Development of an online borehole database to engage citizen science

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ABSTRACT

The development of an online borehole database to engage citizen science stems for the challenges of attaining borehole related data. The institutional databases, the National Groundwater Archive (NGA) and the Groundwater Resources Information Project (GRIP) are focal points for data access. The NGA is faced with incomplete datasets due to backlogs and capacity shortages, while the GRIP is only implemented in Limpopo province.

An online borehole database has been developed based on the Standard Geosite Descriptors (SGDs) and structured from the NGA and GRIP databases. The database is accessed through a mobile application which citizens can use to capture and access data. A user ranking system and user credits respectively allow for the verification and equitable use of the data. Engaging citizen scientists in borehole data collection enables the expansion of existing databases and gives the public a sense of responsibility in their contributions to this scientific endeavour. The contributions of data by the public facilitates hydrocensus processes to assess the state of groundwater.

Borehole, Citizen Science, Database, Database Management System (DBMS), Standard Geosite Descriptors (SGDs), Relational Database, Entity-Relationship (E-R) Model.

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ABBREVIATIONS

ACSII	American Standard Code for Information Interchange
AGO	ArcGIS Online
API	Application Programming Interface
AWS	Amazon Web Service
BLOB	Binary Large Object
CBM	Community based monitoring
DBMS	Database Management System
DDL	Data Definition Language
DML	Data Manipulation Language
DWA	Department of Water Affairs
DWAF	Department of Water and Forestry
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
ESRI	Environmental Systems Research Institute
GIS	Geographical Information System
GGIS	Global Groundwater Information System
GPS	Global Positioning System
GRIP	Groundwater Resource Information Project
GUI	Graphical User Interface
IaaS	Infrastructure as a Service
IGRAC	International Groundwater Resource Assessment Centre
IWRM	Integrated Water Resource Management
NGA	National Groundwater Archive
NGIS	National Groundwater Information Systems
NGS	National Groundwater Strategy
NIWIS	National Integrated Water Management Information System
NORAD	Norwegian Agency for Development Cooperation

OS	Operating System
PaaS	Platform as a Service
PPSR	Public participation in scientific research
RIMS	Ramotswa Information Management System
SaaS	Software as a Service
SADC-GMI	South African Development Community-Groundwater Management Institute
SDG	Standard Descriptor for Geosites
SDK	Software Development Kit
SGD	Standard Geosite Descriptor
SQL	Standard Query Language
UI	User Interface
UML	Unified Modified Language
VGI	Volunteered Geographic Information
WARMS	Water Authorisation and Registration Management System
WMA	Water Management Area
WMS	Water Management System
WRC	Water Research Commission
WSA	Water Service Authorities

CHAPTER 1 - INTRODUCTION

1.1 Background

This section gives context to the different components underlying the direction of this research, i.e., boreholes, databases and citizen science. It also gives a basis for the issue addressed in this research, the aims to do so and the significance thereof.

1.1.1 Borehole Data and Databases

The importance of boreholes in providing information on subsurface conditions, groundwater levels as well as rates and volumes of abstractions cannot be denied (DWA, 2007).

Borehole data can be concisely classified into three groups: general, stratum and engineering properties (Chang & Park, 2004:890). General properties refer to the project name or company constructing the borehole, the borehole location, drilling method and geometry (water table, casing depth and hole diameter). Stratum properties refer to the layering of the rock and soil formations, their depths and thicknesses. Test and engineering properties are concerned with characteristics such as water content, permeability, weathering, fracturing, density and core shape.

An orthodox description for borehole data comes from a geosite. A geosite is a natural or artificial subterranean hole used for water storage, abstraction or monitoring and collecting data regarding the state of an aquifer (Xu *et al.*, 2003). In South Africa, borehole data collection follows the nomenclature introduced by the Standard Descriptors for Geosites (SDGs), also referred to as the Standard Geosite Descriptors (SGDs). The SGDs encompass the measurement of borehole positions, construction, topographic and underground conditions, including their current function and state. SGDs allow for homogenised data collection between all parties that record, share and receive borehole information. The National Groundwater Archive (NGA), the most comprehensive database of borehole information in the country, is based on SGDs (DWA, 2013:3).

The most prevalent method of borehole data collection comes from groundwater monitoring. Groundwater monitoring is necessary to know the availability of water and its suitability for consumption (DWAF, 2004a:5). It requires regular record keeping of water levels below ground level. In this regard, role players (such as the Department of Water and Sanitation (DWS), municipalities and pump operators) play a fundamental role in groundwater management. The record keeping of pump operators, for example, allows Water Service Authorities (WSAs) to maintain their databases and manage over-pumping or under-pumping as well as reporting to the DWS, the principal custodian of groundwater in South Africa (DWAF, 2004a:6).

1.1.2 Database Management

Coronel and Morris (2018:6) and Rigaux *et al.* (2002:3) describe a database as an integrated, digital structure housing a collection of related data. This data can be classified into two classes, end-user data and metadata. End-user data is the raw data of interest to the users. Metadata is “data about data”, data about the characteristics and relationships relating to data. The structure, access and operation of databases is referred to as database management and is handled through a database management system (DBMS).

Various data models have been developed for databases and DBMSs. Among these, relational data models have risen to prominence and are widely used for an assortment of database applications. Most databases are able handle alphanumeric data types i.e., letters numbers and special characters. The main attribute of relational models and databases, however, is that they can be normalised, i.e., their data can be structured, to overcome redundancies such as duplicated data.

Borehole data offers a different kind of data type that considers the location and shape of the data, spatial data. Spatial data, also referred to as geographically referenced data or geospatial data, is attributed to a location at or near the earth’s surface (Yeung & Hall, 2007:94). This data requires a spatial database system for storage; these database systems can store spatial data types such as points, lines and polygons. An enhancement of these models is the object-oriented model, which is commonly used for Geographical Information System (GIS) applications as it is adapted to handling multi-dimensional data.

1.1.3 Citizen Science

A “science by the people”, citizen science is described by Bonney (2016) (cited by Strasser *et al.* (2019:54)) as the participation of the public in scientific research as well as a means of promoting public understanding of science. This recent definition should not negate the long history of collaborations between laypersons and professionals. Astronomy and ornithology are typical fields where amateur scientists and enthusiasts have assisted in tracking movement patterns as well as identifying unknown phenomena.

Presently, smartphones have expedited the sharing of information across the globe. They have empowered the citizen scientist with the sophistication of collecting data in various dimensions on a single device. These include:

- the audio-visual dimension through the capture of audio, images and video
- the temporal dimension through time stamps and time-lapsed imagery, and

- the spatial dimension through georeferenced media using a global positioning system (GPS).

There are various means of conducting citizen science. Volunteered Geographic Information (VGI) is one such concept bearing reference in the collection and sharing of environmental data.

1.1.4 Hydrocensus

The assessment of groundwater resources is fundamental in the Integrated Water Resource Management (IWRM) process (DWAF, 2006:26). One of the key steps in this assessment is conducting a hydrocensus.

A hydrocensus is used to determine the state and amount of groundwater, its use and dependence thereof (DWAF, 2006:68). The activity of a hydrocensus involves the collection of information specific to water features, supply sources, quantity and quality (DWAF, 2004b:6). A borehole database facilitates a hydrocensus through aggregating data in an organised fashion. Citizens and communities can play a key role in a hydrocensus by assisting with the collection and dissemination of data as well as providing unconventional insights on the influence of the water resource in their communities.

1.2 Problem Statement

Groundwater management requires information and monitoring of the water resource. Borehole data collection enables this by approximating groundwater occurrence, use and quality in an area This data collection frequently requires the tedious and costly task of navigating through several locations, often in remote areas. In the case of a hydrocensus, this often requires borehole data to be noted in detail. The official course for capturing and uploading data to the NGA involves populating a DWS issued hydrocensus form (Appendix A). The completed form is then submitted to the National Groundwater Archive (NGA) where the information will be verified, processed then uploaded onto its online database.

Although there has been a shift to online databases that allow the sharing of borehole data remotely, there continues to be challenges faced by databases. Some of the challenges experienced with existing databases include lack of disclosure, incomplete and variable data as well as management and capacity issues. These are described herein, considering the prevailing databases in South Africa.

1.2.1 Lack of disclosure

Although considerable borehole data exists in the public domain there are other databases having restricted access. In this context, restrictions refer to structural or institutional mandates to render data and the resulting information inaccessible to individuals and/or entities that are not directly involved in its creation.

The International Groundwater Resource Assessment Centre (IGRAC) laments that a recurring theme in groundwater resource management is the reluctance to share groundwater data, contributing to the lack of groundwater data throughout the globe. (IGRAC, 2013:4) The South African Development Community-Groundwater Management Institute (SADC-GMI) and the DWS both identify limited data collection and sharing between groundwater users and owners (DWS, 2016:86; SADC-GMI *et al.*, 2019:2). This may be attributed to the cost of data collection and the competitive advantage the data may provide, as well as the challenge of accessing the data on public databases. The DWS (2016:83) explains that although the non-disclosure of private data gives short-term competitive advantages to organisations, it is detrimental in the long term to groundwater management and, broadly, hydrogeology as a profession. The existence of comprehensive databases held privately, by groundwater contractors and consultants (Pietersen *et al.*, 2011:27) intensifies the challenge of accessibility.

1.2.2 Incomplete and variable data

Groundwater monitoring is an ongoing challenge. The financial and human resources required in undertaking this activity regularly and accurately are often inadequate, if not absent (Braune & Yongxin, 2008:703; Knüppe, 2011:72). This aspect goes hand in hand with the challenge of governance, where powers and functions of institutions are misdirected. This is particularly problematic because the monitoring data informs the regulations and policies regarding water use and licensing. Incomplete data means that the extent of aquifers (their recharge, discharge and storage) as well as the processes under which groundwater operates are misunderstood and, consequently, incorrectly inform legislation (Knüppe, 2011:72).

Also, there exist a number of boreholes having identical coordinates on the NGA (Dennis & Dennis, 2019:114). The absence of GPS at the time of their siting meant that the positions of these boreholes were assigned using the centroids of the plots or farms they were situated on. As a result, slight deviations were recorded to avoid duplications in coordinates (Figure 1-1). Some of these boreholes may never be located and consequently, they cannot be monitored, and their records updated.

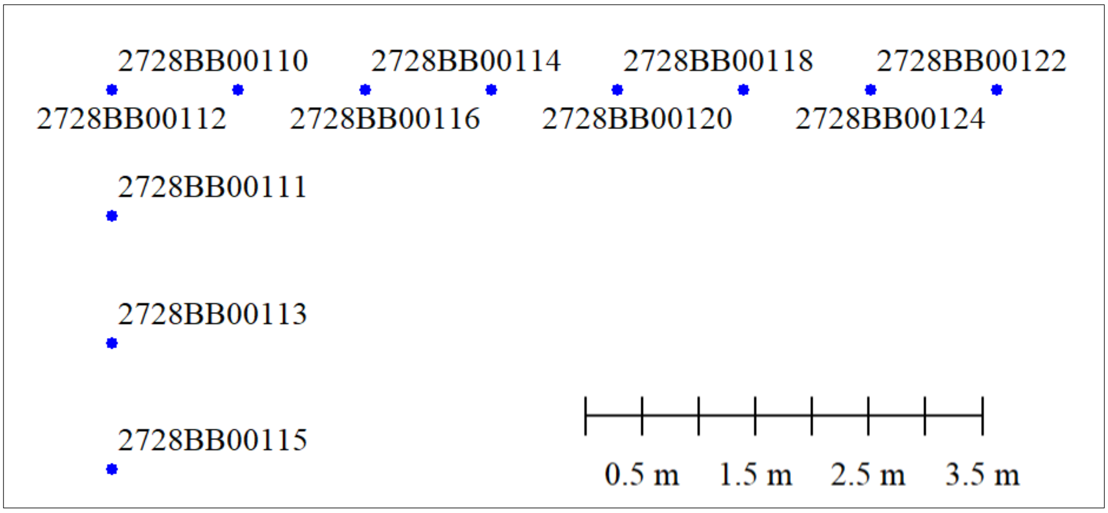


Figure 1-1: **Deviation of boreholes having duplicate coordinates (Dennis & Dennis, 2019:114)**

1.2.3 Management and capacity issues

Groundwater governance is a global concern as it is responsible for the planning and functions in addition to the assessment of the characteristics of the resource (van Wyk & Ubombo-Jaswa, 2020:25). The shortage of skilled managers, operators and technicians necessary for informed planning and decision making further perpetuates poor information and, consequently, resource management.

The restructuring of the DWS integrated the Department's groundwater specialists into other water management functions and consequently led to disbandment of the Geohydrology Directorate (DWS, 2016:4). This decision has left a significant gap in technical and management expertise for groundwater planning and development in the department. A lack of coordination in the reporting and sharing of groundwater information is a current consequence thereof. This is realised in the backlog of borehole data to be captured on the NGA, including the data from the Groundwater Resources Information Project (GRIP).

Similarly, Adams *et al.* (2015:12) describe the transfer of functions from national to local governments as a contributor to failures of groundwater schemes at municipal level. Newly established municipal administrators became responsible for the management of thousands of groundwater schemes, exposing the logistical detail and capacity shortages necessary for the operation of water service providers. As municipalities should collect groundwater data for resource planning and management, it is imperative that the capacity to do so is available.

Consequently, there needs to be a more efficient means of exchanging this information between individuals and entities. Moreover, the public, as groundwater users, should be given a platform to participate in this exchange of information without the restraints of having extensive technical knowledge or equipment concerning boreholes. Advances in smartphones, and the technology they possess, provide citizen scientists with the freedom to take part in this exchange.

Considering these challenges, this dissertation intends to develop an online borehole database to engage in citizen science. In doing so, it intends to use the collaborative efforts of citizen scientists and professionals alike to collect and share borehole information. It also intends to make the database accessible, in real time through a smartphone application, to all users that may require it.

The subsequent chapters, sections and subsections will outline the processes involved in developing this virtual database. This includes the structure of a borehole database, the selection of platform and interfaces it will be built on as well as the ranking and storage of the data it will house.

1.3 Aims and Objectives

The aim of this study is to develop an online borehole database, accessible through a mobile app for a smartphone/device, that will be used to capture borehole information in the field and give access to historic records. The study intends to engage citizen science by allowing users, the public and professionals, to actively participate in the population and management of the database.

The objectives of the study are outlined as follows:

- To determine the parameters required for capturing data in the database from the Standard Descriptors for Geosites (DWAF, 2004c).
- To construct a data model based on the Standard Geosite Descriptors (SGDs) for a borehole geosite.
- To create an online database which is populated with existing borehole information (from the Groundwater Resource Information Project (GRIP) & National Groundwater Archive (NGA)) and information from new users.
- Develop a mobile application interface for accessing and extracting data from the database for analysis purposes.
- To develop a mobile application for the Android and iOS platforms, as these are the most common mobile operating systems (OSs). The application must be map-based and provide a mini description for a selected borehole.
- To engage the public (citizens) in uploading data to, and accessing data from, the database

- To develop a grade/verification mechanism that is implemented as part of the database application.

1.4 Significance of research

This research was funded by the Water Research Commission (WRC) under the Project K5/2872 titled *Mobile App for Hydrocensus and Groundwater Monitoring*. The project engages citizen science in the collection and sharing of borehole data. Consequently, this research intends to contribute meaningfully to those outcomes.

The National Groundwater Strategy (NGS) has highlighted several challenges related to groundwater data. Among these the inaccessibility and decentralisation of private data (DWS, 2016:86) and the harmonisation of public and private databases (DWS, 2016:89). Developing an online borehole database where users can enter or receive information in real time provides an alternative to the centrality, and inefficiencies, of the established databases. It will allow users to actively participate in information sharing of borehole information, giving them greater involvement as groundwater users. Also, the accessibility to remote areas is increased as the database operates on mobile devices.

Additionally, the development of an online borehole database enhances the involvement of citizens and professionals (water pump operators, geohydrologists, engineers) by allowing them to enter their logging information on site in a cloud-based DBMS. This reduces the steps of moving information between mediums and possible losses in time or information arising. Similarly, the need to keep records on site is vastly reduced as the information is stored as it is entered to the database.

The engagement of citizens in groundwater data collection and monitoring will assist in addressing the challenge of water resource management. Increasing the number of sites observed, an improved groundwater assessment can be undertaken to support decision-making regarding sustainability of the resource.

1.5 Scope of applicability

This thesis will focus solely on the development of a database as intended for the previously defined borehole geosite. Thus, other geosite types, such as springs, sinkholes, drains and seepage ponds among others will be excluded.

The mechanism to store and access and operate on borehole related data is central feature of this thesis. The conceptualisation and construction of the database is key. The development of the front-end of the DBMS is discussed in this dissertation through the development of a mobile graphical user interface (GUI) to access the database.

CHAPTER 2 – LITERATURE REVIEW

2.1 Preamble

This chapter considers the aspects and related work involved in developing an online borehole database. This begins with the prevailing knowledge on databases, cloud hosting and mobile application development. Thereafter, considerations on the applications of citizen sciences are made with reference to volunteered geographical information, mobile GIS and hydrocensus. Lastly, boreholes are discussed with consideration of standardised borehole characteristics. These aspects will inform the database development and results in later chapters.

2.2 Database Development, Application and Management

Databases are collections of data organised for easy access and operation. This data consists of two types. The first is end user data, which is the captured data; the second is the metadata which describes the features and relationships between the data in the database (Coronel & Morris, 2018). This information can be contained, structured and accessed digitally through a DBMS. As previously described, a DBMS enables the processes of defining, constructing, manipulating querying and updating a database (Rigaux *et al.*, 2002:4). Through these processes, the users handle data without having to access its storage or understand how it is organised, a principle referred to as data abstraction.

Figure 2-1 provides a basic representation of the structure and operation of a DBMS. It shows how the three levels of abstraction (i.e., the physical, logical and external levels) are connected in a database environment. The physical level refers to the storage of data. The logical level is the presentation of data to users. The external level is focused on how a database is seen when accessed from an application.

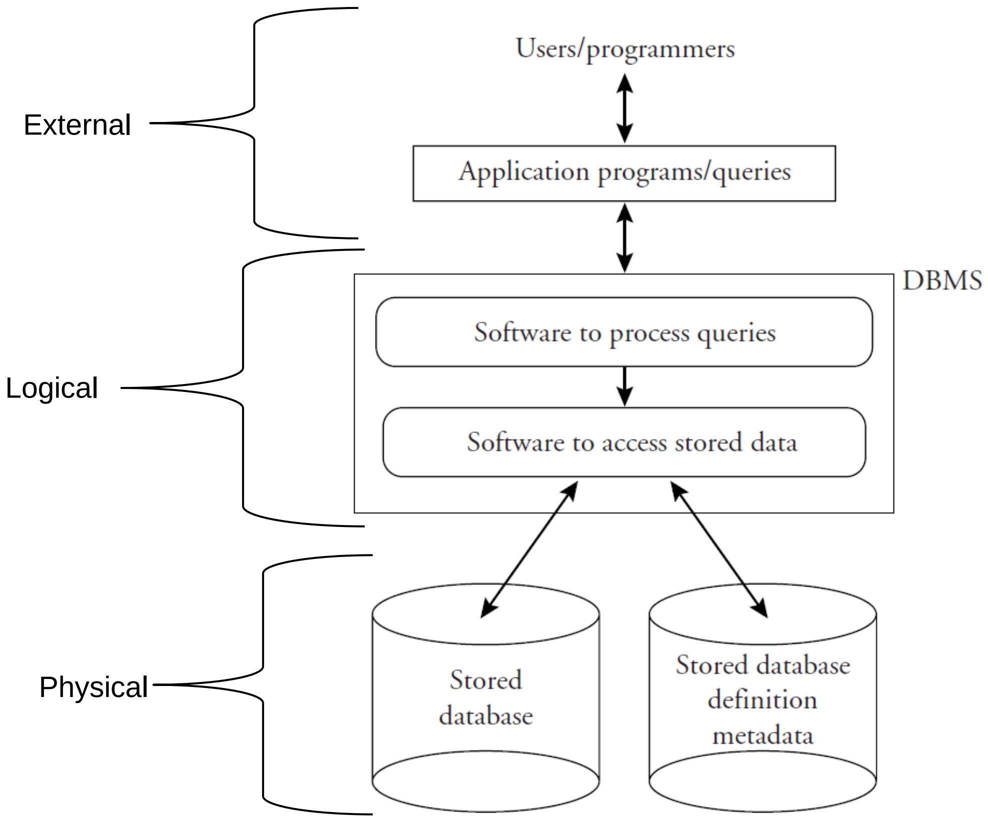


Figure 2-1: A basic DBMS environment (Rigaux *et al.*, 2002:5)

To understand how databases are developed, applied and managed, the following subsections will discuss database components and processes.

2.2.1 Data models and databases

The idea of showing how data can be framed and organised comes in the form of a data model. The data model informs how data will be structured once a database is in operation. The following subsections describe major model and database types as they have evolved in the data management discipline.

2.2.1.1 Hierarchical and network models

The earliest databases were created from network and hierarchical models (Elmasri & Navathe, 2015:23; Gupta, 2018:127; Ramakrishnan & Gehrke, 2018:6).

2.2.1.1.1 The hierarchical model

The hierarchical model was developed to handle large datasets. Replicating tiers found in nature, the model is based on the overturned tree-root configuration. Each tier, level or segment, is characterised by a parent-child relationship; the higher tier being the parent and the tier immediately below it being the child. This continues in the same way moving down the tiers. As such, the model shows relationships of one parent to many children (the relationship denoted by the “1:M” notation). The converse is impossible as many parents cannot have one child. A common parallel drawn is that of a music label having many artists, each artist having one or many albums and each album having many songs.

The simplicity of this model means that tables have clear connections, allowing data to be easily retrieved. This provides a degree of integrity in that data remains consistent because every record in a child table is connected to a record in the parent table. However, there are some drawbacks to this model. The one-to-many relationship limits the ability to associate other parent tables to a child table. The data model is not standardised, and the way it is organised must be known by the database user to navigate around it. Also, the model cannot be altered without affecting the entire database.

2.2.1.1.2 The network model

The hierarchical model’s challenges of standardising databases, relating data more intricately and effectively, were considered in the creation of the network model. Like its predecessor, the network model and database are amalgams of records connected by one-to-many relationships. The difference is that a child (referred to as a member) can have more than one parent (referred to as an owner). Thus the model established the many-to-many relationship (denoted by the “M:N” notation).

The network model was a seminal innovation. It brought about the standardisation of databases (Gupta, 2018:125; Ramakrishnan & Gehrke, 2018:6). Much of the terminology used in current data models such as schema, data manipulation language (DML) and data definition language (DDL) were derived from the network model (Coronel & Morris, 2018:41).

Although, it was an improvement to the hierarchical model, the network model presented similar challenges. The database user needs to understand its structure to improve its efficiency. In addition, when modifications are required, it proved labour intensive to restructure the model and its database.

2.2.1.2 The relational model and database

The successor of the network model, the relational model is founded on the theory of relational algebra introduced by Codd (1970:377). Codd presented the relation as the cross product of domains (all existing values of an independent variable) resulting in the group of all possible tuples. As such, a relation is regarded as a table consisting of rows (tuples or entities) and columns (attributes or entity sets) populated by values.

Tables are connected through a shared attribute. The attribute, called a key, distinguishes the identity of each row or tuple such that each tuple has its own distinct key value, and the value of the key cannot be empty (not-null). Consequently, data redundancy, i.e., the repetitive data across tables, is greatly reduced.

The benefit of this model is in the ease of use; users do not need to understand the underlying theory, and data is retrievable from one or many related tables. The structural integrity is also key in that the schema can change without affecting the ability to access the data. The use of Standard Query Language (SQL) programming also enables users to retrieve data more efficiently than other database types. In contrast, the software requirement may be costly and structures having more than one-to-one relationships are difficult to build. Complex and intricate structures also pose a challenge. Large data types such as binary large objects (BLOBs) assigned to multimedia data have also proved difficult to handle (Baxter, 2003:25).

2.2.1.2.1 The entity-relationship (ER) model.

The entity relationship model is an enhancement to the relational model. A popular model developed by Peter Chen (Coronel & Morris, 2018:45), it enables more complex and tight structures to be developed and visualised through entity relationship diagrams. It comprises of the two components. The first, the entity, the descriptor for data that is collected and stored. It is conventionally denoted with block capital letters and enclosed in a rectangle. The second is the relationship which comes in three forms: one-to-many, many-to-many and one-to-one. There are various notations to illustrate the model, but the Crow’s foot and class diagrams are the most common.

2.2.1.2.2 The Geodatabase

The geodatabase is a hybrid of the object-oriented and relational databases, an object-relational model (Twumasi, 2002:17). It organises co-ordinates, attributes and geographic features as a relational database as well as expressing and storing their relationships like an object-oriented database would. Vector and raster data can be stored and linked to the real world by a coordinate system and attributes. It can also query and operate on data using SQL without causing structural changes to or conflicts within the database.

2.2.1.3 The object-oriented models and databases

In attempting to give a closer representation of the complexities of reality, the object–orientated data model was conceived. The model focussed on the object, a depiction of real entities as groupings of data having information describing their internal and external relationships all together within the object (Coronel & Morris, 2018:47). This means that the attributes, operations, relationships and uniqueness of an object are defined by the model.

The components and operation of the model are dissimilar, in some ways, to the previous models discussed. An object is analogous to an entity and is described by an attribute. Objects having similar features, structures and functions are gathered in collections called classes. The method, i.e., the fixed instructions for each class, describes the behaviour of an object. Classes imitate the hierarchical model with the overturned tree and each one having one parent. This brings about the ability of a lower class to have the features of the classes above, called inheritance. The model is programmed in the Unified Modelling Language (UML) with illustrations of class diagrams.

The model is favourable in its ability to handle complex objects having intricate relationships. Data integrity is also maintained. However, the model lacks a unified standard to avoid individual enhancements. There is also a considerable learning curve required for the end user as the model is targeted at programmers.

2.2.2 Cloud hosting and computing

The online database to be developed will enlist components of cloud computing and hosting. This is to access and upload data remotely. As such, gaining some understanding of the intricacies involved with this technology eases the process to select suitable products for developing the database.

Cloud computing is described by Mourlin and Farinone (2019:15) as providing large sets of servers and services to large sets of users. Analogous to a water or electricity utility, it allows users access to services based on their requirements irrespective of where they are hosted or how they reach the user (Hyseni & Ibrahimi, 2017:236). Thus, its architecture differs from the traditional in that it consists of three service layers along with the cloud client (Figure 2-2). The service layers are, namely, Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a service (IaaS)

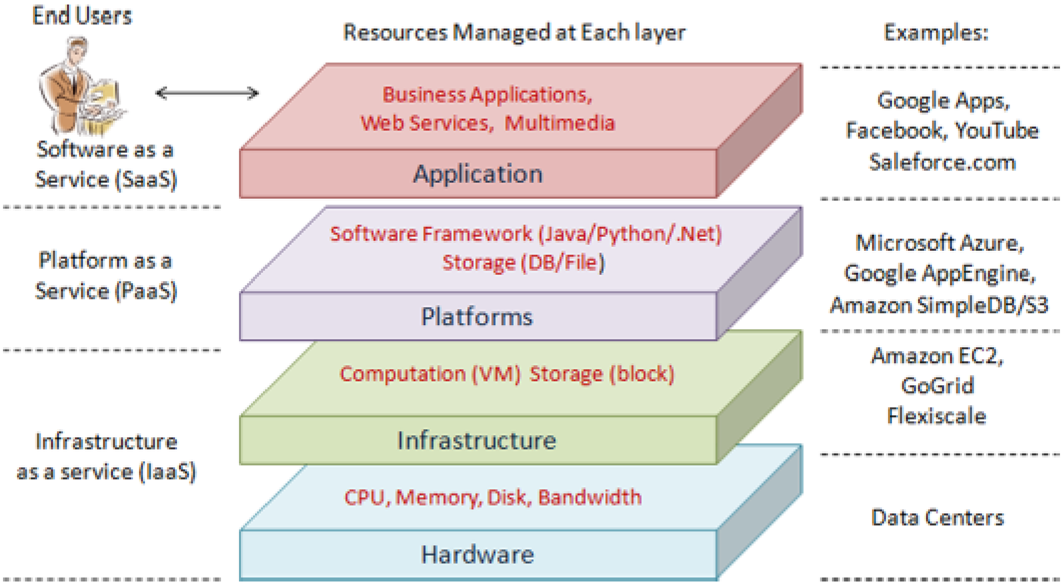


Figure 2-2: Cloud Architecture (Zhang *et al.*, 2010:9)

IaaS provides hardware and infrastructure (physical machines, storage, networks, etc.) that enable users to design, organise and run OSs and applications based on the OSs (Yang *et al.*, 2011:310; Zhang *et al.*, 2010:10). PaaS is the higher level service providing application development as well as cloud-based software, OS support and Application Programming Interfaces (APIs) for building higher level services (Yang *et al.*, 2011:310; Zhang *et al.*, 2010:10).

Zhang *et al.* (2010:7) list several compelling features of cloud computing.

- No initial investment: service providers benefit from cloud computing by renting/paying for usage according to their usage and resource requirements.
- Scalability: Service providers can harness vast data centres availed to them by infrastructure provides. This enables rapid expansion if demanded.
- Accessibility: Being web-based, cloud hosted services are accessible through an assortment of devices having an internet connection
- Reduced operating costs: Resources can be quickly diverted and/or scaled according to demand without having to account for the cost of these provisions.
- Lessened business risks and maintenance expenses: By outsourcing infrastructure use, service providers transfer their liabilities to providers more capable of handling these risks. Moreover, the cost of staff training, and hardware maintenance is diminished.

There are a variety of products on offer to harness this technology. Some of the prominent platform and infrastructure services include Amazon Web Services (AWS) and Microsoft Azure.

2.2.3 Mobile application development platforms

Applications are independent software or programs intended to carry out specific functions for their users (Sturm *et al.*, 2018:5). Mobile applications apply the computing power of smartphones and other mobile devices to undertake a variety of functions for their users. The online database to be developed will require an end-user, or front end, component that users can access and query the database from. A mobile application provides such a vehicle. As such, considerations of mobile application development platforms are considered in this section. A development platform is a framework in which the software can be created, or integrated, to operate an application (Sturm *et al.*, 2018:5). These platforms also shape the user interface (UI), the functionality (i.e., interaction with data) and the user experience of the application. Mobile development platforms exist in two forms, native development and cross-platform development.

Native development focuses on designing applications that work on specific OSs (Dennis, 2018; Luetic, 2021). Examples of this include the use of Java or Kotlin programming languages for developing applications to run on the Android mobile OS, or the use of Swift or C++ languages for building applications to run on iOS. Software Development Kits (SDKs) and Integrated Development Environments (IDEs) are instruments used in native application development. The benefit of these applications is that they perform better, are more secure and provide developers with all the features of the devices wherein the application will be used (Luetic, 2021). However, they are more time consuming to develop and maintain once in operation and have associated financial implications.

Cross-platform development allows applications to function on multiple OSs using the same source code. Applications take advantage of (APIs). APIs are supported by SDKs and are used to overcome incompatibility issues with OSs that don’t support original programming languages (Luetic, 2021). This adaptability makes cross platform development faster in application creation, broader in market reach through different platforms as well as less labour intensive than native development. The drawback however, is in the limited power and speed of application causing the users to complain about performance issues (Dennis, 2018).

The chapter on the mobile database application will use the above-mentioned comparisons to select a suitable platform for developing the mobile application

2.3 Citizen Science

As described in the introduction, citizen science is the voluntary involvement of ordinary people in science. Woolley *et al.* (2016:2) describe it as an all-encompassing term for activities where the public is involved in science. A lexicon of interchangeable and associated terms has emerged.

Community science, crowdsourcing, citizen observatories, public participation in scientific research (PPSR) and volunteer-based monitoring are synonymous with citizen science; while civic science, volunteered geographic monitoring, community-based and volunteer biological monitoring are esoteric variations of the term (Muller, 2018:32; Njue *et al.*, 2019:3).

Community based monitoring (CBM) is a method that pursues, and responds to, communal issues through the collaborative efforts of affected citizens government, academia, industry and local organizations (Conrad & Hilchey, 2011:274). Civic science engages a cultural aspect to citizen science wherein knowledge unattainable from traditional scientific methods is possessed by citizens (Potshin & Haines-Young (2006:165) cited by Muller (2018:32)). Volunteered geographic information (VGI) describes the creation and sharing of geographic information by private citizen's "user generated content" (Goodchild, 2007:212). VGI is of particular interest as it relates to the map-based component of this study and is considered in the approaches of citizen science section.

The public's interest and participation in scientific matters, gathering and sharing their findings, plays in crucial role in the scientific process. The citizen scientist is more of an independent contributor in this regard, unlike the conventional scientist who is responsible for the planning, analysis and interpretation of the results of a research study (Muller, 2018:32). However, there are variations to the extent of citizen contributions. Also, independent contributions of citizen scientists should not be twisted with exploitation.

In a retort to Cooper *et al.* (2007), Lakshminarayanan (2007) argues for a line to be drawn between using citizens to do science and partnerships with citizens in doing science. He explains that the common practice of field collectors (which tend to be laypersons) gathering data for the benefit of scientists to produce papers cannot be called "citizen science". Rather the actual participation and involvement of citizens, whose contributions should be held in equal regard to those of professional scientists, is citizen science in its truest form. Pocock *et al.* (2014:3) maintain that citizen engagement in the scientific process gives the layperson a sense of ownership in contributing to the process while bridging the gap of understanding between professionals and their intended audiences. As such, the activity of citizen science should be collaborative in its conduct and deliver outcomes to the benefit of all involved. The aspects of participation, engagement and involvement overlap in this endeavour (Figure 2-3).

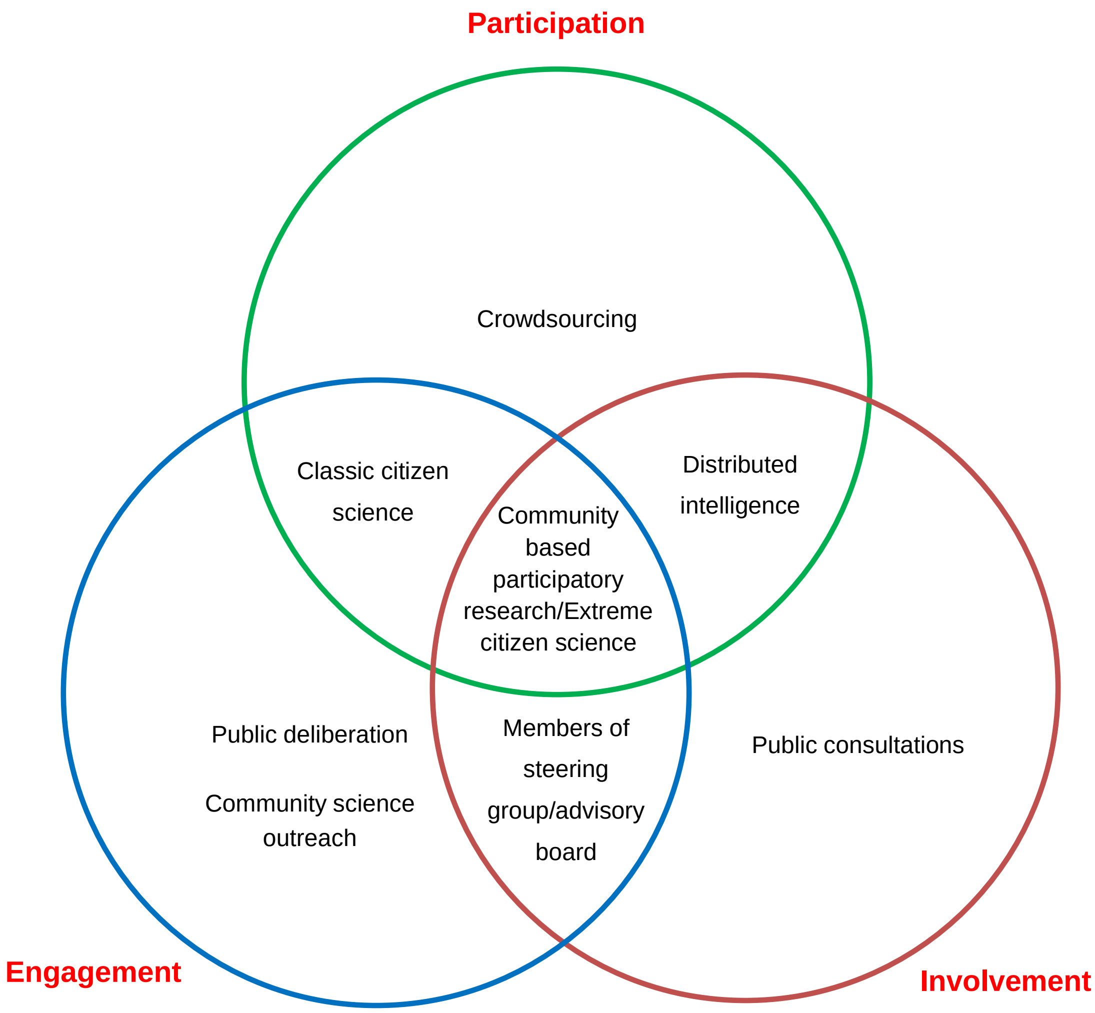
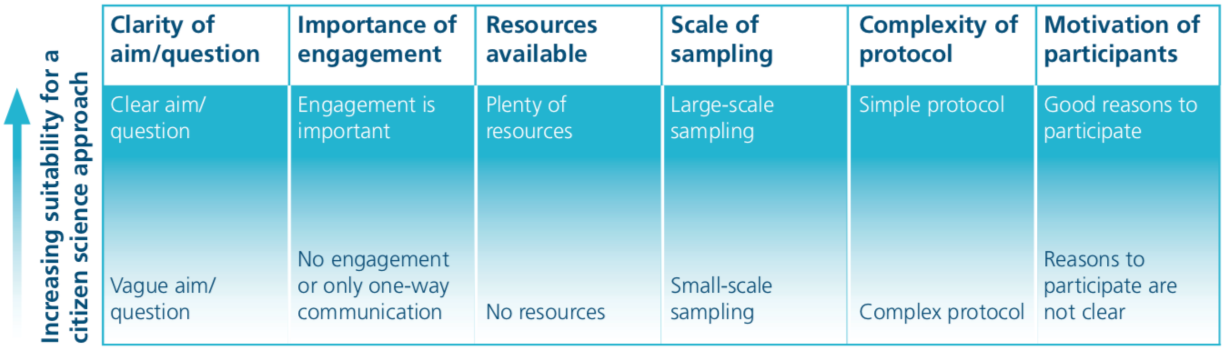


Figure 2-3: The overlap in engagement, involvement and participation in citizen science (adapted from Woolley *et al.* (2016:3)).

The *Ten Principles of Citizen Science* described by Robinson *et al.* (2018:29) highlight that a consensus is followed in good practice of citizen science. They state citizen science projects should have active participation of citizens (single or multi-stage), tangible scientific outcomes, benefit sharing between scientists and citizens, bias and limitation regulation, accessible information, acknowledgment of citizen contributions as well as legal and ethical considerations of their endeavour.

Similarly, Pocock *et al.* (2014:7) use a decision framework comprising of six aspects for evaluating the suitability of engaging in citizen science. This framework was focused on biological research but its relevance spans across the spectrum of citizen science projects. The suitability framework is presented as six aspects of increasing suitability i.e., the clarity of aim, the importance of engagement, resource availability, sampling scale, protocol complexity and participants' motivation (Figure 2-4). These criteria are further examined through typical questions asked for each suitability criterion as presented in Table 2-1.


Increasing suitability for a citizen science approach

Clarity of aim/question	Importance of engagement	Resources available	Scale of sampling	Complexity of protocol	Motivation of participants
Clear aim/ question	Engagement is important	Plenty of resources	Large-scale sampling	Simple protocol	Good reasons to participate
Vague aim/ question	No engagement or only one-way communication	No resources	Small-scale sampling	Complex protocol	Reasons to participate are not clear

Figure 2-4: **Citizen science criteria for suitability (Pocock *et al.*, 2014:7)**

Table 2-1: **Suitability criteria associated questions (Pocock *et al.*, 2014:8)**

Suitability Criteria	**Typical question associated**
Clarity of the aim	Do you have a precise and clearly- defined aim for your citizen science project?
Importance of engagement	Can you extend your engagement activity into meaningful and relevant citizen science, or should you simply undertake excellent engagement for its own sake?
Resources available	Do you have sufficient resources available to ensure you can support your volunteers for the entirety of the project?
Scale of sampling	Do you need many people (or volunteer time or commitment) to achieve your aims?
Complexity of the protocol	Is your protocol practical for volunteer involvement? Are you expecting too much from the volunteers?
Motivations of participants	Does your project resonate with potential volunteers, and are there clear and appropriate triggers for people to make records?

Success factors for citizen science are presented by (Garcia-Soto *et al.*, 2017:26). These factors (Figure 2-5) are interlinked and can be described as follows: The basis of successful citizen science is the setting of clear goals to reduce the scope of data capturing from all-encompassing to focussed and specific. This influences citizen engagement through the time spent in data collection and their interest in it. For example, the longer it takes to collect data, the quicker citizens are to lose interest in the endeavour.

In attaining an improved database, reliable data, i.e., quality and verified data, supports proper analysis, and consequently, contributes to science. The quality and verification of data can be achieved through clear lines of communication and training to the network of participants undertaking the data collection.

Figure 2-5: Citizen science success factors (Garcia-Soto *et al.*, 2017:26).

2.3.1 Approaches to Citizen Science

A variety of approaches exist within the realm of citizen science. However, they are unified by following the orthodoxy of the scientific method. Shirk *et al.* (2012:4) lay out five models for citizen science based on the degree and quality of engagement and participation. These models are, namely: contractual, contributory, collaborative, co-created and collegial.

The contractual model is one where communities seek an answer or explanation to a question of concern through the services of scientific professionals. In this context, the community's interest actively drives the scientific research in contrast to the tradition of gaps in the field or the curiosities of scientists doing so. Consequently, the participation of the citizen is limited to that of a consumer and the scientist the producer of knowledge (Shirk *et al.*, 2012:5).

In the contributory model, scientists lead research to which the public contributes data (Bonney *et al.*, 2009:11). The public is involved in data capturing and/or sample collecting. They may also analyse data as well as distribute, or act on, the results of the study. The collaborative model involves citizens in data contribution, analysis, research refinement and the dissemination of results.

A step above the collaborative model, the co-creator model is a shared undertaking where all the steps, activities of process of a research study are done by the citizen and the scientist together. The citizen scientist is actively involved in outlining study questions, collecting relevant resources, forming hypotheses, developing methodologies, collecting and analysing data, interpreting results and reaching conclusions as well as disseminating findings and discussing the implications thereof (Bonney *et al.*, 2009:11).

The collegial model is like the collaborative model but escalates the responsibilities and contributions of the citizen scientist in the independence of the research they conduct. The citizen may collaborate with the scientist in the preparation for publication of their results. Amateur astronomers, archaeologists and taxonomists are some of the types of citizen scientists who make significant scientific contributions working independently (Stebbins (1980), Hopkins and Freckleton (2002) cited by Shirk *et al.* (2012:5)). The amateur citizen scientist may not have the accreditation or credentials of a professional scientist but may make contributions that would not have been made if not for a lack of time, expertise, resources or interest given by the scientific profession.

Haklay (2013:11) describes citizen science in a similar fashion. Four levels of participation are described in this framework (Figure 2-4) with terms synonymous with those used by Shirk *et al.* (2012). The difference between the descriptions lie in the aggregation of collegial and collaborative model by Shirk *et al.* (2012) into extreme citizen science (level 4) as described by Haklay (2013:11).

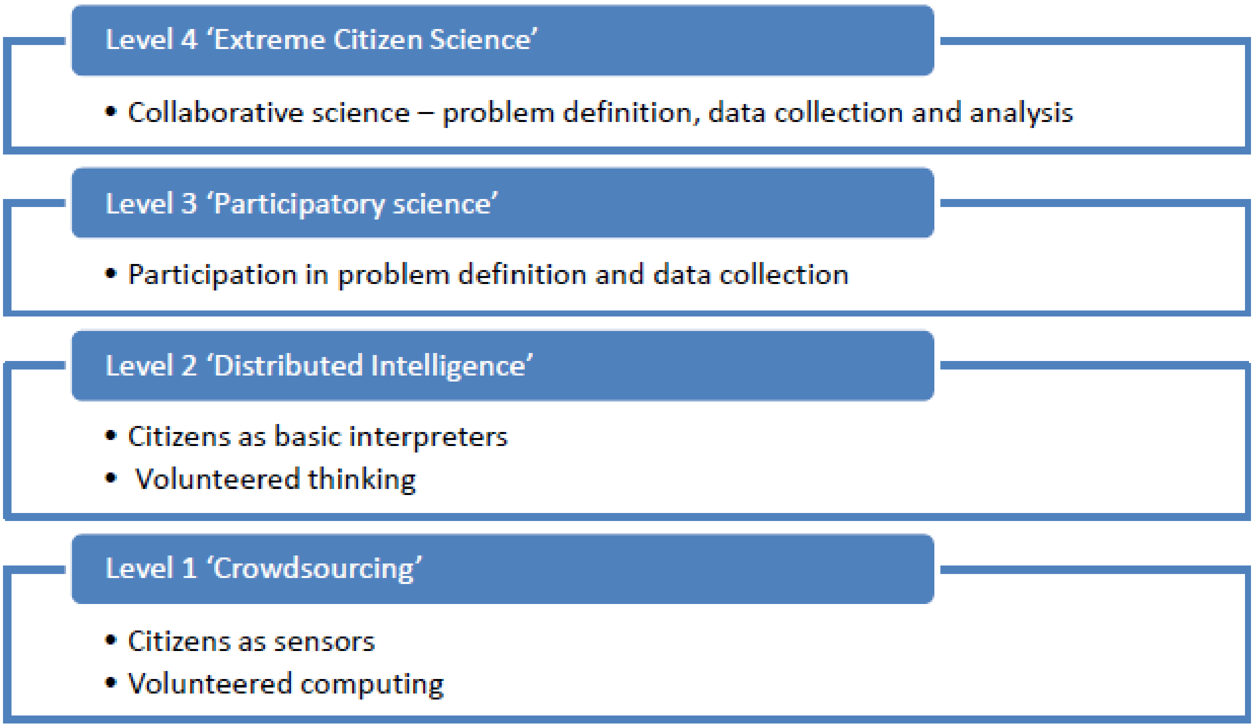


Figure 2-6: Haklay's levels of engagement and participation in citizen science (Haklay, 2013:11)

Wiggins and Crowston (2011:5) deviate from the classifications based on the participatory contributions of citizens. They consider the significance of the design and management of citizen science-based research and, in so doing, site five citizen science categories – action, investigation, conservation, education and virtual. Table 2-2 gives a brief description of each.

Table 2-2: Categories of citizen science described by Wiggins and Crowston (2011)

Type	Description
Action	- A grass root method is applied where citizen agendas are supported by the tool of scientific research. - The professional scientist is a consultant and not an initiator - The knowledge gained from this endeavour focusses on interventions for the public rather than scholarly dissemination and review.
Investigation	- Concentrated on scientific research aims and field-based data collection - They offer educational materials or means of supporting continual learning - Participation ranges from regional to international levels.

Conservation	- Uses outreach to engage citizens in natural resource management and stewardship. - Volunteer participation concentrates on data collection - These tend to be conducted at a regional level and supported by, or affiliated to, the government or government agencies.
Educational	- Education and outreach are the key objectives. - They facilitate informal and formal learning opportunities - Similar to the investigation type, learning is continuous and cumulative
Virtual	- Participation is remote and supported by information and communications technologies. - Also like the investigation type in that they focus on scientific research aims

The various approaches to citizen science that have been outlined are threaded by the involvement, engagement and participation of the public in scientific endeavour.

2.3.2 Volunteered Geographic Information (VGI)

VGI is the product of the “Web 2.0” phenomenon, a concept introduced in 2006 to define the advancement and convergence of application, technology and socialisation streams in web development (Vossen & Hagemann, 2007:65). Through VGI, many private citizens have been involved in the creation of geographic information i.e., anyone, anywhere with an internet connection can provide a description of a location and anyone can edit, review and monitor this information (Goodchild, 2007:212). This evolution has enabled unique ways to engage the public, share information and global observations.

Platform based VGI such as Google Maps and Google Earth have created sharing communities with access to spatial data that would alternatively been available to governments and professionals only (Verplanke *et al.*, 2016:310). Several factors have enabled this phenomenon to thrive. Verplanke *et al.* (2016:310) highlight the cheaper technologies and mobile data exchanges, more user-friendly interfaces and increased internet access in developing countries as some of the reasons for this. The avenues available for collecting VGI have also been enhanced through the tools provided by mobile GIS.

2.3.3 Mobile GIS

The integration of mobile devices, wireless internet access and GPS has introduced mobile GIS (ESRI, 2007:3). The technology presented by mobile GIS provides a range of benefits. These include the replacement of paper-based work environments and faster data collection. These in turn improve the accuracy and effectiveness of field operations and allow for informed decision making in real time.

In the development of an online borehole database these features are integral. Cellular networks are commonly used for mobile devices and tend to be out of range while doing remote field work. Mobile GIS enables GPS coordinates to be accessed from a device without the presence of an internet connection. The data collected on the device without a network connection can also be cached and transferred to the online database once a network connection is available.

2.3.4 Citizen science in the context of a Hydrocensus

In conducting hydrocensus studies, the role of the public, in particular affected communities, is essential. It provides several advantages to both experts and the community. The Department of Water Affairs and Forestry (DWAF) (DWAF, 2004b:7) list some of these as:

- Improved awareness of groundwater contamination
- Using water information to empower communities
- The potential to inspire locally generated corrective actions, where groundwater is, or could be, polluted
- Exposing technical experts to community facilitation in providing inputs to water related projects and activities.

In terms of collecting borehole information, active citizen participation allows for an effective and efficient borehole data collection and dissemination. As most boreholes are not registered and are privately owned, participation from the public allows for a truly reflective hydrocensus to occur.

2.4 Borehole Data

In the collection and recording of borehole data, the nationally recognised standard for describing groundwater associated data are the SDGs. While other public and private tools exist, this one will be discussed for its orthodoxy and thoroughness in describing the data required for boreholes.

2.4.1 Standard Descriptors for Geosites (SDGs)

In harmonising the exploration of groundwater sources, professionals, institutions and the government have come together to develop the SDGs, referred to as the SGDs in this dissertation from this point moving forward. The Norwegian Agency for Development Cooperation (NORAD) assisted in the development of the SGDs through the DWAF-managed Community Water and Sanitation Programme (DWAF, 2004c). The SGDs succeeded the Standard Descriptors for Boreholes, which gave a detailed account of boreholes but not of other geosites. The SDGs were a progression in that they fully comprehended the parameters of all geosites (e.g., springs, sinkholes, drains, seepage ponds, etc.) not just boreholes.

By the same token, the SGDs are informed by the SANS 10299 series: *Development, maintenance and management of groundwater resources* (WRC, 2003:5). The 9-part series draws on the key aspects of groundwater use and sustainability ranging from borehole siting, pump testing and installation to rehabilitation and decommissioning. These are reflected in the various chapters of the SGD document.

2.4.1.1 The significance of standards

The use of SGDs made it possible for the sharing of groundwater data using the same vocabulary (DWAF, 2004c:8). Consequently, misinterpretation and inconsistencies in data capturing were avoided to ease the comparisons and reciprocity of data amongst databases and users. Establishing conventions for co-ordinate systems and water levels measurements are some of the examples of confusions avoided.

The SADC-GMI *et al.* (2019:41) uphold the notion that groundwater departments are responsible for the development, adoption and implementation of national data collection guidelines. As the DWS is the national custodian groundwater data through its Geohydrology directorate (DWS, 2018), the absence of a standardised format for capturing data would lead to shortcomings in database integration.

Focussing on boreholes, as these are within this document’s scope of applicability, the following subsections will briefly elaborate on each of the borehole geosite descriptors.

2.4.1.2 Geosite Basic Information

The basic information descriptor refers to the where and how the borehole is located. This information draws heavily on the method and tools used to site the borehole. Specifically, the accuracy, reference datum, determination method and date of coordinates are elaborated upon.

Also, the purpose, current condition setting (i.e., geomorphology) as well as the confidentiality of the site are described.

2.4.1.3 Geosite Construction

Construction descriptors are mainly the drilling characteristics of the borehole. These are, namely: the method, fluid, diameter and depth, final depth, penetration rate, contractor, data quality, contractor and date connected to the drilling.

2.4.1.4 Geology

The geology of the borehole is described with lithological and stratigraphic features. A comprehensive appreciation of the groundwater environment can be gained from the accurate description of these features (DWAF, 2004c:53). The lithology component varies between hard rock and soil/unconsolidated formations and their observable and interpretive features. The stratigraphic component deals with the lithostratigraphy (i.e. the units of organisation of the Earth's crust) and chronostratigraphy (the relationship between the ages of strata) (DWAF, 2004c:59).

2.4.1.5 Geohydrology

Running parallel to the geology of the borehole, the geohydrological features allow for the underlying aquifer to be conceptualised (DWAF, 2004c:60). The strike depth, static water level, water quality and yield are the main characteristics considered. These inform the design and development of high water-yielding boreholes.

2.4.1.6 Geosite Design, Development and Completion

To ensure the highest water yield, long operating life, structural soundness and limited sediment, borehole design specifications are documented. The types, material and dimensions of borehole casings, screens, filter and gravel packs are characterised.

Development and completion considers the optimisation of borehole yield, with emphasis on the method and chemicals used as well as the duration of the borehole development (DWAF, 2004c:73; SADC-WSCU, 2001:5-1).

2.4.1.7 Geosite and Aquifer testing

Pump testing measures the hydraulic and performance characteristics of a borehole and its aquifer with respect to flow patterns, sustainable yield and supply potential. The characteristics of interest in during pump tests are the test start dates and times, pumping rates, borehole and pump inlet depth, borehole diameter, specific yield and transmissivity, static water level, fractures and strike depths, drawdown and recovery as well as the method of data analysis. Notably, these should follow the SANS 10299 standard (DWAF, 2004c:76).

2.4.1.8 In-situ Geophysical Logging

Like the geology and geohydrology descriptors, geophysical logging gives an appreciation of the groundwater environment. It does so by specifying the rock layers the borehole traverses, typically from the drilling exercise. The types of logging conducted, notable observations, measurements connected to depths, and logging personnel information are the main data captured from the activity.

2.4.1.9 Operational Management and Installed Equipment

Sustainable use and monitoring of boreholes is realised from the analysis and recommendations of data recorded during borehole and aquifer testing. Operational management and specifications for pumping equipment considers abstraction and pump information, monitoring recommendations, limits to water level drawdown, ideal range of water quality, and the size borehole protection zone. This information needs to be provided to the design engineer and/or pump supplier for implementation (DWAF, 2004c:85).

2.4.1.10 Groundwater Monitoring

Monitoring forms the basis of sustainability; it allows the protection, effectiveness and maintenance of resources to be gauged. Borehole and groundwater monitoring has many parameters; the (DWAF, 2004c:86) distinguishes them according to:

- data quality and quantity.
- time series flow and pumping rates, static or dynamic water levels, and abstractions.
- physical, chemical and specialised measurements.

These monitoring variables are carried out through networks at the national, catchment and local level as foreseen by van Wyk (cited by DWAF, 2004c:86). This would be aided by well-defined and communicated purposes to support the monitoring.

2.5 Chapter Summary

Three key areas were covered in this chapter, i.e., databases, citizen science and boreholes. From the discussion on databases the development and management thereof was understood from the various data models and database types available. The database environment can be delivered virtually through cloud computing and hosting services.

Thereafter, citizen science featured with the assortment of approaches developed depending on the needs of the study undertaken. In the information age, VGI has ascended into the practical realm through the smartphone, allowing citizens greater capabilities to share data and contribute to research. Contextualising this to the groundwater realm, citizen science improves hydrocensus activities by engaging and empowering communities to interact with experts, to learn about ground water related issues and to take preventive and corrective measures to manage the resource.

Lastly, a discursive look was taken on the components required to collect borehole data. The SGDs, being the harmonising standard for collecting borehole data in the public domain, were elaborated upon. The parameters described in the SGDs give a thorough account of the data required from a borehole.

In the next chapter, the groundwater databases available in South Africa are investigated. The challenges facing these databases are also identified and elaborated upon.

CHAPTER 3 – GEOHYDROLOGICAL DATABASES IN SOUTH AFRICA

3.1 Preamble

The following chapter provides an overview on the existing borehole databases in South Africa. It begins with an international and transboundary perspective and narrows down to national and regional databases.

3.2 Existing Databases

Globally, there are a variety of database projects underway. The Global Groundwater Information System (GGIS), for example, is an international database system for groundwater information. It is intended to aid in collecting, analysing and sharing information among various stakeholders (water experts, decision makers and the public) (Stefan & Ansems, 2018:155). It runs several modules based around major groundwater themes associated with transboundaries, national contexts, aquifer recharge, small islands, monitoring and projects.

Nationally, the DWS (through the National Groundwater Information Systems (NGIS)) has established a group of projects aimed at addressing the groundwater information needs of the sector (Table 3-1). This is a legal mandate enacted through the NWA (Act 36 of 1998) which necessitates the mechanisms of collecting and monitoring information in the sector. The major projects are namely the NGA, CHART and the Geohydrological Reports System. Associated projects include the Hydstra, the Water Management System (WMS) and the Water Authorisation and Registration Management System (WARMS). At regional level the GRIP has been introduced in the provinces of Limpopo, Eastern Cape and Kwa-Zulu Natal. These projects are amalgamated (along with databases on rainfall, runoff, dams, droughts and settlements) into the National Integrated Water Management Information System (NIWIS). The databases analysed and most relevant to this dissertation are the NGA and the GRIP.

Table 3-1: Existing geohydrological databases in South Africa

Database	Administered by	Data types
NGA	DWS	Geosites, predominantly boreholes
Geohydrological Reports System	DWS	Technical groundwater reports

WARMS	DWS	Geosites, predominantly boreholes
WMS	DWS	Point-source water quality
GRIP	Provincial DWS or water management associations (Witthüser *et al.*, 2009:2-2) and consultants (Weidemann, 2020:47)	Geosites, predominantly boreholes
Privately held databases	Consultants, municipalities, drilling and testing contractors (Witthüser *et al.*, 2009:2-2)	Various data types, sources, and formats

The next subsections consider the international, national and regional databases.

3.2.1 Ramotswa Information Management System (RIMS)

A localised product of the GGIS is the Ramotswa Information Management System (RIMS). The governments and institutions of South Africa and Botswana contributed to the development of this database as Ramotswa is a transboundary aquifer shared by both countries. The web-based geodatabase consists of map overlays (using the open-source platform ©OpenStreetMap) accompanied by pictures, tables and documents from the aquifer. Data about the aquifers boreholes, geography, hydrogeology, geophysics, livelihoods, climate, water and sanitation are available on the database.

RIMS operates using two workspaces; one for the public where data can be accessed by anyone with an internet connection, and another which is password protected and where authorized users can manage and upload data. Authorized users are the owners, i.e. the South African DWS, the DWA in Botswana as well as contributors and partners of the RIMS project (IGRAC, 2018:3). This observation suggests that the database contributions are one-sided as governments and institutions are the custodians. As one of the projects objectives is to capacitate and increase awareness regarding the aquifer’s vulnerability, buy-in from the public may be challenging if they are unable to contribute meaningfully to the database.

As with many groundwater databases, data gaps are an issue. A challenge faced is the effect of the shortage of long-term hydrogeological modelling and database completeness (IWMI, 2019:10). The incorporation of early monitoring systems to the database are suggested to address the challenge. This would aid in improving the quantity and quality of data available.

3.2.2 National Groundwater Archive (NGA)

Currently, the National Groundwater Archive (NGA) is the most comprehensive borehole database in spanning the country. This centralised database takes the form of an ArcGIS geodatabase and stores confirmed spatial geohydrological data (IGRAC (2013:11)). Its development arose from the legislative requirement to establish national monitoring and information systems as defined in the NWA (Act 36 of 1998), Chapter 14 Part 2. Section 139 (c) gives the specific mandate of establishing a groundwater information system. Its predecessor, the National Groundwater Database (NGDB) was the national repository for groundwater related data from the late 1980s up until the early 2000s (Botha, 2005; Hughes, 2005:17).

The NGA database consists of 23 tables, referred to as business modules, grouped into 6 classes, referred to as business values. Figure 3-1 depicts these components along with the parts for user information and security (blocked in a purple outline). The borehole classes/business values and tables/modules echo the SGDs the database is based on (DWA, 2013:3). The database is implemented using Informix (Hughes, 2005:13), a relational DBMS offered within the suite of IBM products.

The database is web-based and access to its front-end interface is obtained by registering with credentials and creating a password. One can register as a user, for accessing information only, or data owner that provides data to the database. For data owners there is prerequisite training involved to have data uploading privileges. These processes are outlined in Figure 3-2.

Data can be captured, altered, observed and downloaded from the database. It takes a considerable amount of time to upload and request information. Queries are made through a geo-request and, depending on the nature of the query, data may be retrieved immediately or over hours or days. Chemistry data, for example, requires the geo-request form to be populated and submitted and for the administrator to search for the data and return it to you. Moreover, being the largest groundwater database in the country, updating groundwater information on a regular basis is difficult. Consequently, retrieved data is often outdated and lacking features such as pump test and water level data. These issues contribute to the public perception that NGA database is inferior compared to the GRIP (Dennis & Dennis, 2019:107).

The front-end lacks GIS capabilities, such as mapping borehole coordinates, distance measurements or selecting geosites over an area. A snapshot of the borehole geosite data available on the NGA is illustrated from Figure 3-3 to Figure 3-9. The snapshots reveal the following data limitations (WRC (2019) cited by (Dennis & Dennis, 2019:113)):

- 46% of boreholes have one or more water level
- 14% of boreholes have one or more electrical conductivity (EC) measurements
- 6% of boreholes have one or more chemistry datasets
- 28% of boreholes have yield values
- 38% of boreholes have water strike data
- 50% of boreholes have borehole logs

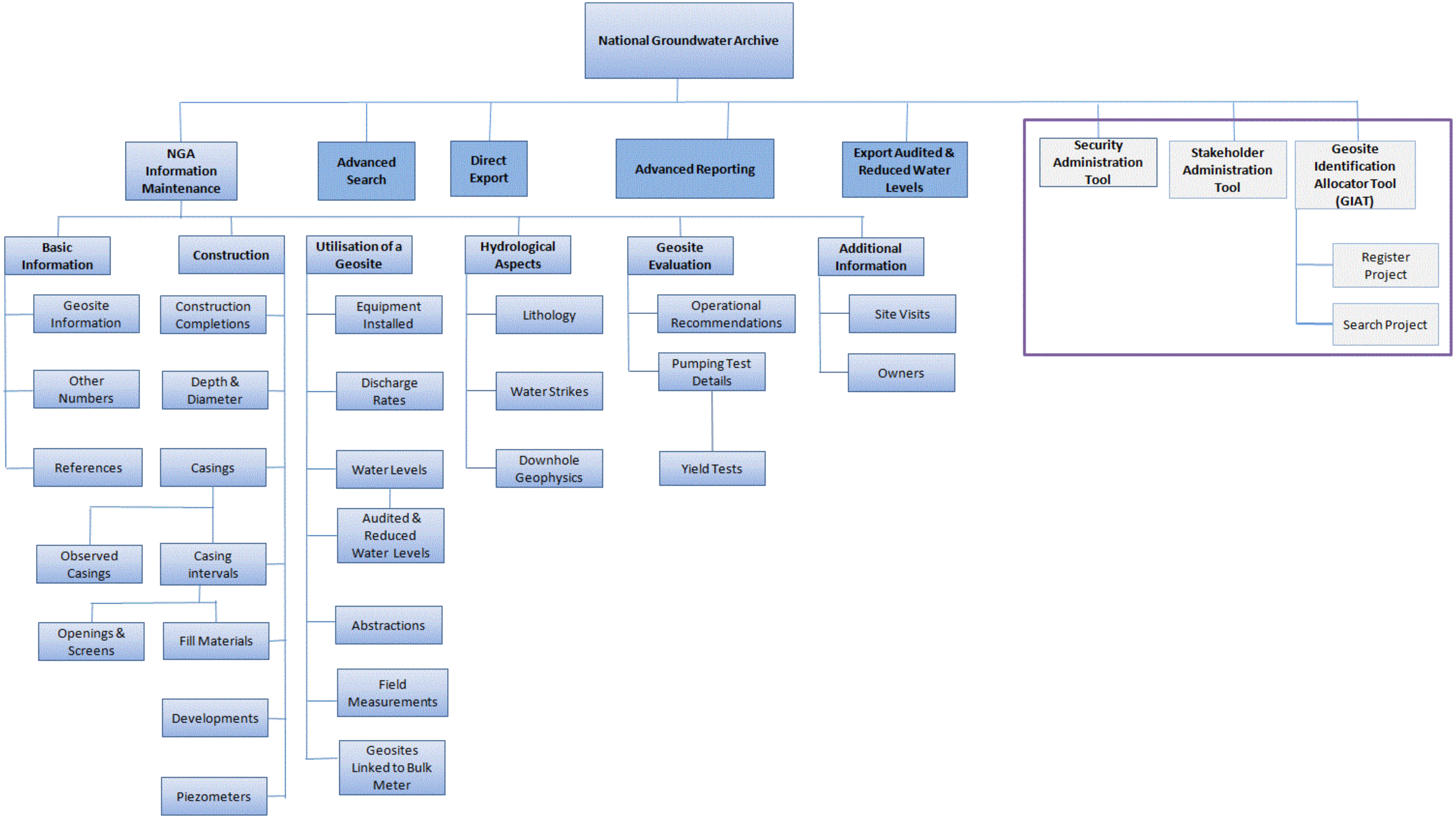


Figure 3-1: Components of the NGA (DWS, 2008a).

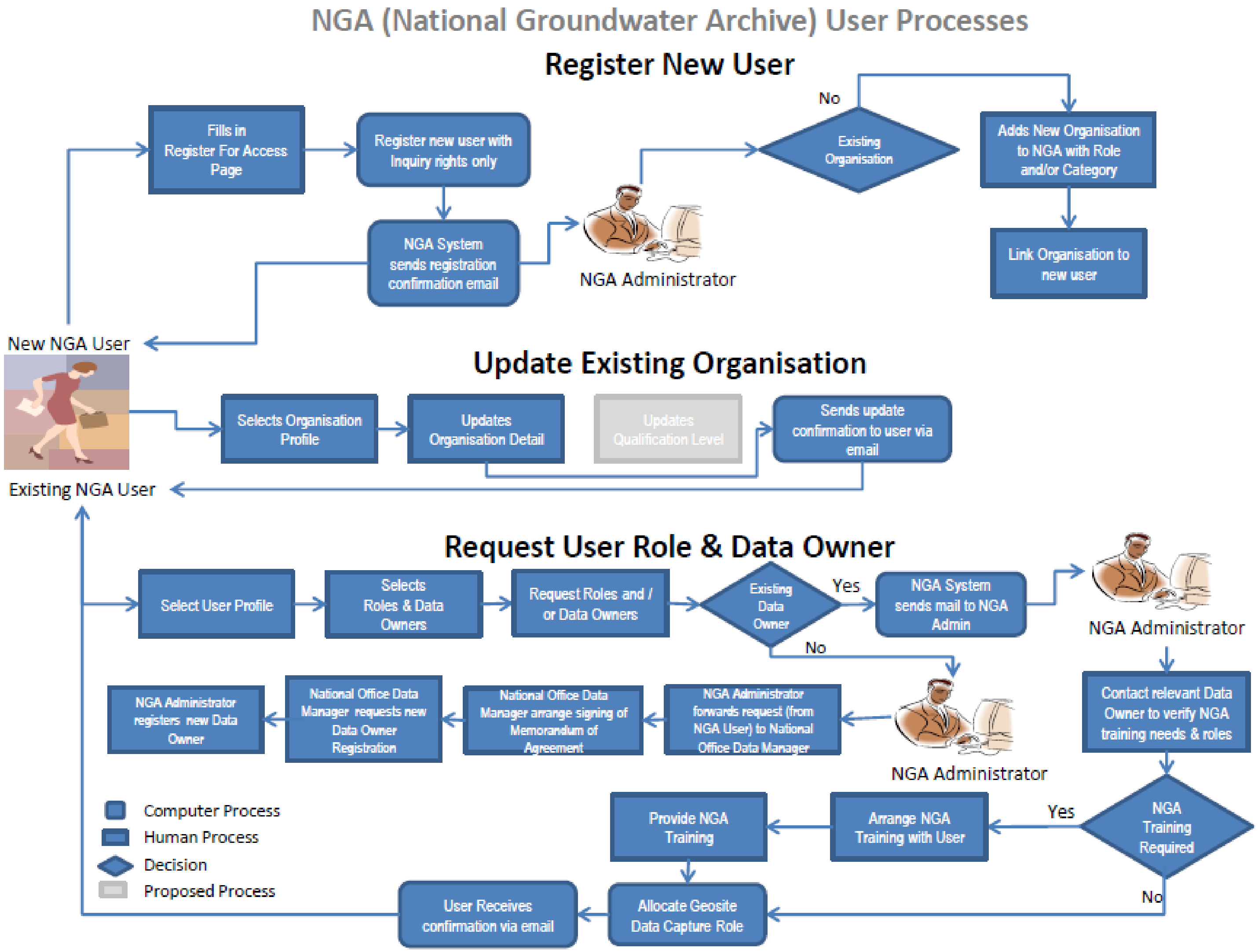


Figure 3-2: **NGA user processes and verification (DWS, 2008b)**

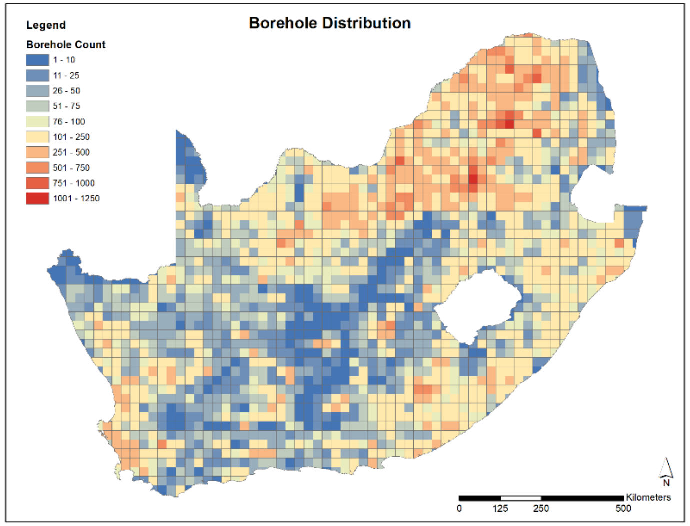


Figure 3-3: NGA distribution of boreholes

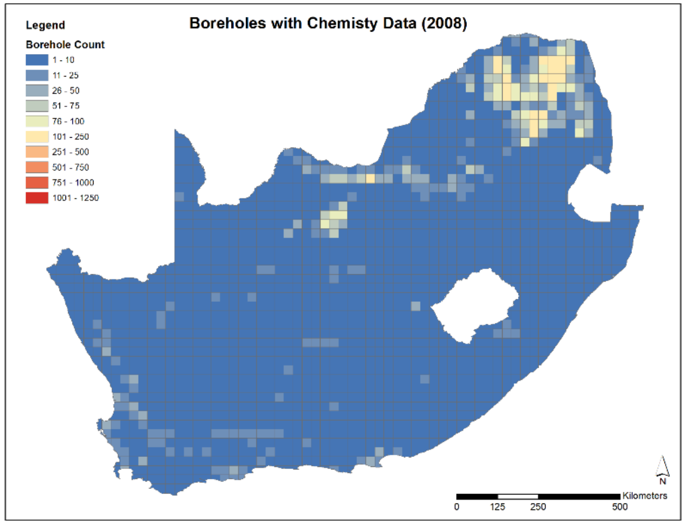


Figure 3-4: NGA distribution of boreholes having chemistry data

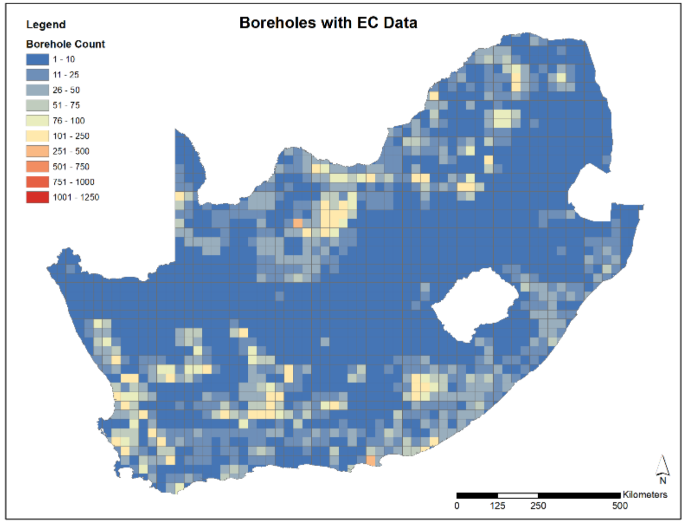


Figure 3-5: NGA distribution of boreholes having EC data

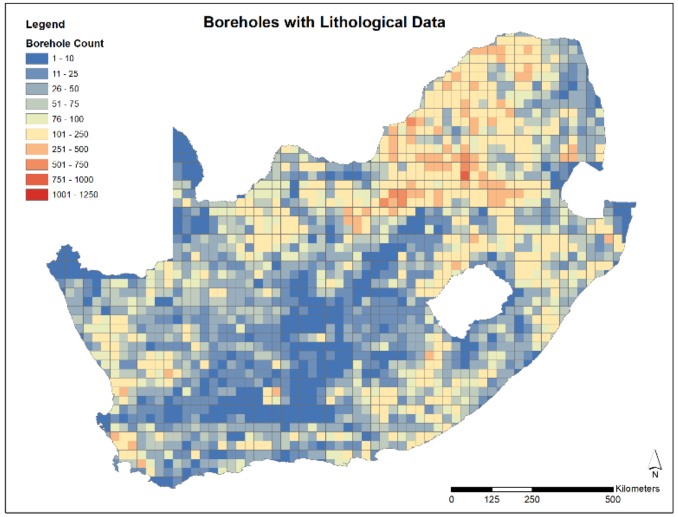


Figure 3-6: NGA distribution of boreholes having lithology data

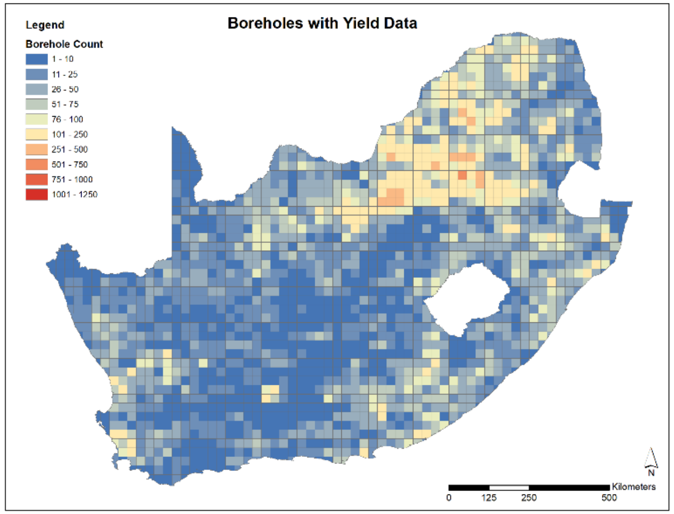


Figure 3-7: NGA distribution of boreholes having yield data

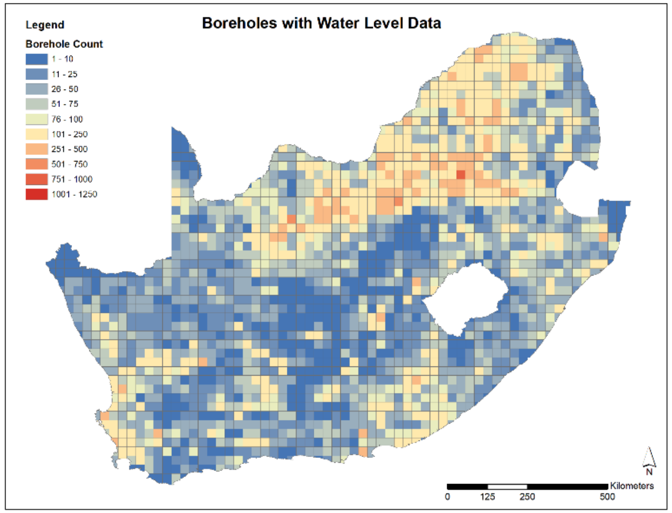


Figure 3-8: NGA distribution of boreholes having water level data

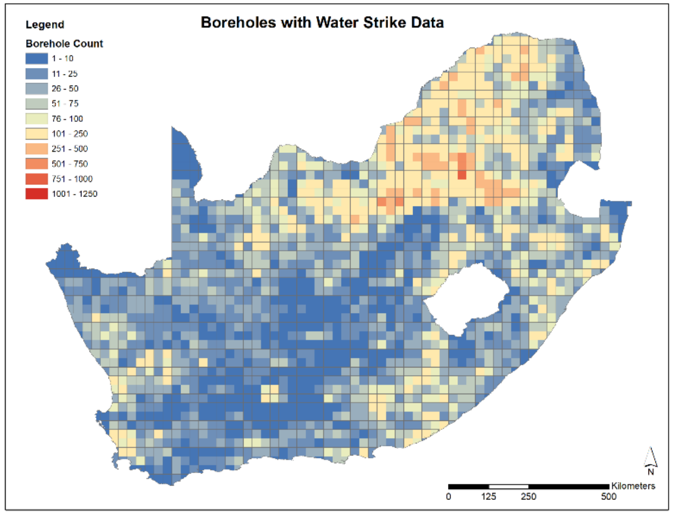


Figure 3-9: NGA distribution of boreholes having water strike data

3.2.3 Groundwater Resource Information Project (GRIP)

Since its inception in 2002, the GRIP has given access to unpublished/private and new groundwater information in priority areas through reliable borehole monitoring (DWS, 2016:82). Consequently, the knowledge gained from it has enabled improved integrated water resource management as well as greater success in borehole drilling (DWS, 2016:82). The GRIP was introduced in the provinces of Limpopo, Eastern Cape and extended to Kwa-Zulu Natal. Unfortunately, funding and capacity shortages have meant the project has only been fully realised in Limpopo Province.

With more than 2,500 villages visited and in excess of 31,000 geosites verified, the GRIP implementation in Limpopo Province has produced the most comprehensive dataset on rural groundwater resources in the country (DWS, 2016:82). GRIP Limpopo is fully online and provides functionality similar to the NGA. The ultimate intent of the GRIP was to regularly supply verified data to the NGA (Weidemann, 2020:47). This was realised through term contracts set-up by the DWS with appointed consultants. The intent thereof was to carry out the regular updates, evaluate existing and new data, drill and test yields of boreholes in priority areas as well as producing a groundwater planning report for the province (Witthüser *et al.*, 2009:2-1).

In order to ensure the accuracy of the groundwater information it offers to the public, the GRIP runs an extensive verification system involving several entities, i.e., the DWS, consultants, engineers and web developers. Figure 3-10 illustrates the roles of these stakeholders and how they circulate and verify the data. Figure 3-11 to Figure 3-16 illustrate the distribution of the boreholes on the GRIP database with respective borehole features, i.e., water levels, chemistry, yield, etc. The borehole statistics from the database (WRC (2019) cited by (Dennis & Dennis, 2019:113)) and illustrated in the figures indicate that of the 26 912 boreholes captured:

- 10 333 have water level data
- 7 884 have EC data
- 7 050 have chemistry data
- 10 002 have borehole yield data
- 2 386 have water strike data
- 3 403 have borehole logs

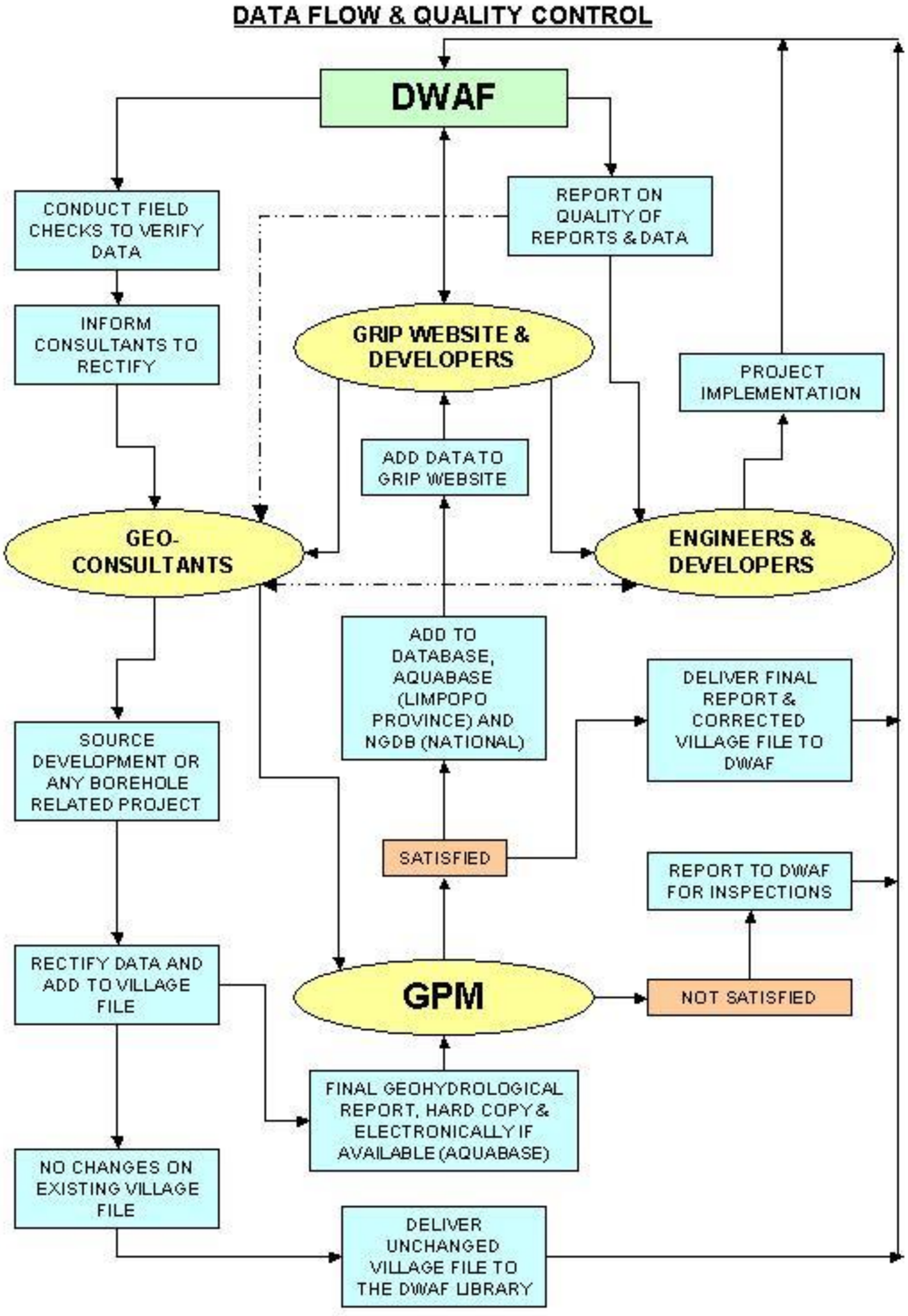


Figure 3-10: **GRIP Data flow and Quality Control (GRIP, 2013)**

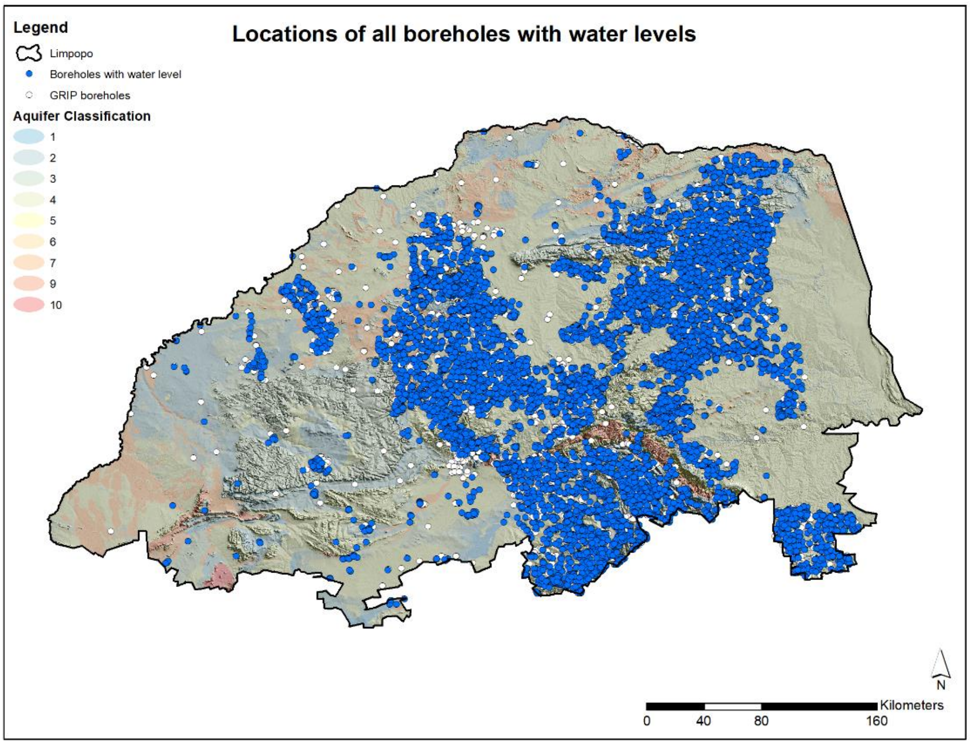


Figure 3-11: GRIP distribution of boreholes having water level data (Weidemann, 2020:49)

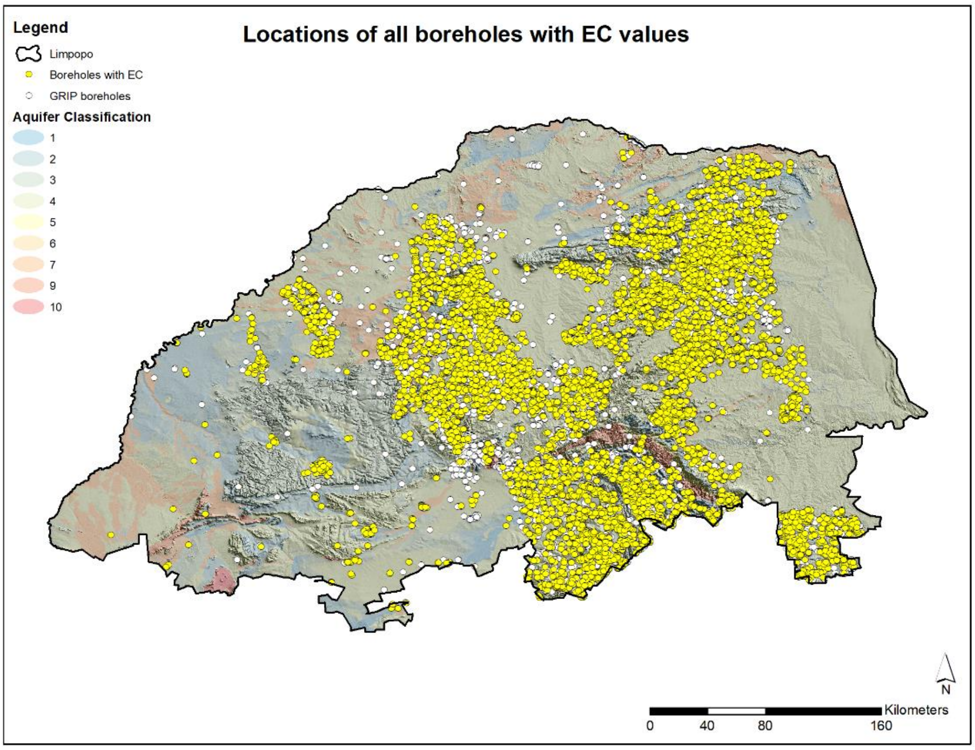


Figure 3-12: GRIP distribution of boreholes having EC data (Weidemann, 2020:49)

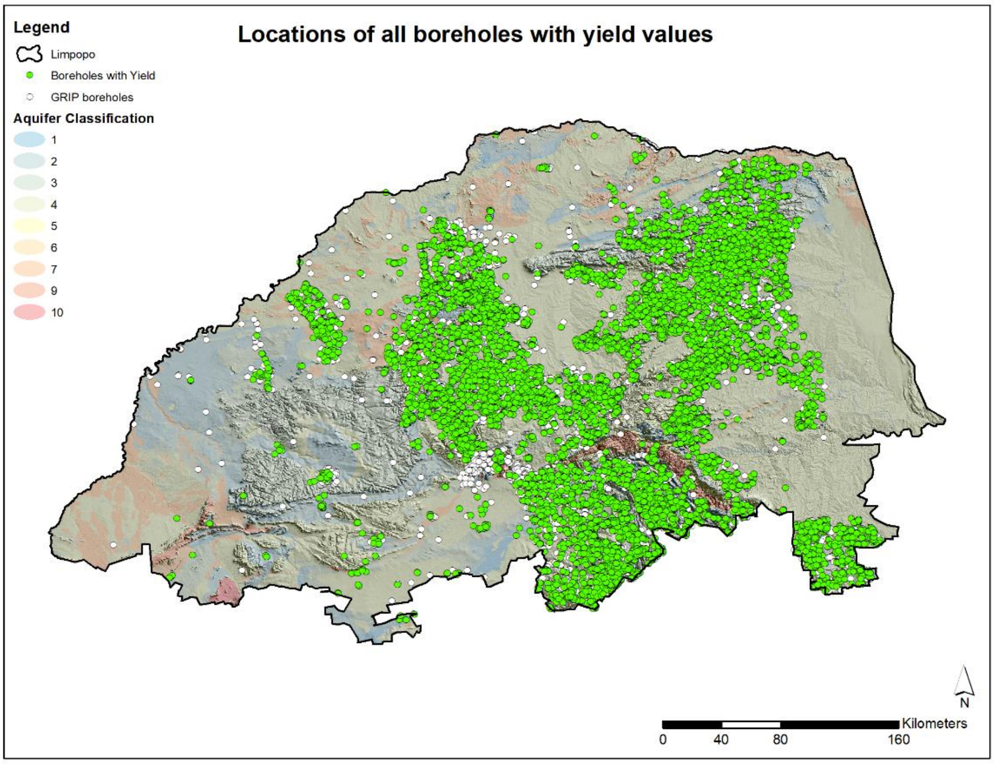


Figure 3-13: GRIP distribution of boreholes having yield data (Weidemann, 2020:50)

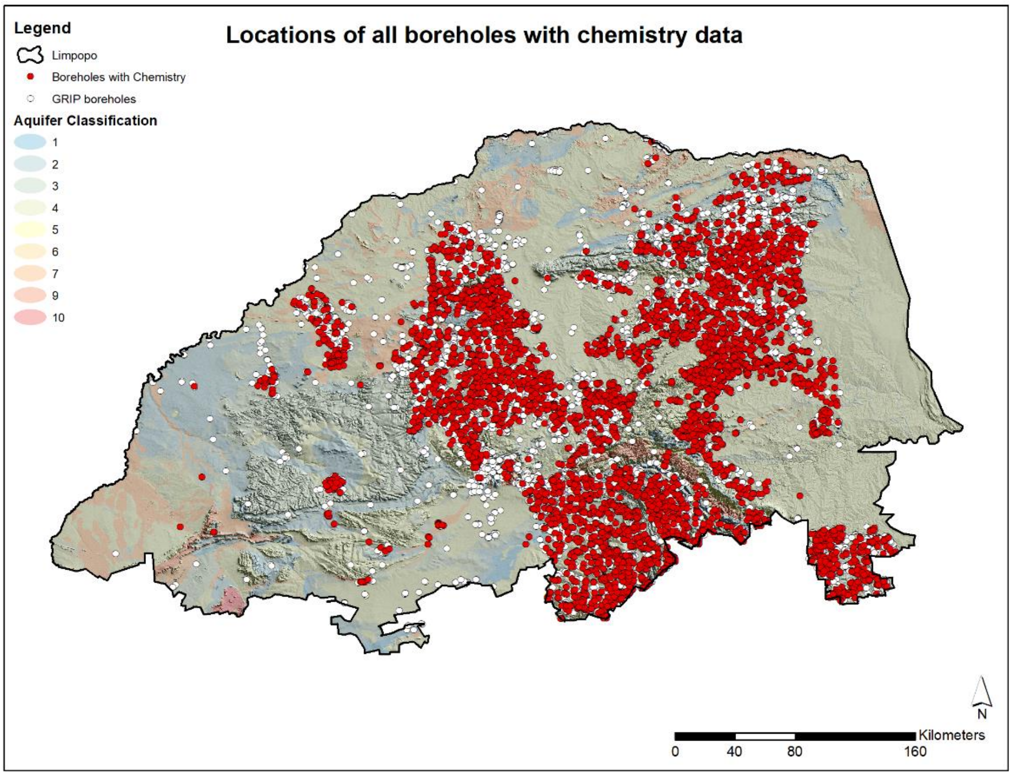


Figure 3-14: GRIP distribution of boreholes having chemistry data (Weidemann, 2020:50)

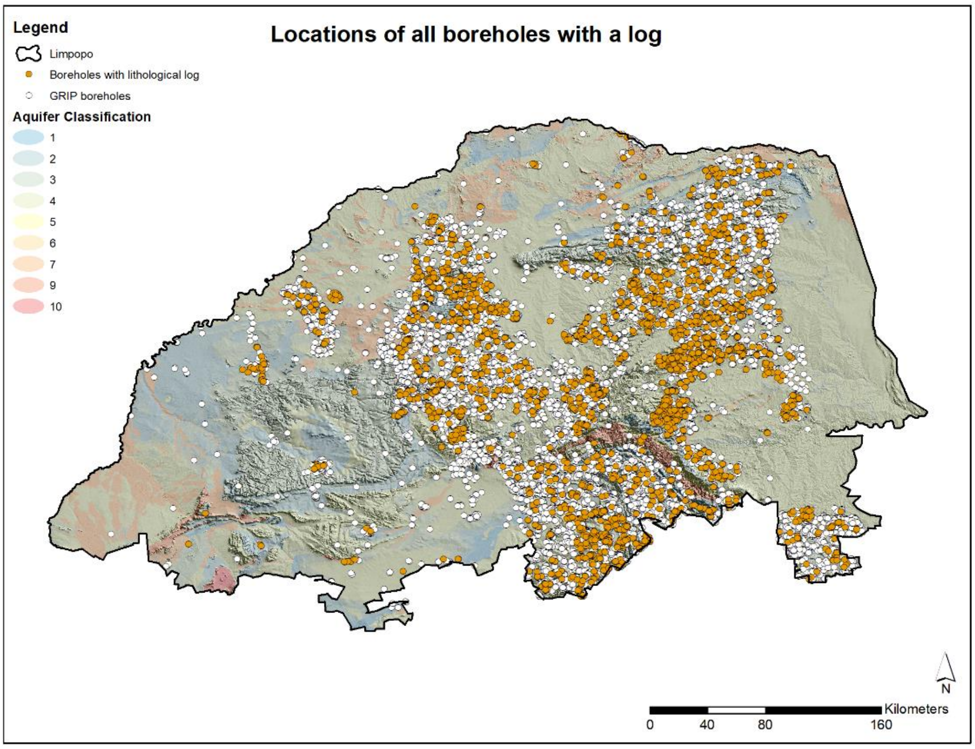


Figure 3-15: GRIP distribution of boreholes having borehole logs (Weidemann, 2020:51)

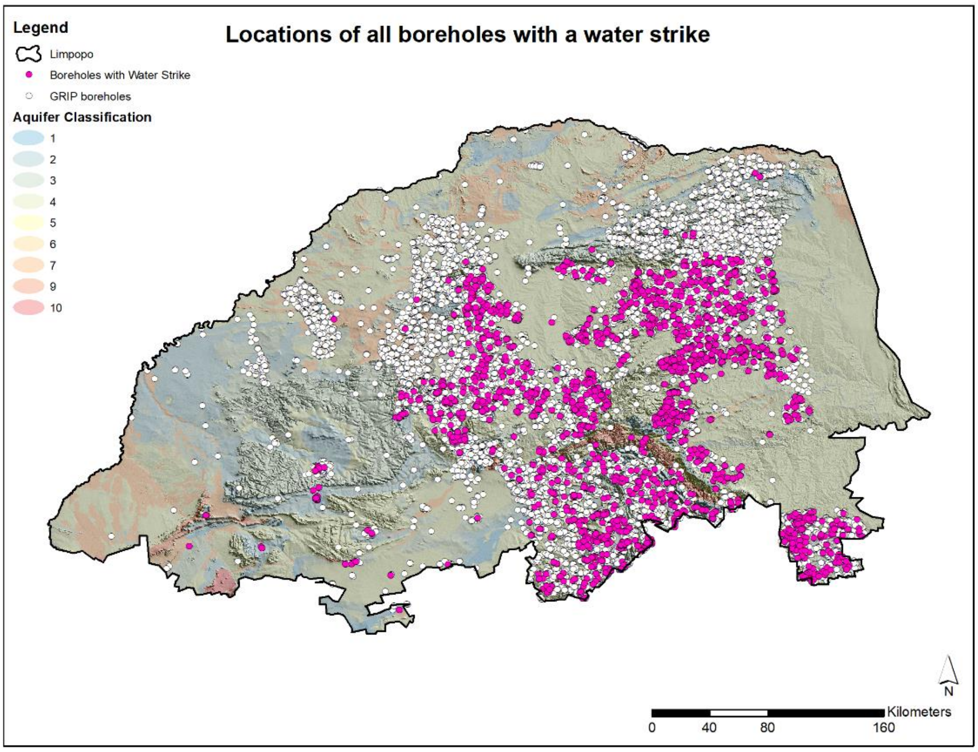


Figure 3-16: GRIP distribution of boreholes having water strike data (Weidemann, 2020:51)

The GRIP database has been applied to several groundwater planning and management activities. Water Management Areas (WMAs), such as the Limpopo, Luvubu\Letaba and Olifants WMAs have used the GRIP's data in their Internal Strategic Perspectives (ISPs) (Botha, 2005:140). ISPs provide a structure from which the DWS manages water resources in WMAs until the management can be given to the recognised Catchment Management Agency (CMA). The GRIP data was employed by the DWS in water situation assessments and Water Service Development Plans (WSDPs) of municipalities, such as Mopani District Municipality (Botha, 2005:115).

Although, the database has been considered to have a high level of reliability (Weidemann, 2020:47), the non-renewal of term contracts means data will no longer be regularly updated. This raises the concern that records on this database and, consequently, the NGA will become outdated for future groundwater planning and management in the Limpopo region.

3.3 Chapter summary

This chapter discussed the major borehole databases in South Africa. RIMS, a transboundary database managed by the nations of South Africa and Botswana, is open for public viewing online but its data is institutionally controlled. The NGA is similar in having an online platform, but the public are users and contributors to the database. The GRIP feeds the NGA with more thorough regional data and is only fully operational in Limpopo.

CHAPTER 4 – DATABASE DEVELOPMENT

4.1 Preamble

This chapter considers two components in developing the database. The first is the investigation of the characteristics which the database tables are structured on. The second considers how the relationships between these characteristics are modelled by introducing and discussing the entity-relationship (E-R) model.

4.2 Database development

Heywood *et al.* (2011:117) detail the process of database development, i.e., conceptualisation, design and implementation. Determining the general characteristics (e.g., size, type, quality, etc.) of data is the initial step. User requirements for inputting and accessing data are also determined. Thereafter, an idea of how the characteristics relate to the data is introduced. This produces a practical plan for creating the database. This plan is realised when the database is created and populated with data and allowed to operate. Of course, monitoring and maintenance of the database should also be carried out.

The procedure provides coherent navigation to develop the database and will be followed through this chapter as well as the next chapter with the mobile application.

4.2.1 Data Investigation

Requirements of the database, structure, size and operation can be identified from the data investigation. Boreholes are geosites and their data is collected following the SGDs. As discussed in the previous chapter, SGDs define the major descriptors and their aspects. The nature of the data entries for each aspect or sub-characteristic can be classified into fixed entries, i.e., they do not change over time, or non-fixed entries that are time dependent.

Similarly, the values of data entries can be arranged into data types, such as text and numeric or variable. Determining data types allows data users to know what kinds of operations that can be performed on the data to gain information and knowledge. The data entries for each SGD characteristic can be grouped into five distinct types as follows:

List	A pre-determined selection menu from which an entry can be chosen from.
Float	A reduced term for floating point, a numeric value signified by its decimal form.

Time	Refers to the data format for displaying dates, durations, moments and/or a combination of these.
Character	Refers to the data formats represented by strings of American Standard Code for Information Interchange (ASCII) characters including upper- and lower-case alphabetic letters, numbers, punctuations and control characters.
Boolean	A data type representing two possible values typically denoted by the “true” or “false”, and “yes” or “no” options.

The data types can be further distinguished into static and non-static data types. The static data type is one whose entries are not subject to frequent change or editing i.e., fixed entries. Geosite position parameters as reference datum have static data because there are only a set variety of reference data that can be chosen from. In contrast, chemistry parameters, such as pH or EC, will have non-static data inputs as the data is time dependent.

In view of these factors, the following tables (Table 4-1 to Table 4-8) show how the SGDs are characterised and sub-characterised as well as determining the type of data and whether its values are fixed. A consideration was made to combine similar characteristics of the SGDs. This was done to reduce the size and connections in the subsequent database. This resulted in the characteristics of the basic information descriptor being grouped into on category called basic data. A similar procedure followed with the other descriptors to produce the following simplified table categories.

Table 4-1: Characteristics and data types for the basic information descriptor

Characteristic	Parameter	Fixed entry	Data Type
Geosite Type	None	Yes	List
	Latitude, longitude	Yes	Float
	Elevation	Yes	Float
	Geosite position determination methods	Yes	List
	Accuracy of co-ordinates	Yes	List
Geosite Position	Reference datum	Yes	List
	Date Co-ordinates Determined	Yes	Time
Geosite Setting	Land cover classification	Yes	List
	Geomorphological classification	Yes	List
	Geosite selector	Yes	List

Characteristic	Parameter	Fixed entry	Data Type
Geosite Selector, Method of Selection and Target Feature	Geosite selection methods	Yes	List
	Geological target features	Yes	List
Purpose of Geosite	None	Yes	List
Geosite status	In-use (functional)	No	Boolean
	Standby (production)	Yes	Boolean
	Inaccessible	Yes	Boolean
	Abandoned	Yes	Boolean
	Destroyed	Yes	Boolean
	Geosite Sketch Map	Yes	Image
Confidentiality	None	Yes	Boolean

Table 4-2: Characteristics and data types for the construction descriptor

Characteristic	Sub characteristic	Fixed entry	Data Type
Drilling method	None	Yes	List
Drilling fluid types	Water-based	Yes	List
	Air-based:	Yes	List
Formation sampling	None	Yes	List
Drilling diameter	None	Yes	Float
Drilling depth	None	Yes	Float
Final/total depth	None	Yes	Float
Drilling data quality	None	Yes	List
Drilling penetration rate	None	Yes	Float
Drilling contractor information	Name of company	Yes	Character
	Postal and physical address of company	Yes	Character
	Telephone and fax number of company	Yes	Character
	Name of driller and professional affiliation	Yes	Character
	Contact telephone number (cell and/or land line) of driller	Yes	Character
Drilling date	None	Yes	Time

Table 4-3: Characteristics and data types for the geology descriptor

Characteristic	Sub characteristic	Fixed entry	Data Type
Lithology: Soil and unconsolidated strata	Origin of the sample	Yes	List
	Colour (Munsell colour chart)	Yes	List
	Particle size	Yes	List
	Particle shape	Yes	List
	Lithological composition	Yes	List
	Origin	Yes	List
	Overburden thickness	Yes	List
Lithology: Hard rock component	Lithological composition	Yes	List
	Colour	Yes	List
	Degree of weathering	Yes	List
	Discontinuity spacing	Yes	List
	Formation strength	Yes	List

Table 4-4: Characteristics and data types for the geohydrology descriptor

Characteristic	Sub characteristic	Fixed entry	Data Type
Water Strike Depth	Unconsolidated strata	Yes	List
	Consolidated strata	Yes	List
Water Strike Yield	None	Yes	List
Water Quality	Electrical conductivity	No	Float
Chemical Analysis	H	No	Float
	Electrical conductivity	No	Float
	Potassium	No	Float
	Sodium	No	Float
	Calcium	No	Float
	Magnesium	No	Float
	Sulphate	No	Float
	Chloride	No	Float
	total alkalinity	No	Float
	Nitrate	No	Float
	Iron	No	Float
	Fluoride	No	Float

Table 4-5: Characteristics and data types for the design, development and completion descriptor

Characteristic	Sub characteristic	Fixed entry	Data Type
Casing material	Casing type	Yes	List

	Casing ID	Yes	Character
Screens	Wall thickness	Yes	Float
	Screen material	Yes	List
	Screen construction	Yes	List
Filter and Gravel Packs	Depth to top and bottom	Yes	List
	Nature of filter/gravel pack material	Yes	List
	Filter/gravel pack width	Yes	List
	Effective filter/gravel particle grain size	Yes	List
Geosite Development	Method used for borehole development	Yes	List
	Duration of borehole development	Yes	Time
	Chemical borehole development additives	Yes	List

Table 4-6: Characteristics and data types for the aquifer testing descriptor

Characteristic	Sub characteristic	Fixed entry	Data Type
Type of pump test	None	Yes	List
Data Collection	Start date and time of the test	Yes	Time
	Water level measurement or drawdown	Yes	Float
	Time or elapsed time		Time
	Rate of discharge	Yes	Float
	Date and time of each measurement		Time
	Static water level + date and time	Yes	Float and Time
	Depth of the borehole/dug well + date of measurement	Yes	Float and Time
	Distance between pumped borehole and each observation borehole	Yes	Float
	Depth of pump inlet	Yes	Float
	Depth at which water was struck	Yes	Float
	Diameter of the borehole at surface	Yes	Float
	Diameter of the borehole/dug well at the pump inlet depth	Yes	Float
	Measurement of any rainfall that occurs during the test period	Yes	Float
	Final recovered water level	Yes	Float
	Time after pumping stopped for the final recovered water level reading	Yes	Time
	Distance to all the respective observation boreholes	Yes	Float
Data Analysis	Analysis method	Yes	List
	Specific yield	Yes	Float
	Storage coefficient	Yes	Float
	Transmissivity	Yes	Float

	Leakage factor	Yes	Float

Table 4-7: Characteristics and data types for the in-situ geophysical logging descriptor

Characteristic	**Sub characteristic**	**Fixed entry**	**Data Type**
Name and contact details of logging company	None	Yes	Text
Name and contact details of the person carrying out the logging	None	Yes	Text
Type of logging performed	None	Yes	List
Actual depth-related measurement values – currently optional	None	Yes	Float
Relevant observations and recommendations	None	Yes	Text

Table 4-8: Characteristics and data types for the operational management and installed equipment descriptor

Characteristic	**Sub characteristic**	**Fixed entry**	**Data Type**
Abstraction Recommendations	Pumping rate	Yes	Float
	Abstraction duration (duty cycle)	Yes	Time
	Recovery period (if applicable)	Yes	Time
	Production pump installation depth	Yes	Float
	Maximum allowable water level drawdown	Yes	Float
	Target water quality range (electrical conductivity)	Yes	Float
	Extent of a borehole protection zone – up gradient	Yes	Float
Monitoring recommendations	Borehole water levels (whilst pumping)	Yes	Float
	Period that monitoring is to be conducted	Yes	Time
	Daily abstraction rate	Yes	Float
	Pumping hours per day	Yes	Time

	Water quality (EC) and specific analysis	Yes	Float
	Rainfall	Yes	Float
Installed Equipment	Installers contact details	Yes	Text
	Installation type	Yes	List
	Depth to pump intake (m)	Yes	Float
	Riser main material (steel, uPVC or flexible hosing)	Yes	List
	Riser main nominal diameter (mm ID)	Yes	Float
	Type of power	Yes	List
	Pump motor power rating (kW)	Yes	Float
	Serial number of the pump	Yes	Text
	Suppliers contact details	Yes	Text
	Electrical meter number	Yes	Text
	Dipper tube present (Yes/No). If yes, then Dipper tube depth (m) Dipper tube nominal diameter (mm ID)	Yes	Boolean
	Equipped with water meter (Yes/No). If yes, then provide details regarding make, type, number, etc.	Yes	Boolean

These descriptors are the general characteristics shaping the database. As they all separately describe different aspects of a borehole, their information needs to be interconnected with the locality of the borehole.

The base datasets to be used in the online borehole database are from the NGA and GRIP. Both databases are relational, consisting of tables and shared attributes (keys). Although the same data is found in both databases, their tables and attributes are presented differently. Thus, mapping one database and its components to another will inform how the online database should be designed to include the GRIP and NGA datasets. The database tables from which associations in Table 4-9 are made can be found in Annexure B and Annexure C.

Table 4-9: A rough association of the NGA and GRIP tables/attributes describing borehole features.

Future	**NGA Table/Attribute**	**GRIP Table/Attribute**
Basic borehole information	*GeositeInfo*	*basicinf*
Abstraction	*Abstraction*	*mreading*
Casing information	*Casing*	*casing__*

Chemistry	*Chemistry*	*chem_000 chem_001 chem_002 chem_003 chem_004 chem_005*
Comments	-	*comments*
Construction information	*Construction*	*constrct*
Depth and diameter information	*Depth*	*basicinf* *holediam*
Discharge information	*Discharge*	*discharg*
EC profile	*Field*	*eleccond*
Equipment information	*Equipment*	*installa* *instdetl*
Field chemistry information	*Field*	*Userchem* *fldmeas_*
Geosite status information	*GeositeStatus*	*basicinf*
Lithological information (borehole logs)	*Lithology*	*geology_*
Material information	*Material*	*holefill*
Operational information	*Operation*	*recommnd*
Other number information	*Other*	*otherid_*
Owner information	*Owner*	*nameownr*
Piezometer information	*Piezometer*	*piezomet*
Pump test information	*PumpTest*	*pumptest* *testdetl*
Reference information	*Reference*	*reference*
Screen information	*Screen*	*casing_*
Water level information	*WaterLevel*	*waterlev*
Water strike information	*WaterStrike*	*aquifer_*
Yield test information	*YieldTest*	*waterlev*

The relationships between and the structure of these characteristics are defined in the next section.

4.2.2 Data modelling and design

4.2.2.1 Choice of Model

Relational databases are most applicable to this development due to the nature of the geosite descriptors. That is, each category of borehole descriptor can be tabulated and connected to another category through a common ID. The entity relationship model will be used to illustrate these associations. It can produce a complex display of the relationships between the various descriptors.

4.2.2.2 Entity-Relationship (E-R) Model

Considering the SGDs, the descriptors (location, construction, geology, geohydrology, etc.) are regarded as entities in that they represent distinguishable types of characteristics. The characteristics of each descriptor, such as the drilling method in the construction descriptor or chemistry in the geohydrology descriptor, are regarded as attributes of their respective entities. They characterise each entity and consist of a name and data type. This is analogous to a table with columns. Each relationship between entities was defined, allowing the structure of the database to take shape. With each entity, the associated attributes were defined with the name, type and format in a simple data dictionary.

Treating each descriptor as an entity having attributes allows relationships to be identified and described. From the previous chapter the three relationships defined were used to identify the association between the various entities. These relationships are: one-to-many (1:M), many-to-many (M:N) and one-to-one (1:1). A one-to-many relation can be described through one user or organization recording many boreholes. A many-to-many relation can be described as multiply entries of one attribute/table are connected to multiple entries of another. Many-to-many relations will not be modelled as there are not required in the database. The one-to-one relation happens when one characteristic is linked to only one and only one other characteristic, such as in the case of a boreholes unique identity having only one location associated to it. Figure 4-1 is a simple illustration of the relationships between borehole site, observer/user, organisation tables.

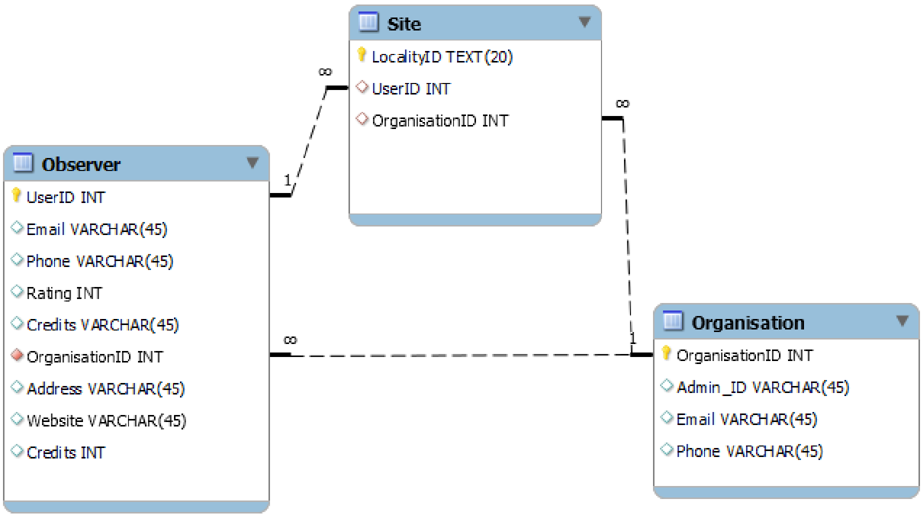


Figure 4-1: **A simple representation of relationships between the characteristics of an observer (user), organisation and a borehole site**

Each table consists of a unique identifier, called a primary key, which is assigned to each table entry. In Figure 4-1, “LocalityID”, “UserID” and “OrganisationID” are primary keys of each respective table (denoted by the key symbol). When a primary key is referred to in another table it is a called foreign key of that other table. Foreign keys enable data from one or more tables to be linked to the data of other tables. The red and pink coloured diamond entries in Figure 4-1 denote the foreign keys. The dashed lines in the figure connecting the tables illustrate the relationships between the tables. The one-to-many relationship is a common feature between the tables and is shown with the 1 and ∞ symbols at the end of each dashed line. As such one observer may record many borehole sites, one organisation may have many observers and, consequently, one organisation may have recorded many borehole sites.

From the understanding of these kinds of associations, Figure 4-2 illustrates the complete set of SGD relationships in an E-R diagram. This diagram serves as the conceptual model from which the physical database is developed. Each of the tables displayed contain a set of attributes, each of which are described by a data type and, where applicable, constraints to the length of data that can be captured.

The central attribute of the model is based on site information. This table has a primary key, (LocalityID) that is referenced in neighbouring descriptor tables. The “LocalityID” is denoted as the interchangeable terms “SiteID” and “Identifier” in parallel tables. This feature references relating to the LocalityID will be unique and unduplicated. As such, the entity integrity of the database will be maintained. The next section will detail how the unique locality identifier for each new borehole is generated. Of course, legacy SiteIDs from NGA and GRIP databases are preserved in the database.

4.3 Process of creating unique borehole identities

The generation of a unique site identifier for each borehole captured in the database follows a method developed by Dennis (2021:46). The method consists of a calculation combining the latitude and longitude (in decimal degrees) of the borehole location through hexadecimal conversions into a 13-digit identity.

The calculation is as follows:

$$ID = DecToHex(LAT * 100 + LON) + DecToHex(lat * 1000000) + DecToHex(lon * 1000000)$$

where:

ID = Locality ID

DecToHex = Function converting decimal to hexadecimal values

LAT = Absolute integer part of the latitude

lat = Decimal part of the latitude to 6 decimals

LON = Absolute integer part of the longitude

Lon = Decimal part of the longitude to 6 decimals

For instance, a borehole with the coordinates (-34.820720, 20.014630) would have an identity calculated to be D5C03926C85F0.This method has the benefit of the unique identity being able to be reversed back into its coordinates. More importantly, the identity can be generated without an internet connection as the coordinated are accessible from the GPS component.

Additionally, it ensures that the length of the LocalityID will never be longer than 13 characters. This makes the labelling manageable as it can be displayed on a map. Comparatively, legacy NGA SiteIDs typically had a length of 11 characters.

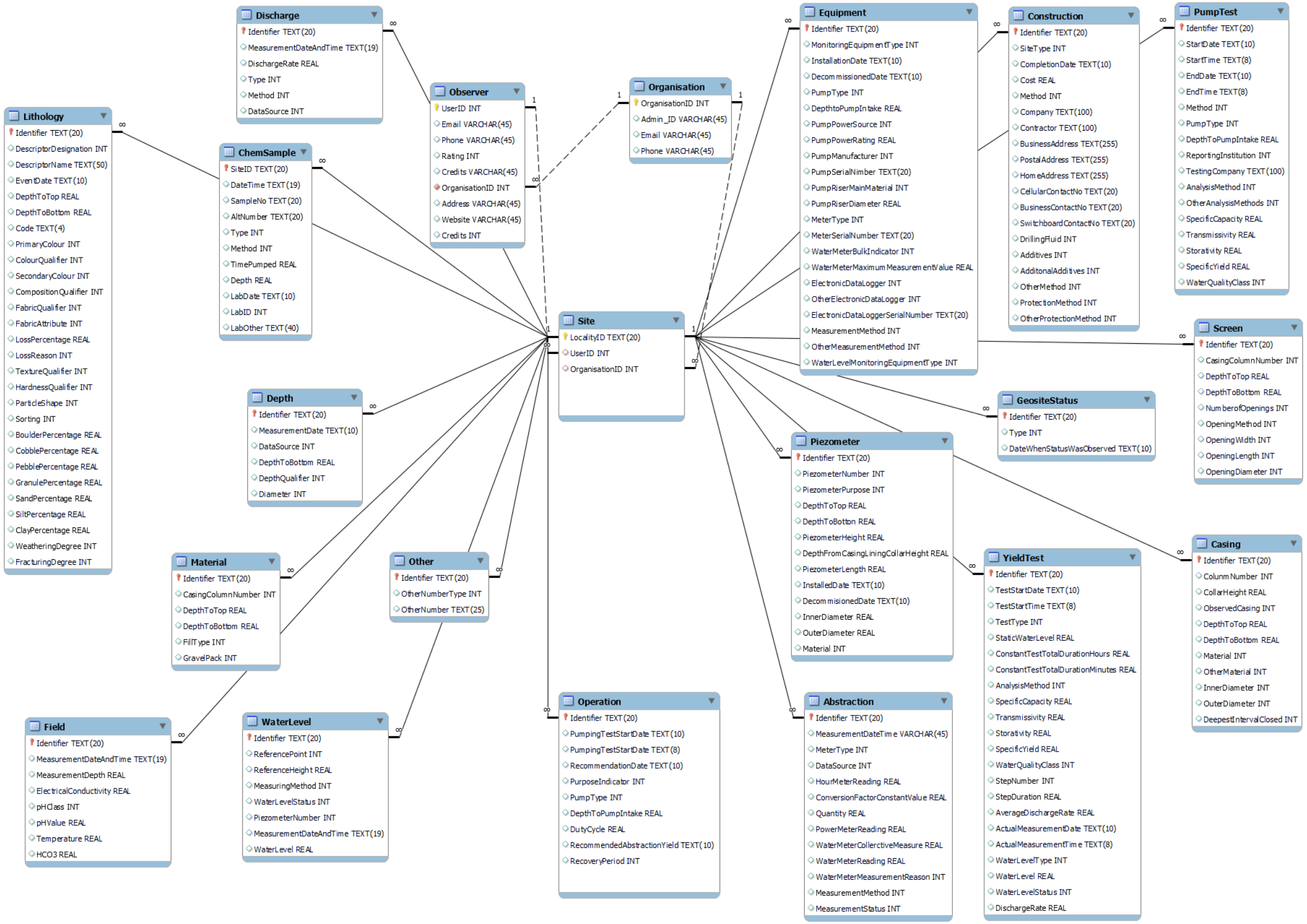


Figure 4-2: E-R diagram for the borehole database using the SGDs.

4.4 Chapter Summary

The development of the database was undertaken in this chapter. This was done through the investigation of descriptors, their attributes and the nature of their data entries. A comparison of attributes from the NGA and GRIP databases was then made. These aspects informed the choice of ER model used for mapping the relationships between tables and, accordingly, create the database structure from the SGDs. This structure will inform how the database is designed and implemented in the mobile application in the next chapter.

CHAPTER 5 – APPLICATION DESIGN AND DEVELOPMENT

5.1 Preamble

Data access and manipulation is facilitated through application programming and utility software (Coronel & Morris, 2018:23). The front-end component of the DBMS, the application, is considered in this chapter. The requirements of the application, the choice of development platforms, data validation and unique borehole identifiers are covered in this chapter.

5.2 Application Requirements

Before application development can be undertaken, considerations should be made on what is needed from the application for both its users and developers. As the mobile application attempts to address the challenges experienced in fieldwork, it should be able to support mobile GIS in order to capture location data in remote places as well as caching support for instances when the mobile device is out of network range. Another consideration should be the availability of the platform on the popular mobile OSs. Android and iOS have the greatest global market share, with Android dominating at 70.97% and iOS tailing with a respectable 28.27% (Statcounter, 2021). Thus, the application to be developed should cater for both OSs. Similarly, the following criteria is also considered:

- Cost: the application should not be expensive to make and maintain such that the cost does not transfer to the users.
- Speed: The development time should be short to avoid time constraints tied to the project as well as avoid competitors reaching the market first.
- Adaptability: Users should not be constrained to one OS to use the application. As such the code for the application should be able to be implemented many times on a variety of devices, and OSs.

5.3 Choice of mobile development platforms

From the application requirements described, the cross-platform development presents as a compelling option for the development of the mobile application due to its reduced cost, speed and reusable code. It is accepted that the challenges resulting from the use of the platform, and the application produced, will have to be addressed as and when they emerge.

Two potential platforms have been identified, AppStudio (to be referred to as AppStudio from here onwards) and Embaracadero RadStudio (to be referred to as RadStudio from here onwards). These will be juxtaposed in determine the suitable solution to develop the application

5.3.1 AppStudio

A product of Environmental Systems Research Institute (ESRI), AppStudio has an open-source toolkit at its disposal, the SDK for Qt, capable of creating cross platform applications and graphical user interfaces (GUIs) with minimal alterations to the underlying codebase. The application is still native and has the accompanying speed and capabilities. Similarly, AppStudio allows for applications to be simultaneously ready for iOS, OS X, Windows, Android and Linux after just one build as well as supporting any OS upgrades that may emerge in future. The platform also has generic templates available, reducing development time.

5.3.2 RadStudio

RadStudio supports a broad range of functions. It supports iOS and Android cross-platform development through FireMonkey, an Embarcadero proprietary GUI framework. It also supports mobile GIS (through FireMonkey), the use of the programming languages C++ and Delphi as well as cloud services (using REST API). Developers can build custom solutions to have complete control of the application functions.

5.3.3 Comparison between AppStudio and RadStudio platforms

The two platforms are assessed using the metrics of cost (financial) and functionality (technical) (Table 5-1). These align with the previous deliberations when choosing between native and cross-platform developments. The comparison reveals the benefit and appeal of AppStudio is that the ESRI mobile solutions automatically upgrades to incorporate new OSs as they emerge. In doing so it eliminates the need for developers to actively update applications for new OSs.

Table 5-1: Comparisons of AppStudio and RadStudio platforms in terms of financial and technical measures.

Measure		Platform	
		AppStudio	RadStudio
Financial	Advantages	- Low storage costs - Complete system development is realised through having an academic license	- A free tier subscription is available for small databases and system loads

		- Uploads are free and only downloads are paid for	
	Disadvantages	- Licensing may be costly outside of the academic realm	- Pricing negotiations aren’t favourable for lower scale customers - Usage is not capped and may lead to increased billing
Technical	Advantages	- New OSs are supported through automatic upgrades of ESRI mobile solutions - Desktop applications can connect through REST API - Products are maintained and supported	- Developers have full control of development functionality - Cloud storage is available - Development of mobile and desktop application occurs in the same environment
	Disadvantages	- Developmental control using AppStudio may not be as complete as in RadStudio - Only a single cloud storage service is available for ESRI - AppStudio only caters for mobile application development. Other development platforms are needed for developing desktop applications	- Longer development time needed - New OSs require active updates from developers

5.4 Database Hosting and user management

The ArcGIS Online (AGO) portal provides the hosting services for the AppStudio developed application. AGO acts as an interface between users and the online databases. It allows users access to the mobile application on the front end through a login with an AGO accounts. A public account can be registered for public users not having organisational access to AGO. Only registered AGO users can access the mobile application.

The user management implemented by the application considers individual users and organisations as users. Consequently, a method is necessary to differentiate users and organisations based on the reliability of the data they provide and their contributions to the database. This method is incorporated into the application using star ratings and user credits.

5.4.1 Star ratings and user credits

5.4.1.1 Star ratings

As mentioned in a previous section, there needs to be some form of determining the reliability of information added to the database. This is from the understanding that the public or citizen users of the database may not be as technically adept to the data capturing process as industry professionals would be. As such, the star rating procedure has been introduced to aid in such a determination.

A range of zero to five stars is assigned to each user of the application. Novice users are initially assigned a zero-star rating as the abovementioned reasons imply that the confidence in the data they have captured is low. This rating does not deny users from adding data, they can add as much data as they want to. The rating merely assigns a lower, ‘quasi’ confidence to their data. Conversely, a five-star rating will be assigned to users deemed to be professionals and those having demonstrated the ability to provide trustworthy data. Industry consultants, organisations and government officials would be typically rated as 5-star users.

Star ratings will be progressed for lower rated users when higher rated users validate the data for the same entity. This progression will take place once the lower rated user reaches a threshold of entries captured matching those of higher rated users. Thus, lower rated users are incentivised to be active on the application as their ratings may increase based on the data they capture in the field.

5.4.1.2 User Credits

The user crediting system aims to facilitate fair and just use of data. It intends to do so by issuing users credits based on the frequency of data captured or recorded to the database and deducting credits from users for every instance they download records from the database. Of course, user circumstances differ, with some users having a limited vicinity to upload data from. Thus, the credit system will not be an exact give-and-take, but rather skewed to downloads subtracting a fraction of upload credits. The system encourages the sharing of data; thus, it is not designed to restrict users. Rather it lets users to download data provided they contribute to the database.

A distinction should be made between AGO credits and the mobile application user credits. The credits used in the mobile application are for the uploading and downloading of data from the database. AGO credits are for developers and are for maintaining the online database and the mobile application.

5.5 Database design

This section considers how the database development in the previous chapter will be realised in the mobile application. Table 5-2 illustrates how the initial data investigation of the SGD has evolved into the categories entities and parameters to be used in the mobile application. For the application, the SGDs are grouped into six categories bated on site, level, abstraction, chemistry, construction and equipment related data. Figure 5-1 illustrates the database schema developed from these categories. The SQL code used to create the database, the DDL, as well as the database table specifications can be found in Annexure D and Annexure E respectively.

Table 5-2: The categories, entities and parameters to be employed in the mobile application

Category	**Entity**	**Parameter**	**Data Type**
SITE	**Basic Information**	Site Status	Static (selection)
		Water Taste	Static (selection)
		Water Use	Static (selection)
		Water Consumer	Static (selection)
		Equipment	Static (selection)
	Site Information	Data Owner	Static (selection)
		Coordinate Method	Static (selection)
		Elevation Method	Static (selection)
		Elevation Reference	Static (selection)
		Intended Purpose	Static (selection)
	Other Number	Other Number	Static
		Number Type	Static (selection)
	Photo	Photo	Image
LEVEL	**Water Level**	Water Level	Time
		Reference Point	Static (selection)
		Reference Height	Static

		Measuring Method	Static (selection)
		Water Level Status	Static (selection)
		Piezometer Number	Static
	Water Strike	Water Strike	Depth
ABSTRACTION	**Abstraction**	Quantity	Time
		Water Meter Reading	Time
		Power Meter Reading	Time
		Measurement Reason	Static (selection)
	Discharge	Discharge Rate	Time
		Discharge Type	Static (selection
		Discharge Method	Static (selection)
	Pump Test	Start Time	Static
		End Time	Static
		Method	Static (selection)
		Pump Type	Static (selection)
		Depth to Pump	Static
		Analysis Method	Static (selection)
		Water Quality Class	Static (selection)
CHEMISTRY	**Field Chemistry**	EC, pH, HCO3	Time
	Physical	COLR, TUR, TSS	Time
	Major Ions	Major Ions	Time
	Minor Ions	Minor Ions	Time
	Organic	Organics	Time
	Isotopes	Isotopes	Time
CONSTRUCTION	**Casing**	Collar Height	Static
		Material	Depth
		Outer Diameter	Depth
		Inner Diameter	Depth
	Construction	Date	Static
		Method	Static (selection)
		Drilling Fluid	Static (selection)
		Additives	Static (selection)
		Protection Method	Static (selection)
		Company	Static
		Contractor	Static

	Depth	Depth	Depth
		Diameter	Depth
	Lithology	Lithology Code	Depth (selection)
		Colour	Depth (selection)
		Composition	Depth (selection)
		Fabric Attribute	Depth (selection)
		Fabric Qualifier	Depth (selection)
		Fracturing Degree	Depth (selection)
		Hardness Qualifier	Depth (selection)
		Loss Reason	Depth (selection)
		Particle Shape	Depth (selection)
		Primary Colour	Depth (selection)
		Secondary Colour	Depth (selection)
		Sorting	Depth (selection)
		Texture Qualifier	Depth (selection)
		Weathering Degree	Depth (selection)
	Screen	Depth	Depth
		Openings Method	Depth (selection)
		Openings Width	Depth (selection)
		Openings Length	Depth (selection)
		Openings Diameter	Depth (selection)
	Piezometer	Number	Static
		Purpose	Static (selection)
		Depth	Static
		Height	Static
		Install Date	Static
		Inner Diameter	Static (selection)
		Outer Diameter	Static (selection)
		Material	Static (selection)
EQUIPMENT	**Equipment**	Install Date	Static
		Decom Date	Static
		Pump Type	Static (selection)
		Pump Depth to Intake	Static
		Pump Power Source	Static (selection)
		Pump Power Rating	Static

		Pump Manufacturer	Static (selection)
		Pump Serial Number	Static
		Pump Riser Material	Static (selection)
		Meter Type	Static (selection)
		Meter Serial Number	Static
		Meter Bulk Indicator	Static (selection)
		Meter Max Value	Static
		Electronic Logger	Static (selection)
		Logger Manufacturer	Static (selection)
		Logger Serial Number	Static
		Measurement Method	Static (selection)
	Operation	Pump Test Date	Static
		Pump Test Time	Static
		Recommendation Date	Static
		Purpose	Static (selection)
		Pump Type	Static (selection)
		Depth to Intake	Static
		Duty Cycle	Static (selection)
		Recommended Yield	Static
		Recovery Period	Static
		Operational Period	Static
		Purpose Indicator	Static (selection)

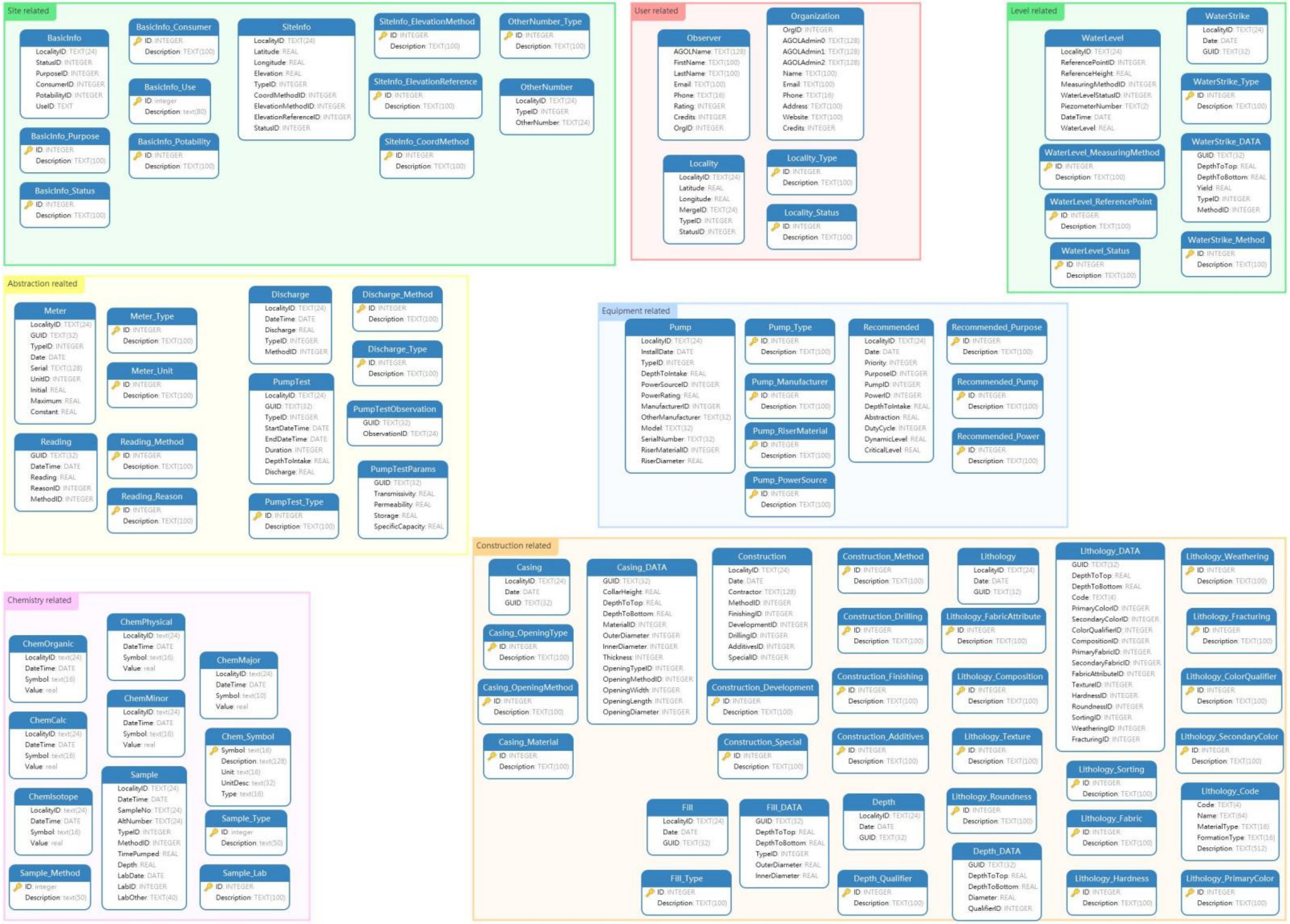


Figure 5-1: **A simple database structure (schema) for the mobile application**

CHAPTER 6 – RESULTS

6.1 Preamble

This section deals with the results of the study in three components. Firstly, the evaluation of the project as a citizen science project. This is followed by a pilot study for the application. Lastly, the implementation of the database through the mobile application is covered.

6.2 Evaluation as a citizen science project

The case for employing citizen science has been made in the second chapter of this dissertation. It’s cost effectiveness and long-term monitoring are among its key advantages. Before citizen science is implemented, it is apt to assess its suitability and success potential for the database.

Using the criteria introduced by Pocock *et al.* (2014:7) the suitability of the project for citizen sciences is described in Table 6-1

Table 6-1: Assessment of suitability criteria

Criteria	Motivation for suitability	Suitability
Clarity of the aim	The project clearly defined as seen in the aims of this dissertation.	High
Importance of engagement	Citizen engagement is necessary as it is useful in gathering data and populating the database. Moreover, its importance will be greater through encouraging the public to take ownership of the database by contributing to the database.	High
Resources available	The costs that come with storage and use may be an issue, but these costs are covered by an academic license. Once the application becomes commercial, the custodial costs will have to be transferred elsewhere. Considerations of the application costs will need to be made to avoid the costs falling to the users.	Moderate
Scale of sampling	The project has the potential to have large scale use especially because of the large area the application could cover. Also, long term use is necessary in data monitoring.	High

Complexity of the protocol	Some training may be required to use the mobile application. The user interface is relatively easy to navigate but the public may be limited in their knowledge to capture all borehole parameters. The protocol is as practical as it can be for citizen engagement.	Moderate
Motivations of participants	Boreholes require specialised measuring equipment, and this aspect may discourage the public. However, parameters such as borehole coordinates, photos and other basic data may be captured by the public. Citizens may be drawn to the project by being part of a narrative (I'm taking part with others) or having a sense of jeopardy ("my trees are under threat") (Pocock *et al.*, 2014:10)	Moderate

Likewise, the success factors from Garcia-Soto *et al.* (2017:26) were used to assess the potential for the citizen science. The following considerations were made using the success factors:

- In terms of clear goals, an initial aim of the study is for users to determine the location of boreholes in the field even if the other borehole parameters cannot be measured. This would aid in reducing the duplicate boreholes recorded using the farm centroid method
- Citizen engagement would be realised if the public adopts the database collectively as a necessary tool for water management beyond impending crises.
- Data reliability is employed through the user rating mechanism.
- The database will be improved through capturing borehole data. A larger database will need to be maintained and optimised for users.
- The scientific contribution of the database will be in management practices employed from the spatial and temporal data gained therein.
- Good communication will be achieved through user workshops and training. The WRC will fund the training as the benefactor of the project.

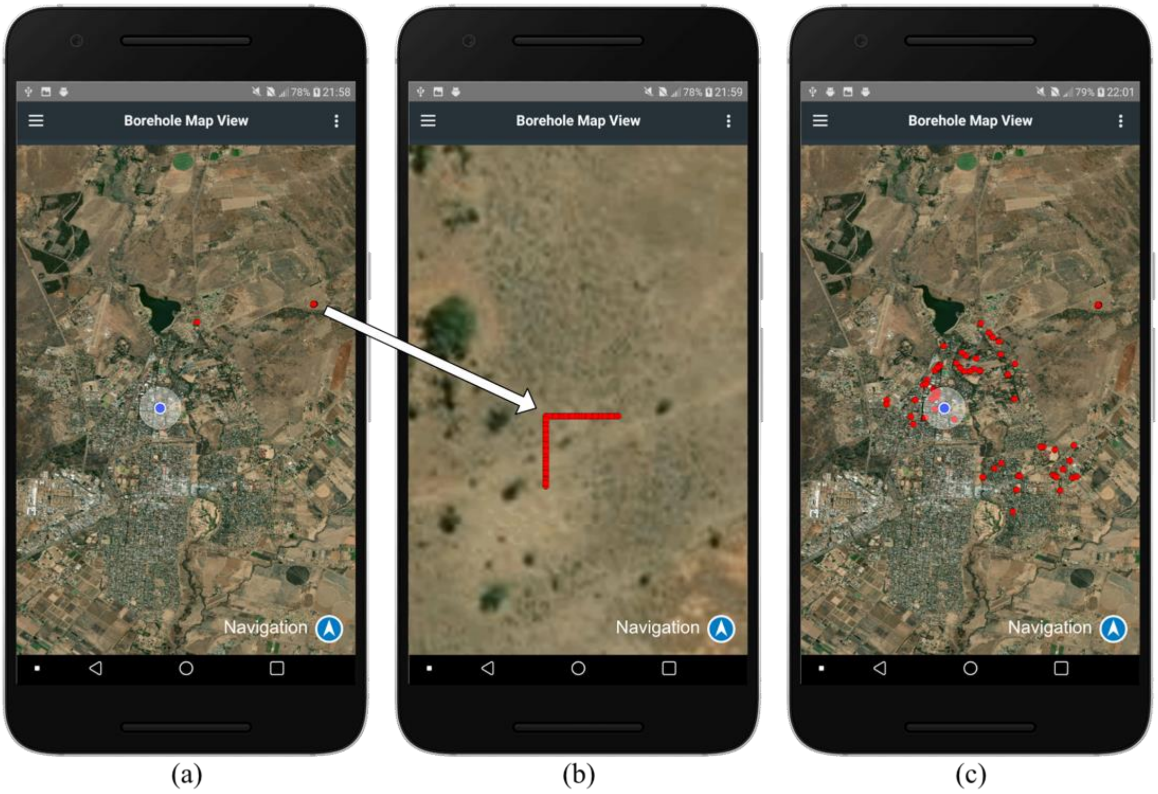
6.3 Considerations for implementation

To test the viability of the device as a citizen science tool, the access to the application should be given to a user group competent in the aspects of borehole data collection. This will inform the initial technicalities experienced by using the mobile application before the broader public is included in its development. This should also be implemented in area where a small sample size can be determined. This would reduce the cost of initial operation and the AGO credits required for the database.

6.4 Pilot Study

The Potchefstroom area of the North-West Province (South Africa) was selected as the initial study for the mobile application. The application was availed to a user group comprising of a resident consultant in the environment sector, students and everyday citizens. The selection of the group was attributed to the technical understanding the user group has related to borehole data collection.

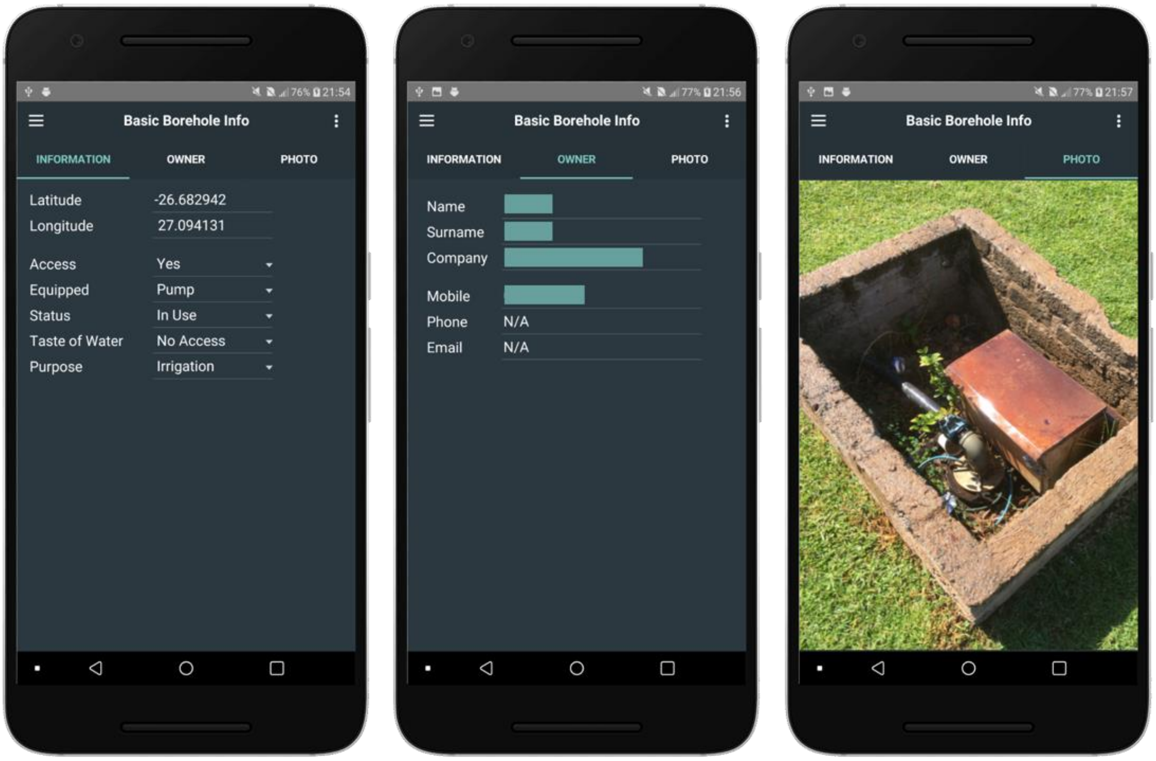
Initially, data from 46 boreholes derived from the NGA were available on the database. The majority of these boreholes were located at the centroids of farms as previously described with the old assignments Figure 6.1 (a) illustrates the distribution of the initial boreholes, while Figure 6.1 (b) illustrates the centroid phenomenon. The data available increased with a further 63 boreholes being provided by the application users as follows: 11 boreholes from the resident consultant, 19 boreholes from the student contingent, and 39 from regular citizens. The distribution of the 109 boreholes is shown in Figure 6.1 (c).



(a) (b) (c)

Figure 6-1: **(a) Initial boreholes (b) Boreholes with duplicated (and slightly offset) localities from the centroid method (c) Boreholes logged from the study**

Data verification was not carried out in the pilot study. The initial data had difficulty being located due to the centroid method. The user added data was primarily basic borehole information provided by the citizen and student cohorts (Figure 6-2) while the consultant provided data on water levels for unequipped boreholes. The main data added to the database was supplied by the public (52%). This is encouraging in that it may allow misplaced boreholes (from the centroid method) to be consolidated as the public identifies boreholes not on the database. Of course, this would be contingent on the availability of sufficient information to make these connections. However, the pilot study did not make this case, merely succeeding in the aspect of adding boreholes with verifiable field locations.



Latitude -26.682942
Longitude 27.094131

Access Yes
Equipped Pump
Status In Use
Taste of Water No Access
Purpose Irrigation

Name [redacted]
Surname [redacted]
Company [redacted]

Mobile [redacted]
Phone N/A
Email N/A

(a) (b) (c)

Figure 6-2: Site related data. (a) Basic information (b) Data ownership (c) Imagery data.

The pilot study assisted in the verification of borehole localities, a valuable contribution to hydrocensus studies especially considering the tedium of locating boreholes in the field. Knowledge of localities enables professional users to conduct appropriate measurements and assessments. This will in turn give access of this information to all contributors to the database.

6.5 The mobile database application

A mobile application was developed to facilitate access to the database. As previously mentioned, the database application was developed on AppStudio, an ESRI development platform. This PaaS is accessible through an ArcGIS Online and is subsidised by a university academic licence. The graphical user interface and the functionality of the mobile application are presented and discussed here.

6.5.1 Graphical User Interface

The user interface attempts to reflect the requirements of a borehole database by incorporating a variety of features and tools to register users, display data and adjust application features.

6.5.1.1 Landing and Login Pages

These pages are the access point to the mobile application. Upon opening the mobile application, the landing page (Figure 6-3(a)) offers the user two options:

- ***Create Public Account*** **–** this option allows any first-time user the opportunity to register a public account with ArcGIS Online (AGO) from which the application will be accessed
- ***Sign-in*** – For previous users and AGO account holders, this option takes the user to the Sign-in page and requires them to provide their AGO username and password to access the application (Figure 6-3(b)).

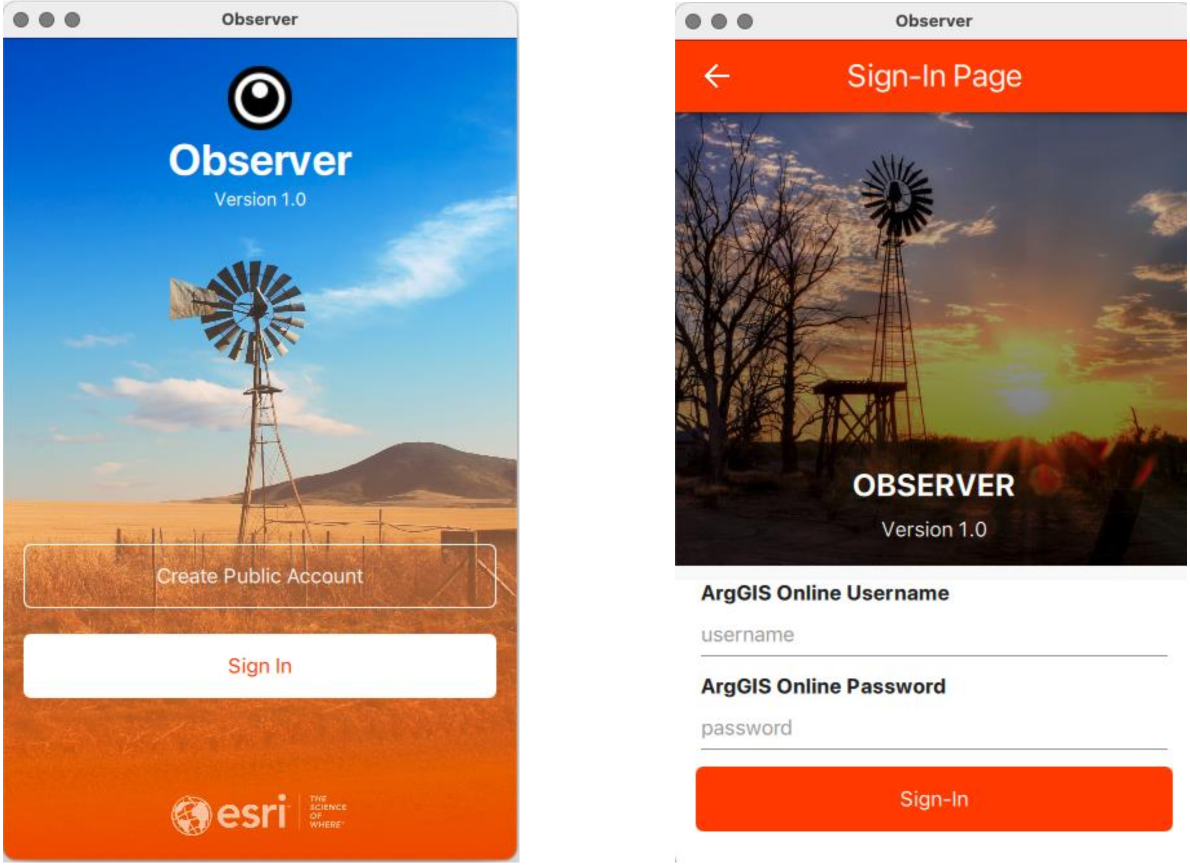


Figure 6-3: **The Observer mobile application. (a) The landing page, and (b) the sign-in page.**

6.5.1.2 Map Page

The main page (Figure 6-2) consists of various features such as a main toolbar on the top with a menu button (left icon) and tool button (right icon). As seen in the figure, when users are signed into the application, they will have their initials displayed on the menu button. The larger portion of the display houses a base map beneath the data layer where all the locations of the database's boreholes are pinned.

6.5.1.3 Location Menu

The position of the mobile device is revealed by the location menu (bottom right icon in Figure 6-4). Once selected, the menu opens a set of location options to turn the visibility of the location on or off (on the data layer) as well as re-centring the location and an option to exit the menu (Figure 6-5(a)). If the "Re-Center" option is selected, the position of the device is turned on and zoomed-in aerial view is displayed (Figure 6-5(b)).

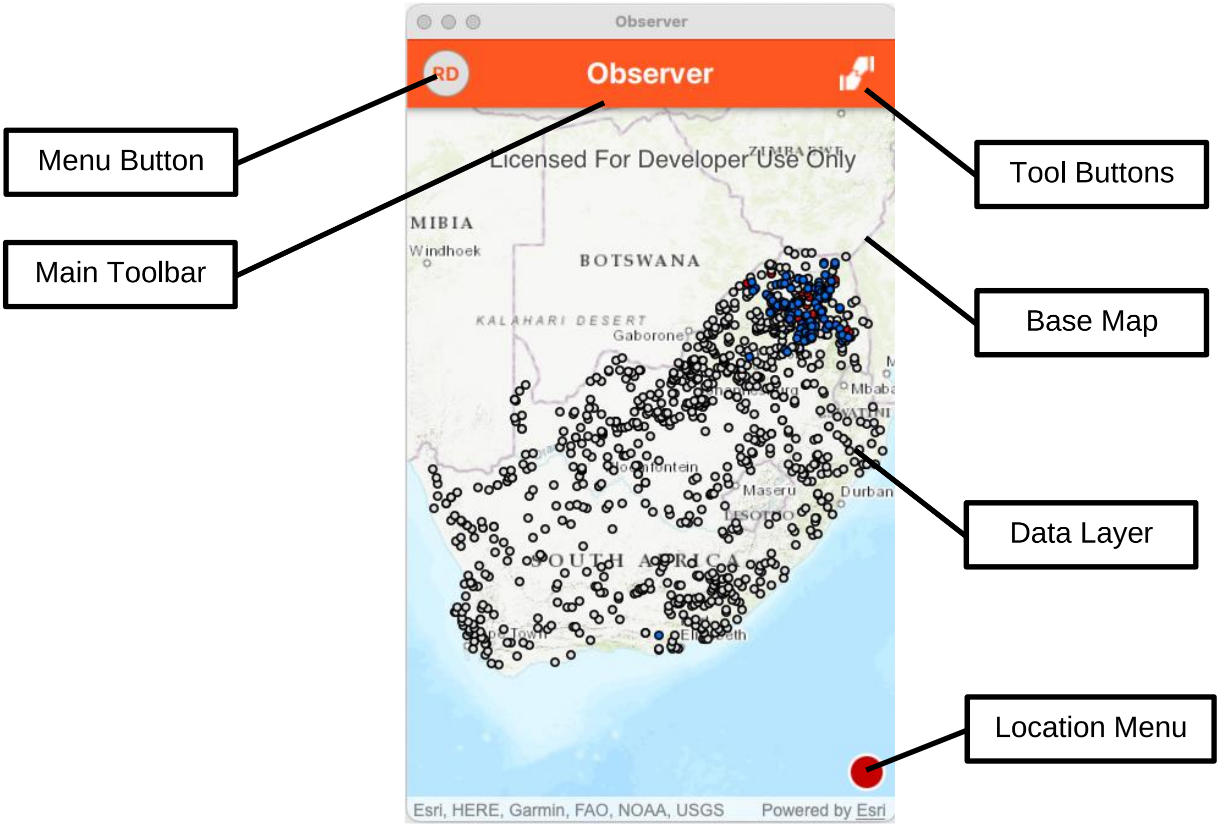


Figure 6-4: **Map page components**

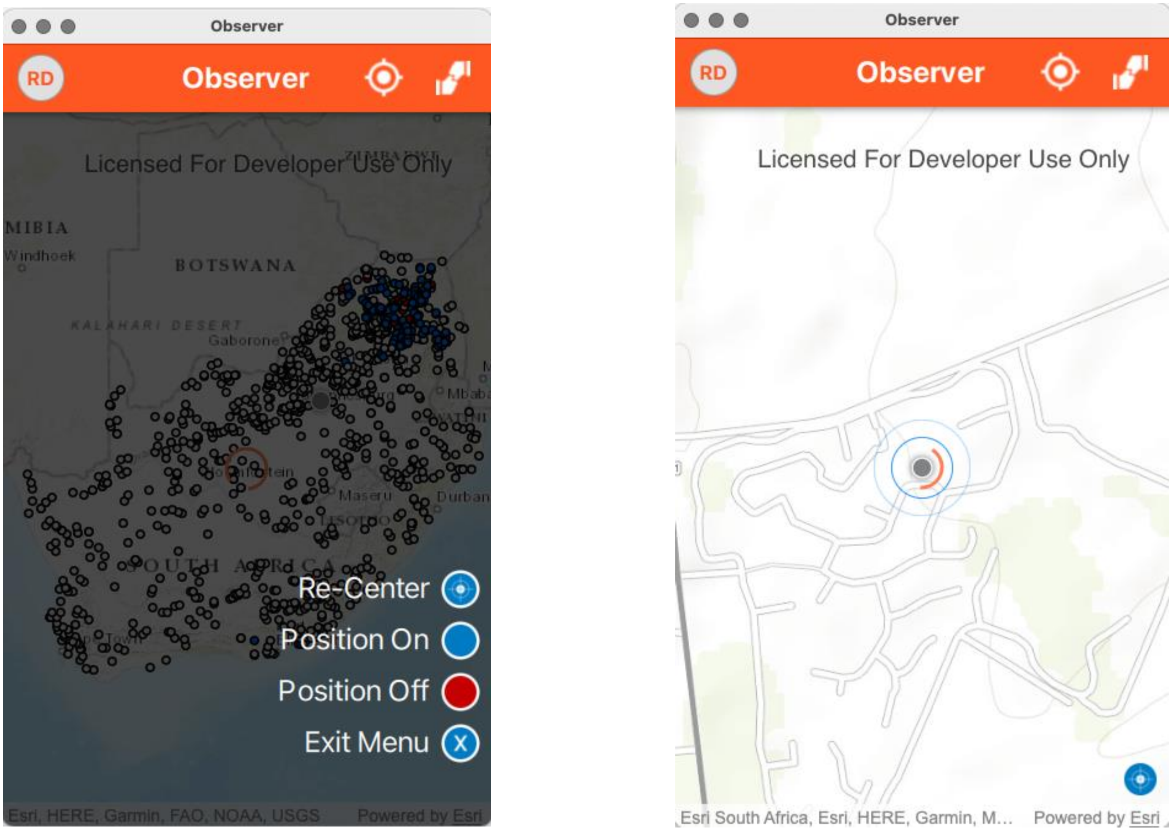


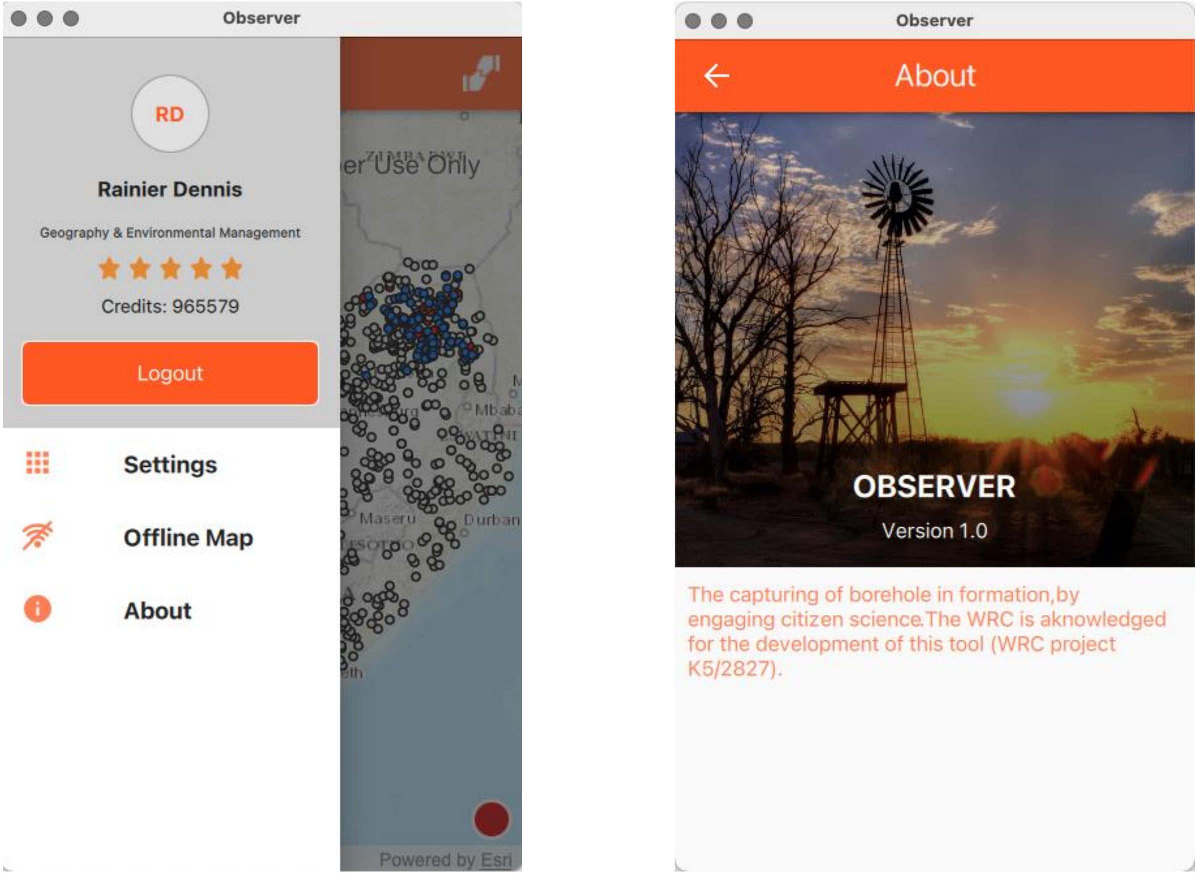
Figure 6-5: **Location menu. (a) location options (b) location visibility**

6.5.1.4 Main Menu

By selecting the menu button on the Map Page, a side tap reveals application's menu (Figure 6-6(a)). All user information, i.e., name, organisation, star-rating and user credits appears for logged-in users as well as the option to log out. Sections to open settings, offline map, and about pages also offered on the Main Menu tab. The Settings page is discussed in the next section.

The Offline Map section is ideal in cases where the mobile device is out of network range and without access to an internet connection (offline). It caches the current data by creating a local copy of the map. Once the application is online, the local data is resynchronised with AGO and the database is updated.

The About Page (Figure 6-6(b)) shares information on the application version, acknowledgements and miscellaneous information related to the application.



Rainier Dennis

Geography & Environmental Management

Credits: 965579

The capturing of borehole in formation,by engaging citizen science.The WRC is aknowledged for the development of this tool (WRC project K5/2827).

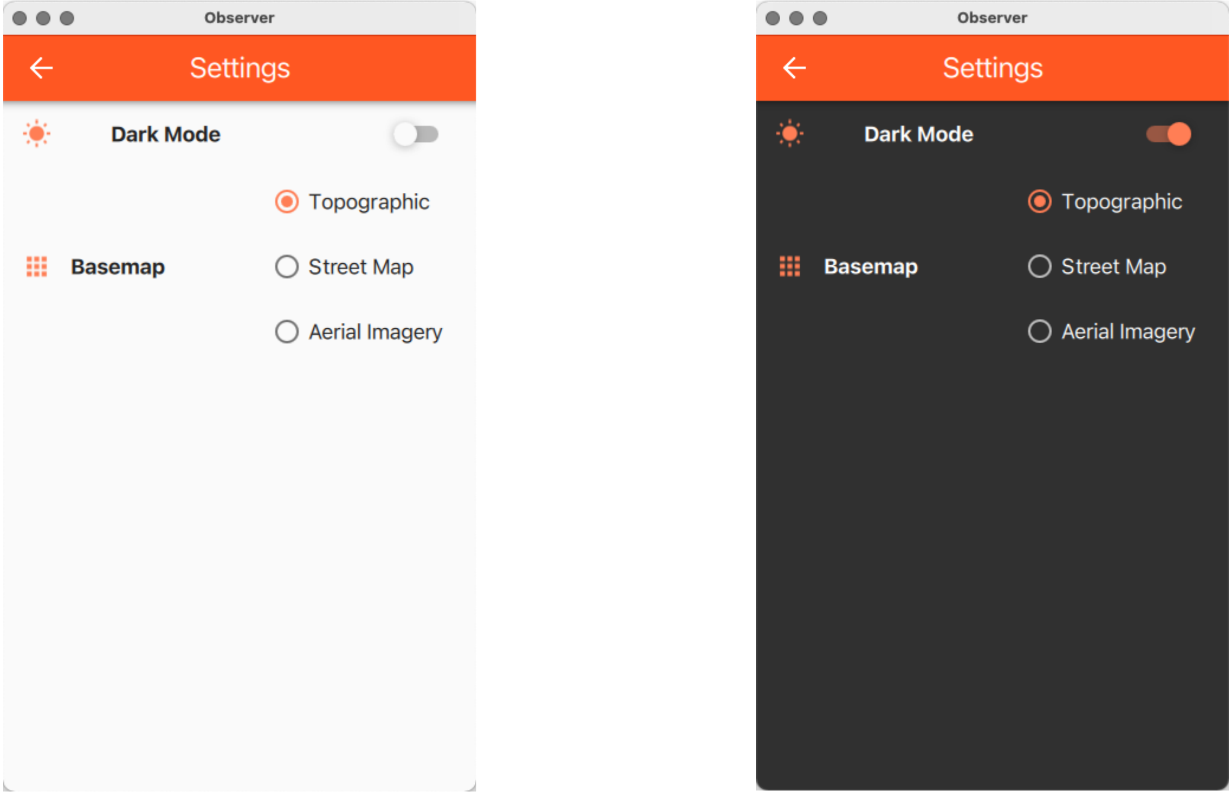
Figure 6-6: (a) Main Menu tab (b) About Page

6.5.1.5 Settings Menu

Users will be provided with a variety of displays through the applications settings page. The first setting shows the option to switch the applications theme between light mode Figure 6-7(a) or dark mode Figure 6-7(b). The application’s default setting in light mode

The next setting offers users the choice between one of three base maps that can be displayed the map page at a time. The choices are between a topographic view (Figure 6-8(a)), the street map view (with labelled roads, streets, landmarks, etc.) and an aerial image view (Figure 6-8(b)). The topographic view is the default setting for the application.

As new considerations for the application arise, the options available on the settings page will also evolve to cater for them.



Dark Mode ○

Basemap
● Topographic
○ Street Map
○ Aerial Imagery

Dark Mode ●

Basemap
● Topographic
○ Street Map
○ Aerial Imagery

Figure 6-7: Settings page (a) in light mode (b) in dark mode

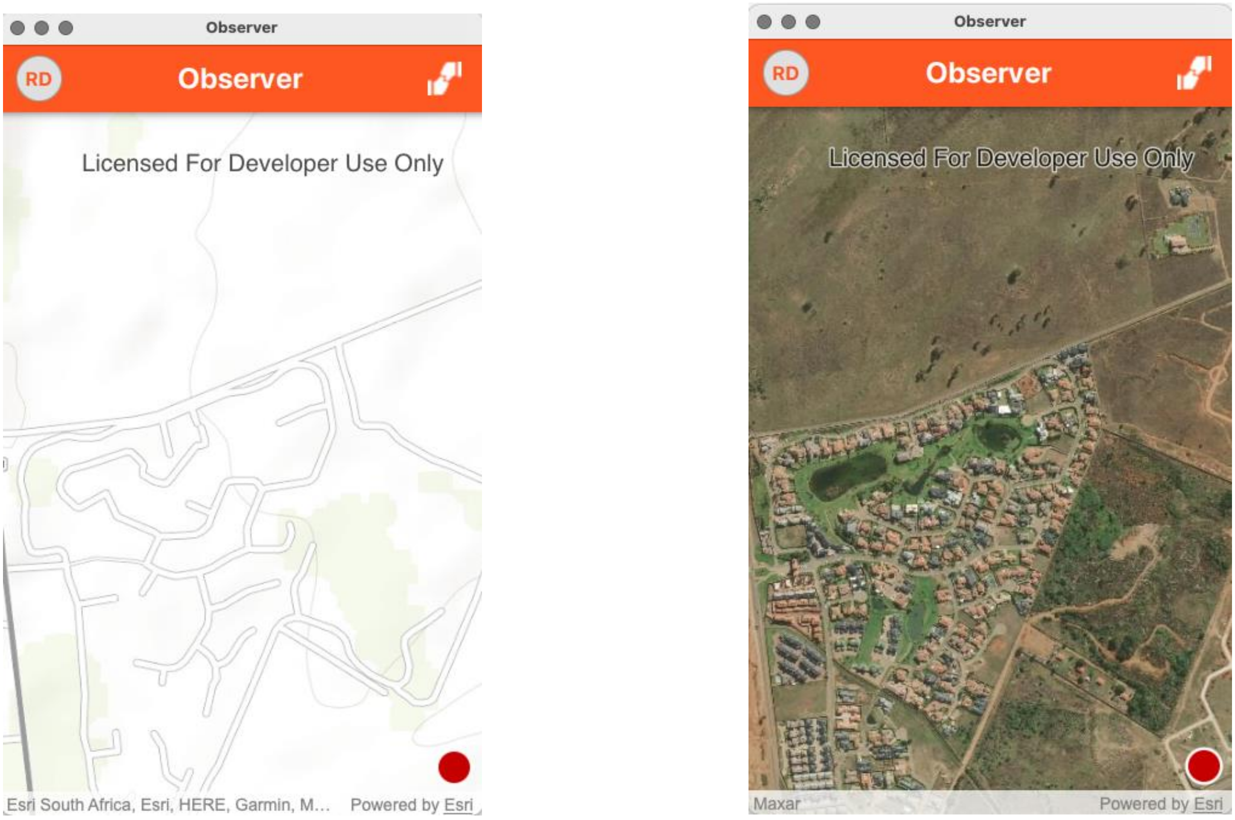


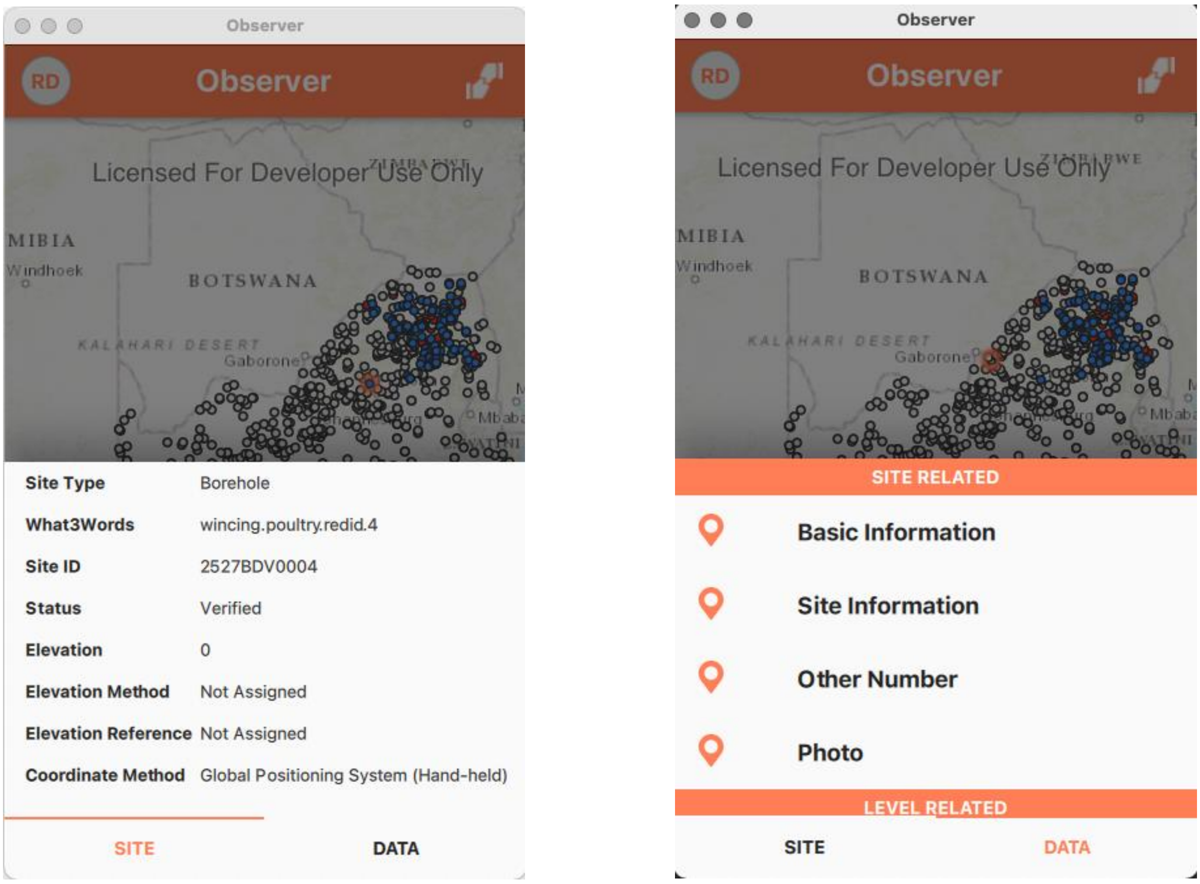
Figure 6-8: **Base map views (a) topographic map view (b) aerial imagery view**

6.5.2 Application functionality

6.5.2.1 Data Viewing

The user can view data on a borehole by selecting the borehole location on the map. This dots the borehole in orange and expands a SITE information window from the bottom of the screen. The window contains the basic information about the borehole Figure 6-9(a). At the bottom of the screen, a site selection button and data button are displayed to change between the basic site data and the more detailed borehole information.

When the data tab is selected (Figure 6-9(b)), a panel with 23 entities/characteristics grouped into 6 categories; site related, level related, abstraction related, chemistry related, construction related, and equipment related (Figure 6-10). The data groups and entities mirror the back-end database structure on which the application is built upon. By selecting a data entity, the specific properties about a borehole are seen. If the field chemistry data is selected, for instance, the data is displayed depending on the field chemistry parameter, such as the EC data displayed in Figure 6-11(a). Similarly, if construction related data such as a borehole log, the data is available graphically as seen in Figure 6-11(b).



Site Type	Borehole
What3Words	wincing.poultry.redid.4
Site ID	2527BDV0004
Status	Verified
Elevation	0
Elevation Method	Not Assigned
Elevation Reference	Not Assigned
Coordinate Method	Global Positioning System (Hand-held)

Figure 6-9: Viewing Data (a) Site tab (b) Data tab

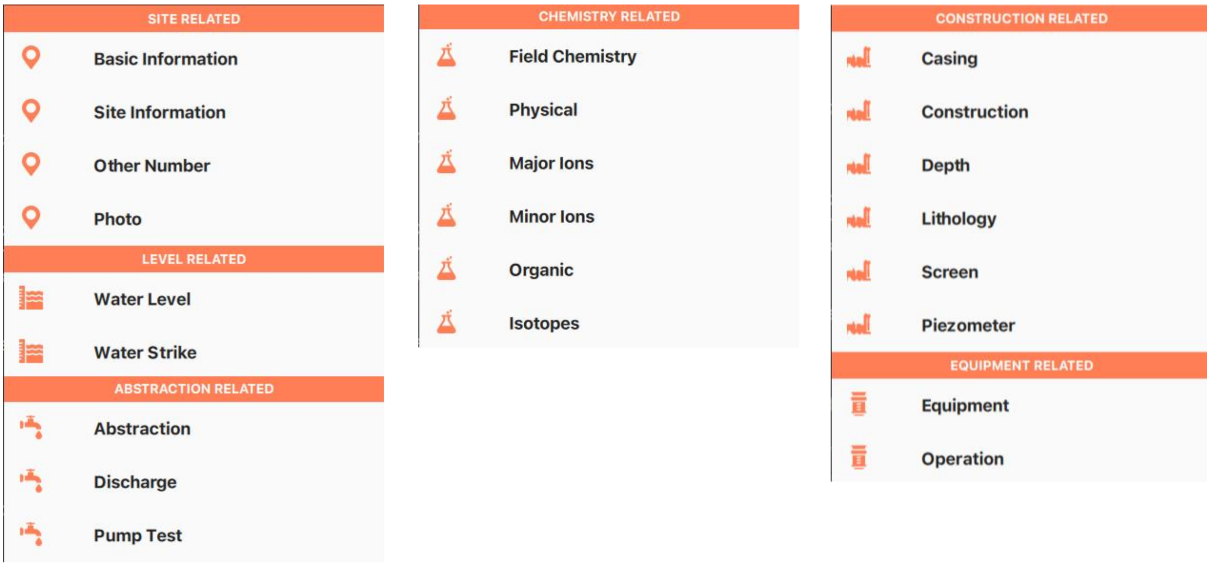
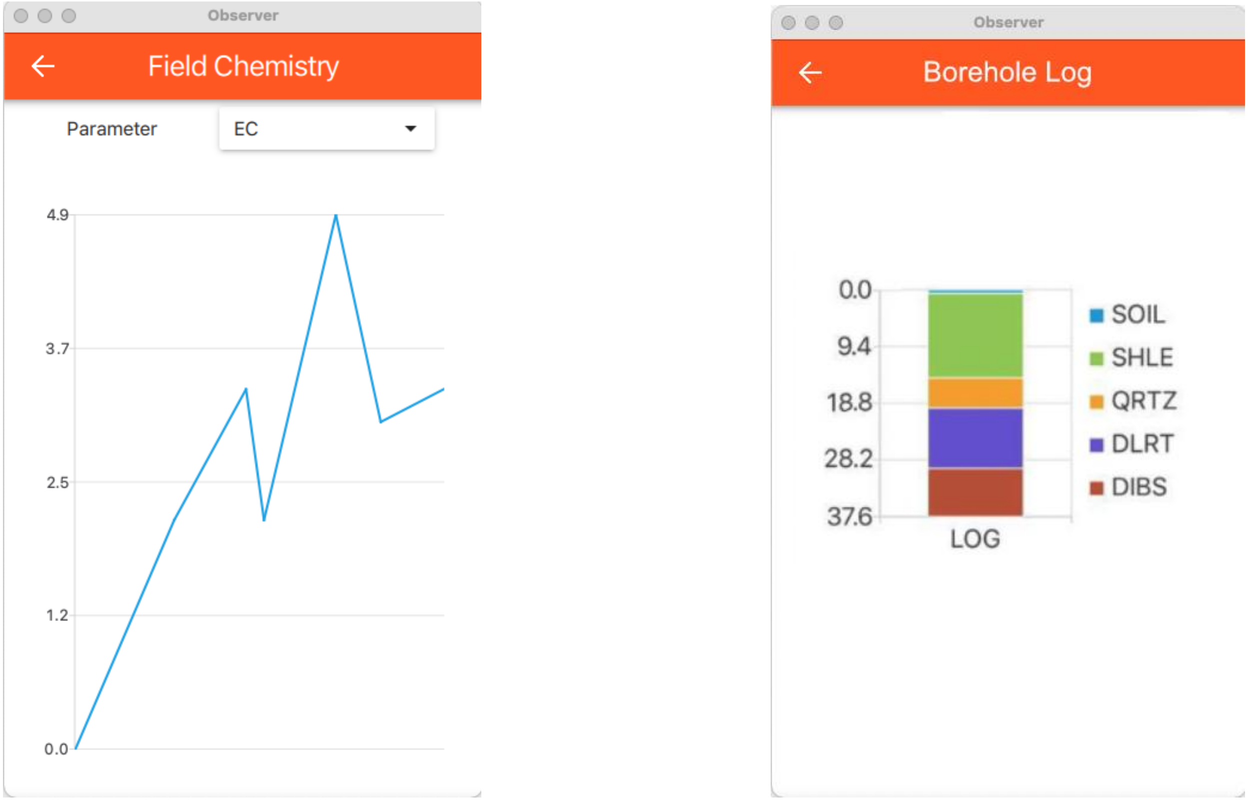


Figure 6-10: The 23 data entities grouped into 6 categories.



Parameter EC

Figure 6-11: **The basic data entity template for capturing and editing data on the application**

6.5.2.2 Data capturing and updating

Data capturing will entail the populating of the various parameters that form part of an entity. The parameters available for each entity were discussed in the previous chapter and listed in Table 5-2. Each parameter can be selected from its entity and a template for populating its data appears (Figure 6-12). The top half of the template is a display section where various features can be observed as they are entered or edited, such as a line graph as time related data is captured.

Table 6-2 is a guide to the data types, display features and controls used for capturing and editing data. The application uses five data types to capture data. The static data type is one that remains unchanged and is used for identifying and labelling features. Static data can be entered or edited with the keyboard, or be selected from a combo box (i.e., an options list). Image data, such as borehole pictures, can be captured or edited with the camera button. Time data, such as dates and times of chemical samples, displays as a line graph and can be edited or captured using a spin box or by typing through the keyboard. Depth data is displayed as bar graphs, as in the case of the borehole log, and can be captured or edited in a textbox.

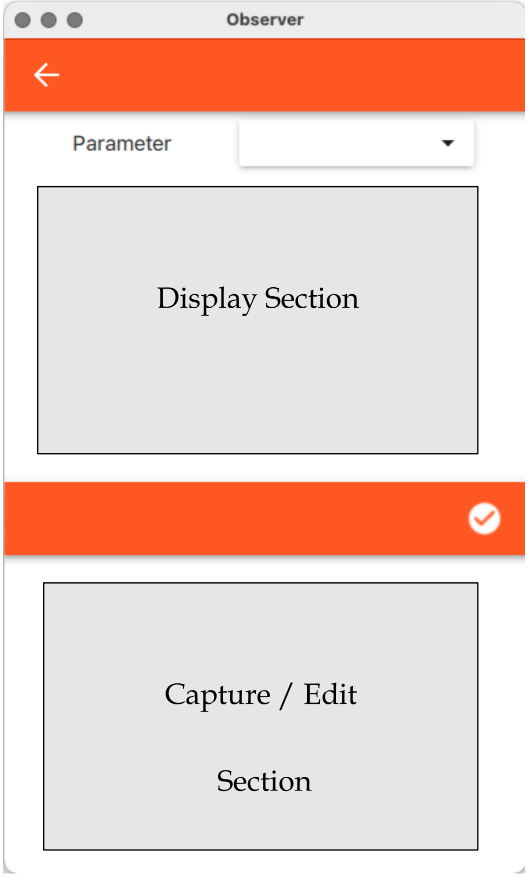


Figure 6-12: **The basic data entity template for capturing and editing data on the application**

Table 6-2: **Data types, display features and controls used for capturing and editing data.**

Data Type	**Display feature**	**Control used for data capturing and editing**
Static	Label	Edit
Static (selection)	Label	Combo Box
Image	Image	Camera Button
Time	Line Graph	Date Time Spin Box Edit Box (value)
Depth	Bar Graph	Edit Box (depth) Edit Box (value)

Throughout the various operations, the database maintains a functional record of the data changes. The data entries correspond to the inputs in the application in real time and can be seen as the database refreshes. Similarly, as data is added to the database it appears on the front-end database application as it is refreshed. Thus, data operations are truly reflected in real time.

Although static data has been described as unchanging, there are cases where updates to the data may be required. For instance, when a boreholes equipment is changed such as a new pump type and power source are used, or if casing and screen material are altered. The application makes provisions to these kinds of changes in static data by allowing any updates to be captured with a time stamp of the change. The previous static data continues to be on record but reflects an earlier time stamp on the data. As such data is updated without compromising previous data records. This also ensures that users cannot erase data that was not captured by themselves.

CHAPTER 7 – DISCUSSION AND CONCLUSION

7.1 Discussion

The discussion deals with the implications of the results, considering their successes and failures in achieving the aims and objectives of the study. These considerations are addressed in three areas: citizen science, the database, and the mobile application.

7.1.1 Citizen Science

7.1.1.1 Suitability and Potential

The engagement of citizens in the use of the online database is one of the aims of this project. The means of assessing whether this endeavour is appropriate and has the potential to prosper was to follow the suitability criteria designed by Pocock *et al.* (2014) and the success factors described by Garcia-Soto *et al.* (2017).

The assessment was found to favour the project for citizen science for several reasons. It sets a clear purpose as to what the citizen science is intended for i.e., to improve access to groundwater data for all stakeholders, assess groundwater status and facilitate informed decision-making in groundwater management. It initiates meaningful citizen engagement by enabling the public to contribute to, and draw from, the database. It also introduces a star rating mechanism to verify the quality of data on the database.

It does, however, raise concerns regarding resources available, complexity of methods and motivations of citizens. The development of the application is subsidised through an academic license. This will change once the application goes live. The implication is that whoever has custodianship of the database will require an AGO license to host the database and another license to distribute the mobile application. If the costs are not bearable for the custodian, they may be transferred to the users through the pricing of the mobile application. The application pricing may deter users if it is not justifiable.

Other deterrents include the complexity of data collection in the field as well as the usability of the application. The public may not have the technical acumen nor the instruments for collecting borehole data which professionals do. How would the public be incentivised to take part? Pocock *et al.* (2014:10) identify the publics affinity to becoming part of a narrative. The sense of community gained from sharing groundwater data with others may be a draw. A sense of jeopardy is also identified as an incentive. The water shortages in Johannesburg (Monama, 2016) and the prospect of a “Day Zero” in Cape Town (City of Cape Town, 2019) have given citizens a cause for concern which they have addressed with the construction of boreholes (Philander, 2017). This sense of threat may be used to encourage the public to contribute to groundwater monitoring and consequently, assessment and management.

With all these aspects considered, the project makes a compelling case to be employed as a citizen science project. Additionally, it has the potential to succeed as it attempts to address concerns it raises.

7.1.1.2 Approach to citizen science

The manner which citizen science is conducted influences the outcomes of its purpose. Overlapping with the suitability and potential the clarity of goals guides the approached to be followed by the research. The project can be analysed through the various approaches presented by Shirk *et al.* (2012), Bonney *et al.* (2009) , Haklay (2013) , Wiggins and Crowston (2011) in the literature review considering the levels of engagement and participation. From this, the approach followed in this project is assessed to be the hybrid of a contributory model with distributed intelligence and falling under the categories of investigative, conservational, and virtual citizen science. These characterisations are expanded upon subsequently.

The collaborative model is employed as the public is not leading the research (i.e., developing study questions, research methods, etc.). The public does, however, take part by collecting borehole data collection, analysing data (graphical representations of their data on the application) and the dissemination of data through the open access of the application to its users.

The project is regarded as one of distributed intelligence, the second level in of engagement and participation described by Haklay (2013:11). Citizens capture data and can interpret the results thereof in the application. Some training may be required for intricate components of the application and a star rating system is employed to validate data quality. This draws parallels with a similar project with a zoo project mentioned by Haklay (2013). It also requires an awareness of the enquiries from citizens as part of the work and the means to support their understanding throughout the project.

With regards to the citizen science research categorisation, it can be considered as a combination of investigative, conservational and virtual. The investigative component is realised from its emphasis on data collection, the virtual component arises from online mobile application having remote online functionality, while the conservational component arises from the fieldwork of capturing borehole data. These components run parallel in addressing the aim of citizen engagement, sharing and access of borehole data. It also has a scope ranging from regional to international. Borehole data collection as a field endeavour can span local communities to neighbouring countries. The database and the application facilitate this functionality and scalability. A similar example is one were pollinators were studied; volunteers participated by providing data on bees in their gardens using a specified observation and reporting method (Wiggins & Crowston, 2011:6). Issues experienced in such projects include the reliability of validation methods and volunteer screening. These are similar issues experienced in this research which were addressed through the implementation of the user ratings (to rank the publics data quality to professionals) and user credits (to ensure fair use and contribution of borehole data). This hybrid approach to citizen science has contributed to the various outcomes which the project aimed to achieve.

7.1.2 The Database

The database was developed considering existing databases. The database schema has allowed for the relationships between the SGDs and their parameters to be charted into a cohesive information system. The SGDs were employed in identifying the parameters necessary in describing a borehole. The link between the NGA and the GRIP databases attributes determined the parameters required for capturing data in the database The database tables although summarized, maintain the SGDs in the columns and thus maintain a standardised format for geosite data.

The effectiveness of the E-R model is that it illustrates tables, column data, connections, and connection type in a mapped format. The subsequent database schema developed (Figure 4-1) shows the tables and columns generated from the model. The schema exhibits clearly defined tables, columns, data types and constraints. The DDL specified the tables to be created in the database as well as the constraints i.e., data types, size, and data options to individual columns. The DDL also provided the privileges of the respective tables.

Data integrity, the long-term consistency of data entered to the database was also considered. Domain integrity i.e., the consistency of the data entered in a column of a specific data type was enforced with various operations such as character lengths. Entity integrity was upheld with uniquely defined rows having primary keys recorded. This also aided in restricting data replications by enforcing the not-null limitation and, thus, maintained referential integrity between various tables having the same key identifier

7.1.3 The Mobile Application

The mobile application addresses the aims of the study having been developed in a cross-platform environment. AppStudio caters for both Android and iOS through the ArcGIS Runtime SDK. The SDK also enables the offline functionality of the application through caching data on the device until it is online again. However, the cached data on mobile devices was not fully considered. The memory on the mobile device is consumed by caching and overtime may be entirely consumed (Pickell, 2019). Thus, it is worth exploring how offline usage of the application may impact their device’s memory.

The base maps incorporated, from AGO, in the application serve a key purpose of allowing users to visualise data at local, regional and national scale. The variety of base maps provide context for the user as they observe their overlying data. This is pertinent for data that changes over time such as the addition of new boreholes, water levels and chemistry related data.

The user interface performs its intended function of accessing and uploading data. User experiences have not been noted yet. In terms of user engagement with the application, the pilot study indicates that the contributions of the public were greater than those of professionals. This is encouraging for the expansion of the application.

The mobile application, although functional and convenient for field work, poses some challenges in data collection. Data can be uploaded through the application at the rate of one borehole at a time. The screen size of mobile devices limits the ability to capture large datasets in the same instance.

7.2 Conclusion

This dissertation presented the development of an online borehole database to engage citizen science. In doing so, it contextualised the topics of borehole data collection, database management and citizen science.

From the literature and data investigation, the SGDs provided a comprehensive and clearly defined framework for groundwater data collection and management. The logical model of the database, the E-R diagram, and, consequently, the database design and application interface drew immensely from this source. This, together with the NGA and the GRIP databases narrowed the gathering of user requirements for a borehole database.

The major databases concerned with boreholes in Southern Africa, RIMS, NGA, and GRIP were analysed. The databases differed in scale, user access and control. The dissertation mainly focussed on the GRIP and the NGA databases as they were most relevant. Both give users access to collect and contribute data, while RIMS restricts user inputs. All three of the databases did however experience the challenge of data shortages although these were more apparent in the NGA as opposed to the GRIP, which is the most comprehensive borehole database in the country. The lack in skilled technical personnel in the public sector and the lack of disclosure of privately held data inhibits informed decision making about groundwater management.

On the suitability and potential for citizen science, the assessment of suitability criteria indicated that the database development does fit to the conditions to engage citizen science. The clarity of aims, the engagement of citizens, and the contributions to the science proved to be compelling reasons to engage in citizen science. The hybridised approach to citizen science saw components of investigative, conservation and virtual citizen science working simultaneously to achieve data collection, and access using the database. Similarly, the possibility of scaling this research using citizen science is encouraging as it may include more users and communities to assess and manage groundwater.

The elements of a database and database management system were studied through existing databases and literature. The result was a database model selection suitable for borehole data using the SGDs as well as the GRIP and the NGA databases. The relational database is effective as it structures data in tables columns and rows and connects tables with keys. A relational database model was used to understand the relationships between SGDs and visualised through the ER diagram. This enabled the database to be developed using SQL and for the database schema to be visualised.

Using the AGO platform and AppStudio, a mobile application was developed to manage the database in real time. The application being publicly available through registering an AGO account enables anyone with an internet connection and a smartphone to use the application. Offline functionality is also enabled through the caching of data which is uploaded once network and internet connectivity are within range. Furthermore, the cloud hosting services offered by AGO enable this data access remotely. Moreover, the application provides spatial features, visualisation of time series data and a user rating system to validate data quality. As such the aims of creating a cross platform mobile application with cloud storage and a user verification mechanism was achieved.

The pilot study indicated that once the application was in use, boreholes captured to the database doubled in number with more than half the contributions coming from the public. Thus, in adding new borehole data to the database, the pilot study is considered as a success. Public participation could lead to the challenge of duplicate boreholes arising from the centroid method being overcome. This would be through the identification of new locations compared and replacing duplicate boreholes provided there is adequate data to substantiate these findings. Unfortunately, the pilot study did not provide any evidence of this. Hence the aim of addressing challenges of duplicate boreholes was not achieved.

Overall, the online database may prove a suitable addition and alternative to the existing institutional databases as it accesses and operates on data in real time and users only need to register an AGO account to access it. It empowers the citizen scientist to access as well as make meaningful contributions in borehole monitoring and, in the bigger picture, groundwater management.

CHAPTER 8 – LIMITATIONS AND RECOMMENDATIONS

8.1 Limitations

The application unfortunately performs operations on data, one borehole at a time. The challenge resulting in this is that an individual or organisations having data for many boreholes are constrained, regardless of the real time synchronisation of the database. Distributing data entries to many users might assist with this issue. However, user interactions on the database application are not certain.

To keep the use of AGO credits to a minimum, the application is designed for elementary functions. Consequently, functions such as the exporting of data into other formats (pdf, excel and text files) and geoprocessing operations (clipping, buffering, merging, etc.) are not available. They may not be necessary for the citizen users but may prove challenging for professional users who may require them for external purposes such as modelling and analysis. As differentiated in Chapter 6, AGO credits are developer credits, not user credits, and should not be muddled in this case.

8.2 Recommendations

Although the development of an online database achieved many of its aims, there are opportunities for improvements and possibly, future work on the mobile application. Increasing functionality of the application through the development of data exporting processes as well as geoprocessing tools. These would require more intricate application design and may prove more costly to the custodian once the application becomes commercial, but they would be of great benefit to users, particularly professionals, in carrying out their work in the field. Similarly, incorporating other complex functions such as entering or editing data for multiple boreholes will speed up user upload time.

Considering ease of use for the citizen scientist, the development of a tutorial within the application or an accompanying user guided may assist novice users to understand the complicated components of the application. This together with a user forum to share challenges with other users within the environment may improve the users experience as well as inform the developer on any enhancements worth working on.

The development of a database monitoring dashboard to visualise database statistics in real time would also be ideal. It would improve the users experience by providing them with the most relevant data immediately.

A broader recommendation may be to roll out an education and awareness strategy especially targeting areas and communities affected by groundwater challenges. This should incorporate different role players to strengthen and integrate the study. With citizen and broader stakeholder buy-in, not only will it increase the borehole data captured to the database, but it may also and, more importantly, support the crucial purpose of improving informed decision making in groundwater management.

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ANNEXURE A: DWS HYDROCENSUS FORM

Page 1 Of 6

water & sanitation
Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

NGA GROUNDWATER HYDROCENSUS FORM

Mandatory fields are indicated with red text and an asterisk (*).
Conditional Mandatory fields are indicated with green text and a double asterisk (**)

Notes, Tips and/or Preferences are indicated within Brackets ( ).

Owner Information			
1	* Owner Surname * Organisation Name		
2	* Owner Initials, First Name Organisation Reg.No., Abbreviation		
3	* Visit Date (ccyy-mm-dd)		
	Home Address (Owner)		
4	**Address Location**	☐ Home	
5	**Address Type**	☐ Postal	☐ Physical
6	**Address Text**		
7	**Suburb**		
8	**Town/City**		
9	**Postal Code**		
	Business Address (Owner)		
10	**Address Location**	☐ Business	
11	**Address Type**	☐ Postal	☐ Physical
12	**Building Name**		
13	**Office Number**		
14	**Street Name and Number**		
15	**Suburb**		
16	**Town/City**		
17	**Postal Code**		
18	**Telephone Number Location**	☐ Business	☐ Home
19	**Contact Type**	☐ Switchboard ☐ Cellular ☐ Email	☐ Fax ☐ Telephone
20	**Dialling code**		
21	**Telephone Number**		
22	**Extension**		

Geosite Information			
1	* **Data Owner**	☐ Dept Water - Eastern Cape ☐ Dept Water - Free State ☐ Dept Water - Gauteng ☐ Dept Water - Kwazulu Natal ☐ Dept Water - Limpopo ☐ Dept of Agriculture ☐ DMR-Department Mineral Resources ☐ DWS - Compliance Monitoring: Industry	☐ Dept Water - Mpumalanga ☐ Dept Water - Northern Cape ☐ Dept Water - North West ☐ Dept Water - Pretoria ☐ Dept Water - Western Cape ☐ Groundwater Consulting Services ☐ Management Authority (COHWHS) ☐ Petroleum Agency South Africa
2	* **Identifier**		
3	* **Reporting Institution**		
4	* **Geosite Type**	☐ Borehole ☐ Drain ☐ Dug Well ☐ Lateral / Radial Arm Collector ☐ Mine	☐ Seepage Pond ☐ Sinkhole ☐ Spring ☐ Tunnel ☐ Well Point
5	* **Reference Datum**	☐ Cape Datum (Clarke 1880)	☐ Hartbeeshoek Datum (WGS 84)
6	* **Latitude**	DDMMSS	DD.dddd
7	* **Longitude**	DDMMSS	DD.dddd
8	* **Coordinate Method**	☐ Differential GPS with Base Station ☐ Differential GPS without Base Station ☐ District and Farm Name and Number ☐ Estimated 1:10 000 map	☐ Estimated 1:250 000 map ☐ Estimated 1:50 000 map ☐ Global Positioning System (Hand-held) ☐ Surveyed
9	** **Coordinate GPS Accuracy** (m) Estimated Position Error (EPE)		
10	* **Elevation** (mamsl)		
11	* **Elevation Method**	☐ Altimeter ☐ Differential GPS with Base Station ☐ Differential GPS without Base Station ☐ District and Farm Name and Number ☐ Estimated 1:10 000 map	☐ Estimated 1:250 000 map ☐ Estimated 1:50 000 map ☐ Global Positioning System (Hand-held) ☐ Surveyed
12	** **Elevation GPS Accuracy** (m) Estimated Position Error (EPE)		

Version: NGA 4.3 2017/03/03 10:17 AM

13	* **Farm**		
14	* **Farm Number**		
15	**Geosite Status**	☐ Abandoned ☐ Destroyed ☐ Dry ☐ In Use	☐ Inaccessible ☐ Not Drilled ☐ Standby (Production)
16	**Date when Status Observed** (ccyy-mm-dd)		
17	**Map Number**		
18	**Province**	☐ Eastern Cape ☐ Free State ☐ Gauteng ☐ Kwazulu Natal ☐ Limpopo	☐ Mpumalanga ☐ North West ☐ Northern Cape ☐ Western Cape
19	**Quaternary Drainage Region**		
20	**Water Management Area**	☐ Berg ☐ Breede ☐ Crocodile (West) and Marico ☐ Fish to Tsitsikama ☐ Gouritz ☐ Inkomati ☐ Limpopo ☐ Lower Orange ☐ Lower Vaal ☐ Luvubu and Letaba	☐ Middle Vaal ☐ Mvoti to Umzimkulu ☐ Mzimvubu to Keiskamma ☐ Olifants ☐ Olifants / Doorn ☐ Thukela ☐ Upper Orange ☐ Upper Vaal ☐ Usutu to Mhlatuze
21	**Municipal District**		
22	**Geomorphology**	☐ Alluvial Fan ☐ Flat / Gently Undulating Surface ☐ Hill / Mountain Top ☐ Low Gradient Hill Slope ☐ Near Sinkhole ☐ Raised Terrace	☐ Riparian Zone ☐ Steep Mountain Slope ☐ Unvegetated Shifting Dunes ☐ Valley Floor ☐ Vegetated Dunes ☐ Water Body (Wetlands, Pan, River, Spring)
23	**Land Cover**	☐ Barren Rock ☐ Cultivated: Commercial Dryland ☐ Cultivated: Permanent – Commercial Irrigated ☐ Cultivated: Permanent – Commercial Sugarcane ☐ Cultivated: Temporary - Commercial Irrigated ☐ Cultivated: Temporary – Commercial Dryland ☐ Cultivated: Temporary Semi-Commercial / Subsistence Dryland ☐ Degraded: Forest and Woodland ☐ Degraded: Grassland ☐ Degraded: Herbland ☐ Degraded: Shrubland and Low Fynbos ☐ Degraded: Thicket and Bushland (etc.) ☐ Dongas and Sheet Erosion Scars ☐ Forest plantations (Indicate Eucalyptus) ☐ Forest plantations (Indicate Pine)	☐ Forest plantations (Indicate Wattle) ☐ Grassland ☐ Herbland ☐ Mines and Quarries ☐ Natural Forest ☐ Natural Forest and Woodland ☐ Shrubland and Low Fynbos ☐ Thicket and Bushland (etc.) ☐ Urban / Built-Up Land: Commercial ☐ Urban / Built-Up Land: Industrial / Transport ☐ Urban / Built-Up Land: Residential ☐ Urban / Built-Up Land: Residential (Small Holdings: Bushland) ☐ Urban / Built-Up Land: Residential (Small Holdings: Grassland) ☐ Urban / Built-Up Land: Residential (Small Holdings: Shrubland) ☐ Urban / Built-Up Land: Residential (Small Holdings: Woodland)
24	**Taste of Water**	☐ Brack ☐ Fresh	☐ Salty
25	**DWAF Geosite Purpose**	☐ Dewatering ☐ Drainage ☐ Exploration ☐ Observation	☐ Production (Water Supply) ☐ Recharge ☐ Standby ☐ Waste Disposal
26	**Observed / Actual Water Uses**	☐ Agriculture ☐ Bulk Water Supply ☐ Commercial ☐ Domestic ☐ Gardening ☐ Industrial ☐ Irrigation	☐ Mining ☐ Nature Conservation ☐ Power Generation ☐ Public ☐ Recharge ☐ Reservoir ☐ Stock Watering

Other Number Information

	* Other Number Type	* Other Number		* Assignor
1	☐ Aquabase Number		17	N/A
2	☐ Borehole Number (BHNO)		18	
3	☐ Boring Branch Number (BBNO)		19	N/A
4	☐ Dept of Water Affairs Forestry Number		20	
5	☐ G Number		21	N/A
6	☐ Hydrocom Number (HYDR)		22	N/A
7	☐ Hydrological Station Number (HSTA)		23	N/A
8	☐ Monitoring Feature ID (MFID)		24	N/A
9	☐ Old Hydrological Station Number (OHST)		25	N/A
10	☐ NGDB Number (SITE ID)		26	N/A
11	☐ Regional Borehole Number (RBHN)		27	N/A
12	☐ T Number		28	N/A
13	☐ W Number		29	N/A
14	☐ Water Level Monitoring Point (WLMP)		30	N/A
15	☐ ZQC QUAL Number		31	N/A
16	☐ ZQM QUAL Number		32	N/A

Reference Information

1	* Reference Type	☐ NGA Groundwater Hydrocensus Form	☐ Consultants Report ☐ GH Report
2	* DWAF Library Report Number		
3	* Located at	☐ Dept Water - Eastern Cape ☐ Dept Water - Free State ☐ Dept Water - Gauteng ☐ Dept Water - Kwazulu Natal ☐ Dept Water - Limpopo	☐ Dept Water - Mpumalanga ☐ Dept Water - Northern Cape ☐ Dept Water - North West ☐ Dept Water - Pretoria ☐ Dept Water - Western Cape
4	* Report Name		
5	* Report Date		
6	Non DWAF-Registered Documentation Number		
7	Non DWAF-Registered Documentation Located at	☐ Dept Water - Eastern Cape ☐ Dept Water - Free State ☐ Dept Water - Gauteng ☐ Dept Water - Kwazulu Natal ☐ Dept Water - Limpopo	☐ Dept Water - Mpumalanga ☐ Dept Water - Northern Cape ☐ Dept Water - North West ☐ Dept Water - Pretoria ☐ Dept Water - Western Cape

Construction Completion Information

1	**Construction Completion Date** (ccyy-mm-dd)		
2	**Construction Cost (Rand)**		
3	**Construction Method**	☐ Augered ☐ Cable Tool ☐ Core Drilling ☐ Direct Circulation (Mud Rotary) ☐ Driven Wells ☐ Dug By Hand ☐ Earth Augers: Bucket ☐ Earth Augers: Hollow-Stem ☐ Earth Augers: Solid Stem	☐ Excavated by Machine ☐ Hydraulic Rotary ☐ Jetting: Percussion Drilling ☐ Jetting: Well Point ☐ Reverse Circulation (Mud Rotary) ☐ Jetting: Well Point ☐ Rotary Air Percussion ☐ Tube Wells ☐ Other
4	**Construction Company**		
5	**Construction Contractor**		
6	**Drilling Fluid**	☐ Air ☐ Air With Additives ☐ Drill Foam	☐ Water ☐ Water With Additives
7	**Water Additives**	☐ Clay	☐ Polymers
8	**Air Additives**	☐ Clay ☐ Polymers	☐ Surfactant ☐ Water
9	**Additional Additives**		

Casing: Observed Information

1	* Casing Column Number (1 - 9)				
2	**Casing Collar Height** (m)				
3	* Observed Casing Details	☒ Yes			
4	**Casing Material**	☐ Concrete ☐ PVC ☐ Other		☐ Stainless Steel ☐ Steel	
5	**Other Casing Material**				
6	**Inner Diameter** (mm)	☐ 053.60 mm (2.00") ☐ 063.80 mm (2.50") ☐ 076.60 mm (3.00") ☐ 079.80 mm (3.10") ☐ 093.60 mm (3.75") ☐ 099.92 mm (4.00") ☐ 100.00 mm (4.00") ☐ 103.00 mm (4.00") ☐ 110.80 mm (4.25") ☐ 114.20 mm (4.50")	☐ 123.00 mm (4.75") ☐ 127.00 mm (5.00") ☐ 130.00 mm (5.00") ☐ 141.00 mm (5.50") ☐ 145.00 mm (5.75") ☐ 146.00 mm (5.75") ☐ 150.00 mm (6.00") ☐ 156.00 mm (6.00") ☐ 164.40 mm (6.50") ☐ 167.00 mm (6.50")	☐ 169.00 mm (6.50") ☐ 170.38 mm (6.75") ☐ 175.00 mm (6.75") ☐ 181.60 mm (7.00") ☐ 203.00 mm (8.00") ☐ 205.00 mm (8.00") ☐ 209.00 mm (8.25") ☐ 220.00 mm (8.75") ☐ 227.00 mm (9.00") ☐ 254.00 mm (10.0")	☐ 255.00 mm (10.0") ☐ 261.00 mm (10.25") ☐ 266.70 mm (10.50") ☐ 296.00 mm (11.50") ☐ 305.00 mm (12.00") ☐ 312.00 mm (12.25") ☐ 337.00 mm (13.25") ☐ 344.00 mm (13.50") ☐ 387.00 mm (15.25") ☐
7	**Outer Diameter** (mm)	☐ 063.00 mm (2.50") ☐ 075.00 mm (3.00") ☐ 090.00 mm (3.50") ☐ 110.00 mm (4.25") ☐ 112.00 mm (4.50") ☐ 113.00 mm (4.50") ☐ 125.00 mm (5.00") ☐ 140.00 mm (5.50")	☐ 142.00 mm (5.50") ☐ 146.00 mm (5.75") ☐ 160.00 mm (6.25") ☐ 165.00 mm (6.50") ☐ 168.00 mm (6.50") ☐ 175.00 mm (6.75") ☐ 179.00 mm (7.00") ☐ 180.00 mm (7.00")	☐ 186.00 mm (7.25") ☐ 200.00 mm (7.75") ☐ 203.00 mm (8.00") ☐ 210.00 mm (8.25") ☐ 216.00 mm (8.50") ☐ 221.00 mm (8.75") ☐ 225.00 mm (9.00") ☐ 250.00 mm (9.75")	☐ 266.00 mm (10.50") ☐ 273.00 mm (10.75") ☐ 280.00 mm (11.00") ☐ 315.00 mm (12.50") ☐ 324.00 mm (12.75") ☐ 349.00 mm (13.75") ☐ 356.00 mm (14.00") ☐ 399.00 mm (15.75")

Depth & Diameter Information

1	**Measurement Date** (ccyy-mm-dd)						
2	* Data Source						
3	**Reporting Institution**						
4	* Depth to Bottom (m)						
5	**Penetration Information Available**	☐ Yes					
6	**Depth Qualifier**						
7	**Diameter** (mm)	☐ < 100 (4.0") ☐ 127 (5.00") ☐ 152 (6.00")	☐ 165 (6.50") ☐ 203 (8.00") ☐ 216 (8.50")	☐ 219 (8.75") ☐ 250 (10.00") ☐ 254 (10.00")	☐ 305 (12.00") ☐ 312 (12.50") ☐ 324 (12.75")	☐ 356 (14.00") ☐ 406 (16.00") ☐ 451 (18.00")	☐ ☐ ☐

Version: NGA 4.3 2017/03/03 10:17 AM

Discharge Rate Information

	* **Measurement Date** (ccyy-mm-dd)	* **Measurement Time** (hh:mm)	* **Discharge Rate** (l/s)
1			
2			
3	**Discharge Type**	☐ Airlift ☐ Bailer	☐ Flowing ☐ Pump
4	**Discharge Method**	☐ Estimated ☐ Flow Meter ☐ Flume ☐ Submerged Orifice ☐ Totalling Meter	☐ Venturi Meter ☐ V-Notches ☐ Volumetric Measurement ☐ Weir
5	**Data Source**	☐ Check by Reporting Institution ☐ Driller's Log ☐ Geo Specialist's Record ☐ Memory	☐ Owner's Record ☐ Pump Operator's Record ☐ Report/File

Water Level Information

1	**Reference Point**	☐ Casing Collar ☐ Concrete Block	☐ Ground Surface ☐ Intelligent Top Cap (ITC) Platform
2	**Piezometer Number**		
3	**Measuring Method**	☐ Airline ☐ Autographic Recorder ☐ Capacity Probe ☐ Dip Meter ☐ Electronic Data Logger ☐ Estimated	☐ Pressure Gauge Measurement ☐ Reported ☐ Steel Tape
4	**Water Level Status**	☐ Affected by Pump (In Hole) ☐ Affected by Pump (Nearby) ☐ Artesian ☐ Obstructed	☐ Static Water Level ☐ Suspect Data ☐ Temporarily Dry
	* **Measurement Date** (ccyy-mm-dd)	* **Measurement Time** (hh:mm)	* **Water Level** (m)
5			
6			
7	**Data Source**	☐ Check by Reporting Institution ☐ Driller's Log ☐ Geo Specialist's Record ☐ Memory	☐ Owner's Record ☐ Pump Operator's Record ☐ Report/File

Site Visit Information

1	**Visit Date** (ccyy-mm-dd)		
2	**Visit Reason**		
3	* **Site Visitor Surname**		
4	* **Site Visitor Initials**		
		Home Address (Site Visitor)	
5	**Address Location**	☐ Home	
6	**Address Type**	☐ Postal	☐ Physical
7	**Address Text**		
8	**Suburb**		
9	**Town/City**		
10	**Postal Code**		
		Business Address (Site Visitor)	
11	**Address Location**	☐ Business	
12	**Address Type**	☐ Postal	☐ Physical
13	**Building Name**		
14	**Office Number**		
15	**Street Name and Number**		
16	**Suburb**		
17	**Town/City**		
18	**Postal Code**		
19	**Telephone Number Location**	☐ Business	☐ Home
20	**Contact Type**	☐ Switchboard ☐ Cellular ☐ Email	☐ Fax ☐ Land Line
21	**Dialling code**		
22	**Telephone Number**		
23	**Extension**		

Equipment Installed Information (Monitoring)

1	* Monitoring Type	☐ Abstraction Monitoring ☐ Non Monitoring	☐ Rainfall Monitoring ☐ Water Level Monitoring

Water Level Monitoring

2	* Installed Date (ccyy-mm-dd)	3	**Decommissioned Date** (ccyy-mm-dd)
4	**Data Source**	☐ Check by Reporting Institution ☐ Driller's Log ☐ Geo Specialist's Record ☐ Memory	☐ Owner's Record ☐ Pump Operator's Record ☐ Report/File
5	* Equipment Type	☐ Autographic Recorder ☐ Electronic Data Logger ☐ Hand ☐ Other	☐ No Equipment ☐ Volumetric Meter (Cummulator)
6	* Electronic Data Logger	☐ Airline bubbler OTT Orphimedes ☐ Other ☐ Shaft encoder OTT Thalimedes ☐ Transducer Aquanaut (OTT) ☐ Transducer: Eijkelkamp Baro ☐ Transducer: Eijkelkamp Diver (CTD) ☐ Transducer: Eijkelkamp Diver (OTD)	☐ Transducer: Eijkelkamp Diver (TD) ☐ Transducer: OTT Mini Orpheus ☐ Transducer: Solinst Barologger ☐ Transducer: Solinst Levellogger LT ☐ Transducer: Solinst Levellogger LTC ☐ Transducer: STS
7	** Other Electronic Data Logger Type		
8	**Electronic Data Logger Manufacturer**	☐ Eijkelkamp ☐ Other	☐ OTT ☐ STS
9	** Other Electronic Data Logger Manufacturer		
10	**Serial Number (Data Logger)**		
11	**Measurement Method**	☐ Airline (Orphimedes) ☐ Echosounder ☐ Other	☐ Float Principal (Thalimedes) ☐ Transducer

Rainfall Monitoring

2	* Installed Date (ccyy-mm-dd)	3	**Decommissioned Date** (ccyy-mm-dd)
4	**Data Source**	☐ Check by Reporting Institution ☐ Driller's Log ☐ Geo Specialist's Record ☐ Memory	☐ Owner's Record ☐ Pump Operator's Record ☐ Report/File
5	* Equipment Type	☐ Electronic Data Logger ☐ Hand	☐ Volumetric Meter (Cummulator) ☐ Other
6	** Other Equipment Type		

Abstraction Monitoring
Pump

2	* Installed Date (ccyy-mm-dd)	3	**Decommissioned Date** (ccyy-mm-dd)
4	**Data Source**	☐ Check by Reporting Institution ☐ Driller's Log ☐ Geo Specialist's Record ☐ Memory	☐ Owner's Record ☐ Pump Operator's Record ☐ Report/File
5	* Pump Type	☐ Jet ☐ Mono Type Pump ☐ Positive Displacement	☐ Submersible Pump ☐ Turbine
6	**Depth to Pump Intake** (m below surface)		
7	**Pump Power Source**	☐ Compressed Air ☐ Electricity ☐ Fuel	☐ Hand ☐ Sun ☐ Wind
8	**Power Rating** (kW)		
9	**Pump Manufacturer**		
10	**Serial Number**		
11	**Riser Main Material**	☐ Flexible Hosing ☐ uPVC	☐ Steel
12	**Riser Diameter** (mm)		

Abstraction Monitoring
Meter

2	**Installed Date** (ccyy-mm-dd)	3	**Decommissioned Date** (ccyy-mm-dd)
4	**Data Source**	☐ Check by Reporting Institution ☐ Driller's Log ☐ Geo Specialist's Record ☐ Memory	☐ Owner's Record ☐ Pump Operator's Record ☐ Report/File
5	**Meter Type**	☐ Hour Meter (h) ☐ Power Meter (kWh)	☐ Water Meter (m^3)
6	**Serial Number**		
7	**Supplying Company**		
8	**Supplying Contractor**		

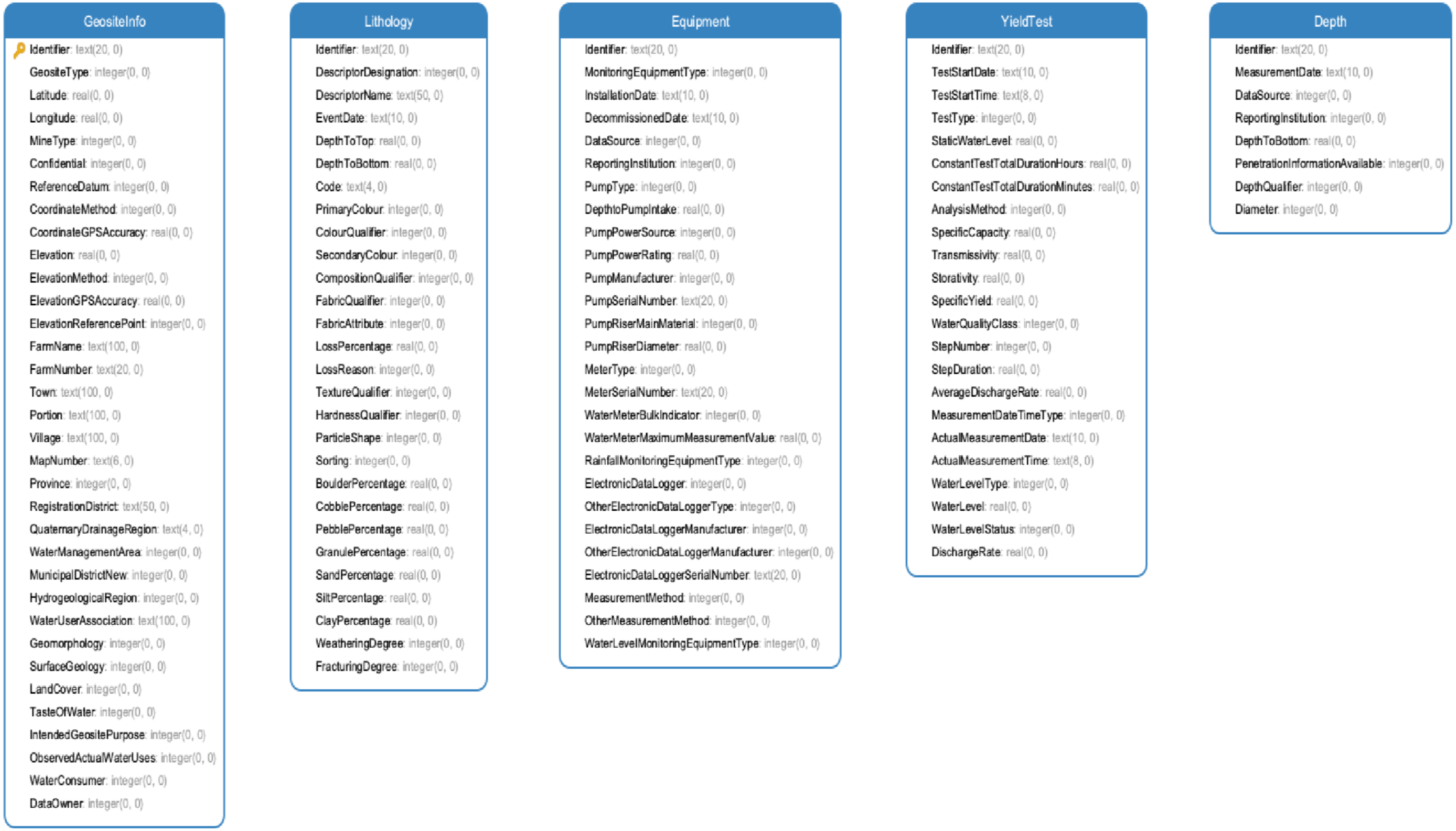
Equipment Installed Information (Non-Monitoring)

1	* Installed Date (ccyy-mm-dd)	2	Decommisioned Date (ccyy-mm-dd)
3	**Data Source**	☐ Check by Reporting Institution ☐ Driller's Log ☐ Geo Specialist's Record ☐ Memory	☐ Owner's Record ☐ Pump Operator's Record ☐ Report/File
4	* Pump Type	☐ Jet ☐ Mono Type Pump ☐ Positive Displacement	☐ Submersible Pump ☐ Turbine
5	**Depth to Pump Intake** (m below surface)		
6	**Pump Power Source**	☐ Compressed Air ☐ Electricity ☐ Fuel	☐ Hand ☐ Sun ☐ Wind
7	**Power Rating** (kW)		
8	**Pump Manufacturer**		
9	**Serial Number**		
10	**Riser Main Material**	☐ Flexible Hosing ☐ uPVC	☐ Steel
11	**Riser Diameter** (mm)		

Field Measurement Information

	Sampling point	☐ **NON - STATION**	☐ **STATION**
	* Sample #		
1	* Measurement Date (ccyy-mm-dd)		
2	* Measurement Time (hh:mm)		
3	**Measurement Depth** (m)		
4	* Electrical Conductivity (EC) (mS/m)		
	OR		
5	* pH (values 0-14)		
	OR		
6	* Temperature (°C)		
	OR		
7	* Bicarbonate (HCO_3) (mg/l)		
8	**Data Source**	☐ Check by Reporting Institution ☐ Driller's Log ☐ Geo Specialist's Record	☐ Owner's Record ☐ Pump Operator's Record ☐ Report / File
9	**Piezometer Number**		
		Water Sample For Chemical Analysis	
1	**Sampling Type**	☐ Groundwater ☐ Surface water	☐ Rainfall water
2	**Sampling Method**	☐ Irregular Interval GRAB ☐ Pumped	☐ Flowing
3	**Analyse for**	☒ Macro (Normal) ☐ Micro (Cl < 5 mg/l) ☐ Macro + Boron (B) ☐ Macro + Turb ☐ Al + Fe ☐ Total Organic Carbon (TOC)	☐ Macro + KN +TP ☐ Macro + B + KN +TP ☐ Toxicity ☐ Hg ☐ Trace Elements ☐ Li
		radio isotopes	
		☐ Carbon ^{14}C (radioactive) ☐ Tritium (Hydrogen ^{3}H (radioactive)) ☐ Chlorine ^{36}Cl (radioactive)	☐ Strontium ^{87}Sr ☐ Radon ^{222}Rn (radioactive)
		stable isotopes	
		☐ Deuterium (Hydrogen ^{2}H) ☐ Oxygen ^{16}O, ^{18}O ☐	☐ Carbon ^{12}C, ^{13}C ☐ Nitrogen ^{14}N ^{15}N ☐
4	**Preserve Type**	☐ Unpreserved ☐ Hg Cl_2 ☐ HNO_3	☐ H_2SO_4 ☐ Na OH ☐ Cooling
5	**Sampler Name & Initials**		
6	**FOR OFFICE USE ONLY**	**Sample number**	☐☐☐☐☐☐☐☐☐☐☐
			☐☐☐☐☐☐☐☐☐☐☐
			☐☐☐☐☐☐☐☐☐☐☐

ANNEXURE B: NGA DATABASE TABLES



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Longitude: real(0, 0)
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Confidential: integer(0, 0)
ReferenceDatum: integer(0, 0)
CoordinateMethod: integer(0, 0)
CoordinateGPSAccuracy: real(0, 0)
Elevation: real(0, 0)
ElevationMethod: integer(0, 0)
ElevationGPSAccuracy: real(0, 0)
ElevationReferencePoint: integer(0, 0)
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FarmNumber: text(20, 0)
Town: text(100, 0)
Portion: text(100, 0)
Village: text(100, 0)
MapNumber: text(6, 0)
Province: integer(0, 0)
RegistrationDistrict: text(50, 0)
QuaternaryDrainageRegion: text(4, 0)
WaterManagementArea: integer(0, 0)
MunicipalDistrictNew: integer(0, 0)
HydrogeologicalRegion: integer(0, 0)
WaterUserAssociation: text(100, 0)
Geomorphology: integer(0, 0)
SurfaceGeology: integer(0, 0)
LandCover: integer(0, 0)
TasteOfWater: integer(0, 0)
IntendedGeositePurpose: integer(0, 0)
ObservedActualWaterUses: integer(0, 0)
WaterConsumer: integer(0, 0)
DataOwner: integer(0, 0)

Lithology

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DescriptorName: text(50, 0)
EventDate: text(10, 0)
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DepthToBottom: real(0, 0)
Code: text(4, 0)
PrimaryColour: integer(0, 0)
ColourQualifier: integer(0, 0)
SecondaryColour: integer(0, 0)
CompositionQualifier: integer(0, 0)
FabricQualifier: integer(0, 0)
FabricAttribute: integer(0, 0)
LossPercentage: real(0, 0)
LossReason: integer(0, 0)
TextureQualifier: integer(0, 0)
HardnessQualifier: integer(0, 0)
ParticleShape: integer(0, 0)
Sorting: integer(0, 0)
BoulderPercentage: real(0, 0)
CobblePercentage: real(0, 0)
PebblePercentage: real(0, 0)
GranulePercentage: real(0, 0)
SandPercentage: real(0, 0)
SiltPercentage: real(0, 0)
ClayPercentage: real(0, 0)
WeatheringDegree: integer(0, 0)
FracturingDegree: integer(0, 0)

Equipment

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InstallationDate: text(10, 0)
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ReportingInstitution: integer(0, 0)
PumpType: integer(0, 0)
DepthtoPumpIntake: real(0, 0)
PumpPowerSource: integer(0, 0)
PumpPowerRating: real(0, 0)
PumpManufacturer: integer(0, 0)
PumpSerialNumber: text(20, 0)
PumpRiserMainMaterial: integer(0, 0)
PumpRiserDiameter: real(0, 0)
MeterType: integer(0, 0)
MeterSerialNumber: text(20, 0)
WaterMeterBulkIndicator: integer(0, 0)
WaterMeterMaximumMeasurementValue: real(0, 0)
RainfallMonitoringEquipmentType: integer(0, 0)
ElectronicDataLogger: integer(0, 0)
OtherElectronicDataLoggerType: integer(0, 0)
ElectronicDataLoggerManufacturer: integer(0, 0)
OtherElectronicDataLoggerManufacturer: integer(0, 0)
ElectronicDataLoggerSerialNumber: text(20, 0)
MeasurementMethod: integer(0, 0)
OtherMeasurementMethod: integer(0, 0)
WaterLevelMonitoringEquipmentType: integer(0, 0)

YieldTest

Identifier: text(20, 0)
TestStartDate: text(10, 0)
TestStartTime: text(8, 0)
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StaticWaterLevel: real(0, 0)
ConstantTestTotalDurationHours: real(0, 0)
ConstantTestTotalDurationMinutes: real(0, 0)
AnalysisMethod: integer(0, 0)
SpecificCapacity: real(0, 0)
Transmissivity: real(0, 0)
Storativity: real(0, 0)
SpecificYield: real(0, 0)
WaterQualityClass: integer(0, 0)
StepNumber: integer(0, 0)
StepDuration: real(0, 0)
AverageDischargeRate: real(0, 0)
MeasurementDateTimeType: integer(0, 0)
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ActualMeasurementTime: text(8, 0)
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WaterLevel: real(0, 0)
WaterLevelStatus: integer(0, 0)
DischargeRate: real(0, 0)

Depth

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MeasurementDate: text(10, 0)
DataSource: integer(0, 0)
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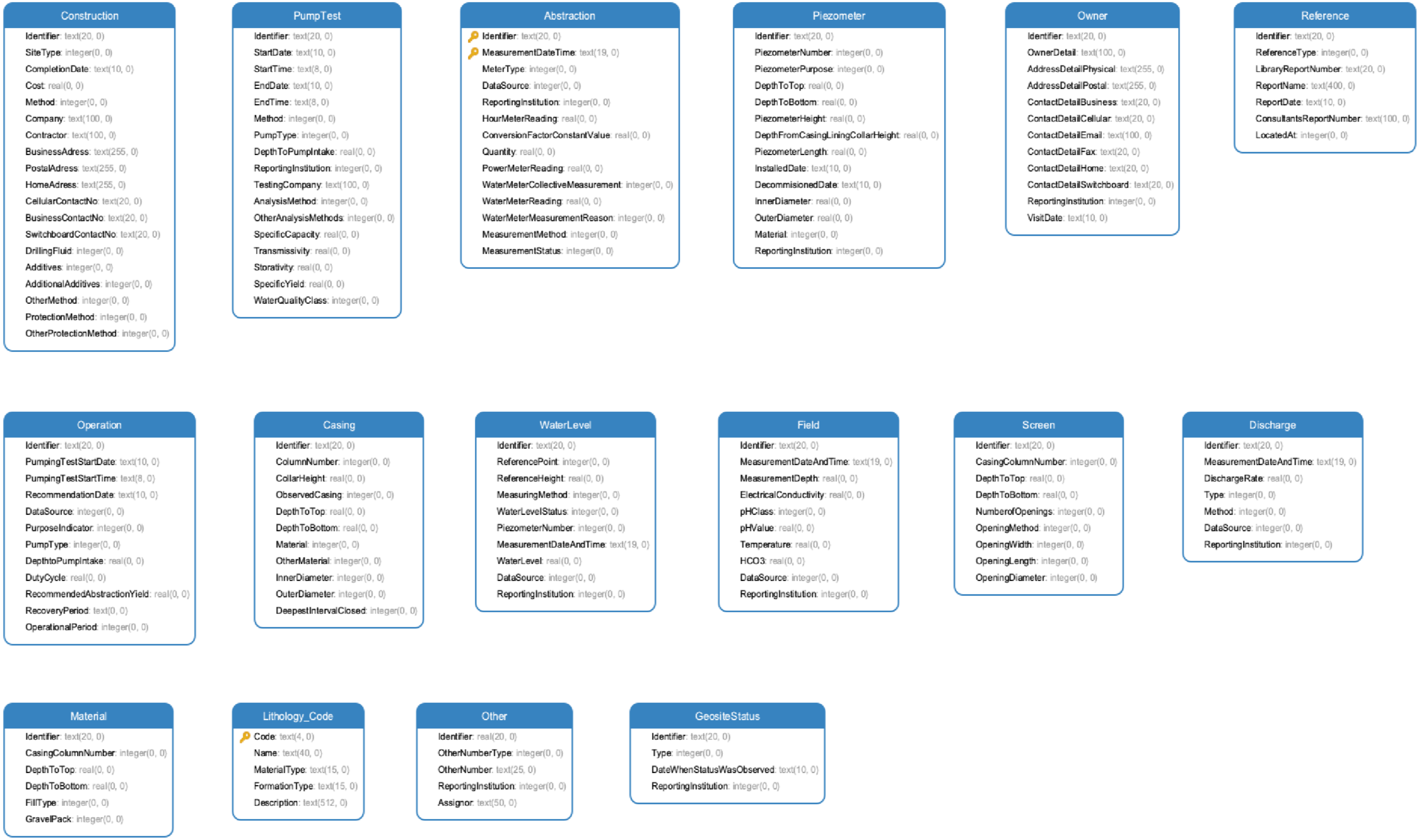
DepthQualifier: integer(0, 0)
Diameter: integer(0, 0)



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- SiteType: integer(0, 0)
- CompletionDate: text(10, 0)
- Cost: real(0, 0)
- Method: integer(0, 0)
- Company: text(100, 0)
- Contractor: text(100, 0)
- BusinessAdress: text(255, 0)
- PostalAdress: text(255, 0)
- HomeAdress: text(255, 0)
- CellularContactNo: text(20, 0)
- BusinessContactNo: text(20, 0)
- SwitchboardContactNo: text(20, 0)
- DrillingFluid: integer(0, 0)
- Additives: integer(0, 0)
- AdditionalAdditives: integer(0, 0)
- OtherMethod: integer(0, 0)
- ProtectionMethod: integer(0, 0)
- OtherProtectionMethod: integer(0, 0)

PumpTest
- Identifier: text(20, 0)
- StartDate: text(10, 0)
- StartTime: text(8, 0)
- EndDate: text(10, 0)
- EndTime: text(8, 0)
- Method: integer(0, 0)
- PumpType: integer(0, 0)
- DepthToPumpIntake: real(0, 0)
- ReportingInstitution: integer(0, 0)
- TestingCompany: text(100, 0)
- AnalysisMethod: integer(0, 0)
- OtherAnalysisMethods: integer(0, 0)
- SpecificCapacity: real(0, 0)
- Transmissivity: real(0, 0)
- Storativity: real(0, 0)
- SpecificYield: real(0, 0)
- WaterQualityClass: integer(0, 0)

Abstraction
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- 🔑 MeasurementDateTime: text(19, 0)
- MeterType: integer(0, 0)
- DataSource: integer(0, 0)
- ReportingInstitution: integer(0, 0)
- HourMeterReading: real(0, 0)
- ConversionFactorConstantValue: real(0, 0)
- Quantity: real(0, 0)
- PowerMeterReading: real(0, 0)
- WaterMeterCollectiveMeasurement: integer(0, 0)
- WaterMeterReading: real(0, 0)
- WaterMeterMeasurementReason: integer(0, 0)
- MeasurementMethod: integer(0, 0)
- MeasurementStatus: integer(0, 0)

Piezometer
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- PiezometerNumber: integer(0, 0)
- PiezometerPurpose: integer(0, 0)
- DepthToTop: real(0, 0)
- DepthToBottom: real(0, 0)
- PiezometerHeight: real(0, 0)
- DepthFromCasingLiningCollarHeight: real(0, 0)
- PiezometerLength: real(0, 0)
- InstalledDate: text(10, 0)
- DecommisionedDate: text(10, 0)
- InnerDiameter: real(0, 0)
- OuterDiameter: real(0, 0)
- Material: integer(0, 0)
- ReportingInstitution: integer(0, 0)

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- OwnerDetail: text(100, 0)
- AddressDetailPhysical: text(255, 0)
- AddressDetailPostal: text(255, 0)
- ContactDetailBusiness: text(20, 0)
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- ContactDetailEmail: text(100, 0)
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- ContactDetailSwitchboard: text(20, 0)
- ReportingInstitution: integer(0, 0)
- VisitDate: text(10, 0)

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- Identifier: text(20, 0)
- ReferenceType: integer(0, 0)
- LibraryReportNumber: text(20, 0)
- ReportName: text(400, 0)
- ReportDate: text(10, 0)
- ConsultantsReportNumber: text(100, 0)
- LocatedAt: integer(0, 0)

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- PumpingTestStartDate: text(10, 0)
- PumpingTestStartTime: text(8, 0)
- RecommendationDate: text(10, 0)
- DataSource: integer(0, 0)
- PurposeIndicator: integer(0, 0)
- PumpType: integer(0, 0)
- DepthtoPumpIntake: real(0, 0)
- DutyCycle: real(0, 0)
- RecommendedAbstractionYield: real(0, 0)
- RecoveryPeriod: text(0, 0)
- OperationalPeriod: integer(0, 0)

Casing
- Identifier: text(20, 0)
- ColumnNumber: integer(0, 0)
- CollarHeight: real(0, 0)
- ObservedCasing: integer(0, 0)
- DepthToTop: real(0, 0)
- DepthToBottom: real(0, 0)
- Material: integer(0, 0)
- OtherMaterial: integer(0, 0)
- InnerDiameter: integer(0, 0)
- OuterDiameter: integer(0, 0)
- DeepestIntervalClosed: integer(0, 0)

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- MeasuringMethod: integer(0, 0)
- WaterLevelStatus: integer(0, 0)
- PiezometerNumber: integer(0, 0)
- MeasurementDateAndTime: text(19, 0)
- WaterLevel: real(0, 0)
- DataSource: integer(0, 0)
- ReportingInstitution: integer(0, 0)

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- MeasurementDateAndTime: text(19, 0)
- MeasurementDepth: real(0, 0)
- ElectricalConductivity: real(0, 0)
- pHClass: integer(0, 0)
- pHValue: real(0, 0)
- Temperature: real(0, 0)
- HCO3: real(0, 0)
- DataSource: integer(0, 0)
- ReportingInstitution: integer(0, 0)

Screen
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- CasingColumnNumber: integer(0, 0)
- DepthToTop: real(0, 0)
- DepthToBottom: real(0, 0)
- NumberofOpenings: integer(0, 0)
- OpeningMethod: integer(0, 0)
- OpeningWidth: integer(0, 0)
- OpeningLength: integer(0, 0)
- OpeningDiameter: integer(0, 0)

Discharge
- Identifier: text(20, 0)
- MeasurementDateAndTime: text(19, 0)
- DischargeRate: real(0, 0)
- Type: integer(0, 0)
- Method: integer(0, 0)
- DataSource: integer(0, 0)
- ReportingInstitution: integer(0, 0)

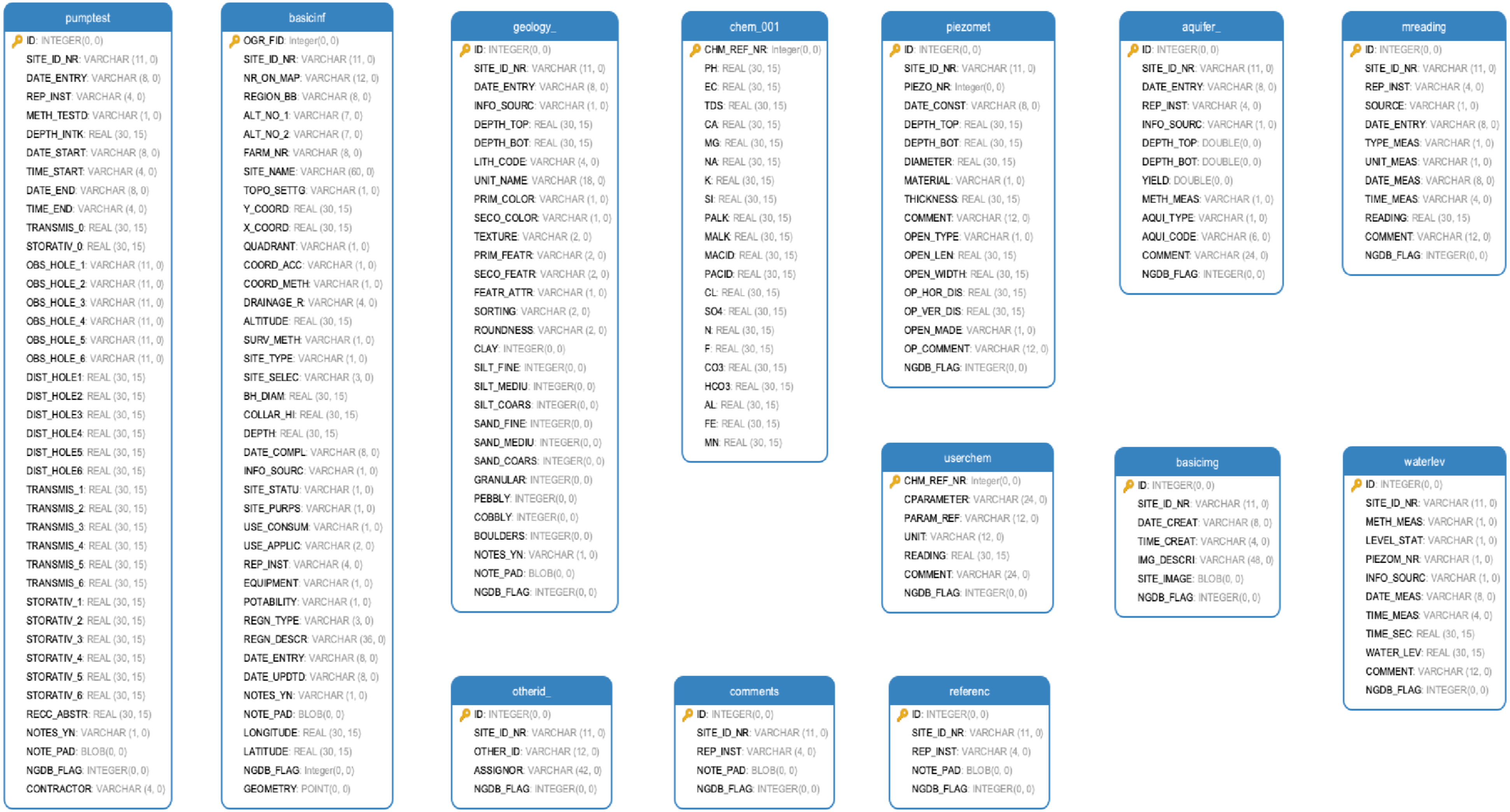
Material
- Identifier: text(20, 0)
- CasingColumnNumber: integer(0, 0)
- DepthToTop: real(0, 0)
- DepthToBottom: real(0, 0)
- FillType: integer(0, 0)
- GravelPack: integer(0, 0)

Lithology_Code
- 🔑 Code: text(4, 0)
- Name: text(40, 0)
- MaterialType: text(15, 0)
- FormationType: text(15, 0)
- Description: text(512, 0)

Other
- Identifier: real(20, 0)
- OtherNumberType: integer(0, 0)
- OtherNumber: text(25, 0)
- ReportingInstitution: integer(0, 0)
- Assignor: text(50, 0)

GeositeStatus
- Identifier: text(20, 0)
- Type: integer(0, 0)
- DateWhenStatusWasObserved: text(10, 0)
- ReportingInstitution: integer(0, 0)

ANNEXURE C: GRIP DATABASE TABLES



pumptest

ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
DATE_ENTRY: VARCHAR (8, 0)
REP_INST: VARCHAR (4, 0)
METH_TESTD: VARCHAR (1, 0)
DEPTH_INTK: REAL (30, 15)
DATE_START: VARCHAR (8, 0)
TIME_START: VARCHAR (4, 0)
DATE_END: VARCHAR (8, 0)
TIME_END: VARCHAR (4, 0)
TRANSMIS_0: REAL (30, 15)
STORATIV_0: REAL (30, 15)
OBS_HOLE_1: VARCHAR (11, 0)
OBS_HOLE_2: VARCHAR (11, 0)
OBS_HOLE_3: VARCHAR (11, 0)
OBS_HOLE_4: VARCHAR (11, 0)
OBS_HOLE_5: VARCHAR (11, 0)
OBS_HOLE_6: VARCHAR (11, 0)
DIST_HOLE1: REAL (30, 15)
DIST_HOLE2: REAL (30, 15)
DIST_HOLE3: REAL (30, 15)
DIST_HOLE4: REAL (30, 15)
DIST_HOLE5: REAL (30, 15)
DIST_HOLE6: REAL (30, 15)
TRANSMIS_1: REAL (30, 15)
TRANSMIS_2: REAL (30, 15)
TRANSMIS_3: REAL (30, 15)
TRANSMIS_4: REAL (30, 15)
TRANSMIS_5: REAL (30, 15)
TRANSMIS_6: REAL (30, 15)
STORATIV_1: REAL (30, 15)
STORATIV_2: REAL (30, 15)
STORATIV_3: REAL (30, 15)
STORATIV_4: REAL (30, 15)
STORATIV_5: REAL (30, 15)
STORATIV_6: REAL (30, 15)
RECC_ABSTR: REAL (30, 15)
NOTES_YN: VARCHAR (1, 0)
NOTE_PAD: BLOB(0, 0)
NGDB_FLAG: INTEGER(0, 0)
CONTRACTOR: VARCHAR (4, 0)

basicinf

OGR_FID: Integer(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
NR_ON_MAP: VARCHAR (12, 0)
REGION_BB: VARCHAR (8, 0)
ALT_NO_1: VARCHAR (7, 0)
ALT_NO_2: VARCHAR (7, 0)
FARM_NR: VARCHAR (8, 0)
SITE_NAME: VARCHAR (60, 0)
TOPO_SETTG: VARCHAR (1, 0)
Y_COORD: REAL (30, 15)
X_COORD: REAL (30, 15)
QUADRANT: VARCHAR (1, 0)
COORD_ACC: VARCHAR (1, 0)
COORD_METH: VARCHAR (1, 0)
DRAINAGE_R: VARCHAR (4, 0)
ALTITUDE: REAL (30, 15)
SURV_METH: VARCHAR (1, 0)
SITE_TYPE: VARCHAR (1, 0)
SITE_SELEC: VARCHAR (3, 0)
BH_DIAM: REAL (30, 15)
COLLAR_HI: REAL (30, 15)
DEPTH: REAL (30, 15)
DATE_COMPL: VARCHAR (8, 0)
INFO_SOURC: VARCHAR (1, 0)
SITE_STATU: VARCHAR (1, 0)
SITE_PURPS: VARCHAR (1, 0)
USE_CONSUM: VARCHAR (1, 0)
USE_APPLIC: VARCHAR (2, 0)
REP_INST: VARCHAR (4, 0)
EQUIPMENT: VARCHAR (1, 0)
POTABILITY: VARCHAR (1, 0)
REGN_TYPE: VARCHAR (3, 0)
REGN_DESCR: VARCHAR (36, 0)
DATE_ENTRY: VARCHAR (8, 0)
DATE_UPDTD: VARCHAR (8, 0)
NOTES_YN: VARCHAR (1, 0)
NOTE_PAD: BLOB(0, 0)
LONGITUDE: REAL (30, 15)
LATITUDE: REAL (30, 15)
NGDB_FLAG: Integer(0, 0)
GEOMETRY: POINT(0, 0)

geology_

ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
DATE_ENTRY: VARCHAR (8, 0)
INFO_SOURC: VARCHAR (1, 0)
DEPTH_TOP: REAL (30, 15)
DEPTH_BOT: REAL (30, 15)
LITH_CODE: VARCHAR (4, 0)
UNIT_NAME: VARCHAR (18, 0)
PRIM_COLOR: VARCHAR (1, 0)
SECO_COLOR: VARCHAR (1, 0)
TEXTURE: VARCHAR (2, 0)
PRIM_FEATR: VARCHAR (2, 0)
SECO_FEATR: VARCHAR (2, 0)
FEATR_ATTR: VARCHAR (1, 0)
SORTING: VARCHAR (2, 0)
ROUNDNESS: VARCHAR (2, 0)
CLAY: INTEGER(0, 0)
SILT_FINE: INTEGER(0, 0)
SILT_MEDIU: INTEGER(0, 0)
SILT_COARS: INTEGER(0, 0)
SAND_FINE: INTEGER(0, 0)
SAND_MEDIU: INTEGER(0, 0)
SAND_COARS: INTEGER(0, 0)
GRANULAR: INTEGER(0, 0)
PEBBLY: INTEGER(0, 0)
COBBLY: INTEGER(0, 0)
BOULDERS: INTEGER(0, 0)
NOTES_YN: VARCHAR (1, 0)
NOTE_PAD: BLOB(0, 0)
NGDB_FLAG: INTEGER(0, 0)

chem_001

CHM_REF_NR: Integer(0, 0)
PH: REAL (30, 15)
EC: REAL (30, 15)
TDS: REAL (30, 15)
CA: REAL (30, 15)
MG: REAL (30, 15)
NA: REAL (30, 15)
K: REAL (30, 15)
SI: REAL (30, 15)
PALK: REAL (30, 15)
MALK: REAL (30, 15)
MACID: REAL (30, 15)
PACID: REAL (30, 15)
CL: REAL (30, 15)
SO4: REAL (30, 15)
N: REAL (30, 15)
F: REAL (30, 15)
CO3: REAL (30, 15)
HCO3: REAL (30, 15)
AL: REAL (30, 15)
FE: REAL (30, 15)
MN: REAL (30, 15)

piezomet

ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
PIEZO_NR: Integer(0, 0)
DATE_CONST: VARCHAR (8, 0)
DEPTH_TOP: REAL (30, 15)
DEPTH_BOT: REAL (30, 15)
DIAMETER: REAL (30, 15)
MATERIAL: VARCHAR (1, 0)
THICKNESS: REAL (30, 15)
COMMENT: VARCHAR (12, 0)
OPEN_TYPE: VARCHAR (1, 0)
OPEN_LEN: REAL (30, 15)
OPEN_WIDTH: REAL (30, 15)
OP_HOR_DIS: REAL (30, 15)
OP_VER_DIS: REAL (30, 15)
OPEN_MADE: VARCHAR (1, 0)
OP_COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

aquifer_

ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
DATE_ENTRY: VARCHAR (8, 0)
REP_INST: VARCHAR (4, 0)
INFO_SOURC: VARCHAR (1, 0)
DEPTH_TOP: DOUBLE(0, 0)
DEPTH_BOT: DOUBLE(0, 0)
YIELD: DOUBLE(0, 0)
METH_MEAS: VARCHAR (1, 0)
AQUI_TYPE: VARCHAR (1, 0)
AQUI_CODE: VARCHAR (6, 0)
COMMENT: VARCHAR (24, 0)
NGDB_FLAG: INTEGER(0, 0)

mreading

ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
SOURCE: VARCHAR (1, 0)
DATE_ENTRY: VARCHAR (8, 0)
TYPE_MEAS: VARCHAR (1, 0)
UNIT_MEAS: VARCHAR (1, 0)
DATE_MEAS: VARCHAR (8, 0)
TIME_MEAS: VARCHAR (4, 0)
READING: REAL (30, 15)
COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

userchem

CHM_REF_NR: Integer(0, 0)
CPARAMETER: VARCHAR (24, 0)
PARAM_REF: VARCHAR (12, 0)
UNIT: VARCHAR (12, 0)
READING: REAL (30, 15)
COMMENT: VARCHAR (24, 0)
NGDB_FLAG: INTEGER(0, 0)

basicimg

ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
DATE_CREAT: VARCHAR (8, 0)
TIME_CREAT: VARCHAR (4, 0)
IMG_DESCRI: VARCHAR (48, 0)
SITE_IMAGE: BLOB(0, 0)
NGDB_FLAG: INTEGER(0, 0)

waterlev

ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
METH_MEAS: VARCHAR (1, 0)
LEVEL_STAT: VARCHAR (1, 0)
PIEZOM_NR: VARCHAR (1, 0)
INFO_SOURC: VARCHAR (1, 0)
DATE_MEAS: VARCHAR (8, 0)
TIME_MEAS: VARCHAR (4, 0)
TIME_SEC: REAL (30, 15)
WATER_LEV: REAL (30, 15)
COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

otherid_

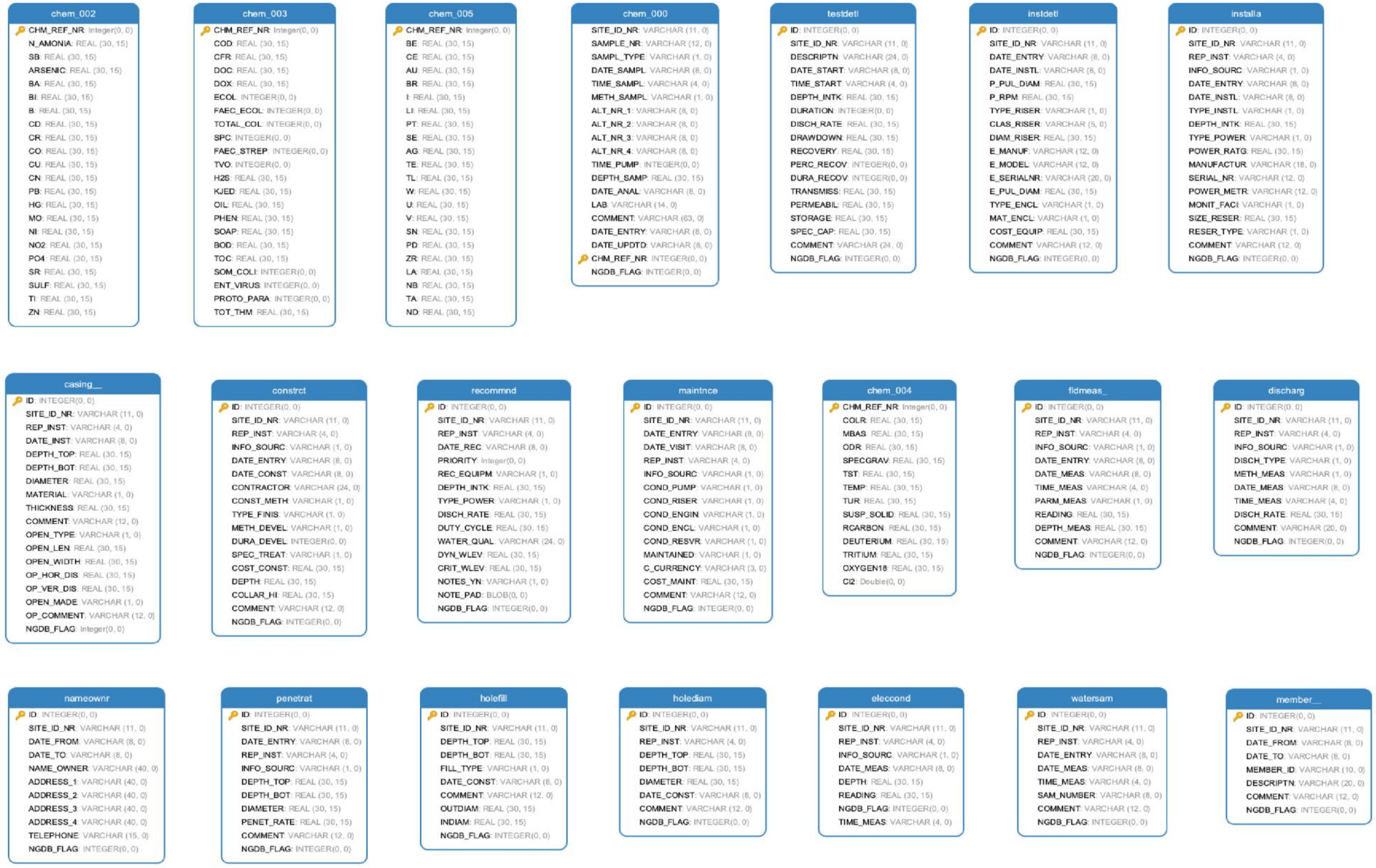
ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
OTHER_ID: VARCHAR (12, 0)
ASSIGNOR: VARCHAR (42, 0)
NGDB_FLAG: INTEGER(0, 0)

comments

ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
NOTE_PAD: BLOB(0, 0)
NGDB_FLAG: INTEGER(0, 0)

referenc

ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
NOTE_PAD: BLOB(0, 0)
NGDB_FLAG: INTEGER(0, 0)



chem_002
🔑 CHM_REF_NR: Integer(0, 0)
N_AMONIA: REAL (30, 15)
SB: REAL (30, 15)
ARSENIC: REAL (30, 15)
BA: REAL (30, 15)
BI: REAL (30, 15)
B: REAL (30, 15)
CD: REAL (30, 15)
CR: REAL (30, 15)
CO: REAL (30, 15)
CU: REAL (30, 15)
CN: REAL (30, 15)
PB: REAL (30, 15)
HG: REAL (30, 15)
MO: REAL (30, 15)
NI: REAL (30, 15)
NO2: REAL (30, 15)
PO4: REAL (30, 15)
SR: REAL (30, 15)
SULF: REAL (30, 15)
TI: REAL (30, 15)
ZN: REAL (30, 15)

chem_003
🔑 CHM_REF_NR: Integer(0, 0)
COD: REAL (30, 15)
CFR: REAL (30, 15)
DOC: REAL (30, 15)
DOX: REAL (30, 15)
ECOL: INTEGER(0, 0)
FAEC_ECOL: INTEGER(0, 0)
TOTAL_COL: INTEGER(0, 0)
SPC: INTEGER(0, 0)
FAEC_STREP: INTEGER(0, 0)
TVO: INTEGER(0, 0)
H2S: REAL (30, 15)
KJED: REAL (30, 15)
OIL: REAL (30, 15)
PHEN: REAL (30, 15)
SOAP: REAL (30, 15)
BOD: REAL (30, 15)
TOC: REAL (30, 15)
SOM_COLI: INTEGER(0, 0)
ENT_VIRUS: INTEGER(0, 0)
PROTO_PARA: INTEGER(0, 0)
TOT_THM: REAL (30, 15)

chem_005
🔑 CHM_REF_NR: Integer(0, 0)
BE: REAL (30, 15)
CE: REAL (30, 15)
AU: REAL (30, 15)
BR: REAL (30, 15)
I: REAL (30, 15)
LI: REAL (30, 15)
PT: REAL (30, 15)
SE: REAL (30, 15)
AG: REAL (30, 15)
TE: REAL (30, 15)
TL: REAL (30, 15)
W: REAL (30, 15)
U: REAL (30, 15)
V: REAL (30, 15)
SN: REAL (30, 15)
PD: REAL (30, 15)
ZR: REAL (30, 15)
LA: REAL (30, 15)
NB: REAL (30, 15)
TA: REAL (30, 15)
ND: REAL (30, 15)

chem_000
SITE_ID_NR: VARCHAR (11, 0)
SAMPLE_NR: VARCHAR (12, 0)
SAMPL_TYPE: VARCHAR (1, 0)
DATE_SAMPL: VARCHAR (8, 0)
TIME_SAMPL: VARCHAR (4, 0)
METH_SAMPL: VARCHAR (1, 0)
ALT_NR_1: VARCHAR (8, 0)
ALT_NR_2: VARCHAR (8, 0)
ALT_NR_3: VARCHAR (8, 0)
ALT_NR_4: VARCHAR (8, 0)
TIME_PUMP: INTEGER(0, 0)
DEPTH_SAMP: REAL (30, 15)
DATE_ANAL: VARCHAR (8, 0)
LAB: VARCHAR (14, 0)
COMMENT: VARCHAR (63, 0)
DATE_ENTRY: VARCHAR (8, 0)
DATE_UPDTD: VARCHAR (8, 0)
🔑 CHM_REF_NR: INTEGER(0, 0)
NGDB_FLAG: INTEGER(0, 0)

testdetl
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
DESCRIPTN: VARCHAR (24, 0)
DATE_START: VARCHAR (8, 0)
TIME_START: VARCHAR (4, 0)
DEPTH_INTK: REAL (30, 15)
DURATION: INTEGER(0, 0)
DISCH_RATE: REAL (30, 15)
DRAWDOWN: REAL (30, 15)
RECOVERY: REAL (30, 15)
PERC_RECOV: INTEGER(0, 0)
DURA_RECOV: INTEGER(0, 0)
TRANSMISS: REAL (30, 15)
PERMEABIL: REAL (30, 15)
STORAGE: REAL (30, 15)
SPEC_CAP: REAL (30, 15)
COMMENT: VARCHAR (24, 0)
NGDB_FLAG: INTEGER(0, 0)

instdetl
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
DATE_ENTRY: VARCHAR (8, 0)
DATE_INSTL: VARCHAR (8, 0)
P_PUL_DIAM: REAL (30, 15)
P_RPM: REAL (30, 15)
TYPE_RISER: VARCHAR (1, 0)
CLAS_RISER: VARCHAR (5, 0)
DIAM_RISER: REAL (30, 15)
E_MANUF: VARCHAR (12, 0)
E_MODEL: VARCHAR (12, 0)
E_SERIALNR: VARCHAR (20, 0)
E_PUL_DIAM: REAL (30, 15)
TYPE_ENCL: VARCHAR (1, 0)
MAT_ENCL: VARCHAR (1, 0)
COST_EQUIP: REAL (30, 15)
COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

installa
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
INFO_SOURC: VARCHAR (1, 0)
DATE_ENTRY: VARCHAR (8, 0)
DATE_INSTL: VARCHAR (8, 0)
TYPE_INSTL: VARCHAR (1, 0)
DEPTH_INTK: REAL (30, 15)
TYPE_POWER: VARCHAR (1, 0)
POWER_RATG: REAL (30, 15)
MANUFACTUR: VARCHAR (18, 0)
SERIAL_NR: VARCHAR (12, 0)
POWER_METR: VARCHAR (12, 0)
MONIT_FACI: VARCHAR (1, 0)
SIZE_RESER: REAL (30, 15)
RESER_TYPE: VARCHAR (1, 0)
COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

casing__
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
DATE_INST: VARCHAR (8, 0)
DEPTH_TOP: REAL (30, 15)
DEPTH_BOT: REAL (30, 15)
DIAMETER: REAL (30, 15)
MATERIAL: VARCHAR (1, 0)
THICKNESS: REAL (30, 15)
COMMENT: VARCHAR (12, 0)
OPEN_TYPE: VARCHAR (1, 0)
OPEN_LEN: REAL (30, 15)
OPEN_WIDTH: REAL (30, 15)
OP_HOR_DIS: REAL (30, 15)
OP_VER_DIS: REAL (30, 15)
OPEN_MADE: VARCHAR (1, 0)
OP_COMMENT: VARCHAR (12, 0)
NGDB_FLAG: Integer(0, 0)

constrct
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
INFO_SOURC: VARCHAR (1, 0)
DATE_ENTRY: VARCHAR (8, 0)
DATE_CONST: VARCHAR (8, 0)
CONTRACTOR: VARCHAR (24, 0)
CONST_METH: VARCHAR (1, 0)
TYPE_FINIS: VARCHAR (1, 0)
METH_DEVEL: VARCHAR (1, 0)
DURA_DEVEL: INTEGER(0, 0)
SPEC_TREAT: VARCHAR (1, 0)
COST_CONST: REAL (30, 15)
DEPTH: REAL (30, 15)
COLLAR_HI: REAL (30, 15)
COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

recommnd
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
DATE_REC: VARCHAR (8, 0)
PRIORITY: Integer(0, 0)
REC_EQUIPM: VARCHAR (1, 0)
DEPTH_INTK: REAL (30, 15)
TYPE_POWER: VARCHAR (1, 0)
DISCH_RATE: REAL (30, 15)
DUTY_CYCLE: REAL (30, 15)
WATER_QUAL: VARCHAR (24, 0)
DYN_WLEV: REAL (30, 15)
CRIT_WLEV: REAL (30, 15)
NOTES_YN: VARCHAR (1, 0)
NOTE_PAD: BLOB(0, 0)
NGDB_FLAG: INTEGER(0, 0)

maintnce
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
DATE_ENTRY: VARCHAR (8, 0)
DATE_VISIT: VARCHAR (8, 0)
REP_INST: VARCHAR (4, 0)
INFO_SOURC: VARCHAR (1, 0)
COND_PUMP: VARCHAR (1, 0)
COND_RISER: VARCHAR (1, 0)
COND_ENGIN: VARCHAR (1, 0)
COND_ENCL: VARCHAR (1, 0)
COND_RESVR: VARCHAR (1, 0)
MAINTAINED: VARCHAR (1, 0)
C_CURRENCY: VARCHAR (3, 0)
COST_MAINT: REAL (30, 15)
COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

chem_004
🔑 CHM_REF_NR: Integer(0, 0)
COLR: REAL (30, 15)
MBAS: REAL (30, 15)
ODR: REAL (30, 15)
SPECGRAV: REAL (30, 15)
TST: REAL (30, 15)
TEMP: REAL (30, 15)
TUR: REAL (30, 15)
SUSP_SOLID: REAL (30, 15)
RCARBON: REAL (30, 15)
DEUTERIUM: REAL (30, 15)
TRITIUM: REAL (30, 15)
OXYGEN18: REAL (30, 15)
Cl2: Double(0, 0)

fldmeas_
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
INFO_SOURC: VARCHAR (1, 0)
DATE_ENTRY: VARCHAR (8, 0)
DATE_MEAS: VARCHAR (8, 0)
TIME_MEAS: VARCHAR (4, 0)
PARM_MEAS: VARCHAR (1, 0)
READING: REAL (30, 15)
DEPTH_MEAS: REAL (30, 15)
COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

discharg
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
INFO_SOURC: VARCHAR (1, 0)
DISCH_TYPE: VARCHAR (1, 0)
METH_MEAS: VARCHAR (1, 0)
DATE_MEAS: VARCHAR (8, 0)
TIME_MEAS: VARCHAR (4, 0)
DISCH_RATE: REAL (30, 15)
COMMENT: VARCHAR (20, 0)
NGDB_FLAG: INTEGER(0, 0)

nameownr
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
DATE_FROM: VARCHAR (8, 0)
DATE_TO: VARCHAR (8, 0)
NAME_OWNER: VARCHAR (40, 0)
ADDRESS_1: VARCHAR (40, 0)
ADDRESS_2: VARCHAR (40, 0)
ADDRESS_3: VARCHAR (40, 0)
ADDRESS_4: VARCHAR (40, 0)
TELEPHONE: VARCHAR (15, 0)
NGDB_FLAG: INTEGER(0, 0)

penetrat
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
DATE_ENTRY: VARCHAR (8, 0)
REP_INST: VARCHAR (4, 0)
INFO_SOURC: VARCHAR (1, 0)
DEPTH_TOP: REAL (30, 15)
DEPTH_BOT: REAL (30, 15)
DIAMETER: REAL (30, 15)
PENET_RATE: REAL (30, 15)
COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

holefill
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
DEPTH_TOP: REAL (30, 15)
DEPTH_BOT: REAL (30, 15)
FILL_TYPE: VARCHAR (1, 0)
DATE_CONST: VARCHAR (8, 0)
COMMENT: VARCHAR (12, 0)
OUTDIAM: REAL (30, 15)
INDIAM: REAL (30, 15)
NGDB_FLAG: INTEGER(0, 0)

holediam
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
DEPTH_TOP: REAL (30, 15)
DEPTH_BOT: REAL (30, 15)
DIAMETER: REAL (30, 15)
DATE_CONST: VARCHAR (8, 0)
COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

eleccond
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
INFO_SOURC: VARCHAR (1, 0)
DATE_MEAS: VARCHAR (8, 0)
DEPTH: REAL (30, 15)
READING: REAL (30, 15)
NGDB_FLAG: INTEGER(0, 0)
TIME_MEAS: VARCHAR (4, 0)

watersam
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
REP_INST: VARCHAR (4, 0)
DATE_ENTRY: VARCHAR (8, 0)
DATE_MEAS: VARCHAR (8, 0)
TIME_MEAS: VARCHAR (4, 0)
SAM_NUMBER: VARCHAR (8, 0)
COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

member__
🔑 ID: INTEGER(0, 0)
SITE_ID_NR: VARCHAR (11, 0)
DATE_FROM: VARCHAR (8, 0)
DATE_TO: VARCHAR (8, 0)
MEMBER_ID: VARCHAR (10, 0)
DESCRIPTN: VARCHAR (20, 0)
COMMENT: VARCHAR (12, 0)
NGDB_FLAG: INTEGER(0, 0)

ANNEXURE D: SQL CODE (DDL)

```
CREATE TABLE "BasicInfo" (
  "LocalityID" TEXT(24),
  "StatusID" INTEGER,
  "PurposeID" INTEGER,
  "ConsumerID" INTEGER,
  "PotabilityID" INTEGER,
  "UseID" TEXT
);

CREATE TABLE "BasicInfo_Consumer" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "BasicInfo_Potability" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "BasicInfo_Purpose" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "BasicInfo_Status" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "BasicInfo_Use" (
  "ID" integer NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" text(80)
);

CREATE TABLE "Casing" (
  "LocalityID" TEXT(24),
  "Date" DATE,
  "GUID" TEXT(32)
);

CREATE TABLE "Casing_DATA" (
  "GUID" TEXT(32),
  "CollarHeight" REAL,
  "DepthToTop" REAL,
  "DepthToBottom" REAL,
  "MaterialID" INTEGER,
  "OuterDiameter" INTEGER,
  "InnerDiameter" INTEGER,
```

```
  "Thickness" INTEGER,
  "OpeningTypeID" INTEGER,
  "OpeningMethodID" INTEGER,
  "OpeningWidth" INTEGER,
  "OpeningLength" INTEGER,
  "OpeningDiameter" INTEGER
);

CREATE TABLE "Casing_Material" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Casing_OpeningMethod" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Casing_OpeningType" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Chem_Symbol" (
  "Symbol" text(16) NOT NULL,
  "Description" text(128),
  "Unit" text(16),
  "UnitDesc" text(32),
  "Type" text(16),
  PRIMARY KEY ("Symbol")
);

CREATE TABLE "ChemCalc" (
  "LocalityID" text(24),
  "DateTime" DATE,
  "Symbol" text(16),
  "Value" real
);

CREATE TABLE "ChemIsotope" (
  "LocalityID" text(24),
  "DateTime" DATE,
  "Symbol" text(16),
  "Value" real
);

CREATE TABLE "ChemMajor" (
  "LocalityID" text(24),
  "DateTime" DATE,
  "Symbol" text(10),
  "Value" real
```

```
);

CREATE TABLE "ChemMinor" (
  "LocalityID" text(24),
  "DateTime" DATE,
  "Symbol" text(16),
  "Value" real
);

CREATE TABLE "ChemOrganic" (
  "LocalityID" text(24),
  "DateTime" DATE,
  "Symbol" text(16),
  "Value" real
);

CREATE TABLE "ChemPhysical" (
  "LocalityID" text(24),
  "DateTime" DATE,
  "Symbol" text(16),
  "Value" real
);

CREATE TABLE "Construction" (
  "LocalityID" TEXT(24),
  "Date" DATE,
  "Contractor" TEXT(128),
  "MethodID" INTEGER,
  "FinishingID" INTEGER,
  "DevelopmentID" INTEGER,
  "DrillingID" INTEGER,
  "AdditivesID" INTEGER,
  "SpecialID" INTEGER
);

CREATE TABLE "Construction_Additives" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Construction_Development" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Construction_Drilling" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Construction_Finishing" (
```

```
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Construction_Method" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Construction_Special" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Depth" (
  "LocalityID" TEXT(24),
  "Date" DATE,
  "GUID" TEXT(32)
);

CREATE TABLE "Depth_DATA" (
  "GUID" TEXT(32),
  "DepthToTop" REAL,
  "DepthToBottom" REAL,
  "Diameter" REAL,
  "QualifierID" INTEGER
);

CREATE TABLE "Depth_Qualifier" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Discharge" (
  "LocalityID" TEXT(24),
  "DateTime" DATE,
  "Discharge" REAL,
  "TypeID" INTEGER,
  "MethodID" INTEGER
);

CREATE TABLE "Discharge_Method" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Discharge_Type" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);
```

```
CREATE TABLE "Fill" (
  "LocalityID" TEXT(24),
  "Date" DATE,
  "GUID" TEXT(32)
);

CREATE TABLE "Fill_DATA" (
  "GUID" TEXT(32),
  "DepthToTop" REAL,
  "DepthToBottom" REAL,
  "TypeID" INTEGER,
  "OuterDiameter" REAL,
  "InnerDiameter" REAL
);

CREATE TABLE "Fill_Type" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Lithology" (
  "LocalityID" TEXT(24),
  "Date" DATE,
  "GUID" TEXT(32)
);

CREATE TABLE "Lithology_Code" (
  "Code" TEXT(4),
  "Name" TEXT(64),
  "MaterialType" TEXT(16),
  "FormationType" TEXT(16),
  "Description" TEXT(512)
);

CREATE TABLE "Lithology_ColorQualifier" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Lithology_Composition" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Lithology_DATA" (
  "GUID" TEXT(32),
  "DepthToTop" REAL,
  "DepthToBottom" REAL,
  "Code" TEXT(4),
  "PrimaryColorID" INTEGER,
  "SecondaryColorID" INTEGER,
```

```
  "ColorQualifierID" INTEGER,
  "CompositionID" INTEGER,
  "PrimaryFabricID" INTEGER,
  "SecondaryFabricID" INTEGER,
  "FabricAttributeID" INTEGER,
  "TextureID" INTEGER,
  "HardnessID" INTEGER,
  "RoundnessID" INTEGER,
  "SortingID" INTEGER,
  "WeatheringID" INTEGER,
  "FracturingID" INTEGER
);

CREATE TABLE "Lithology_Fabric" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Lithology_FabricAttribute" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Lithology_Fracturing" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Lithology_Hardness" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Lithology_PrimaryColor" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Lithology_Roundness" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Lithology_SecondaryColor" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Lithology_Sorting" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
```

```
);

CREATE TABLE "Lithology_Texture" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Lithology_Weathering" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Locality" (
  "LocalityID" TEXT(24),
  "Latitude" REAL,
  "Longitude" REAL,
  "MergeID" TEXT(24),
  "TypeID" INTEGER,
  "StatusID" INTEGER
);

CREATE TABLE "Locality_Status" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Locality_Type" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Meter" (
  "LocalityID" TEXT(24),
  "GUID" TEXT(32),
  "TypeID" INTEGER,
  "Date" DATE,
  "Serial" TEXT(128),
  "UnitID" INTEGER,
  "Initial" REAL,
  "Maximum" REAL,
  "Constant" REAL
);

CREATE TABLE "Meter_Type" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Meter_Unit" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
```

```
);

CREATE TABLE "Observer" (
  "AGOLName" TEXT(128),
  "FirstName" TEXT(100),
  "LastName" TEXT(100),
  "Email" TEXT(100),
  "Phone" TEXT(16),
  "Rating" INTEGER,
  "Credits" INTEGER,
  "OrgID" INTEGER
);

CREATE TABLE "Organization" (
  "OrgID" INTEGER,
  "AGOLAdmin0" TEXT(128),
  "AGOLAdmin1" TEXT(128),
  "AGOLAdmin2" TEXT(128),
  "Name" TEXT(100),
  "Email" TEXT(100),
  "Phone" TEXT(16),
  "Address" TEXT(100),
  "Website" TEXT(100),
  "Credits" INTEGER
);

CREATE TABLE "OtherNumber" (
  "LocalityID" TEXT(24),
  "TypeID" INTEGER,
  "OtherNumber" TEXT(24)
);

CREATE TABLE "OtherNumber_Type" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Pump" (
  "LocalityID" TEXT(24),
  "InstallDate" DATE,
  "TypeID" INTEGER,
  "DepthToIntake" REAL,
  "PowerSourceID" INTEGER,
  "PowerRating" REAL,
  "ManufacturerID" INTEGER,
  "OtherManufacturer" TEXT(32),
  "Model" TEXT(32),
  "SerialNumber" TEXT(32),
  "RiserMaterialID" INTEGER,
  "RiserDiameter" REAL
);
```

```
CREATE TABLE "Pump_Manufacturer" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Pump_PowerSource" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Pump_RiserMaterial" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Pump_Type" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "PumpTest" (
  "LocalityID" TEXT(24),
  "GUID" TEXT(32),
  "TypeID" INTEGER,
  "StartDateTime" DATE,
  "EndDateTime" DATE,
  "Duration" INTEGER,
  "DepthToIntake" REAL,
  "Discharge" REAL
);

CREATE TABLE "PumpTest_Type" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "PumpTestObservation" (
  "GUID" TEXT(32),
  "ObservationID" TEXT(24)
);

CREATE TABLE "PumpTestParams" (
  "GUID" TEXT(32),
  "Transmissivity" REAL,
  "Permeability" REAL,
  "Storage" REAL,
  "SpecificCapacity" REAL
);

CREATE TABLE "Reading" (
```

```
  "GUID" TEXT(32),
  "DateTime" DATE,
  "Reading" REAL,
  "ReasonID" INTEGER,
  "MethodID" INTEGER
);

CREATE TABLE "Reading_Method" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Reading_Reason" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Recommended" (
  "LocalityID" TEXT(24),
  "Date" DATE,
  "Priority" INTEGER,
  "PurposeID" INTEGER,
  "PumpID" INTEGER,
  "PowerID" INTEGER,
  "DepthToIntake" REAL,
  "Abstraction" REAL,
  "DutyCycle" INTEGER,
  "DynamicLevel" REAL,
  "CriticalLevel" REAL
);

CREATE TABLE "Recommended_Power" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Recommended_Pump" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Recommended_Purpose" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "Sample" (
  "LocalityID" TEXT(24),
  "DateTime" DATE,
  "SampleNo" TEXT(24),
  "AltNumber" TEXT(24),
```

```
  "TypeID" INTEGER,
  "MethodID" INTEGER,
  "TimePumped" REAL,
  "Depth" REAL,
  "LabDate" DATE,
  "LabID" INTEGER,
  "LabOther" TEXT(40)
);

CREATE TABLE "Sample_Lab" (
  "ID" INTEGER NOT NULL,
  "Description" TEXT(100),
  PRIMARY KEY ("ID")
);

CREATE TABLE "Sample_Method" (
  "ID" integer NOT NULL,
  "Description" text(50),
  PRIMARY KEY ("ID")
);

CREATE TABLE "Sample_Type" (
  "ID" integer NOT NULL,
  "Description" text(50),
  PRIMARY KEY ("ID")
);

CREATE TABLE "SiteInfo" (
  "LocalityID" TEXT(24),
  "Latitude" REAL,
  "Longitude" REAL,
  "Elevation" REAL,
  "TypeID" INTEGER,
  "CoordMethodID" INTEGER,
  "ElevationMethodID" INTEGER,
  "ElevationReferenceID" INTEGER,
  "StatusID" INTEGER
);

CREATE TABLE "SiteInfo_CoordMethod" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "SiteInfo_ElevationMethod" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "SiteInfo_ElevationReference" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
```

```
  "Description" TEXT(100)
);

CREATE TABLE "WaterLevel" (
  "LocalityID" TEXT(24),
  "ReferencePointID" INTEGER,
  "ReferenceHeight" REAL,
  "MeasuringMethodID" INTEGER,
  "WaterLevelStatusID" INTEGER,
  "PiezometerNumber" TEXT(2),
  "DateTime" DATE,
  "WaterLevel" REAL
);

CREATE TABLE "WaterLevel_MeasuringMethod" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "WaterLevel_ReferencePoint" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "WaterLevel_Status" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "WaterStrike" (
  "LocalityID" TEXT(24),
  "Date" DATE,
  "GUID" TEXT(32)
);

CREATE TABLE "WaterStrike_DATA" (
  "GUID" TEXT(32),
  "DepthToTop" REAL,
  "DepthToBottom" REAL,
  "Yield" REAL,
  "TypeID" INTEGER,
  "MethodID" INTEGER
);

CREATE TABLE "WaterStrike_Method" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
  "Description" TEXT(100)
);

CREATE TABLE "WaterStrike_Type" (
  "ID" INTEGER NOT NULL PRIMARY KEY AUTOINCREMENT,
```

```
  "Description" TEXT(100)
);
```

ANNEXURE E: DATABASE TABLE SPECIFICATIONS

BasicInfo

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	StatusID	INTEGER	Allow Null
	PurposeID	INTEGER	Allow Null
	ConsumerID	INTEGER	Allow Null
	PotabilityID	INTEGER	Allow Null
	UseID	TEXT	Allow Null

BasicInfo_Consumer

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

BasicInfo_Potability

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

BasicInfo_Purpose

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

BasicInfo_Status

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

BasicInfo_Use

	Field	Type	Extra
P	ID	integer	Auto Increment
	Description	text(80)	Allow Null

Casing

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	Date	DATE	Allow Null
	GUID	TEXT(32)	Allow Null

Casing_DATA

	Field	Type	Extra
	GUID	TEXT(32)	Allow Null

	CollarHeight	REAL	Allow Null
	DepthToTop	REAL	Allow Null
	DepthToBottom	REAL	Allow Null
	MaterialID	INTEGER	Allow Null
	OuterDiameter	INTEGER	Allow Null
	InnerDiameter	INTEGER	Allow Null
	Thickness	INTEGER	Allow Null
	OpeningTypeID	INTEGER	Allow Null
	OpeningMethodID	INTEGER	Allow Null
	OpeningWidth	INTEGER	Allow Null
	OpeningLength	INTEGER	Allow Null
	OpeningDiameter	INTEGER	Allow Null

Casing_Material

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Casing_OpeningMethod

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Casing_OpeningType

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Chem_Symbol

	Field	Type	Extra
P	Symbol	text(16)	
	Description	text(128)	Allow Null
	Unit	text(16)	Allow Null
	UnitDesc	text(32)	Allow Null
	Type	text(16)	Allow Null

ChemCalc

	Field	Type	Extra
	LocalityID	text(24)	Allow Null
	DateTime	DATE	Allow Null
	Symbol	text(16)	Allow Null
	Value	real	Allow Null

ChemIsotope

	Field	Type	Extra
	LocalityID	text(24)	Allow Null

DateTime	DATE	Allow Null
Symbol	text(16)	Allow Null
Value	real	Allow Null

ChemMajor

Field	Type	Extra
LocalityID	text(24)	Allow Null
DateTime	DATE	Allow Null
Symbol	text(10)	Allow Null
Value	real	Allow Null

ChemMinor

Field	Type	Extra
LocalityID	text(24)	Allow Null
DateTime	DATE	Allow Null
Symbol	text(16)	Allow Null
Value	real	Allow Null

ChemOrganic

Field	Type	Extra
LocalityID	text(24)	Allow Null
DateTime	DATE	Allow Null
Symbol	text(16)	Allow Null
Value	real	Allow Null

ChemPhysical

Field	Type	Extra
LocalityID	text(24)	Allow Null
DateTime	DATE	Allow Null
Symbol	text(16)	Allow Null
Value	real	Allow Null

Construction

Field	Type	Extra
LocalityID	TEXT(24)	Allow Null
Date	DATE	Allow Null
Contractor	TEXT(128)	Allow Null
MethodID	INTEGER	Allow Null
FinishingID	INTEGER	Allow Null
DevelopmentID	INTEGER	Allow Null
DrillingID	INTEGER	Allow Null
AdditivesID	INTEGER	Allow Null
SpecialID	INTEGER	Allow Null

Construction_Additives

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Construction_Development

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Construction_Drilling

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Construction_Finishing

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Construction_Method

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Construction_Special

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Depth

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	Date	DATE	Allow Null
	GUID	TEXT(32)	Allow Null

Depth_DATA

	Field	Type	Extra
	GUID	TEXT(32)	Allow Null
	DepthToTop	REAL	Allow Null
	DepthToBottom	REAL	Allow Null
	Diameter	REAL	Allow Null
	QualifierID	INTEGER	Allow Null

Depth_Qualifier

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Discharge

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	DateTime	DATE	Allow Null
	Discharge	REAL	Allow Null
	TypeID	INTEGER	Allow Null
	MethodID	INTEGER	Allow Null

Discharge_Method

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Discharge_Type

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Fill

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	Date	DATE	Allow Null
	GUID	TEXT(32)	Allow Null

Fill_DATA

	Field	Type	Extra
	GUID	TEXT(32)	Allow Null
	DepthToTop	REAL	Allow Null
	DepthToBottom	REAL	Allow Null
	TypeID	INTEGER	Allow Null
	OuterDiameter	REAL	Allow Null
	InnerDiameter	REAL	Allow Null

Fill_Type

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	Date	DATE	Allow Null
	GUID	TEXT(32)	Allow Null

Lithology_Code

	Field	Type	Extra
	Code	TEXT(4)	Allow Null
	Name	TEXT(64)	Allow Null
	MaterialType	TEXT(16)	Allow Null
	FormationType	TEXT(16)	Allow Null
	Description	TEXT(512)	Allow Null

Lithology_ColorQualifier

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology_Composition

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology_DATA

	Field	Type	Extra
	GUID	TEXT(32)	Allow Null
	DepthToTop	REAL	Allow Null
	DepthToBottom	REAL	Allow Null
	Code	TEXT(4)	Allow Null
	PrimaryColorID	INTEGER	Allow Null
	SecondaryColorID	INTEGER	Allow Null
	ColorQualifierID	INTEGER	Allow Null
	CompositionID	INTEGER	Allow Null
	PrimaryFabricID	INTEGER	Allow Null
	SecondaryFabricID	INTEGER	Allow Null
	FabricAttributeID	INTEGER	Allow Null
	TextureID	INTEGER	Allow Null
	HardnessID	INTEGER	Allow Null
	RoundnessID	INTEGER	Allow Null
	SortingID	INTEGER	Allow Null
	WeatheringID	INTEGER	Allow Null
	FracturingID	INTEGER	Allow Null

Lithology_Fabric

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology_FabricAttribute

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology_Fracturing

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology_Hardness

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology_PrimaryColor

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology_Roundness

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology_SecondaryColor

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology_Sorting

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology_Texture

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Lithology_Weathering

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Locality

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	Latitude	REAL	Allow Null
	Longitude	REAL	Allow Null
	MergeID	TEXT(24)	Allow Null
	TypeID	INTEGER	Allow Null
	StatusID	INTEGER	Allow Null

Locality_Status

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Locality_Type

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Meter

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	GUID	TEXT(32)	Allow Null
	TypeID	INTEGER	Allow Null
	Date	DATE	Allow Null
	Serial	TEXT(128)	Allow Null
	UnitID	INTEGER	Allow Null
	Initial	REAL	Allow Null
	Maximum	REAL	Allow Null
	Constant	REAL	Allow Null

Meter_Type

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Meter_Unit

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Observer

Field	Type	Extra
AGOLName	TEXT(128)	Allow Null
FirstName	TEXT(100)	Allow Null
LastName	TEXT(100)	Allow Null
Email	TEXT(100)	Allow Null
Phone	TEXT(16)	Allow Null
Rating	INTEGER	Allow Null
Credits	INTEGER	Allow Null
OrgID	INTEGER	Allow Null

Organization

Field	Type	Extra
OrgID	INTEGER	Allow Null
AGOLAdmin0	TEXT(128)	Allow Null
AGOLAdmin1	TEXT(128)	Allow Null
AGOLAdmin2	TEXT(128)	Allow Null
Name	TEXT(100)	Allow Null
Email	TEXT(100)	Allow Null
Phone	TEXT(16)	Allow Null
Address	TEXT(100)	Allow Null
Website	TEXT(100)	Allow Null
Credits	INTEGER	Allow Null

OtherNumber

Field	Type	Extra
LocalityID	TEXT(24)	Allow Null
TypeID	INTEGER	Allow Null
OtherNumber	TEXT(24)	Allow Null

OtherNumber_Type

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Pump

Field	Type	Extra
LocalityID	TEXT(24)	Allow Null
InstallDate	DATE	Allow Null
TypeID	INTEGER	Allow Null
DepthToIntake	REAL	Allow Null
PowerSourceID	INTEGER	Allow Null
PowerRating	REAL	Allow Null
ManufacturerID	INTEGER	Allow Null
OtherManufacturer	TEXT(32)	Allow Null

	Model	TEXT(32)	Allow Null
	SerialNumber	TEXT(32)	Allow Null
	RiserMaterialID	INTEGER	Allow Null
	RiserDiameter	REAL	Allow Null

Pump_Manufacturer

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Pump_PowerSource

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Pump_RiserMaterial

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Pump_Type

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

PumpTest

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	GUID	TEXT(32)	Allow Null
	TypeID	INTEGER	Allow Null
	StartDateTime	DATE	Allow Null
	EndDateTime	DATE	Allow Null
	Duration	INTEGER	Allow Null
	DepthToIntake	REAL	Allow Null
	Discharge	REAL	Allow Null

PumpTest_Type

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

PumpTestObservation

	Field	Type	Extra
	GUID	TEXT(32)	Allow Null
	ObservationID	TEXT(24)	Allow Null

PumpTestParams

	Field	Type	Extra
	GUID	TEXT(32)	Allow Null
	Transmissivity	REAL	Allow Null
	Permeability	REAL	Allow Null
	Storage	REAL	Allow Null
	SpecificCapacity	REAL	Allow Null

Reading

	Field	Type	Extra
	GUID	TEXT(32)	Allow Null
	DateTime	DATE	Allow Null
	Reading	REAL	Allow Null
	ReasonID	INTEGER	Allow Null
	MethodID	INTEGER	Allow Null

Reading_Method

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Reading_Reason

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Recommended

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	Date	DATE	Allow Null
	Priority	INTEGER	Allow Null
	PurposeID	INTEGER	Allow Null
	PumpID	INTEGER	Allow Null
	PowerID	INTEGER	Allow Null
	DepthToIntake	REAL	Allow Null
	Abstraction	REAL	Allow Null
	DutyCycle	INTEGER	Allow Null
	DynamicLevel	REAL	Allow Null
	CriticalLevel	REAL	Allow Null

Recommended_Power

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Recommended_Pump

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Recommended_Purpose

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

Sample

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	DateTime	DATE	Allow Null
	SampleNo	TEXT(24)	Allow Null
	AltNumber	TEXT(24)	Allow Null
	TypeID	INTEGER	Allow Null
	MethodID	INTEGER	Allow Null
	TimePumped	REAL	Allow Null
	Depth	REAL	Allow Null
	LabDate	DATE	Allow Null
	LabID	INTEGER	Allow Null
	LabOther	TEXT(40)	Allow Null

Sample_Lab

	Field	Type	Extra
P	ID	INTEGER	
	Description	TEXT(100)	Allow Null

Sample_Method

	Field	Type	Extra
P	ID	integer	
	Description	text(50)	Allow Null

Sample_Type

	Field	Type	Extra
P	ID	integer	
	Description	text(50)	Allow Null

SiteInfo

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	Latitude	REAL	Allow Null
	Longitude	REAL	Allow Null
	Elevation	REAL	Allow Null

	TypeID	INTEGER	Allow Null
	CoordMethodID	INTEGER	Allow Null
	ElevationMethodID	INTEGER	Allow Null
	ElevationReferenceID	INTEGER	Allow Null
	StatusID	INTEGER	Allow Null

SiteInfo_CoordMethod

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

SiteInfo_ElevationMethod

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

SiteInfo_ElevationReference

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

WaterLevel

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	ReferencePointID	INTEGER	Allow Null
	ReferenceHeight	REAL	Allow Null
	MeasuringMethodID	INTEGER	Allow Null
	WaterLevelStatusID	INTEGER	Allow Null
	PiezometerNumber	TEXT(2)	Allow Null
	DateTime	DATE	Allow Null
	WaterLevel	REAL	Allow Null

WaterLevel_MeasuringMethod

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

WaterLevel_ReferencePoint

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

WaterLevel_Status

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

WaterStrike

	Field	Type	Extra
	LocalityID	TEXT(24)	Allow Null
	Date	DATE	Allow Null
	GUID	TEXT(32)	Allow Null

WaterStrike_DATA

	Field	Type	Extra
	GUID	TEXT(32)	Allow Null
	DepthToTop	REAL	Allow Null
	DepthToBottom	REAL	Allow Null
	Yield	REAL	Allow Null
	TypeID	INTEGER	Allow Null
	MethodID	INTEGER	Allow Null

WaterStrike_Method

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null

WaterStrike_Type

	Field	Type	Extra
P	ID	INTEGER	Auto Increment
	Description	TEXT(100)	Allow Null