the Groundwater Province mapping from the National Land and Water Audit website.</td>
</tr>
<tr>
<td>DATECOMP</td>
<td>Date when drilling and construction of each bore was completed.</td>
</tr>
<tr>
<td>MAPSHEET</td>
<td>Attribution of bores based on the 1:100K map sheets</td>
</tr>
<tr>
<td>SURFACEGEO</td>
<td>Assignment of surface geology tag to each bore using the 1:250K geology layer</td>
</tr>
<tr>
<td>STRATIGRAPHY</td>
<td>Enables bores used in the stratigraphy mapping to be identified</td>
</tr>
<tr>
<td>GW_CONTOUR</td>
<td>Enables bores used in the potentiometric mapping to be identified</td>
</tr>
<tr>
<td>SALINITY_CONTOUR</td>
<td>Enables bores used in the water quality mapping to be identified</td>
</tr>
<tr>
<td>TRANS_MAPPING</td>
<td>Enables bores used in the yield/transmissivity mapping to be identified</td>
</tr>
<tr>
<td>RLTOP</td>
<td>Height of top of bore casing relative to the Australian Height Datum (where available)</td>
</tr>
<tr>
<td>OUTCROP_BEDROCK</td>
<td>Flag attributed in GIS to identify those bores located in the bedrock areas</td>
</tr>
<tr>
<td>BOREDEPTH</td>
<td>Depth of bore</td>
</tr>
<tr>
<td>AQ.Screened</td>
<td>Manual field to allow the allocation of a screened aquifer to bores</td>
</tr>
<tr>
<td>PUMPINGTEST</td>
<td>Manual field to allow bores with pumping test information to be identified</td>
</tr>
<tr>
<td>TRANSMISSIVITY</td>
<td>Manual field to allow the allocation of transmissivity values to specific bores</td>
</tr>
<tr>
<td>PUMP_SOURCE</td>
<td>Manual field to allow the source of pumping test information to be recorded</td>
</tr>
<tr>
<td>EXCLUDE</td>
<td>Manual field to enables suspect/unreliable bores to be identified and removed from the analysis</td>
</tr>
</tbody>
</table>
### Construction Detail Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RECNO</td>
<td>As per location table</td>
</tr>
<tr>
<td>BOREID</td>
<td>As per location table</td>
</tr>
<tr>
<td>DATASOURCE</td>
<td>As per location table</td>
</tr>
<tr>
<td>CONSTRUCTED_DEPTH</td>
<td>Constructed depth of bore. This may differ from the drilled depth of bore in some instances where the driller may have backfilled the well to install the casing/screen across a specific aquifer unit.</td>
</tr>
<tr>
<td>SCREENFROM</td>
<td>Depth at which the screen starts</td>
</tr>
<tr>
<td>SCREENTO</td>
<td>Depth at which the screen length finished</td>
</tr>
<tr>
<td>LITHOLOGY</td>
<td>Lithology of the screened interval (unique to the GMS)</td>
</tr>
</tbody>
</table>

### Stratigraphy Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RECNO</td>
<td>As per location table</td>
</tr>
<tr>
<td>BOREID</td>
<td>As per location table</td>
</tr>
<tr>
<td>DATASOURCE</td>
<td>As per location table</td>
</tr>
<tr>
<td>LOG_SOURCE</td>
<td>Differentiates whether the bore log is a driller’s log or a geologist’s log</td>
</tr>
<tr>
<td>DEPTH_FROM</td>
<td>Starting depth interval for log description</td>
</tr>
<tr>
<td>DEPTH_TO</td>
<td>Concluding depth interval for log description</td>
</tr>
<tr>
<td>DESCRPT</td>
<td>Driller/geologist description for given depth interval</td>
</tr>
<tr>
<td>STRATIGRAPHY</td>
<td>Stratigraphic unit allocated for selected depth interval</td>
</tr>
</tbody>
</table>
### Water Quality Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RECNO</td>
<td>As per location table</td>
</tr>
<tr>
<td>BOREID</td>
<td>As per location table</td>
</tr>
<tr>
<td>DATASOURCE</td>
<td>As per location table</td>
</tr>
<tr>
<td>OBS_DATE</td>
<td>Observation date for the water quality reading</td>
</tr>
<tr>
<td>SALEC</td>
<td>Measured Electrical Conductivity (EC) in $\text{s/cm}$</td>
</tr>
<tr>
<td>SALTDS_SOURCED</td>
<td>Measured Total Dissolved Solids (TDS) in mg/L</td>
</tr>
<tr>
<td>SALTDS_CONVERT</td>
<td>Converted TDS value from the SALEC field. Conversion formula is provided in Chapter Four</td>
</tr>
<tr>
<td>SALCTDS</td>
<td>Selected TDS value, this field takes the SALTDS_SOURCED value where it is available and the SALTDS_CONVERT value where the sourced value is not available</td>
</tr>
<tr>
<td>DATAQC</td>
<td>Data quality code based assigned to each bore and water quality reading on the basis of the reading date (see Chapter Four for more detail)</td>
</tr>
<tr>
<td>USE_DQ</td>
<td>Manual Flag that indicates which reading has been selected for inclusion in the water quality mapping. Along with aquifer screens this enables the bores used to develop the quality layers to be identified.</td>
</tr>
</tbody>
</table>

### Waterlevel Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RECNO</td>
<td>As per location table</td>
</tr>
<tr>
<td>BOREID</td>
<td>As per location table</td>
</tr>
<tr>
<td>DATASOURCE</td>
<td>As per location table</td>
</tr>
<tr>
<td>OBSERSTATUS</td>
<td>Flag to indicate whether the bore has time series waterlevel data or just a single water value taken at the time the bore was drilled</td>
</tr>
<tr>
<td>OBS_DATE</td>
<td>Observation date for the waterlevel reading(s)</td>
</tr>
<tr>
<td>COND_CODE</td>
<td>Bore condition code. Indicates whether there was uncertainty associated with particular waterlevel readings (only applies to GMS data)</td>
</tr>
<tr>
<td>DEPTH_BDP</td>
<td>Depth of groundwater in a bore below a datum point. Commonly the datum point refers to the surveyed top of the bore casing.</td>
</tr>
<tr>
<td>DEPTH_BNS</td>
<td>Depth of groundwater in a bore below the natural surface</td>
</tr>
<tr>
<td>MRWL</td>
<td>Groundwater level in a bore relative to Australian Height Datum calculated from the surveyed elevation of the bore</td>
</tr>
<tr>
<td>DRWL</td>
<td>Groundwater level in a bore relative to Australian Height Datum calculated by subtracting the DEPTH_BNS from the DEM_RLNS (see location table). Effectively this gives a reduced waterlevel relative to the terrain model</td>
</tr>
<tr>
<td>DATAQC</td>
<td>Data quality code assigned to each bore and waterlevel reading on the basis of the reading date (see Chapter 4 for more detail).</td>
</tr>
<tr>
<td>USE_DQ</td>
<td>Manual Flag that indicates which reading has been selected for inclusion in the potentiometric mapping. Along with aquifer screens this enables the bores used to develop the potentiometric layers to be identified.</td>
</tr>
</tbody>
</table>
# Appendix C – Borehole Database Table Fields

## Aquifer Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQF_CODE</td>
<td>Code to define the groundwater mapping unit</td>
</tr>
<tr>
<td>DESCR</td>
<td>Description of groundwater mapping unit</td>
</tr>
</tbody>
</table>

## Bore Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BORE_ID</td>
<td>Unique identifier for each bore</td>
</tr>
<tr>
<td>EASTING</td>
<td>GDA 94 Zone 55</td>
</tr>
<tr>
<td>NORTHING</td>
<td>GDA 94 Zone 55</td>
</tr>
</tbody>
</table>

## Stratigraphy Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SG_CODE</td>
<td>Code to define the stratigraphic grouping of the unit</td>
</tr>
<tr>
<td>STRATGRP</td>
<td>Unique identifier of stratigraphic grouping of the unit</td>
</tr>
<tr>
<td>COMMENT</td>
<td>Comment</td>
</tr>
<tr>
<td>AQF_CODE</td>
<td>Code to define the groundwater mapping unit</td>
</tr>
</tbody>
</table>

## Stratigraphic Reference Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BORE_ID</td>
<td>Unique identifier for each bore</td>
</tr>
<tr>
<td>REF</td>
<td>Report reference</td>
</tr>
</tbody>
</table>
### Stratigraphic Interpretation Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BORE_ID</td>
<td>Unique identifier for each bore</td>
</tr>
<tr>
<td>RLNS_DEM</td>
<td>Natural surface value assigned to each bore from the project digital elevation model (DEM)</td>
</tr>
<tr>
<td>TOP_QA</td>
<td>Top Quaternary including the Newer Volcanics, Werribee Delta Sediments, Port Melbourne Sand, Bridgewater Formation, Quaternary Alluvial deposits, Yarra delta Group</td>
</tr>
<tr>
<td>BASE_QA</td>
<td>Base Quaternary (Note: this was not used in the production of the surfaces)</td>
</tr>
<tr>
<td>TOP_UTA</td>
<td>Top Upper Tertiary includes Moorabool Viaduct (Otway basin and west of Port Phillip Basin), Brighton Group (Port Phillip and Nepean Peninsula), Baxter Formation (Western Port Basin)</td>
</tr>
<tr>
<td>BASE_UTA</td>
<td>Base Upper Tertiary</td>
</tr>
<tr>
<td>TOP_MTA</td>
<td>Top Middle Tertiary includes the Gellibrand Marl, Jan Juc Formation (Otway Basin), Fyansford Formation, Batesford Limestone (Port Phillip Basin), Sherwood Formation (Western Port Basin)</td>
</tr>
<tr>
<td>BASE_MTA</td>
<td>Base Middle Tertiary</td>
</tr>
<tr>
<td>TOP_LTA</td>
<td>Top Lower Tertiary includes the Dilywn Formation, Demons Bluff and Eastern View Formations (Otway Basin and Nepean Peninsula), Werribee Formation, Older Volcanics (Port Phillip), Childers Formation, Older Volcanics (Western Port)</td>
</tr>
<tr>
<td>BASE_LTA</td>
<td>Base Lower Tertiary</td>
</tr>
<tr>
<td>TOP_PC2</td>
<td>Top Bedrock (defined as Pre-Tertiary for the Melbourne/Westernport area)</td>
</tr>
<tr>
<td>BASE_PC2</td>
<td>Base Bedrock</td>
</tr>
<tr>
<td>BH_BASE</td>
<td>The elevation of the base of the borehole (mAHD)</td>
</tr>
</tbody>
</table>
### Lower Tertiary Unit Reduced Waterlevel (RWL) Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BORE_ID</td>
<td>Unique identifier for each bore</td>
</tr>
<tr>
<td>RLNS_DEM</td>
<td>Natural surface value assigned to each bore from the project digital elevation model (DEM)</td>
</tr>
<tr>
<td>AQLF_CODE</td>
<td>Code to define the groundwater mapping unit</td>
</tr>
<tr>
<td>OBS_DATE</td>
<td>Observation date</td>
</tr>
<tr>
<td>DBNS</td>
<td>Depth of the waterlevel below the ground surface</td>
</tr>
<tr>
<td>RWL</td>
<td>Elevation of the waterlevel in metres to the Australian Height Datum, determined using (RLNS_DEM - DBNS)</td>
</tr>
<tr>
<td>OUTLIER</td>
<td>Flag to identify those data excluded from the analysis</td>
</tr>
</tbody>
</table>

### Lower Tertiary Unit Total Dissolved Solids (TDS) Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BORE_ID</td>
<td>Unique identifier for each bore</td>
</tr>
<tr>
<td>OBS_DATE</td>
<td>Observation date</td>
</tr>
<tr>
<td>TDS</td>
<td>Groundwater salinity as milligrams per litre (mg/L) total dissolved solids (TDS)</td>
</tr>
<tr>
<td>OUTLIER</td>
<td>Flag to identify those data excluded from the analysis</td>
</tr>
</tbody>
</table>
### Upper Tertiary Unit Reduced Waterlevel (RWL) Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BORE_ID</td>
<td>Unique identifier for each bore</td>
</tr>
<tr>
<td>RLNS_DEM</td>
<td>Natural surface value assigned to each bore from the project digital elevation model (DEM)</td>
</tr>
<tr>
<td>AQF_CODE</td>
<td>Code to define the groundwater mapping unit</td>
</tr>
<tr>
<td>OBS_DATE</td>
<td>Observation date</td>
</tr>
<tr>
<td>DBNS</td>
<td>Depth of the waterlevel below the ground surface</td>
</tr>
<tr>
<td>RWL</td>
<td>Elevation of the waterlevel in metres to the Australian Height Datum, determined using (RLNS_DEM - DBNS)</td>
</tr>
<tr>
<td>OUTLIER</td>
<td>Flag to identify those data excluded from the analysis</td>
</tr>
</tbody>
</table>

### Upper Tertiary Unit Total Dissolved Solids (TDS) Table

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BORE_ID</td>
<td>Unique identifier for each bore</td>
</tr>
<tr>
<td>OBS_DATE</td>
<td>Observation date</td>
</tr>
<tr>
<td>TDS</td>
<td>Groundwater salinity as milligrams per litre (mg/L) total dissolved solids (TDS)</td>
</tr>
<tr>
<td>OUTLIER</td>
<td>Flag to identify those data excluded from the analysis</td>
</tr>
</tbody>
</table>
**Watertable Reduced Waterlevel (RWL) Table**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BORE_ID</td>
<td>Unique identifier for each bore</td>
</tr>
<tr>
<td>OBS_Date</td>
<td>Observation date</td>
</tr>
<tr>
<td>BORE_DEPTH</td>
<td>Total depth of the bore</td>
</tr>
<tr>
<td>DEM_RLNS</td>
<td>Natural surface value assigned to each bore from the project digital elevation model (DEM)</td>
</tr>
<tr>
<td>RWL</td>
<td>Elevation of the waterlevel in metres to the Australian Height Datum, determined using (DEM_RLNS - DBNS)</td>
</tr>
<tr>
<td>DBNS</td>
<td>Depth of the waterlevel below the ground surface</td>
</tr>
<tr>
<td>OUTLIER</td>
<td>Flag to identify those data excluded from the analysis</td>
</tr>
</tbody>
</table>

**Watertable Total Dissolved Solids (TDS) Table**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BORE_ID</td>
<td>Unique identifier for each bore</td>
</tr>
<tr>
<td>OBS_DATE</td>
<td>Observation date</td>
</tr>
<tr>
<td>TDS</td>
<td>Groundwater salinity as milligrams per litre (mg/L) total dissolved solids (TDS)</td>
</tr>
<tr>
<td>OUTLIER</td>
<td>Flag to identify those data excluded from the analysis</td>
</tr>
</tbody>
</table>
## Reference List

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
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</thead>
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<tr>
<td>REF_ID</td>
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</tr>
<tr>
<td>AUTHOR</td>
<td>Author of reference document</td>
</tr>
<tr>
<td>PUB_DATE</td>
<td>Publication date of reference document</td>
</tr>
<tr>
<td>TITLE</td>
<td>Title of reference document</td>
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<tr>
<td>GSV</td>
<td>Geological Survey of Victoria</td>
</tr>
<tr>
<td>AVAIL</td>
<td>Reference document available in the specified media</td>
</tr>
<tr>
<td>SOURCE</td>
<td>Source of reference document</td>
</tr>
</tbody>
</table>