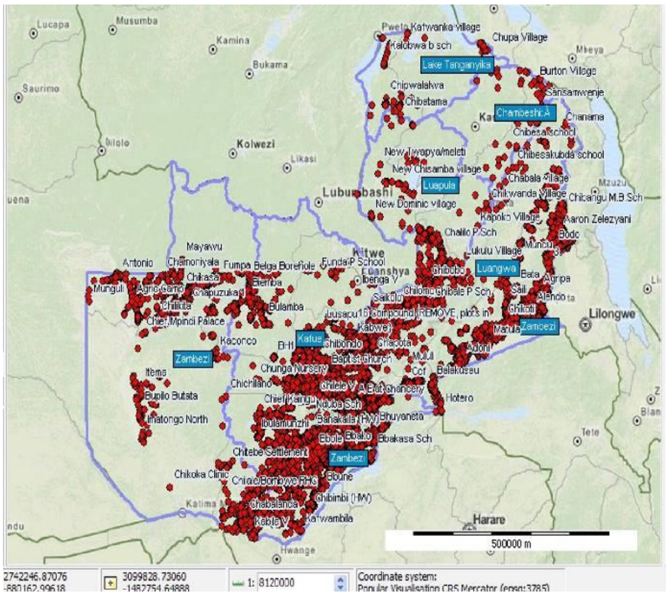
Zambian Groundwater Information Management System (GRIMS)



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Authors: Tewodros Tena (GReSP), Marcus Fahle (BGR/GReSP), Dr. Tobias Godau (BGR/GReSP) & Violet Mkandawire (WARMA)

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Project: Groundwater Management in Zambia with Focus on the Upper Kafue Catchment

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SUMMARY

Authors: Tewodros Tena (BGR/GReSP), Marcus Fahle (BGR/GReSP), Tobias Godau (BGR/GReSP) & Violet Mkandawire (WARMA)

Title: Zambian Groundwater Information Management System (GrIMS)

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Abstract

Groundwater is of crucial importance to satisfy the various water demands in Zambia. Sustainable management of the groundwater resources is key to the well-being of the country. As management has to be based on suitable data, the Groundwater Information Management System (GrIMS) was introduced in Zambia in 2005. GrIMS is a tool to manage and archive groundwater-related data. The tool which is centred around the commercial GeODin® borehole database developed by Fugro Germany Land GmbH, provides an interface to GIS software and allows imports and exports to and from MS Excel®. This report describes the structure of GrIMS, how data are being entered, which data are stored, and the tool's functionalities and queries to extract information from the database. Furthermore, the sources of the data entries are given and the current status of GrIMS is presented. Topics arising when working with GrIMS, like the water point numbering and the workflow suggested for data entry, are also addressed. In sum, the report is not a manual of GeODin® but rather gives an overview about GrIMS and draws the bigger picture of how GrIMS can be used for national integrated water resources management purposes.

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ABBREVIATIONS

BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
CMMU	Community Management & Monitoring Unit
GIS	Geographical Information System
GReSP	Groundwater Resources Management Support Program
GrIMS	Groundwater Information Management System
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
KfW	Kreditanstalt für Wiederaufbau (German Development Bank)
MEWD	Ministry of Energy and Water Development
MLGH	Ministry of Local Government and Housing
MWDSEP	Ministry of Water Development, Sanitation and Environment Protection
NORAD	Norwegian Agency for Development Cooperation
QGIS	Quantum Geographic Information System
WARMA	Water Resources Management Authority
WGS84	World Geodetic System 1984
WP-No	Water point number
WRM	Water Resources Mangement
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
UNZA	University of Zambia

LIST OF REPORTS COMPILED BY THE PROJECT "GROUNDWATER MANAGEMENT IN ZAMBIA WITH FOCUS ON THE UPPER KAFUE CATCHMENT"

Date	Authors	*Title*	Type
October 2018	Bäumle, R. & Fahle, M.	Development of a regional groundwater monitoring network *- Theoretical considerations and case study for the project area in the Upper Kafue catchment -*	Technical Report 01
March 2017	Krekeler, T.	Field Guide - Second revised edition –	Technical Note 01
July 2017	Fahle, M., Karen, M., El-Fahem, T., Krekeler, T. & Kolala, M.	Specifications of the Monitoring Network Installed in the Mpongwe Karst Area and the Kafubu and Kafulafuta Catchments	Technical Note 02
September 2017	Karen, M., El-Fahem, T. & Tena, T.	Groundwater Resources of the Kafue Catchment - Desktop Review for the Kafue Catchment Management Plan	Advisory Report 01
December 2019	Tena, T., Fahle, M., Godau, T. & Mkandawire, V.	Zambian Groundwater Information Management System (GrIMS)	Advisory Report 02
March 2018	Seeger, S., Bäumle, R., Karen, M., El-Fahem, T. & Namayanga, L.	Re-edition of National Hydrogeological Map 1:1,500,000	Map
December 2016	Banda, K., Zulu, J. & Praagman-Banda, E.	Technical Content for Draft Regulations or Statutory Instruments under the WRM Act No 21 of 2011	Consultant Report
May 2017	Banda, K.	Development of an internal workflow process for WARMA to assess applications for permission to drill	Consultant Report
July 2017	Banda, K.	Support to legal drafting of regulations on groundwater & boreholes and licensing of drillers – Key highlights	Consultant Report

EXECUTIVE SUMMARY

The Groundwater Information Management System (GrIMS) presented in this report is an important tool for effective management and development of groundwater resources. The GReSP project introduced the GrIMS in 2005. The main purpose was to concentrate groundwater-related data in Zambia within one database. GReSP (formerly: Groundwater Resources for Southern Province, now: Groundwater Resources Management Support Programme) is a project between the German Federal Institute for Geosciences and Natural Resources (BGR) and its Zambian partner institutions.

The GrIMS collects hydrogeological and technical data of so-called water points (such as boreholes, open wells and springs) for the whole of Zambia and provides instant and easy access to these data. The basis of GrIMS is GeODin®, a commercial borehole database developed by the company Fugro Germany Land GmbH. The database was adjusted to Zambian local conditions. It composes general information such as water point information, water point type, water source, catchment, basin block (i.e., sub-catchment), and administrative information, water user, well construction information and data record information as well as the owner and location of a borehole. It also captures the hydrogeological information such as type of aquifer, yield, borehole profile, purpose of the borehole, groundwater quality and the availability of the groundwater resources. The database can be linked to a Geographic Information System (GIS) to visualize groundwater information for stakeholders, policy makers and the public. As of December 2019, there are about 31,000 water points captured in the Zambian national database, which are organized within hydrological units (six catchments and 35 sub-catchments, referred to as basin blocks). Out of all water points, about 15,000 water points have general and basic hydrological information.

The GrIMS has been designed to reliably organize and manage information about Zambia's groundwater resources within a database for national integrated water resources management purposes. Hence, it provides fundamental information needed for development of adaptive strategies and actions in response to the adverse effects of climate change on water resources, poverty alleviation, food security, environmental protection and socio-economic development.

The report gives a brief overview about GrIMS, its functionality, status, potential uses and its role in groundwater and integrated water resources management in Zambia.

1. INTRODUCTION

The Groundwater Resources Management Support Programme (**GReSP**) has been established to support various aspects of groundwater resources management in Zambia. The project is funded by the Federal Ministry for Economic Cooperation and Development (BMZ) of the Federal Republic of Germany and implemented by the Federal Institute for Geosciences and Natural Resources (BGR) together with its Zambian partner institutions, currently the Water Resources Management Authority (WARMA). The project is part of the German-Zambian "Water Sector Reform Program”. GReSP is designed to respond to national and local groundwater management challenges.

The main aim of GReSP is to support the implementation of sustainable groundwater development and protection as well as Integrated Water Resources Management (IWRM) activities within catchments and sub-catchments. The project scope is in line with the National Water Policy (NWP, 2010), the Water Resources Master Plan for Zambia (JICA, 1995), the Water Resources Management Act (2011) and the Seventh National Development Plan (SNDP, 2017). The project aims at facilitating knowledge transfer, institutional and human capacity building, and enhancing the performance of the water sector to foster national socio-economic growth.

The Groundwater Information Management System (**GrIMS**) is one of the main outputs of the project. The system is designed to provide reliable groundwater resources data and to improve information management for national integrated water resources management purposes. By providing fundamental information, it enables the development of adaptive strategies and actions in response to the adverse effects of climate change and poverty alleviation as well as to improve food security, environmental protection and socio-economic development.

The establishment of a national groundwater database, a GIS-based groundwater information system and the issuing of hydrogeological maps for several Zambian catchments are considered major milestones of the project. A combination of the different activities is necessary to develop a groundwater management strategy (Figure 1).

Various institutions and stakeholders such as WARMA, Department of Water Resources Development and Ministry of Local Government have been participating at different levels in the design and implementation of the Zambian groundwater information management system. The aim of this report is to give an overview of the GrIMS, its function and status at the time of the editing of this report.

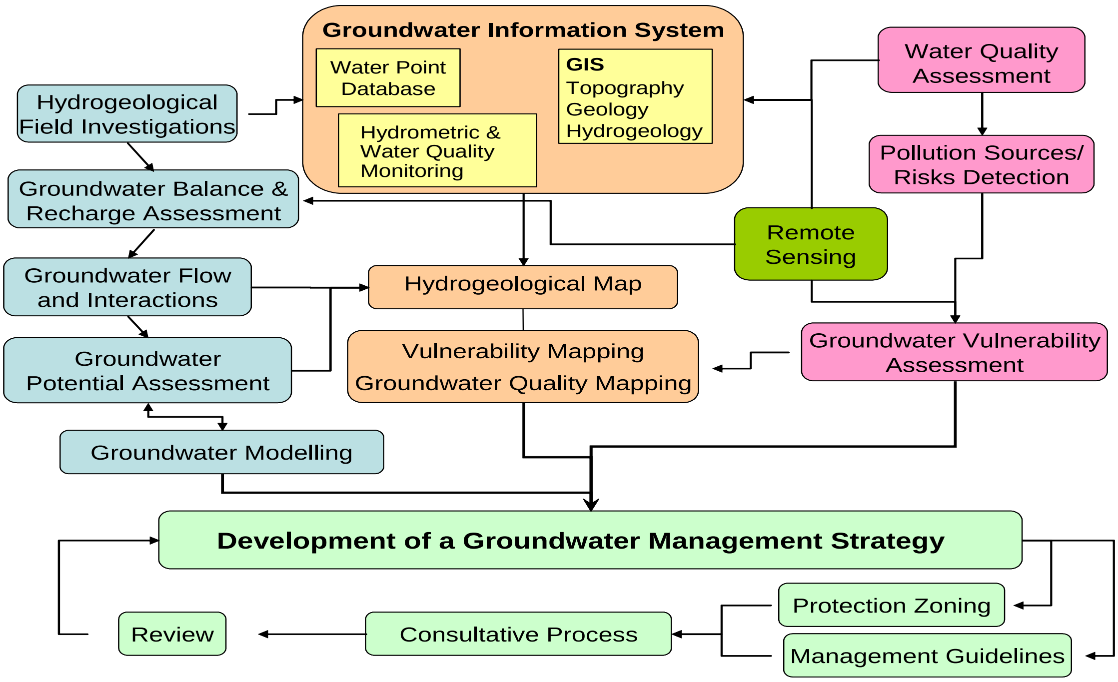


Figure 1: Simplified illustration of the project's approach to develop a groundwater management strategy (after Bäumle & Kang'omba, 2009).

2. GROUNDWATER RESOURCES

Groundwater is a vital natural resource for the reliable and economic supply of potable water for both urban and rural environments. Groundwater plays a fundamental role in Zambia for domestic, industrial and agricultural use and therefore the protection of groundwater resources should be imperative. In general, groundwater is an important element of the water cycle that supplies springs, swamps, streams, rivers and other water bodies (Figure 2). Rivers and streams depend significantly on aquifer discharge to sustain the flow during the dry season by means of base flow.

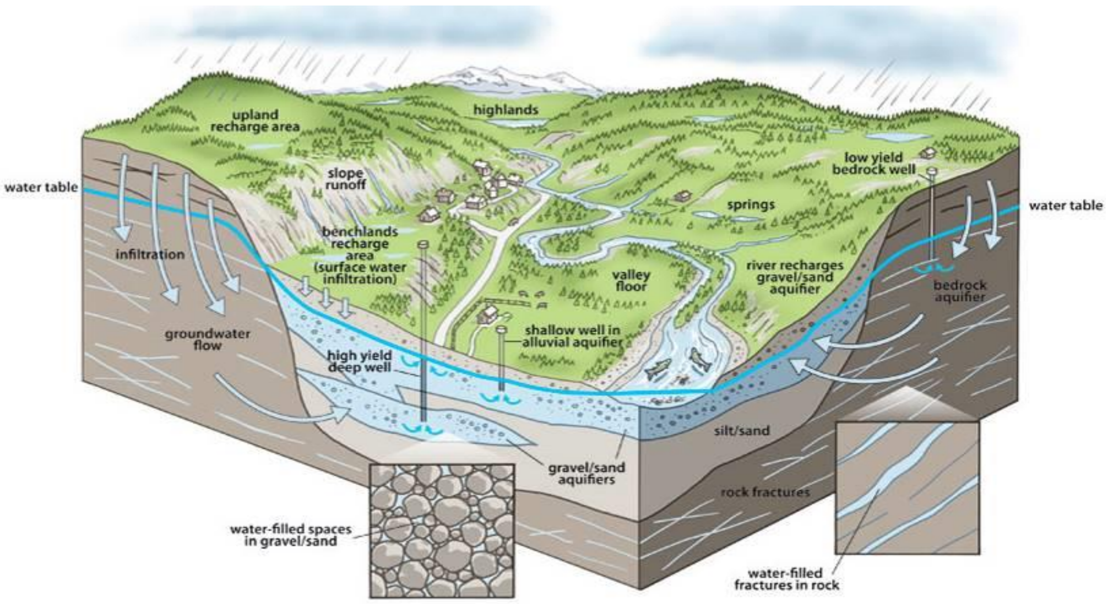


Figure 2: Groundwater Cycle.
(Source: http://www.satplan.co.za/desk-finding-groundwater-thermal-imagery/)

2.1. GROUNDWATER RESOURCES, MANAGEMENT CHALLENGES & PERSPECTIVE OF IWRM

Over the years, Zambia has faced several challenges with regard to managing water resources. Pollution, insufficient information for decision making, limited financing to develop the resources and inadequate participation of stakeholders has led to inappropriate management of water resources and inadequate supplies to meet the various needs. In most parts of Zambia, groundwater is the most important resource for water supply. For example, more than 52% of the Lusaka domestic water supply is provided from the underlying groundwater resources (LWSC, 2014). Due to its relatively stable yield of good quality water, groundwater has emerged as a very important water resource for meeting domestic, industrial and agricultural demands. Poor management and inadequate protection of the groundwater resources has on the other hand resulted in negative impacts such as a declining groundwater table, groundwater quality deterioration, and drying up of streams, especially in areas of high groundwater consumption like cities and farming blocks.

Groundwater is one of the essential resources for socio-economic development, but it is an often overlooked element in sustainable development frameworks. It is very important to give special attention to the management and protection of groundwater resources to enable sustainable management of water resources. Both groundwater and surface water need to be included in the integrated water resources management approach and should be equally addressed in governance and management approaches.

The Water Resources Management (WRM) Act No. 21 of 2011 established the Water Resource Management Authority (WARMA) as the leading agency to manage and regulate water resources in Zambia. In this regard, it is WARMA's role to follow an integrated approach of managing surface and groundwater resources together in cooperation with all relevant partners in the water sector, and to comply with the regulatory framework and the IWRM principles. However, the effort to establish IWRM serves the greater objective to secure maximum efficiency on use of water resources, equity in the allocation of water across different social and economic groups and environmental sustainability to protect the water resources base and associated ecosystems.

2.2. GROUNDWATER REGULATION AND GROUNDWATER INFORMATION

One of the major changes in the new WRM Act No 21 of 2011 is the abolition of "private ownership of water" (Water Act of 2011, Section 6 (i)) while keeping all water subject to regulation.

The implementation of the WRM Act requires the development of subsidiary legislation. The subsidiary legislation in form of statutory instruments will give specifications and guidelines for the implementation of the WRM regulations. The issuance of the statutory instruments "Licensing of Drillers and Constructors" and "Groundwater and Boreholes" played already an important role for the regulation, planning, protection and management of groundwater resources by requiring a permit to drill a borehole, defining minimum standards for drilling companies and minimum distances for boreholes to pollution risks. Further, by obliging drilling companies to hand in standardized borehole completion reports, it enhances the data availability for the groundwater database.

Thus, the permitting system will provide transparency to the decision-making processes, security of tenure and sustainable utilization of the groundwater resources. WARMA will regulate groundwater resources through a system of drilling and abstraction permits and register information on drilled boreholes in the database using the GeODin® software. GeODin® is a commercial groundwater and borehole database software programmed by the company Fugro Germany Land GmbH.

3. GROUNDWATER INFORMATION MANAGEMENT SYSTEM (GRIMS)

The Groundwater Information Management System (GrIMS) established by the GReSP project aims to enhance capacities of the Zambian water sector to manage the groundwater resources. In 2005, the groundwater database GeODin® was introduced to Zambia by the GReSP project. The GeODin® software includes capabilities to store, interpret and present groundwater data (Figure 3). In 2013, the GeODin® database was handed over to WARMA, forming an integral part of sustainable groundwater resource management.

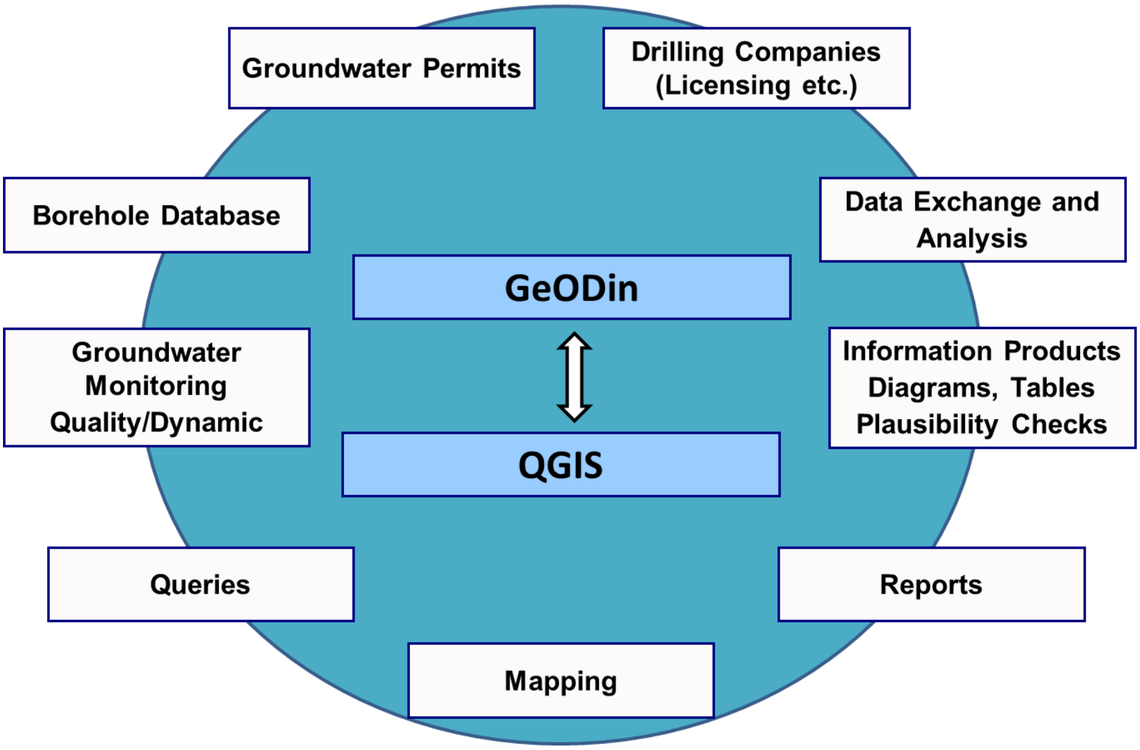


Figure 3: Functionalities of GrIMS.

GrIMS is an organized set of resources (data, procedures, software, etc.) for collecting, storing and processing geological, hydrogeological and hydrochemical data, and for delivering information, knowledge and digital products. The primary purpose of GrIMS is to provide reliable groundwater data sets and information for decision making, planning and management purposes. The main functions are integration of data from different sources, archiving and management as well as visualization and analysis, also by means of GIS software (Figure 3 and Figure 4). In sum, GrIMS forms the basis of sustainable management of groundwater resources. However, it must be emphasised that the software alone cannot produce good data sets. WARMA's role is also to assure a quality control of all data entering GrIMS in order to obtain reliable data for interpretation: An important aspect of the build-up of GrIMS is therefore the continued capacity development of WARMA's staff.

Figure 4: Distribution of Water Points in Basin Blocks (sub-catchments) within the Kafue Catchment.

GrIMS consists of:

1. The GeODin® groundwater database, and
2. A connection to the geographic information system (GIS) software QGIS,

and could become a component of an Integrated Water Resources Management (IWRM) information system for use at WARMA and its catchment offices. It provides the necessary groundwater data, including groundwater quality, for ensuring groundwater resources management at national level. WARMA has delineated and established six catchments throughout the country to manage and regulate the water resources in an appropriate way (Figure 5). The data in GrIMS is equally organized in six catchments and 35 basin blocks (based on JICA's Water Resources Master Plan of 1995). Technical personnel of WARMA headquarter and the existing catchment offices has been extensively trained to use GrIMS. The following outcomes are expected from the use of GrIMS, especially if WARMA will intensify its groundwater monitoring efforts in the future:

- Timely, reliable and representative groundwater resources data and information readily accessible to all stakeholders;
- Improved methods for collecting, processing, archiving and sharing of groundwater data and information through a digital database;
- Staff skilled in groundwater management using GeODin® and QGIS software, data analysis and information presentation for decision-making;
- Improved interpretation and visualization of groundwater information in different formats needed to support water management, disaster mitigation and policy development at catchment and sub-catchment level.

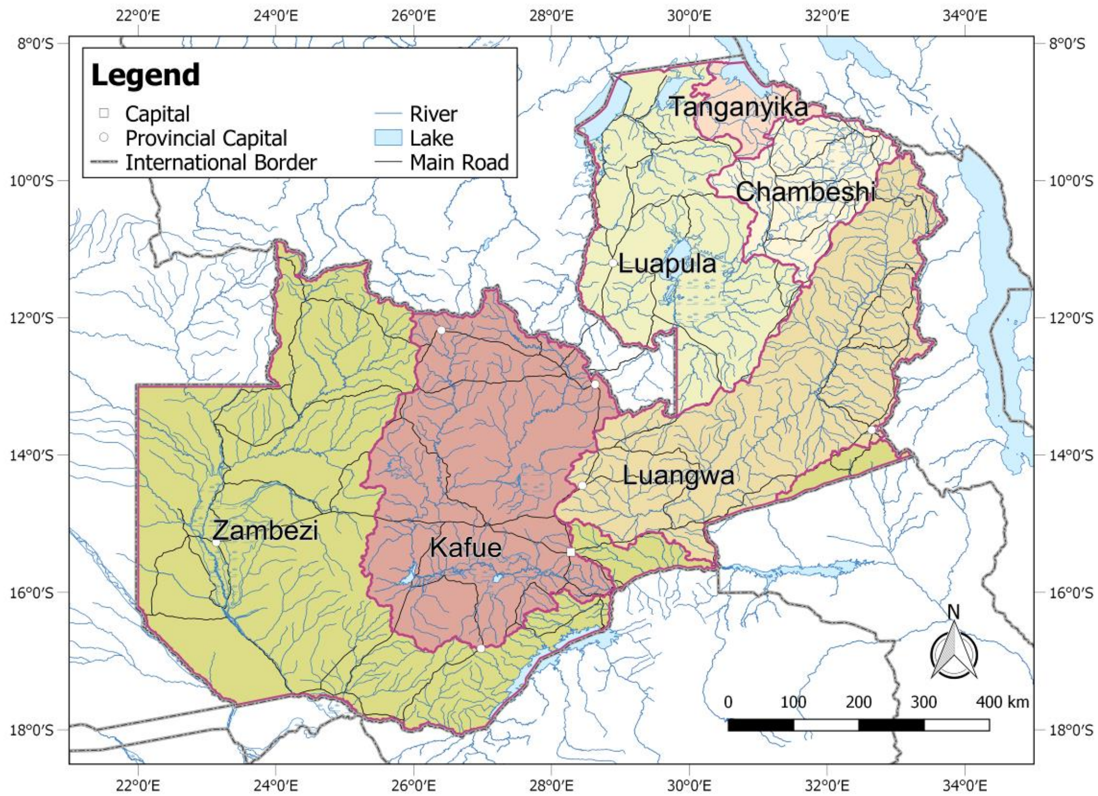


Figure 5: Main hydrological catchments of Zambia.

3.1. Groundwater Database

The groundwater database was established using the commercial software package GeODin® (www.geodin.com). The software is based on the MS Access® database system and provides user-friendly data input masks (Figure 6). The individual input masks were modified to meet the specific needs and requirements of the Ministry of Water Development, Sanitation and Environmental Protection (MWDSEP). Certain fields work with dropdown lists to facilitate a quick data entry and to prevent spelling mistakes.

3.2. DATA SOURCES

The data entered into the database were assembled from the following sources:

- Results of the groundwater resources inventory commissioned by the UNESCO/NORAD Water Research Project and the National Council for Scientific Research (Chenov, 1978);
- Borehole completion and construction reports from projects commissioned by the Ministry of Energy and Water Development (MEWD) and the Japan International Cooperation Agency (JICA) between 1986 and 2003;
- Water Point questionnaires collected by the Water Point Inventory Community Management & Monitoring Unit (CMMU) between the early and mid-1990's under supervision of the two former ministries in the water sector, namely the Ministry of Energy and Water Development (MEWD) and Ministry of Local Government and Housing (MLGH);
- Results of the water supply and sanitation project commissioned by the Ministry of Local Government and Housing (MLGH) & the German Development Bank (KfW) from 2010 to2011;
- Data of drilling of rural water supply boreholes funded by UNICEF between 2002 and 2015;
- Borehole completion reports at the Department of Water Affairs (DWA), particularly from the groundwater drilling works in the Gwembe Valley between 2001 and 2014 that were funded by the Seventh-day Adventist Church;
- Data collected from groundwater mapping and groundwater quality surveys prepared by the GReSP project from 2005 to 2017;
- Data collected from MLGH (various District Council Offices) between 2010 and 2014;
- Data collected from Ministry of Health 2015, and
- Data collected from private drillers from 2012 onwards.

3.3. GRIMS SOFTWARE PLATFORM

GrIMS was established to enhance groundwater management through increased access to groundwater information using GeODin® software and GIS packages. The data stored comprises general information data like geographic coordinates and name of the borehole, but also, where available, comprehensive technical details on borehole design, geology, groundwater hydraulics and water quality (Table 1).

GrIMS provides instant and easy access to hydrogeological data for groundwater points (such as boreholes, open wells and springs). Further, the database can be linked to a

Geographic Information System (GIS) to visualize groundwater information for users, stakeholders, policy makers and the public.

Table 1: Type of information captured in the GeODin® database.

General information	
Location	Borehole name and number Geographic coordinates Elevation Location with regard to drainage catchment Location with regard to administrative/political unit
Drilling	Drilling /completion dates Drilling contractor Water point funding, etc.
Status	Type and purpose of water point usage Water user
Hydrogeology	
Aquifer	Borehole and aquifer depth(s) and thickness Aquifer type(s) Static water levels (single values or time-series)
Hydraulic (Pump-) testing	Hydraulic test summary Hydraulic test data Hydraulic characteristics (yield, permeability)
Groundwater quality	Water chemistry Comparisons to drinking water standards Water type and quality
Borehole Profile	
Geology	Lithological and stratigraphical log
Design	Position of casing, screens, etc.

3.4. Composition of Water Point Number

For reasons of structuring and identifiability, the database uses a water point numbering system. Each water point number (WP-No) is unique and is composed by seven digits with the first digit representing the catchment ("1" for Zambezi Catchment), the second and third representing the basin block (i.e., sub-catchment) and the remaining four digits specifying the individual water point by a serial number (Table 2). Formerly, the numbering method represented administrative instead of hydrological boundaries.

Table 2: Example for composition of water point number system in GeODin® database.

<u>**First digit**</u> **Catchment**	<u>**Second and third digit**</u> **Basin Blocks** **(Sub-catchment)**	<u>**Digits four to seven**</u> **Water Point**	**Resulting WP-No**
Zambezi Catchment = 1 Kafue Catchment = 2 Luangwa Catchment = 3 Luapula Catchment = 4 Chambeshi Catchment = 5 Tanganyika Catchment = 6	*For Example:* *Zambezi Catchment* Zambezi Headwaters= 01 Kabompo = 02 Watopa = 03 Barotse = 04 Sesheke = 05 Victoria Falls = 06 Kariba Dam = 07 Lusitu = 08 Chongwe = 09 Cahora Bassa = 10	Indexed numbers ranging from 0001 to 9999	*For example:* Water point numbers of the Chongwe basin block range from 1090001 to 1099999. For Kabompo basin block: 1020001 – 1029999. For Victoria Falls basin block: 1060001 – 1069999.

3.5. VIEWING AND EDITING WATER POINT INFORMATION

General information about the water point is captured in General Data Input Mask (Figure 6). The General Input Mask consists of six (6) individual input masks for the categories Water point, Water point type and Data source, Administrative information, Water user, Well construction and Data record. Corresponding sub-parameters can be found in these six categories.

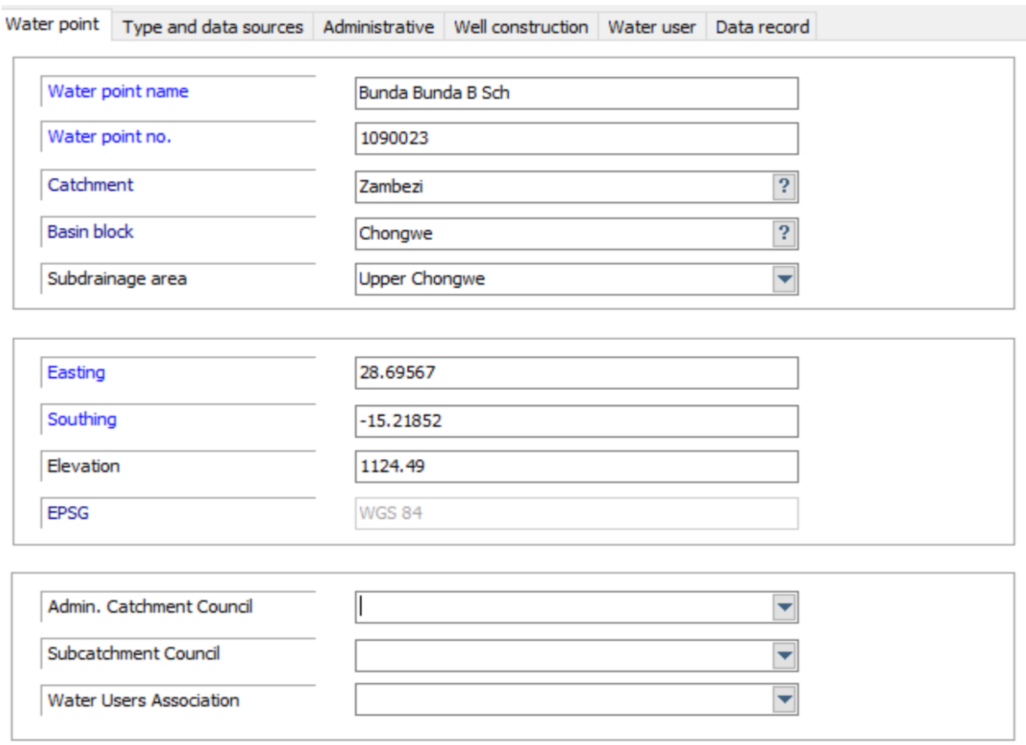


Figure 6: Example of GeODin® data input mask showing “Water point” information.

Water Point Information

Several parameters to be entered are critical. Besides the water point name (in Figure 6 'Bunda Bunda B Sch') and number (1090023), the location expressed by the coordinates of longitude (Easting) and latitude (Southing) in decimal degrees within the World Geodetic System 1984 (WGS 84) reference system. The Southing must be entered always with a negative (-) sign to express that the location is south of the equator. Additional information about catchment, basin blocks, water point type and purpose can be selected from pull down lists.

Hydrogeological Information

The hydrogeological information mask allows for technical information to be captured. This information includes the geology, borehole profile, water level, pumping test and main aquifer parameters. Under the technical information, parameters such as total borehole depth, water level, water first struck, water level during drilling (all entered in meters) etc. are listed (Figure 7). This information is collected from borehole drilling reports or borehole completion forms. The mask for Pumping test can be used to capture corresponding parameters, while the mask Main aquifer summarises the geology of the borehole.

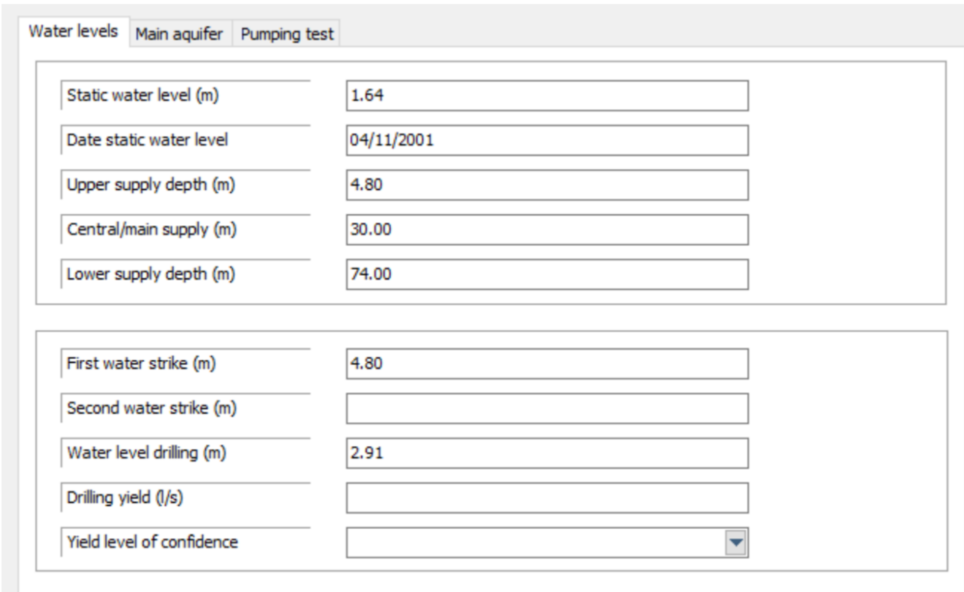


Figure 7: Example of hydrogeological information entered in GeODin®.

After capturing all the required information of the water point in the database, GeODin® provides templates to visualize the entered hydrogeological information, geological profile, borehole construction, water quality and water level information, including time series. Under the tab "Page layout" different outputs can be visualised. The geology and casing data that have been entered are now shown as what is called the borehole log (Figure 8).

Likewise, results of pumping tests and water chemistry can be visualised (Figure 9 and Figure 10). However, the pumping test data analysis has to be done by external software packages.

Time series can be included for pumping tests, groundwater chemistry, groundwater levels and groundwater discharge. These data can be entered individually or imported from Excel files.

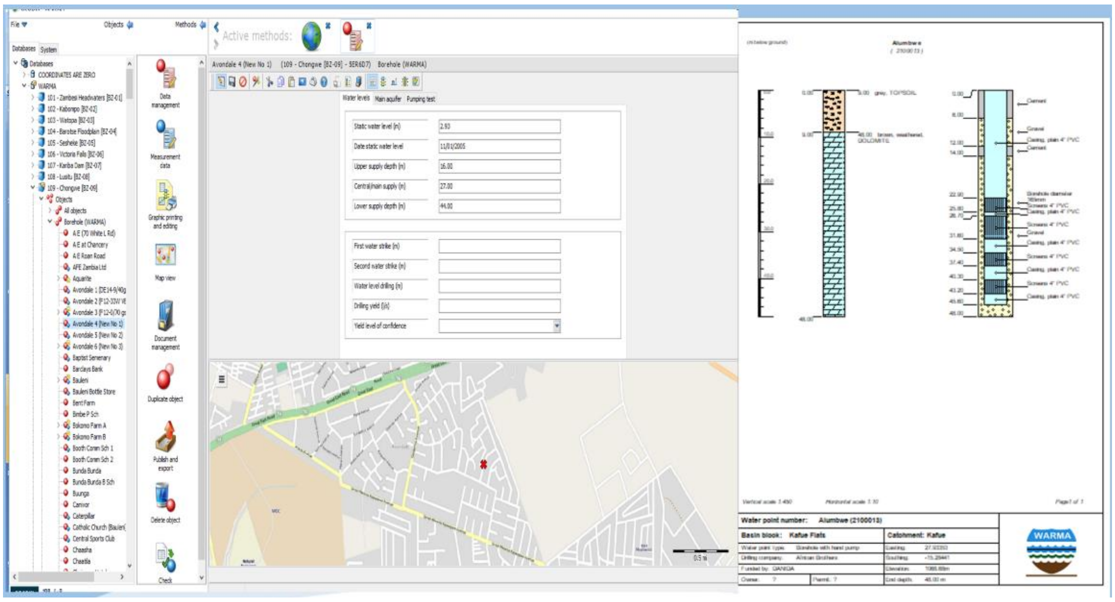


Figure 8: Hydrogeological, borehole log and general information output.

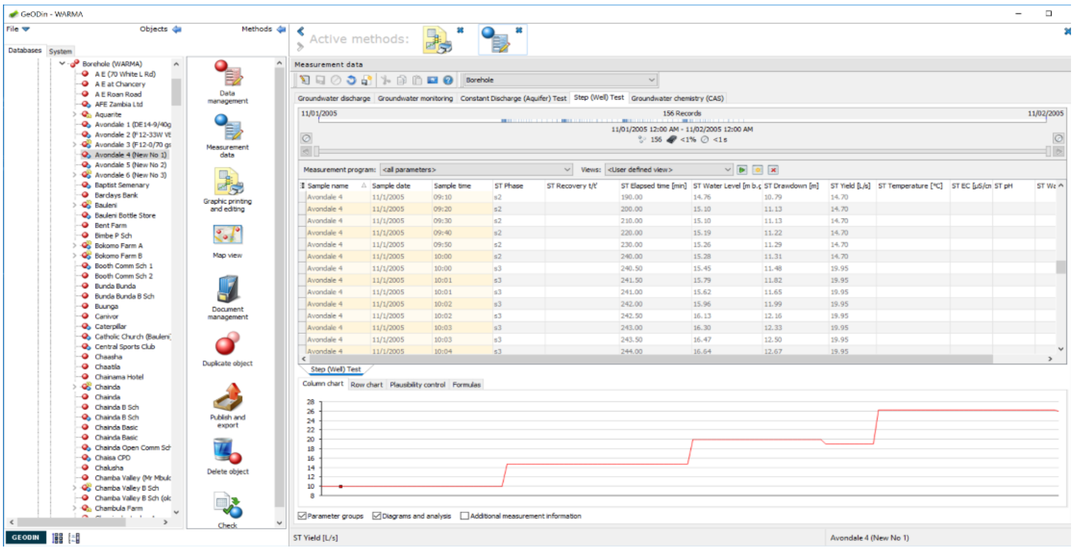


Figure 9: Pumping test graph visualisation for a production borehole.

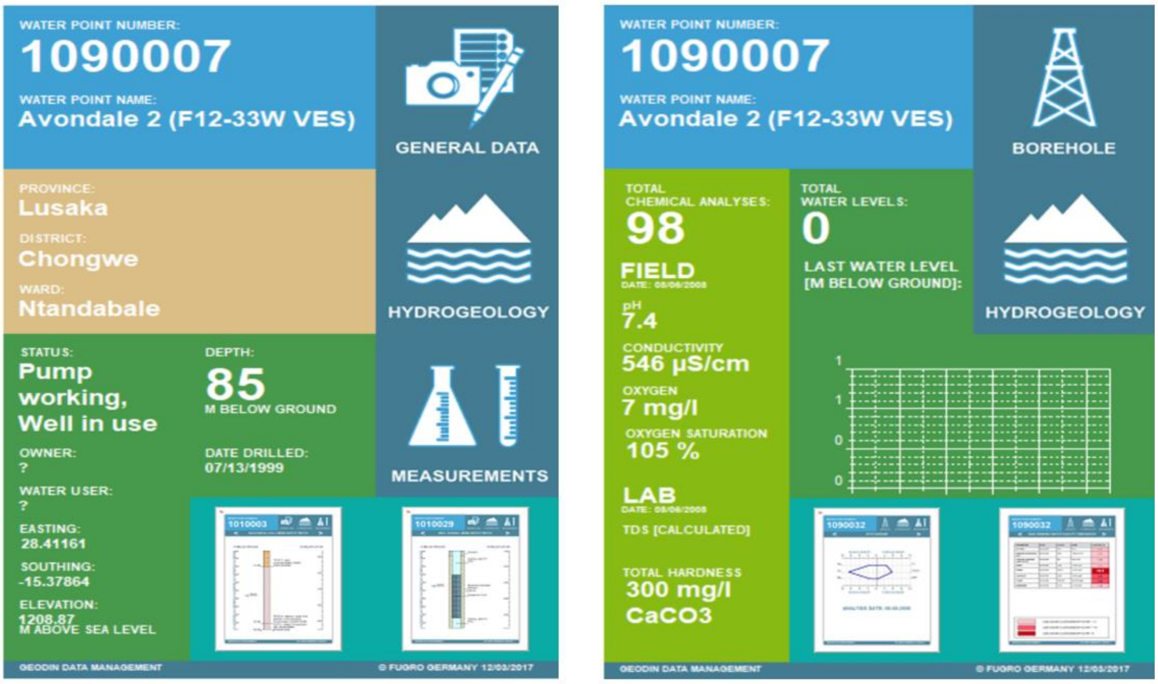


Figure 10: Visualisation of water chemistry in GeODin®.

3.6. GEOGRAPHIC COORDINATE SYSTEM

A Geographic Coordinate System is a coordinate system that enables every location on Earth to be specified by a set of numbers. The coordinates are usually chosen such that one of the numbers represents the vertical position, and two numbers represent the horizontal position. A common choice of coordinates is latitude, longitude and elevation. The provided coordinates in GeODin® are decimal degrees. To avoid projection issues, the World Geodetic System 1984 serves as coordinate reference system; the corresponding European Petroleum Survey Group Geodesy (EPSG) code is EPSG 4326.

Converting Between Decimal Degrees and Degrees, Minutes and Seconds

Geographical coordinates can be expressed in either decimal degrees (i.e. a decimal fractions) or degrees, minutes and seconds as shown in Table 3. Both systems convey the same information and can be converted to the other format.

<u>Conversion from Degrees (dd), Minutes (mm) and Seconds (ss) to Decimal degrees (dd.ff)</u>

dd = whole degrees, mm = minutes, ss = seconds

dd.ff = dd + mm/60 + ss/3600

Example:

30 degrees 15 minutes 22 seconds = 30° 15’ 22’’ = 30 + 15/60 + 22/3600 = 30.2561°

Conversion from Decimal degrees (dd.ff) to Degrees (dd), Minutes (mm) and Seconds (ss)

ff = the fractional part of a decimal degree

mm = 60 · ff

ss = 60 · (fractional part of mm)

Use only the whole number part of mm in the final result.

Example:

30.2561° => 30° and fractional part ff = 0.2561°

ff · 60 = 0.2561° · 60 = 15.366 minutes => 15' and fractional part 0.366 minutes

0.366 minutes · 60 = 22 seconds

Hence, 30.2561° corresponds to 30 degrees 15 minutes 22 seconds = 30° 15' 22''.

The Universal Transverse Mercator (UTM)

The Universal Transverse Mercator (UTM) coordinate systems use a metric-based Cartesian grid laid out on a conformally projected surface to locate positions on the surface of the Earth. The UTM system is not a single map projection but a series of map projections. The UTM system is still common in Zambia. Coordinates given in WGS 84 can be converted into UTM coordinates given the right datum (typically Arc 1950 or Arc 1960) and the right zone (Zambia lies within the zones 34S, 35S and 36S).

Table 3: Example of different coordinates for the same location

	Latitude (Y)	Longitude (X)
Degree Minute Second	-13°.59' 46.2''	29°.21'48.0''
Degree Minute	-13°.59.770'	29°.21.800'
Decimal Degree	-13.99617°	29.36333°
UTM	8,495,672	739,988

3.7. QUERIES

A query is a request for specific data from a database. This data may be generated as results returned by structured query language or as graphs or complex results. Queries in GeODin® can select records that fit certain criteria. They are essentially powerful filters that allow deciding which records and which fields of information (i.e. borehole depth) of each record are to be displayed. Queries filter information and can be applied to individual projects[1] (i.e.

[1] A GeODin® database is made up of projects. These projects contain objects. In GrIMS, every GeODin® project represents a basin block and each object in this project represents one water point.

basin blocks) or the complete database (i.e. project-independent, which means all basin blocks). For example, queries can be used to extract all commercial groundwater users or all boreholes with shallow water levels.

The query language is mostly based on mathematical operators. Examples are found under the help function and the GeODin@ manual. Some standard queries have been developed together with WARMA according to specific needs.

3.8. Protection of Groundwater and Boreholes

Protection of groundwater requires a proper legal backing, in Zambia by means of statutory instruments specifying the WRM Act of 2011. The statutory instrument "Groundwater and boreholes" defines minimum distances of new boreholes to potential pollution sources and neighbouring boreholes. The latter distances differ according to the existing geological conditions. Assessment of these minimum distances can be done using GrIMS, as neighbouring boreholes of an area can be extracted, and their geological information can be visualized. It also gives reliable information on the geological conditions and type o aquifer for the development of new boreholes

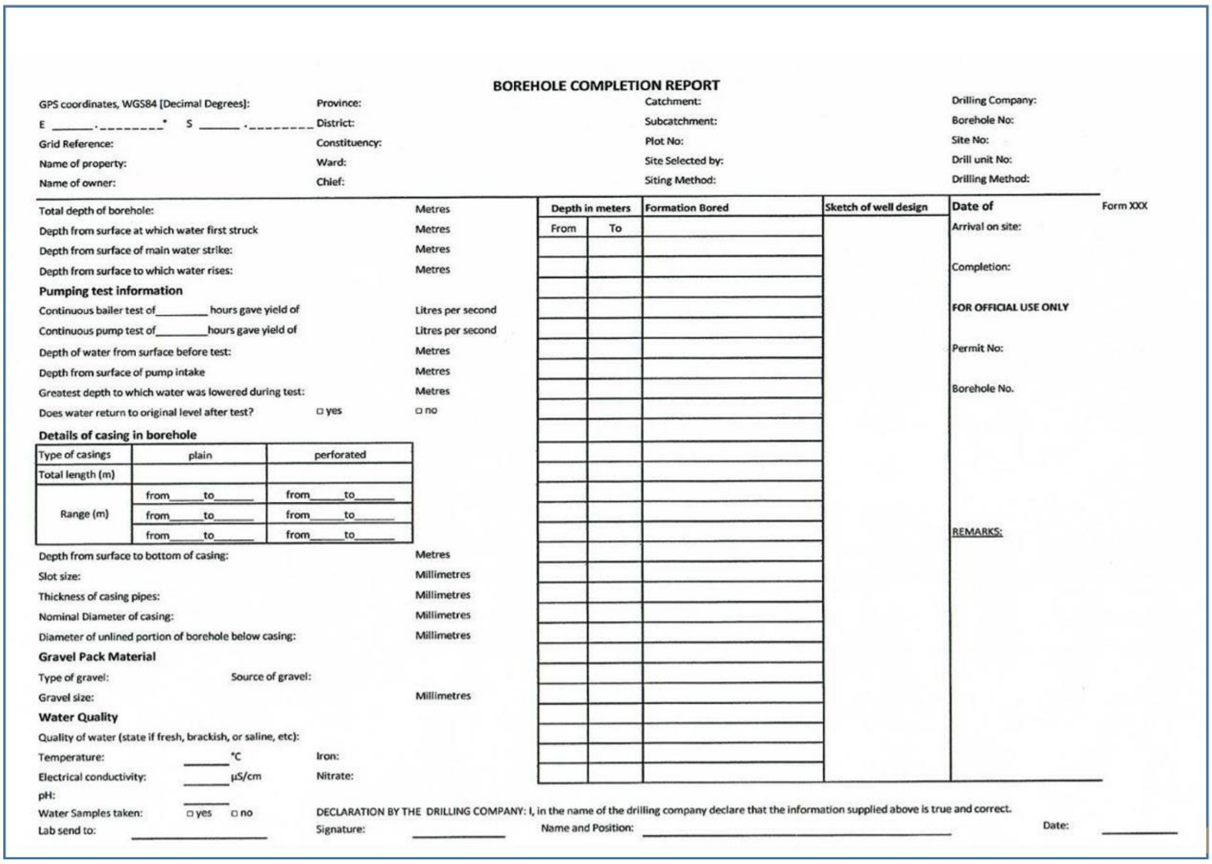
For the yet to be implemented statutory instruments concerning protection areas and water recharge zones, GrIMS data will be also required. For example, GrIMS could be used to show areas of groundwater pollution by retrieving water points with water quality parameters exceeding defined standards using queries. Also areas with high densities of boreholes and possible over-abstraction of groundwater can be easily detected using the mapping tools.

3.9. Borehole Completion Form

The 2018 statutory instruments concerning the WRM Act of 2011 also oblige drillers to deliver borehole completion reports for newly drilled boreholes and collect the according data specified in the form. The reports must be submitted to WARMA.

It is imperative to maintain good records of borehole drilling work and archive original documents in a manner which makes them readily accessible. A standardized borehole completion form is crucial for the GeODin® database to capture all necessary information. The designed borehole completion form has been disseminated to all drilling companies to keep uniformity and standardize the reporting throughout the country. At present, most of the drilling companies and individuals use the standard borehole completion form (Figure 11).

A standard borehole completion report must contain the following information: location (geographical coordinates in WGS 84), depths, lithology, method of drilling, casing design, yield test, pumping test, water quality, type of pump installed and purpose of the water point.



BOREHOLE COMPLETION REPORT

GPS coordinates, WGS84 [Decimal Degrees]:
E ______.________° S ______ .________
Grid Reference:
Name of property:
Name of owner:

Province:
District:
Constituency:
Ward:
Chief:

Catchment:
Subcatchment:
Plot No:
Site Selected by:
Siting Method:

Drilling Company:
Borehole No:
Site No:
Drill unit No:
Drilling Method:

Form XXX

Total depth of borehole: Metres
Depth from surface at which water first struck Metres
Depth from surface of main water strike: Metres
Depth from surface to which water rises: Metres

Pumping test information

Continuous bailer test of________ hours gave yield of Litres per second
Continuous pump test of________hours gave yield of Litres per second
Depth of water from surface before test: Metres
Depth from surface of pump intake Metres
Greatest depth to which water was lowered during test: Metres
Does water return to original level after test? □ yes □ no

Details of casing in borehole

Type of casings	plain	perforated
Total length (m)		
Range (m)	from_____to______	from_____to______
	from_____to______	from_____to______
	from_____to______	from_____to______

Depth from surface to bottom of casing: Metres
Slot size: Millimetres
Thickness of casing pipes: Millimetres
Nominal Diameter of casing: Millimetres
Diameter of unlined portion of borehole below casing: Millimetres

Gravel Pack Material

Type of gravel: Source of gravel:
Gravel size: Millimetres

Water Quality

Quality of water (state if fresh, brackish, or saline, etc):
Temperature: ______°C Iron:
Electrical conductivity: ______µS/cm Nitrate:
pH: ______
Water Samples taken: □ yes □ no
Lab send to: ____________________

Depth in meters		Formation Bored	Sketch of well design
From	To		

Date of
Arrival on site:
Completion:
FOR OFFICIAL USE ONLY
Permit No:
Borehole No.
REMARKS:

DECLARATION BY THE DRILLING COMPANY: I, in the name of the drilling company declare that the information supplied above is true and correct.
Signature: ____________ Name and Position: ____________________ Date: ________

Figure 11: Revised borehole completion form.

3.10. Workflow for Data Entry

GrIMS gathers all groundwater related information in a national database. Yet due to the lack of a WARMA network, the decentralized structures of WARMA at catchment and sub-catchment offices cannot access the database from the main server. Thus data entry has to be coordinated and managed by the IT department at WARMA HQ.

A workflow recommendation was discussed and agreed upon by WARMA and GReSP during training workshops as well as in meetings of the groundwater information management working team. The workflow is based on the requirements of WARMA, the project management expertise of GReSP and Fugro’s long experience advising national geological survey organisations and water authorities worldwide.

The following workflow should be conducted:

1. The catchment offices should digitize new boreholes for the basin blocks (i.e., sub-catchments) that are located within their catchment. In case sub-catchment offices exist, the according catchment office has to give instructions for which basin blocks theses offices are responsible for.

   For example, the catchment office for the Zambezi should enter the data of all boreholes located in the Zambezi catchment, i.e. all boreholes whose water point number starts with a "1". No data should be entered in any basin block located outside the Zambezi catchment.

2. The (sub-)catchment offices submit their versions of the GeODin® database regularly to the WARMA HQ to update the WARMA database. It is advisable to update the WARMA database six times per year.
3. At the WARMA HQ, the data digitized at the basin blocks of the respective (sub-) catchment have to be replaced in the national database.
4. The hydroinformatics specialists and hydrogeologists at WARMA HQ should do a quality check of the delivered data, e.g. checking whether water point numbering is consistent, and the geological data entered is meaningful.
5. The WARMA HQ sends the updated national GeODin® database back to the respective (sub-)catchment. During the time of submission of the local database to the WARMA HQ and the receipt of the updated national database, no data shall be entered at the respective (sub-)catchment office!

In case data entry should be also conducted in the WARMA HQ it is crucial to tightly coordinate the data entering with the respective (sub-)catchment office. It is vital not to have the same water point number appearing more than once in the database. Otherwise different versions of one and the same basin block would exist in parallel and could not be merged without losing information about the water points with identical water point numbers. Hence in that case it needs to be agreed which water point numbers the HQ and which the (sub-)catchment office should use. It is strongly recommended to restrict data entry on catchment office level to simplify the workflow. Borehole completion reports submitted to the HQ should be transferred as digital copies to the respective (sub-) catchment office for data entry!

The hydroinformatics specialists and hydrogeologists at WARMA HQ should supervise the maintenance and continuous updating of the database and facilitate the workflow from catchment to WARMA HQ. They are also responsible to ensure data quality by checking entered data. It is advisable to regularly report the status of GrIMS at the national level along with the Integrated Water Resources Management Information System.

4. STATUS OF THE GROUNDWATER DATABASE

Since 2005 boreholes, open wells and springs throughout the country were captured in the national GeODin® groundwater database (Figure 12). The database combines water point data from all catchments.

In addition to this database, WARMA established another GeODin® database called "Registered Borehole" to capture the boreholes that were registered in consequence of the enforcement of the statutory instrument "Groundwater and boreholes". These registered boreholes typically do not provide much more than only basic data like name and location as borehole completion reports were not collected at the time of their drilling. However, the knowledge about existing boreholes in an area is still needed when deciding on application for new boreholes to be drilled, for which minimum distances to existing boreholes are defined. To not overburden the main database with data entries without any relevant groundwater management data, it was decided to keep these borehole points separate and to use it for registration purpose only.

Finally, another GeODin® database was created to host all boreholes with missing or wrong coordinates. This database is called "Zero Coordinates". All the boreholes included here have to be re-checked and validated in the respective catchment and sub-catchment offices.

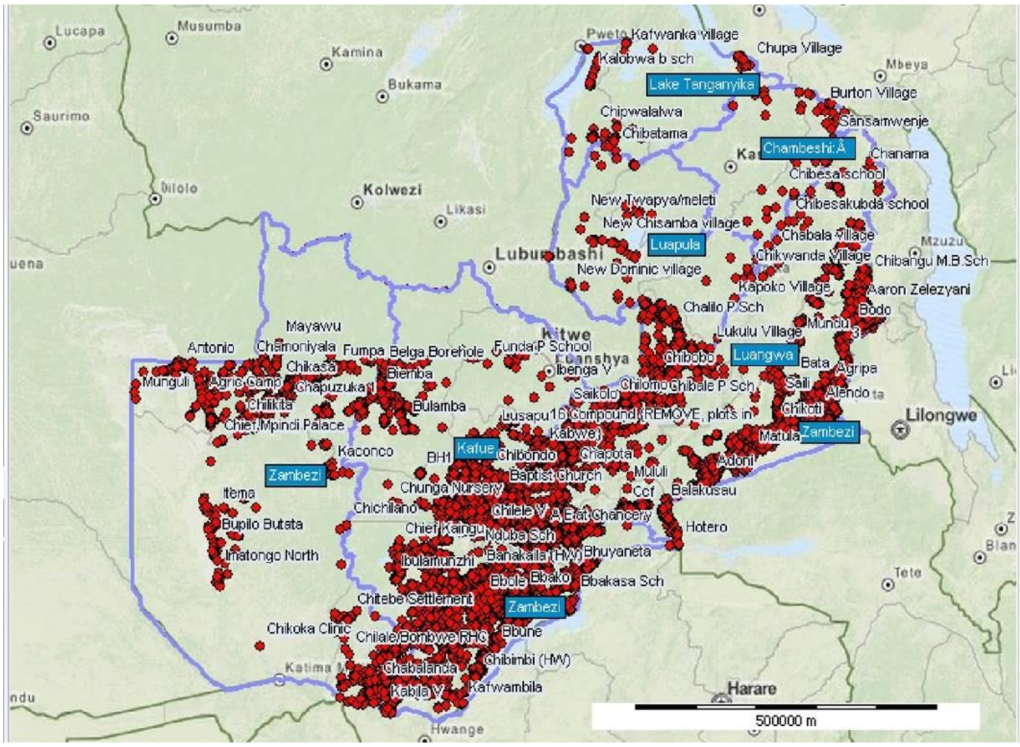


Figure 12: Boreholes captured in GrIMS.

Over 30,600 water points have been captured in all these 3 databases together (Table 5) by December 2019. There are 3,959 boreholes with zero coordinates and 691 boreholes with wrong coordinates (Table 4). Using queries, 3,271 boreholes were found in the Zero

Coordinates database that were constructed for various commercial purposes such as irrigation, industry, livestock etc. and therefore need respective permits for groundwater abstraction. Identifying the location of these boreholes is therefore of crucial interest to check the ownership, actual use and whether they have a valid permit or not in case they are still functional.

Table 4: Number of water points captured in the national GeODin® database (as of December 2019).

Catchment	Number of Basin Blocks	Number of Water Points Captured in the Database
Zambezi	10	3,781
Kafue	11	7,108
Luangwa	5	3,560
Chambeshi	2	57
Luapula	5	505
Lake Tanganyika	2	11
Total	**35**	**15,022**

Table 5: Number of water points captured in the registered borehole and zero coordinates database (as of December 2019).

Description	Number of Water Points Captured in the Database
Total Registered Boreholes	10,962
Boreholes with Zero Coordinates	3,959
Check Coordinates	691
Total	**15,612**

In addition to extracting data from the database to fulfil WARMA's mandate, various other stakeholders regularly use the groundwater information data for planning, management, development and research purposes. A total of 552 people constituted from various government, non-government, private, research and consultancy institutions received groundwater information, technical reports and advises from the project and WARMA.

All data entries were scrutinized and checked for plausibility. In this process, the correct spelling of names was checked and harmonized, coordinates were verified on the map or in the field, and measurement data corrected wherever possible and necessary. It is recommended to update the database regularly according to the work flow outlined in the previous chapter. The quality and information of the collected water points from the individual sources varied considerably. This variation in quality of borehole information was caused by the former lack of a standard borehole completion report. Some completion report of boreholes drilled in the past contain very little information such as the 'type of water point' and the 'name of owners' without geographical coordinates. More recent drilling reports provided detailed description of geology and borehole design, hydraulic test data and results and some chemical analyses.

5. CAPACITY BUILDING

Between 2016 and 2018 five training sessions, building upon each other's content, on GrIMS using the GeODin® software were conducted for a total of 13 participants. The participants were chosen from WARMA HQ, its catchment offices and sub-catchment offices. The trainings were conducted by Fugro Germany and BGR/GReSP professionals, mainly focussing on strengthening and enhancing the capacities of the WARMA staff. In addition, instructors and lecturers from the University of Zambia (UNZA) were also trained on the application and use of GrIMS. The main training topics were groundwater data management, changes in GeODin®'s new software version 8.3, collecting and documenting groundwater data, GPS measurements with hand-held devices, data analysis and designing queries. The training was supported by practical tests. The new GeODin® 8.3 software was appreciated by all participants as being user-friendly and easily manageable. A training manual and GeODin® technical guides was provided to the trainees and relevant staff of WARMA and UNZA. Additional on-the-job-training was conducted for 8 WARMA employees between 2018 and 2019.

In addition, 25 individual GeODin® 8.3 licenses have been provided to WARMA HQ and Catchment offices to ensure continuous update and management of the database. A campus license has been installed at the IT-Department of the School of Mines at UNZA for practical training of the IWRM graduate students and in-service trainees from the water sector. It also enables to respond to further training and coaching requests from WARMA.

6. CONCLUSION AND RECOMMENDATION

The GrIMS is vital for sustainable management and effective use of groundwater resources in Zambia. Groundwater drillers are now obliged to deliver standard borehole completion reports for every borehole drilled. These reports will contribute to improve hydrogeological analyses and reports - for better management and protection of groundwater resources.

The GrIMS can serve to extract information on aquifer characteristics and other hydrogeological information at different hydrological or administrative units, making it available to planners and decision makers. The inherent information forms the basis for a proper groundwater permitting system. For example, by applying queries, it is possible to list commercial boreholes that need permits for groundwater abstraction.

The GeODin® database is using basin blocks (sub-catchments) to administer water points, which is in line with the decentralized structure of WARMA as stipulated by the Water Resources Management Act of 2011. The structured database can be easily used by local authorities and WARMA to register and regulate all boreholes.

The following recommendations are given:

- The workflow between the (sub-)catchments and WARMA HQ should be strictly followed. Data for the same basin block should be only entered at the (sub-) catchment level to avoid confusion and a loss of data when updating the database. Should WARMA decide to enter data at the HQ as well, a clear communication with the (sub-)catchment offices about who is using which water point numbers is required.
- A "Groundwater Information System Officer" at WARMA HQ and the catchment offices should be appointed. The officers should have profound knowledge in the database software package GeODin® and basic knowledge in MS Access®. The main task of the Groundwater Information System Officer should be to supervise the maintenance and continuous updating of the database, and to facilitate the workflow from catchment to WARMA HQ and vice versa. She/he will thus ensure a regular transfer of updated projects from catchment offices to WARMA HQ and vice versa and will also perform data quality checks of the transferred data.
- Capacity development and monitoring activities should be intensified in all catchments to advance the GrIMS.
- The GrIMS provides an open interface to export and import different data formats. Data can also be easily visualized in GIS tools. This open concept has been intentionally chosen to enable GrIMS users to connect groundwater information to other databases, GIS-projects and information systems. WARMA can also use the GrIMS in the development of an IWRM information platform that can bring together data from groundwater and surface water bodies, the river flow monitoring stations, the surface water permit management system as well as meteorological data.

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