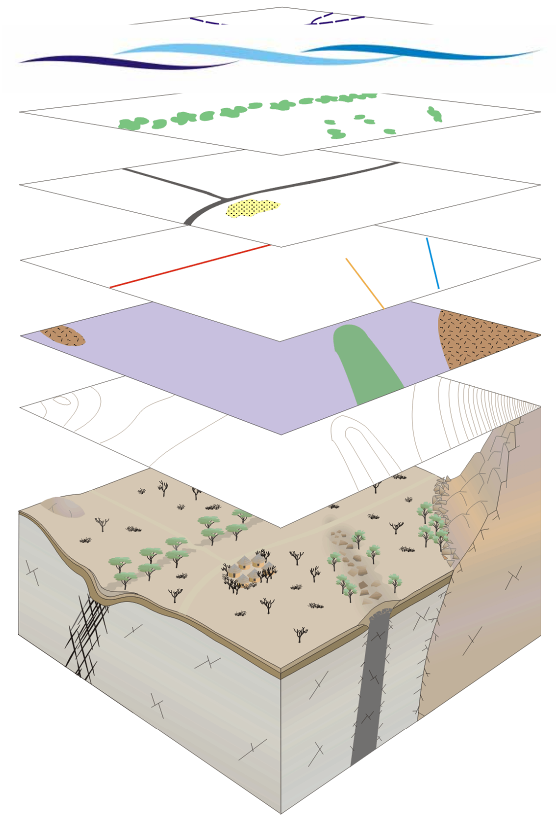
SADC Hydrogeological Mapping Project

Hydrogeological Mapping Procedures and Guidelines



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A technical report to the Southern African Development Community (SADC) and Cooperating Partners:

European Union and GTZ

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Preface

The Southern African Development Community (SADC) hydrogeological map provides an overview of the groundwater of the SADC region in the form of an interactive web-based regional map and atlas. The map is a first and vital step in supporting groundwater resource planning at international level and transboundary scale.

The SADC hydrogeology map is a general hydrogeological map providing information on the extent and geometry of regional aquifer systems. The map is intended to serve as a base map for hydrogeologists and water resource planners, whilst at the same time presenting information to non-specialists. Thus, the map is a visual representation of groundwater conditions in SADC. The map serves as a starting point for more detailed regional groundwater investigations by showing data and knowledge gaps.

The SADC hydrogeological map is not intended to replace:

- National groundwater maps
- Borehole siting tools and methods
- Site-specific investigations

In compiling the SADC hydrogeological map the following deliverables were produced as an outcome of the project:

- Interactive web-based SADC hydrogeological map and atlas
- Explanatory brochure for the SADC hydrogeological map and atlas
- Hydrogeological Mapping Procedures and Guidelines
- Borehole database and associated procedures
- Geographic Information Systems (GIS) database
- Capacity building strategy
- Updated country reports
- Training material emerging from capacity building workshops
- Final report
- First interim and second interim reports
- Monthly reports

The project has produced the following two main priority results as required by the terms of reference:

- Comprehensive, interactive web-based hydrogeological map and atlas of the SADC region;
- Enhanced institutional capacity for producing and using hydrogeological maps in water resources planning, development and management

This document sets out procedures and guidelines to assist SADC Member States' hydrogeological staff to produce or update hydrogeological maps. This is done through documenting the procedures followed in the compilation of the SADC hydrogeological map. This document does not detail step-by-step procedures for compiling hydrogeological maps as each mapping programme will be unique but rather serves as a template for hydrogeological mapping.

In compiling the document the authors relied heavily on the ground-breaking work done by Dr Wili Struckmeier, who has supported the SADC hydrogeological map from inception

and hydrogeology mapping in general. Mr Jeff Davies is also thanked for providing papers and information on hydrogeological mapping to support the implementation of the project. The project team is also grateful to the country participants who supported the project, enthusiastically participated in the activities of the programme and made invaluable comments. Ms Helene Mullin from the Department of Water Affairs, South Africa is acknowledged for her efforts in arranging the first capacity building workshop in Pretoria on hydrogeological mapping.

The project team was hosted by the Department of Geological Survey in Lobatse, Botswana. We are grateful to our counterparts Oteng Lekgowe, Magowe Magowe, Pelonomi Matlotse, Keoagile Kgosiesele and Charles Chibidika for their participation in the project.

The SADC Project Manager, Mr Othusitse Katai, is thanked for his leadership and valuable input throughout the consultancy. The SADC Infrastructure and Services Directorate – Water Division is also thanked for its contribution to the project. We are grateful to the European Union and GTZ for their financial support to the project.

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1. Introduction

1.1. The Southern African Development Community (SADC) Hydrogeological Map

Hydrogeological maps help us to characterise and understand groundwater resources.

Two distinct groups of hydrogeological maps are defined, which correspond to the roles of the maps and their uses (Struckmeier & Margat, 1995):

- General hydrogeological maps and groundwater systems maps are associated with reconnaissance or developing scientific understanding and are suitable tools for introducing the importance of groundwater resources into the political and social development sphere;
- Parameter maps and special purpose maps form the basis for economic development, planning, engineering and management; they differ greatly in content and representation according to whether they are designed for specialists or non-specialists in hydrogeology.

The SADC hydrogeological map is a general hydrogeological map which informs on the extent and geometry of regional aquifer systems.

The map is intended to serve as a base map for hydrogeologists and water resource planners, whilst at the same time presenting information to non-specialists. The map is a visual representation of groundwater conditions in SADC and serves as a starting point for the design of more detailed regional groundwater investigations by exposing data and knowledge gaps.

It is important to note that the SADC hydrogeological map is published as an interactive web-based map and is not a printed map. This has implications for the cartographic procedures to be followed.

1.2. This document

1.2.1. Purpose

This document sets out procedures and guidelines to assist SADC Member States' hydrogeological staff to produce hydrogeological maps. This is done through documenting the procedures followed in the development of the SADC hydrogeological map. Figure 1 sets out the SADC hydrogeological map schema with associated data sources. Figure 2 present the work flow diagram for the SADC hydrogeological map.

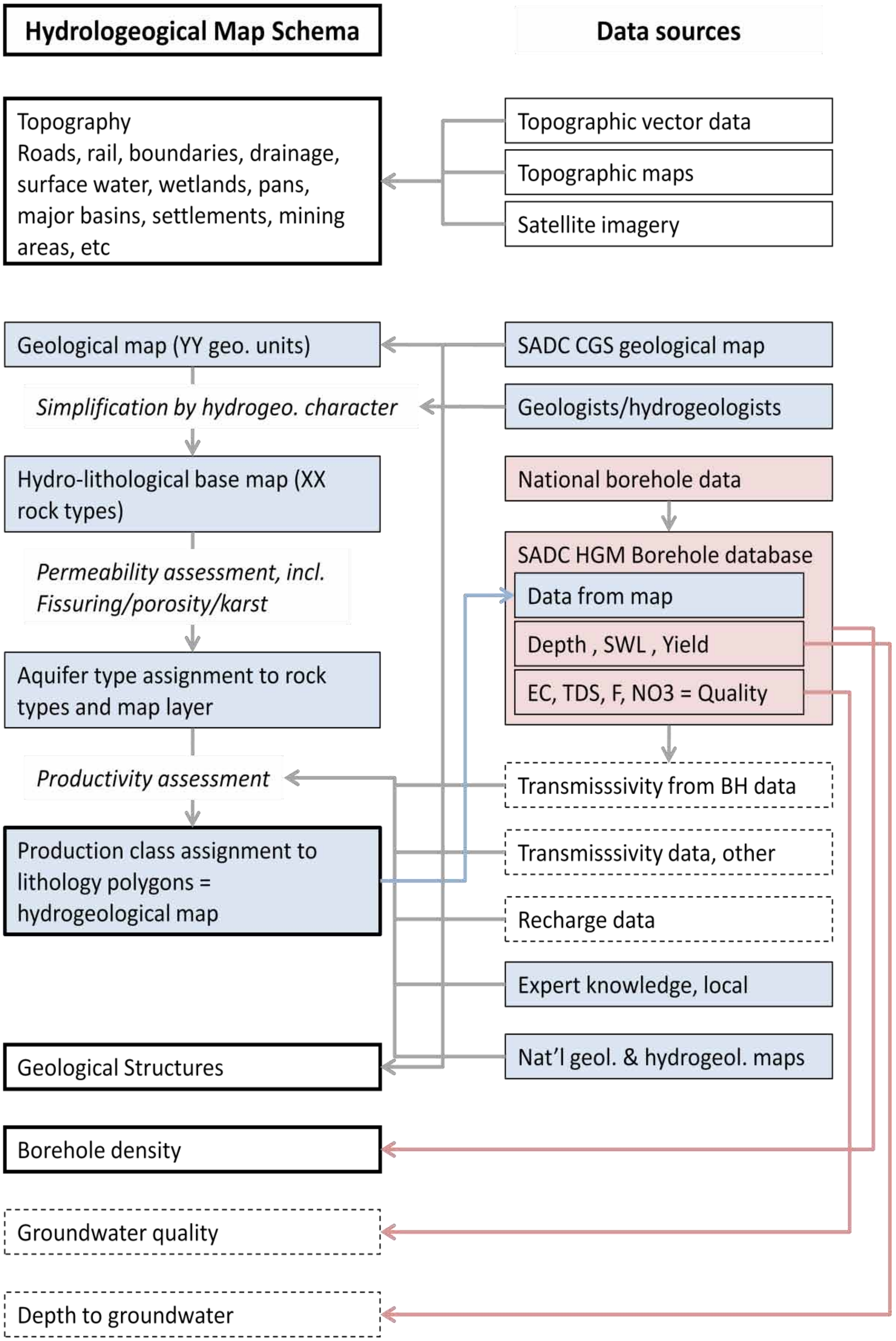


Figure 1: Hydrogeological map schema

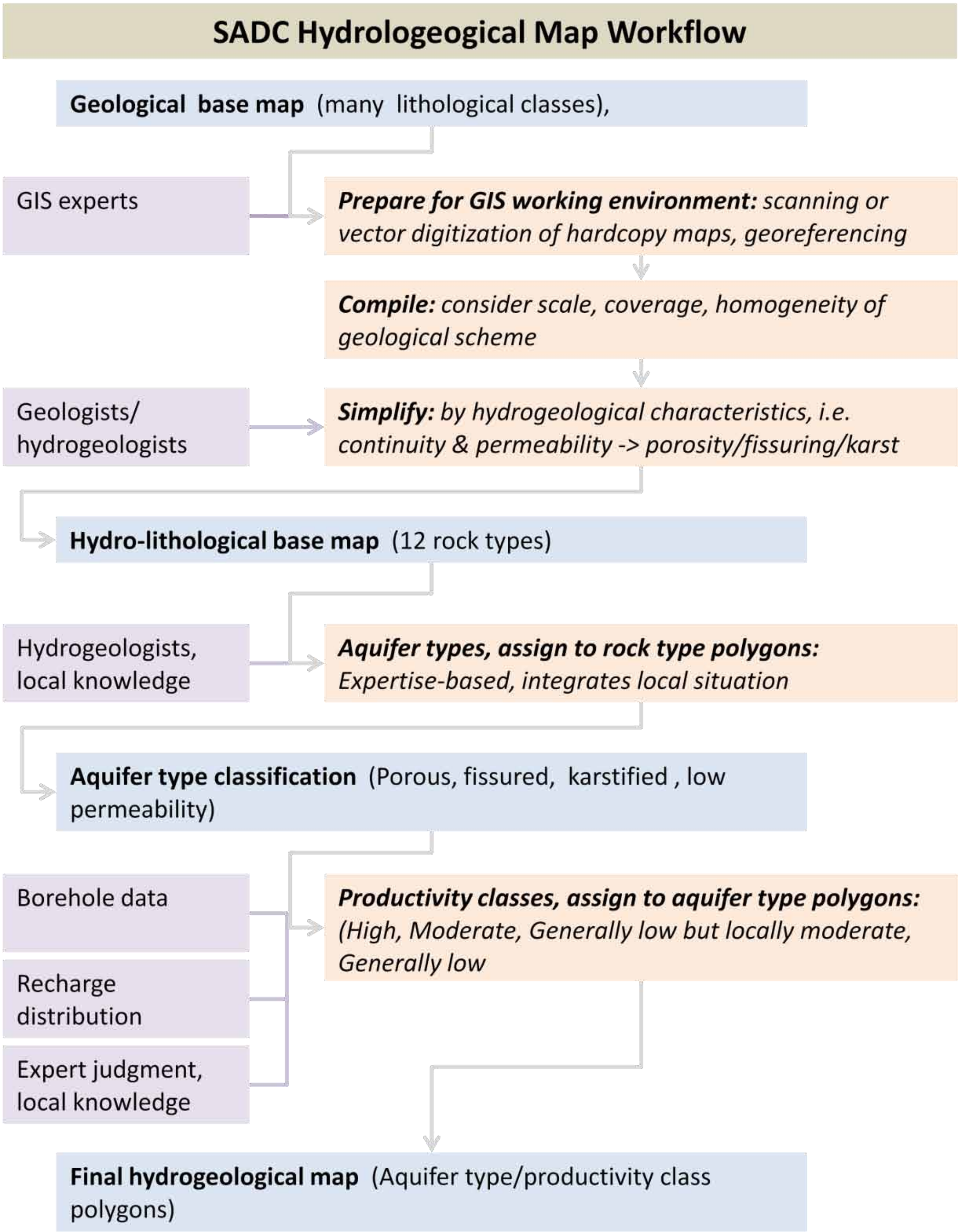


Figure 2: SADC Hydrogeological map workflow.

1.2.2. Scope

The methodology followed in producing the SADC hydrogeological map was constrained by the terms of reference and the time-limits imposed on the project. In developing national scale or sub-national scale hydrogeological maps there may be opportunity to refine or utilise different methods that exist in the literature.

This document is neither a text book nor a complete guide to hydrogeological mapping. Readers are urged to consult other literature, e.g. (Struckmeier & Margat, 1995)for a detailed synthesis of hydrogeological mapping and procedures. Nevertheless, it is hoped that the material presented in the guide is relevant and will assist Member States in their mapping programmes.

1.3. Orientation

Chapter 2 *Planning and Preparation of the SADC hydrogeological map and atlas* describes the planning and preparation carried out by the project, and serves as a generally applicable guideline for similar projects.

Chapter 3 *Developing the Lithological Base Map* describes the process developed by the project for deriving a SADC lithology base map, starting from the SADC geological map.

Chapter 4 *Borehole Data Processing* discusses the processing of borehole data for use in the SADC hydrogeological map carried out by the project team.

Chapter 5 *Developing the Groundwater Resource Productivity Map* describes the algorithm developed by the project to move from the hydro-lithological base map described in Chapter 4 to the final productivity map, the heart of the SADC hydrogeological mapping effort. The process serves as a guideline for similar mapping projects.

Chapter 6 *Cartographic Guidelines* discusses the cartographic approach taken by the project, with recommendations relevant to similar projects.

Chapter 7 *Dissemination* describes the various kinds of outputs of the project, that is, the digital map, printed map, web-based map, database and brochure.

Chapter 8 *Data Management* describes the borehole GIS data management in the project and gives general recommendations, particularly regarding documentation, metadata, terminology and naming conventions.

1.4. Other sources of information

Struckmeier & Margat, 1995

The project methodology builds on the methodology presented in "Hydrogeological Maps, A Guide and a Standard Legend" (1995) by Wilhelm Struckmeier and Jean Margat, and this document borrows much from that guide.

UNESCO, 1983

The "UNESCO, International Legend for Hydrogeological Maps, Revised version, 1983" is an early international standard for the classification and organization of content in hydrogeological maps, which is still relevant.

RSA DWAF Standards, 1997

The Republic of South Africa DWAF "Standards and Specifications for the Mapping Programme" by the Mapping Management Team (1996/1997) is also a very useful example of a processes/guidelines document.

Project reports

The following project reports and material are available on the SADC hydrogeological map and atlas website (www.sadc-hgm.com).

- Inception report and appendices
- Second Interim report and appendices
- Final report
- Explanatory Brochure for the South African Development Community (SADC) Hydrogeological Map and Atlas
- Training workshop materials

2. Planning and preparation for a hydrogeological mapping programme

This chapter presents the planning and preparation process required for a hydrogeological mapping programme.

2.1. Planning

2.1.1. Define the purpose (use, users)

- Define the purpose of the map. See (Struckmeier & Margat, 1995) which have an extremely useful discussion and classification of different map types. The classification system is given in Table 1.
- Define the users for the intended map. Try to formulate how the map will be used and by whom in order to define the necessary content and resources that need to be devoted to the project as well as information to be excluded from the project.
- Based on purpose/use/user definition, identify information needed to compile the map.

2.1.2. Decide medium of output

- Decide whether the output will be print (wall maps, atlases, brochures), digital, web-based or some combination of these, as this has a bearing on costs and to some degree the content decisions.
- Depending on intended medium of output, investigate the costs of the necessary resources (e.g. specialists such as GIS or cartography staff, web hosting agents, broadband capacity, etc.).

Table 1: Classification system for hydrogeological maps (Struckmeier & Margat, 1995)

Level of information / *Possible use*	*Low (scarce and heterogeneous data from various sources)*	*Advanced (+ systematic investigation programmes, more reliable data)*	*High (+ hydrogeological systems analysis and groundwater models)*
Reconnaissance and exploration	General hydrogeological map (aquifer map)	Hydrogeological parameter maps (map sets, atlases)	Regional groundwater systems map (conceptual model representations)
Planning and development	Map of groundwater resource potential	Specialised hydrogeological maps (planning maps)	Graphic representation derived from geographic information systems (maps, sections, perspective diagrams, scenarios)
Management and protection	Map of groundwater vulnerability		
Possible use / *Parameters of representation*	Static------------------------time-dependence-------------------------dynamic Low--------------------------reliability----------------------------------high Low--------------------------cost per unit area------------------------high Large------------------------area represented-------------------------small Small-------------------------scale--------------------------------------large		

2.1.3. Identify and secure required staff

- Identify required positions, time needed for different positions and available staff who can fill the positions.
- Reserve the required staff for the time needed. Put into place contingency plans in the case of loss of staff.

2.1.4. Identify and secure required GIS and cartographic resources

2.1.4.1. GIS and cartographic software

- Most modern maps are produced with digital technology (probably a GIS program but also CAD). Decide on the software development environment and its availability for all phases of the production.
  - Besides the main GIS/CAD software, consider other needs such as scanning software; coordinate conversion, georeferencing of rasters, etc.
- Secure the necessary software environment.
  - Licenses
  - Functionality

- Sufficiently powerful hardware for the software
- IT support
- Metadata standards

2.1.4.2. Computer and other hardware

– Determine necessary hardware.
  - Workstations for software environment
  - Large format scanner
  - Printers and plotter for draft output
  - Consumables
  - IT support
  - Backup procedures

2.1.4.3. Internet

– Broadband connections to access data, within the project or from the internet.

2.1.5. Develop and secure budget

– Develop a budget related to the purpose, use, medium of output, and, if applicable, income expected from the target map.
– Secure the budget.

2.1.6. Develop formal project plan and detailed specifications

– Develop a formal project plan. Standard project planning tools and approaches are recommended.
– Develop detailed specifications for the project. For a national-scale, general purpose map, the minimum datasets required would be:
  - High-quality and recent topographic base map, preferably digital, at similar scale to the target map
  - A geologic base map, preferably digital, at a similar scale as the target map
– and preferably
  - Borehole database
  - Additional datasets for all information layers agreed on

2.1.7. Identify data gaps

– Identify the gaps between required and available datasets, taking into account coverage and quality.

- If necessary, revise the level of scope of the project if the datasets are not available; alternatively identify actions needed to meet the requirements, and whether time and budget constraints permit filling the gaps.

2.2. Resource acquisition and compilation phase

2.2.1. Fill data gaps

- Carry out the necessary and feasible actions to fill the data gaps.
  - Field work is of course a major undertaking, requiring long-term planning.
  - If borehole databases are not in compiled formats and directly useable by the mapping staff, compile them.
    - Consider the SADC hydrogeological mapping borehole data management reports and lessons learnt. These reports are available on the SADC Hydrogeological Map and Atlas website (www.sadc-hgm.com)
    - It may be necessary to accept major simplifications and manipulation of borehole data to obtain something useable for mapping.
    - Note that the process of transferring field records such as borehole drilling and pump-test logs to database format suitable to support mapping is a very time-consuming process.

2.2.2. Acquire a library of all existing national geology and hydrogeological maps at all scales

All maps should be scanned with a high-quality scanner, to facilitate use in a digital cartography environment, and to preserve the map. The scanned maps should be geo-referenced using appropriate software.

2.2.3. Acquire a library of the most recent topographic maps or digital data

Topographic maps are necessary for the topographic base map. If the topographic information is available in GIS format it should also be acquired. Printed maps should be scanned if the budget permits this, as in digital format they will be more useful for deriving vector topographic layers, if that is required.

2.2.4. Acquire remote sensing images, if necessary

Remote sensing images can be useful in many ways in hydrogeological mapping projects, see (Struckmeier & Margat, 1995) and other relevant literature. However, interpreting the images is a specialized and time-consuming operation, only to be undertaken if time and budget allow. Besides updating and refining the topographic base map, they may yield information on the structural setting, lithology, soils and land use (Struckmeier & Margat, 1995).

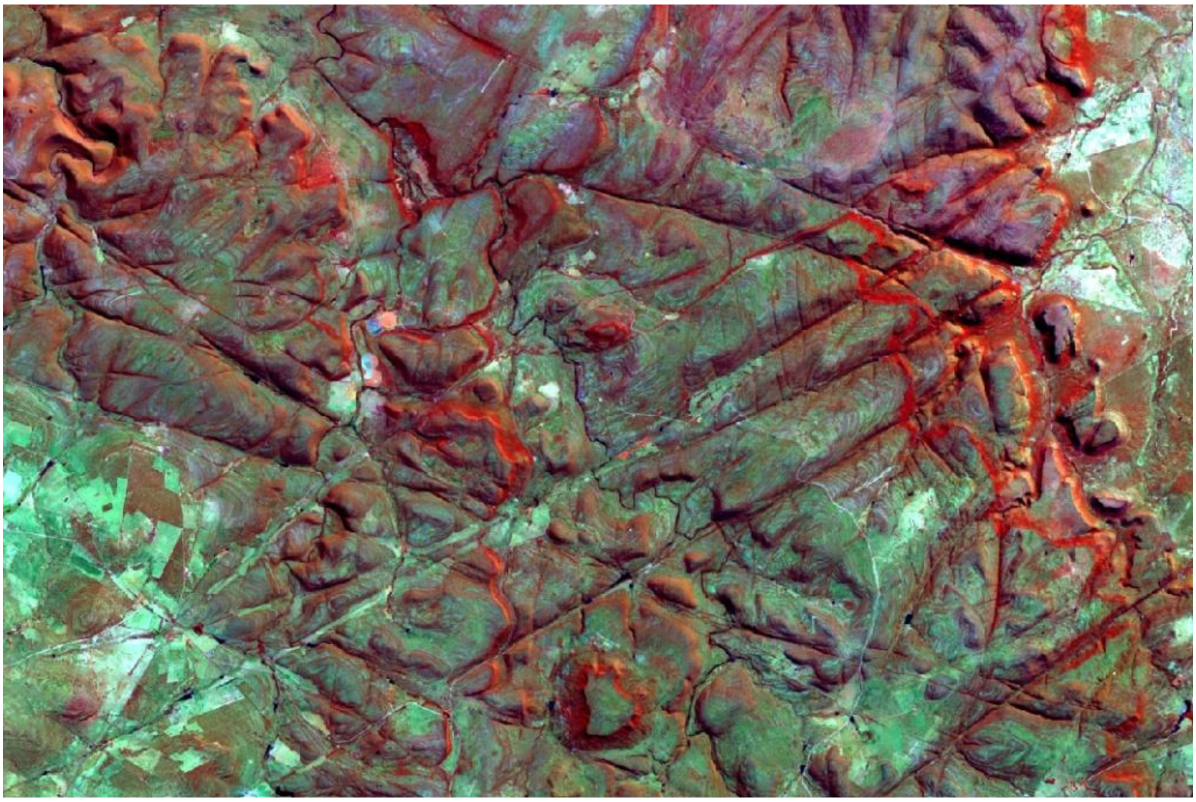


Figure 3: Distinct structural features of potential hydrogeological significance that can be mapped from remote sensing data *(Limpopo Province, South Africa, Landsat ETM, RGB 453)*

2.2.5. Contract or otherwise ensure participation of staff and experts

The necessary key staff and experts should be engaged or contracted to ensure that the mapping project proceeds according to the project plan.

2.3. Results of planning and preparation, the SADC hydrogeological map example

2.3.1. Purpose of the SADC hydrogeological map

The SADC hydrogeological map is a general hydrogeological map that displays aquifer type and indicates aquifer productivity. Aquifer productivity, normally, are based on judgements of the typical long-term abstraction rate from a properly sited and constructed borehole. In the case of the SADC hydrogeological map, the level of information is relatively coarse because of its small-scale (1:2 500 000) characteristics, poor data availability and the heterogeneity of information from various sources. The use of the map is at a transnational scale for:

- Reconnaissance and exploration; and
- Planning and development

A note on scale

In thematic cartography, the following definitions of scales are commonly used:

Large scale – 1:10 000 to 1:100 000
Medium scale – 1:200 000 to 1:500 000
Small scale - 1:1 million to 1:10 million

(Struckmeier & Margat, 1995)

2.3.2. Project plan

Interim Reports were produced at various "milestones" of the project cycle, which detailed information on the phase activities, project work plan and the timing of activities. This also provided an opportunity to update the financial plan. In addition monthly progress reports were produced.

2.3.3. Medium of output

The SADC hydrogeological map was published in a web-based format.

2.3.4. Staff specification

The staff specifications are given in Table 2 as required by the terms of reference for this project.

2.3.5. Software specification – SADC hydrogeological map

While this document is intended to be "platform-independent" i.e. the procedures and recommendations in it are applicable regardless of the hardware and software used by the Member State mapping staff, it might be helpful to list the project software used:

- Paper map digitization
    - Scanning of paper maps – scanner software
    - Georeferencing of paper maps - ArcGIS

- GIS operations – ArcGIS
- Cartography - ArcGIS
- Borehole database – Access, MapWin GIS ActiveX
  - Preparation of submitted files – MS Excel, MS Access
  - Coordinate transformation – Fransons CoordTrans, ArcView
  - Export from database – MS Excel, Google Earth
  - Statistical borehole productivity evaluation - Statgraphics Centurion Version XV. (Statpoint, Inc., USA, www.statgraphics.com).
- Web publishing – ArcGIS Server using the ArcGIS API for Flex

2.3.6. Planning for dissemination and sustainability

Part of the planning process is to consider the eventual dissemination of the map, as well as considering sustainability. These issues can have a bearing on the entire production process, and on decisions about the feasibility and scope of the project.

- Secure a stable, long term environment for the storage, updating and continued dissemination of the map. Some of the issues to consider are:
  - Documentation – staff come and go, so process documentation should exist to allow new staff to maintain and update the map.
  - Backup of all digital files.

Table 2: Key experts and their profiles (skills only)

Expert	Qualifications and skills	General professional experience	Specific Professional experience
Team Leader/ Hydrogeological Expert	– A University degree in Hydrogeology or a related field – Minimum of 15 years practical professional experience.	– Not less than 10 years of proven professional experience in the relevant field	– Significant working knowledge of hydrogeological principles and experience in groundwater resources assessment and management. – Extensive experience in project management, coordination and monitoring of large scale projects in similar fields. – Practical knowledge of common hydrogeological software – Ability to ensure good communication and coordination with project partners and other stakeholders, motivation and report writing skills – Familiarity with institutional capacity strengthening/ building and/or organisational development – Knowledge of Integrated Water Resources Management principles and transboundary watercourses issues
Database Management Specialist	– A University degree in Information Technology or a related subject	– Not less than 10 years of proven professional experience in the relevant field	– Significant expertise in database development/ management and working experience with Arc Info and other related database software

Expert	Qualifications and skills	General professional experience	Specific Professional experience
	– Minimum of 15 years of overall professional experience		programs. – Development of database procedures and quality assurance standards – Ability to ensure good communication and coordination with project partners and other stakeholders, motivation and report writing skills – Familiarity with institutional capacity strengthening/ building and/or organisational development
Remote Sensing/GIS Expert	– A University degree in Remote Sensing or a related subject – Minimum of 15 years of overall professional experience	– Not less than 10 years of proven professional experience in the relevant field.	– Significant expertise in remote sensing and working experience with GIS applications. – Development of GIS/ Remote Sensing procedures and quality assurance standards – Manipulation, interpretation and characterisation of remote sensing data for groundwater resources assessment – Ability to ensure good communication and coordination with project partners and other stakeholders, motivation and report writing skills – Familiarity with institutional capacity strengthening/ building and/or organisational development

Expert	Qualifications and skills	General professional experience	Specific Professional experience
Cartographer	– A University degree in Cartography or a related subject – Minimum of 10 years of overall professional experience	– Not less than 5 years of proven professional experience in the relevant field.	– Significant expertise in development of cartography map production, contact photography and map re-production. – Geo-referencing various datasets, templates and legend development – Digitising and manipulation of various datasets for map production – Development of cartographic procedures and quality assurance standards – Familiarity with international standard geological and hydrogeological code/symbols and legends – Ability to ensure good communication and coordination with project partners and other stakeholders, motivation and report writing skills – Familiarity with institutional capacity strengthening/ building and/or organisational development

3. The Base Map

This chapter presents the process of deriving the base map for the compilation of the hydrogeological map.

Depending on the scale of the final product, the following up-to-date maps and images may be required:

- Geology (at the best scales available)
- Topographical
- Meteorological and hydrological
- Satellite images
- Aerial photographs

The topographic map is a basic element for any hydrogeological mapping programme (Struckmeier & Margat, 1995). Its importance is twofold, firstly as a guide for orientation on the surface and secondly as a source of useful hydrological information, e.g. river network, watersheds and surface properties (Struckmeier & Margat, 1995).

If the digital data is unavailable the hardcopy data may be captured into digital format by:

- digitising
- scanning

3.1. Digitising procedures

ArcGIS and ArcScan are normally used for data capture. ArcScan is an extension that is included with the full version of ArcGIS, and is used for the rapid vectorisation of especially line material from images or rasters. The scanned image should be classified into two classes and the raster colour can be selected as black or green to facilitate viewing.

The settings of the correct values of the following parameters are an important prerequisite in ArcScan vectorisation:

- Intersection solution
- Line width related to scanning resolution
- Compression tolerance
- Number of vertices to represent lines
- Smoothing factor
- Distance for node shift
- Gap closure

After vectorisation and editing, the geodatabase topology must be created. Topology concerns the spatial relationships between features. It is applied according to rules, ensures integrity of data and facilitates editing.

3.2. Scanning and georeferencing procedures

3.2.1. Scanning

All material required for data capture needs to be scanned. The maps should be scanned at a resolution of at least 300 dpi, as black and white or alternatively grayscale **.tif** images. The setting of the correct threshold on the scanner is important in order to avoid the merging of narrowly spaced lines into blobs. Coloured maps may be scanned as a 24-bit colour image and saved as a .**tif** file.

3.2.2. Georeferencing

In order to accurately represent features of a map to scale, the map should be projected using the projected corner coordinates of the map or any other clearly discernible points of which the coordinates are known.

Georeferencing can then be done by either manually entering the coordinates, or by digitizing the existing projected points with known coordinates. The procedure becomes slightly more complicated when a datum transformation is involved in the process e.g. converting the map from Cape datum to the WGS84 datum. Only in the absence of projection parameters should a map be georeferenced in geographic coordinates, as this will necessarily introduce a margin of inaccuracy

3.3. The geology base map

3.3.1. Scale

A suitable scale needs to be selected for the compilation of the hydrogeological map. The geology map needs to be represented at the same scale. The GIS specialists normally do this. In the case of South Africa the hydrogeology maps were compiled at a scale of 1:500 000. The geology maps were available at a scale of 1:250 000 which meant that the geology maps needed to be joined by the GIS analyst.

Most national maps are compiled at a scale of 1:1 000 000 to 1:2 000 000 for the larger countries.

3.3.2. Simplification of the geology

The geology map needs to be transformed into a hydro-lithology base map. The process is started by ensuring that each formation has a geological code. This is normally straightforward as most geological maps should have this information. It is best to capture the geological rock types and their codes in a spreadsheet to assist in the conversion process.

The next step is the conversion of the litho-stratigraphic units into hydro-lithological units.

This process is best completed by involving a geologist, familiar with the area, together with a hydrogeologist in the conversion process.

The hydro-lithological conversion of a geological map may be done at different levels (Struckmeier & Margat, 1995):

- The distinction between unconsolidated and consolidated, permeable and impermeable rock bodies is made on a rather crude and qualitative basis. The rock bodies considered permeable are then classified as:
    - continuous or discontinuous after the nature of the groundwater bodies
    - porous/intergranular or fissured according to the dominant flow characteristics.

  This leads to a hydro-lithological classification into three main aquifer types (porous, fissured, karstified), possibly complemented by intermediate classes. An aquifer is a permeable, saturated geologic unit that can transmit significant quantities of water. Prominent examples of such aquifers are:

    - gravel, sand and volcanic scoria beds (porous)
    - sandstone, marlstone, basalt (frequently fissured)
    - limestone, dolomite, gypsum (frequently karstified).

In the SADC hydrogeology map the geology was simplified to 12 hydro-lithological classes (Table 3). This process is fairly time consuming and exact capturing of the conversion process is essential. The geology needs to be linked to the assigned lithologies by assigning codes. The derived polygons were reassigned attributes.

Table 3: Hydro - lithological classes of the SADC HGMs

Hydro - lithological classes
Unconsolidated sands and gravel
Clay, clayey loam, mud, silt, marl
Unconsolidated to consolidated sand, gravel, arenites, locally calcrete, bioclastites
Sandstone
Shale, mudstone and siltstone
Interlayered shales and sandstone
Tillite and diamictite
Dolomite and limestone
Volcanic rocks, extrusive
Intrusive dykes and sills
Paragneiss, quartzite, schist, phyllite, amphibolite
Granite, syenite, gabbro, , gneiss and migmatites

3.4. Structural information

Dykes, fractures and faults are highly relevant to groundwater occurrence either acting as groundwater conductors or as barriers to groundwater in fractured aquifers. These need to be depicted on the lithology base map if they have hydrogeological significance.

3.5. Topographic information

3.5.1. Meteorological and hydrological information

Most countries have meteorological and hydrological services where the following can be obtained:

- Rainfall
- Temperature
- Surface water features such as:
  - Wetlands
  - Rivers (perennial and non-perennial)
  - Catchments
  - Irrigated areas
  - Discharge areas

3.5.2. Map and Survey information

Topographical information can normally be obtained from maps and surveys departments in the countries: Useful information includes:

- Political boundaries
- Roads/rails
- Towns and major settlements
- Digital elevation models
- Vegetation

3.6. Inset maps

3.6.1. Recharge/Rainfall

Recharge is a difficult parameter to determine but is of fundamental importance for any hydrogeological map as it is one limiting factor for exploitation. Recharge is usually displayed as a layer for the aquifer productivity or as an inset map.

In the absence of recharge calculations, rainfall is used as a proxy and upper limit for recharge. The climatic conditions largely influence the components of the water balance as well as the flow of groundwater systems (Struckmeier & Margat, 1995).

3.6.2. Borehole density

This gives an indication of the distribution of borehole information that was used in the compilation of the hydrogeological map. This is normally depicted as an inset map (Figure 4).

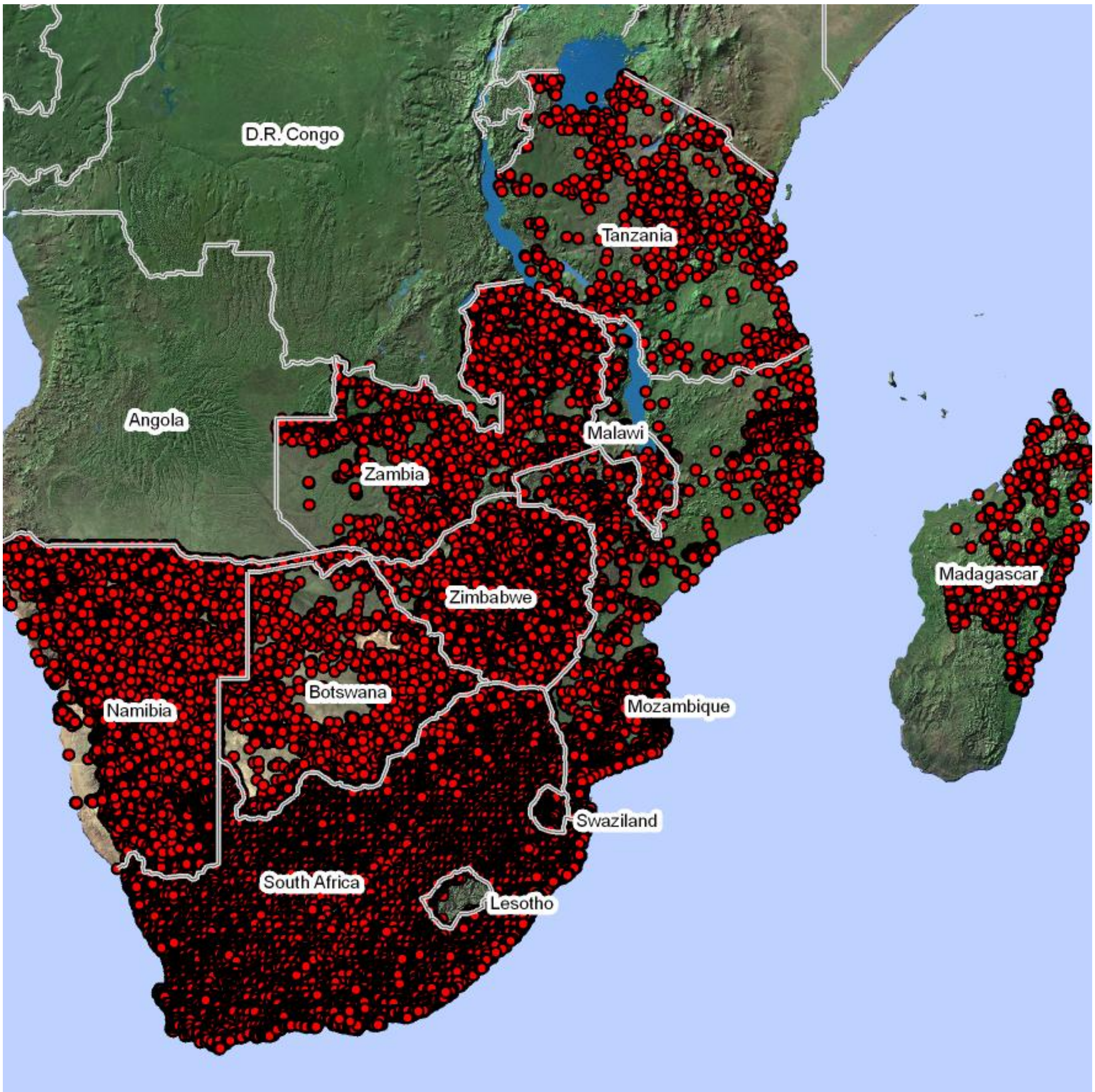


Figure 4: Borehole density map.

3.6.3. Water quality

The following water quality parameters are usual depicted on hydrogeological maps as insets, but any other relevant measured constituent may be presented:

- Nitrate
- Fluoride
- Electrical conductivity

3.7. Remote sensing

The SADC hydrogeological mapping team did not use remote sensing due to the small scale of the SADC area. Otherwise, both satellite imagery and aerial photography are often used in mapping, to confirm topographic information, derive structural or lithological features (Figure 5) relevant to the hydrogeology, or derive hydrogeological information indirectly from vegetation, soil moisture etc.

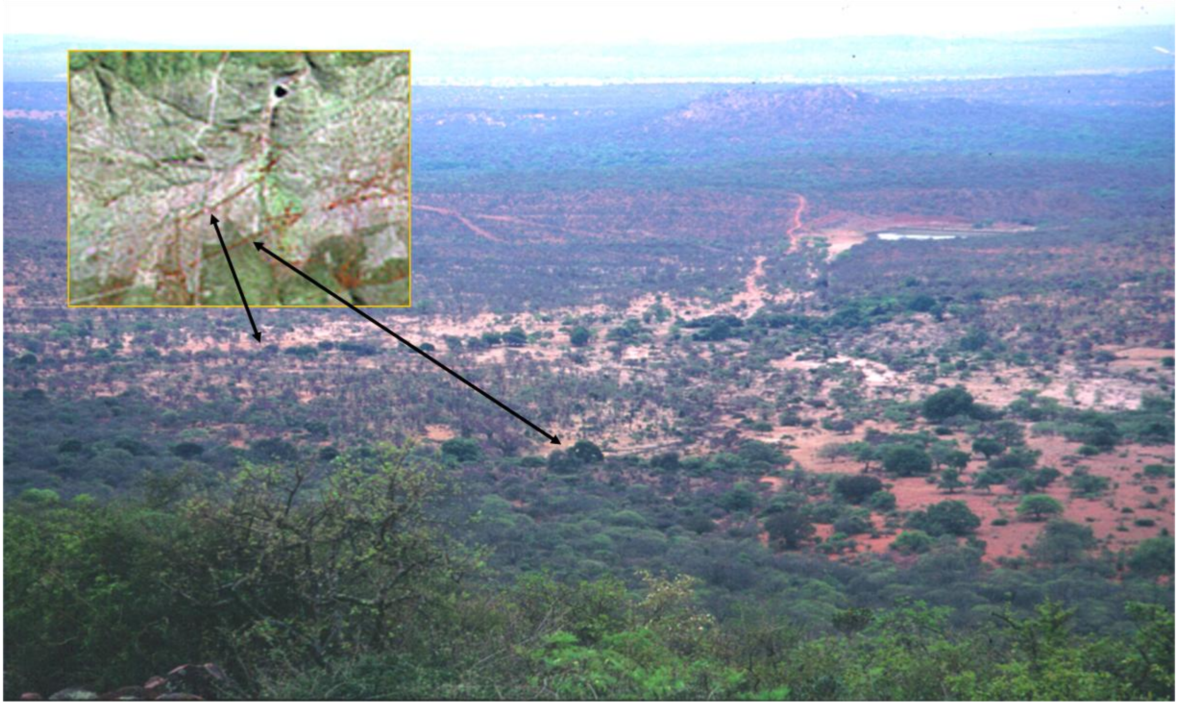


Figure 5: Dolerite dykes enhanced by prominent vegetation, Limpopo Province South Africa. Inset picture: Landsat TM- *(Photograph courtesy of Nils Kellgren)*

4. Borehole Data Processing

4.1. Role of borehole data

A high-quality set of borehole data is central to hydrogeological mapping. While the critical process of assigning productivity ratings to discrete lithological areas (i.e. map polygons) should ideally use borehole data (specific capacity, rest water level, borehole depth, more direct indications of productivity if available), it is possible to use expert knowledge and inspection of existing maps instead, as the SADC hydrogeological mapping project has done.

Besides being used to determine productivity, the borehole data in itself represents a number of thematic layers, such as borehole density, water table surface, water quality layers, etc. Depending on the type of data present in the dataset, a number of advanced layers for larger-scale (local) maps may be derived, such as groundwater flow regimes or recharge and discharge areas.

It should be noted that borehole data without location information (as coordinates of a point) are essentially useless for mapping.

4.2. Borehole databases

Unfortunately, many countries in the world do not maintain central databases of borehole information. Even if such a database exists, there may be serious problems with completeness, description of contents and data quality in general. A mapping project should allot a considerable amount of time to acquire, evaluate and process borehole data.

4.3. Characterization of SADC hydrogeological mapping borehole data

In the case of the SADC hydrogeological mapping project, a restricted number of borehole data parameters were requested from SADC Member States, for the purposes of map production in the project. The borehole data requested is likely to be sufficient for producing national hydrogeological maps of the same kind as the SADC map, i.e. general purpose and aquifer productivity maps at a country or regional scale (around 1:1 000 000 if printed).

The data requested by the project was:

- Borehole information, not springs, wells, seepages or other groundwater types
- the latest date for any data sampled repeatedly, in other words the database contains no time series, but just a single snapshot of data
- Latitude, longitude in WGS84 geodetic datum, to 5 decimals
- hydrogeological parameters:
    - borehole depth (m)

    - completion date
    - most recent rest water level (m)
    - that rest water level date
    - yield (L/s)
    - yield type (Blow, Tested, Unknown)
- water quality parameters:
    - EC, mS/m
    - TDS, mg/L
    - F, mg/L
    - NO_3, mg/L

The data received was processed before inclusion in the database, including validation of units, occurrence, and range etc, conversion where necessary of coordinates and units, rounded to one decimal for many parameters, collapsing to one record per borehole where multiple dates were submitted, etc.

More information on the processing history for each submission is available from the project (additionally, submissions are registered in the database and relevant documents are linked to it).

Database users should always bear in mind the origin of the data and the considerable processing involved, and use the database with caution. It may contain systematic, specific and random errors, but large samples tend to neutralise the inherent specific and random errors in the statistic analysis.

4.3.1.Processing

The data submitted to the project has undergone considerable processing to prepare it a) in a standard format, and b) as suitable for support for map production. The database user should always bear this in mind and read the following notes carefully.

The authoritative version of the data of course resides with the Member State organisations, and users are referred to these regarding validity of the borehole data.

A borehole data processing protocol was produced by the project; see "SADC hydrogeologic map Submitted Data Processing Protocol"; Inception report, Appendix 7.

4.3.1.1. National borehole code

In some cases, no borehole code was submitted to the project. The project assigned a code, since the database requires a unique code for each borehole. The invented codes include "SADC" and a country abbreviation in some form, as well as a serial number, or reference to a locality.

4.3.1.2. *Coordinates*

Most coordinates of boreholes were submitted to the project without conversion to the requested specification of Latitude, Longitude in the WGS84 datum. The project has performed conversions on the submitted coordinates where required, mostly using the Coordtrans program from Franson (for Madagascar the ArcGIS transformation was used).

In some cases exact characteristics of the submitted coordinates were not supplied by Member States, so the project has made assumptions, for example making assumptions about the most common geodetic datum used in a particular country.

Any errors introduced by these assumptions and by conversion are in fact too small (usually <200 meters for datum shifts) to matter at the scale of continental, or indeed country-wide mapping.

4.3.1.3. *Altitude*

The database includes both reported altitude and altitude derived from a GIS operation capturing the value of a Digital Elevation Model (DEM) for each borehole location. The altitude shown in the database application is the DEM-derived one.

Comparison of the DEM-derived altitude with the submitted one showed a small number of unlikely values for the submitted data. These however have been retained in the database, since the DEM values are in any case those presented in the application.

4.3.1.4. *Completion date*

In many cases, the borehole completion date was not explicitly indicated in the submitted data, and the date recorded is an estimate based on, for example, the earliest occurrences of a rest water level date in a time series.

4.3.1.5. *Borehole depth*

Although borehole depth can occasionally change if a borehole is drilled deeper or collapsed. In almost all cases the project received one depth value for the borehole. In the few cases where multiple depths were received, the most recent one was used.

Almost all data submitted to the project gave depth in meters.

4.3.1.6. *Rest water level and rest water level date*

Rest water level changes considerably over time. The project has captured a single rest water level value for a borehole, usually the most recent one. However, where other parameters such as water quality were associated with one of multiple dates, the date associated with other data was used.

4.3.1.7. *Yield*

Yield was submitted in a variety of units, besides the requested L/s. The conversions have been straightforward, but for the few cases where no units were indicated, assumptions have been made concerning the most likely units. Users should bear this in mind if mean yield or other statistics for groups of boreholes seem doubtful.

Yield has been rounded to 0.1/L/s, and up to a minimum of 0.1 L/s for all values >0 and <0.5.

4.3.1.8. *Yield type*

A wide range of yield type descriptions were submitted, rather than the requested Blow or Tested alternatives. The descriptions as submitted have been recorded in a field in the database ("Yield type, free text", Borehole. yield_type_freeText), as well as a field for Blow or Tested where so reported or interpreted.

4.3.1.9. *Electrical conductivity (EC)*

A wide range of units for EC were submitted. The conversions have been straightforward, but for the few cases where units were uncertain, assumptions have been made concerning the most likely units. Users should bear this in mind if mean yield or other statistics for groups of boreholes seem doubtful.

EC values were generally rounded to approximately 3 significant figures in mS/m.

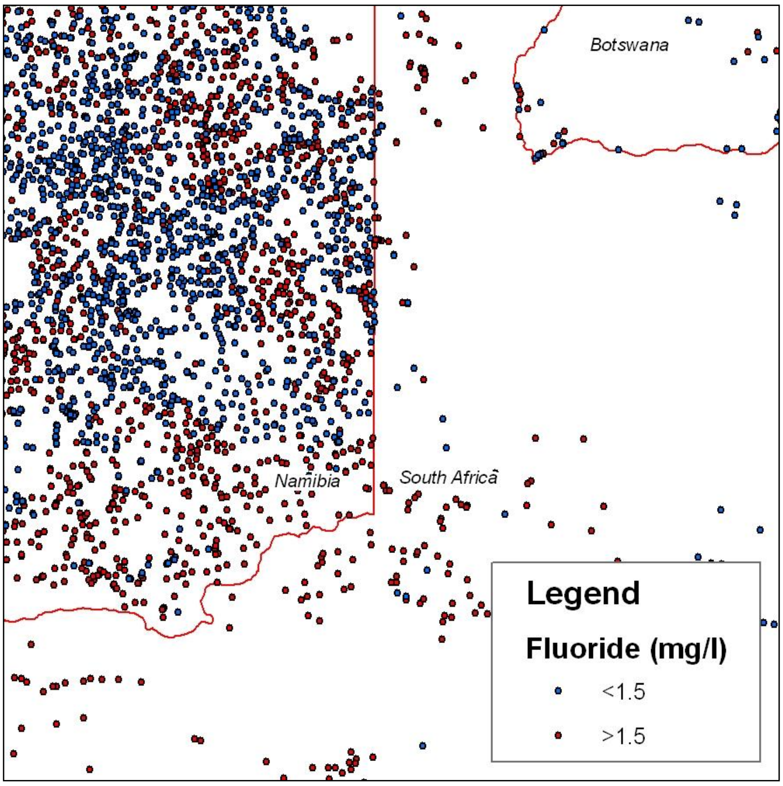
4.3.1.10. Nitrate

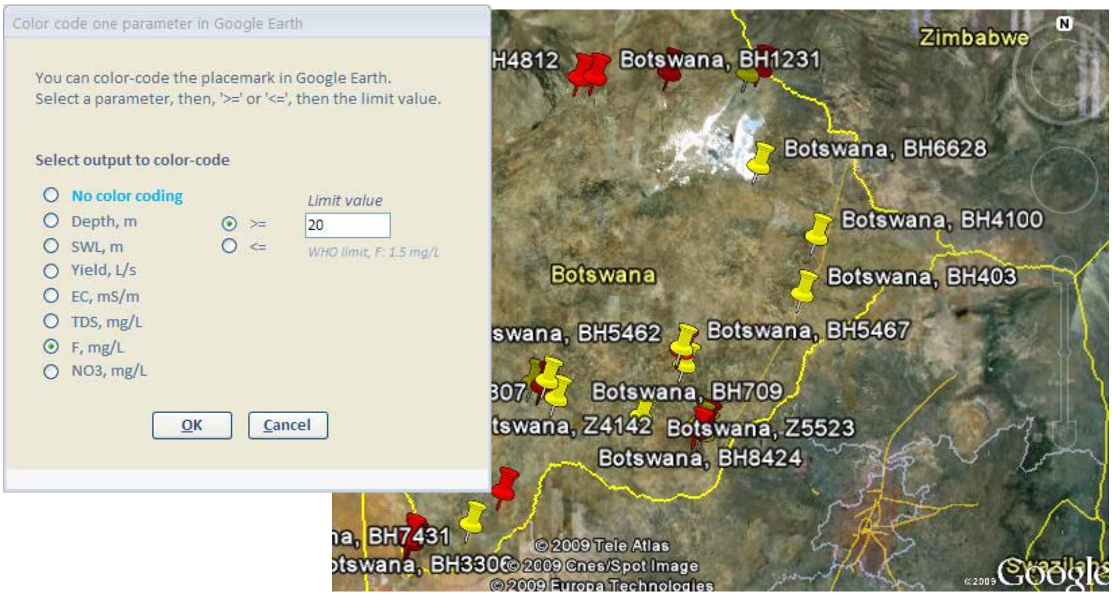
In some cases nitrate data was submitted as NO_3-N, i.e. the nitrate concentration expressed as the nitrogen concentration. Additionally, in some cases the values represented combined nitrate/nitrite. Standard, and approximate, conversions (for example multiplication * 4 for NO_3-N) have been made where this situation was known.

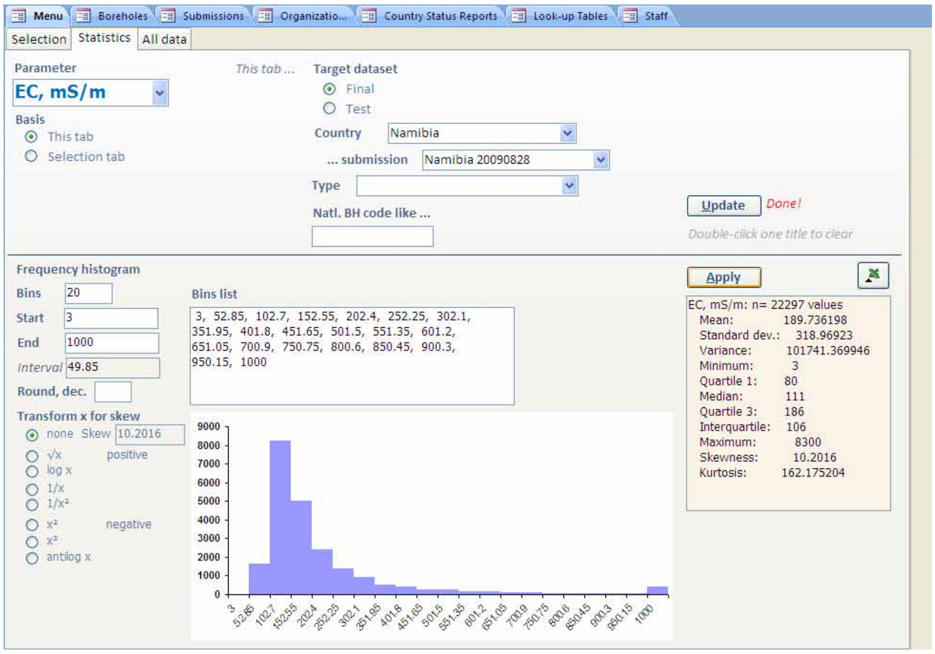
4.3.1.11. Other parameters

TDS and fluoride were consistently submitted in mg/L. All values have been rounded to 0.1 mg/L and up to a minimum of 0.1 mg/L for all values >0 and <0.5.

4.4. Outputs from the borehole database:







4.5. Points to consider

- The project has seen that many of the Member States do not maintain a complete borehole and hydrogeological database, for a number of reasons, with cost and institutional fragmentation being important ones. The importance of such a central, national-level database cannot be over-estimated, not only, for the production of maps, but generally for management of groundwater resources.

- The question of coordinates and geodetic parameters is always troublesome:

  - Always capture of coordinates for all boreholes

  - Besides X, Y coordinates, record geodetic datum used when capturing (either the GPS unit setting or the map datum), UTM zone if using UTM coordinates, altitude if possible, source of capture (map, GPS, GIS).

  - Record all these details in the database.

  - Transformation is always possible with GIS programs, including specialized programs such as Franson Coordtrans, which available for free online. The important point is to capture consistently and to know exactly what the coordinates mean.

  - Train field staff, and prepare field procedures e.g. sampling procedures

  - Record UTM to the metre level (6 digits for E/W, 7 for N/S) and to the fifth decimal for geographic coordinates in decimal degrees (0.00001 degree latitude is roughly at the metre order of resolution.)

- Allow considerable time for acquisition, evaluation, understanding and processing of borehole datasets.

5. Developing the Groundwater Resource Productivity Map

5.1. Groundwater flow regime

The first transformation is to separate the lithologies derived from the geology map into permeable and non-permeable hydro-lithologies based on groundwater flow considerations.

This transformation requires expert judgement based on an understanding of the hydrogeological characteristics of the rock types.

5.1.1. Permeable formations

The permeable lithologies are further subdivided into the following aquifer types based on their dominant flow characteristics:

- Porous/intergranular
- Fissured, and
- Karstic aquifers

Mixed flow characteristics (porous and fissured) often occur in sedimentary (sandstone) and volcanic (alternation of thin scoria and lava beds) lithologies, but may also be characteristic of basement areas with a relatively thick cover of alteration products (regolith) (Struckmeier & Margat, 1995).

5.1.1.1. Porous/Intergranular aquifers

In porous or intergranular aquifers, groundwater is produced from pore spaces between particles of gravel, sand and silt.

Examples are:

- Alluvial aquifers (sands and gravels associated with river channels etc.)
- Coastal aquifers (sands and gravels associated with marine sedimentary processes)
- Inland deposits (Kalahari aquifers)

5.1.1.2. Fissured aquifers

Rocks that are highly fractured have the potential to make a good aquifer via fissure flow. This is provided the rock has an appreciable hydraulic conductivity to facilitate movement of water for abstraction.

Examples are:

- Karoo sandstone aquifers
- Volcanics
- Cape Fold Belt aquifers (quartzite)

5.1.1.3. Karst aquifers

Karst aquifers are water-bearing, soluble rock layers in which groundwater flow is concentrated along secondarily enlarged fractures, fissures, conduits, and other interconnected openings. They are formed by the chemical dissolving action of slightly acidic water on highly soluble rocks, most notably limestone and dolomite.

Examples are:

- Lusaka dolomite aquifers
- Dolomite aquifers of Botswana, Namibia and South Africa

5.1.2. Low permeability formations

Low permeability formations are normally associated with basement aquifers. The poor connectivity of bedrock fractures and considerable heterogeneity together with narrow open fractures and low fracture frequency results in significant local variations in yield and response to abstraction. These formations occur extensively throughout the SADC-region. In southern Africa, basement aquifers constitute approximately 55 per cent of the land area.

5.2. Aquifer productivity

The permeability of the rock types can be further refined by on the basis of permeability considerations often derived from pure analogy between geology (lithological rock type) and hydrogeology (hydraulic conductivity values) (Struckmeier & Margat, 1995). This provides a measure of aquifer productivity.

Recharge is sometimes used in assigning aquifer productivity or more strictly, theoretical upper limit for the aquifer productivity. Small-scale hydrogeological maps, such as the Hydrogeology Map of Africa and the World Hydrogeological Map, often depict aquifer recharge as a measure of aquifer productivity.

The aquifer types can be grouped according to the groundwater productivity. The International Association of Hydrogeologists (IAH) standard legend for groundwater proposes:

- High productivity
- Moderate productivity
- Generally low but locally moderate productivity
- Generally low productivity

The applied distinction of aquifer classes based on hydraulic characterisation from borehole data is given in the Table 4.

Table 4: Hydraulic characterisation of aquifer classes (Struckmeier & Margat, 1995).

Aquifer Category	Specific Capacity (L/s/m)	Transmissivity (m2/d)	Hydraulic conductivity (m/d)	Very approx. Expected yield (L/s)	Groundwater Productivity
A, B, C	>1	>75	>3	>10	High: Withdrawals of regional importance (supply to towns, irrigation)
A, B,C	0.1 – 1	5 – 75	0.2 – 3	1 – 10	Moderate: Withdrawals for local water supply (smaller communities small scale irrigation etc.)
D1	0.001 – 0.1	0.05 – 5	0.002 – 0.2	0.01 – 1	Generally low productivity but locally moderate productivity: Smaller withdrawals for local water supply (supply through hand pump, private consumption)
D2	<0.001	<0.05	<0.002	<0.01	Generally low productivity: Sources for local water supply are difficult to ensure

The following scheme was adopted for the SADC hydrogeology map (Table 5):

Table 5: Hydrogeology and aquifer productivity of rock bodies

Productivity Class / **Aquifer Type**	1. High productivity	2. Moderate productivity	3. General low productivity but locally moderate productivity	4. Generally low productivity
A. Unconsolidated Intergranular aquifers	A1	A2	X	X
A. Fissured aquifers	B1	B2	X	X
B. Karst aquifers	C1	C2	X	X
C. Low permeability formations	X	X	D1	D2
		Denotes an extensive aquifer overlain by cover		

5.2.1. Assigning aquifer productivity to the SADC hydrogeological map

The following process is used to assign productivity:

- Evaluation of borehole data to characterise hydraulic properties
- Recharge distribution
- Expert judgment

Due to lack of reliable data and sufficient coverage of information the SADC hydrogeological map algorithm relied mostly on expert judgement.

5.2.1.2. Evaluation of borehole data

Pump tests are normally done to determine the hydraulic properties of an aquifer. However, only on rare occasions is this information available in national groundwater information systems.

In the absence of hydraulic properties derived from pumping test such as transmissivity and hydraulic conductivity, specific capacity or blow/airlift yields are normally used to estimate aquifer productivity in hydrogeological mapping programmes. Databases normally only contain blow yield and borehole depth and occasionally associated drawdown information. Specific capacity and blow yields give information on the borehole productivity and to a limited extent, the short term aquifer productivity at the local borehole site.

Specific capacity, which is the yield divided by the drawdown, is a reflection of the hydraulic transmissivity, which is a hydrogeological property. The higher the transmissivity and specific capacity, the more prolific the aquifer and as a result less drawdown is observed in the borehole.

Statistical analysis is done on the data and productivity can be assigned to the polygons or contoured.

5.2.1.3. Recharge

The distribution of recharge is an import layer in assigning aquifer productivity. In the case of the SADC hydrogeological map it was not possible to develop a recharge map due to the complexity of information required which was not readily available.

However, Döll & Fiedler (2008)[1] have developed an algorithm to estimate the diffuse groundwater recharge at

[1] Döll, P., and Fiedler, K., 2008, Global-Scale Modelling of Groundwater Recharge,Hydrol. Earth Syst. Sci, 12, 863-885

the global scale, with a spatial resolution of 0.5o. This algorithm has been adopted to create a recharge layer for the African Hydrogeology Map and for the World Hydrogeological Map. The team has investigated the data sets kindly provided by Professor Döll and created a grid layer over the SADC region. The data set can be used to display the variation of recharge at a continental scale, on a regional and national scale the information may prove uncertain. This data will be included as a layer, showing defined ranges of recharge (as mean annual recharge per annum) to the web based map, but can only be displayed and viewed on small scale down to 1:4M.

5.2.1.4. *Expert judgement*

The following process is normally used to assign productivity:

- Evaluation of borehole data to characterise hydraulic properties
- Recharge distribution
- Expert judgment

The algorithm for the SADC HGM had to take into account data scarcity, as some countries were not able to furnish the required data and information. As a result, expert knowledge was utilised for the development of the hydrogeological map. Expert knowledge is mainly based on local experience at national level. Input and contribution from the project steering committee and national hydrogeologist was of vital importance.

The main rock types have been grouped into permeable and low permeability formations using the lithology base map and expert judgement. Permeable formations have been further grouped into porous (gravel, alluvium, sand etc), fissured (sandstone, basalt, etc) and karst (limestone, dolomite, gypsum, etc). The following aquifer types have been depicted based on the groundwater flow regime.

- Unconsolidated intergranular aquifers
- Fissured aquifers
- Karst aquifers
- Layered aquifers
- Low permeability formations

The aquifer types were grouped into eight classes according to aquifer productivity (Table 5). The aquifer classes were adopted from Struckmeier and Margat (1995). The classification combines information on aquifer productivity (lateral extent) and the type of groundwater flow regime (intergranular or fissured) (Struckmeier and Margat 1995).

The following data constraints affected the development of the approach to assign aquifer productivity that was finally adopted:

- Highly variable data availability in the member countries and complete lack of data from some countries.
- Questionable data quality lack of key data such as coordinates, yield, borehole depth etc.
- Lack of relevant thematic maps such as soil maps and geomorphology information.
- Furthermore, certain other characteristics of the project also affected the approach:
- Large size of the SADC region, and the need to present information meaningful at continental scales, with significant generalization of lithology and hydrogeological data inputs.
- Ground verification was not possible within the scope of the project.
- Time constraints (project duration).

The following approach was adopted to assign aquifer productivity:

- Delineate permeable areas of productivity ranging from high to moderate productivity using expert knowledge based on local experience and knowledge. The low permeability formations were grouped into locally moderate productivity and low productivity.
- Ask national contact persons from member countries to verify and update pertinent data to improve the hydrogeological map.

To assign aquifer productivity to the different hydro-lithological units a scheme (Figure 6) was adopted. The Productivity assigned of an aquifer type is based on flow properties (transmissivity) and sustainability (local recharge). As an example, moderate recharge conditions combined with a highly transmissive aquifer will be assigned as 1, a productive aquifer. The long-term aquifer productivity of hydro-lithological domains is primarily governed by both the inherent lithology properties (i.e. conductive material properties) and water supply (i.e. groundwater recharge to the material). Hydro-lithological domains can be classified by these two basic parameters. Hydro-lithological domains in the upper right corner of the matrix are more productive than those of the lower left corner. Hydro-lithological domains to the left require boreholes over a larger area than the domains to the right

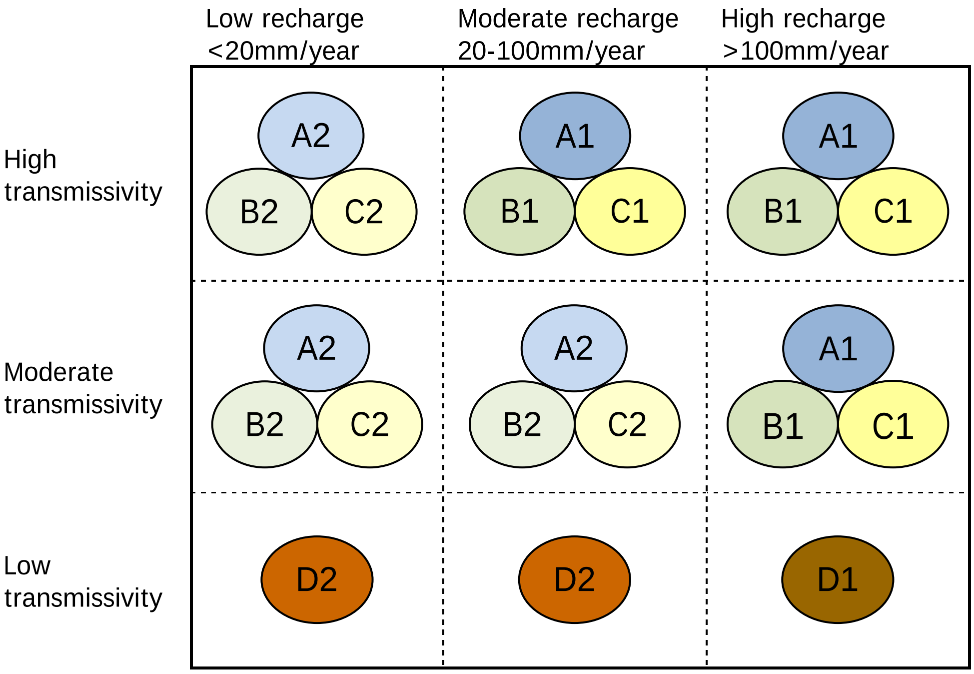


Figure 6: Scheme adopted for assigning aquifer long term productivity to hydro-lithological domains on the SADC hydrogeological map. Refer to table 5 for the aquifer productivity classes.

The combination between transmissivity and recharge has different significance of aquifer productivity. For instance high transmissivity and low recharge will imply:

- a high short term aquifer yield, and;
- a low long term productivity

Whereas, low transmissivity and a high recharge will imply:

- a high short term productivity from many boreholes
- low short term productivity from a few, boreholes, and;
- a high long term productivity from many boreholes

The water balance must be met in the long run, which implies that the long term aquifer productivity is limited by the magnitude of recharge to the aquifer.

The productivity map should only be seen as a starting point from which countries should be able to update the information whenever new field data becomes available.

The various techniques employed in determining aquifer productivity are technical and require hydrogeological professionals with some relatively good GIS skills. Training of staff from the member countries in such techniques is thus critical in the context of sustainability.

Note that this step was a lengthy process where all available geological and hydrogeological materials were considered for each area (in map terms, a polygon or a set of polygons). In effect, the rock type polygons were overlain, using a GIS or manually, with relevant reference layers (primarily the scanned national hydrogeological maps), and an essentially 'manual', expertise-based decision was made for each area.

This was followed by national contact persons from Member States to verify and update pertinent data to improve the hydrogeological map, reassigning production classes according to improved knowledge, or even re-defining them if necessary. The result was the SADC hydrogeology map.

6. Cartographic Guidelines

The approach to map legend, style and conventions was adapted from (Struckmeier & Margat, 1995) and the UNESCO (1983) legend.

This chapter presents SADC hydrogeological map cartographic representations, together with lessons learned from the project, and general recommendations on cartographic best practice.

6.1. Hydro-lithology

The hydro-lithology legend (i.e. categories displayed) was based on the SADC geology map, since that map served as the basis for the hydrogeological map (Figure 7).

6.2. Aquifer productivity classes

The legend for the aquifer productivity produced by the SADC hydrogeological map algorithm is shown Figure 7.

6.3. Cartographic best practice

The details of cartographic methodology and best practice are beyond the scope of this document, but a few comments might be helpful.

Cartography is an art as well as a science and advanced cartographic skills take many years to acquire. Most Member States have many experienced cartographers, who, however, might not be working at the relevant hydrogeological institution. While non-specialists can come quite far in map production with today's GIS and other digital tools, it is still preferable to involve cartographic expertise on all projects, if possible. Certainly the final stages of "polishing" a map for printed output needs experienced cartographers, but even at earlier stages or for output that is intended for a GIS environment or internal department users, the value of the effort will be greatly increased by consultation with cartographers.

All good maps should have:

- Scale (use even numbers)
- Orientation (N,S)
- Title and logos
- Border
- Legends
- Map credits which includes source of data, date of publication, date of map data and projection
- Locator map
- Source map (optional)

– Inset maps (optional)

For non-cartographic specialists to understand what cartographers are doing, and to improve their own cartographic skills when specialists are not available in map projects, standard cartographic textbooks are recommended. An overview and links may be found at http://www.adelaide.edu.au/library/guide/soc/geog/cart.html#star), as well as online resources such as Elements of Cartographic Style, Harvard University Graduate School of Design http://www.gsd.harvard.edu/gis/manual/style/index.htm

Figure 7: Symbol sets for the SADC HGM Legend.

7. Dissemination

7.1. Considerations when publishing a printed map

7.1.1. The SADC hydrogeological map output

Both information and communication should be considered when designing maps for the internet. There are no hard and fast rules, but it is best to use commonly recognized symbols for features such as streams, water bodies, roads and railways.

The SADC hydrogeological map is intended primarily for digital display, but can also be printed at a scale of 1:2 500 000. The resolution of information is such that it would be appropriate at that scale, but it can also support zooming in a digital environment to somewhat larger scales. Printing is from GIS content that has been processed to a fairly high cartographic level, but not to the same degree of cartographic manual editing typically applied to printed output. Note that for most users and in most situations, the printed output at this level is sufficient.

A general discussion of appropriate scale for printed output, and appropriate resolution of map content is beyond the scope of this document. The reader is referred to the general cartographic literature and online resources – examples are provided in section 7.

7.2. Inset maps

A hydrogeological map is already quite crowded with information, combining as it does relatively complex lithological and hydrogeological information in various colours. It is very difficult to add much more without rendering the map illegible. Therefore the use of inset maps is recommended, particularly for general reference layers such as rainfall, recharge, vegetation etc.

7.3. Atlas

If there are many thematic layers associated with a mapping project, it may be preferable to include them in a stand-alone map atlas, rather than try to crowd them into the map.

7.4. Brochure

It is standard practice to produce a brochure to accompany hydrogeological maps, since there is usually a lot of written explanatory material that cannot and should not be put on the map.

7.4.1. RSA DWAF reference

The RSA DWAF document "Working Document" on hydrogeological mapping from 1995 includes as section 2 "Guidelines for the Preparation of the Explanatory Brochure" which contains many useful recommendations.

7.4.2. SADC hydrogeological mapping brochure

The SADC hydrogeological map and atlas explanatory brochure describes the groundwater situation in SADC and also the hydrogeological map.

7.5. Borehole database

The borehole database, containing the borehole data submitted to the project and then processed, is an independent output of the project that can be used by SADC in maintaining the map or in separate investigations of the region's hydrogeology. See the project reports and relevant chapters in this document for more information on the database.

It is recommended that mapping projects maintain a database of the borehole data used by the project, particularly if it is processed or evaluated compared to the source data held by the national water authority or other organizations.

7.6. Considerations when developing a web-based map

7.6.1. Background

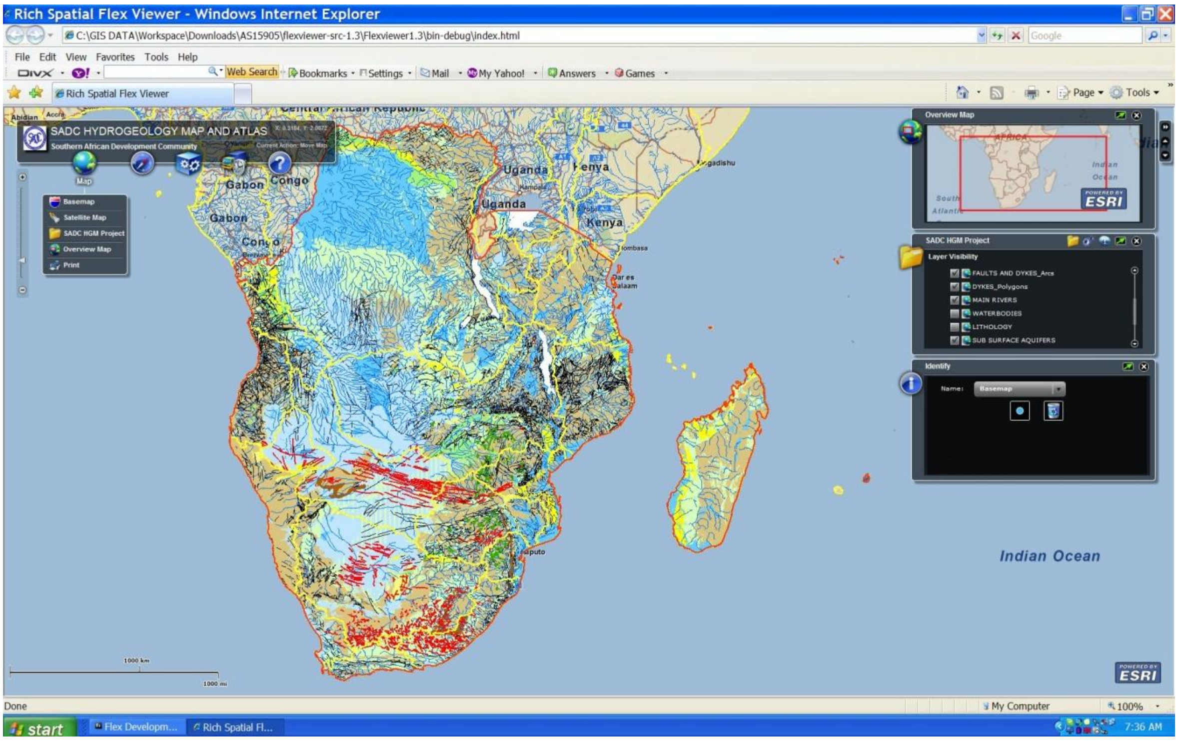
Publishing a digital map to the web involves many new design decisions, hosting hardware and software decisions, and issues of bandwidth, web access by users, permissions and web site management.

The SADC hydrogeological map project has published the hydrogeological map on the web, utilizing the expertise and support services of the South African Council for Geoscience.

It should be noted that the effort to publish maps on the web requires considerable technical expertise at start-up time, considerable bandwidth out from the web-server and in by likely users, and adequate funding for sustaining the initiative. An alternative that should be considered is the copying of the GIS-based dataset to a CD or DVD, and distribution of this to interested parties, which the project has done in parallel with the web-based map.

7.6.2. SADC hydrogeological map solution

A screen shot of the web interface is presented in the figure below. The interactive capabilities of the map include, for example, a facility to toggle layers on and off, zooming, panning, measuring and querying. Three ArcGIS Online Services namely a shaded relief background, a topography layer and satellite imagery have been incorporated to give users immediate access to consistent content on the web.



The map atlas has been compiled in five group layers so that the level of detail and information displayed is dependent on the zoom level, i.e. view scale. Each group layer consists of one or more of the map layers described in section 2.4.1 – 2.4.3. The total scale range for displaying the data is approximately between 1:30 000,000 and 1:150 000.

8. Data Management

8.1. Borehole data

An essential part of this SADC HGM project has been the acquisition of a basic set of borehole data from Member States. An MS Access database application has been created to host and serve the borehole data at DGS. A User Manual has been prepared to cover all essential functionality and support of the database, for both users and the Database Manager.

8.2. GIS data

Various geospatial datasets have been collected from a number of sources, ranging from national, regional and international organisations. Data has been requested with the focus on supporting the compilation of a regional SADC hydrogeological map and atlas. All data has been analysed and examined for its potential use in producing the map. Only data that has been used to produce the map and associated layers has been incorporated into the SADC hydrogeological map GIS database.

The SADC hydrogeological map GIS database comprises two sets of data:

- The SADC Hydrogeological Map and Atlas and its associated layers;
- Other pertinent data collected during the course of work that has supported the map compilation process, e.g. scanned and geo-referenced national hydrogeological maps.

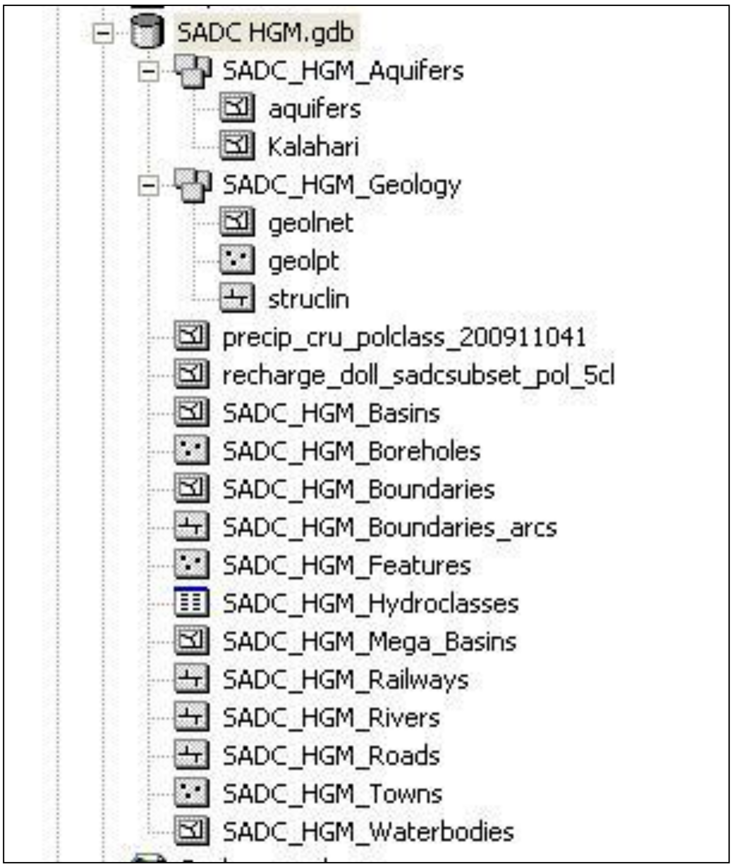
All files are compatible with ArcGIS package version 9.3.

The file formats comprise:

- Vector points, e.g. Towns
- Vector lines, e.g. Rivers
- Vector polygons, e.g. Lithologies
- Raster data, e.g. Digital Elevation Model (DEM)
- Raster images, e.g. Scanned maps
- Attribute tables, i.e. non-geographic information associated with a map feature such as the yield of a borehole.
- Map Files, i.e. a file that represents geographic information in a map view as a collection of layers and other elements (scale bar, legend, data frame, title, annotations) consistent with the cartographic layout of a map.

- Layer files, i.e. files that store the path to a data source set and control layer definitions and symbology - i.e. how map layers are displayed in a map view.
- Metadata, i.e. information on data layers

The files are stored in a Geodatabase workspace that is accessed and managed in ArcCatalog, which is a part of the GIS package. The Geodatabase is used to organize, query and manipulate spatial data and can store geometry, spatial reference systems, and attributes. The file structure within the SADC hydrogeological map Geodatabase is shown below.



8.3. Documentation, metadata, terminology, naming conventions

8.3.1. Documentation

Documentation is essential for the sustainability of mapping initiatives (updating of maps, maintaining institutional capacity), and for communicating decisions and information within the mapping project and to outside actors, not least those funding the project, or departmental heads.

The importance of documentation is typically ignored in all kinds of projects. Only a strong administrative initiative to budget time and resources for documentation and to insist on producing it will ensure that it in fact gets produced.

Documentation can take many forms and cover many areas – the important point is always to remember why it is being produced - for whom and in order to know or be able to do what. The purpose and intended audience should be thought about carefully and expressed, in writing, precisely. Keeping this focus will avoid the production of irrelevant or excessive documentation.

8.3.2. Metadata

The maintenance of metadata, particularly for the many digital files typically produced, is essential, for the same reasons that documentation generally is essential (see above).

GIS programs usually have special modules for recording metadata for files and projects – this functionality should be used. However, it is also advisable to maintain a separate metadata structure in Excel or other suitable format, for digital files and other items that are created in a mapping project (for example map versions).

Metadata is similar to documentation in that the same general rule applies as stated above – if you focus on the question "who will read the metadata in order to do what, exactly", then the task will become much easier. It is also necessary that the mapping project administration allocates time and resources for producing metadata and insists on it being completed.

8.3.3. Terminology

Considerable confusion and delay can be avoided by defining and strictly following terminology. This can apply to the terminology used for the map contents (geological or hydrogeological units, for example), or for cartographic objects or ideas. If international or national standard terminologies exist, they should be followed. The same terminology should be used for all items in the map in any context, for example in brochures or on printed maps. Develop terminology early in the project, avoid imprecisely defined terms, check terminology with someone outside the project to make sure meaning is clear, maintain a central list or database, and insist that all material uses the correct, agreed-on terminology.

8.3.4. Naming convention

It is very important to define, promulgate and strictly adhere to various naming conventions, particularly for the many digital files that will be used in producing the map, or that are generated during production. Many files will exist in different versions during production, so a convention that makes versions of files obvious is very helpful. A recommended convention is to name the file according to the format:

<name>_<YYYYMMDD><staff initials>.<extension>

For example "recharge_surface_sAfrica_20091212nilk.bmp

The "name" part should always remain exactly the same through different versions as long as the file is the essentially the same. The date part should be in YYYYMMDD format, without spaces, hyphens or slashes – this means that different file versions in the same folder will be listed chronologically if the folder is listed alphabetically. The staff initials are a convenient way to mark different editing versions by different staff (the MS Word review technology is generally too complicated to be used successfully in most organizations).