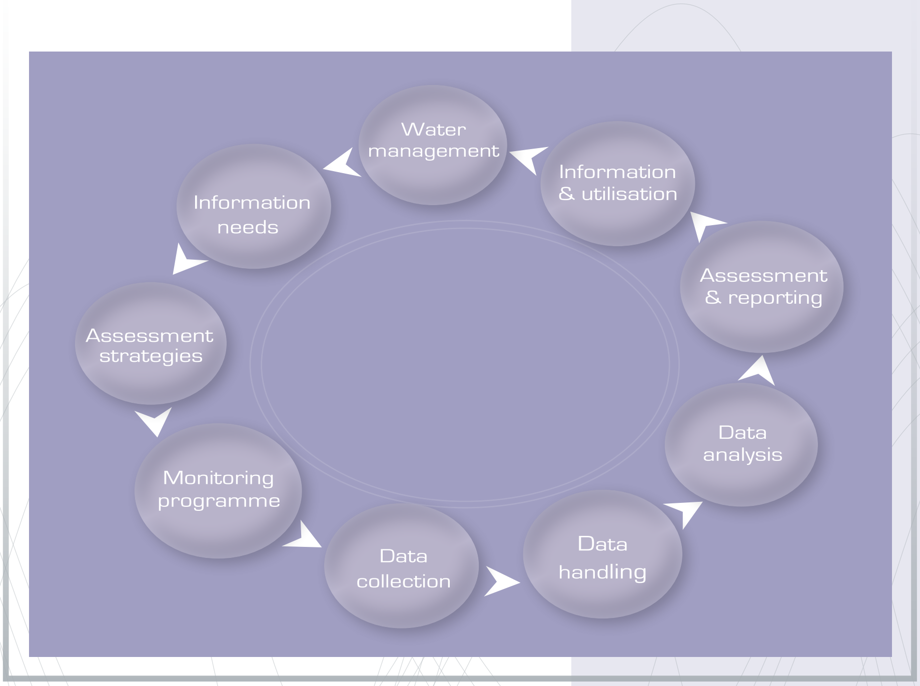
Iullemeden Aquifer System

Mali - Niger - Nigeria

Volume V

MONITORING & EVALUATION OF TRANSBOUNDARY RISKS



OSS
SAHARA AND SAHEL OBSERVATORY

V

Iullemeden Aquifer System

Mali - Niger - Nigeria

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MONITORING & EVALUATION OF TRANSBOUNDARY AQUIFERS

Guidelines

Tunis, 2011

Other documents (IAS)

Volume I : Transboundary diagnostic Analysis

Volume II : Common Database

Volume III : Hydrogeological Model

Volume IV : Participatory management of transboundary risks

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Water Programme coordinator

Abdelkader Dodo

Executive Secretary

Dr Chedli Fezzani

Contents

LIST OF ACRONYMS/ABBREVIATIONS

ADT	Analyse diagnostique transfrontalière
AEP	Alimentation en eau potable
AGRHYMET	AGRonomie - HYdrologie - METéorologie du CILSS
AIEA	Agence internationale de l'énergie atomique
BDD	Base de données
CDI	Centre de documentation et d'informatique (du Mali)
CI	Continental intercalaire
CT	Continental terminal
DIEPA	Décennie internationale de l'eau potable et de l'assainissement
DNH	Direction nationale de l'hydraulique (Mali)
DRE	Direction des ressources en eau (Niger)
DRHE	Direction régionale de l'hydraulique et de l'énergie (Mali)
DWC	Digital Word Chart
ESRI	Environmental Science Research Institute
GEF	Global Environmental Facility
GTOPO30	Modèle numérique de terrain pour le Globe développé par USGS.
IGN	Institut géographique national
IRH	Inventaire des ressources hydrauliques (service rattaché aux DRE)
MCBD	Modèle conceptuel de la Base de données commune
MCD	Modèle conceptuel de données
MNT	Modèle numérique de terrain
NGM	Niveau général des mers
NP	Niveau piézométrique
NS	Niveau statique
OAD	Outil d'aide à la décision
ODBC	Open Database Connectivity
OSS	Observatoire du Sahara et du Sahel
PAC	Programme d'action communautaire
PM5	Processing Modflow version 5
PNUD	Programme des Nations unies pour le développement
PNUE	Programme des Nations unies pour l'environnement
SAD	Système d'aide à la décision
SAI	Système aquifère de l'Iullemeden
SAP	Strategic Action Programme (Programme d'action stratégique)
SASS	Système aquifère du Sahara Septentrional
SGBD	Système de gestion de base de données
SGBDR	Système de base de données relationnelle (DBMS en anglais)

SI	Système d’information
SIG	Système d’information géographique
SIGMA	Système d’information géographique du Mali (= Base de données)
SIGNER	Système d’information géographique du Niger
SISAI	Système d'information géographique du SAI
SRP	Stratégie de réduction de la pauvreté
SRTM	Shuttle Radar Topography Mission
UNESCO	United Nations Educational, Scientific and Cultural Organization

PREFACE

In the framework of the project initiated by the Observatory of the Sahara and the Sahel (OSS) entitled "Managing Hydrogeological risks in the Iullemeden Aquifer System (IAS)" shared by Mali, Niger and Nigeria, these riparian countries joint their efforts to identify, analyse and assess the transboundary risks affecting their common groundwater resources. These risks are: the reduction of water resources, the water quality degradation, and the impacts of climatic variability/changes.

Recognizing that no country alone can control these risks, Mali, Niger and Nigeria adopted the creation and the implementation of a consultative mechanism for an integrated, concerted and sustainable water resource management of the Iullemeden Aquifer System to avoid water stress issue.

According to its achievements and experiments reached in the study of the North Western Sahara Aquifer System, OSS strengthened the capacities of the countries by building their Database, developing the Geographical Information System and elaborating the mathematical model of IAS. This model allowed specifying the water budget of the System, the existing hydraulic relations between the aquifers, the Niger River supply by groundwater flow. These tools were developed on the basis of information and data provided by the three countries (topographic maps, geological maps, data from wells and boreholes, water abstractions, hydrochemistry, etc.).

However, up to now, a reference piezometric network does not exist for the whole IAS basin. This network allows monitoring and assessing the transboundary groundwater resources in terms of quantitative and qualitative level, to alert the decision makers to control and reduce the risks or the transboundary impacts on their common resources.

This document is intended to assist governments and joint bodies in developing harmonised rules for the setting up and operation of networks for IAS transboundary groundwater monitoring and assessment. These networks will contribute to strengthen tripartite cooperation between countries pumping in the same resources.

This guideline is a synthesis and an adaptation of a methodology developed by the European Economic Commission on the strategies for groundwater monitoring and assessment. These strategies are based on achievements of regional workshops and especially experiments acquired from the implementation of the first directives on the monitoring and assessment in pilot projects by the Parties of the Convention on the water (adopted in Helsinki in 1992).

This guideline is also based on experiments and lessons learnt from the study of the North-Western Sahara Aquifer System (NWSAS) initiated by the OSS and which relates to transboundary groundwater shared by Algeria, Libya and Tunisia. The study of the NWSAS also transposed and adapted these European Economic Commission (EEC) directives based on their achievements to define the NWSAS networks.

This document is a tool that aims to provide advice countries for better identifying the transboundary issues and highlighting new requirements in data and informations. The EEC directives provide an approach on the steps to monitor and assess groundwater transboundary aquifers. National teams have duty to make these directives operational by adapting them to their realities, through regional workshops and field works.

The document is divided in two major components.

- the issue to define the IAS piezometric network, and
- the steps of the process to monitor the transboundary aquifers.

The process for monitoring and assessing transboundary aquifers is a cycle of dependent activities that countries will have to study jointly to determine the specific long-term evolution of aquifers characteristics and behaviour.

I. ISSUE TO DEFINE THE IAS GROUNDWATER MONITORING NETWORK

I.1. Background on the Iullemeden Aquifer System

The Iullemeden Aquifer System is a simplified set of two aquifers: the Continental intercalaire overlapped by the Continental Terminal (figure 1). The Continental Terminal groups the tertiary aquifers and includes the shallow aquifers located in quaternary alluviums; it extends to around 203000 km^2. The Continental intercalaire's area is around 486000 km^2, and integrates the upper level of the Lower Cretaceous. An aquitard which separated these two aquifers is mainly composed by Palaeocene and Eocene formations and integrate locally the part of Upper Cretaceous in Mali.

Figure 1: IAS aquifers.

I.2. State of knowledge of monitoring network in IAS countries

I.2.1. Background on the objectives and types of water resources monitoring networks

Within a national context, monitoring networks generally have two broad categories of objectives: 1) these are basic or reference monitoring networks and, 2) specific purpose monitoring networks. The objectives of these networks are twofold providing data for:

- characterising the groundwater regime,
- detecting long-term trends in groundwater levels (quantity) or groundwater quality.

Within a context for groundwater of transboundary aquifers, statutory monitoring will primarily be linked to agreements between riparian countries. The following five objectives for monitoring and assessment in transboundary groundwaters arise from the Convention:

- state assessment;
- compliance with standards or provision of the agreement (related to functions/use);
- emergency response;
- special protection areas;
- remediation and restoration.

These types are summarised in the following table:

Objectives	Types of Groundwater monitoring	Information
❶ State assessment and compliance **❷ Compliance with standards or provision of the agreement**	(a) Basic/reference	• natural situation • trends (natural, diffuse pollution, hydraulic regime) • baseline (to detect human impact). Background levels • spatial distribution • compliance • reference situation
❸ Emergency response	(b) Early-warning and surveillance	• early-warning • thresholds • trends • risks • effectiveness of measures • impacts
❹ Compliance special protection areas **❺ Remediation and restoration**	(c) Monitoring linked to functions/uses (d) Specific purposes	• quality standards • criteria, thresholds • health risk • environmental risk • validation • forecasting • effectiveness of measures • implementation monitoring

Table 1: Main types of groundwater monitoring arising from the Convention

Four types of groundwater monitoring are described below:

Basic/reference monitoring

Basic/reference monitoring includes monitoring for state assessment. This type of monitoring establishes a background (reference) situation to enable the determination of trends caused by transboundary anthropogenic impacts and natural impacts.

For state assessment, long-term records are needed to determine the possible impact of changing land use and pumping patterns through statistical analysis. It is often performed on very different scales (national, regional, local) and is also prescribed by several international directives and conventions. In a transboundary context, monitoring networks on both sides of the border could be used, but the statistical analysis requires central guidance from a joint body as the Coordination Unit of the consultative mechanism between riparian countries.

▸▸▸ Monitoring linked to functions and uses (compliance)

This strategy is linked to regulations, laws and directives related to the use of groundwater. This type of monitoring serves as a protection of functions and water uses. The monitoring should answer the question, of whether the groundwater use complies with these above-mentioned regulations and standards. For groundwater of transboundary aquifers, this means that riparian parties have to establish and agree upon the groundwater uses and functions in the transboundary aquifer they pump.

Since monitoring results may be used as a basis for further action or measures, it is recommended that a transboundary quality assurance programme should be established to ensure the reliability of the water-quality laboratories of the concerned countries.

▸▸▸ Monitoring for specific purposes

Some groundwater resource management activities require special types of investigation and monitoring. For instance:

- the development and evaluation of special protection areas;
- the implementation and evaluation of remediation and restoration measures;
- the investigation of interconnection of surface water and groundwater ;
- modelling to predict migration of contaminants;
- the investigation of the possible sources of nitrate in groundwaters as a basis for pollution control measures.

▸▸▸ Early-warning and surveillance

This strategy aims at collecting information on whether and where accidental spills may affect particularly the drinking water supply, to determine public health hazards of "abandoned or illegal" land disposal sites, or to determine actual sources of groundwater quality deterioration. For early-warning, special wells may be drilled, whereas for surveillance production wells can often be used.

The resulting information should provide a sufficient basis for an emergency response, which can be either specific additional measures or remedial actions. Riparian countries should agree on all the aspects of this strategy as well as on the emergency response.

I.2.2. Review of water resources monitoring networks in the IAS countries

▸▸▸ Mali

In Republic of Mali, the piezometric network is recent. The 1970's drought led especially the implementation of serial research and exploitation programmes on groundwaters to promote a piezometric network by the National Direction of Hydraulic and Environment (NDH) supported by various projects such as PNUD/DCTC and the participatory of several projects to supply rural population in particular Helvetas, Mali aqua Viva, KBK, CMI, Caritas, etc. This network primarily located in the basin of the Niger River, had 70 sites of observations composed with 210 piezometers according to the NDH Data Base SIGMA, 88 boreholes and 122 wells. In 1992, this network had 95 observation sites with 231 piezometers among which 37 were equipped with continuous record (piezographs).

The piezometers in the inner Niger basin are as following (table 2). Drilling of 5 boreholes is ongoing in IAS part.

Region	Site of measurements (1981 – 2002)			
	Manual		Limnigraphs (boreholes)	Total
	Wells	Boreholes		
Koulikoro	31	13	22	62
Sikasso	57	36	4	96
Ségou	0	5	3	8
Mopti	7	3	11	21
Tombouctou	2	5	1	8
Gao	0	5	0	5
District de Bamako	0	1	0	1
Total	106	81	43	225
Total functioning in 2003	0	9 (Sikasso)	0	9

Source : National report on water resources assessment, 2004

TABLE 2: Repartition of piezometric measurements points located in Niger river basin.

The almost totality of the piezometers including the severals types of piezometers, are not monitored because of lack of financial and material supports. The monitorings stopped with the end of the projects that initiated them. According to the Division of the Hydraulic Inventories of the National Direction of Hydraulic (NDH), less than 10 piezometers were monitored in 2003.

The field works done in 2002 by the technical teams of NDH in Koulikoro, Sikasso, Ségou and Mopti revealed that:

- no measurement was done since 1991 for some, since 1994 for others,
- all limnigraphs must be revised,
- some limnigraphs were removed and the boreholes closed.

The network to monitor water quality does not exist. Recently, within the framework of project GHENIS, a network was set up to monitor 33 sampling stations. Otherwise, the NDH laboratory has no network to monitor water quality (surface, groundwater). The majority of the analyses are done by the civil and private companies that transmit the informations to the NDH. Some sporadic analyses are carried out on the rivers.

Finally, monitoring water resources requires the implementation of network essential for the study of the aquifers in particular to monitor the mechanisms of hydraulic transfers to allow to establish water budget of these aquifers. Also, it is important to proceed regularly to:

- inventory the water points (wells and boreholes) and their characteristics of the basin ;
- measure frequently the water level fluctuations in the piezometers and some boreholes.

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The actual monitoring network has 308 water points for different aquifers. This network is composed by 132 boreholes, 103 wells, 72 piezometers and one well-borehole.

This network is not well organised as for surface water. The monitoring is done by the local offices of the Ministry of Hydraulic for some vulnerable aquifers for which a least network was set up with 83 water points in 1999.

The selection of target aquifers depends on their hydrogeological potentialities, the intensity of abstraction and their likely development.

The water table fluctuation is mainly monitored and is characterised by the high variability of the frequency measurements from region to another region, and in the same region. Indeed, the frequency of the observations varies from 2 or 3 per month to 1 or 2 per year.

The analysis of the data collected shows that the quality of these data is not so good although these data allow understanding the groundwater flow.

▸▸▸ NIGERIA

The Department of Hydrology and Hydrogeology in the then Federal Ministry of Water Resources in 2001 established a Hydrological and Hydrogeological GIS Database for the entire country. Then ArcGIS 8.0 versions with Microsoft Access DBMS were used to create a Relational Database Management System. In 2007 the GIS software used was replaced by the ArcGIS 9.1 version.

Currently, the Database contains maps of Nigeria in different themes such as state, Local Government, 12 River Basins and 8 Hydrological area boundaries as well as other attributes. Also linked to these maps are data on borehole points, river gauging stations and other water infrastructures.

Currently too, there are on-going projects on data collection to beef up the Database. These projects are at advanced stages of completion.

Furthermore the Department which is now transforming into The Nigeria Hydrological Services Agency is about to embark on Networking to facilitate PCs easy access of data and information from the Database. This is to be done under the project called the National Hydrological Information Systems Networking (HYDRONET).

The Iullemeden Aquifer System project will benefit from this Database. Specific monitoring network of IAS will allow to understand these aspects as water balance and the recharge which is fundamental to correct the ground water resources management for the ongoing intensive irrigation projects the municipal water abstractions. Since the motorized and hand operated water schemes are expanding rapidly corresponding ground water monitoring wells should also be installed at strategic location within the Iullemeden Aquifer System.

The State Water Boards of Katsina, Kebbi, Sokoto and Zamfara/Federal Ministry of Agriculture and Water Resources embarked on numerous borehole programmes largely for municipal and rural water supplies (table 3, page 16). To date the following borehole statistics have been recorded within the Sokoto Rima Basin. However further studies are required to delineate those that have direct influence on the Iullemeden Aquifer System, particularly in Katsina, Kebbi and Zamfara States.

I.3. Conclusion

Mali, Niger and Nigeria have a monitoring network that depends strongly to the existing project. But these projects are limited in time and space.

In addition, their piezometric network requires a control to be ensured of their functionality but especially the distribution of water points according to each target aquifer and their representativeness so as to monitor the evolution of water table fluctuation in space and time due to water abstraction, The results from IAS mathematical model reached in the framework of the project "Managing Hydrogeological Risks in the Iullemeden Aquifer System" highlighted **the need for developing a reference piezometric network on a regional scale**, in particular to specify the risks and for alerting the political decision makers.

To allocate the three countries, for the first time, by a piezometric network extended to the natural boundary limits of the transboundary aquifers jointly pumped, a methodological step is proposed in the following chapters. It is about the setting of the piezometric network of the North Western Sahara Aquifer System (NWSAS).

S/No	State	Number of functional boreholes	Projected Programme 2007
1	Katsina	100 +25*	300 + 150*
2	Kebbi	300 +50*	500 + 350*
3	Sokoto	600 +200*	1500 + 500*
4	Zamfara	201 +100*	250 + 400*
	Total	1,706	3850

* represent boreholes drilled or sponsored by the FMWR

Table 3: Borehole Statistics in the Federal States of Nigeria included in the IAS project

II. MONITORING AND ASSESSMENT CYCLE OF TRANS-BOUNDARY AQUIFERS

II.1. Background

II.1.1. Definitions

▸▸▸ Monitoring

Monitoring is usually understood as a process of repetitive measurements, for various defined purposes, of one or more elements of the environment according to pre-arranged schedules in space and time, using comparable methodologies for environmental sensing and data collection. As far as possible, measurements should be made and samples collected at the same locations at regular time intervals.

One purpose of monitoring is to enable assessments of the current state of water quantity and quality and their variability in space and time. Often such assessments are appraisals of the hydrological, morphological, physicochemical, chemical, biological and/or microbiological conditions in relation to reference conditions, human health effects and/or the existing or planned uses of water. Such reference conditions may take into account elevated concentrations of specific determinants due to "natural" geophysical and geochemical processes.

Another purpose of monitoring is to support decision-making and operational water management in critical situations. In critical hydrological situations (i.e. floods, droughts, pollutions). Reliable hydro-meteorological data are needed, which often requires early warning systems to signal when critical levels are reached or exceeded. In these cases, models can often support decision-making. For example, the IAS mathematical model highlighted water abstraction compared to the renewable resource whose threshold of overexploitation was crossed in 1995, year as from which the abstraction estimated to 152 million m^3 exceed the average recharge (red line) estimated to 150 million m^3 in 1970.

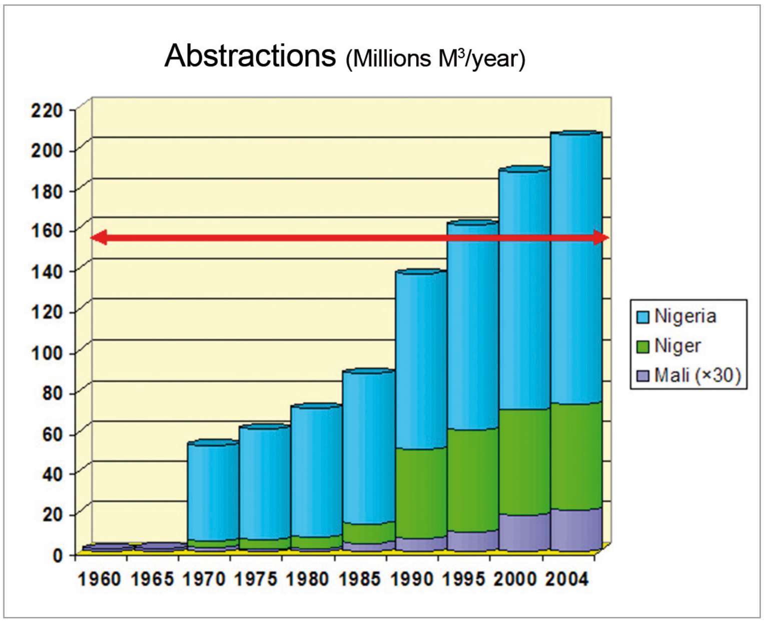

Figure 2: Threshold of overexploitation (red line) was crossed in 1995.

▸▸▸ Assessment

Assessment is the evaluation of the hydrogeological, chemical and/or micro-biological state of groundwaters in relation to the background conditions, human effects, and the actual or intended uses, which may adversely affect human health or the environment.

II.1.2. Specific aspects of groundwater monitoring

When implementing transboundary monitoring and assessment programmes, it is essential to present the hydrogeology in conceptual models and/or in graphic schemes. This should comprise a characterisation of the transboundary aquifer (geometry), the flow conditions, including recharge and discharge areas, and the evolution of the groundwater quality.

The characterisation and description of relevant transboundary aquifer systems are a prerequisite for the monitoring of transboundary waters in general and of transboundary groundwaters in particular. Features that influence the way groundwaters are monitored and assessed and that distinguish them from surface waters are:

- slow movement (long residence times) of groundwaters increases the potential for their quality to be modified by the interaction between the water and the surrounding aquifer material. Also, once groundwaters are polluted, they may remain so for many years and it is difficult to intervene effectively in this process;
- the interaction between aquifer material and water causes the natural hydrogeochemistry to evolve as the infiltrating groundwater moves down. To be able to detect and quantify the superimposed impacts of human activities, the "baseline"(or reference) quality of groundwater with its lateral and depth variations must be assessed (i.e; Tibiri case);
- groundwater flow can be intergranular and/or through fractures. Groundwater flow will be much more rapid but variable and difficult to estimate through intensely fractured rocks. Intergranular groundwater flow increases the potential for interaction between aquifer material and groundwater;
- recharge and discharge areas need to be determined and activities that might affect the quantity or quality of groundwater need to be understood. Knowledge of the groundwater flow system means in particular the locations of groundwater recharge and discharge zones, and the way groundwater flows through aquifers from zone to zone (figure 3a). Activities in the recharge areas on one side of the border might adversely affect the quality of quantity of groundwater on the other side. To determine recharge and discharge conditions in some areas, the interaction between surface and groundwaters need to be understood (figure 3b);
- background conditions change over time and these spatial, temporal and depth variations have to be determined before it is possible to detect any impact of human activity;
- multi-lay National Hydrological Information Systems Networking ered systems. When there is more than one aquifer separated by aquitards of less permeable material, the possible pathways or connections between them need to be understood.

So, to characterise groundwater occurrence, information on geology, geophysics and hydrogeology in the transboundary area is needed. Also, the dynamics of the groundwater flow system, such as seasonal or longer-term responses and variations and changes in flow rate or direction caused by human activities, particularly groundwater abstraction, must be understood. Groundwater quality is infinitely variable in space and time, but on different spatial and temporal scales to surface waters.

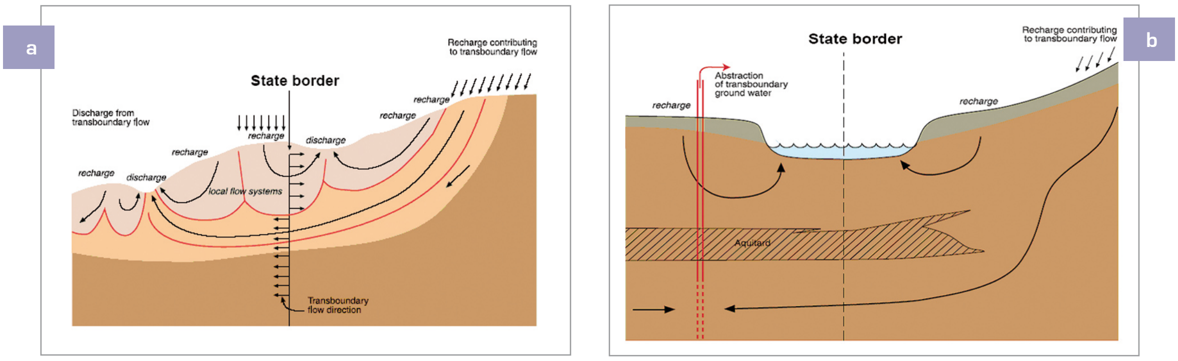

Figure 3: Transboundary groundwater flow systems on both sides of the state border.

II.1.3. Integrated approach

The harmonisation of surface water and groundwater monitoring networks must be envisaged, in order to manage and protect transboundary water resources effectively. Basic/reference and compliance monitoring should be linked in the most appropriate way.

In developing monitoring programmes, the following aspects which allow for further integration, should be taken into consideration:

- **integration of data gathering and storage:** monitoring of groundwater and surface water and of water quality and quantity is often performed by different authorities and the resulting information should be assessed in combination (and modelled jointly);
- **groundwater - surface water interaction:** surface water and groundwater monitoring and assessment could be integrated further, especially when recharge is through seepage of surface waters or in the case of vulnerable ecosystems;
- **quantity – quality:** : there are often clear relationships and interactions between quantity and quality of groundwater. Measurements of groundwater quantity, such as levels and discharges, are used to characterise the groundwater flow system, both in its natural state and under the superimposed influence of human activities, especially groundwater exploitation. Such exploitation may also have impact on quality, for example intrusion of saline or highly mineralized water into a heavily exploited aquifer. These impacts (and any measures to alleviate them) can therefore be assessed most effectively by observing groundwater quantity and quality together.

The mathematical model elaborated within the framework of the project "managing hydrogeological risks in the Iullemeden Aquifer System (IAS)", highlighted the hydraulic exchanges existing between the aquifers on the one hand, these aquifers and the Niger River on the other hand in particular the support of Niger river flows by groundwater. Thus, **Ithe Niger River receives approximately 46 million m³ per year from the Continental intercalaire and 79 million m³/year from the Continental Terminal, and then 125 million m³ annually. An affluent of Niger, the Rima River** (or Goulbi de Maradi in Niger), **supplies the Continental intercalaire by approximately 20 million m³/year and receives approximately 12 million m³/year from the Continental Terminal before its junction with the Niger River**.

II.2. Methodology

An exchange of information (and joint assessment/modelling) between riparian parties is meaningful only if the data are comparable. This can be achieved when all components of groundwater monitoring activities on both sides of the border use similar principles or adopt an approach such as the monitoring cycle presented below (figure 4).

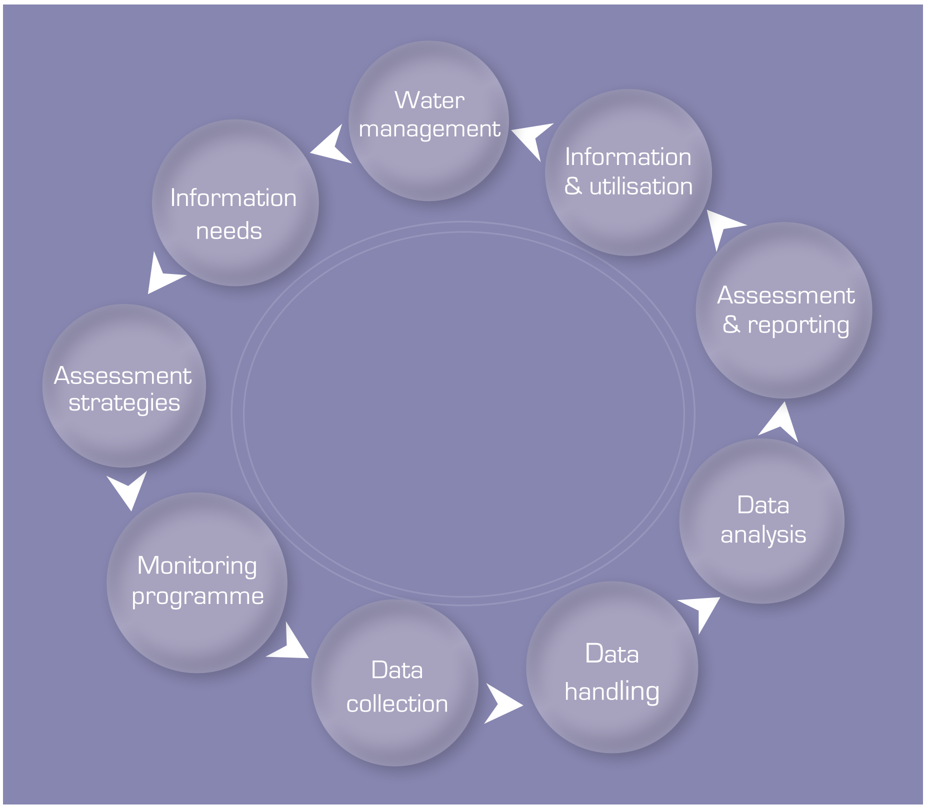

Figure 4: Monitoring cycle (from UN/ECE, 2000)

The outputs produced by each of these elements are used in the consecutive element(s) of the cycle. Ideally, at the end of the cycle, the information needed for planning, decision-making and operational water management at local, national and/or transboundary levels is obtained in the form of a report or other agreed-on format. It should also become clear what kind of information is still needed for better decision-making and other water management tasks, given that policies and/or targets may have changed in the meantime. Thus, a new cycle would start leading to redefined or fine-tuned information needs, an "upgraded" information strategy, and so on.

II.2.1. Identification of groundwater management issues

Functions, pressures and targets

Groundwater management is part of integrated water resources management and protection. The core elements in groundwater management as functions, pressures and impacts on transboundary aquifers, should be identified and priorities should be set. These core elements are:

- the functions and uses of the aquifers (par example conservation of wetlands (function), drinking water or irrigation (use),
- the problems and pressures (threats) (par example declining groundwater table, pollution) and
- the impact of measures on the overall functioning of the water body. Measures can include investigations of the problems and threats, risk analyses, remediation (reduction in groundwater withdrawal and/or artificial recharge (infiltration)), existing monitoring programmes, control of polluting activities or excessive withdrawal.

When establishing transboundary groundwater monitoring strategies, the following need to be identified and jointly agreed by including the quantitative and qualitative aspects:

- the transboundary aquifer and relations to surface water and associated ecosystems;
- specific human uses of transboundary groundwaters;
- ecological function of transboundary groundwater resources;
- pressures which have an impact on human uses and on the functioning of ecosystems that are dependent on groundwater;
- quantified, or otherwise clearly defined, management targets which should enable the establishment of restrictions and which can be implemented within a specified time period.

II.2.2. Information needs

The analysis of water management issues is the basis for specifying the information needs. Information needs are related to:

- uses and functions of the aquifers that put requirements on the quality and availability;
- issues (e.g. salinization, pollution) that hinder proper use and functioning of the aquifers; and
- measures taken to address the issues or improve the use or functioning of the aquifers, including environmental aspects.

The analysis of information needs is the most critical step in developing a successful, tailor-made and cost-effective monitoring programme. To properly design and implement a monitoring and assessment programme, information needs should be specified as precisely as possible for different levels (e.g. river basin-scale and local levels), and using the components of the DPSIR framework (Driving Forces–Pressures–State–Impact–Responses) adopted by the European Environment Agency (EEA) (figure 6).

Driving forces describe the human activities. The **pressures** describe the stress that the problems put on the functions/uses of the aquifer. The **state of the aquifer** is described in terms of concentrations or hydraulic characteristics. The **impact** describes the loss of function/use like potability or use for drinking water supply. **Responses** describe the policies that have been or are being developed to deal with the problem.

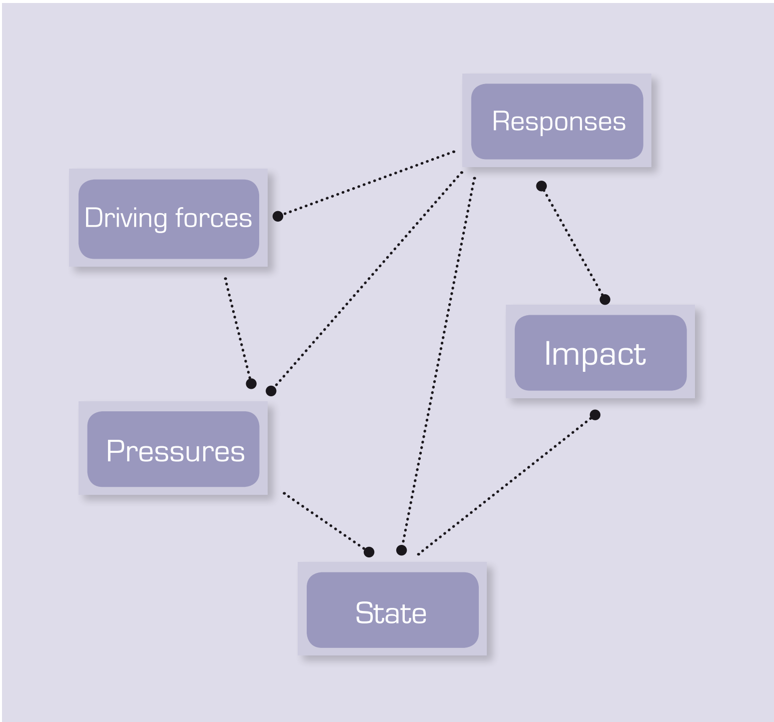

Figure 6: The Driving Forces - Pressures - State - Impact - Responses (DPSIR) framework

The DPSIR framework assumes that social, economic and environmental systems are interrelated. These links are illustrated conceptually by driving forces of environmental change, which create pressures on the environment. These in turn affect the state of the environment (fig. 6). The subsequent changes in status, or “impacts”, include impacts on ecosystems, economies and communities. The **negative impacts** will eventually lead to responses by society, such as the development of policies basin protection. If a policy has the intended effect, its implementation will influence the driving forces, pressures, status (state) and impacts.

The Steps in the specification of information needs are:

- identify functions or uses and issues (such as pollution and declining groundwater level) of the groundwater system.
- establish a function-issue table to see whether the issues are in conflict with the functions of the groundwater systems.

Management objectives should be formulated and agreed upon to protect these groundwater resources. When budgets are restricted, a **function-issue table** can be used as a tool for priority setting. The urgency of a problem and the available (technical and financial) means determine priorities.

- collect at least the following information about place- and time- dependent factors:
- the hydrological and geochemical functioning of the groundwater system at spatial and temporal scales;
- the users of information (policy makers and/or managers at the operational level);
- the stage of the management (problem identification, policy development, policy implementation and control);
- use the DPSIR concept for further specifying information needs. The system approach of this concept is helpful in finding causalities between environmental problems (pressure), the impact on groundwater resources (impact, state) and measures to be taken (response).
- make a checklist with criteria that have to be met, linked to the factors mentioned above.

Information needs should be further specified so as to be able to design a monitoring and assessment programme. The specified information needs should at least lead to:

- appropriate variables to be monitored;
- criteria for assessment (e.g. indicators, early warning criteria for floods or accidental pollution);
- specified requirements for reporting and presenting information (e.g. presentation in maps, Geographic Information System);
- relevant accuracy for each monitoring variable;
- degree of data reliability;
- specified response time (i.e. the period of time within which the information is needed), for example, for flood forecasts or early warning systems (e.g. minutes/hours), for trend detection (e.g. number of weeks after sampling) and other tasks.

The indicators often refer to a set of core variables, thereby directing the monitoring strategy for a certain issue. Indicators provide a means of communicating monitoring results to decision makers. Indicators can also be used to illustrate the different aspects of the desired information (table 4).

II.2.3. Strategies for monitoring and assessment

Monitoring strategies should serve as a guide in establishing realistic monitoring priorities, not only in terms of what should be monitored and where, but also in terms of timing and funding. Joint bodies should periodically evaluate their monitoring activities to confirm that they are meeting their objectives in the most effective and economical manner.

Problems	Driving forces	Pressure	State	Impact	Response
Excess nutrients	Intensification of farming	N-load on farms	Nitrate in groundwater	Nitrate in drinking water	Control of manure/ fertiliser use
Pollution with hazardous substances	Chemical industry production (or mining)	Emissions heavy of metals	Concentration Heavy of metals	Potability problems	Changes of toxic contents in products and production processes
Declining groundwater level	Economic development	Drinking/ industrial water demand	Declining groundwater level	Loss of yields	Control of abstraction Artificial recharge
Salinization/salt water intrusion	Economic development	Over-exploitation	High chloride concentration	Impairment of drinking water quality	Artificial recharge

Table 4: Problems for which indicators could be developed, using the DPSIR-concept.

Key strategic aspects

After the objectives have been derived, a more specific strategy has to be developed before starting the actual technical design of a monitoring network. The following aspects have to be dealt with in a proper strategy:

- **existing information and monitoring systems**: information should be gathered on the relevant parts of the transboundary aquifer subject to the agreement signed between the riparian countries.
- **required assessments**: what kind of assessments has to be carried out (e.g. natural situation, background situation, compliance with requirements of uses and functions, pollution levels, risk assessments with regard to public health and/or environment, early-warning assessment)?
- **type of monitoring**: if monitoring is needed, what type of monitoring will be required? Will a single survey be sufficient or is more extended monitoring necessary?
- **monitoring techniques**: what are the available and suitable monitoring techniques (e.g. surface water monitoring, meteorological monitoring, remote sensing techniques, early assessment monitoring (for example the use of pesticides), water use, geophysical methods, unsaturated zone monitoring network system, continuous recording monitoring system)?
- **stepwise approach**: is a stepwise approach to develop a monitoring network system, leading from coarse to fine assessments, worthwhile?
- **responsibilities**: who will be responsible for the organisation of the monitoring system (for the design, implementation, operation and evaluation)?
- **financial and human resources**: what is the available budget and, consequently, what human resources can be made available? The responsible authorities should realise that groundwater monitoring should most often be guaranteed for a long time.
- **integration**: the integration of monitoring activities for reasons of cost-effectiveness in an early stage of the monitoring cycle may cause an over- or under sizing of monitoring networks. Therefore, an information strategy should be developed per monitoring objective or information need.

Elements of monitoring and assessment strategies

The outcome of the development of the monitoring strategy should be the specification of one or more monitoring options for which a system should be designed. The following sections deal with the design of the different components of a monitoring system:

- **Inventory and preliminary surveys:** inventories and other preliminary activities should be carried out by riparian countries prior to a monitoring effort in transboundary aquifers. The extent of these activities depends on the objectives of the programme, the complexity of the hydrogeology and the number and nature of issues to be addressed. Surveys provide the basic information needed to set up the monitoring as effectively and efficiently as possible. Inventories include a general screening of all available information relevant to the aspect under consideration, an evaluation of aquifer characteristics, the hydrogeologic setting, a screening of the occurrence of pollutants by surveys or of adverse impacts at varying groundwater levels. Moreover, the need - if any - for other data will become more clear as a result of these inventories. Surveys should be undertaken where the inventory shows that data are lacking. Surveys are also helpful in determining the variability of monitoring parameters in time and space.
- **Stepwise approach:** As monitoring serves different aims and as the information needs vary from broad indications to fine-tuned diagnostic features, the choice of parameters and methods also depends on them. In general, a phased approach to bring into operation monitoring efforts, going from simple to advanced, is advisable for reasons of cost effectiveness. Additionally, prioritisation in time is recommended for the introduction of new monitoring strategies, going from labour-intensive to technology intensive methods. In many cases, the lack of appropriate and reliable data and the absence of an adequate baseline against which progress can be measured make this approach the most realistic.
- **Aquifer vulnerability mapping:** in general, more vulnerable aquifers or parts of aquifers will require greater monitoring efforts and therefore aquifer vulnerability mapping can provide a means for prioritising monitoring efforts.
- **Risk assessment:** risk assessment can help considerably in prioritising the monitoring activities. For example, a relatively small transboundary aquifer in a sparsely populated area is rarely affected by threats. Risk assessment can also be used to determine whether the chosen monitoring strategy will cover most of the information need. The use of models will help in screening alternative policies. The optimisation of a network design will also include an element of risk assessment.
- **Models:** models, especially mathematical models, play several roles in the monitoring and assessment of transboundary groundwaters. Models can be used in addition to monitoring, but also as part of monitoring optimisation programmes. **When riparian countries decide on the modelling of transboundary aquifers, they should realise that the standardisation and the accessibility of data (interfaces to databases and to Geographic Information System) are of the utmost importance, rather than the standardisation of software.**
- **Indicators:** finding the right indicators requires a balanced approach between information needs of decision makers and the costs and constraints of obtaining the appropriate data. A stepwise approach to select and develop indicators is emphasised. It can be based on the core elements of groundwater management; problems, pressures (threats) and the impact of measures on the overall functioning of the groundwater system.
- **Integrated assessment:** the need to integrate the monitoring of groundwater and surface water will depend on the extent to which processes and variables in groundwater and surface water are interrelated.

II.2.4. Monitoring programmes

Groundwater monitoring and assessment programmes will develop gradually, because of administrative, budgetary and personnel constraints. The allocation of monitoring resources should follow a tailor-made approach.

Ranking and sectioning areas where potential pollution sources (for example) are located, or where groundwater use is high, will make the programme more effective.

▸▸▸ General aspects

Once the technical objectives have been established and specific strategies have been developed for the respective monitoring programme, each strategy can be linked to a monitoring network design.

The design of monitoring networks includes the determination of:

- the network density and location of measuring points;
- monitoring parameters;
- types of monitoring points;
- the measuring and sampling frequency.

The design is a function of the selection of sampling-point type, density and location, sampling method and frequency and the choice of parameters (table 5).

Sampling point/measurements		Sampling/measurements frequency	Choice of parameters/ Water heads
Type	Density		
Hydrogeology (complexity)	Hydrogeology (complexity)	Hydrogeology (residence time)	Water uses
	Geology (aquifer distribution)	Hydrology (seasonal influences)	Water quality issues
	Land use		Statutory requirements
	Statistical consideration	Statistical consideration	
Cost	Cost	Cost	Cost

Table 5: Factors that determine network design (After Chilton et al., 1996)

The hydrogeological characteristics of the transboundary aquifers, water use and land use, and the availability of funds are among the basic factors to be considered when constructing a monitoring network.

The technical aspects of monitoring programmes as a) **Network density**, b) **Selection of sites**, c) **Parameters**, d) **Quantity measurement and sampling procedures**, e) **Frequency of sampling and quantity measurements**, f) **Indirect methods of groundwater quality monitoring**, and g) **Costs**, are discussed below.

❶ Network density

The desirable or target density of a network is basically determined by the hydrogeological and the hydrochemical complexity of the aquifer. Hydrogeological units with a high degree of heterogeneity will require a denser network of monitoring sites.

In aquifers affected by intensive exploitation and/or other anthropogenical impacts (industry, intensive agriculture, minig activities, landfills, abandoned municipal or industrial sites, etc.), the network density should be higher. As a general rule, weighting factors as aquifer characteristics, vulnerability, groundwater exploitation, water use and land use, and population served with groundwater can be used as a reference in network design.

❷ Selection of sites

The choice of both the type and location of observation points is usually governed by two interrelated criteria:

- the specific representativeness of the observation points in the aquifer;
- the possibility of determining the spatial trend in the groundwater levels or hydraulic head pressures on the required scale.

The sites or observation points of a network should be representative of:

- the delineation of the relevant groundwater flow systems;
- the extent of aquifers, aquitards and aquicludes or the delineation of hydrogeological units;
- additional information.

When selecting a site, the following different activities should be carried out

- characterisation of the groundwater systems and of the geometry of the principal aquifers;
- vulnerability assessment, mainly based on the groundwater flow conditions, soil composition and geology;
- identification of the threats to which the groundwater system is exposed and the problems which affect the aquifer.

Monitoring sites for groundwater level observation can be wells or boreholes, provided that they are not substantially affected by groundwater abstraction in the neighbouring areas. For groundwater quality networks, use can be made of observation boreholes or pumping wells. It should be noted that springs can also be used as monitoring sites, in particular for groundwater sampling purposes. With regard to representative data, one spring can replace a number of monitoring wells.

❸ Parameters

The choice of the monitoring parameters can be linked to the core elements of groundwater management and will depend on:

- the requirements of the defined functions and uses of the groundwater system;
- the threats to which the groundwater system is exposed;
- the problems which are already occurring.

Prior to the selection of parameters, an inventory should be drawn up. It should include the following:

- aquifer characterisation, quantitative and qualitative (**basic/reference networks**);
- identification of the actual groundwater functions, uses and quality requirements (e.g. ecological function, water supply for drinking purposes, agriculture and industry) (**compliance networks**);
- specification of the threats to which the groundwater system is exposed (e.g. generally reflected in land use: agriculture, industry, waste sites, military sites) (**early-warning and surveillance networks**);
- specification of the problems already experienced by the groundwater system (drying up, salinization, pollution) (**monitoring for specific purposes**).

A basic set of parameters for groundwater quantity assessment in relation to some issues and functions/uses is grouped in the following table 6:

A basic set of parameters for groundwater quality assessment (table 7) is grouped into inorganic

Issues	Functions and uses	Parameters
Desiccation (drying up)	Ecosystems, agriculture	Groundwater levels
Hydromorphic soil	Ecosystems, agriculture	Surface water and groundwater levels
Water supply	Drinking water, agriculture, ecosystems	Groundwater levels, discharge (abstraction)
Water quality aspects	Drinking water, ecosystems	Groundwater levels/heads, discharge (abstraction), surface water levels
Land subsidence	Urban area, agriculture	Groundwater levels and surface water levels, discharges (abstractions)
Salinization/ salt water intrusion	Agriculture, drinking water	Groundwater levels/heads, discharges (abstractions)

TABLE 6: Parameters for groundwater quantity assessment related to some issues and functions/uses

and organic compounds and by method of analysis. This table, important with respect to information needs, outlines only an approach, but is not sufficiently detailed to be of direct use. Further subdivision is required, as it is highly desirable to have a formal approach within which metals, pesticides and other organic compounds can be chosen, so that suites 3, 4 and 5 can be related to local conditions.

Problems	Functions and Uses	Suite/groups	Parameters
Acidification, salinization	Ecosystems, agriculture	❶ Field parameters	Temperature, pH, Dissolved Oxygen (DO), Electrical Conductivity (EC)
Salinization, excess nutrients	Drinking water, agriculture, ecosystems	❷ Major ions	Ca, Mg, Na, K, HCO_3, Cl, SO_4, PO_4, NH_4, NO_3, NO_2, TOC, EC, ionic balance.
Pollution with hazardous substances	Drinking water, ecosystems	❸ Minor ions and trace elements	Choice depends partly on local pollution sources as indicated by land-use approach
Pollution with hazardous substances	Drinking water, ecosystems	❹ Organic compounds	Aromatic hydrocarbons, halogenated hydrocarbons, phenols, chlorophenols. Choice depends partly on local pollution sources as indicated by land-use approach.
Pollution with hazardous substances	Drinking water, ecosystems	❺ Pesticides	Choice depends in part on local usage, land-use approach and existing observed occurrences in groundwater.
Pollution with hazardous substances	Drinking water, agriculture	❻ Bacteria	Total coliforms, faecal coliforms.

TABLE 7: Parameter suites for groundwater quality assessment related to some problems and functions/uses. (After Chilton et al., 1994). List II substances are Fe, Mn, Sr, Cu, Pb, Cr, Zn, Ni, As, Hg, Cd, B, F, Br and Cyanide. (Drinking Water and Nitrate Directive)

The results of the inventory, as described above, will help in choosing the parameters

❹ Quantity measurement and sampling procedures

Groundwater levels have **to be measured in relation to a fixed reference point**. The observed level data from the wells should be written on special forms and mailed to the institution involved.

Consideration needs to be given to the degree to which the measured water level is representative of the actual hydraulic head conditions. For example, where groundwater abstraction occurs, the influence of this pumping on groundwater levels should be taken into account. **In confined or multi-layered transboundary aquifers, the construction of clusters of monitoring points at different depths should be envisaged. This may also apply to quality networks.**

Sampling procedures vary, depending on which parameter or group of parameters is to be measured. Some parameters, like temperature, pH, Dissolved Oxygen (DO) and Electrical Conductivity (EC), can be measured directly in situ. Other parameters have to be analysed in the laboratory. In this case samples have to be taken and must be transported, sometimes under special conditions. When a large suite is required, several samples may be necessary, each stored in a different type of container and using a different preservation technique.

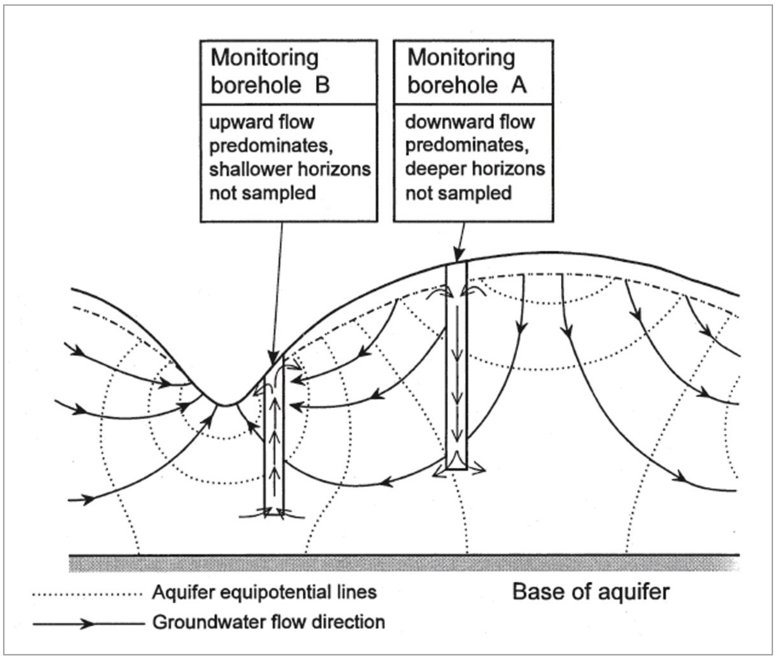

Figure 7: The effect of vertical flow components on fully-screened or open monitoring boreholes (After Foster and Gomes, 1989).

Water samples can be drawn from wells, abstraction boreholes and/or from observation boreholes. Samples of raw water from boreholes or springs operating more or less continuously at relatively high discharges can provide reasonable aggregate samples of water quality, especially if the boreholes more or less fully penetrate the aquifer and are screened through a significant proportion of its thickness (figure 7).

These samples are less representative if there are vertical variations in groundwater chemistry. A water sample drawn from an abstraction borehole can also be a variable mixture of the groundwater which has entered the screened or open section of the borehole, which can be quite long. In this case water is drawn from a considerable thickness of the aquifer or perhaps more aquifers. Discharge samples from this type of borehole may be an insensitive indicator of possible deterioration in groundwater quality arising from activities on the land surface.

Another problem of sample representativeness is related to the borehole itself when it is situated in groundwater recharge or discharge areas with significant vertical components of groundwater flow.

The collection of groundwater samples in monitoring wells must be taken in two steps:

- **the first step is to remove standing water from the well:** a powerful electrical pump can be used, but the pumping capacity has to be adapted to the hydrogeological conditions. In general, the lowering of the groundwater level may not exceed 2 metres or more than 10% of the thickness of the saturated zone of the aquifer. For the sample itself a small pumping rate is usual to prevent air getting in. The pump is lowered into the well down to the screen, but still above it (to avoid damage to the pump with sand input but also due to well hydraulics). The removal of standing water must be controlled by measuring pH value, groundwater temperature and/or electrical conductivity.

- **the second is to take the sample itself:** samples should be taken when these parameters have stabilised.

Samples for inorganic analysis should usually be filtered before preservation to remove suspended particulate matter, which could dissolve when acid preservatives are added, causing distorted values of solution concentration.

Riparian countries (Mali, Niger, Nigeria) **should agree on standard methods of sampling.** Sampling should be carried out by trained staff. The chemical analyses should be performed by licensed laboratories.

❺ Frequency of sampling and quantity periodicity measurements

Sampling frequencies in groundwater quality monitoring programmes are usually based on budgetary and resource considerations, as well as on strategies. However, there are also scientific and technical considerations. Sampling frequency has hydrological and hydrogeological dimensions (table 5).

The hydrological dimension implies the possibility of seasonal variations in some quality parameters. Groundwater recharge occurs seasonally. The onset of recharge may produce increased leaching of solutes from the land surface and (or be followed by) greater dilution. Seasonal considerations may also be important in relation to parameters whose use is strongly seasonal, for example agricultural and non-agricultural pesticides.

Observation frequencies for groundwater levels depend largely on groundwater fluctuation, which is determined by the hydrogeological situation (type and depth of the aquifer), hydrological circumstances (meteorology) and human impact (groundwater abstractions, induced recharge, return flow from irrigation, surface water level control). Some specific factors to be considered are:

- the frequency of measurement should be adjusted to the temporal fluctuation of the levels and the required accuracy in identifying fluctuation patterns;
- monitoring long-term variations and trends requires a relatively low frequency of observation, whereas accurate identification of seasonal fluctuations demands a higher frequency;
- network design should be tailored to the relevant set of objectives and the design criteria must be appropriate, given the available funds.

In practice, a wide range of frequencies is used, from once a year through twice a month to continuous monitoring.

❻ Statistical methods

For network design, there are several approaches and statistical methods (Loaiciga et al., 1992). Two general areas can be identified:

- **representativeness:** to optimise the network to ensure the hydrogeological complexity and quality variables are adequately represented;
- **reliable assessment:** to give guidance on the required sampling frequency to detect changes in the mean concentration of any parameter over time.

❼ Indirect methods of groundwater quality monitoring

In some circumstances, for specific objectives and parameters, indirect methods of monitoring groundwater quality may be used as follow:

- the use of **fluid conductivity logging** in observation wells to monitor the three-dimensional development of saline intrusion is a case in point.

- the use of **geophysical methods** is most effective where groundwater quality differences are sufficiently big to cause physical contrasts, i.e. well logging. The measurement of ground resistivity by surface geophysics may be used in some hydrogeological situations to assess the lateral spread of salinity through an aquifer.
- the use of **soil gas detection methods**, for point source pollution involving volatile hydrocarbons, may provide a cost-effective means of studying the development of a contaminant plume.

Both of these indirect methods depend, as all such methods do, on adequate control being provided from some direct sampling by investigation drilling and the construction of permanent monitoring points.

8 Costs

Existing monitoring sites or production wells located in the transboundary aquifer should always be considered at the initial stage of the monitoring programme, in particular for groundwater sampling purposes. Where possible, publicly owned wells should be selected to ensure continuity of access.

Considering the financial aspects of network design, **a distinction can be made between capital, sampling and analytical components**.

For groundwater quantity networks (table 8) in general the capital costs and the sampling (observation) costs will be somewhat lower than for groundwater quality networks. The processing on groundwater observation data (levels), like verification and quality control, is considered part of data management. So, in this case there are no analytical costs.

Improving groundwater quantity monitoring has major observation costs implication if a higher density of measuring points and a higher measuring frequency are needed. The extra data management costs are relatively modest in comparison with measurement costs.

Cost component	Measuring points		Measuring frequency
	Type	Density	
Capital cost	major influence	major influence	negligible influence
Observations cost (measurements)	minor influence	major influence	major influence
Data management cost	negligible influence	minor influence	minor influence

Table 8: Influence of groundwater quantity network design on monitoring costs.

Improving groundwater quality monitoring (table 9) has major capital cost implications only if significant numbers of newly constructed sampling points are required to replace unsuitable points or to provide additional coverage. In comparison, capital cost requirements for additional sampling pumps or field equipment are relatively modest. There always needs to be some long-term capital cost provision to keep up with developments in instrumentation and to meet ever-lower detection limit requirements.

Specific design requirements for different monitoring types

Different monitoring and assessment strategies often mean different monitoring networks and monitoring programmes. In developing monitoring programmes for transboundary aquifers, the

Cost component	Sampling points		Sampling frequency	Choice of parameters
	Type	Densité		
Capital cost	major influence	major influence	negligible influence	minor influence[1]
Sampling cost	minor influence	major influence	major influence	minor influence[2]
Analysis cost	negligible influence	major influence	major influence	major influence

[1] May have some influence on instrument requirements in laboratory.

[2] Introduction of field parameters increases sampling costs.

TABLE 9: Influence of groundwater quality network design on monitoring costs (Chilton and Milne, 1994).

purpose and requirements of each monitoring programme should be established and agreed upon by the riparian countries.

➊ Basic/reference monitoring

For basic/reference monitoring, a basic network should be installed or existing networks can be sampled. The measuring and sampling points act as reference stations and are regularly monitored at moderate intervals. **The frequency of monitoring** is about one to **four times a year**, depending on the characteristics of the aquifer. In an unconfined aquifer the measuring and sampling frequency will be higher than in a confined aquifer. Also, the density of this type of network is moderate. The parameters to be sampled are normally the field parameters and major ions (table Parameter suites for groundwater quality assessment related to some problems and functions/uses) but they also depend on the targets, land use and the type of well. For transboundary groundwaters, riparian countries should agree on the objectives and the resulting consequences for the network design.

➋ Monitoring linked to functions and uses (compliance)

The density of the networks and the sampling frequency depend on the functions and uses of the groundwater. One example is the quality-assurance monitoring of drinking water supplies, involving periodic sampling of public wells to determine whether drinking water standards are met. As for drinking water supplies, each function has its own standards.

➌ Monitoring for specific purposes

The density of the network and the frequency of measuring and sampling will often are higher than of the previously mentioned monitoring networks and are closely related to land use and the type of aquifer. In a transboundary context, this type of monitoring requires close cooperation between the riparian countries.

➍ Early-warning and surveillance monitoring

Early-warning and surveillance monitoring activities are mostly performed at a local level and have a higher density than the basic or reference networks. The sampling and observation frequencies are often somewhat higher too. Specific parameters have to be sampled, depending on the threats and land use.

The basic rules for a successful monitoring programme are as following:

- the objectives must be defined first and the programme adapted to them and not vice versa (as is often the case with multi-purpose monitoring). Adequate financial support must then be obtained;
- the type and nature of the aquifer must be fully understood (most frequently through

preliminary surveys), including the spatial and temporal variability within the aquifer. Very helpful information sources are maps of an appropriate scale (e.g.: 1:200.000) of the transboundary aquifer concerned:

- hydrogeological and vulnerability map of the area (if it exists);
- isoline maps of the aquifers' underlying and overlying geologic formations;
- maps of changes in groundwater levels;
- maps and lists of the hydrogeological boreholes (characteristic profiles and hydrogeological parameters), monitoring wells (with their basic data), significant groundwater abstractions (wells or well fields), location and abstraction data, and wells of regular water quality sampling (list of parameters);
- all isotope data concerning the age and origin of the groundwater (example for Niger River inner delta);

- the appropriate well type (or spring) must be chosen (or spring);
- the parameters, type and frequency of measurements and sampling, and the locations must be chosen with respect to the objectives;
- the analytical field equipment and the laboratory and data analysis facilities (e.g. models) must be selected in relation to the objectives and not vice versa;
- a complete and operational data treatment scheme (DAP = Data Analysis Protocol) must be established;
- groundwater monitoring should be coupled with surface water monitoring when applicable;
- the quality of the collected data must be regularly checked through internal and external control. The data should be given to decision makers, not merely as a list of variables and their concentrations or levels, but interpreted and assessed by experts with relevant recommendations for management action (such as indicators or indices);
- the programme must be evaluated periodically, especially if the general situation or any particular influence on the groundwater flow system has changed, either naturally or by measures taken.

II.2.5. Data management

Monitoring data collected by riparian countries in transboundary aquifers should be comparable, available for integration with information from a variety of sources and easily aggregated spatially and temporally.

Data produced by groundwater monitoring programmes should be validated, stored and made accessible. The goal of data management is to convert data into information that meets the specified information needs and the associated objectives of the monitoring programme.

Data management steps

Collecting and processing data is expensive. The key aspects are collecting the right data in a quality-controlled manner, using the appropriate statistical tools and techniques and communicating the messages in a timely and understandable fashion. Although these appear to be simple requirements, they are not often met and require considerable investment in knowledge and equipment to ensure the desired return on the investment in data collection. Riparian countries had already harmonised monitoring methods and agree on standard forms.

To safeguard the future use of the collected data, several data management steps are required before the information can be properly used:

- data should be analysed, interpreted and converted into defined forms of information using appropriate data analysis techniques;
- collected data should be validated or approved before they are made accessible to any user or entered into a data archive;
- information should be reported to those who need to use it for decision-making, model validation, management evaluation or in depth investigation. The information should also be presented in tailor-made formats for different target groups (e.g. GIS maps are easily accessible);
- data and information necessary for future use should be stored, and the data exchange should be facilitated not only at the level of the monitoring body itself, but also at all other appropriate levels (international, aquifer, etc.).

Data dictionary

The first archiving of monitoring data generally takes place at the monitoring agencies in each riparian countries. Transboundary cooperation will involve the exchange of data, especially when modelling is used in joint assessments. Then databases should be harmonised to the necessary extent.

To facilitate the comparability of data, strict and clear agreements should be made on the coding of both data and extra-data. If data are to be stored, attention should be given to standardised software packages for data management, and to data storage formats to improve the possibilities for data exchange.

Furthermore, agreements regarding the availability and distribution of data may facilitate the data exchange. A **data dictionary** containing this information and agreements on the definitions of terms used for the exchange of information or data **should be agreed and jointly drawn up**.

Data validation

Nevertheless the quality control of separate procedures (well drilling, sampling, analysis), data validation should be an intrinsic part of data handling. The regular control of newly produced data should include the detection of outliers, missing values and other obvious mistakes (mg/l versus µ/l). Computer software can help to perform the various control functions, such as correlation analysis and application of limit pairs.

Where the data have been thoroughly checked and the necessary corrections and additions made, the data can be approved and made accessible.

Data storage and extra-data

To be available for future use, data should be stored in such a manner that they are accessible and complete with respect to all the conditions and qualifiers (e.g. detection limits) pertaining to data collection and analysis. Information on the dimensions and units (NO3-N or NO3) should be stored.

Furthermore, a sufficient amount of extra data, which is necessary for interpretation, has to be stored. Characteristics regarding place and depth of sampling, type of observation point, preconditioning and analytical techniques are commonly stored.

The huge amounts of data collected from groundwater monitoring networks are preferably **stored in relational databases**, which should be **the cornerstone of an integrated Geographical Information System** (GIS). Although stored in a well-designed database, an information system is needed to manage, retrieve and visualise the stored data in such formats as maps, graphs, diagrams, and reports. Graphical interfaces will make the information management system more user-friendly as knowledge of the physical structure of the database is no longer necessary. GIS can act as a shell around the database.

Within the IAS project, the information and the data collected in Mali, Niger and Nigeria (climatology, hydrology, geology, hydrogeology), allowed to set up a common Information System made up of Database and a Geographical Information system (GIS). The database has nearly 17 200 water points where 740 in Mali, 16 170 in Niger and 300 in Nigeria (figure 8).

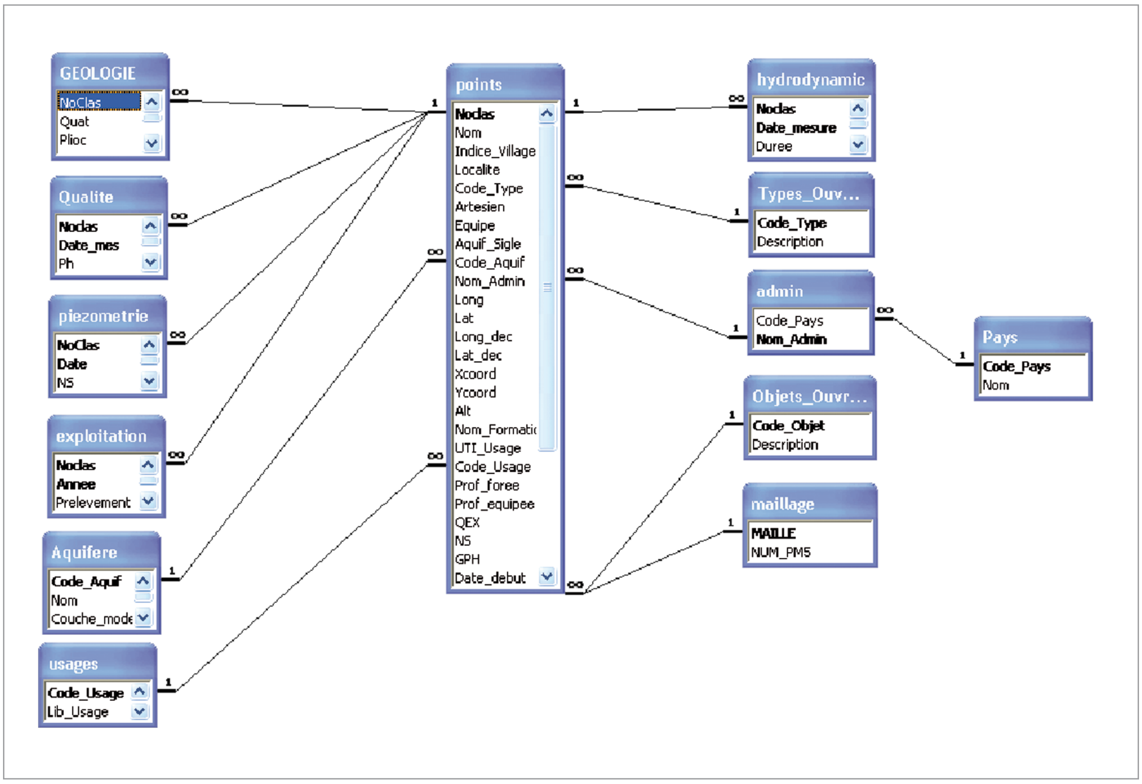

Figure 8 : The Structure of IAS Database.

The GIS allows to better visualize information and to facilitate its treatment due to the thematic maps produced like the maps of decennial evolution of the number of water points (figure 9), the piezometric maps and the maps of the hydrodynamic parameters of the system.

It is essential that any database system is safeguarded against the entering of data without proper extra-data. Often joint modelling by riparian countries has to be performed and this requires agreed upon digital data exchange formats.

▸▸▸ Data analysis and data interpretation

The conversion of data into information involves data analysis and interpretation. The data analysis should be embedded in a Data Analysis Protocol (DAP) which clearly defines a data analysis strategy and takes into account the specific characteristics of the data concerned, such as missing data, detection limits, censored data, data outliers, non-normality and serial correlation. The adoption of DAPs gives the data-gathering organisation or joint body certain flexibility in its data analysis procedures, but requires that these procedures should be documented.

In general, data will be stored on computers and the data analysis, mostly a statistical operation, can make use of generic software packages and/or GIS. To achieve standard automated data analysis, the use of tailor-made software is recommended. A DAP should comprise procedures

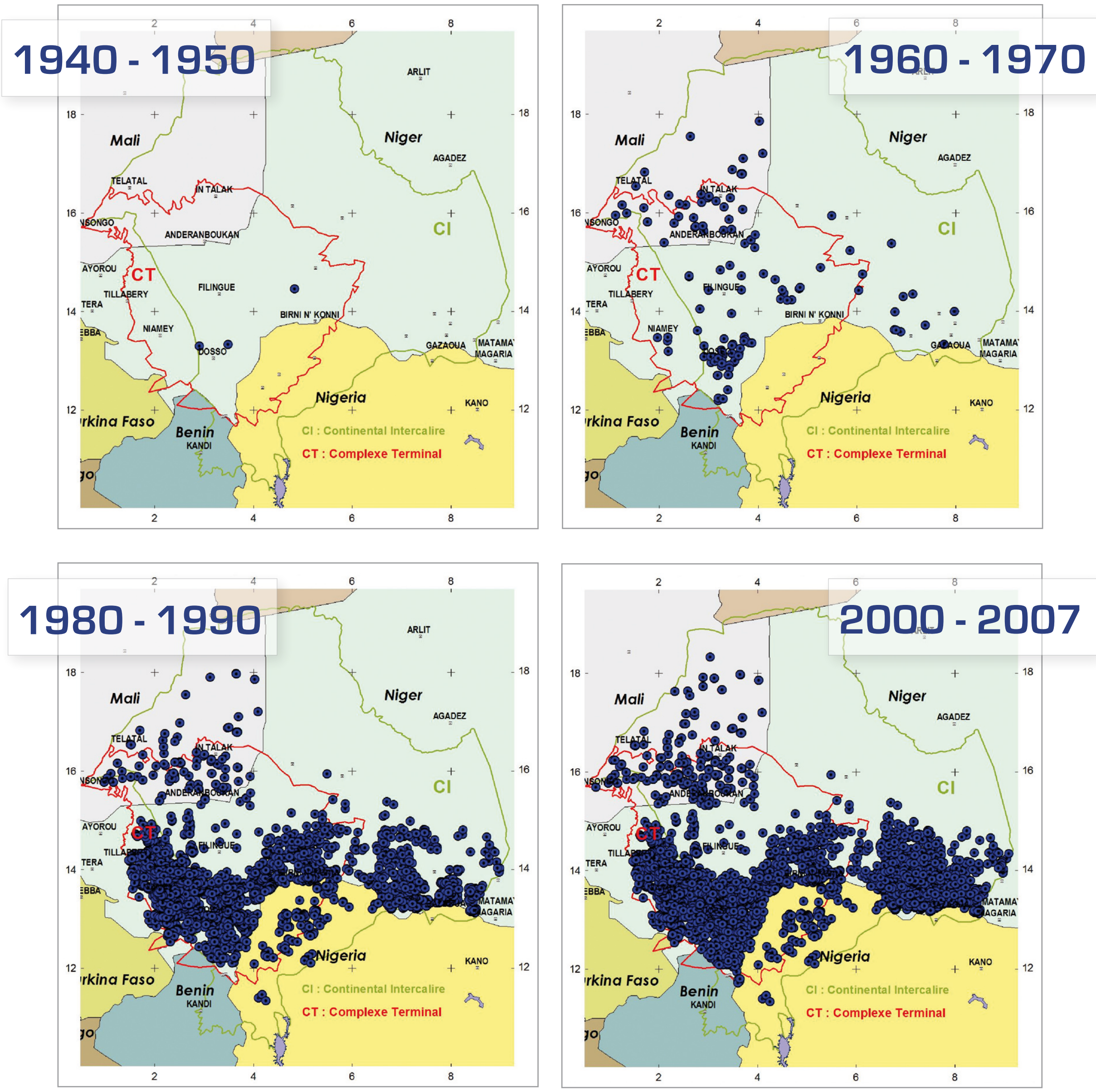

Figure 9 : Map of distribution of water points carried out per decade in IAS.

for processing the monitoring data in order to meet the specific needs for data interpretation (e.g. calculations based on individual measurement data or yearly averages, and statistical techniques used to remove non-relevant deterministic influences). Such procedures should also include accepted methods for trend detection and testing for compliance.

▸▸▸ Data exchange

A standard (or format) was elaborated for the purpose of exchanging digital data. The data dictionary should be the basis for the definition of such a standard or format. Data storage systems of riparian countries should be able to handle the agreed data exchange format and ideally allow data to be imported into modelling or analysis packages. For storage purposes, a common system could be envisaged, under the coordination of a joint body (Coordination Unit of the consultative mechanism).

▸▸▸ Reporting

The DAP may be extended to reporting formats for the resulting information (e.g. GIS maps).

A reporting protocol can help to define the different characteristics for each use or audience and should include certain Guidelines regarding frequency of production, information content/ detail and presentation format. Monitoring objectives should always be presented as part of the reported information.

Standardisation of reports and maps is encouraged for each transboundary aquifer. Reliable reports from riparian countries describing the state of their transboundary groundwaters as regards safe human uses and ecological functioning will require improvements in data comparability (e.g. standardisation of well drilling, sampling and modelling), and the development of a DAP.

Reporting information is the final step in the data management programme and links the gathering of information to the information users. To distribute the information, reports should be prepared on a regular basis. The frequency and the level of detail depend on the use of the information. Technical staff will need detailed reports more frequently than policy makers. It is recommended that (annual) state reports should be provided for each transboundary groundwater system to focus on the link between policy measures (societal response) and the state of the groundwaters concerned.

A wide reporting which would cover all identified transboundary groundwater aquifers of the riparian countries is also recommended (e.g. every three years) to encourage the evaluation of progress made, stimulate commitment of the members involved, and make results available to the public.

III. CONCLUSION AND RECOMMENDATIONS

During the regional seminar (Rome, 19 –20 October 2006), Mali, Niger and Nigeria reached a clear consensus on the need for, and on the structure and mandate of, the consultative mechanism, and on the approach to be followed for its establishment. Countries approved an amended outline of the Memorandum of Understanding concerning the mechanism that will be submitted to the competent authorities.

In this Memorandum of Understanding, include monitoring and assessment of transboundary groundwaters in the activities. Riparian countries should, where appropriate:

- assign to the joint body the task of transboundary groundwater monitoring and assessment;
- make the joint body responsible for assessing the effectiveness of the agreed measures and the resulting improvements in groundwater management.

In general, the tasks of joint bodies include the following:

- collect, compile and evaluate data in order to identify pollution sources likely to cause transboundary impact;
- develop joint monitoring programmes concerning water quality and quantity;
- draw up inventories and exchange information on the pollution sources mentioned above;
- establish emission limits for waste water and evaluate the effectiveness of control programmes;
- elaborate joint water-quality objectives and criteria for the purpose of preventing, controlling and reducing transboundary impact, and propose relevant measures for maintaining and, where necessary, improving the existing water quality;
- develop concerted action programmes for the reduction of pollution loads from both point sources (e.g. municipal and industrial sources) and diffuse sources (particularly from agriculture);
- establish warning and alarm procedures;
- serve as a forum for the exchange of information on existing and planned uses of water and related installations that are likely to cause transboundary impact;
- promote cooperation and exchange of information on the best available technology as well as to encourage cooperation in scientific research programmes;
- participate in the implementation of environmental impact assessments relating to transboundary water, in accordance with appropriate international regulations;
- where two or more joint bodies exist in the same catchment area, they shall endeavour to coordinate their activities in order to strengthen the prevention, control and reduction of transboundary.

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Iullemeden Aquifer System

Volume V – Monitoring & Evaluation of Transboundary Risks

The study of hydrogeological risks of the Iullemeden Aquifer System (IAS) shared by Mali, Niger and Nigeria powered the countries with essential assets for coordinated and concerted water resource management. This action strengthens their capacities and provides to them available common tools: a Database, a Geographic Information System and a Mathematical Model. Countries have adopted the creation and establishment of a consultation mechanism to sustain the achievements and work towards integrated, coordinated and sustainable SAI water resources.

After updating knowledge of the system, it is necessary to establish a monitoring network of aquifers. However, there is still no reference piezometric network across the entire basin that can monitor and assess water resources in term of quantity and quality, to alert the decision makers to control and mitigate transboundary risks or impacts on their common resources.

This paper is a methodological guideline for officials responsible assigned for managing water resources to implement network(s) for monitoring and assessment of transboundary aquifers of the IAS that will strengthen cooperation between riparian countries jointly exploiting the resource.

It is strongly inspired by the methodology developed by the European Economic Commission (EEC) on strategies for monitoring and evaluation of transboundary groundwater. It also draws on experiences and lessons learned from the study lead by OSS on the North Western Sahara Aquifer System shared by Algeria, Libya and Tunisia. The approach and steps to monitor and evaluate groundwater aquifers is widely developed

- Volume I: Transboundary Diagnostic Analysis
- Volume II: Common database
- Volume III: Hydrogeological Model
- Volume IV: Participatory management of transboundary risks

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