Development of an Integrated Groundwater Database and Visualisation Tools for Cape Town and Environs

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

The Water Research Commission has awarded a contract to Immo Friedrich Blecher, a private consultant, for a research project titled **Development of an integrated groundwater database and visualisation tools for Cape Town and environs**. The first part of the project is the initial database and Aquabase set-up, which had to identify the database and the front-end software to be used and the initial population of the database with readily available data.

The most suitable front-end software for the management and visualisation of the data is the open-source Aquabase Water Resources Management software, which runs on almost all versions of Windows and also Linux. It can use and connect to a variety of database systems to store the data and the most suitable one for this project was selected to be PostgreSQL, which is open-source and has the most comprehensive spatial functions built-in to make it suitable for a web-based mapping visualisation tool to be developed during a later phase of the project.

Once the database was created on a PostgreSQL server with a script, the database was populated with imported data for the Western Cape from the National Groundwater Archive of the Department of Water and Sanitation, imported chemistry data from the Water Management System of the same Department and manually typed-in data from reports generated during various projects conducted within the study area. Additionally data was imported from datasets in spreadsheet and printed format received from the City of Cape Town and various consultants and organisations who have worked in the area for many years. However, it is almost impossible to create a “complete” database with data accumulated over decades by various organisations, taking into account that several tens of boreholes are drilled daily in the study area for which the information may never reach the database.

A number of additional functions for the Aquabase front-end software were identified and developed under the project. These included new and improved import routines to make data transfer from different formats to Aquabase easier, improved chemistry reports with charts and new lithology profile functionality.

During the web-map research process, which involved the feasibility and testing of map server and client options, there was a tendency towards the open-source QGIS server already, as the map themes and layouts (styling of layers on the web-based maps is easily achieved) can be updated by GIS personnel using the QGIS front-end GIS software without requiring the project consultant’s specialists in future. QGIS has become an important role-player in the GIS software world and has been implemented in many organisations due to its versatility and power, but also due to immense cost savings.

The web mapping components essentially consist of three parts: a) the QGIS Server, which serves the spatial data to b) the QWC2 QGIS Web Client (Ver. 2) and c) the databases that hold the spatial and non-spatial data to be used and shown on the maps. The two databases used to store the data used for the layers are the PostgreSQL/PostGIS database (Ver. 10.x) for the groundwater, surface water and meteorological data and a Spatialite (SQLite) database for the polygon and line layers displaying hydrogeological and hydrological information. The layers generated for the QGIS project and served to the web map include amongst others the study area, geosites (boreholes/well, springs, river/dam monitoring and meteorological stations), hydrogeological (harvest potential, groundwater occurrence, depth-to-water level, etc.) and hydrological (rivers, dams, catchments, etc.) layers and 4 base maps (OpenStreetmap, OpenTopoMap and others) loaded directly from the Internet.

Several users were set up with different roles (read-only, read-write) on the PostgreSQL server. As the database resides in the cloud, user permissions are important to allow only certain functions on the database. The project team users were all assigned read-write access, while all other users, including City of Cape Town and University of the Western Cape users, read-only access. Unfortunately most of the latter users cannot access the database through their corporate networks (port 5432 needs to be open) due to IT policies.

The training of potential users of the database, the Aquabase front-end software, and the mapping tools was determined by the current set-up of the database/mapping system. Therefore two separate Aquabase 2-day training courses were presented: 1) at the City of Cape Town Witzands Treatment Plant (Atlantis) on 12 and 13 September 2019 for the City staff, and 2) at the University of the Western Cape Applied Geology Department (Chemical Science Building) on 26 and 27 September 2019. The participants at the City Witzands training course were mostly from the technical department of the Witzands Treatment Plant who were involved in monitoring data acquisition from the Atlantis wellfields in some form or another, but also Candice Lasher Scheepers who is in charge of the groundwater database at the City DWS. The participants at the UWC training course were two of the UWC students identified for the capacity building part of this project, Aqeela Parker and Ashleigh Tomlinson, but also two other students who will be involved in groundwater data accumulation for their department.

By the time of writing this report, a final installation location could not be determined due to limitations by the City of Cape Town IT policies (network and Internet access). Although an off-site location (not on the City network) of the database and web map service could be considered for the short term, Internet access to the relevant database ports are not possible due to City IT policies so that City users cannot access the database on an external server (in the cloud). Database updates would have to be done from outside the City's network. Therefore a not-so-elegant solution for the groundwater database for the short to medium term could be the transfer of the data presently residing in the PostgreSQL database into a SQLite/Spatialite database, which is a local file-based database system (the Aquabase default) and almost as powerful as the PostgreSQL database in terms of spatial capabilities and speed, but cannot be cloud based.

The sustainability of the project is therefore dependent on the City's groundwater personnel and new data from consultants working in the area and willing to share the data will have to be audited and appended to the database manually. If the City decides to produce a web-based map and share some information publicly, a new City project will have to be created and executed, which may or may not use the installed database.

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1 INTRODUCTION

It has been shown over many years that the efficient management of water resources is almost impossible without a database containing historical and up-to-date information, and data of high integrity. When it comes to groundwater the situation is even worse as groundwater was often not seen as a viable resource, and if it was used, then in many cases, it was poorly managed due to the lack of monitoring and poor data collection.

This has changed in recent years as groundwater now forms a large part of the water resources in several communities, towns and metros. Therefore, the need for properly managed groundwater data has increased tremendously, leading to urgent requirements for a water database in whatever form. Unfortunately off-the-shelf groundwater databases relevant to the South African market did not really exist for many years, while international packages were expensive and needed a lot of adaptation to work for South African conditions. Therefore, most groundwater practitioners used various forms of database software and/or spreadsheets without much integrity leading to data hosted on various computers around South Africa, but not one central system available to be accessed by groundwater managers or scientists.

However, there were, and still are, several attempts by various Government Departments to create and maintain groundwater/surface water databases, without much success and often with duplication of efforts. These databases are mostly cumbersome to use and contain old data that is without much value. But they are often a starting point for new water management database systems, like the one implemented during this project for the City of Cape Town and Environs, which could also be applied in other metros, provincial or national offices.

This research project will have a large impact on informing policy and decision making for the database users, especially for the City of Cape Town, as the recent drought has put the City water managers under immense pressure to avoid "Day Zero", the day the taps were estimated to run dry. The pressure was increased by the need to start using more and more groundwater resources, especially for critical City and province institutions like hospitals, clinics and care centres around the Western Cape, which were developed under the Western Cape Government Water Business Continuity Project. For this project a comprehensive database had already been established, which is now being used in the process of Water Use License Applications from the DWS, but also provides valuable groundwater resource information for future decision making.

2 PURPOSE OF THIS REPORT

This report presents all steps in the process of establishing the groundwater database and visualisation tools and takes a look at the sustainability of such a system during this final phase of the project:

1) Identify the front-end software to be used for data entry, retrieval and visualisation
2) Identify the database to be used for storing and sharing data (dependent on software capabilities)
3) Population of the initial database
4) Identify additional requirements from the front-end software (specific functions for groundwater managers)
5) Identify sources of data for the initial database and investigate incentives for the contribution of data
6) Data Capture and Import of data obtained from various sources

7) Development of additional Aquabase Features

8) Set-up of a Web-based Mapping Platform

9) Set-up of users, define and execute training

10) Finalise installation

11) Sustainability of this case study and similar projects in future

3 Identification of the front-end and Database Software Packages

3.1 Identification of the Front-end Software

Fortunately there was a suitable front-end software readily available called Aquabase. The Aquabase Water Resources Management Database Software is a free and open-source software (FOSS) which has been developed over many years and can access a range of databases for storing and visualising groundwater, surface water and meteorological data for water related projects. The development of the latest version 7.x (development has been dormant for more than 6 years) has been funded partly by a Department of Water and Sanitation project to clean-up and adapt the Limpopo Aquabase database, which has been updated by various consultants in the province over many years, for upload onto the National Groundwater Archive (which is still in progress).

Aquabase has a large number of data entry forms (see list and examples in Appendix A) which all have data integrity checking built-in to reduce user errors. But the import of columnar data is also possible and this process is mostly used to import large volumes of time-dependent data like water levels or chemistry results and also depth-dependent data like down-the-hole Electrical Conductivity or geophysics. Various charting (see examples in Appendix B) and reporting (see examples in Appendix C) functions allow visualisation of the data and a SQL Query tool can be used to export data to other formats for processing in other software. The main focus of Aquabase is on groundwater, but surface water details like chemistry, stage heights, flow rates, etc. and meteorological data like rainfall and pan evaporation can also be stored and displayed and brought into context with groundwater (e.g. water levels vs. rainfall). Aquabase runs on most Windows platforms and also on Linux.

There is no other comparable database software on the market that has this wide variety of water resources management tables and data management tools. Additionally Aquabase-supported databases are spatially enabled, meaning that any tables with coordinate fields automatically create and update geometry fields which are directly accessible in GIS software packages. Therefore the database can be used in web mapping applications as well and this functionality was part of the project at the more advanced stages.

Aquabase also comes with an integrated comprehensive Help System which aids the user with data entry and management. The Help System will in the future also be available on the Internet (possibly a Wiki-like system) where it will be more visually attractive, easily searchable and have links between the different sections of the Help System.

3.2 Choice of Database

Although Aquabase supports a number of databases there are only a few that have the most extensive spatial capabilities, including PostgreSQL, which is the preferred database for this project. PostgreSQL is an open-source database server system with the largest spatial capabilities (and extensive database tools like user and table management. It is actively maintained by the open-source community and can be installed on a variety of operating systems, including Windows and Linux.

The actual groundwater database is a set of 80+ tables and a number of views (queries to create subsets of data) and triggers ("functions" that do something in the database automatically if and when something changes) which have been created to accommodate the groundwater and other water- related data. As the database develops, a creation script, which is too long to include in this report, is created from time to time to reflect the changes and which can then be used to create a new (empty) database. Typically one could create a database per country, province, project area, water management area or, as in this case a Metro area, depending on the need of the users and on the sizes of areas investigated/managed. So if a project stretches over a provincial or municipality area then it might be preferable to have a country or province database respectively. It would also be preferable to have data adjacent to the area of interest/project as those may have an influence of e.g. groundwater in the area of interest. Additionally groundwater and surface water does not follow provincial/municipal or other man-made boundaries and therefore it was proposed that the database for this project covers an as large area as possible around the "Cape Town and Environs" interest area, including the water management areas intersected and/or adjacent which are defined by the major river systems.

4 POPULATION OF THE INITIAL DATABASE

The initial database was populated with data covering the whole of the Western Cape as it was initiated by the Western Cape Government – Water Business Continuity Project (WCG-WBCP), which covered groundwater development projects for several government hospitals, clinics and other office buildings around the province. For this database several datasets were combined into one database and include:

1. The National Groundwater Archive (not all the tables) of the Department of Water and Sanitation (DWS) as at October 2017
2. The DWS Water Management System chemistry dataset of July 2018
3. The WCG-WBCP groundwater resource development report data from the various consultants on the project

While the WCP-WBCP data had to be captured in Aquabase manually from reports (mostly in PDF or Word formats) and sheets from pumping test contractors or laboratories, the NGA and WMS data had to be prepared for import into the database. This data came mostly in CSV or XLS format and had to be modified to comply with the strict Aquabase database rules to be ready for import.

In this process the biggest challenge was the combination of the data of the two import datasets as they use different numbering systems: the two systems do not "speak" to each other, although both have the same sites in their database, but mostly with different numbers. So the site numbers from both systems had to be compared in different fields and matched up, and when this was not possible, a spatial query in a GIS had to be utilised to search for same (or almost same, then using various radii from 50m- 300m) coordinates. After the spatial query there were still more than 2500 sites on WMS which had no match on the NGA and these were subsequently created on the Western Cape Aquabase database as new sites that only have chemistry information. This means that they may well be duplicates of existing sites, but with wrong or inaccurate coordinates and numbers not found on the NGA.

This is, unfortunately, a huge problem with several database systems storing different information on same sites, in this case the one system storing groundwater information, the other chemistry information, and both not using the same numbering system, and therefore a combined database like the one Aquabase is using is definitely preferable.

The initial dataset for the Western Cape therefore has kept the numbers as on the NGA, which can be referred back to when uploading back to the NGA and new sites are created with an identifiable unique number which can be accommodated by the NGA. This also makes the download of additional data to be imported for tables that have not been imported initially a lot easier.

Any additional data for this Cape Town groundwater database project had to be sourced from the various consultants that have worked and are working in the area and from the Metro itself, especially the registered private boreholes, which are recorded and archived either electronically or on paper records.

5 IDENTIFICATION OF ADDITIONAL USER REQUIREMENTS

Fortunately Aquabase, the front-end software, has a huge variety of entry forms (with the associated database tables), which not only cater for groundwater data, but also surface and meteorological data, which should be part of any scientist's or groundwater manager's data analysis to assist with groundwater resources management. As Aquabase is developed by volunteers progress on new functions (and bug-fixing) is not always constant, sometimes releasing updates weekly, but sometimes only once every two months, depending on urgency of bug-fixes or time required to develop a specific function. For this project a number of days were budgeted for the identification and development of additional functions as per user-requirements, which include, but were not limited to:

- Enhance existing and develop new functions for importing or linking to other online water resources databases
- Develop a new function to enable the import of telemetry data from various data sources
- Develop an import function for data logger data in various formats
- Develop 3 to 5 reports to present the data, possibly with associated charts
- Add 3 to 5 ecological monitoring entry forms and associated tables (i.e. soil moisture, South African Scoring System (SASS) Ver. 5 Rapid Bio-assessment method for rivers, vegetation status, ecological score, etc.)
- The originally proposed web-based mapping tool should be developed in a way so that the public can use it to educate themselves, i.e. with links to online explanatory resources (dictionaries) by clicking on the information displayed on the map. The map should also be updated live from the database to display always the latest available information, even from other online resources.

6 DATA SOURCES

Data sources for the database consisted of electronic and paper based (reports) data in various formats. The initial database created during the first phase of the project consisted of National Groundwater Archive (DWS) download and conversion to Aquabase database format, Water Management System (DWS) chemistry data, which was linked to the NGA data (not always the same number system used) and Western Cape Government Water Business Continuity project data, which is not yet available to share, but should be available during or by the end of the project.

The latter dataset was created for the whole Western Cape province and will eventually by clipped to the "Cape Town and Environs" region, which was defined through discussions with the "Reference Group" to be at least the City of Cape Town Metro, but including the areas where the City has water supply boreholes and dams, and covering the Cape Flats Aquifer, Malmesbury shales and parts of the Table Mountain Group. A provisional project area is shown in Appendix 1. The outline of the project area is mainly based on the borders of the Water Management Areas Berg and Breede, but also on Local Municipality boundaries which may have City boreholes and dams located within. The area may become smaller, depending on the final dataset and importance of data for the City and project.

Data to be added to the initial database would primarily come from the City itself, but also various consultants and organisations, who have been contacted and asked to contribute to the project by providing their groundwater related data, which would add value to the City database. The approach followed was on a "you give me and I'll give you" basis, the feasibility and benefits of which were investigated during later phases of the project.

Generally it was found that consultants are willing to share their data, provided their clients (in many cases also the City itself) agree to it, but the feasibility of just providing a site location with a reference to the consultant were discussed. This would mean that one would at least know of a groundwater geosite location when accessing the database, but then also know whom to contact for further information.

The following data sources had been identified (not in any particular order) and import/capturing progress listed:

- City of Cape Town Department of Water and Sanitation – Contact person: Candice Lasher Scheepers – Some of these datasets have been compiled by some of the consultants further down in this list or other consultants and may not be up-to-date any longer. The hydrogeological information in some of the datasets is limited, but these may still be useful in statistical scenarios and investigations.
    - Landfill Boreholes, Cemetery Boreholes – Spreadsheets: *not received*
    - Sports fields and recreational area Boreholes – Scanned PDFs: *received and captured*
    - Western Cape School Boreholes – Spreadsheets and PDF laboratory results:
    - CoCT Residential Boreholes – Spreadsheets: *not received, not valuable groundwater information and coordinate accuracy limited to erf location*
    - CoCT Springs – Spreadsheets and electronic reports: *received and imported*
    - CoCT Production Boreholes – Spreadsheets and scanned PDFs: *received and imported for Atlantis and Cape Flats aquifers*
    - CoCT Monitoring Boreholes – Spreadsheets and scanned PDFs: *received and imported for Atlantis and Cape Flats aquifers*
- GEOSS (Geohydrological and Spatial Solutions International) – Contact person: Dale Barrow – This consultancy has probably one of the biggest compilations of data from numerous projects in the Western Cape, but not organised in one database, but rather numerous spreadsheets and reports. They have recently started entering/importing data into Aquabase to build a reference database of boreholes to projects. Their potential datasets (mostly spreadsheets) that may be available pending client approval are:
    - Department of Local Government Municipal Groundwater development projects (client – DLG). This project is current: *Nothing received, but part of AGES data described below*

- Municipality projects (for relevant municipalities within study area): *received and captured for Drakenstein Municipality, nothing received for Stellenbosch/Franschhoek (data sharing approval pending)*

- City of Cape Town projects: Springs, Table Mountain Group, Landfills (see City of Cape Town above)

- DWS TMG monitoring: *nothing received, but overlaps with data the City and other consultants have*

- AGES (Africa Geo-Environmental Engineering and Science) – Contact person: Jan Myburgh – Presently appointed by the DLG as one of the consultants for the development, upgrading and management of groundwater sources in prioritized drought-stricken municipalities. There is a strong drive within the municipalities to add existing and new data to a database system, which the consultant is required to develop and their cooperation with this project may have benefits and follow-up potential for both, which eventually would lead to the uploading of data onto the NGA. Their datasets in spreadsheet format (have also started to use Aquabase) contain:

    - over a 100 existing and new boreholes, some of which fall into the study area's enclosed municipalities, with hydrogeological information, including equipment information, pumping test details and management recommendations: *not received, but will be followed up to ascertain whether these are really important/necessary for this database*

- SRK (Steffen Robertson and Kirsten, Western Cape Branch) – Contact person: Desmond Visser – Have worked in the area for many years and have a large number of data on boreholes, mostly in reports, which they are busy capturing now in their own in-house database

    - Eskom's Duynefontein borehole monitoring and hydrocensus data (Access Database) – Permission for sharing required from Eskom: *received and imported*

    - Borehole data (monitoring included) for Roger Parson's WC Gov project (which is already on the database, but monitoring data needs to be added): *monitoring data not received/updated*

    - Borehole data for various schools and parks in the WC and CoCT, which we are busy compiling in an internal ARCGIS and Excel database: *ongoing, not ready for sharing*

    - Numerous municipal and private client borehole data for the WC and other provinces – some of these (for last 10 years) for the WC will be included in their internal ARCGIS and Excel database, however, many are contained in older reports/files in our archives and library: *ongoing, not ready for sharing*

- DeltaH – Contact person: Helen Seyler – Mostly working on desk studies and modelling with existing supplied data, but want to contribute the latest GIS (background) layers for the online mapping; this could include:

    - Point data (borehole, geology, water level, hydraulic properties, groundwater quality) at 4 x schools in the metro. Project for Atvantage Pty Ltd on behalf of WCG DTPW

    - Spatially discretised recharge dataset for the greater Cape Flats area (our model area). The recharge takes into account the urban land use and should be seen as an improvement for this area on GRAII – WRC project

- Interpolated current groundwater level for the greater Cape Flats area, for the Koeberg quat catchment and for entire west coast area – so this covers much of the Berg but excluding all high lying areas. This could give an expected WL where there isn't a nearby borehole. Completed between 3 x previous projects – from WRC, and from Koeberg/Worley Parsons.

- Delineations for the strategic water source areas for groundwater – WRC. The areas are hosted on http://bgis.sanbi.org/Projects/Detail/145. Would have to talk to the previous WRC project leader about rights to hosting.

- Quaternary catchment scale data, which should be seen as an update (or as an alternative if people don't agree with the numbers) to GRA II, including (per quaternary across Berg and Breede-Gouritz): [permission from DWS required]

  - groundwater contribution to baseflow, recharge, groundwater use (processed WARMS data), and "remaining groundwater availability"

  - groundwater category (replaces groundwater "class") in terms of groundwater use and groundwater quality, per quaternary catchment

  - prioritisation of quaternary catchments, to demonstrate those for which RQOs are developed

  - RQOs for prioritised quaternary catchments.

- Umvoto Africa – Contact person: Kornelius Riemann – Have worked on many projects in the study area, mainly on monitoring (TMG), but also groundwater resource development; suggested to also include ecological monitoring data for the TMG project, which was collected for many years and may add value to the City database. They also recommended uploading their incoming monitoring data directly onto the database to have information available immediately. Three datasets relevant to this project are:

  - Atlantis Aquifer (Witzand and Silwerstroom wellfields) – already in Aquabase format: *received from City and correlated with existing boreholes, nothing received from consultant*

  - Cape Flats Aquifer – already in Aquabase format: *received from City and correlated with existing boreholes, nothing received from consultant*

  - Table Mountain Aquifer (Steenbras to Wemmershoek region) – multiple spreadsheets, also on ecological monitoring data: *ongoing project and therefore not yet imported*

- UWC (University of the Western Cape) – Contact person: Jaco Nel – There are quite a few students working in different areas who have collated borehole data. There is also a strong interest from the university's side to also use Aquabase in future for their projects so that the data can be easily supplied back to the City's database, but also for own use on their student projects. The two students identified for the capacity building phase of the project presently work in the Saldanha area and asked for their data to be included in the database: *After their training they started capturing data in Aquabase format, nothing received yet*

- Parsons and Associates – Contact person: Roger Parsons – Often appointed as project coordinator with other consultants on the team; may have additional data sets: *nothing received*

- Groundwater Africa – Contact person: Ricky Murray: *Has not recently worked on projects in Cape Town area; mostly involved in desk studies with data supplied.*
- L2K2 – Contact person: Kevin Pietersen: *Mainly datasets created by UWC students*

The following organisations/institutions have been named by the consultants and Reference Group members, who also may have data to contribute to the project (although they may have worked in collaboration with some of the above):

- UCT (University of Cape Town)
- CSIR (Council for Scientific and Industrial Research)
- Aurecon: *received and imported borehole data on schools, see also City data above*
- Maluti Water – Contact person: Phillip Ravenscroft
- Jeffares Green – Contact person: Regaen Rose
- Mineral Water Association – Contact Person John Weaver

The map layers for the online visualisation tool came from various sources, including DWS groundwater harvest potential and other "Vegter" maps (WRC project), but also reworked GIS maps, and all will be referenced in the "Attributions" on the map.

7 DATA CAPTURE AND IMPORT

Data sources for the database consist of electronic and paper based (reports) data in various formats. The initial database created during the first phase of the project consisted of National Groundwater Archive (DWS) download and conversion to Aquabase database format, Water Management System (DWS) chemistry data, which was linked to the NGA data (not always the same number system used) and Western Cape Government Water Business Continuity project data, which is not yet available to share, but should be available during or by the end of the project.

The latter dataset was created for the whole Western Cape province and will eventually by clipped to the "Cape Town and Environs" region, which was defined through discussions with the "Reference Group" to be at least the City of Cape Town Metro, but including the areas where the City has water supply boreholes and dams, and covering the Cape Flats Aquifer, Malmesbury shales and parts of the Table Mountain Group.

During the previous phase of the project it was found that consultants are generally willing to share their data, provided their clients agree to it, and the idea of just providing a site location with a reference to the consultant are acceptable. This would mean that one would at least know of a groundwater geosite location when accessing the database, but then also know whom to contact for further information.

It is also important to realise that the consultants would have to spend some time in preparing the data to be shared for which they would not be reimbursed and therefore are reluctant to contribute during the project time frame. This should not be a major setback as most consultants work for the City on various projects and can always submit (or upload) data at a later stage.

While data capture from reports is pretty straight forward with the Aquabase entry forms it is a tedious process and takes a considerable amount of time. Some of the PDF reports often lack important date information (date constructed, tested, measured, etc.) and many do not even mention a water level with a date. There are also no coordinates given, only a site map on Google Maps, location of which has to be manually searched and coordinates obtained from Google Maps/Earth. In order to maintain data integrity Aquabase does certain checks and needs data in certain fields to make sense, like dates, that were therefore “guessed” from other information in the report.

Import of data is only really worth it if there are more than 10 sites with groundwater information, or 10 chemistry records or water levels, already organised in a columnar format (spreadsheets). Often the columns have to be formatted (numeric columns may not contain character data) and additional columns generated, e.g. a column for the site type, as the spreadsheet user may know that the spreadsheet contains boreholes or springs or other sites, but the database does not know this and a field needs to be populated to show what type of site it is. Chemistry data often comes with “<” and “>” values indicating detection limits of the reporting laboratory. These have to be separated from the actual values as they are imported into a different table.

Fortunately Aquabase provides a couple of import routines which make the import process easier. Some of these were also developed, others enhanced, under this project and are discussed in chapter 8 (Development of additional Aquabase features) below.

Over and above the import and capture of additional data from the sources above the initial dataset has been cleaned and information enhanced with the following actions:

1. The initial Western Cape database has been spatially clipped to the study area (Cape Town and Environs) and moved to a new PostgreSQL server available through the Internet, not only for the entry/import of additional data by various participants of the project, but also for the development of the mapping function of the project. Of the more than 26 000 sites of the Western Cape database just over 7 800 sites fall within the study area, but this number is expected to grow quickly with the import of additional datasets.

2. WMS chemistry data, that had been previously imported by linking the sites on the WMS with the initial NGA data by first comparing existing numbers from both systems and then spatially within a set radius, was reimported with the newly developed Aquabase WMS Import tool. With that process about 2000 sites could not be linked with numbers or a spatial search (of 150m) and have been created and added to the database with unique numbers in order to easily identify them for further processing (or deletion, if necessary). The coordinate accuracy on both systems (NGA and WMS) is sometimes questionable and coordinates from the WMS are still in Cape Datum longitude/latitude format and had to be converted to Hartebeesthoek94 coordinates. Depending on the scale of the area of investigation the coordinate accuracy might be more or less important, but at least the WMS data provides some background chemistry information, which in some cases is more than 40 years old. Some of the sites are no longer being monitored, others are still “active”. A newer WMS dataset (from July 2018) may be requested towards the end of the project for inclusion in the database to have the latest chemistry monitoring data available.

3. Elevations/Altitudes of the sites on the WMS are not available, but have been generated and added to the new sites by running a spatial match over a SRTM Digital Elevation Model (DEM). Altitudes of the initial NGA data indicated to have been generated by the so-called “ArcView” method, which is actually a DEM method, were compared with a newer SRTM DEM and where discrepancies found corrected.

4. Sites that obviously had wrong coordinates (e.g. plotting in the sea or outside the Western Cape or study area) were corrected manually by looking at their site descriptions and map references. Often these were marked as “Accurate to within 100m” on the NGA, which they are obviously not,

leading to the conclusion that the accuracy of coordinates of other sites in the NGA is sometimes questionable.

5. The enhanced online data import function for the import of DWS Hydrology data (discussed below) has been used to import surface water (river and dam levels) and meteorology data (rainfall/evaporation) for a couple of monitoring sites, which were obtained from the DWS Hydrology website for the study area.

It is almost impossible to create a “complete” database with data accumulated over decades by various organisations and taking into account that several tens of boreholes are drilled daily in the study area, for which the information may never reach the database.

Some of the data received was only in PDF report format, sometimes even scanned from hard copies. The actual report documents are then also stored in the database and boreholes mentioned in the reports referenced back to the reports. These can be downloaded in order to receive more information in written context.

8 DEVELOPMENT OF ADDITIONAL AQUABASE FEATURES

Fortunately Aquabase, the front-end software, has a huge variety of entry forms (with the associated database tables), which not only cater for groundwater data, but also surface and meteorological data, which should be part of any scientist’s or groundwater manager’s data analysis to assist with groundwater resources management. For this project a number of additional functions have been identified, development progress of which is indicated:

1. Enhance existing and develop new functions for importing or linking to other online water resources databases: *Two functions have been implemented – a) a function for the easy import of chemistry data from the DWS Water Management System and b) a function for the import of surface water and meteorological monitoring data from DWS Hydrology online datasets. Both these functions provide users easy access to data and visualisation in charts within Aquabase, which would otherwise be difficult to achieve.*

2. Develop a new function to enable the import of telemetry data from various data sources: *Unfortunately there are many telemetry output formats and storage options available and therefore one telemetry import function to serve all formats is not easily achieved. However, the Aquabase table import function has been improved to allow import of any CSV or other database formats into the existing tables with only a few data manipulation steps and can therefore be used to import any telemetry data. A more automatic process with warning functionality when certain levels are reached may need some sophisticated development for specific telemetry server access and might need a more modular or plug-in approach for Aquabase.*

3. Develop an import function for data logger data in various formats: *This import function has now been newly developed for the most widely used data loggers in South Africa, but needs refinement in future to cater for almost any format from different loggers. This includes the choice of date/time formats, units of measurement, and types of data measured (water levels, temperature, EC, etc.)*

4. Develop 3 to 5 reports to present the data, possibly with associated charts: *Two new chemistry charts (Stiff and Box-and-Whisker) have been added due to user requests (mainly from the consultants in the province) and some chemistry charts can now be incorporated in the chemistry report. This needs some adaptation in future to allow the choice of different chemistry diagrams on the reports.*

5. Add 3 to 5 ecological monitoring entry forms and associated tables (i.e. soil moisture, South African Scoring System (SASS) Ver. 5 Rapid Bio-assessment method for rivers, vegetation status, ecological score, etc.): *This is still in it's infancy (planning phase) and the value to this project database is not clear yet. It will further be discussed with the consultants involved in the monitoring and how the data is stored and presented.*
6. One additional functionality was identified by students during the training process: The generation of a lithological profile, which assists with identifying aquifers from lithological characteristics by placing a line along a section of boreholes: *This function has also been developed during the project and allows selecting display of lithologies not only by type, but also colours.*

Aquabase development is a continuous process and new functionality is added with each update. These updates are distributed automatically to the users, who benefit from the constantly evolving development.

9 SET-UP OF THE WEB-BASED MAPPING VISUALISATION TOOL

Initial web-map tests were carried out during some of the previous phases already to try and pin down a potential web map server software, which could easily handle the PostgreSQL/PostGIS database. Viable options at that stage appeared to be the OpenLayers web-map framework or the QGIS web-map server, both of which are open-source, each one with its advantages and disadvantages. One needs more development than the other, but may have more options for the user, but fortunately the database could be the same for both. There was a tendency towards the QGIS server already, as the map themes and layouts (styling of layers on the web-based maps is easily achieved) can be updated by GIS personnel using the QGIS front-end GIS software without requiring the project consultant's specialists in future. QGIS has become an important role player in the GIS software world and has been implemented in many organisations due to its versatility and power, but also due to immense cost savings.

9.1 Set-up of the Web Mapping Components

The web mapping components essentially consist of three parts: a) the QGIS Server, which serves the spatial data to b) the QWC2 QGIS Web Client (Ver. 2) and c) the databases that hold the spatial and non-spatial data to be used and shown on the maps. All these are installed on the same Ubuntu 18.04 LTS Linux office server currently set-up with secure (SSL) Apache 2 to serve the pages to the Internet in Stellenbosch, Western Cape under https://blecher.dyndns.org. This set-up needs to be transferred to another server (also preferably Linux) once a server has been determined by the future database/mapping users or the WRC. The new link accessing the online map will then be published on die WRC website and also on https://www.blecher.co.za/index.php/projects/groundwater-database-for-cct.

a) The QGIS Server (https://qgis.org/en/site/) is usually also installed with the installation of QGIS desktop on any server or PC. The current version at the time of writing this report is Ver. 3.10.1, but it might be preferable to use one of the next LTS (long-term-support versions) for the production environment. QGIS Server can also be installed without the desktop software. Essentially, QGIS Server uses QGIS desktop projects which are set up with all the layers, symbologies, labels, projections, etc. and are displayed on the web map tool as themes. Many projects can be created and added as themes to the web map tool, where the themes can also be combined. Most importantly, the QGIS Server settings of each layer in the project and the project itself have to be set, including a "Short name", a "Title", an "Abstract" to say what is displayed, a "Keyword list" (for search engines), and a "Data URL" to provide additional descriptions on the data displayed in the layer. Additionally the "Attribution" (the origin of the data), the “MetadataURL” (when available) and the “LegendURL” (if the standard legend is not used) can be specified.

b) The QWC2 web client (https://github.com/qgis/qwc2) consumes the data from the QGIS Server and turns it into a web page for the Apache webserver. It is a large set of Java scripts (ReactJS) and CSSs (cascading style sheets) running under a Node.js server environment, also using the OpenLayers (https://openlayers.org/) JavaScript framework for some of the functions. It is installed from GitHub. The greatest advantage of using this web client is the fact that it renders the symbologies and labels used and set up in the QGIS projects almost 100% the same on the web page and no additional tweaking and development is necessary on the web client side. That also means that the symbologies and other settings like labels (sizes, font, etc.) can be changed at any time within the QGIS project and are immediately changed on the web page without additional code changes or development. Another possible (and as powerful) web client that works with QGIS, LizMap (https://www.3liz.com/en/lizmap.html), was investigated, but was found to be more of a challenge to set up. However, this option is still possible, maybe at a later stage of the project, even as another option for the user.

c) Two databases are used to store the data used for the layers: i) the PostgreSQL/PostGIS database (Ver. 10.x) (https://www.postgresql.org/) for the groundwater, surface water and meteorological data and ii) a Spatialite (SQLite) (https://www.gaia-gis.it/fossil/libspatialite/index) database for the polygon and line layers displaying hydrogeological and hydrological information. Eventually the latter could also be stored in the PostgreSQL database for better security and integrity (user permissions), where the PostGIS extension provides the spatial capabilities of the database. Now it is important to mention that QGIS accesses only the data in fields necessary for the display on the map from the database with SQL (Structured Query Language) queries and no other data is visible or accessible by the web map user. That also means that even sensitive data (like chemistry results or water levels or abstractions) can be stored in the database without being visible to the web map user, in fact any other database user without the required permissions.

Over and above the use of the web map in a browser the project can be accessed by any GIS software capable of opening WMS/WMTS (web map service) layers, including QGIS, by specifying the URL https://blecher.dyndns.org/cgi-bin/coct_db/qgis_mapserv.fcgi?VERSION=1.3.0 in the WMS set-up. This address will change once the final mapping website set-up is conducted.

It must be noted here again that all the components above are open-source projects and support is widely available on the Internet.

9.2 Requirements for the Set-up

In order for this set-up to be duplicated or transferred to another server the following requirements need to be met:

- Preferably a Linux server computer accessible through the Internet
- PostgreSQL database server (> Ver. 10.x) installed (database transferred with backup/restore procedure)
- QGIS Server installed
- QWC2 web client installed with all the modified files for this project (including Node.js and yarn to rebuild the layer information from the QGIS server)
- Apache2 web server installed

- QGIS on any desktop to modify and add to the projects
- Possibly a cloud account to synchronise QGIS projects between desktop and server (not necessary if only working on a local network)

9.3 How-to use the Web Mapping Tool

The map may be accessed by going to https://blecher.dyndns.org with your favourite web browser. This is a temporary Linux Home Office server, which will be discontinued at the end of the project, and therefore this URL may change.

Once the basic map has been built/loaded with the OpenStreetMap background and all boreholes, wellpoints and dug wells coloured differently more layers can be added (switched on and off) by selecting the “Map & Tools” menu in the top right corner of the map.

The layers are grouped according to different information items. Each layer has a icon and a icon. Clicking the icon will remove the group or the layer, which can only be undone by clicking the button in the bottom right toolbar to start over or refreshing the browser. Clicking the icon opens a small sub-menu where the transparency of the layer can be changed, the layer moved up or down to be above or below other layers respectively and a ⓘ icon which opens the Layer Info box. The little ⓘ next to the layer also opens the information box directly.

The Layer Info box provides an abstract of the information for that layer, some keywords for search engines and often also a data URL, which provide additional online resources on where the data comes from or is defined, and a legend for the layer.

To the left of the layer name is a legend which increases in size when hovering over it with the mouse cursor.

The “Show layer map tips” checkbox, when ticked, allows the display of number, names, values, etc. for the layers active under the mouse cursor. The “Compare top layer” splits the screen in two where different layers can be switched on to compare items on each side.

The “Import layer” function allows the “import” of a local file (*.kml file only) or an online URL to a WMS, WFS or KML link. This will bring additional layers into the map which can be switched on and off and moved up or down as all other layers. These do not stay on the map when the browser is closed or moved to another site.

The printer icon on top of the menu allows the printing of the legend, which shows all legend items of the active layers. Clicking the icon next to it allows the removal of all layers. The “Themes” option has then to be used to restore the original (default) map.

The round icons at the bottom right allow (from top to bottom) going Home, which is the default zoom to show the entire map, then panning and zooming to your current location (as determined by Google from your bowser or phone location), then zoom in and out at a default factor (otherwise the mouse wheel can be used instead) and the button at the bottom allows changing the background map or switching it off completely.

As the default view is quite a small scale due to the size of the project area no labels are shown and most of the labels only come on once the zoom goes below 1 : 250 000 or 1 : 100 000, depending on the layer.

The status bar at the bottom of the map (from left to right) shows a scale bar, the current coordinates of the mouse cursor in the coordinate system chosen in the drop-down next to it (currently the 4 most-widely used for the area) and a Scale drop-down to choose a desired scale.

Clicking anywhere on the map will open a Feature Info box which shows the published fields for all the active layers under the mouse cursor within a certain radius. The features will also be highlighted in red on the map and hovering over the features in the box will highlight them individually on the map. Clicking on the little ⓘ icon will again open the Information box for that layer. Both the Layer Info box and the Feature Info box can be resized and moved around.

This help function is also available in the web browser by going to “Help” in the “Map & Tools” menu. It must also be mentioned here that some of the available functions are still under development and testing and that they may be “broken” when accessing the website at that particular time.

There is also a **Disclaimer / Terms of Use** link explaining some legalities when using the map:

This mapping website and its data displayed should be used with caution! It is not intended to be used for groundwater management purposes, for which an in-depth groundwater study may be required. Some of the data from the database may be quite old and may not necessarily represent current conditions. Any links to other online resources and the information displayed from them are the responsibility of the relevant web page creators/maintainers/owners.

Although the data displayed on this web site has been produced and processed from sources believed to be reliable, no warranty, expressed or implied, is made regarding accuracy, adequacy, completeness, legality, reliability or usefulness of any information. This disclaimer applies to both isolated and aggregate uses of the information. The information is provided on an "as is" basis. All warranties of any kind, express or implied, including but not limited to the implied warranties of merchantability, fitness for a particular purpose, freedom from contamination by computer viruses and non-infringement of proprietary rights are disclaimed. Any action you take upon the information on this website is strictly at your own risk and we will not be liable for any losses and damages in connection with the use of our website and data displayed.

Changes may be periodically made to the information herein; these changes may or may not be incorporated in any new version of the map publication. If you have obtained information from the owners of this website from a source other than the owner’s web site, be aware that electronic data can be altered subsequent to original distribution. Data can also quickly become out-of-date. It is recommended that careful attention be paid to the contents of any data associated with a file, and that the originator of the data or information be contacted with any questions regarding appropriate use. If you find any errors or omissions, please report them to immo[AT]blecher.co.za.

9.4 Current Layers on the Map

The current layers as at the time of writing this report are briefly described below. This list of layers is permanently expanded as new data and information comes in and will be tweaked and improved until the end of the project.

From the top down the following layers are currently presented on the map (this order may change as new layers are added):

- The study area, an “inverted” polygon layer that fades out the area outside the study area
- A 0.25° grid (lines) covering the study area
- Five Geosites (points layers) that occur in the area: 1) Boreholes, Wellpoints, Dug wells coloured differently, 2) Fountains/Springs, 3) Seepage Ponds, 4) River, Dam, Pan, Canal Monitoring Stations (gauges, weirs, etc.), and 5) Meteorological Stations (rainfall)
- Four Monitoring Network Stations (not all stations under the Geosites are actively monitored): Water level, River stage heights and flows, Dams (and Pans) stage heights (most of these sites have URLs to other online resources, including “near live” charts), Rainfall (monthly, depicted in pie charts)

- Groundwater chemistry: Electrical Conductivity and Iron (coloured themes according to their value (SANS 241 and Water Quality Classes as basis); more layers will be added depending on availability of new data
- Borehole properties: Borehole Depths and Blow yield as coloured theme points
- Administrative and Infrastructure: These may mainly be used when not using the background layers to show major roads (lines), Major Town and Cities (polygons), but also the Water Management Areas and Local and Metropolitan Municipality boundaries (as polygons)
- Hydrogeology layers (all polygons): Depth to water level, Major Faults, Simplified Lithology, Groundwater Occurrence, Harvest Potential (Safe Abstraction), Borehole Prospects (chances of drilling successful boreholes)
- Hydrology layers: Rivers (lines), Dams and Lakes (polygons), Quaternary Catchments (polygons), may also be used when not using the background layers
- Base maps (background maps loaded directly from the Internet): OpenStreetMap and OpenTopoMap, the NGI 1 : 50 000 topographic maps and the NGI Aerial maps. More may be added in future.

10 SET-UP OF USERS

The set-up of users is determined by the tasks they have to fulfil on the data or the map visualisation. These users will have to be created on the PostgreSQL database server and grouped into so-called roles. As the present PostgreSQL database is hosted on a temporary server, this set-up, or an advanced version of it, has to be regenerated on the final hosting server.

Presently two major roles have been defined: a) a read-only role, which will give access to the whole database and all tables in it, but nothing can be added or changed, and b) a read-write role which allows adding and changing, but also deleting data. The latter, however, also allows creating new Views (which are essentially read-only subsets of data defined by SQL queries) but does not allow the creation of new databases on the server.

A couple of users were created within role a) to give consultants who submitted data, access to the data to see what is there and what not. Some of the consultants' users may be moved to role b) in the future to do live updates of the data as it comes in on their projects, but this will have to be determined by the end user, the City of Cape Town. The two UWC students, who were trained in the use of the Aquabase Water Resources Management software (see also section 4 below) were also added to this role, but they can access the database only from outside UWC as their Internet access does not allow traffic to the PostgreSQL server. But they may be valuable data contributors in future with their research projects and database access may be enabled and determined by the City.

There are presently only 3 users within role b) who are the project researchers, who are still adding and changing data in the database, probably until the end of the project.

As the mapping visualisation component needs access to the database a special "qgis" user login has been created in role a) as this user only needs to read the data from the database to send to the map. This is done within the QGIS Project, which is served to the map web client by the QGIS Server, using SQL queries and Views.

Several users of the City of Cape Town will be created once the database access has been enabled by the City IT department, which has to enable the PostgreSQL port 5432 on their network to let through traffic to and from the PostgreSQL server. A first meeting to that effect, and also future hosting ideas, for the database and the mapping tool did not have the desired outcome with various IT policies in place for different users. Additional feature development on the software front-end side may also be necessary to cater for specific needs of the City, but these will be available for all Aquabase users using this kind of set-up due to the open-source nature of the software. This might involve additional fields and/or tables to flag database records for access by certain users only, e.g. allowing upload of data into the database by certain users, which only becomes available after an auditing process by a database/groundwater data champion.

It must be noted here again that this is a temporary set-up which can change dramatically on the final installation of the database and mapping server and web client. Additional training and guidance may be necessary for the IT personnel of the City (or designated consultant/organisation, possibly including the Water Research Commission) to manage the database, including backups, the user access to the database with Aquabase and the maintenance of the mapping component. This will be provided once the final set-up location has been decided upon. The current server is also not really made for hosting a project of such scale (speed limitations), which would need a more powerful IT infrastructure and fast and stable Internet access.

As the City's IT infrastructure may not be able to accommodate this open-source database/server/Internet set-up, an alternative will have to be investigated during the final phase of the project. This alternative may have cost implications for hosting and maintenance and will be discussed under chapter 12 (Finalise Installation) below.

11 DEFINITION AND EXECUTION OF TRAINING

The training of potential users of the database, the Aquabase front-end software, and the mapping tools was determined by the current set-up of the database/mapping system. The most important part at this stage was to provide an understanding of the database and the use of the front-end software to populate the database and extract data from it for visualisation and presentation.

The preparation and modification of the QGIS project(s), which are used for the mapping visualisation, needs a more in-depth training of a GIS-orientated person, who has a sufficient knowledge of spatial data and the SQL functions. Over and above that a good knowledge of QGIS and Linux would be an advantage. This person needs to be identified and is dependent on the final hosting set-up (see also chapter on sustainability below).

Two separate Aquabase 2-day training courses were presented: 1) at the City of Cape Town Witzands Treatment Plant (Atlantis) on the 12 and 13 September 2019 for the City staff, and 2) at the University of the Western Cape Applied Geology Department (Chemical Science Building) on 26 and 27 September 2019. The programme for the training was:

Day 1:

1. Understanding the Aquabase databases and choice of database
2. The difference between databases and spreadsheets
3. The Aquabase tables and database structure
4. Installation options
5. The importance of location (coordinates)
6. The South African coordinate systems used (and the importance of the map reference)
7. Entering sites (this is the beginning)
8. Entering other information (water levels, chemistry, pumping tests, etc.)

9. Searching for information in the database
10. Creating Views (for filtering data)
11. Marking and bookmarking sites
12. Simple charts (chemistry and time dependent)
13. The Preferences (system set-up) – and where they are located
14. Using some of the tools (changing Site identifiers, creating backups, managing views, etc.)

Day 2:

1. The lookup codes
2. Advanced SQL queries to export data
3. Using scripts to manipulate data
4. Creating additional chemistry parameters
5. Importing data (other workspaces, tables from spreadsheets, etc.)
6. Advanced charting from imported data (the importance of import table format)
7. Using Aquabase tables in other applications and GIS (Google Maps, QGIS, Web-maps, etc.)

Course participants were advised beforehand to have access to a PC or notebook during the course so that hands-on training on the software and database would be possible. This, however, was not possible for the City Witzands training and therefore the material was presented as a demonstration over a projector, but with active participation of the attendees.

The participants at the City Witzands training course were mostly from the technical department of the Witzands Treatment Plant who were involved in monitoring data acquisition from the Atlantis wellfields in some form or another, but also Candice Lasher Scheepers who is in charge of the groundwater database at the City DWS. A course evaluation/questionnaire form was sent to all participants to assess the quality of the course, the knowledge of the presenter and general feedback.

The participants at the UWC training course were two of the UWC students identified for the capacity building part of this project, Aqeela Parker and Ashleigh Tomlinson, but also two other students who will be involved in groundwater data accumulation for their department, data of which will become available for the database of this project. It was discussed earlier with the students and their supervisors that they want to be involved with the City groundwater database in future and contribute data, mostly generated during their Masters Degree theses and working in different areas, to the City groundwater database. This would be achieved by using Aquabase internally and creating databases for their projects, which could later be uploaded to the City database. Again, a course evaluation/questionnaire form was sent to all participants to assess the quality of the course, the knowledge of the presenter and general feedback, but most of the forms had not been returned at the time of writing this report.

The third student identified for the capacity building (Arantxa Blecher) has only been trained mainly on the GIS component (web-based map) of the project at the end of October over several days due to time limitations.

The course participants were also advised to consult the extensive Aquabase help system, which is part of the software and basically is a manual, not only on how to use specific functions, but also specific database requirements for data integrity. This help system is in the process of being built into a web page, which will become part of an Aquabase dedicated web presence.

12 FINALISE INSTALLATION

By the time of writing this report a final installation location could not be determined due to the limitations described in chapter 13 (Sustainability Study) below. Although an off-site location (not on the City network) of the database and web map service could be considered for the short term, Internet access to the relevant database ports are not possible due to City IT policies so that City users cannot access the database on an external server (in the cloud). Database updates would have to be done from outside the City's network.

A not-so-elegant solution for the groundwater database management requirements of the City for the short to medium term could be the transfer of the data presently residing in the PostgreSQL database into a SQLite/Spatialite database, which is a local file based database system (the Aquabase default) and almost as powerful as the PostgreSQL database in terms of spatial capabilities and speed, but cannot be cloud based. There is also no user permission set-up required making it ideal for the City groundwater database manager's intent to identify a "database champion" who would be responsible for the population and upkeep of the database. This SQLite database could be handed over at the end of this project, which could go hand-in-hand with another short training session with the "database champion".

This local database set-up would still allow the use of all the visualisation tools available in Aquabase, but also allow access by GIS systems for mapping functions. Unfortunately the web mapping functions would not be available, not for the public and also not internally, but the QGIS workspace used for the web-map could be adapted to access the groundwater data from the local SQLite database (instead of the PostgeSQL server) and therefore used internally to create groundwater management maps and presentations.

Access by other consultants to upload or update data would also not be possible and this therefore will have to be a more manual process of receiving the data (preferably in Aquabase format) and appending it to the City database. Careful database management for this is essential to avoid duplication of data.

13 SUSTAINABILITY STUDY

There are a few facets to look at on a project like this one in terms of sustainability:

1. The potential user's requirements and planning
2. The potential user's present IT set-up and policies
3. The potential user's scientific, database and GIS knowledge
4. Cooperation and support of consultants/organisations
5. Ongoing development of the database front-end software and web map service
6. Implementation in other areas/metros/municipalities – Marketing
7. Commercialisation of the system

13.1 The potential User's Requirements and Planning

Before any database project of this scale is planned and advertised an investigation into the potential user's requirements must be conducted to ascertain what will be possible within the envisaged time frame and budget. The user might be limited in capacity, or has limited staff, or needs to store specific data not necessarily related to groundwater, or already has some system in place which needs to be developed further, or any combination of these.

I must also be ascertained what the user has planned for a system in future and how the planning fits into the greater picture of the organisation. This should return a “must have list” of requirements and a “nice to have list” of functionality so that there is a guideline for project planning and implementation.

For this project this facet was not conducted sufficiently and therefore a system proposed which could be a hydrogeologist’s or scientist’s “dream”. In the end the outcome was an “almost perfect” groundwater database set-up in the cloud which updates the web-based map in real-time and it certainly can be developed further and adapted to different user requirements.

13.2 The potential User’s present IT Set-up and Policies

The IT set-up and policies of the user’s organisation must be taken into account when planning the implementation of the system. The organisation may have certain preferences in terms of software and may not be able to set up a system built completely with open-source software due to ignorance and/or resistance to change.

In this case the City of Cape Town has some form of groundwater database, which seems to be a combination of various database systems (or spreadsheets) recording abstraction, water levels and groundwater quality, but not really available to the groundwater managers (or the public). And even if a database like the one created during this project and combining all these recordings could be set up outside the City’s network it is not possible for the users on the network to access the outside database due to Internet usage restrictions. In such a case the question of data custodianship comes up and what data can be posted into an “external” database over which the City has little control.

A question was also raised on what data may be available to the public. There may be certain data in the database which is “sensitive” and therefore cannot be published, but the intention to publish some groundwater information on the City’s website is planned. In what form that would be was not yet clear, but, if it would be in a web-based mapping platform, a new project would have to be created within the City’s budget for the development and implementation of such a system. This would certainly be an expensive and time consuming exercise and not necessarily make use of the database or web-based mapping system created under this project.

The availability of data to the public, in whatever form, would have to go through an approval process which might need careful planning to be effective. In reverse, an upload of data by the public, which is totally possible (but not enabled) with the developed system, would require user registration with passwords and access rights and a rigorous auditing process before it can become part of the database and published information.

It was also stated that no “external” code is allowed on the City’s servers/network, again ignoring the open-source character of the project which allows viewing, changing and auditing the code as pleased under the terms of the GNU Public License. So the risk of “infected” code is zero and there is no danger to the network or servers.

13.3 The potential User’s scientific, database and GIS Knowledge

In order for the implemented database and visualisation tools to be sustainable it is important that the user, or at least the “database champion”, has sufficient knowledge of the data, the database structure and front-end software and should have a good understanding of GIS systems to set up the projects which are published through the web-based map. This would ensure that after the finalisation and implementation of the project the user is self-sustainable and needs minimum input from the project consultants to update the database or the map, or even create new maps.

13.4 Cooperation and Support of Consultants/Organisations

When it comes to data sharing the concept of "open data" is pretty much in its infancy. Although most consultants and organisations are generally willing to share their data (with client's approval) the concept is "if you share, then I'll share, but how do I know".

When starting any groundwater project consultants often go through the same process over and over again: first obtain data for the desktop study. And this is where it becomes complicated as other consultants may have worked in the area before, but have not made their groundwater data available to the National Groundwater Archive of the Department of Water and Sanitation or any other database for that matter leading to repetition of work already done.

That makes groundwater projects more expensive and could be avoided if a system like the one developed under this project was available and could be maintained. Anybody, including the public, could get basic groundwater information at a click of a mouse button and with the front-end Aquabase software even more detailed data on boreholes and groundwater from the database in the cloud. But that requires cooperation from all consultants and ongoing development of the database software and web map service organisations working on groundwater projects.

13.5 Ongoing Development of the Database front-end Software and Web Map Service

Open-source software development is a continuous process and results in updated software and code without cost of licenses to the end-user. That makes the products of this project to be updated from time to time and while the front-end software and database is relatively easy to update by the users themselves the web map service may require a bit more technical knowledge and input from external specialists, which the user's organisations may have to consult if internal capacity is not available.

13.6 Implementation in other Areas/Metros/Municipalities – Marketing

The development of the database and web map service took into account the possibility of implementing the same in other areas or municipalities relatively easily. While there is not necessarily any cost involved with the actual products from the project there may be a cost involved to implement and adapt the system to those particular users' requirements.

In general the QGIS project used for this particular study area can just be adapted to zoom/pan to another area and the database connection changed to another groundwater database for that area. If the preferred groundwater database is not one of the Aquabase databases then a few more changes may be required in the QGIS project for the web map service to work as expected.

13.7 Commercialisation of the System

The database and visualisation tools as they currently are can be promoted as a viable system for use by other organisations like municipalities, councils, water management agencies, nature conservation organisations and other. That would require demonstrations and information distribution of the system through various platforms, including groundwater related conferences, workshops and exhibitions like at the recent (October 2019) Biennial Groundwater Conference in Port Elizabeth, groundwater related websites (including the WRC website) and direct contact making by the project researchers through the WRC. Monetary value would not be achieved by selling the software and code components or intellectual property, but rather the fees for services for implementation and adaptation of the system.

In this way funds could be generated to improve the system further and develop new features, both on the software and web map server side.

14 CONCLUSIONS AND RECOMMENDATIONS

The development of a groundwater database and visualisation tools for the City of Cape Town and Environs resulted in a comprehensive database with over 7 800 geosites with groundwater related information, the installation of the front-end Aquabase software at the City offices and a web-based mapping tool which can be accessed with any browser on the Internet. Data was imported from various sources, including National Groundwater Archive and Water Management System data of the Department of Water and Sanitation, multiple datasets in spreadsheet format and data was manually captured from PDF reports. City personnel were trained in the use of the software and the database concept explained.

The system consists of a PostgreSQL database hosted on a temporary Linux home office server in the cloud, the front-end Aquabase water resources management software and a web-based map produced with the QGIS Server component, which reads a QGIS desktop project specifically created to show only certain information from the database, and then served to the QWC2 web client for display in a browser.

As currently a planned final installation of the system within the City of Cape Town's IT infrastructure and policies is not possible, a "scaled-down" version of the database as a local file-based SQLite/SpatiaLite database will be installed at the end of the project for use by the City's groundwater team, who will identify a "database champion" to take control of the population of the database to keep it updated as information comes in. The developed mapping website will unfortunately not be available with this set-up, but the QGIS project for the web map can still be used locally by the personnel to produce exactly the same map or additional maps for groundwater decision making.

The sustainability of the project is therefore dependent on the City's groundwater personnel and new data from consultants working in the area and willing to share the data will have to be audited and appended to the database manually. If the City decides to produce a web-based map and share some information publicly, a new City project will have to be created and executed, which may or may not use the installed database.

It is, however, recommended to keep the mapping website with the data from the PostgreSQL database alive for the short- to medium term, but maybe not specifically with the current study area and name but extend it to the Western Cape Province, and use it to promote not only the sharing of groundwater data and possible implementation in other areas, but also the use of open-source software to achieve such a valuable source of groundwater information. Database access would then be restricted to the current project researchers. But that would also entail the installation of the system on a different server than the current temporary home office server, which would be ideally located at the WRC and could become part of the WRC website.

But a set-up of a shared server facility at one of the consultants or other organisations could be investigated to motivate all consultants and organisations working in the area to contribute their data to the database and therefore also have free access to the database. That would mean IT infrastructure (server computers and network/Internet access), capital layout and maintenance of such, but also personnel to keep the database and mapping website updated.

Appendix A

List of relevant Entry Forms:

<u>General:</u>

Basic Information

<u>Groundwater:</u>

Borehole logs: Aquifer, Geology and Penetration rate

Groundwater Properties: Temperature, Electrical Conductivity, Flow Velocity and User-defined Parameters

Discharge Rate

Water Level

Aquifer Testing: Pumping Tests, Testing Details

<u>Chemistry:</u>

Water Samples

Standard Parameters

User-Defined Parameters

<u>Engineering:</u>

Construction: Hole Finish

Hole Construction: Hole Diameter, Casings, Piezometers, Fill Material

Borehole Properties: Caliper, Dip

Installation (Pump and Reservoir)

Pump/Engine Details (incl. Riser details)

Maintenance

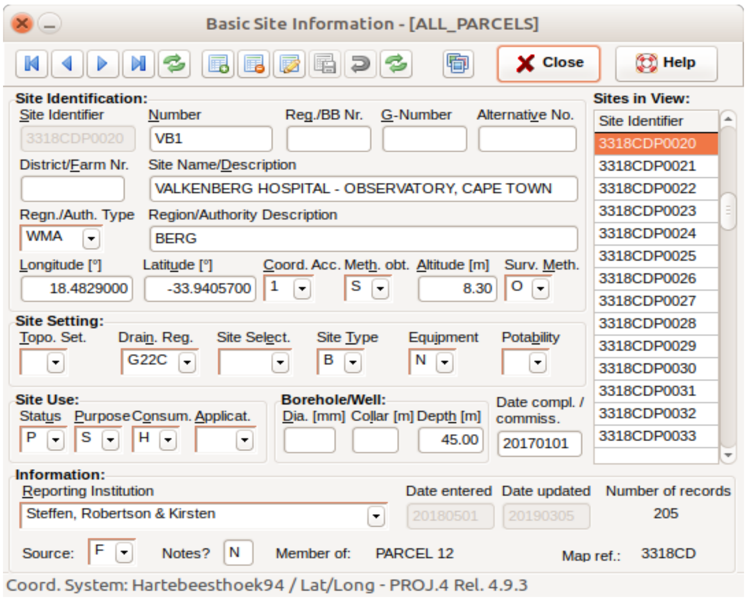


Figure 1: Basic Information entry form

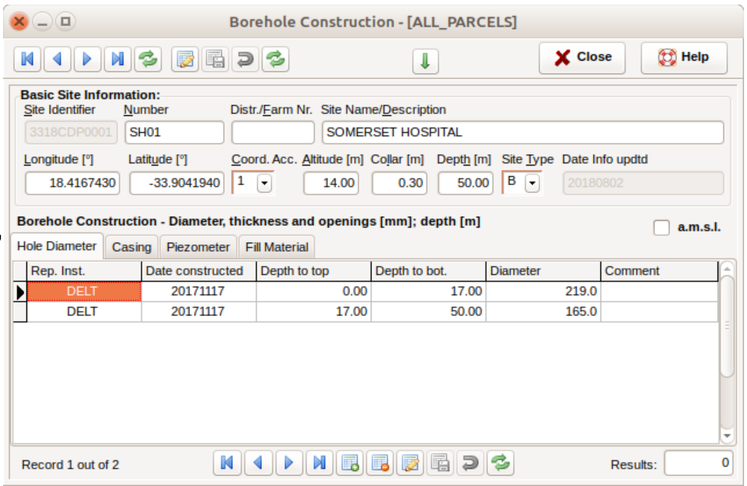


Figure 2: Borehole Construction entry form

<u>Down-The-Hole Geophysics:</u>

Geo-electric Methods: Long-Normal, Short-Normal, Self Potential

Radioactive Methods: Gamma ray, Gamma-Gamma, Neutron-Gamma

Magnetic Susceptibility

<u>Additional Information:</u>

Instrumentation (e.g. loggers)

Name of Owner

Visits to site

References and Comments

Field Measurements

Site Status

<u>Site Management:</u>

Report documents (linked to sites)

Management Recommendations

Meter Readings

Other Identifiers and Group Memberships

<u>Meteorology:</u>

Hydrologic Parameters: Rainfall, Pan Evaporation, Humidity

Atmospheric Parameters: Temperature, Pressure, Solar Radiation, Wind Velocity and Direction

<u>Surface Hydrology:</u>

Stage Height

Stream Discharge and Flow Velocity

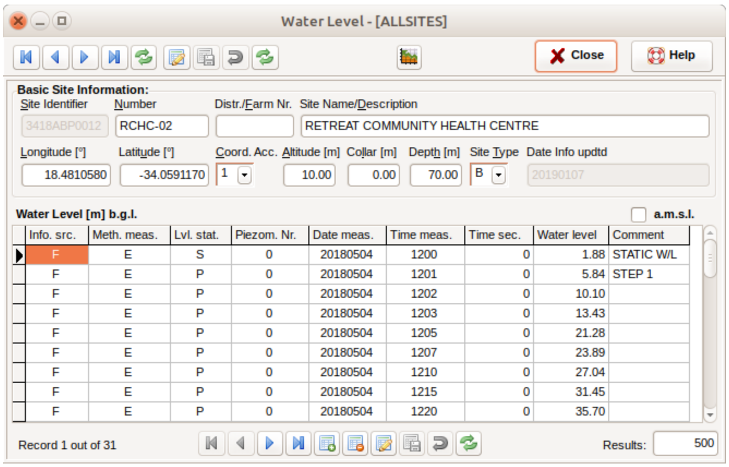


Figure 3: Water Level Entry Form

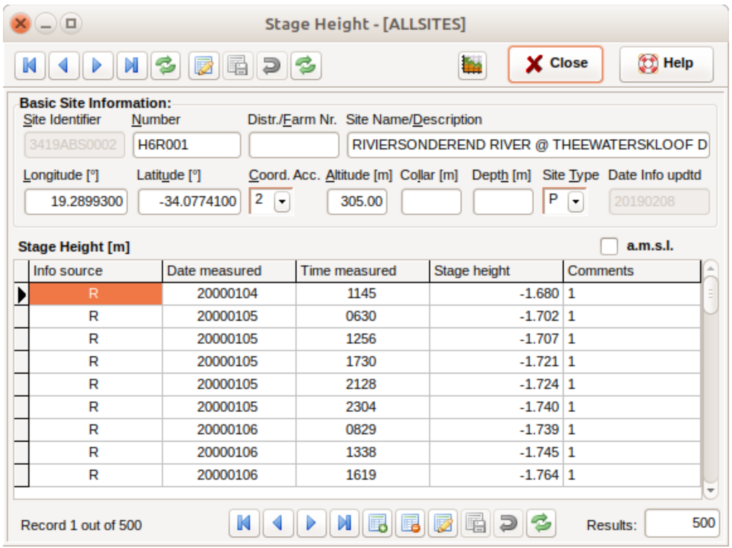


Figure 4: Stage Height Entry Form

Appendix B

Examples of Charts:

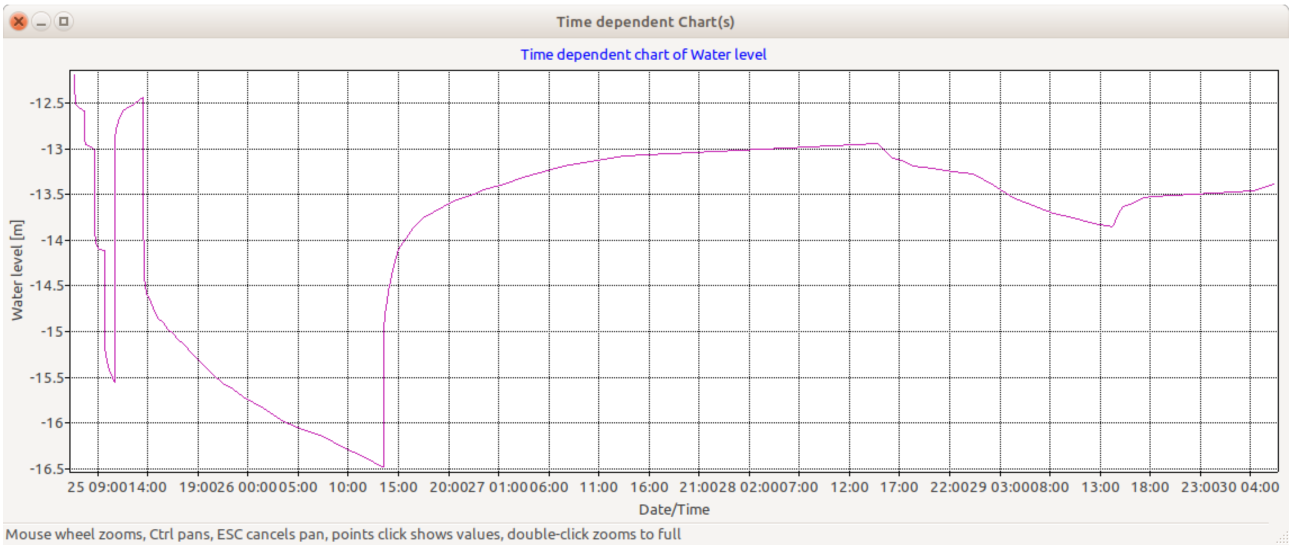


Figure 5: Time-dependent chart of Water Level (Pumping Tests)

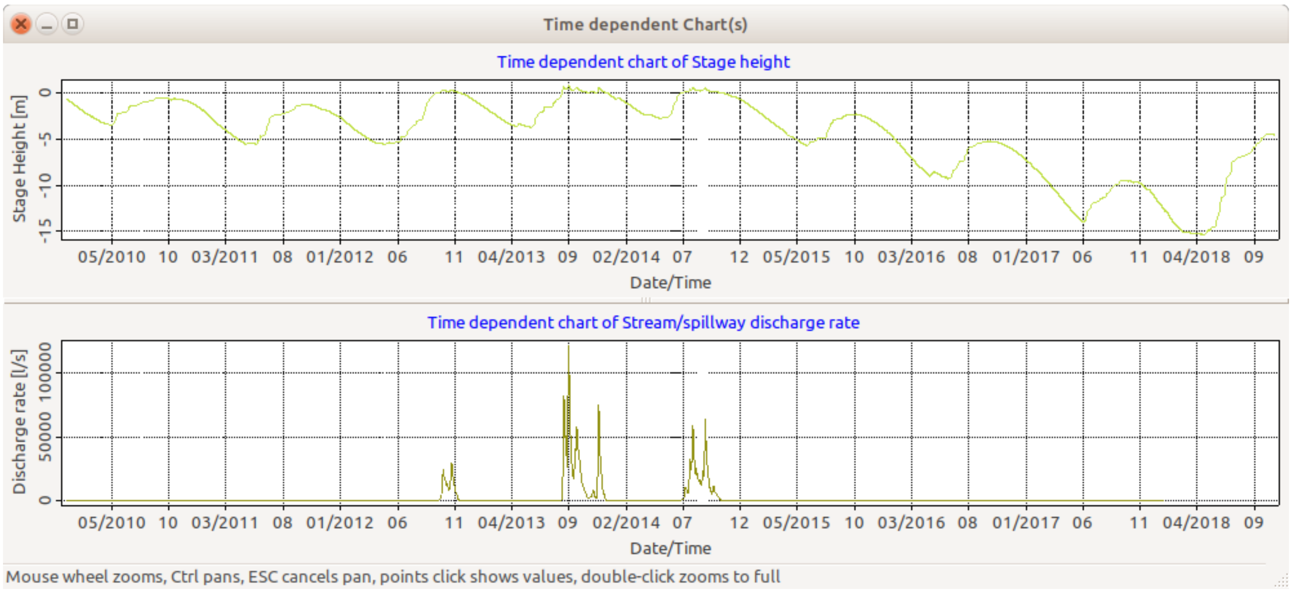


Figure 6: Long-term time-dependent Chart of Theewaterskloof dam Stage Height and Riviersonderend Spillway

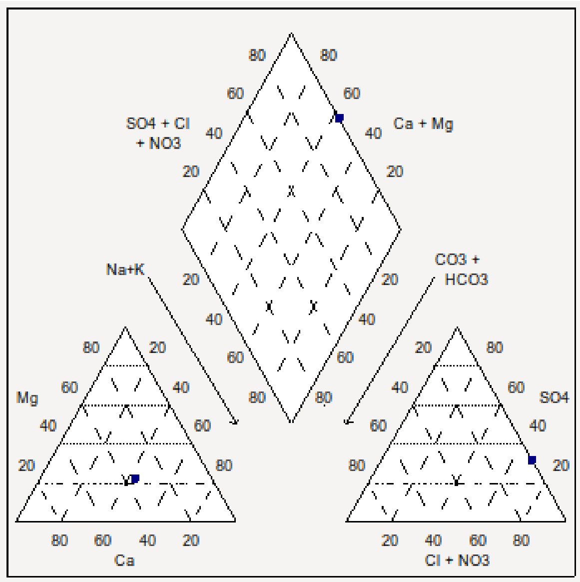


Figure 7: Piper Chemistry Diagram

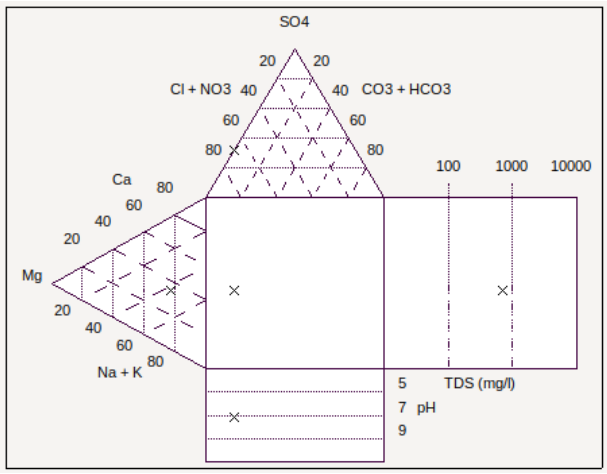


Figure 8: Durov Chemistry Diagram

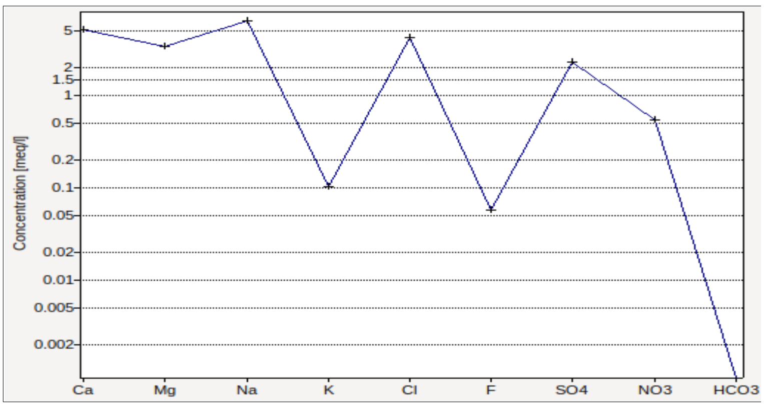


Figure 9: Schoeller Chemistry Diagram

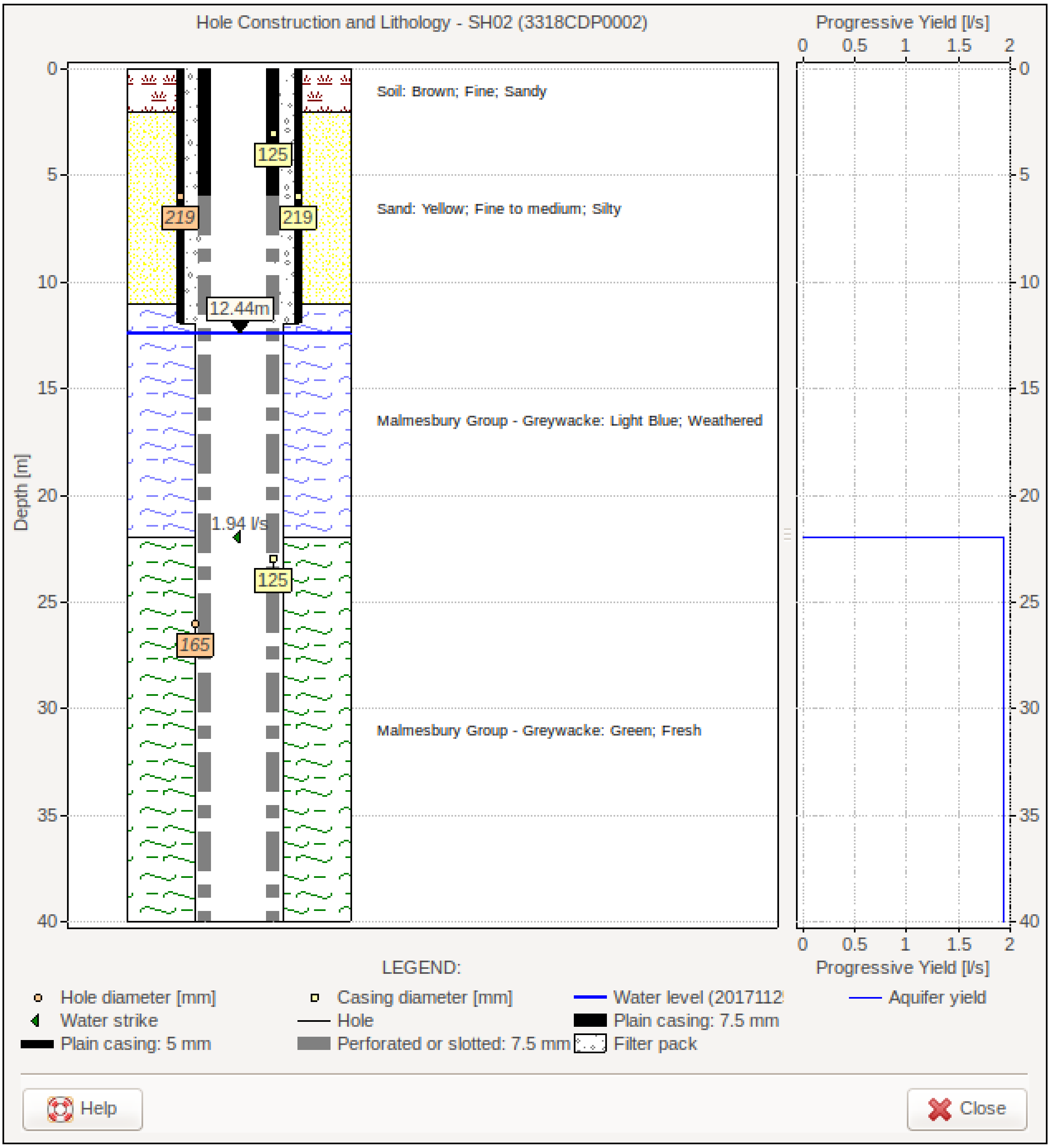


Figure 10: Borehole Construction, Lithology and Progressive Yield Chart

Appendix C

Examples of Reports:

PUMPING TEST REPORT Date Compiled: 12/03/2019

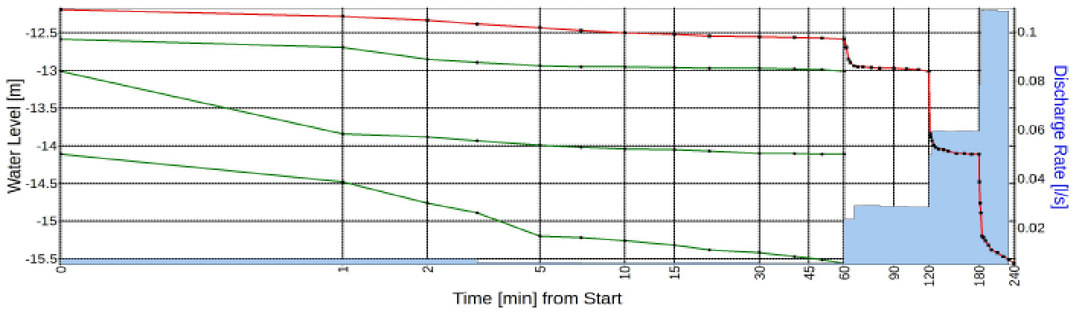
BASIC SITE INFORMATION: ***Site Identifier:*** 3318CDP0002 ***Number:*** SH02 ***Site Type:*** Borehole

Distr./Farm No.: ***Site Name:*** SOMERSET HOSPITAL

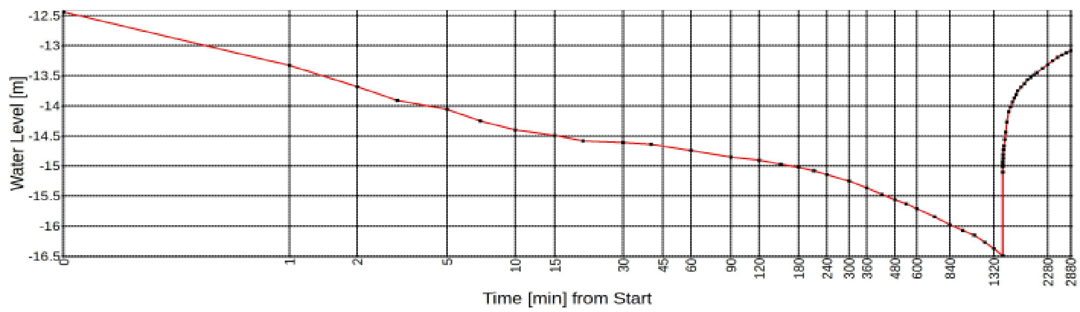
Latitude [°]	-33.9048010	***Alt. No. 1:***		***Diam. [mm]:***	165	***Last static water lev. [m]:***	12.19
Longitude [°]	18.4174440	***Alt. No. 2:***	SH2	***Depth [m]:***	40.00	***Piezometer:***	0
Altitude [m]:	13.00	***Rep. Inst.:***	Delta H Water Systems Modelling	***Col. Ht. [m]:***	0.30	***Date WL meas.:***	20171125

Coordinate System: Hartebeesthoek94 / Lat/Long

MULTIRATE / STEP / CALIBRATION TEST



CONSTANT RATE TEST



PUMPING TEST ***Rep. Inst.***	***Meth. tested***	***Depth to intk. [m]***	***Starting Date***	***Time***	***End Date***	***Time***	***Transm. [m²/d]***	***Storativity***
Delta H Water Systems Modelling	Multirate test	36.10	20171125	0640	20171125	1040		
Delta H Water Systems Modelling	Recovery test	36.10	20171125	1040	20171125	1310		
Delta H Water Systems Modelling	Constant rate test	36.10	20171125	1330	20171126	1330	1.2E2	0.00084
Delta H Water Systems Modelling	Recovery test	36.10	20171126	1330	20171127	1330		
Delta H Water Systems Modelling	Constant rate test		20171128	1450	20171129	1420		
Delta H Water Systems Modelling	Recovery test		20171129	1450	20171130	0620		

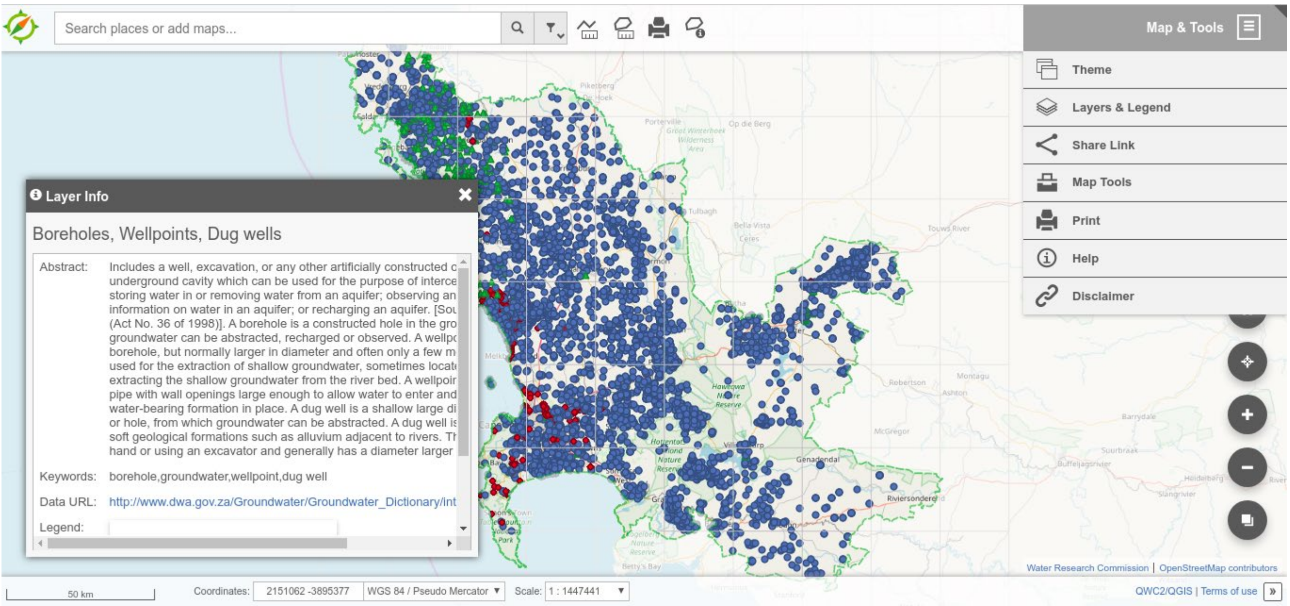
TESTING DETAILS: ***Description***	***Time started***	***Durat. [min]***	***Depth to intake [m]***	***Disch. rate [l/s]***	***Drawd. [m]***	***Recovery: [m]***	***%***	***Durat. [min]***	***Transm. [m²/d]***	***Perm. [m/d]***	***Storat.***	***Spec. Capac.***	***Q/st***
STEP1	0640	60	36.10	0.34	0.39								0.872
STEP2	0740	60	36.10	1.73	0.82								2.110
STEP3	0840	60	36.10	3.57	1.92								1.859
STEP4	0940	60	36.10	6.53	3.37								1.938
CONSTANT	1330	1440	36.10	5.03	4.05	3.41	84	1440					1.242

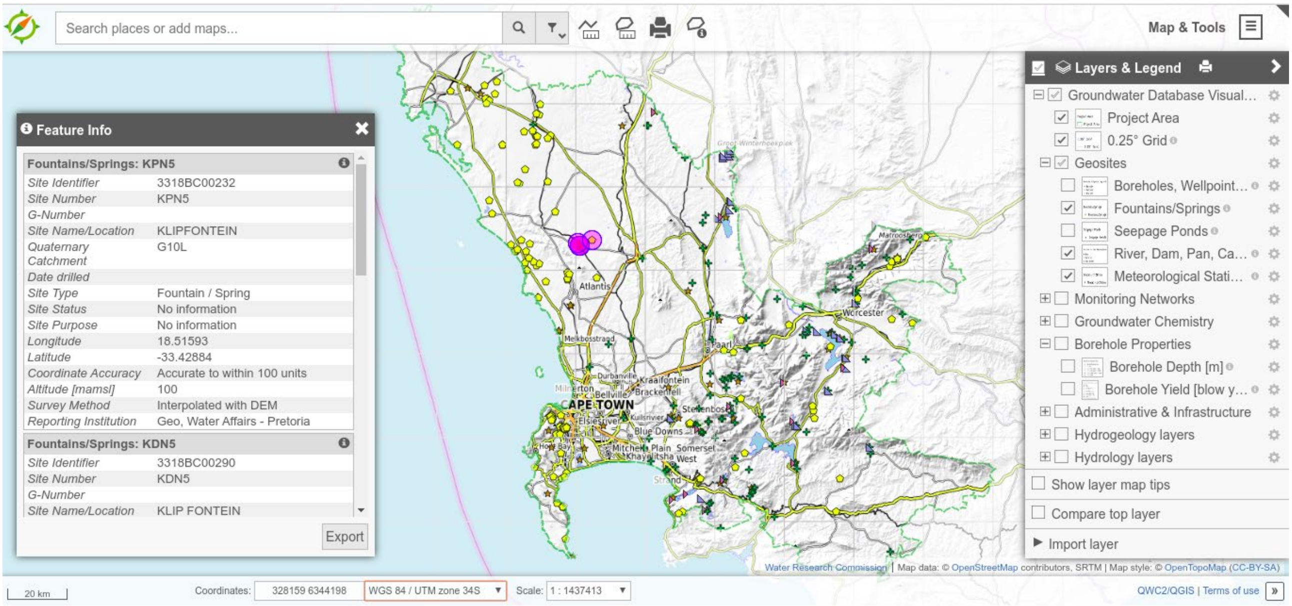
Reporting Institution Details:
Delta H Water Systems Modelling

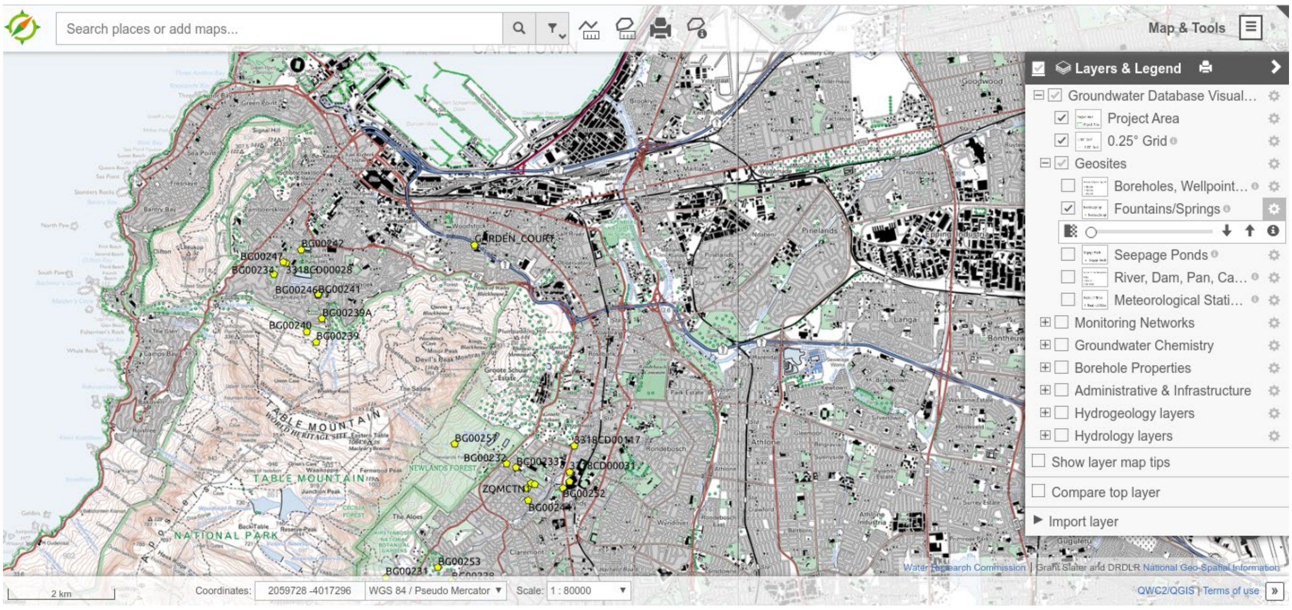
Page 1

Appendix D

Examples of web-based Maps:






Search places or add maps...
Map & Tools
Layers & Legend
Groundwater Database Visual...
Project Area
0.25° Grid
Geosites
Boreholes, Wellpoint...
Fountains/Springs
Seepage Ponds
River, Dam, Pan, Ca...
Meteorological Stati...
Monitoring Networks
Groundwater Chemistry
Borehole Properties
Administrative & Infrastructure
Hydrogeology layers
Hydrology layers
Show layer map tips
Compare top layer
Import layer
TABLE MOUNTAIN
NATIONAL PARK
GARDEN COURT
2 km
Coordinates:
2059728 -4017296
WGS 84 / Pseudo Mercator
Scale:
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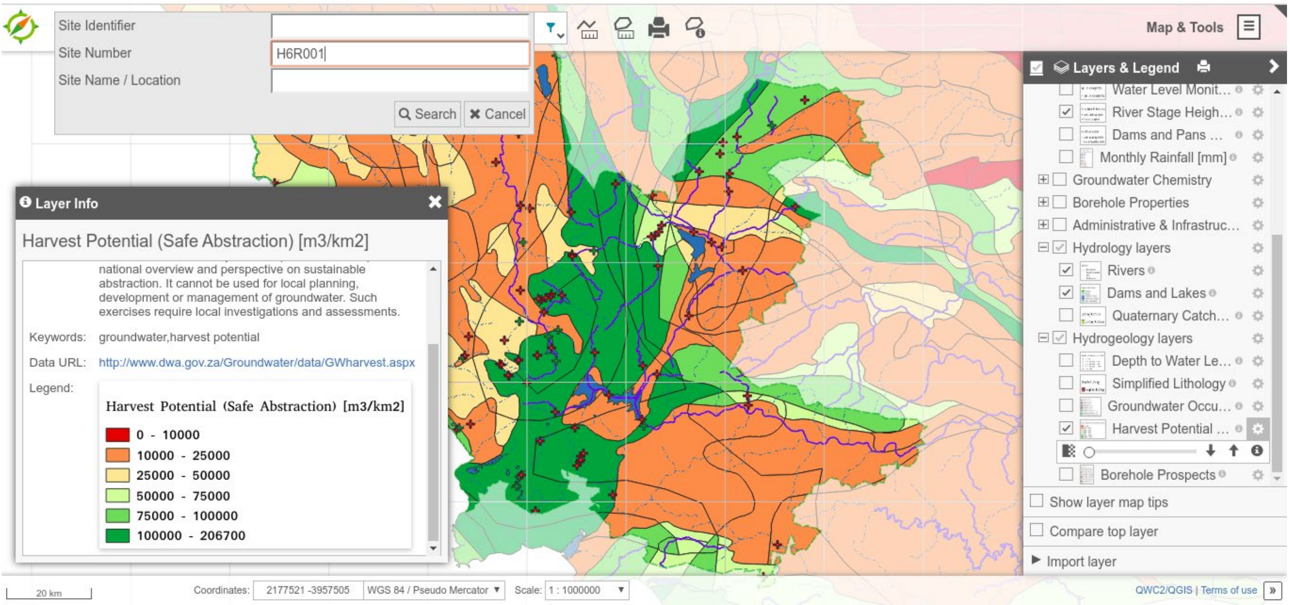
QWC2/QGIS | Terms of use


Site Identifier
Site Number
H6R001
Site Name / Location
Search
Cancel
Map & Tools
Layers & Legend
Water Level Monit...
River Stage Heigh...
Dams and Pans ...
Monthly Rainfall [mm]
Groundwater Chemistry
Borehole Properties
Administrative & Infrastruc...
Hydrology layers
Rivers
Dams and Lakes
Quaternary Catch...
Hydrogeology layers
Depth to Water Le...
Simplified Lithology
Groundwater Occu...
Harvest Potential ...
Borehole Prospects
Show layer map tips
Compare top layer
Import layer
Layer Info
Harvest Potential (Safe Abstraction) [m3/km2]
national overview and perspective on sustainable abstraction. It cannot be used for local planning, development or management of groundwater. Such exercises require local investigations and assessments.
Keywords: groundwater,harvest potential
Data URL: http://www.dwa.gov.za/Groundwater/data/GWharvest.aspx
Legend:
Harvest Potential (Safe Abstraction) [m3/km2]
0 - 10000
10000 - 25000
25000 - 50000
50000 - 75000
75000 - 100000
100000 - 206700
20 km
Coordinates:
2177521 -3957505
WGS 84 / Pseudo Mercator
Scale:
1 : 1000000
QWC2/QGIS | Terms of use