B: BOTSWANA

B.1 INTRODUCTION

Botswana is a large landlocked country centrally located within southern Africa. It shares borders with South Africa, Namibia, Zambia and Zimbabwe and has a total land area of 582,000 km^2. The country was visited by Flenner Linn representing Groundwater Consultants during the week of 4 - 12 April 2002.

B.2 BACKGROUND

B.2.1 Physiography and Climate

The southern, eastern and a portion of the northern borders of Botswana are formed by rivers (the Molopo, Limpopo and Chobe Rivers respectively) and a large wetland (the Okavango Delta) is present in the northwest of the country at the terminus of the Okavango River. The majority of the country is characterised by flat savannah and is devoid of major mountains, although more hilly country is present along the eastern margin.

The climate of Botswana is generally semi-arid with rainfall ranging from approximately 250 mm/yr in the southwest to 550 mm/yr in the east up to a maximum of 690 mm/yr at Kasane (extreme north). Annual open water evaporation is of the order of 2,000 mm and exceeds average rainfall in all months of the year. Average temperatures are also high, with a mean annual temperature in Gaborone of 28.4°C and in Maun (northwest) of 30.3°C.

B.2.2 Water Resources

Botswana has relatively limited surface water resources, with major rivers developed only in the eastern and northern regions. Due to limited rainfall, limited surface water resources and regularity of droughts, the country relies considerably on groundwater for supply for both rural and urban populations. The total estimated runoff for the country is 705 Mm^3 or 1.2 mm which is extremely small compared to other similar countries (e.g. Australia) and emphasises the meagre surface water resources of Botswana.

B.2.3 Overall Institutional Framework Of Water Sector

The Ministry of Minerals, Energy and Water Affairs has a primary role in the water sector in Botswana. Two departments that are involved in groundwater development in the ministry are the Department of Water Affairs (DWA) and Department of Geological Services (DGS). Other government departments that are involved in the groundwater sector are the Ministry of Health, the Department of Irrigation (Ministry of Agriculture), the Department of Local Government and Development (Ministry of Local Government, Lands and Housing), and the District Water Departments under the District Councils. Water supply to Gaborone, Francistown and several other towns and large villages is provided by the Water Utilities Corporation, a parastatal corporation which operates several wellfields. Among private users the largest groundwater users are the Jwaneng and Orapa diamond mines and the BCL copper-nickel mine. Many private boreholes are operated by individuals or syndicates for livestock watering throughout the country.

B.2.4 Role of Groundwater in Water Sector

Groundwater resources have in the past and continue to play a critical role in water supply. The importance of groundwater results from the lack of surface water and rural nature of habitation for much of the population. The government takes an active role in developing and managing the resource.

Groundwater supply for large towns such as Maun, Tsabong, Jwaneng, Ghanzi and Serowe is provided from dedicated wellfields managed by DWA or Water Utilities Corporation (a parastatal organisation). The Palla Road and Lobatse Wellfields are reserved for emergency supply to the North-South Carrier and the Lobatse township, respectively. Water supply to the diamond mines at Jwaneng and Orapa is met from wellfields developed for this purpose.

B.2.5 Groundwater Development

The majority of groundwater exploration, development and management is carried out by DWA and DGS. Other government departments (e.g. Department of Roads) are infrequently involved and usually carry out their work through the DWA. Private individuals, farmers and mining companies carry out a sizable amount of groundwater development work.

DWA is responsible for providing drinking water to all villages and towns. Water Utilities Corporation (WUC) is responsible for supply to mostly urban areas. The DGS carries out regional scale exploration and resource assessment based on long term development and management plans. The water supply utility, Water Utilities Corporation, does not carry out any groundwater investigations and is primarily concerned with urban supply. It relies on DWA for groundwater development and currently uses groundwater from the Lobatse, Sua and Palla Road Wellfields.

B.3 GEOLOGICAL AND HYDROGEOLOGICAL FRAMEWORK

B.3.1 Geology

The geology is characterised by a complex association of Archean and Proterozoic cratons overlain by Mesozoic volcano-sedimentary sequences (Karoo Supergroup). These units have been intruded extensively by dykes and sills, including a major dyke swarm in the north of the country and kimberlite pipes. These intrusives are of Triassic to Cretaceous age. Mantling most of the central and western sections of the country is a sedimentary sequence of sand, calcrete, silcrete and clays informally grouped as the Kalahari Beds. The Kalahari Beds occur along an extended belt covering South Africa, Namibia, Zimbabwe, Zambia, Angola and DRC. In Botswana, the Kalahari Beds attain a thickness of > 500 m in the northwest of the country.

B.3.2 Hydrogeology

Aquifers have been divided into major types (NWMP, 1991) represented by porous, fractured-porous, fractured and karstified fractured types. A summary of the aquifer types and their distribution is presented in Table 1.

Table 1. General Classification of Aquifer Types in Botswana

Aquifer Type	Geological Formation	Age	Extent (% of country)
Porous	Recent Sediments: Fluvial Alluvium	Quaternary	35
	Kalahari Beds	100 to 1 Ma	
Fractured Porous	Karoo Supergroup: Ntane Sandstone Ecca Group Mea Arkose	290 to 135 Ma	37
Fractured	Karoo Supergroup: Stormberg Basalt	200 to 135 Ma	27
	Precambrian Basement: Ghanzi Group Waterberg Supergroup Transvaal Supergroup	 1200 to 570 Ma 2500 to 1200 Ma 2500 to 1200 Ma	
	Archean Basement	>2500 Ma	
Fractured Porous	Precambrian Basement: Transvaal Supergroup	2500 to 1200 Ma	1

B.3.3 Natural Groundwater Quality

Groundwater quality is highly variable, reflecting the diversity of hydrogeological environments and rainfall-recharge conditions across the country. Groundwater quality over large areas, such as in the southwest of the country, does not meet drinking water standards due to high dissolved solids. TDS values vary from < 100 mg/l in basement aquifers to > 60,000 mg/l in brines, which are developed for salt and alkali production. Elevated nitrate and fluoride concentrations in groundwater is reported in a number of localities. High iron content is also occasionally reported, particularly in shallow alluvial aquifers.

B.4 DATA ACQUISITION

B.4.1 Institutional Framework for Data Collection

The institutions and personnel contacted as part of this project are summarised in Table 2.

Table 2. Institutions and Personnel Contacted in Botswana

COMPONENT	INSTITUTION	PERSONNEL
General GW Information Monitoring Data (GW, SW)	Dept. of Water Affairs	Mr. I. Mannathoko, P. Hydrogeologist Mr. J. Ntsatsi, P. Hydrogeologist Dr. L. Carlsson, P. Hydrogeologist Mr. A. Adams, A. Hydrogeologist Mr. T. Reikel, Drilling Expert Mr. C. Nkile, Hydrogeologist Mr. B. Morake, Hydrogeologist Mr. P. Makobo, P. Hydrogeologist Mr. R. Rampha, Technical Officer
General GW Information Monitoring Data (GW) Hydrogeological Mapping	Dept. of Geological Survey	Mr. P. Phofuetsile, Deputy Director Mr. T. Kellenar, Senior Hydrogeologist Mr. M. Magoe, Senior Hydrogeologist Mr. A. Gondo, Senior IT Officer
	Dept. of Meteorological	Ms. K. Mmopi, Principal Tech.

COMPONENT	INSTITUTION	PERSONNEL
Monitoring Data (rainfall)	Services	Officer Ms. E. Setlhogile, Snr. Tech. Assistant Mr. I. Kusane, Meteorologist
Mapping (tgeneral)	Dept. of Surveys and Mapping	Dr. R.K. Das, Principal Surveyor
General GW Information	Wellfield Consulting Services	Mr. J. Farr

GW: groundwater
SW: surface water

B.5 GROUNDWATER INFORMATION SYSTEMS

B.5.1 Hardware and Software

During the past decade, DWA has tried different GIS solutions, ultimately resulting in the proliferation of many GIS software applications. As a result, data flow and data exchange among the user community was never smooth. So there was a need for a broad based centralised database management system to improve access and retrieval of the data held in several existing and planned databases. This was accomplished through the development of the Water Resources Information System (WRIS), which links the existing databases in use by DWA. Some hardware components are still being set up, but it is expected that the system will be in full use by July 2002. Training of users within DWA is also still pending. Key recommendations of the final report for the project are that the WRIS system be marketed both internally and externally to educate users on its functionality and capabilities. The ultimate objective of the WRIS is to allow government staff, consultants or private individuals to have easy access to all the available hydrogeological data. Eventually this is expected to include internet access to the WRIS.

A summary of the information system for DWA is presented in Table 3 with details of specific data collected provided in Section 5.2.1.

Table 3. Summary of DWA Information Systems

Database / Source	In use	No. of records	Format	Useable[1]	comments
WRIS	yes	See comments	SQL 7.0	yes	Front end, links all existing databases; just beginning to be used
NBA	yes	>20,000	Dbase IV	yes	National borehole archive
WELLMON	yes	*	SQL 7.0	yes	All monitoring data, data from 1980s
Aquabase	yes	*	SQL 7.0	yes	Water quality data
WAB	yes	*	SQL 7.0	yes	Water rights, apportionment

[1] Easily useable for the regional hydrogeologic map
* information awaited from institution

Before the implementation of the WRIS project, a number of database applications were in use within the Groundwater Division at DWA, which now form the foundation of the WRIS. These databases are:

- **WELLMON Database:** Contains water level, abstraction and rainfall data collected from a number of wellfields. This database was based in SQL Server 6.5.
- **National Borehole Archive Database:** Contains static borehole information collected at the time of drilling and recorded on the Borehole Completion Certificates. The database includes information on location, drilling, lithology, airlift testing results and borehole construction. This database was developed in dBase format. There are in excess of 20,000 entries in the database.

- **Water Quality Database (Aquabase):** Contains water quality analyses of surface and groundwater. This database was based in SQL Server 6.5.
- **Water Apportionment Board Database (WAB):** Contains information on individual water rights. It is maintained and held by DWA. This database was developed in MS Access format.

During the implementation of the WRIS project all databases, aside from the NBA, were converted to MS SQL Server 7.0 format. A present there is no database that includes test pumping data. Water level monitoring data collected by automatic recorders, collecting data at rapid intervals, is sampled with data sufficient to define trends entered in the WELLMON database. The complete data are kept in individual Excel files.

Personal computers within DWA are networked. Both hardware and software purchased by consultants for particular projects are handed over to DWA at completion of the project, so generally the standard of both is quite good. Although the individual existing databases are not accessible on the network, as the WRIS comes on line (expected July 2002) they will soon be accessible from any networked computer. The WRIS comprises many components all of which are designed to operate in conjunction with one another. The system components are:

- Data capturing facilities
- Data management facilities, and
- Data utilization facilities.

A pictorial representation of the inter-relationships of the various components of the WRIS is presented in Figure 1 overpage.

Spatial data capture by means of digitisation is based on Arc/ Info and DAK. The following hardware and software facilities are available in the GIS Laboratory-

- Workstation with Windows NT OS
- ESRI's ArcInfo 8.1
- ESRI's ArcView 8.1
- ESRI's Spatial Analyst
- ESRI's Network Analyst
- ESRI's ArcPress for ArcInfo
- ESRI's ArcGrid
- ESRI's Data Automation Kit (DAK) and
- ERDAS Imagine

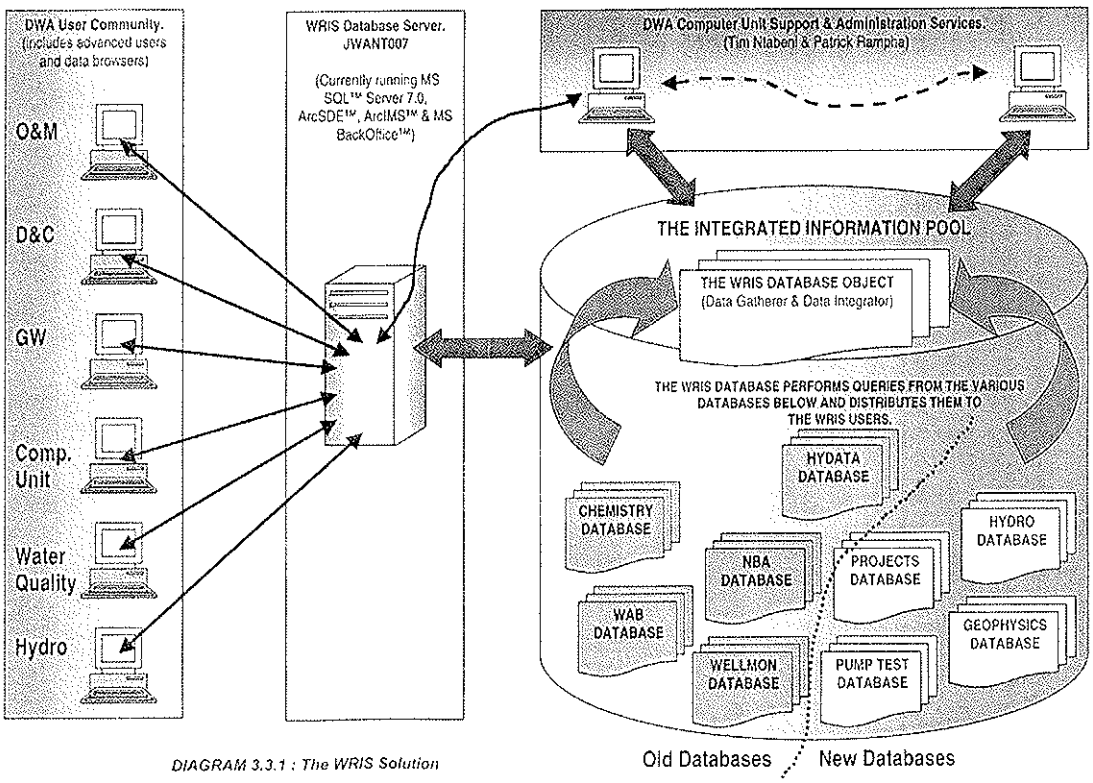

Figure 1. Overview of the WRIS System *(source: DWA, 2002)*

The WRIS data management facility is based on ArcSDE. Software components of the RDBMS are-

- Microsoft's SQL server
- Microsoft's Back Office Suite
- ESRI's ArcSDE
- ESRI's ArcIMS

There are standards for the capture of spatial data and they are available on DWA intranet.

B.5.1.1 Department of the Geological Survey

The DGS at present has only limited capacity in groundwater information systems. The existing sytems are summarised Table 4.

Table 4. Summary of DGS Information Systems

Database / Source	In use	No. of records	Format	Useable[1]	comments
NBA	no	>20,000	Dbase IV	no	Copy of borehole archive from DWA, database is not being updated and as such is well out of date.
WELLMON	yes	Pre-1997 data	SQL 6.5	yes	Contains DGS monitoring data; not updated for 5 years
GEODIN	yes	*	Dbase IV	yes	Used for borehole construction information
Monitoring data	no	Data from 1997	paper	no	Data not yet entered in WELLMON
Project	no	variable	Various,	yes	Various groundwater data

reports			digital and paper		generated through projects and submitted in reports and on data CDs

[1] Easily useable for the regional hydrogeologic map
* information awaited from institution

Similar to DWA, DGS is using the WELLMON software for monitoring data but data entry has been undertaken for approximately five years. Data input is now beginning again, with data first being entered into Excel spreadsheets which can then be imported into WELLMON.

DGS has a copy of the National Borehole Archive (DWA), but this is not being updated.

For borehole data, the GEODIN software is presently beginning to be used. The software automatically sets up a borehole database in a format chosen by the user. Alternatively, an existing database can be utilised by GEODIN. At present the exact format of the borehole database is still evolving and is expected to be finalised very soon. Geology codes from the geologic map are being used with additional detail added as needed. Fill patterns for various geologic units are primarily following the 1996 ISO standards. It is planned that the GEODIN system will be incorporated in the national information system (described in the next section), but the exact format and arrangement of the linkage is not yet defined. This will be addressed as the National Geologic Information System is set up.

B.5.2 Data Saved

The two entities that acquire and store hydrogeologic data are DWA and DGS. Groundwater data are currently available in the form of data sheets, reports and databases with the following institutions:

- Department of Water Affairs (DWA) Groundwater Division
- Department of Water Affairs (DWA) Laboratory
- Department of Geological Survey (DGS)

Hydrogeological data are primarily collected by DWA and DGS, including consultants contracted under their auspices. Additionally, some private and parastatal organisations are also involved in some component of hydrogeologic data collection. These organisations, namely Debswana (de Beers), Water Utilities Corporation (WUC) and Botswana Power Corporation (BPC), all operate wellfields and are required by law to carry out monitoring. The monitoring data (primarily abstraction and water level records) are then submitted to DWA (Water Allocation Board) in an annual report. In the case of the Orapa and Jwaneng Wellfields (Debswana), the annual reports include summaries of the updated numerical models for the wellfields. The DWA laboratory is the primary laboratory for water quality analysis in the country and maintains a database of all analyses carried out. The DGS also operates a laboratory which undertakes water as well as other geologic analyses. Water quality data for the DGS laboratory are kept as paper files.

B.5.2.1 Department of Water Affairs

The Department of Water Affairs is the primary repository of hydrogeological data. As described in the previous sections, hydrogeological data are derived both from DWA activities as well as by projects carried out for DWA by private consultants. The borehole registration system is well enforced and results in the majority of borehole data being recorded and archived with DWA. Limitations in the format of the existing borehole completion certificate (it dates from the early 1980s) are the primary limitation in this area, with some discussion occurring on the development of a new form. Monitoring data are collected by DWA primarily through the local borehole operators in the case of village production boreholes and by DWA technicians for wellfield production boreholes

and observation (non-production) boreholes. DWA is moving quickly toward the use of transducers for most monitoring. Initially, the focus is on water level monitoring, but it is expected that automatic water quality monitoring (i.e. EC) will also become more prevalent.

All water samples analysed by the DWA laboratory are archived at the laboratory in a database. Most production boreholes in use have multiple analyses primarily on a one to three year interval. Water quality analyses carried out by the DGS laboratory are stored in files at the laboratory. Private laboratories are often used for water quality analyses as part of projects carried out by consultants. These data appear in the reports and associated project CDs, but at present are not captured for any other database. Similarly, water quality data reported annually by the major private and parastatal corporations (i.e. WUC) are not systematically entered into a database.

Borehole drilling is controlled through a system of permitting which involves the provision of a unique, consecutive number to the driller/supervisor and includes the requirement that a completion certificate be filed after completing the borehole with basic construction details, location information, a lithologic log, yield and water quality information. Additionally, if a borehole is test pumped, standard data forms are also filed with the borehole completion certificates. These borehole records (completion certificates and test pumping forms), are kept as files in both DWA and a copy at DGS. Full time staff oversee the files which can be checked out by DWA staff as well as private individuals.

Boreholes installed from the early 1980s generally have a borehole completion certificate, although old records are often incomplete. Earlier borehole records are more variable. The most significant problem with older boreholes is the lack of or unclear marking of numbers on the borehole itself. The standard borehole completion form is also somewhat limited in comparison with other international standards and the possibility of replacing the form with an improved version has been variously discussed within DWA but no action has been taken to date.

Test pumping data are required to be submitted to DWA on their standard form or an equivalent provided by a consultant. The data sheets are filed by borehole with the borehole completion certificate. Most data are entered into computer and analysed as part of the respective project, but the data are not at present archived in a systematic fashion. Digital test pumping data are generally included on project data compact disks at the completion of major projects. However, digital data for village scale projects are rarely submitted to DWA.

More advanced data capture will be possible with the WRIS system. For example, although at present test pumping data are not available in the existing databases, within the new framework test pumping data will be included. A summary of the new data capture structure is provided in Table 5.

Table 5. Summary of Data Capture Facility with WRIS

Water Apportionment Board Front-End:
The WAB VB application will have the ability to capture Borehole apportionment data, River apportionment data, Dam apportionment data and draw-off apportionment data. Users will be able to run reports for each of these sections by typing key words into certain data fields. These data will be available from both the Intranet and ArcMap.
Pump Test Data and Test Curve Integration Front-End:
This VB application will have the ability to capture Pump Test data (4 tests) in spreadsheet type interface. Users of Test Curve will then be able to search these data and seamlessly add it into the existing interface. Users will also be able to print out standard Pump Test reports from the application.
Geophysical Data Front-End:

This VB application will have the ability to capture two types of geophysical data: Electro-Magnetics and VES. The users will be able to search for existing sections, as *well* as *print out section reports. The interface will be driven by* a *spreadsheet control. Users will be able to graph data contained within the database.*
Weekly Hydrological Situation Front-End: *This VB application will have the ability to capture weekly hydrological situation data into the database. Users will then be able to print historical situation reports by choosing the week, as well* as *printing the current weeks' report.*
Project Sections Front-End: *This VB application will have the ability to store, view and update information for Design and Construction section. The application will focus on project name, with the two main subsections: Length Section Design & Length Section Construction. The application will have the ability to view dxf or dwg files associated with* a *selected Length Section. These documents can be printed, but not edited in the application -this will be left to the parent application (Auto CAD). Other files (reports, EIA's, Tender Documents, Monthly progress reports, Works orders, Handover certificates, Form 3's, completion certificate, defect liability & payments certificate)will be browseable in MS Office programs.*
Outstations Front-End: *This VB application will have the ability to capture, store, view and e-mail hydrogeological information from outstations to DWA. The concept is to create an application that will decentralize the current data population practices at DWA.*

B.5.2.2 Department of Geological Survey

Similar to DWA, DGS collects data through its own activities as well as projects carried out by consultants. A copy of each borehole completion certificate is also filed with DGS. Water level and less regular water quality monitoring is carried out by DGS field technicians. Data are recorded on data forms which at present are not being entered into any database. Extensive data sets are generated during large scale resource evaluation projects undertaken for DGS by consultants. Interpreted and raw data for these projects are contained in project reports and data CDs submitted at completion of projects.

Both ground and airborne geophysical methods are frequently used in groundwater exploration and development. Ground geophysical methods generally comprise magnetic and EM surveys and Schlumberger array resistivity soundings. TEM soundings are becoming more common as well. When these methods are used in projects for either DWA or DGS, digital data as well as interpretations are included in reports and, in more recent years, on accompanying project data compact disks. Similar to test pumping data, there is at present no central archive for these data.

Digital data for large scale surveys are archived at the DGS. Large scale geophysical surveys include primarily airborne magnetic and regional gravity surveys, with airborne EM and radiometric surveys being carried out in local areas. Digital terrain model (DTM) data on topography are also now regularly collected during aeromagnetic surveys. Some data, primarily aeromag, are also collected from the private sector (mining). All data are maintained in Geosoft, Oasis format grid files.

The National Geological Information System (NGIS) is a still up coming division of the DGS which is planned as a national archive of all geological data. The overall objective of the NGIS will be to create a comprehensive archive and data source for all geologic data in the country. A separate building with library has been constructed to house the NGIS in Lobatse. However, the development of the database systems and definition of their linkages to other major databases, such as the WRIS, is not yet underway. Proposals are being received on two tenders to begin the conceptualisation and development of the system, with the first phase of the project likely to begin in 2002.

B.5.2.3 Department of Meteorological Services

The bulk of rainfall data collection for the country is carried out by the DMS. Although both DWA and DGS operate some rainfall stations, for the regional hydrogeological map the most accessible and best quality data would be available from the DMS.

Rainfall amounts are collected daily, with compilation of data occurring monthly. There are 15 synoptic stations in the country and 90 "bulletin" stations, which submit data in monthly bulletins during the rainy season. Data are stored in the CLICOM database, which can export to text or Excel files. Historical data go back as far as 1909

B.5.3 Quality of Data

B.5.3.1 Department of Water Affairs

Hydrogeologic data quality control is relatively well developed. Although there are no standardised QA/QC systems defined as such, some level of data checking is present for data captured by DWA. Borehole completion certificates, which are the primary source of data for the NBA database, are checked and signed by supervising consultants in the case of groundwater projects (which account for the bulk of drilling activities). Borehole coordinates for recent boreholes (since the early 1990's) are primarily GPS derived, while older borehole records generally have less accurate or erroneous locational data. All incoming water level monitoring data for the WELLMON database, are plotted by technicians and the graphs examined to locate errant data. Similar to many other member countries, the oldest data (1980's) are the most incomplete and least accurate.

The quality of monitoring (water level and abstraction volumes) data collected by borehole operators has been identified as often poor. This relates to the low educational level and often illiterate status of many borehole operators. This is being addressed by on-going training of borehole operators as well the increased use of automatic recorders.

B.5.3.2 Department of Geological Survey

There are no set procedures for quality checking of data coming into DGS. Additionally, since much of the incoming data are not at present being entered in computers, even visual checking of data is not generally occurring. Borehole data being entered in the GEODIN database are plotted in borehole logs and generally reviewed for accuracy. However, since the source of most of the data captured by the DGS is from trained DGS technicians or through groundwater consultants (who are also interpreting and plotting data), the overall data quality should be acceptable in terms of the needs for a regional hydrogeological map.

B.5.4 Resources Available for Maintenance

B.5.4.1 Department of Water Affairs

In general, human resources available for data input and data management are considered acceptable in DWA. During implementation of the WRIS project, extensive training was conducted for DWA employees. Training modules were organised for different level of users under the WRIS training programme as shown in Table 6.

Table 6. Training Carried Out as Part of WRIS Project

Training Phase	User Type

Training Phase	User Type
Data Capturing Training	Specialised Data Capturers
Training on Conversion of Spatial data	System Administrator
Standard ArcGIS Training	ArcWRIS Users
Standard ERDAS Training	A selection of advanced users
Standard ArcSDE Training	System Administrator
ArcSDE Installation Training	System Administrator
Standard ArcIMS Training	WRIS Intranet users
ArcIMS Installation Training	System Administrator
Standard Spatial Analysis Training	ArcWRIS users
VB Training	System Administrator
SQL Server Training	System Administrator
VB Front End Training	Specialised Data Capturers
ArcWRIS Front End Training	ArcWRIS users
Intranet System Retrieval Training	Data browser

B.5.4.2 Department of the Geological Survey

At present, the DGS is heavily understaffed in almost all aspects of its activities. Posts are generally available, but filling the posts and keeping staff are the major problems. As a result, the input of data and operation of databases at DGS lags far behind that of DWA. For example, monitoring data have not been entered into their database for the last five years.

B.6 GROUNDWATER MONITORING

DWA and DGS are government organisations responsible for groundwater monitoring. Other organisations (i.e. WUC, BPC) are given charge of wellfields with the legal requirement that water level monitoring and resource evaluation be carried out and reported annually. Expanded monitoring is also often carried out by consultants in specific areas as part of groundwater projects.

Both DWA and DGS have prioritised the increased use of automatic recorders for hydrogeological monitoring. A detailed assessment of the advantages of moving to automatic monitoring as well as a review of available equipment types was carried out as part of a monitoring project (DWA, 2000). Two types of recorders have been chosen for standard use by DWA, a pressure transducer (In Situ Mini-Troll) and an electronic recorder with a float device (Seba Floater). At present two wellfields, Serowe and Dukwi, are being fully equipped with automatic recorders on a pilot basis. It is planned that during National Development Plan (NDP) 9, which covers 2003 to 2008, there will be a complete change to automatic recorders for water level monitoring. DWA would also like to begin more automatic water quality monitoring (primarily EC) as well as link automatic recorders to telemetry systems to allow remote downloading of data.

B.6.1 Monitoring Network and Frequency

B.6.1.1 Wellfields

Thirty three wellfields are monitored by DWA, DGS, District Councils, Water Utilities Corporation, Botswana power Corporation, BDC and DeBeers. Of these DWA monitors 15 wellfields and DGS monitors seven wellfields. These wellfields have a total of 187 production boreholes and 689 observation boreholes. Of these 117 production boreholes and 477 observation boreholes are monitored. DWA is directly responsible for monitoring 129 production boreholes and 373 observation boreholes in wellfields. The primary objective of wellfield monitoring is the proper management of wellfield abstraction and ensuring the sustainability of these resources.

Water levels in production boreholes are monitored twice daily, before and after pumping. Water levels in observation boreholes are monitored daily or monthly. Abstraction is recorded daily when production boreholes are in operation, with measurements taken from in-line flow meters or in some cases by calculation based on a known pumping rate and duration. Automatic recorders are used in many boreholes. Older chart recorders are in the process of being replaced by electronic recorders (pressure transducers and float type recorders). At present, DWA are using seven chart recorders and 54 electronic recorders to monitor wellfield boreholes.

Monitoring data collected by private and parastatal wellfield operators (e.g. DeBeers) are summarised in annual reports submitted to DWA. However, at present the actual data are not provided to DWA in digital format and copies are submitted to DWA.

Total wellfield production is monitored mostly on a monthly basis. In some wellfields production is monitored weekly or daily. Water chemistry is monitored on production boreholes generally once a year, with some boreholes in large wellfields being monitored bi-monthly or monthly.

B.6.1.2 Village Supply Boreholes

Production boreholes that supply villages and settlements (under DWA) throughout the country are monitored by the borehole operator. The objective of this monitoring is ensuring the supply through appropriate abstraction rates and assessing any water quality deterioration. The borehole operator is a person hired from the area and trained to operate the borehole engine and carry out basic monitoring. Monitoring consists of measuring the pre-pumping water level and recording the abstraction from a flow meter or indicating the number of hours pumped. As discussed in Section B10.2, the quality of these monitoring data can be poor due to illiteracy of the pump operator and/or misunderstanding of monitoring activities and importance. This is being addressed by on-going training of pump operators as well the increased use of automatic recorders.

B.6.1.3 National Monitoring Network

The DGS is responsible for groundwater resources and basin monitoring as part of the National Monitoring Network. This network comprises 476 manually monitored boreholes, 37 autographic water level recorders and 17 rain gauges. The objective of the national monitoring network is resource assessment and protection. Boreholes that are part of the national network include both those in active and defunct wellfields as well as individual boreholes. The data are collected every month. A summary of the National Monitoring Network is provided in Table 7.

Table 7. National Monitoring Network

	Location	Monitoring points
1.	Bokspits	31 boreholes. Includes 4 Automatic recorders
2.	Serowe	39 boreholes, 2 wells (abandoned), 2 automatic recorders, data exists for 6 boreholes which are now blocked/dry.
3.	Palapye	12 boreholes, including 2 automatic recorders and 1 rain gauge.
4.	Ramotswa	40 boreholes + 1 well, 2 automatic recorders, data exist for 9 boreholes which are now blocked/dry
5.	Mochudi	13 boreholes, Includes, 2 automatic recorders, data exist for 2 boreholes which are now blocked/dry
6.	Malotwana	17 boreholes, Includes, 2 automatic recorders, data exist for 1 borehole which is now dry.
7.	Molepolole	35 boreholes, Includes, 3 automatic recorders, data exist for 1 borehole which is now dry.
8.	Metsimotlhabe	14 boreholes, Includes, 1 automatic recorder, data exist for 2 boreholes which are now blocked/dry.
9.	Molepolole/Mochudi Exploitation	48 boreholes. data exists for 11 boreholes which are now blocked/dry.
10.	Pitsanyane/Nnywane	22 boreholes, Includes, 1 automatic recorder, data exist for 4 boreholes which are now blocked/dry.
11.	Lobatse Treatment Plant	11 boreholes, data exists for 2 boreholes which are now blocked/dry.
12.	Kanye	68 boreholes + 2 wells, includes 1 automatic recorder.
13.	Letlhakeng/Botlhapatlou	64 boreholes, Includes 10 automatic recorders, data exist for 1 borehole which is now dry.
14.	Seleka Farm	
15.	Matsheng Area	17 boreholes, Includes, 4 automatic recorders.
16.	Ghanzi/Makunda	20 boreholes.

B.6.1.4 Recharge Monitoring Network

Various recharge studies have been carried out for some time as part of various projects. Recently some stations have been set to allow on-going monitoring of both meteorological, evapotranspiration, soil moisture and groundwater level data. The first of these stations was set up as part of the Serowe Wellfield Extension project. Additional stations have now been installed at Tsabong and Hunhukwe with a further station planned for Maun and possibly Letlakane. Although the existing stations were originally installed as part of specific projects, they are now operated under the Kalahari Research Project through the DGS to provide long term data on recharge throughout the country.

Recharge estimation across the country will be carried out by using the extensive data collected at the stations to calibrate remotes sensing imagery (i.e. Landsat) to assess net recharge throughout the year over the whole country.

B.6.2 Quality of Monitoring Data and QA/QC

B.6.2.1 Department of Water Affairs

In general monitoring data are of good quality and undergo quality checking as described in Section B.5.3.1. A significant limitation of the DWA monitoring data that has been identified is that data collected for the private or parastatal operated wellfields are not presently entered in the WELLMON database.

B.6.2.2 Department of the Geological Survey

Monitoring data collected by DGS are less accessible with the majority of data collected in the last five years not yet entered into digital format. No QA/QC procedures are specified or followed. As such the usability of DGS monitoring data as part of the regional hydrogeologic map would be problematic.

B.7 HYDROGEOLOGICAL MAPPING

B.7.1 Existing Hydrogeological Maps

Existing hydrogeological maps are published by the Department of Geological Survey. The maps are available for a nominal cost from the Department's library in Lobatse in printed form. Digital versions do not exist. The maps currently available are:

- Hydrogeological reconnaissance maps (scale 1:500,000) which summarise the physiographic, geological, hydrogeological data for a map sheet and include yield potential, quality, elevation and water level contours and flow directions. Short descriptions of physiography, geology, hydrogeology and groundwater quality and cross-sections usually accompany the map. There are 11 map sheets which cover the entire country. These were published in 1980. Aquifer extents are based solely on geological units.
- Groundwater Resources Map of the Republic of Botswana of 1987 at 1: 1,000,000 scale. The map is in two sheets.
- Groundwater Vulnerability Map of the Republic of Botswana at 1:1,000,000 scale; some town area maps are available at 1:50,000 scale.

The Groundwater Resources Map is now 15 years old and the Hydrogeological Reconaissance maps are more than 20 years old. It is recognised that they are considerably out of date and the DGS would like to update and revise them. This was originally planned to occur during National Development Plan 7 (1993-98) but is still pending. None of the existing hydrogeological maps indicate any aspect of the shared nature of aquifers (such as Karoo aquifers in the eastern or western parts of the country).

Maps are also generated and updated during regional scale hydrogeological projects. The DWA initiated groundwater Monitoring Project generated digital hydrogeological maps of the wellfields. Investigations carried out in other groundwater projects such as Ghanzi-Makunda, Middlepits-Makopong, Lokolane and Tsabong resulted in updating of the existing geological map area covered by the project or were mapped again at a larger scale. These data are kept by the individual project supervisors at DWA or DGS. Most of the data generated in the last seven years are in digital format (CAD, ArcView, Mapinfo).

B.7.2 Derivative maps

Three derivative maps form part of the Groundwater Resources Map:

- Mean annual rainfall and variation
- Depth to groundwater
- Reliability of Map Information

They are at 1:8,000,000 scale. Both rainfall and depth to groundwater are shown as contours. Reliability of information is based on three categories:

- Poor: map information inferred from sporadic boreholes and general geologic knowledge
- Fair: map information inferred from few boreholes and regional geologic knowledge
- Good: map information derived from numerous boreholes and detailed geologic knowledge.

B.7.3 Classification and Legend of Maps

B.7.3.1 Hydrogeological Reconnaissance Maps at 1:500,000 Scale

The hydrogeological reconnaissance maps at 1:500,000 scale contain detailed legends given under eight categories:

1. Groundwater development prospects.
2. Productive aquifers.
3. Groundwater salinity.
4. Groundwater quality in boreholes and wells.
5. Groundwater features
6. Surface water features
7. Other symbols and
8. Topographic symbols

The groundwater development pattern is shown as filled polygons in light colours with symbols (points and lines) and hatch patterns signifying different aspects. The details are tabulated in Table 8.

Table 8. Hydrogeological Reconnaissance Maps Legend Summary

LEGEND	DETAILS OF LEGEND
Groundwater Development Prospects shown as colour filled polygons in the map sheet. A two way colour coded classification is used that classifies aquifers as having uniform, variable and extremely variable prospects with poor, fair and good yields. Intermediate classes could be poor to fair, fair to good etc.	Classification of yield: • 0 to 0.5l/s poor • 0.5 – 4l/s fair and • >4l/s good. Example Colour code from map sheet 4: • Yellow – uniform prospect and poor yields • Green – uniform prospect and fair yields • Blue – uniform prospect and good yields • Light green – variable and poor to fair yields • Light blue – variable and fair to good yields • Brown – extremely variable and poor to good yields
Productive Aquifers aquifers are shown by hatched areas signifying lithology (sand, sandstone, calcrete, etc.) and lithostratigraphic units and age.	Hatch fill patterns signifies the lithology and lithostratigraphic unit the lithology belongs to. Information on age is given for the symbol in the legend. Both informal and formal stratigraphic terminology is used and can be distinguished by the font used. Hatch symbols are combined where more than one aquifer exists.
Groundwater Salinity Polygons with hatch patterns indicate the extent and association of the groundwater salinity in the aquifer.	Areas of TDS > 1,500mg/L are hatched with symbols showing local salinity, regional salinity and salinity associated with pans.
Groundwater Salinity in Boreholes and Wells Boreholes are classified according to TDS in mg/L.	Symbols used are: • TDS < 1,500mg/L are fresh; blue filled circle • TDS between 1,500 to 5,000 are saline; orange open circle • TDS between 5,000 to 10,000mg/L are moderately saline; orange half filled circle • TDS > 10,000mg/L are very saline; orange filled circle • No information is indicated by open black circle • Wellfields with fresh water are marked by a blue open circle.
Groundwater Features	Features include: • Contour lines on the phreatic groundwater table in meters below ground surface • Contour lines on the piezometric surface (confined) in meters below the land surface. Contour lines are drawn for areas with appropriate data. • Direction of groundwater flow
Surface Water Features	• Rivers, perinial and ephemeral; blue solid and broken line

LEGEND	DETAILS OF LEGEND
	• Dry valley; blue broken lines • Lake, dam, areas of perenial flood; blue polygons • Pan; blue polygons • Surface water devide; blue dotted line
Other Symbols	• Contour lines of mean annual precipitation in mm/year; green solid line with contour values • Aquifer contact; grey dotted line • Boundaries of groundwater prospect areas; black solid line • Fault; thick black solid and broken lines • Ground elevation contours; heights in meters above mean sea level; red solid lines and contour values • Cross section line
Topographic symbols Same as Department of Surveys and Mapping toposheet	Topographic symbols include: • International and district boundaries; tribal territory boundary • Trigonometric stations, spot heights, prominent hills • Main towns, villages • Main roads, track, minor track and railway track

B.7.3.2 Groundwater Resources Map

The National Groundwater Resources Map (1:1,000,000) has a slightly different legend than that of the Groundwater Reconnaissance Maps (Table 9). The map is derived from the hydrogeological reconnaissance maps discussed in the previous section. The map is in the geodetic coordinate system and topographic information is based on the 1:1,000,000 Lands and Surveys Map (1984).

Table 9. Groundwater Resources Map Legend Summary

LEGEND	DETAILS OF LEGEND
Groundwater Resources Potential shown as colour filled polygons in the map sheet. A solid or spotted coding classification is used to indicate aquifers as having regular recharge or occasional or no recharge.	Classifications in either regular or occasional/no recharge: • High and uniform • Fair and uniform • High, but variable • Fair but variable • Generally poor but locally fair
Productive Aquifers Same system as reconnaissance maps	
Groundwater Salinity No regions indicated	
Groundwater Salinity in Boreholes and Wells	Symbols are similar to reconnaissance maps although no symbol for boreholes with no data available; no wellfield symbol
Groundwater Features Not indicated	
Surface Water Features	Same as reconnaissance maps
Other Symbols	• Boundaries of aquifer systems - solid line: outcropping; dashed line: beneath Kalahari Beds • Fossil river beds
Topographic symbols Same as Department of Surveys and Mapping toposheet	Similar to reconnaissance maps

B.7.3.3 Groundwater Vulnerability Map

The groundwater pollution vulnerability map is at 1:1,000,000 scale. The map was published in 1995. The legend is given under categories for vulnerability to pollution, lithology of important aquifer systems, major wellfields, surface water features and geological and topographic information. The

definition of "vulnerability" was as per a specific formula described in an associated report. The legend is summarised in Table 10.

Table 10. Groundwater Vulnerability Map Legend Summary

LEGEND	DETAILS OF LEGEND
Vulnerability to pollution A colour coded classification is used that classifies aquifers between end members of aquifers requiring comprehensive protection and those requiring minimal protection	Classifications of aquifers requiring protection: • Extreme • High • Moderate • Extreme, but saline (TDS >1500 mg/l) • High, but saline (TDS >1500 mg/l) • High but poor groundwater resources Classification of aquifer requiring minimal protection: • Low • Negligible
Lithostratigraphy of Important Aquifers Similar system to the hydrogeologic maps	
Major Wellfields	Wellfields are indicated by blue open circles but symbol gives no other information about the wellfield
Surface Water Features	Similar to hydrogeologic maps
Geologic and Topographic Information	Similar to hydrogeologic maps

B.7.4 Existing Geological Maps

Geological maps are produced by the DGS. The maps are mostly available in printed form, with the exception of the national geologic map which has recently been produced in digital (Arcview) format. This development of the digital version of the national geologic map is considered to be still on-going in terms of revisions and improvements. A summary of the geologic mapping is presented in Table 11.

Table 11. Summary of Available Geologic and Geophysical Maps

Map	Scale	Number of maps
Small Scale Maps: Tectonic, mineral occurrence, elevation contour, photogeology etc.	1:2,000,000 1:1,500,000 1:1,000,000 1:500,000	9
National Geologic Map	1:1,000,000 1:1,500,000	2
Geological maps	1:125,000	51
Geologic maps	1:250,000	3
Aeromag Contours, Profiles	1:500,000	10 of each
Surficial and basement interpretation maps	1:250,000	35

B.7.5

B.7.6 Existing Topographic Mapping

The Department of Surveys and Mapping has just completed a new atlas. The atlas is presently being sold as a book, but digital versions will soon be available, in Arcview format. The atlas includes chapters on Geology and Geomorphology, Surface Hydrology and Hydrogeology. The topography used in the atlas is from the existing interpretation, but a new series of orthophoto maps will be produced beginning this year with 5 m contours, digitally available to 1 m resolution. The contract will be completed in 2003.

B.8 DATA AVAILABLE FOR A SADC HYDROGEOLOGICAL MAP

Based on the existing data sets and mapping, Table 12 summarises the data available for the specific legend items on the Hydrogeological Reconnaissance Maps that may be desirable to portray on a regional hydrogeologic map.

Table 12. Hydrogeological Map Legend Summary

LEGEND	SOURCE DATA	PROCESSED DATA	NOT AVAILABLE
Groundwater Development Prospects	Borehole yield data and success rate (i.e. no. of dry bhs): DWA NBA database		
Productive Aquifers		Digitised geological map from DGS	
Groundwater Salinity	DWA: Aquabase - digital; also paper data from DGS monitoring		
Groundwater Salinity in Boreholes and Wells	DWA: Aquabase - digital; also paper format data from DGS monitoring; consultant reports paper and digital format (DWA and DGS)		
Groundwater Features	Depth to water table and piezometric head: DWA NBA database*; DWA and DGS project reports (digital and paper copy); Direction of groundwater flow (from above data)		
Surface Water Features	Rivers, perennial and ephemeral, dry valley, lake, dam, areas of perennial flood Pan, surface water divide: Dept. of Lands and Survey (Arcview format)		
Other Symbols	Precipitation: Dept. Meteorological Services (digital); Topography, roads, boundaries: Dept. of Lands and Survey (Arcview format)	Aquifer contacts, faults: Digitised geological map from DGS	
Vulnerability to pollution		1995 vulnerability map (paper format)	

*database does not specify whether water level is phreatic or confined; some analysis or filtering would be required

B.9 COMMITMENTS AND CONCERNS

B.9.1 Commitments on Contribution to the Regional Mapping Project

B.9.1.1 Department of the Geological Survey

Depending on the timing of the project, the updating of the national hydrogeological maps by the DGS could be coordinated with the regional mapping effort.

B.9.1.2 Department of Surveys and Mapping

The DSM would like to be kept aware of the regional map activities and could assist with manpower and computer facilities. Definite commitments would only be possible when a time frame and terms of reference are defined.

B.9.2 Concerns

Many members of DWA expressed significant uncertainty over the need and usefulness of a regional hydrogeologic map, although DGS was strongly supportive of the project.

B.10 REFERENCES

Department of Water Affairs, 1991, Natioanal Water Master Plan, Snowy Mountains Engineering Corporation (Australia), SGAB (Sweden), 12 vols.

Department of Water Affairs, 2000, Groundwater Monitoring, Geotechnical Consulting Services (Pty) Ltd., Gaborone, 25 vols.