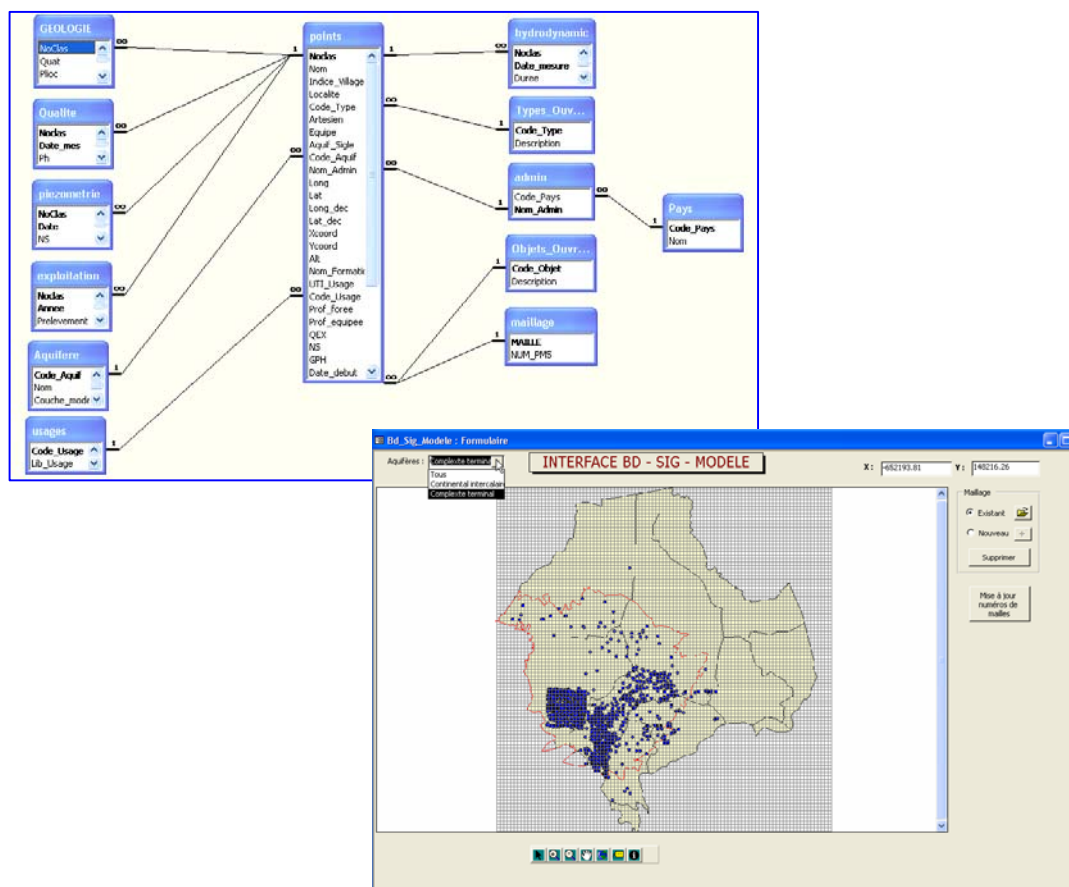




# OBSERVATOIRE DU SAHARA ET DU SAHEL SAHARA AND SAHEL OBSERVATORY

## Project: Management of hydrogeological risks in the Iullemeden Aquifer System



**A COMMON DATABASE OF THE IULLEMEDEN AQUIFER SYSTEM (IAS)**

December 2007

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## LIST OF ACRONYMS AND ABBREVIATIONS

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TDA	Transboundary Diagnostic Analysis
DWS	Drinking Water Supply
IAEA	International Atomic Energy Agency
DB	Database
IC	Intercalary Continental
TC	Terminal Complex
DRE	Water Resource Department (Niger)
DRHE	Regional Water and Energy Department (Mali)
ESRI	Environmental Science Research Institute
GEF	Global Environmental Facility
IRH	Water Resource Inventory (department related to DRE)
CDM	Conceptual Data Model
DTM	Digital Terrain Model
DAT	Decision Aid Tool
ODBC	Open Database Connectivity
OSS	Observatory of Sahara and Sahel
PM5	Processing Modflow Version 5
UNEP	United Nations Environment Programme
DAI	Decision Aid System
IAS	Illumedden Aquifer System
SAP	Strategic Action Plan
NWSAS	North-Western Sahara Aquifer System
DBMS	Database Management System
SI	Information System
SIG	Geographic Information System
SRTM	Shuttle Radar Topography Mission
UNESCO	United Nations Educational, Scientific and Cultural Organization

## PREAMBULE

In the case of original information and diversified formats, the hydrogeological data represent a means of systematic harmonization. This is particularly the case of transboundary aquifer systems whose data are collected in countries sharing the same aquifer system. In this sense, the Illumedden Aquifer System (IAS) is a typical case to establish a common hydrogeological database.

The document aims at recording the undertaken activities within the framework of the project on 'Management of Hydrogeological Risks in the Iullemeden Aquifer System' (IAS), initiated by UNEP (GEF), UNESCO, the basin-sharing countries, i.e. Mali, Niger, and Nigeria, to establish a common database that can be used to elaborate an IAS hydrodynamic model. This specific activity has been translated into many workshops, with the contribution of the project's national teams, as well as the international consultants involved in elaborating the database and the hydrodynamic model in question.

Drafted by a restricted team made up of A. Mamou, M. Baba Sy, B. Abdous and A. Dodo, the report has the duty of reflecting the extended contribution of the mobilised team during the data preparatory phase for the IAS aquifer system modelling, through data collection, the drafting of specific reports, and participation in the meetings and the workshops on the aspects processed by the modelling.

▪ **Meetings and workshops dedicated to Databases or having led to data collection:**

- 
- OSS-IAEA (2004): Workshop on elaborating a common database for the three countries (Mali, Niger, Nigeria), Tunis, from 26 to 30 April 2004 at OSS, with the participation of experts from the three countries (two per country), the CITET Centr-Tunis, OSS, and an international consultant in charge of database structure design.
- OSS- IAEA (2005): Training workshop on elaborating the IAS Database, Niamey. 26 April - 06 May 2007 at the AGRHYMET Regional Centre (CRA), with the participation of country experts (two per country), AGRHYMET Centre, and OSS.
- OSS (2006): Meeting of the IAS Project Steering Committee (Abuja-Nigeria, 25-26 February 2006) in which it was decided to entrust OSS with the task of elaborating a common database, knowing that AGRHYMET had been late in developing the database.
- OSS (2006): Training workshop on modelling and the required data collection: Mastering the IAS modelling tool. Tunis, 18-28 April 2006. Participation of experts from the three countries (two per country).
- OSS (2006): Workshop on Model Analysis: Data analysis and discussion of the preliminary model's results. Tunis, 29 November - 08 December 2006. Participation of experts from the three countries (two per country).
- OSS (2007): Workshop on model validation and the establishment of links between the common database and the IAS mathematical model, with an analysis of the model's results. Tunis, 01 to 10 March 2007. Participation of international consultants in improving the database structure as built by the OSS team, and establishment of links with the model.

▪ **Produced intermediate technical documents:**

- Maïga S. & Bouaré D., (2006) : Collecte des données hydrogéologiques du Système aquifère d'Iullemeden dans la partie malienne. OSS, décembre 2006, tableaux, annexes.
- Moumouni Moussa A. & Rabé S., (Janvier 2007) : Collecte des données hydrogéologiques du Système Aquifère d'Iullemeden dans la partie nigérienne. OSS, Janvier 2007, 12 p., tableaux, annexes.
- OSS (2004) : Rapport de l'atelier sur l'élaboration d'une Base de Données commune aux trois pays (Mali, Niger, Nigeria) ; Tunis, du 26 au 30 avril 2004 à l'OSS.
- OSS-AIEA (2005): Rapport de l'atelier de formation sur l'élaboration de la Base de Données du SAI ; Niamey, du 26 avril au 06 mai 2005 au Centre Régional AGRHYMET (CRA).

▪ **Expanded team participating in the IAS database elaboration:**

- Malian national team: Damassa Bouaré (In charge of the database at the National Hydraulic Department & Seïdou Maïga (National focal point at the National Hydraulic Department).
- National team of Niger: Abdou Moumouni Moussa (National focal point and Head of the Hydrogeological Department at the Water Resources Department) & Seïdou Maïga (National focal point at the National Hydraulic Department).
- Nigerian national team: John Chabo (Federal Director of Hydrology and Hydrogeology at the Federal Ministry of Water Resources) & Stephane Jabo (Federal Director Assistant).
- OSS team: A. Mamou (Expert hydrogeologist), M. Baba Sy (Expert hydrogeologist); and A. Dodo (Project coordinator).
- International consultants: B. Abdous (Database consultant) and G. Pizzi (Hydrogeological model consultant).



## Some definitions

**Information system (IS):** A set of elements that are dynamically interacting and organised in relation to an objective.

**Information system database (DB):** A structured and computer-managed collection of information relating to a specific domain. A database is governed by a model and should meet a number of specificities:

- Full independence between data and processing.
- No redundant information.
- Data integrity and coherence

**DBMS:** Software for manipulating, managing and using a database. Most of the DBMSs available on the market are relational, i.e. based on the set theory and consisting of all the relational algebraic operations (union, join, intersection...)

**Design approach:** The database design process is generally subdivided in three stages: the design stage leading to the data model definition, the logical implementation stage and the operation stage with a machine and the selected DBMS.

**Design tools:** The generalisation of relational databases led to devising design methodological tools which make it possible to set up performing and long-lasting systems since they are based on the mastery of basic information. These tools have operation rules, a formalism and sometimes even support software to facilitate data model elaboration.

**Data model (conceptual model):** A highly intellectual tool used for the representation of the real world through managed information and interrelated links. Such tools provide a graphic schematisation to better symbolise the representation.

**Relational model:** Developed by the end of the 1970s to secure:

- Total independence between data and processing: sustainable and open systems.
- Data access through high-level nonprocedural languages.
- User views may differ from the established ones. Each user may have his own view of the database objects.

**Entity:** This is an information system object with features. It is also referred to as an individual or an object. In our case a water point is an entity.

**Relation: (or Association):** A link which may exist between two entities and reflects the management rules into force.

**Property or (attribute):** Elementary information run by the information system. It is linked to an entity and sometimes to a relation. The name, the altitude and the coordinates of a water point are properties.

**Identifier:** particular property which makes it possible to identify in a single way an entity. The number of classification of a water point is an identifier.

**Table:** data referring to a particular subject. A table represents an essential object of a data base ACCESS where the data are stored. The table "*points*" contains the characteristics of the water points. A well informed table contains several recordings (lines).

**Request:** it is the object of a base ACCESS which is used for posting, modifying or analyzing the data coming from one or more tables.

**Form:** a form is before a whole tool making it possible to seize with the keyboard of the data which are immediately introduced into one or more tables. The form is thus *related to one or several tables, and it inherits their properties*: types of data, properties of the fields.

**Linked table (or attached):** table being in another data base (that it is of type ACCESS or other).

**Field:** element of a table being used to contain information. A table comprises one or more fields (columns).

**Primary key:** single identifier of each line of a table. A key can be either a field, or a concatenation of several fields.

**Referential integrity:** it is the mechanism which preserves the relations defined between several tables when recordings are modified or erased. The referential integrity guarantees the coherence of the values of keys between the tables.

## 1- INTRODUCTION

### 1.1- Project context and historical background

The 'Management of Hydrogeological Risks in the Iullemeden Aquifer System' project (IAS), mainly initiated by UNEP (GEF) and UNESCO in the basin-sharing countries (Mali, Niger and Nigeria) adopted the 'Transboundary Diagnostic Analysis' (TDA) to investigate the state of aquifers and the hydrogeological risks they are confronted with. Such analysis led to the establishment of a 'Strategic Action Programme' (SAP).

From the outset, the analysis of aquifer water resources and usage environments proved to be highly dependent on the available knowledge in the three countries about the aquifer hydrogeological functioning and the way it is used. Yet, so far this knowledge has been the business of the countries. It is presented according to a large national vision marked by shortcomings and gaps resulting from targeted interest and modest allotted means.

The project itself pays little attention to this aspect which is related to the activity that should be led by IAEA for a better knowledge of the IAS transboundary zones. However, the IAEA activity could not develop as planned to accompany the TDA in its progress towards a SAP. In addition, the IAEA vision of the database to be set up is rather intimately linked to the usage which we are expected to make of the data, in the isotopic data interpretation, in order to explain the hydrogeological risks that aquifers face. Indeed, the hydrogeological information on the IAS aquifers, as it appeared, in light of the TDA initial evaluations, should be more extended and profound to account for the work of the aquifer system as well as its reactions to the recharge conditions or operation, and the climate changes (regular droughts) recorded in the region.

On the basis of the TDA initial evaluations (Steering Committee meeting in Abuja, 25-26 February 2006), it was decided to substantially reinforce the hydrogeological knowledge of the IAS aquifers, with the aim of securing a better quantitative evaluation - if possible - of the various hydrogeological risks which the SAI aquifers face. Such reinforcement is planned through establishing an integrated geographic information system including an exhaustive database and a specific hydrogeological modelling to evaluate the water system balance and better quantify the exchanges.

Since then, the OSS, the project implementation agency, started, with the contribution of the teams of the three countries associated to the project, to carry out these two closely related tasks (Database and Hydrogeological Model) with the objective of developing decision aid tools (DAT) so as to facilitate the consultation mechanism for an optimal management of the IAS water resources.

In fact, it is clear that tools are necessary for a shared evaluation of the IAS water resources. Such tools should include the following basic items:

- A Transboundary mapping of the entire aquifer system.
- A database of all the completed, processed and harmonised information as provided by the three countries.
- A modelling using the same hypotheses relating to the aquifer system operation design.

These decision-making tools essentially rely on a perfect control of the aquifer system information:

- Database architecture amenable to updating and visualising.
- Tools of regular updating and data control.
- Decentralised system of new information collection: modules set up in the countries.

The realisation of the IAS mathematical model requires the collection, organisation and homogenisation of available data within the project's three countries. The establishment of the IAS database is an activity whose objectives are spaced out over time. At the start, the need for a water resource evaluation as recognised by the three countries made this database a supporting element for decision aid and enabled the building of the overall model. Subsequently, feeding this database with the information required for a follow-up of the aquifer and the threatening risks turned it into a cooperation facilitating tool and made it more rational. It is, then, an ongoing activity which is planned as a component of the information integrated system. After the project comes to an end in the three concerned countries, it is expected to continue cooperation on the basis of an optimal management of the IAS water resources.

In fact, it is about the gradual development of an information system that is strongly inspired by the SASS experience.

Since the project inception, the control of the new data management technologies is presented as a priority to secure a good Transboundary Diagnostic Analysis of the hydrogeological risks in the Iullemeden Aquifer System. For this reason, the first organised workshop (OSS-Tunis, 26-30 April 2004) dealt with the elaboration of a database common to the three basin-sharing countries. The organisation of this workshop, as part of the IAEA activity, was implemented by OSS with the objective of bringing in its database management and GIS experience to federate the different objectives of the partners contributing to the analysis of the IAS transboundary hydrogeological risks. To this end, we relied on the database management experts in the countries as well as AGRHYMET experience, as a regional body called upon to host the IAS information system. The workshop made it possible to:

- Identify the set of entities which should make up the information system structure including the spatial-type information.
- Adopt a common codification for the IAS database, compatible with the codification used by the countries.
- Suggest various development solutions according to the modelling software which will be selected.
- Elaborate a **strategy for existing file transfer** and manual data entry: old history files, information in study reports...

**A second workshop** was also organised on the elaboration of the IAS common database by the International Atomic Energy Agency (IAEA) at AGRHYMET (Niger-Niamey, 26 April – 06 May 2005), with the aim of completing the work initiated by the national experts to control the management of the IAS information system. During this workshop, the focus was on:

- Initiating the common Database Management System: ACCESS software.
- Designing the organisation of the common database.
- Harmonising the three countries' data: Mali, Niger and Nigeria.

By approaching the common database implementation through real IAS aquifer data, the country representatives felt the need to harmonise information to better depict the hydrodynamic behaviour of the aquifer set (Intercalary Continental, Continental Terminal and water tables). Initially planned for six months (up to November 2005) at AGRHYMET, the collection and harmonisation of country data in the IAS database could not be done because the computer scientist of that organisation left. The country data were left as received.

Given the project's timeframe for completing the other activities, and during the Steering Committee meeting (Nigeria-Abuja, 25-26 February 2006), the OSS took the responsibility of establishing the IAS information system with its own means.

The realisation of the information system generally requires three stages:

- **Phase I: Analysis of the existing information** in the three countries and selection of the organisational solution in light of the project objectives, country specific needs, and the current technological tendency (equipment and software).
- **Phase II: Information system design** and description of the computing solution chosen in collaboration with the countries: common database architecture, identification of GIS layers, codification harmonisation, definition of processing modes.
- **Phase III: Database and GIS implementation** with equipment and software installation in the countries, database and GIS implementation, transfer of existing heterogeneous data in the three countries, and team training (DBMS, GIS, spatial analysis utilities).

In its Abuja meeting, the project's Steering Committee tackled the three stages, thus allowing for the **collection of considerable information** brought together into one relational, uniform, coherent and scalable database. The database design has been made in close collaboration with the country experts associated with this activity on the basis of the required information and the storing and processing facilities available in these countries. For such purpose, the choice was mainly geared to the available tools (software) or the public sector (Excel, Access, ArcView...) or acquired within the project's framework (Processing Modflow – PM5). By focusing on the involvement of the national technical experts in charge of managing the collected data, it was relatively easy to better initiate/improve data management. The collected data in the countries come from archives or databases of the national offices in charge of water resources. A major part of these data was collected in the framework of previous national or regional studies. Their integration in the IAS common database went through a long collection-entry-validation process that the national experts mastered following the two launching workshops and a regular contact with the OSS team in charge of the operation. The parallel elaboration of the IAS common database and the hydrogeological model made it possible to ensure information validity, fill the gaps as the two activities progressed, and better target the searched information.

The established geographical information system is completed with user-friendly exploration and entry tools, synthesis requests, and procedures of new information additions.

Data analysis tools were also elaborated in order to facilitate anomaly and incoherence detection and provide relevant valid information to the digital model. These tools allow the elaboration of processed information in request form, statistical processing and geo-referenced thematic analyses thanks to digital maps elaborated in the framework of the project and covering the whole basin.

The operation of the developed tools constitutes a good storage media for the IAS project information. Similarly these can be later used as information sharing and decision aid tools.

Contrary to previous studies focused on the part of the basin in the country limits, this IAS study has many data sources which were used to feed the common databases.

The database resorted to different data processing types '**to secure its coherence**'. By means of well-defined procedures, the processing is made in the same manner and, therefore, with a good level of **reliability**. The elaborated database facilitates the use of information in the framework of the project and ensures a greater **flexibility** of use, making the handling of such an important information volume plausible and easier.

## 1.2- The SASS project experience

Thanks to the experience acquired from the elaboration of the SASS database, the time allocated to developing the IAS common database was relatively short. In fact:

- All the conceptual part was unnecessary: the Conceptual Data Model (CDM) elaborated during the SASS project was adopted.
- The data collection formats have been harmonised among countries since the beginning.
- The processing tools (entry and display interfaces, link modules with PM5, DB – model links) were just adapted and enriched.
- The control of tools at the OSS level made significant time gains.

The advantage is reinforced by the fact that the used software platform, i.e. MS ACCESS and ARCVIEW is well-controlled by OSS which transmitted the knowledge to the three countries' experts.

The most important task was then essentially accomplished on the proper data:

- File formatting and codification.
- Entry of additional data not available in the country databases.
- Devising transfer requests to the database (DB).
- Formatting GIS layers.

## 2- DESIGN AND IMPLEMENTATION OF THE IAS INFORMATION SYSTEM

### 2.1- Approach presentation

The development of the IAS information system required the following stages:

- **Diagnosis phase:** A diagnosis of what is available and development orientations.
- **Design phase:** The results are the Data Conceptual Model (DCM) and the best adapted organisational and technical solution.
- **Realisation phase:** The translation of DCM into a physical model depending on the Database Management System (DBMS) selected according to the previously chosen technical solution.
- **Implementation phase:** Implementation in the adopted organisational environment after available data transfer.

**The conceptual phase** is the most important and determines the success of the other phases. During such phase, efforts were focused on properly understanding the field, elaborating a representative data model, and defining the best possible development solution.

Given the nature of the required processing, which is particularly geared towards the representation of hydrogeological, hydrological and climatological data, the geo-referenced information system to be developed in the IAS case should be capable of mainstreaming several information categories:

- Descriptive digital data.
- Spatial-referencing type of information.
- History file of measures in chronic series, with heterogeneous extension and continuity.

The system functionalities have been designed to facilitate the use of the modelling software, establish dynamic links between digital and spatial information, and automate pre-model and post-model operations to enable the team in charge of the model to multiply simulations and recuperate results.

## **2.2- Analysis of the current situation in the three countries and collected data review**

The collected and analysed climatic, hydrological and hydrogeological data in the three countries allowed identifying inconsistencies from the beginning and which were corrected thanks to the data processing (ArcView, Rockworks...). The fact that the major part of these data is without any geographical attachment (coordinates) highly limited their direct mainstreaming in the database. The identification of the water points coordinates is a tedious operation, requiring extensive cross-checking and interpretation.

The collected data used to elaborate the IAS common database is done with the objective of ensuring a hydrological synthesis to explain the hydrological functioning of the aquifer system and develop a hydrodynamic simulation model on the basis of which one can infer the system's water balance with the specification of each component.

- IAS geology and specifically the lithostratigraphic boreholes.
- Climatology, especially the recorded rainfall at the different basin stations, used to measure the aquifer system recharge (inflow).
- Hydrology, especially the history files of the Niger River flow, which constitutes a part of the aquifer system outflow.
- Hydrology of the water points capturing the different IAS aquifer system layers (piezometry, drawdown, operation flow, water salinity, transmissivity, storage coefficient...) and the history files of the measurements of different hydrogeological variables (piezometry and operation) which are used to restore the system's hydrodynamic operation in the simulation model.

This common database is likely to be extended to include other data relating to pedological, environmental, geographic and agricultural aspects insofar as it proved necessary to extend the IAS study to other specific aspects of water resources use and its impact on the environment.

The data collection of this database was made in reference to the information available to the administrations in charge of the water resources management in the three concerned countries. One section of this information is equally extracted by the project team from the studies related to the different basin's parts.

The links established between this common database and the geographic information system, on the one hand, and the IAS hydrogeological simulation system, on the other, is a further peculiarity which turns the database into a tool to integrate, process and represent information graphically and cartographically. In fact, these links are materialized by specific links operating from and to the common DB and spare efforts relating to data entry, formatting and processing at the level of IASIS and the hydrogeological model.

### **2.2.1- Mali data**

In 1985, the National Hydraulics and Energy Department (NHED) of Mali developed SIGMA, a national database, within the framework of the UNDP Mali 84/005 project. The database was used to elaborate the hydrogeological synthesis of Mali and the Master Plan for valorising groundwater resources (1991).

At the beginning, SIGMA1 was developed with software in the DOS environment: **dBase IV** for archiving, and digital and statistical processing. **Atlas\*Draw** and **Atlas\*GIS** for cartographic representations, and **LOTUS-123** for the graphic presentations of chronological data.

Between 1986 and 2001, SIGMA1 general architecture and management programmes evolved little, notably at the level of the information technology environment, which remained under DOS. The need to add new fields in the original files and create new files with fragmentary data has gradually destroyed the database structure to the extent that they no longer meet the Administration's needs for hydraulic planning.

In 2001, a development project of the database made it possible to have SIGMA2 in its current format by:

- Changing the information technology environment with the transition from the dBase IV management system (under DOS) to ACCESS (under Windows).
- Giving attention given to the new administrative division of the country.
- Restructuring the old database files into new ones.
- Entering the inventory results of the modern water points.
- Installing the last version of the database, SIGMA2, in the Regional Departments of Hydraulics and Energy (RDHE).

In 2003, the new version made it possible to elaborate the water map of Mali, which is considered as a decision aid tool, providing information on water supply to the population and the functionality of hydraulic infrastructures by region, circle, area and village/fractions. This decision aid tool was put at the disposal of local authorities and the different agents of the water sector in Mali.

Now, with the effort of the National Hydraulics Department (NHD), and in spite of some difficulties, DRHE (National Directorate of Hydraulics and Energy) updates SIGMA2 in collaboration with the regional structures and the Documentation and Computer Centre (DCC) of NHD. The last updating goes back to July 2006.

Thanks to its management software (ACCESS), the database allows for an easy passage from the data to the IAS common database. However, at the graphic level, it is still run by software which does not allow for the geo-referenced digitisation of information. It is, then, possible to partly recover the data which are archived, but to pool the data in a graphic form, it is necessary to use other software (ArcView, Rockworks...).

The database includes tables which are mainly centred on the management structures of water resources and not those specific to the analysis of physical (hydrology and hydrogeology) and

climatological (rain, infiltration, evaporation) data. As a result, it requires a full restructuring to streamline new data specific tables.

The hydro geological data necessary for the modelling of the SAI system are compiled in the synthesis studies. Their extraction was mainly done by the OSS project team

**File format and description, used codification, content analysis (missing information, inconsistencies...) and peculiarities:**

The format of the obtained files is heterogeneous and of three types: Excel, Word and ACCESS. The Excel files include hydrogeological information relating to water points, piezometric levels, hydrodynamic parameters and other operation flow values of underground water. These files include many gaps, notably missing coordinates, water points without identifier, non-informed altitudes...

The ACCESS files are four three of which are empty of data and the fourth does not open. The Word files are 16 and include descriptions of drilling logs.

The Excel files are described as follows:

<b>File name</b>	<b>Description</b>	<b>Line number</b>
ANNEXE II.1	Water point characteristics	1071
ANNEXE II.2	Characteristics of dag wells	455
ANNEXE II.3	Characteristics of dag wells	455
CLIMSTA	Characteristics of climatological stations	5
HYDSTA	Characteristics of hydrological stations	89
IRHFOR	Water point characteristics	388
IRHPTM	Caractéristiques des points d'eau	988
IRHPZO	Data on piezometric levels	61
Puits- Iullemeden_Mali	Well characteristics	802
IRHAEP	Well characteristics	14
IRHCHI	Data on water chemistry	11
IRHEss	Data on static levels	26
IRHPOM	Data on types of works	208
VILLAGES	Water point inventory	453
Villages- Illiulemeden	Water point inventory	349



Tous ces fichiers, en particulier ceux nommés caractéristiques des points d'eau peuvent contenir, en plus des informations sur leur identification, les données sur les coordonnées, les types d'ouvrage, les captages, la piézométrie et la qualité chimique de l'eau (résidu sec).

All these files, in particular those referred to as water point characteristics, may include, in addition to their identification information, data on coordinates, works types, water catchment areas, piezometry, and water chemical quality (TDS:Total dissolved salts).

### **2.2.2- Niger data**

The Ministry of Hydraulics, Environment and Desertification Combating hosts the Water Resources Directorate (WRD), the institution in charge of the resources inventory and management. The Hydraulic Resources Inventory Department (IRH) manages the water resources database within the Water Resources Directorate.

The database, known as SIGNER, was elaborated in conditions similar to those of Mali. Following the same pattern, it offers an architecture which is based on the same processing software. Here also, since the mid 1990s, the structure proved to be limited given that it was mainly oriented towards water usages and sanitation. It presents a statistical approach to highlight the serviced towns and the services system.

Quickly it underwent local modifications and was attached to the GIS to serve as storage media to SIGNER.

It lists the set of water points in Niger but does not give sufficient details on underground water hydrogeology nor the characteristics of water point outside the reached depth, flow and water table level. The database lacks history files of piezometry, operation and water table quality.

The management system initially installed on Dbase III quickly proved to be limited as a software storage medium and there was migration to ACCESS<sup>1</sup> a year ago. Its main current gap is the lack of data geo-referencing, an aspect which is in the process of being reviewed for improvement.

Thus, for structural considerations, the IRH database gradually shifted from a tool for the management of the DB water resources to a tool for the management of water at a national level with links with the IRH, without, nevertheless, being in a position to ensure the representation of the hydrogeological aspect. The IRH has a database (21708 water points) whose GIS is run by AtlasGIS. Staff training sessions are planned in order to transfer the GIS to ArcView. On its side, SIGNER processes data of the HRID database, but for applications other than the WRD ones. It has been operational since 1989. It gives value to the IRH base and allows, among other things, for grouping resources and needs. It serves as a support to the Poverty Reduction Strategy (PRS) and the Community Action Programme (CAP). As long as it is structurally dissociated from the HRID, it is difficult to conceive it as a tool capable of looking into the water resources monitoring problems.

The data review available in the IRH database shows that these are mainly hydrogeological and specifically deal with the modern water points (shaft lined wells and drillings) developed in the framework of the communal Water supply programmes. For these water points, the available information concerns rather the uses and the users and does not address the aspects relating to

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<sup>1</sup> According to Mr. BAKO Maman, a computer and GIS specialist, and a hydraulicist in charge of SIGNER management, the migration was made within the framework of the International Decade of Potable Water and Sanitation (DIEPA).

basic hydrogeological characteristics (data provided at the time of creation, history file of piezometric levels, operation and chemical composition).

As for the 'historical' aspect, the compilation of the different synthetic studies had to be made to extract the searched data and ensure its entry - a task tackled by the IAS project OSS team.

**File format and description, used codification, content analysis (missing information, distortions...) and peculiarities**

The file format is heterogeneous: Excel, Word, pdf, Dbase and jpg pictures. It brings together geological and hydrogeological data relating to water points, piezometric level history, hydrodynamic parameters, and some water table operation flow values. The identified gaps noted are of the following type: missing coordinates, water points without an identifier, missing altitudes, missing dates, and unknown hydrodynamic parameters.

The files are described as follows:

File name	Description	Line number
PEM ULLEMEDEN BASIN.xls	Water point characteristics	13431
Geology Format 2 Revised.xls	Drilling stratigraphic logs	531
Niger_CI_CT1 aquifers	Water point characteristics	125
North and South Niger rainfall data.xls	Monthly rainfall data (6 stations)	180
Hydrochemical data of Italian drillings (Il Nuovo Castoro).xls	Hydrochemical and piezometric data	604
NER009 CHEMICAL DATA FIRST CAMPAIGN.xls	Chemical data	32
NER Sample point maps.doc & RAF	Location map of chemical analysis points.	
038 Map of installed recorders		
RAF 038 CHEMICAL DATA 1st Campaign.	List of water samples withdrawn in the project zone	46
Drillings – AFD Maradi.xls	Chemical data	241
All works – AFD Maradi.xls	Waterhole characteristics	302
BASE-CH.XLS	CI aquifer geometric and hydrodynamic data	50
BASE – CH. XLS		
BASECT1.XLS	CT1 aquifer geometric and hydrodynamic data	76
BASECT1B.XLS	CT1 aquifer geometric and hydrodynamic data	67
BASE-CT2.XLS	CT2 aquifer geometric and hydrodynamic data	91
BASE-CT3.XLS	CT3 aquifer geometric and hydrodynamic data	148

File name	Description	Line number
DALMA1.xls	Piezometric fluctuations level of Dallo Maouri water table	33
DALMA2.xls	Piezometric fluctuations level of Dallo Maouri unconfined aquifer	33
DALMA3.xls	Piezometric fluctuations level of Dallo Bosso alluvial aquifer	33
korama.xls	Piezometric fluctuations level of Koramas aquifer	35
MachayaKOR.xls	Piezometric fluctuations level of Machaya alluvial aquifer	445
PiézoDANTIANDOU.xls	Piezometric fluctuations level of Dantiandou aquifer	62
PiézoMaradi.xls	Piezometric fluctuations level of Goulbi de Maradi alluvial aquifer	140
PiézoTELOUA.xls	Piezometric fluctuations level of Talloua alluvial aquifer	301
piézoZinder1.xls	Piezometric records of GOGO Zinder catchment area	451
piézoZinder.xls	Piezometric records of GOGO Zinder catchment area	156
Water withdrawals statistics.xls	Withdrawals statistics (2001-2005)	185
December 2005 production.xls	Drilling operation parameters: December 2005	179
Operation problems of the 43 centres.xls	Description of the current situation in the 43 centres	103
SAI_Niamey.xls	Water point characteristics	984
IAS_Hapex Sahel Data.xls	Water point characteristics	572
IAS_General File _Niger.xls	Water point characteristics	7725
IAS_General File Tillabery Dept.xls	Water point characteristics	3800
IAS_General File Dasso Dept.xls	Water point characteristics	2765
IAS_General File Tahoua Dept.xls	Water point characteristics	2502
IAS_General File Niger_1.xls	Water point characteristics	427
IAS_General File _Niger_2.xls	Water point characteristics	2684
IAS_General File _Niger_3.xls	Water point characteristics	2418
IAS_General File _Works.xls	Water point characteristics	9067
IAS_Confined aquifer drillings_Dosso Dept.xls	Type of tapped aquifer	1519
IAS_Confined aquifer drillings_Tahoua Dept.xls	Type of tapped aquifer	1880
IAS_Confined aquifer drillings_Tillabéry Dept.xls	Type of tapped aquifer	1246
IAS_Tillabéry.xls	Type of tapped aquifer	110

### 2.2.3- Nigeria data

Contrary to Mali and Niger, we were not aware of the existence of a national database. We have very little information on the part of the basin in the country. The collected information comes from the national archives. The operation histories are obtained by formulating hypotheses and using the 2004 population census data of the main areas located in the basin.

### **File format and description, used codification, content analysis (missing information, inconsistencies...) and peculiarities**

The file format is heterogeneous. It brings together geological and hydrogeological data relating to water points, piezometric level history, hydrodynamic parameters, and some water table operation flow values. The identified gaps noted are of the following type: missing coordinates, water points without an identifier, missing altitudes, missing dates, and unknown hydrodynamic parameters.

The files are described as follows:

File name	Description	Line number
SAI_Nigeria_Boreholes.xls	Hydrogeological and hydrochemical data on waterholes	153
JICA Coordinates seeking.xls	Hydrochemical boreholes data.	95
JICA Sokoto 1990.xls	Piezometry 1988-1989; some hydrodynamic parameters; some withdrawals data.	64
Nigeria Data Boreholes IAS.xls	Isotopic data and boreholes characteristics.	25
SAI_Nigeria_Boreholes.xls	Boreholes characteristics; some piezometric values.	30

It is, then, clear that the water resources data of the three countries is found on information supports within their respective offices. Such information is inadequate to the tasks expected from the IAS project. The major part of these data is not streamlined in the national database. When data are available, they include only one part of the information whose formatting is only partially exploitable. The other data, essentially in the form of graphic documents, require some compilation, entry and verification before streamlining them in the IAS common database. The archived data are heterogeneous, incomplete, and mostly inadapted. The supports of these databases do not at all facilitate the exhaustive information recovery and streamlining in the common database. An updating operation of the supports should be made prior to developing new data in view of having perfectly operational information.

### **2.3- Additional information collected during the project**

The hydrogeological data required for modelling the IAS aquifer system are compiled in the synthesis studies. The OSS project team mainly extracted the information.

Several sources of information were used for data collection:

- National DB of boreholes characteristics (DB-HRID in Niger and SIGMA2 in Mali)

- Excel files containing data deriving from the compilation of national data by the country experts involved in the task of data collection (2).
- Manual entry of archival data (notes, reports, published scientific work, new academic work, technical documents, etc.) by the national experts and the OSS team, specifically in relation to operation history, piezometry, water chemistry as well as hydrodynamic characteristics and geological data related to oil drilling and boreholes, which are missing in the DB of these countries.

### **2.3.1- Geological data**

Several published logs and borehole cross-sections were used to contribute to the definition of aquifer geometry and system design.

### **2.3.2- Other data from study documents**

These are hydrogeological data that are essentially related to water level, operation, chemistry and hydrodynamic parameters (transmissivity, storage coefficient, permeability).

### **2.3.3- Inconsistencies and shortcomings**

#### **2.3.3.1- Abstractions**

The 'Abstractions' table could not be sufficiently fed with specific data (yield, date) as expected. This was due to the lack of a history of flow measurements or the volumes used for a specific usage (water supply, irrigation, livestock, and industry). The main inconsistency in monitoring the IAS aquifers makes model levelling relatively tedious, given that we have to use cross-checking methods to evaluate the operation.

It is then a cross-checking based on **size** (population or animals) and sectoral '**demand**' (water needs/inhabitant/day, water needs/Total needs, water needs/ irrigated ha, etc.), or the size of 'water production' (daily production of communal centres). Operation is approached in a sketchy manner. Other hypotheses are taken into consideration in such evaluation when new appreciation elements are available with a view to presenting the most plausible operation estimates per aquifer and country.

#### **2.3.3.2- Uninformed important Fields**

Since it is an initialisation stage of the information system, the gathered data come from diverse sources:

- Formats are different.
- Codification - when it exists - is heterogeneous.
- The information level differs from one country to another.
- Many data are extracted from study documents (they are not then databases).

For all these reasons, the collected data are not always compatible with the database structure. Consequently, some Fields remain uninformed.

### **Water point characteristics**

Fields are defined to describe the borehole and the adopted solutions to characterise them.

<b>Field</b>	<b>Description</b>	<b>Adopted solution</b>
NoClas	Water point identification number	Manual codification
Code_aquif	Code of the aquifer captured by water point	GIS usage and request

2 This is the case of the teams of Mali and Niger whose contribution is synthesised in two documents specifically produced for the IAS aquifer modelling purposes, i.e.

- Moumouni Moussa A. & Rabé S. (Janvier 2007) : Collecte des données hydrogéologiques du Système aquifère d'Iullemeden dans la partie nigérienne. OSS, Janvier 2007, 12 p et tableaux annexes
- Maïga S. & Bouaré D. : Collecte des données hydrogéologiques du Système Aquifère d'Iullemeden dans la partie malienne. OSS, décembre 2006, tableaux annexes

Nom_admin	Administrative unit	GIS usage
Code_usage	Water point use	Transformation request
Code_etat	Water point status	
Artesien	Artesian drilling or not	Request
Alt	Water point altitude in meters	DEM better resolution 90 meters

## Coordinates

- Many boreholes with a withdrawal history have no coordinates. This excludes them from the PM5 model, since they cannot have a grid number.
- There are duplicates by coordinates: boreholes with different characteristics (identifier, name,...) but with similar coordinates.

## 2.4- Common geographic data

### 2.4.1- Topography and basic maps

Since the launching of the IAS project, we were confronted with the need to have a topographic fund common to the entire Iullemeden basin. This proved necessary to determine the system, especially that the hydrological limits are not necessarily uniform everywhere in the aquifer limits. The OSS developed the topographic map at 1/000000 (Fig.1)

The topographic fund adopted in this map is NGI. Thanks to it, a DEM was designed bringing together the topographical data of the Digital Word Chart (DWC) (Fig.2). The designed topographic map goes beyond the limits of the Iullemeden basin. It extends between the standard parallels 0 degree and 15 degree E and the standard parallels 10 degree and 22 degree N. This voluntarily chosen extension is adopted to examine all the hypotheses on the aquifer hydraulic links of the Iullemeden basin and the other adjacent basins like Lake Chad.

Figure 1: Topographic map of IAS at 1/1000000



The geographic information related to this topographic map is as follows:

- Hydrographic network: permanent water stream, temporary water stream, permanent wetlands, temporary wetlands, lake.
- Contour line: main and secondary with a 100-m contour interval.
- Spot height:
- Main agglomerations: capital, county-town, main town of a department, main town in a subdivision, secondary town.
- Roadway: main, secondary, railways, track.
- Other signs: palm-tree, boreholes, halophytic vegetation, sea vegetation.

These layers are listed in the table below:

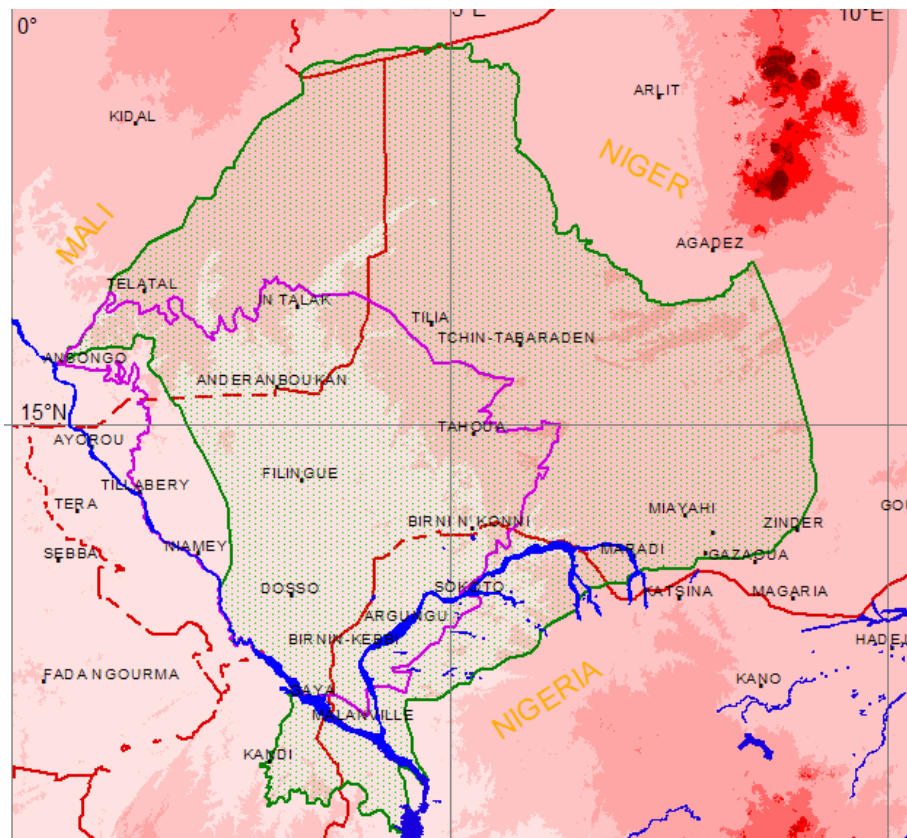
Shp file name	Description	Type	Origin
Hydrography.shp	Hydrographic network	Line	DCW
Fleuve_niger.shp	The Niger River	Polygon	DCW
Villes_principales	Main agglomerations	Point	DCW
Cnv_50_1-int.shp	Contour line (50m equidistance)	Line	Topographic maps
Water_bodies.shp	Lakes	Polygon	Topographic maps
Dallois.shp		Polygon	Topographic maps
Humide.shp	wet lands	Polygon	Topographic maps
Limite_zone	Limits of the IAS zone	Polygon	OSS
Routes.shp	Main roads	Line	Topographic maps
Pcote.shp	Spot height	point	Topographic maps

#### 2.4.2 Digital Elevation Model (DEM)

It is a file with an EsriGrid format made from GTOP030. It has a resolution of 30'' arc. The kilometric resolution, then, varies according to the latitude. The system of original coordinates is in decimal degrees on WGS84 ellipsoide. The altitude is expressed in meters from the sea average level.



Figure 2: DEM in the IAS zone



This resolution does not allow for a very accurate terrain representation. The reconstitution of the boreholes altitudes, which are essential to piezometric processing, can provide exploitable results.

### 2.4.3- Hydrogeology (Aquifers)

The hydrogeological layers displayed on the IAS maps are mainly:

- The '**boreholes**' which are directly linked to the DB and appear on the map following a specific configuration at the point of geographic streamlining.
- The 'the aquifer systems boundaries' and mainly the two aquifer layers of the Continental Intercalaire (CI) and Continental Terminal Continental (CT). These boundaries are established on the basis of a structural analysis which refers to data relating to surface geology, drillings, and geophysical studies.
- The 'faults' or 'major tectonic accidents' are configured on map, on the basis of the available documentation, particularly the tectonic map of Africa (3). This configuration is later validated by a location survey correlations between the mechanical drillings,
- Initial piezometric map: The map brings together all the previous piezometric measures or those made in 1970. They are brought back to this date in order to represent the initial piezometric status. This piezometry is related to the Sea General

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(3) Add map reference

Level (NGM) by referring to the levelling of borehole altitude or the DTM in case local altitude measures are not available.

**Figure 3: CI initial piezometry**

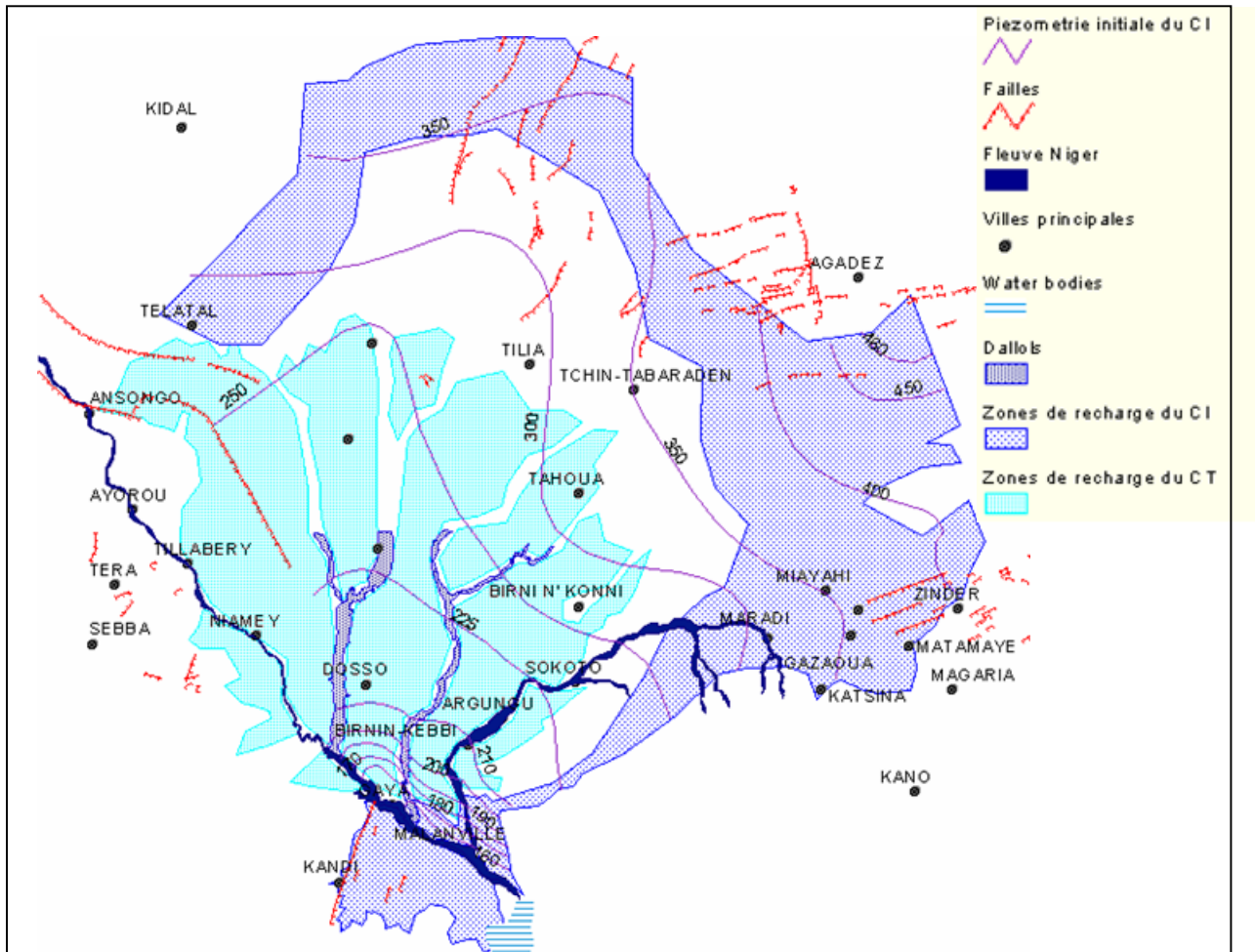
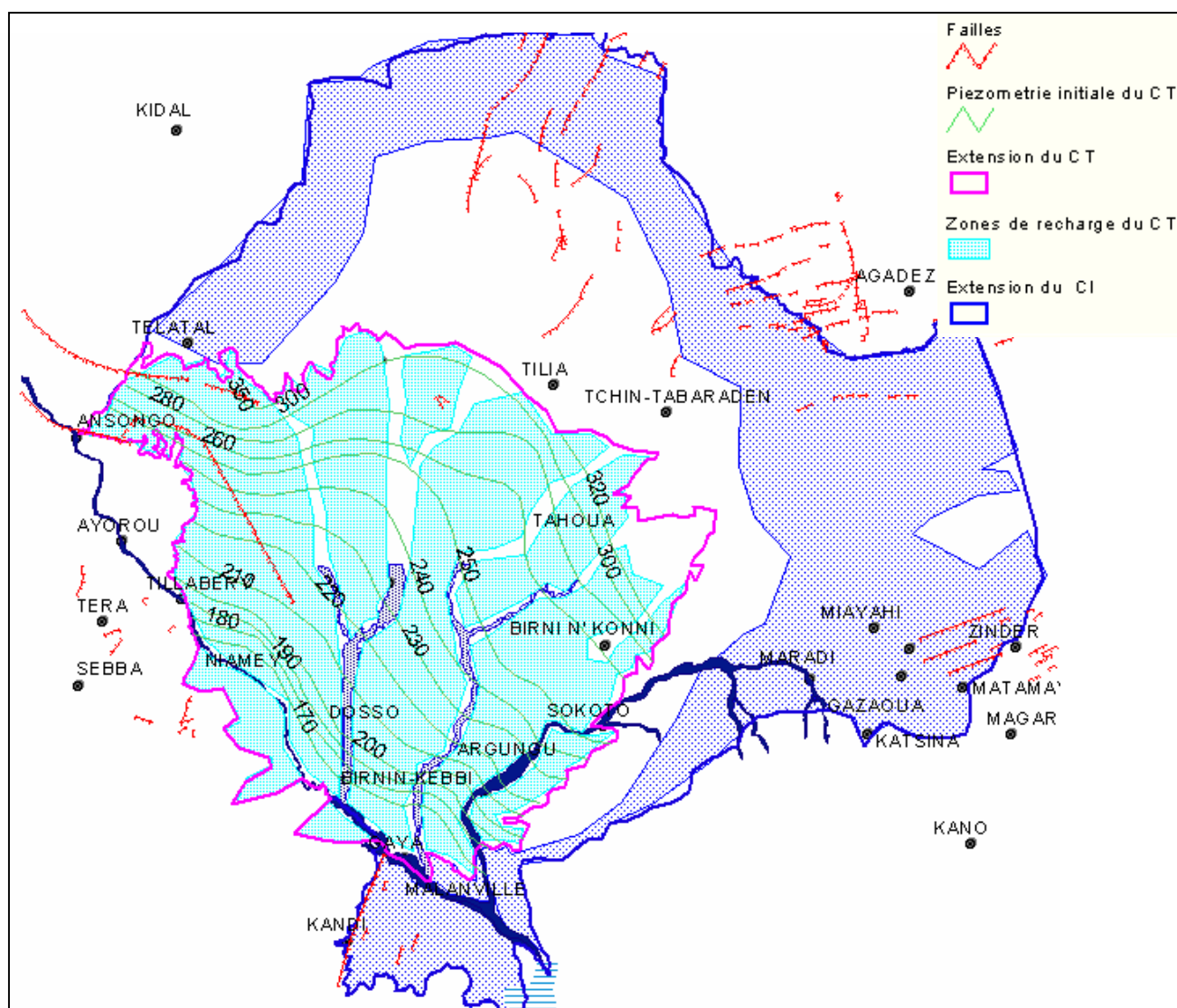


Figure 4: Initial piezometry of CT



#### List of layers:

File name	Description	Type	Source
Faults.shp	Faults	Ligne	Geological maps
Extension_ic_ias.shp	CI limits	Polygon	OSS
Extension_tc_ias.shp	CT limits	Polygon	OSS
Rechargezones_ic	CI recharge areas	Polygon	OSS
Rechargezones_tc	CT recharge areas	Polygon	OSS
Piezo_set-ic.shp	CI initial piezometry	Line	OSS
Piezo_set-tc.shp	CT initial piezometry	Line	OSS
Transmissivities_ic_curv	CI Transmissivity	Line	OSS

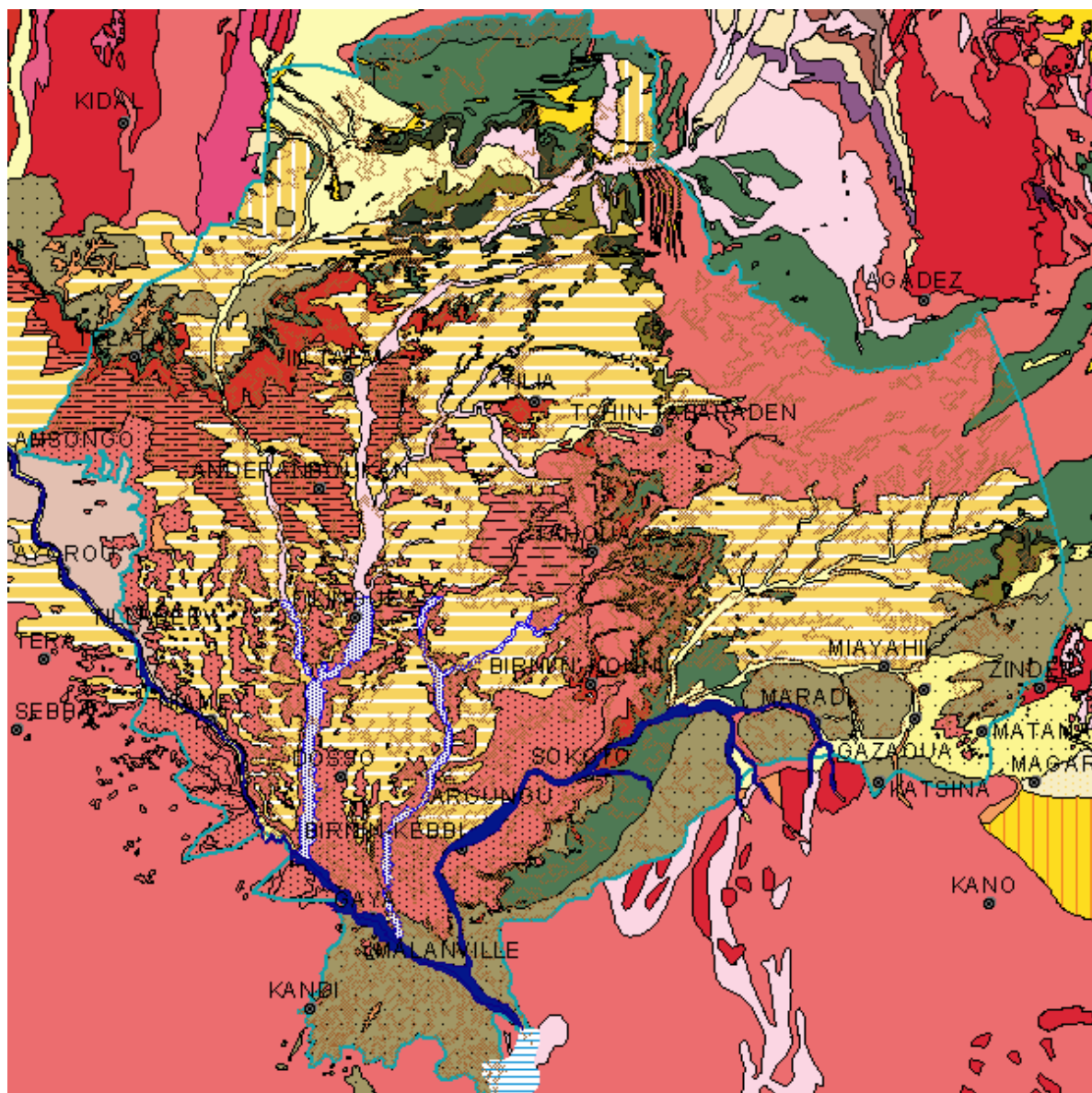


#### 2.4.4- Geology

The geological map of the IAS zone is designed at 1/ 2.000.000 by reference to different available geological documents; especially the geological map of Niger at 1/2 M and 1/1M, the geological map of Nigeria at 1/0.5M and at other sheets of the geological map of Mali and Algeria at 1/0.5M.

The map (Fig.5) was made in the framework of the project. It is a synthesis of the set of geological information on the outcrop of the different layers. It was useful to keep the maximum information, which is specific to the consulted documents (nomenclature of formations and sets), and make the required homogenisation in order to have a common legend.

Figure 5: SAI geological map



### List of layers for the geology theme

Shp file	Description	Type	Source
Geol_iullumenden	IAS geology	Polygone Polygon	OSS
Affl_ci_sai	CI outcrop	Polygone Polygon	OSS
Affl_ct_sai	CT outcrop	Polygone Polygon	OSS
Affl_plio-quat	Plio-quadernary outcrop	Polygone Polygon	OSS
Cretace-sup	Upper Cretaceous outcrop	Polygone Polygon	OSS
Failles	Faults	Ligne Line	Geological maps

The geological information set served to elucidate the IAS subsoil structure and identify the different aquifer levels within the system. Thus, we could delimit, with a great deal of accuracy, the geographic extension of the layers and their distribution among the three aquifer-sharing countries. Similarly, the information was used for the accuracy of the vertical evolution of the layer thickness, which is a key datum for the hydrogeological model. The faults geographic localisation within IAS allowed the delimitation of the different layers as well as the lateral discontinuities they experience.

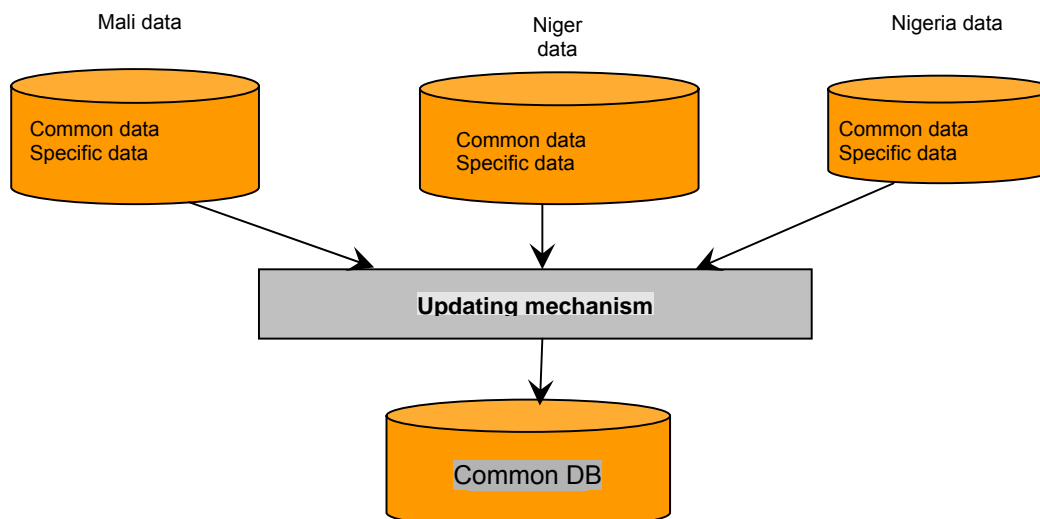
### 3- DESCRIPTION OF ISIAS

The global organisational solution, which was defined to carry out the common information system, is represented in the figure, below, describing collection process and data formatting. The process is based on the contribution of national teams to the data collection and selection required for the project so that it can be later shared by the three countries. The adoption of specific formats in the IAS common database requires the harmonisation and validation of these data. It is at this level that the OSS team intervenes to bring in its 'know-how' in light of the expected objectives and for the use of this information in the aquifer monitoring, design, and evaluation, and in underlying specific trends in the evolution of some climatic, hydrological or hydrogeological parameters. The IAS common database is hence designed as an element in a process of available information analysis and also as a tool to generate results for the Transboundary Diagnostic Analysis (TDA). Such objectives imposed the active participation of the countries' technical teams in charge of the IAS water resources. This choice meant in turn that there was a need to provide training for these teams so as to enable them to take the responsibility of establishing and maintaining the system, and adapting it to national needs. The strategy of the gradual establishment of the IAS common information system is found in table 1:

**Tableau 1: Gradual establishment of ISIAS and its role in the evaluation of hydrogeological risks**

Phase	Regional level	National level
<b>Transboundary Diagnostic Analysis (TDA) :</b> Database Modelling Indicators	- Establishment of the <b>common georeferenced system</b> (digital maps, DB and GIS)  <b>Simulation model</b> of the aquifer system operation	- - Aquifer monitoring improvement (new boreholes, piezometry, operation, and hydrochemistry) <b>Database consolidation and GIS</b> (management performance, recovery of archival data and acquisition of new data)
<b>For the Action Strategic Programme</b> - cooperation mechanism - Monitoring network - Concerted planning	- <b>Consultation framework</b> (controlled management)  - <b>IAS monitoring network</b> (decision aid)  -Monitoring indicators	-Development of water resources strategy  - Better response to water demand  - Conservation of aquifers and water usage areas

**Figure 6:** Total organisational solution of the IAS database



This schema is an organisational solution of the common database instruction, **as jointly approved** with the national teams. It constitutes the basis for harmonising the national databases specific to the management and the follow up of water resources and is reflected by a broad similar architecture in three countries. On such basis, the task of the IAS underground water management becomes more controllable. This database structure meets the needs of the basin's management and can be easily adapted at the level of countries for monitoring purposes and more local and sector-oriented management.

**The conceptual model of the IAS common database (CMDB)** responds to the following objectives in the first place :

- **Harmonisation of data** in the three countries with the aim of ensuring a better understanding of the hydrodynamic functioning of the aquifer system whose one of the first applications is TDA.
- **Collection of all the climatological, geological, hydraulic and hydrogeological data** allowing for the design of a simulation model of the system which restores functioning, water results and exchanges according to the entries, exits and the incurred transformations.
- Collection of overall planning schemes, water demand by sector and vision of needs evolution in order to set up forward-looking simulations, translated into the system future reactions according to pressures to which aquifers are subject, and hence concretise the SAP.

These objectives are translated into a set of 'tables', gathering the required information for the construction of a model representing the IAS aquifers, functioning and the different operating conditions. These tables should be interlinked on the basis of some identification codification to enable inter-table exchanges as well as the recovery of results and their grouping or superposition in thematic layers. The links between the 'Information System' (GIS and common database) and the aquifer simulation model will be subsequently examined within the framework of using the database information to generate hydrogeological models.

For such information system to be adopted as a decision aid tool, and for the IAS short-term and medium-term management, information updating procedures are defined at the same time as the access and privilege protocol of the different common database users.

Given that the immediate purpose of this information system is processing data to design a digital model, simulating the IAS operation, and to design water assessment report, the common database was produced and validated with the countries, on the basis of an overall conceptual model that meets the objectives and approves hypotheses, conditions and rules, as agreed with the three countries (geographical extension, structural configuration, link with a hydrographic network...)

At the structural level, the countries opted for:

- Designing an IAS common database in view of an agreed management of the shared water resources.
- Adopting a structural schema of the common database in view of its mainstreaming in the national DB to ensure water resources management and monitoring, given that this schema is specific to tasks and tolerates additions and modifications to meet the country's needs. In fact, on the basis of the rules of 'rational bases', this system is extendable and adaptable and allows for data harmonisation and ensures its updating,
- Defining clear data updating procedures between partners.
- Setting up a data securisation mechanism.

Each time the structure of the IAS information system or its content is improved; the three countries benefit from them and are associated to them. They have plenty of scope to carry out the expected extensions at the national level in order to use the system as a water resources management tool. They are not called upon to bring uniformity to data which they judge to be necessary to achieve the project objectives.

In case of any modification, the adopted data updating mechanisms are based on the principle of replication which is provided in most of the DBMSs available on the market. During this project phase, it was thought to be more practical not to impose a given system securisation mechanism on the common database, but to opt for a mutual information exchange with reference to the OSS-run database copy until completing all the information implementation operations and their processing for the purposes of the hydrogeological model.

### ***3.1.1- Technical choices and computer tools control***

The technical solution for operating the IAS information system software is adopted by accounting for the following points:

- Availability in the three countries' public sector.
- Implementation simplicity of control by the project national teams.
- Formats and data exchange mode with the digital model.
- Current technological trends.

It is highly important that the used tools are **easily accessible** to water resources administrations technicians in charge of the IAS aquifer management. Since such new software is not available in the public sector, it would be very difficult for the IAS information system managers to obtain the required equipment and control its use at the appropriate time. There is



no use to add new technological tools to the ones which proved little efficient after a few years (the case of Mali and Niger).

**Implementation simplicity and control of information system management tools** are two prerequisite conditions which facilitate its mainstreaming in the countries' underground water management tools. For the project as well, it is highly important that this tool control is done over a long training period to be able to move to the planned applications.

**The information system links** with other applications, particularly the aquifers simulation model, are not negligible. Given the available data heterogeneity, exhaustive volume and the need for its geo-referenced processing, it is practically very difficult to ensure its analysis by modelising and resorting to manual data entry methods only. The information geo-referenced processing is a means to validate and process it.

The information technology context at the project start (2004) was characterised by the growing strength of DBMS (office automation), thus bringing them closer to the real DBMS. This trend should not, therefore, be neglected to avoid being rapidly overtaken by technological evolution and make it then possible for the newly adopted software to migrate to other more performing storage media. For such reason, **ACCESS** was the right choice, and whose most recent version has interesting functionalities.

In its 2000 version, ACCESS has characteristics that allow it to manage databases whose volume is fairly important (up to 2 Go) in a network environment and even intranet.

- **Replication** allows for a central database update by regional databases. The data update by the country teams or the IAS project team is made with the help of a mechanism which synchronizes the content of all databases and maintains data coherence.
- **Concurrent data access** in a multi-user environment
- **An enhanced data securisation** with the possibility of creating several groups with separate authorisations and access rights.
- **Easy migration possibility** to other more important systems such as SQL/SERVER by means of a simple utility programme delivered with the product.

ACCESS was then chosen because the processing nature and the data volume managed by the IAS project do not require a more important DBMS. ACCESS is a component of OFFICE management system and largely used in administrations. The three country teams have sufficient control of it to operate and administer the database it has generated. The selection of the other IAS information management software was made on the same grounds.

The selected IAS information management applications are:

- DBMS: ACCESS is selected for its use and control in the three countries, and its GIS interface. In addition, the 2000 version allows for an easy migration to SQL-SERVER, as planned by Niger whose WRI database evolved from Dbase III to ACCESS, about a year now.

- SIG software: ARCVIEW was selected for easy use, power, perfect compatibility with ACCESS and fairly general use in the water resources field. Endowed with a strong development language, it allows for the writing of customised utility programmes which are required by GIS links-mathematical models. The software is used in the water resources administration in the three countries participating in the project. The GIS ensuring the DB WRI graphic interface (of Niger) is Atlas GIS. The needs for geo-referenced cartographic documents

highlighted the limits of the tool. Training sessions on ArcView are now in progress at the Water Resource Department (Niger) to get the WRI Base users acquainted with this tool, with the aim of migrating from Atlas GIS to ArcView.

- **SPATIAL ANALYST** extension under ArcView, acquired for carrying out interpolation and elaboration operations of iso-value maps.
- Extension of **IMAGE ANALYSIS** under ArcView, for processing of scanned maps and their digitisation.

With the help of these tools, the IAS information system is performing data processing and management system. It lives on for several years on the basis of an exhaustive inventory of the processing procedures and the selected organisational mode.

### 3.1- IASIS general architecture

One of the characteristics of the adopted approach for establishing an IAS common database is the separation between **data structure** and **data processing**. Put differently, to obtain an open and scalable information system, one should first forget about the processing procedures, which are subject to changes. The stress should then be put on the most stable data part by accurately understanding:

- Information sets (entities).
- The nature of the existing links between these sets.
- The management guidelines associated with these entities.

Such approach allows for designing the closest possible representation of the perceived reality. It aims at producing a Data Conceptual Model (DCM) which synthesises the entities and the relations with the help of a formalism derived from the following planned rules:

- A borehole can pick up 1 or many aquifers.
- A borehole at a given date provides a given yield.
- A borehole can serve many users.
- A user can be supplied by many boreholes.
- A borehole has a grid number within a space gridding.

The identification of relations between the different elements of the data model requires the greatest attention so that the applications deriving from it can meet the needs of the expected information.

The separation between data and processing is also reflected in establishing two distinct physical files:

- 'SAI\_DATA.MDB': data-only tables.
- And 'SISAI.MDB': programmes with interface and processing modules.

This structure offers the following advantages:

- The possibility of use in a multi-user environment: 'SAI\_DATA.MDB' on a server and 'SISAI.MDB' on a workstation.
- A better system stability to guarantee openness and evolutivity.

### 3.2- Database description

On the basis of a relational database and considering the need to have a database to design a hydrogeological model and stimulate the operation of the lullemeden aquifer system, the database design is done with a structure where boreholes are a major key to access information. The general database schema is designed in several interrelated 'tables' by univocal and multiple relations to process specific information. (Piezometry, rainfall, implementation...) A set of requests was designed to answer specific questions on the spatio-temporal distribution of information, in view of responding to a given application (ex: operation in a country from a water table during a certain period).

Forms have been used to enter the relevant information in the common DB in a format that allows for its adequate processing. These forms are also used to add or check information. These forms are required for harmonising information with different stored and processed origins. By referring to the options adopted by the representatives of the countries during the two workshops dedicated to the IAS common information system, it was convened that the IAS Database covered the following five thematic domains:

- ❑ Les eaux souterraines ;
- ❑ groundwater resources
- ❑ Surface water resources (and hydraulic infrastructures)
- ❑ Climatology
- ❑ Administrative units
- ❑ Groundwater resources users

#### **The underground water field includes the data which describe:**

- Hydraulic infrastructure implemented in the basin.
- Aquifer characteristics (name, identifier, area, direction, transmissivity, permeability, storage coefficient, and so on).
- Measured piezometric data.
- Aquifer withdrawals.
- Recorded hydrochemical data.
- Completed isotope analyses
- Hydrodynamic parameters
- Zone geological information
- Geophysical data

#### **The surface water field includes the following data which describe:**

- Hydraulic infrastructure (dams) implemented in the basin.
- Description of the aquifer watershed (name, identifier, area drainage density, runoff coefficient, slope)
- Water streams.

- Lakes.
- List of hydrometric stations.
- Solid and liquid flows.
- Recorded hydrochemical data.
- Completed isotope analyses.

**The climatology field includes the data which describe:**

- Climatological stations.
- Rainfall.
- Temperatures
- Evapotranspiration

**The administrative units field includes data which describe:**

- Administrative subdivisions.
- Growth rate by period.
- Localities

**The water users field includes data relating to:**

- Populations
- Irrigated areas.
- Industrial zones.
- Domestic drinking water consumption.
- Agricultural consumption (Irrigation and livestock).
- Industrial consumption

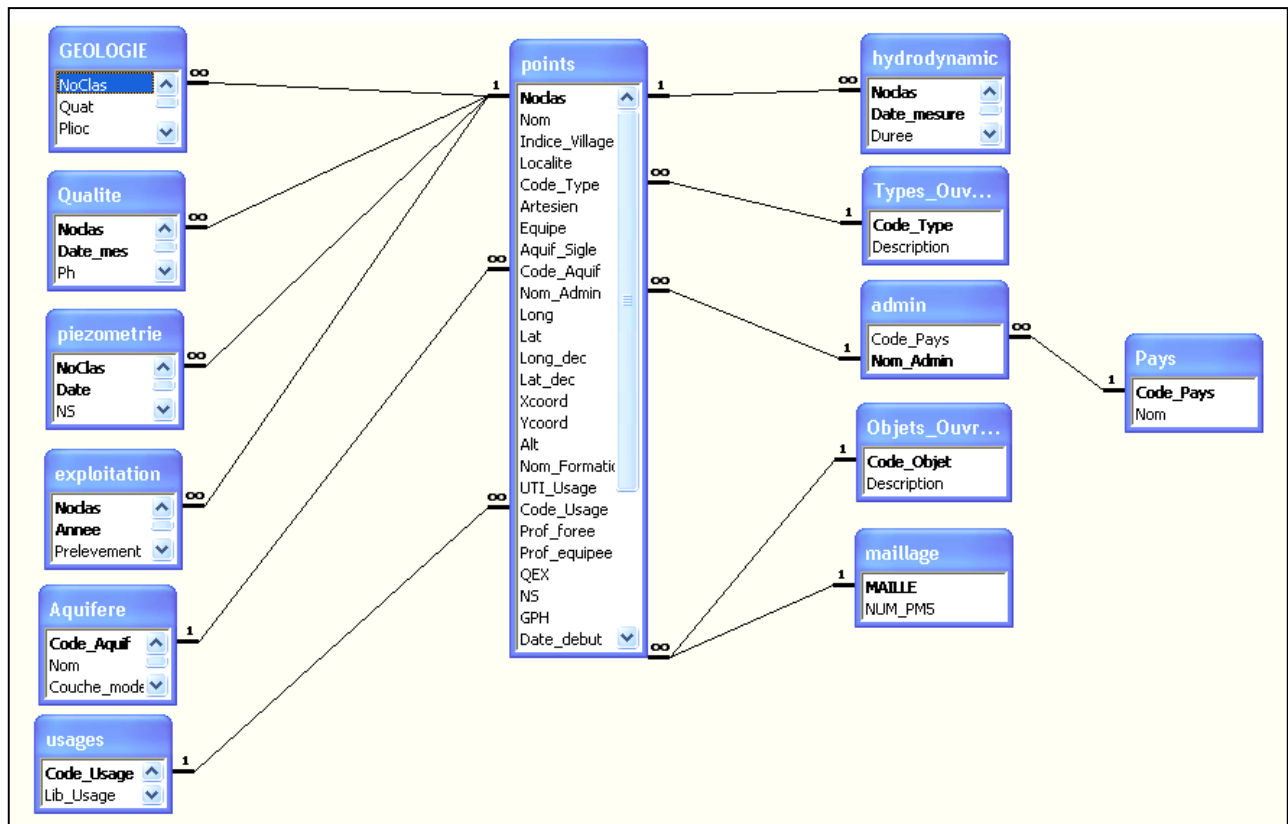
Thus, an exhaustive list of the different entities, which should appear in the information system, was designed in collaboration with the country teams. This list takes into consideration:

- Immediate needs for the model.
- Information evolution possibilities.
- Establishment of links between GIS and the database for data transfer and result restitution.

### **3.2.1- DB Schema**

The database schema is a conceptual model of data (CMD) during the design phase. This schema shows the central role of the 'points' table, which is linked to the identification table (country, hydrodynamic aspects, works type, Admin, etc.) and variable tables (geology, quality, piezometry, exploitation, Aquifers, usages, and so on). The relations which link the 'points' table to the other tables can be univocal (1 to 1) or multiple (1 to many).

Figure 7: IAS Data base architecture



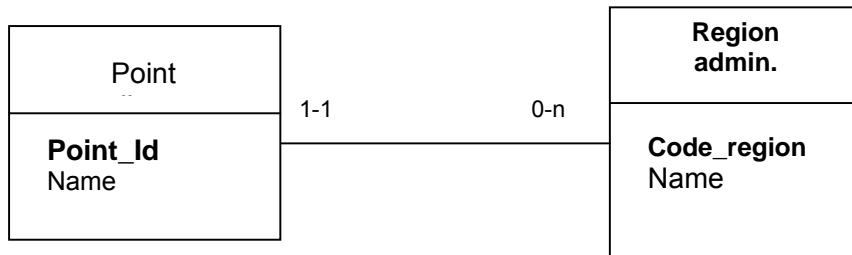
The detailed structure of tables is provided in appendix 1

### 3.2.2- Relational model

The relational model is based on the principle that the DBMS is structured on a set of 'tables', each one of which includes a set of 'fields', and that the whole set is run by defined relations without any confusion or ambiguity. The accomplishment of the relational model is a phase which paves the way for implementing a CDM on SGBD. According to the nature of relations, and on the basis of the cardinalities originating from the management guidelines, transit procedures are applied (OSS 2003). The relational model is tested, in each table and for the set of tables, in view of defining the different relations between the 'field' and the tables enabling combination and data processing.

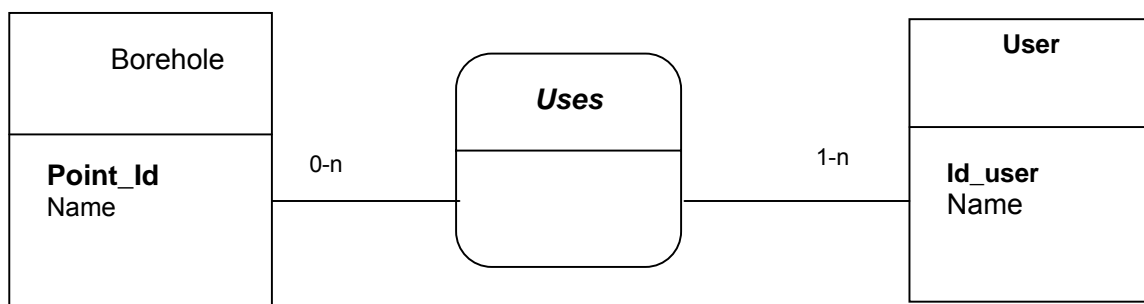
The nature of relations linking the two entities can be summed up as follows:

**Case n°1: relation « 1-1 » to « 0-n »**



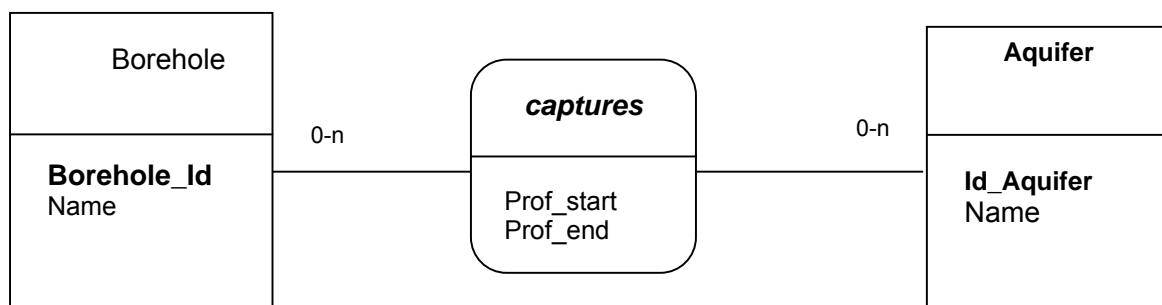
The relation shows the fact that administrative regions have zero or many boreholes. Consequently, a borehole forcibly belongs to one administrative region.

**Cas n°2: Relation « 0-n » à « 1-n »**



Between the 'Borehole' and 'User' entities, the link can be formulated as follows:  
The same borehole can be supplied by one or many boreholes. As for the user, he can be supplied by one or many boreholes.

**Case n°3: Relation « 0-n » à « 0-n »**



Here the relation 'captures' itself includes attributes or properties.  
The rules which govern a DBMS meet the following requirements:

- 1. All the entities become **tables** and their attributes **fields**.
- 2. For the associations of the type '1-n', the identifier of the major entity migrates to the secondary entity.

If we take the example illustrating case n°1, the transition to a relational model leads to establishing two tables: 'borehole' and 'Region Admin'. The 'borehole' table must include a supplementary field i.e. 'code\_region' in order to establish the relation between the two tables.

3. The associations such as '1-n', '1-n' (case n°2) are processed as follows:

- Apply rule 1
- Set up a third table including as an attribute the keys of the two other tables.

The example of the case number 3 shows that in addition to the setting up of tables 'water point' and 'users', a third table 'use' including the identifiers of the first two is set.

4. The association bringing in information (case number 3) is processed the following way:

- The associations derive from the tables.
- For the keys, apply the previous rules.

The result is identical to case number n°2, except that the resulting intermediary table includes the attributes 'prof\_deb' and 'prof\_fin' in addition to the identifier.

### 3.2.3- Tables

In this type of database organisation, the tables are grouped according to specific similarities (piezometry, exploitation, rainfall, and so on). They are the means to bring together the countries' data under one section to ensure critical analysis, harmonisation and use or exchange, through the established links. The tables are basic entities for data updating and processing. They must respond to specific formats in which data and the searched aspects can be displayed.

The IAS common database tables consist of two parts:

- An identification part which includes data allocation to a geographical origin or an aquifer level (country, administration, CI or CT...).
- A variable part which allows one to assess the timely values of the considered variable (operation, piezometry...) in space and time.

The combination of certain fields or columns of two or many tables makes it possible to extract a new table to refer to these common keys. The following table provides the main hydrogeological tables of the IAS common DB.

**Tableau 2: List of IASIS\_DATA tables**

Name	Significance	Type
<b>Admin</b>	First-level administrative unit (department, province) of some significance for the distribution of different thematic variables (population, livestock, boreholes, operation...)	Attached
<b>Inflow</b>	Includes the supply values in m3/s by grid. It completes the 'operation' table for computing flow by grid.	Attached
<b>Aquifer</b>	Natural entity (aquifer, groundwater Bering) delimited in space and according to hydrogeological criteria. This is an evaluation and resource management unit.	Attached
<b>Topographic map</b>	Geographical reference of spatial localisation corresponding to a sheet in delimiting the map, on which the inventoried borehole is located according to its geographic coordinates. The identifier of this	Attached

	entity consists of the scale and the map number.	
<b>Config</b>	Table including the application configuration parameters	Local
<b>GIS layers</b>	List of attributes of GIS layers used by the application	Local
<b>States</b>	Different states of a borehole (operated, non-operated).	Attached
<b>exp_tmp</b>	Temporary table used for Excel data import	Local
<b>Operation</b>	Withdrawals history. The access key is made up of the borehole identifier followed by the measurement date.	Attached
<b>Hydrodynamics</b>	History of borehole hydrodynamic parameters	Attached
<b>Geology</b>	Geological description of the formations tapped by a borehole	Attached
<b>Gridding</b>	Model grid attributes	Attached
<b>Objet_works</b>	Borehole object at the realisation time (reconnaissance, operation...)	Attached
<b>Country</b>	List of countries which share the SAI aquifer system	Attached
<b>Piezometry</b>	History of piezometric levels. The access key is made up of the borehole identifier followed by the measurement date.	Attached
<b>Points</b>	Groundwater catchment works which can be a borehole, a well, a conter-well, a spring, a piezometer.	Attached
<b>Quality</b>	Records of chemical analysis results. The access key is made up of the borehole identifier followed by the measurement date.	Attached
<b>Tmp_Measurements</b>	Temporary table used by the form accompanying the flow measurements.	Local
<b>Tmp_Piezo</b>	Temporary table used by the form accompanying the level measurement.	Local
<b>Types_works</b>	List of works type (borehole, well, spring...)	Attached
<b>Uses</b>	List of possible borehole uses (domestic supply, irrigation, tourism,...)	Attached

### 3.2.3- Requests

Requests constitute a stage in the data processing which allows the generation of new tables with data processed or formatted on the basis of two or many tables. They are divided into two categories:

- **System requests** which are requests used by the application, either by other requests or by modules or forms. They should not, then, in any case be deleted or modified
- **Information requests** which translate the spatio-temporal distribution of the various variables

By combining data with requests, one can extract information which would be difficult to obtain by manual processing. Similarly, it is easier to represent information in a graphic or geo-referenced way for correlation or comparison purposes. Requests are answers to elementary questions on general data or parts of it. Saving request results facilitates their use in new requests or representations.



Table 2 gives examples of requests which were made in the framework of the IAS data processing to answer certain questions relating to operation and piezometry.

**Tableau 3: list of requests**

Name	Nature	Description
Verif_history operation horizontal		Withdrawals by borehole and year for a given aquifer
Depth statistics		Minimal, average, and maximum borehole depth by aquifer
Sum of withdrawals by country		Total withdrawals by country for a given year
Sum of withdrawals by country in 1970		Withdrawals by model grid in 1970 (reference year)
Total withdrawals by administrative unit and year		Withdrawals two-way frequency table by administrative unit and year.
Total annual withdrawals by administrative unit		Table providing for a given year withdrawals and borehole number by aquifer.
Withdrawals by works type and aquifer		Table providing, by aquifer and by given year, the withdrawals distributed by borehole type.
Withdrawals by administrative unit and works type		Table providing, by administrative unit and for a given year, the withdrawals distributed by water point type
Points with coordinates		List of water points with coordinates
Points without operation		List of water points with an operation history
Points with at least two piezo measurements		List of water points with at least two level measurements
The longest piezometric series		Table by administrative unit providing the number of points with at least two level measurements, and a year interval between the measurements.
pm5_observ	System	List of water points and their piezometry. Used for PM5
pm5 boreholes	System	List of water points with an aquifer code, coordinates and number of level measurements. Used by PM5
Piezometers by cell		Piezometers list of by PM5 grid. Extracts the columns: aquifer, line, column and number of water points
piezo distinct	System	List of piezometers (water points with at least a level measurement)
Number of points by aquifer		Table providing the number of water points by aquifer
Number of points with operation		Table providing, by administrative unit, the number of water points with a withdrawal history
Withdrawals history		Two-way frequency table of withdrawals by water point over the period (1956- current year)
Records of withdrawals by cell	System	List of PM5 grid with the sum of annual withdrawals. Used for the preparation of PM5 files
records of withdrawals by aquifer		Two-way frequency table of withdrawals by aquifer for each year. Used for the period (1965-current year)
Piezometry history		Two-way frequency table providing the piezometry list by aquifer with the level value for the period (1959-current year)
Piezometric level records		Two-way frequency table of the levels by water point on the period (1959-current year)

### Requests (follows)

Nom	Nature	Description
Operation history by grid	System	Two-way frequency table providing year, number of PM5 layer, grid (line and column). Used for PM5 preparation
NP Altitude history		Two-way frequency table of the piezometric altitudes by water point for the period (1959-current year)
histo_Withdrawals	System	List of water points grouped by aquifer with coordinates and the annual withdrawals value. Used at the time of flow measurements entry.
histo_Withdrawals_by_aquifer	System	Same with preceding request, but the user must enter the aquifer system. The list concerns the given aquifer only. Used for the entry of a set of flow measurements
histo_Piezo	System	List of water points grouped by aquifer with coordinates and the annual value level. Used at the time of entry of a set of level measurements
histo_Piezo_by_water table	System	Ibid, but the list concerns the aquifer code provided by the user. Used at the time of entry of a set of level measurements
Operation distinct	System	List of water points with at least one withdrawal measure
operation without_coord		List of water points with at least two withdrawal measurements
Withdrawals evolution by administrative unit and aquifer.		Two-way frequency table providing withdrawals by administrative unit for the period (1956-current year)
two piezo measurements		Two-way frequency table providing water points with the number of measurements by period (before and after 1990)
aquifer_piezo		List of water points with at least a piezometric measure with an aquifer code and measure year
aquifer_operation		List of water points with at least a withdrawal measurement with an aquifer code and measurement year
supply by grid	System	Two-way frequency table providing the aquifer, grid (line and column) and the supply value. Used at the time of the PM5 files preparation.
field information rate		Table showing the information rate of the most important fields of the 'points' table

The requests whose nature is 'system' are requests used for the application, either by other requests, or by modules or forms. They should not, therefore, be deleted or modified in any case.

### 3.2.4- Forms

Forms are used to harmonise the data formatting to be included in the database. They are elaborated according to formats which facilitate entry, data processing and the display of results with the aim of securing its validation without any error risk. The prior docking of field formats for the introduction of data and the formatting of the various fields offers a fairly complete graphic vision of the whole data entry process and information processing.

Forms should not under any circumstance be modified or deleted. They constitute the formal aspect of data or information formatting design, thus allowing data sorting and formatting.

**Tableau 4: List of forms**

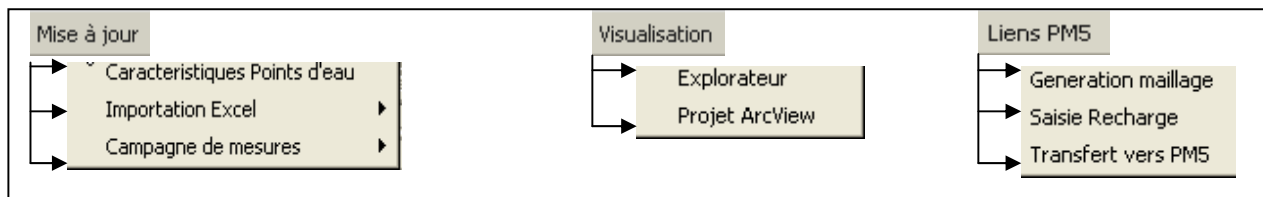
<b>Name</b>	<b>Description</b>
Welcome	Welcome screen which appears at the opening of the application.
DB_SglG Modal	Main form connecting DB, GIS and PM5. It mainly allocates a grid number to the water point.
Layer control	A form allowing the display and the operation of the parameters relevant to the cartographic display in the ' <b>Main</b> ' form.
General data	A form meant to display and modify the information set concerning a water point.
Operation chart	Meant to display the chart of a set of samples. Referred to as the ' <b>General Data</b> ' form.
NS chart	Meant to display the chart of a set of static levels. Referred to as the ' <b>General data</b> ' form.
Piezometric graph	Meant to display the chart of a set of piezometric levels. Referred to as ' <b>General data</b> ' form
Import_flow_without interpolation	A form allowing the choice of an Excel file containing flows and importing them to DB.
Import_levels	A form allowing the choice of an Excel file including levels and importing them to DB.
Measures_of yield	Display, modification and creation of a run of extracted flows.
Piezo_measures	Display, modification and creation of a run of levels.
parm_gridding	A form meant to enter the parameters and create a PM5 gridding. Referred to as the ' <b>DB GIS Model</b> ' form.
Pre-model	Used for the preparation of the necessary files for the PM5 model (for the permanent and the transitory)
Main	An explorer allowing the display of the DB contents. In addition to the display in list view mode, it allows the cartographic display without exiting the ACCESS environment.
Recharge	A form for entering the recharge values on a map. These values are stored in the DB and used at the time of PM5 files preparation.
Search by Nolas	Dialog box allowing the selection of a water point with its own number. If a selection is made, the 'General data' form displays the data of that point.
Piezometric sub-form	Sub-form attached to the 'General data' form allowing the display of the history of current water points levels.
P run_ subform	Sub-form dependent on 'Piezo Measurements'.
D run_ subform	Sub-form dependent on 'Flow measures'.
Exploit sub-form	Sub-form attached to the 'General data' form allowing the display of the history of the current water point levels.
Hydro sub-form	Sub-form attached to the 'General data' form allowing the display of hydrodynamic data of the current water point.
Quality sub-form	Quality data sub-form

### 3.2- Interface description

The application has a general menu which calls on the available functions:

- \* Data updating: entry, modification of relevant water point information and associated histories
- \* Display: surfing through the database contents and GIS
- \* Links with PM5: access to the pre-model processing functions (entry file preparation and their transfer to PM5).

The menu looks like the following:



#### 3.2.1- Data updating

This option is meant to give access to the functions of data entry and updating: integrating new data, correcting existing data... It concerns the set of basic water point information:

- General features: identification, localisation, hydraulic features
- File history of annual water point samples.
- File history of water point levels.
- File history of water quality data.

Three submenus are available for this option:

##### 3.2.1.1- Water point features

This option calls on a form which clusters the set of information on a given water point.

**Tableau 5: Form for water point feature entry**

N° Clas: 10007\_CT    Nom du point: Koutoumbou

Caractéristiques    Historique Exploitation    Historique Piezo    Qualité

**Identification - Localisation**

Type Ouvrage: Forage	Aquifère: Complexe terminal
Pays: Niger	Etat:
Unité administrative: Dosso	Q Max (l/s) Exploitable:
Localisation: Koutoumbou	Artesien: <input type="checkbox"/>
Année réal:	Usage:
Altitude: 182.40	NS:
Prof forée:	Formation Géologique:
Equipé (Oui/Non): <input type="checkbox"/> Prof équipée:	
Observations: Transmissivité - Greigert	

**Coordonnées Géographiques**

Longitude: 3.58  
Latitude: 12.4

**Coordonnées Lambert Niger - Zone II**

X\_Lambert: -491780.5  
Y\_Lambert: -614470.1

**Caractéristiques Hydrodynamiques**

	Date	Débit	Durée	Rabat	NS	Transm.	Coeff emmag
▶	01/01/1978					3.20E-03	
*							

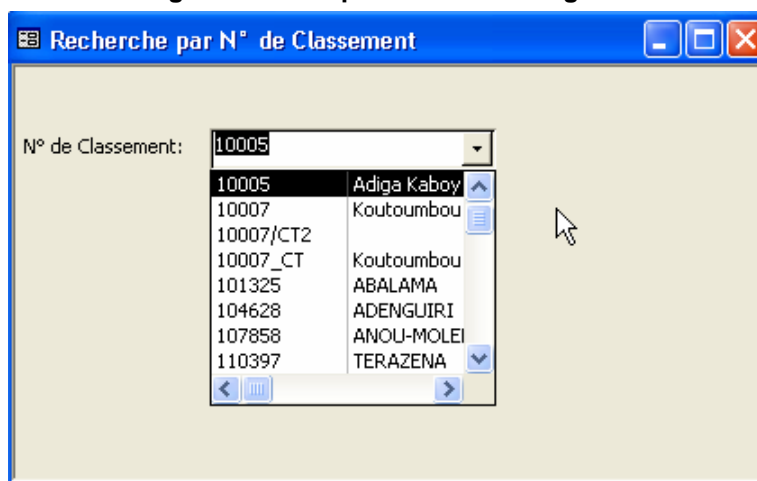
This form consists of a header area with tabs with each corresponding to an information category. The header area is used to:

- Select the water point for which we wish to display data or modify them.
- Enter the code and the name of the water point to be created.

a/ In the case of display/modification, the pink-coloured text area allows the display of the water point number on which the anchor, which browses the table 'points', is set. The keys located at the bottom of the form allow for moving from one record to another according to the ascending order of water point identification numbers.

If the user wishes to have access to a water point whose identification number he knows, he just clicks on the key which displays a dialogue box allowing the selection of the water point identification number (fig .8)

**Figure 8: Water point search dialog box**



The scrolling list displays all the numbers and names of the existing water points in the database to select one of them. We can also type one or many characters that make up the water point key. Each time a character is provided, the system searches and sets on the key which starts with the typed character(s).

In order to validate the selection and set the selected water point, click on OK. Otherwise, click on the 'Cancel' key. In this case, the cursor remains on the position preceding the display of the dialog box.

b/ In the case of the creation of a new point, the procedure is as follows:

- Click on the key to set it on creation mode. At this moment, the text field is empty.
- Type the new water point code to be integrated.
- Complete the remaining information concerning this water point.

Data save is automatic. There is no need to look for a key or a menu option to save the modifications. Nevertheless, to cancel a modification, click on the 'Esc' key.

#### 3.2.1.1.1- The 'characteristics' tab

It consists of basic information such as water point identification or localisation.

### Identification - Localisation

Type Ouvrage : Forage

Aquifère: Complexe terminal

Pays : Niger

Etat :

Unité administrative: Dosso

Q Max (l/s) Exploitable:

Localisation : Koutoubou

Artesien: ☐

Année réal.:

Usage:

Altitude : 182.40

NS:

Prof forée :

Formation Géologique :

☐ Equipé (Oui/Non)
 ☐ Prof équipée :

Observations: Transmissivité - Greigert

### Coordonnées Géographiques

Longitude 3.58

Latitude : 12.4

### Coordonnées Lambert Niger - Zone II

X\_Lambert : -491780.5

Y\_Lambert : -614470.1

### Caractéristiques Hydrodynamiques

	Date	Débit	Durée	Rabat.	NS	Transm.	Coeff emmag
▶	01/01/1978					3.20E-03	
*							

Work types: Scrolling list which provides the content of the 'Work\_types' table. i.e. the following values:

	Code_Type	Description
▶	+	Inconnu
	+	1 Forage
	+	2 Puits
	+	3 Source
	+	4 Piézomètre
	+	5 Groupe de Forages
*		

If one wants to include an inexistent value (new value), one should add it to the 'types\_works' table. The scrolling list will automatically propose it at the next activation.

Country: The scrolling list displays the country where the water point is located (Niger, Mali or Nigeria). Similarly, if one wants to incorporate another country (in case the IAS project is extended to other countries), just add it to the 'Country' table.

Administrative unit: The scrolling list provides the list of departments or provinces located in the IAS zone. Only the administrative units belonging to the selected countries are shown (preceding field).

The list of available administrative units is the following: ('Admin'table)

		Code_Pays	Nom_Admin
▶	+	Ni	Agadez
	+	Ni	Dosso
	+	Ma	Gao
	+	Ng	Katsina
	+	Ng	Kebbi
	+	Ni	Maradi
	+	Ni	Niamey
	+	Ng	Sokoto
	+	Ni	Tahoua
	+	Ni	Zinder
*			

Ma = Mali  
Ng = Nigeria  
Ni = Niger

Location: locality or place where the water point is located. It is a free text.

Realisation year: Year of realisation of the water point on the basis of four positions. A control is being entered to validate the value. The validity condition is the following:

« Year ≥ 1900 and ≤ current year »

Altitude: water point altitude in meters.

Drilled depth: drilled depth of the works in meters.

Equipped: tick the box to show if the water point is equipped or not.

Equipped depth: refers to the equipped depth in meters, if the water point is equipped (preceding field).

Aquifer: a scrolling list allows for the selection of the aquifer captured by the water point. The possible values derive from the 'Aquifer table' whose content is the following ('Name' column)

		Code_Aquif	Nom	Couche_modele	Shape_file
▶	+	CI	Continental intercalaire	2	Extension_CI
	+	CT	Complexe terminal	1	Extension_CT
*					

Status: water point status. The possible values of the scrolling list are extracted from the 'Status' table

	Code_Etat	Description
▶	1	EXPLOITE
	11	A L'ARRET
	3	NON EXPLOITE
	4	ABANDONNE
*		

The list can be extended by the addition of other items to the 'Status' table. This operation, however, should be done by the DB administrator only.

Exploitable maximum quantity: maximum exploitable water point flow in l/s.

Artesian: box to tick showing whether a water point is artesian or not.

Usage: scrolling list allowing the selection of the category of water point users. The values are extracted from the 'Usages' table'.

	Code_Usage	Lib_Usage	Categorie
+	0	Inutilisé	NON
+	1	AEP Urbaine	AEP
+	2	AEP villageoise	AEP
+	3	Irrigation	AGR
+	4	Pastoralisme	AGR
▶ +	5	Industrie	IND
*	0		

SL: Static level in meters at the time of water point creation.

Geological formation: name of the captured formation by the water point. In this version, it consists of a free text.

Remarks: miscellaneous comments on the water point. The maximum length is 60 letters.

Longitude: water point longitude in decimal points. The decimal part should have at least 5 numbers.

Latitude: water point latitude in decimal points. The decimal part should have at least 5 numbers.

X Lambert: X in meters, in the Niger zone II Lambert system.

Y Lambert: Y in meters, in the Niger zone II Lambert system.

The Lambert geographic conversion procedure – is described in the chapter on SIG.

#### 3.2.1.1.2- 'File history' tab

This tab is devoted to the display, modification or creation of set of annual samples related to a water point. It is a sub-form made up of three columns.

Figure 9: Withdrawal data entry form

année	Vol. Annuel	Origine_Info:
1956	219.8	
1957	227.3	
1958	247.0	
1959	266.7	
1960	269.7	
1961	296.3	
1962	316.1	
1963	335.8	
1964	339.6	
1965	343.4	
1966	345.6	
1967	349.5	
1968	365.3	
1969	369.4	
1970	373.5	
1971	377.7	
1972	382.0	

Description des colonnes :

- Année : année où le prélèvement est observé. Un contrôle est effectué à l'aide de la condition « **année comprise entre l'année de réalisation du point d'eau et l'année courante** ».



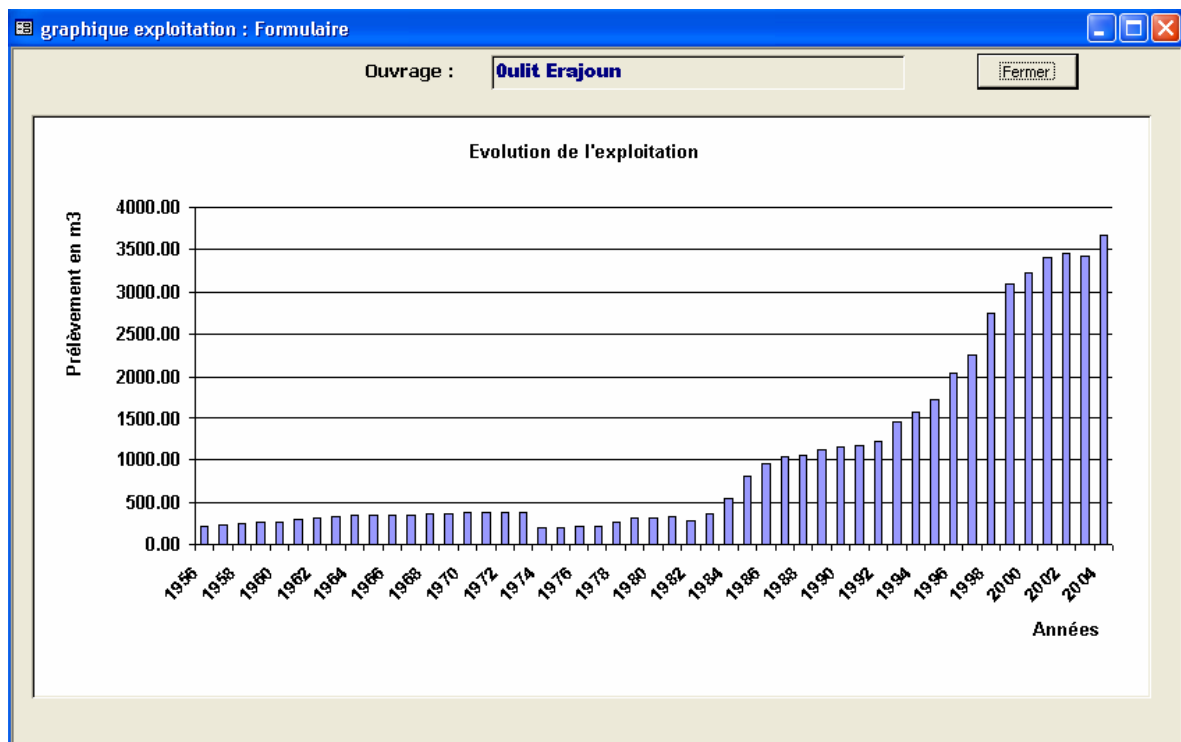
- Vol. Annuel : prélèvement total annuel exprimé en m<sup>3</sup>.
- Origine Info : source de l'information


**Description of columns:**

- Year: year when the withdrawal was observed. A correction is made thanks to the condition: 'year included between the year of the water point realisation and the current year'.
- Annual vol.: total annual withdrawal in m<sup>3</sup>.
- Information origin: Information source.

One can display the chart showing the set by clicking on the Graph key. This leads to the display of the following window:

**Figure 10: Operation graph**



By double clicking on the graph , it is possible to modify the latter's attributes: graph type, titles, colours, and so on.

Closing the graph window is done by clicking on the CLOSE key.

### 3.2.1.1.3- 'Level history' tab

This tab is used for the display, the modification or the creation of a set of levels attached to the current water point (the one which is displayed in the header). It is also a sub-form which includes the following columns:

- Year of measurement (YM): year of measurement

- Static level (SL): Static level in meters (negative sign if artesian)
- \*P Alt : piezometric altitude in meters. This column is calculated either with the help of the water point Z and NS, or directly entered.
- \* Information Origin: source of information

**Figure 11: Level entry form**

	an_mes	NS	ALT_NP	Origine Info
▶	1970	5	190	(projet FAO, 1970)
*				

Enr : 1 sur 1

Graphique NP  
 Graphique NS

It is possible display the PL graphics (piezometric levels) and SL (static levels) by clicking on the keys 'NP Graph' or 'SL Graph'.

#### 3.2.1.1.4- 'Quality history file' tab

This page contains quality data.

**Figure 12: Quality data entry form**

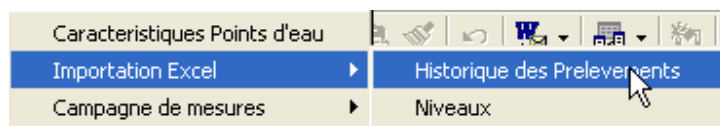
	date	ph	EC	temp	ca	mg	k	Fe2+	Mn	na	HCO32-	co3	cl	NO3	so4	2180	22H	23HTU	14C	13C	Nom_Fichier_Source
▶	1/01/9999	5.9	126		10.7	3.9	5.1	0.1		4.4	57		5.3	1.2	9.8						ANNEXE II-1
*																					

This is also a sub-form containing the following columns:

<u>Date</u> :	Analysis date
<u>pH</u> :	pH values
<u>EC</u> :	Electrical conductivity (Us/cm) at 250° c
<u>Temp</u> :	Temperature in C.
<u>Ca</u> :	Calcium in mg/l
<u>Mg</u> :	Magnesium mg/l
<u>K</u> :	Potassium mg/l
<u>Fe++</u> :	Iron
<u>Mn</u> :	Manganese mg/l
<u>Na</u> :	Sodium mg/l
<u>HCO32</u> :	Bicarbonates
<u>CO3</u> :	Carbonates
<u>Cl</u> :	Chlorine
<u>NO3</u> :	Nitrates in mg/l
<u>SO4</u> :	Sulphate in mg/l
<u>14C</u> :	Carbon 14 (pmc)
<u>13C</u> :	Carbon 13 (pmc)
File-Name-source: file name from which data are imported.	

### 3.2.1.2- Excel import

This option allows the automatic import of available data into Excel format. This concerns the withdrawal and level data.



For each of the two cases, an Excel spreadsheet (model document) is developed. These models should be observed so that the system can read the data.

### 3.2.1.2.1- Import of abstraction time series files

By selecting the 'Withdrawal history file' option, the following form (Fig.13) prompts:

Figure 13: Excel data import form

By clicking on the 'Start' key, data importing from the selected file starts. A gauge shows the evolution rate of the procedure which terminates with an end of processing message.

The Excel document must absolutely have the following format:

Tableau 6: Type of Excel model document for abstractions

Code_Pays	Noclas	Nom	Code_Type	Code_Aquif	Long_dec	Lat_dec	Nom_Admin	1955	1956	....	2004

Country code: 'Ma', 'Ni' or 'Ng'

Noclas: water point identification number

Name: water point name

Code\_Type: water point type code (see table 'Works\_Types')

Aquif code: aquifer code (see table 'aquifer')

Dec long: longitude in decimal degrees (5 decimal numbers at least)

Dec lat: latitude in decimal degrees (5 decimal numbers at least)

Admin name: administrative unit

The following columns should include the withdrawal values, the column headers being years of measurement.

The import procedure follows this rule:

- If the water point exists in the DB, its data are replaced by the ones found in the Excel document (**'points'** and **'tables'**)
- Otherwise, a new water point is created in the **'points'** table with the attributes read in the Excel file. The file history is added to the **'operation'** table.

### 3.2.1.2.2- Level history import

The procedure relating to the import of the level history file is similar to the one for the abstractions. The Excel file format is also similar to the withdrawals ones.

### 3.2.1.3- Measurement campaigns

It is a functionality (Fig.14) developed in the framework of the 'Djeffara1' project which will facilitate periodic data updating without going through the Excel files. This option is particularly useful when a measurement network is set up. Flows (withdrawals) and levels are submitted to the same processing.

Figure 14: Display and entry of a flow measurement campaign

The screenshot displays the 'Mesures de debits' application window. The title bar reads 'Mesures de debits'. The main window has a title 'Campagne de mesure de debits extraits'. Below the title, there are two input fields: 'Nappe : CT' and 'Annee : 1990'. The central part of the window contains a table with four columns: 'Noclas', 'x\_lamb', 'y\_lamb', and 'Prelevement'. The table lists 20 rows of data, with the first row highlighted. To the right of the table, there are two buttons: 'Modification des donnees' and 'Saisie d'une nouvelle campagne'. At the bottom of the window, there are two buttons: 'Enregistrer' and 'Fermer'. The status bar at the bottom indicates 'Enr : 1 sur 563 (Filtré)'.

Noclas	x_lamb	y_lamb	Prelevement
321282	-457517.10	-476109.40	1051.20
321283	-462751.50	-467969.80	168192.00
321284	-467902.50	-481721.20	4204.80
321296	-436992.70	-461777.80	5256.00
321297	-434545.60	-460137.20	12614.40
321298	-427910.70	-459820.80	21024.00
321299	-435021.30	-454424.00	73584.00
321300	-434330.50	-450431.40	75686.40
321301	-434603.60	-449192.50	126144.00
321302	-433113.20	-449841.40	83044.80
321303	-424572.30	-444789.00	34689.60
321304	-418848.80	-444606.30	112478.40
321305	-419482.50	-446132.20	109324.80
321308	-415800.50	-442821.30	100915.20
321309	-412173.60	-442126.70	104068.80
321310	-412173.60	-442126.70	27331.20
321311	-412173.60	-442126.70	104068.80

By selecting the water table, the application extracts the set of water points capturing the groundwater, with coordinates and withdrawal values for the first year of available measures in the DB.

The user can extract data for the set of available years:

- Either by using the Spin key with which can increment or decrement the year.
- Or by typing the year in the text zone.

The 'Data Modification' key

**Modification  
des donnees**

allows access to the withdrawal data to

correct them.

The screenshot shows a software window titled 'Mesures de debits'. Inside, there's a section 'Campagne de mesure de debits extraits'. It features a dropdown menu for 'Nappe' set to 'CI' and a spin control for 'Annee' set to '1956'. Below this is a table with four columns: 'Noclas', 'x\_lamb', 'y\_lamb', and 'Prelevement'. The table lists 12 water points, with the first one, 'Oulit Erajoun', having a withdrawal value of 219.82. To the right of the table are two buttons: 'Modification des donnees' and 'Saisie d'une nouvelle campagne'. At the bottom of the window are 'Enregistrer' and 'Fermer' buttons. A status bar at the very bottom indicates 'Enr : 1 sur 11'.

Noclas	x_lamb	y_lamb	Prelevement
▶ Oulit Erajoun	-680713.30	-142676.40	219.82
Chinazarar	-374095.20	-231845.70	219.82
Ekkineouane	-435477.70	-194265.30	219.82
Fogha	-599973.90	-178780.50	219.82
IN HINITA	-643510.50	-179069.50	219.82
IN HINITA FP1	-643512.90	-179071.80	219.82
Ouarissibitil	-421423.80	-82039.57	219.82
Ouritoufoulout	-526607.60	-183382.50	219.82
Tarara Est	-421423.80	-82039.57	219.82
Tin El Bagara N°2	-437070.10	70470.51	219.82
X-Ni_0418	-626146.70	-161337.50	219.82

The cursor is set on the withdrawal values so that it can ultimately modify them. When the corrections are completed, the user can:

- save the modifications by clicking on the 'Save' key.
- cancel them by clicking on the 'Close' key.

It is possible to enter a new campaign (New Year) by clicking on the 'Entry of new campaign' key

**Saisie d'une  
nouvelle  
campagne**

In this case, the application requests the user to enter the year for which he wishes to introduce the flows.

Annee : 1971

Note that the application displays a value by default in the text zone. This value is equal to the current year incremented to 1.

### 3.2.2- Data display

Data display is secured in the IAS common database, thanks to the explorer, either by tabular mode, or cartographic mode.

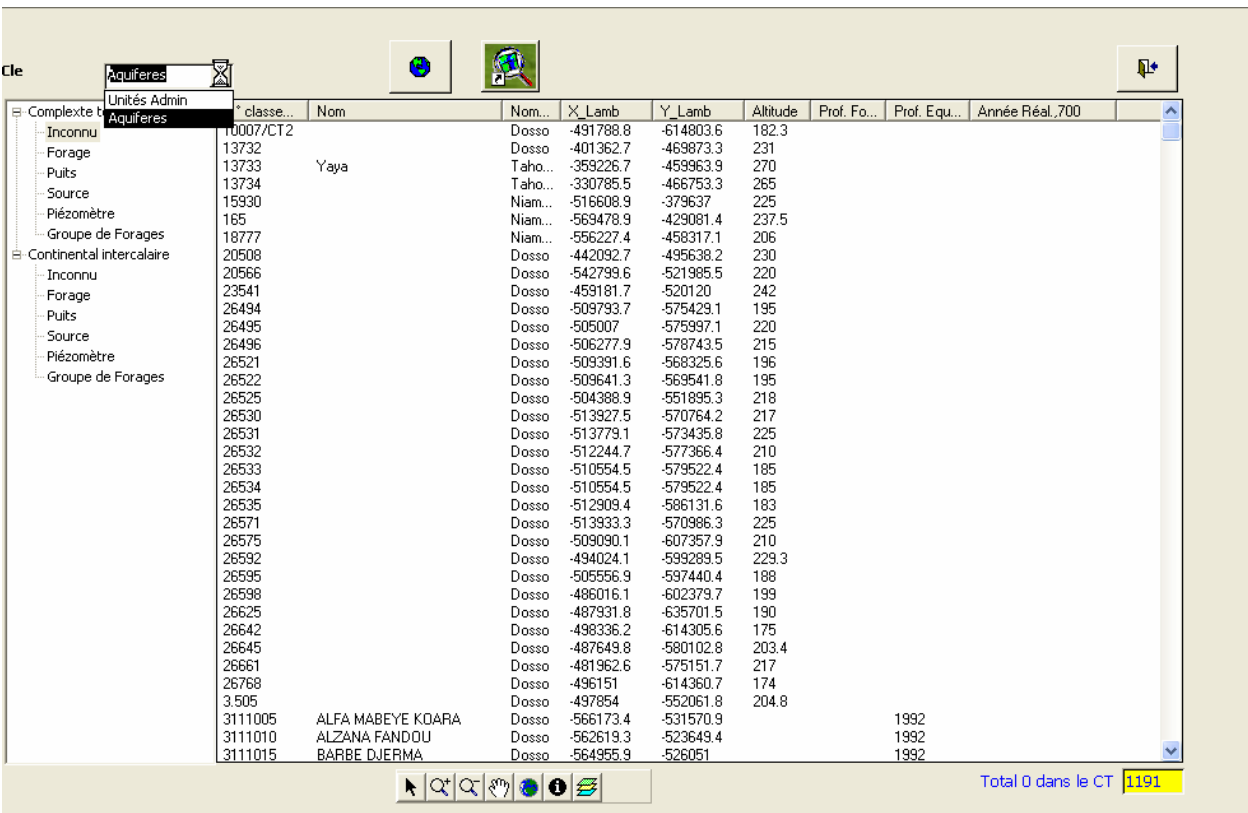
#### 3.2.2.1- The explorer

It allows for water point data display and search, according to various criteria. Two display modes are possible:

##### 3.2.2.1.1- Tabular mode

The displayed data are digital values presented in the form of a listview (Fig.15)

Figure 15: fenêtre d'exploration (mode tabulaire)



	* classe...	Nom	Nom...	X_Lamb	Y_Lamb	Altitude	Prof. Fo...	Prof. Equ...	Année Réal.,700
Inconnu	10007/CT2	Dosso	-491788.8	-614803.6	182.3				
Forage	13732	Dosso	-401362.7	-469873.3	231				
Puits	13733	Yaya	-359226.7	-459963.9	270				
Source	13734	Taho...	-330785.5	-466753.3	265				
Piézomètre	15930	Niam...	-516608.9	-379637	225				
Groupe de Forages	165	Niam...	-569478.9	-429081.4	237.5				
Continental intercalaire	18777	Niam...	-556227.4	-458317.1	206				
Inconnu	20508	Dosso	-442092.7	-495638.2	230				
Forage	20566	Dosso	-542799.6	-521985.5	220				
Puits	23541	Dosso	-459181.7	-520120	242				
Source	26494	Dosso	-509793.7	-575429.1	195				
Piézomètre	26495	Dosso	-505007	-575997.1	220				
Groupe de Forages	26496	Dosso	-506277.9	-578743.5	215				
	26521	Dosso	-509391.6	-568325.6	196				
	26522	Dosso	-509641.3	-569541.8	195				
	26525	Dosso	-504388.9	-551895.3	218				
	26530	Dosso	-513927.5	-570764.2	217				
	26531	Dosso	-513779.1	-573435.8	225				
	26532	Dosso	-512244.7	-577366.4	210				
	26533	Dosso	-510554.5	-579522.4	185				
	26534	Dosso	-510554.5	-579522.4	185				
	26535	Dosso	-512909.4	-586131.6	183				
	26571	Dosso	-513933.3	-570986.3	225				
	26575	Dosso	-509090.1	-607357.9	210				
	26592	Dosso	-494024.1	-599289.5	229.3				
	26595	Dosso	-505556.9	-597440.4	188				
	26598	Dosso	-486016.1	-602379.7	199				
	26625	Dosso	-487931.8	-635701.5	190				
	26642	Dosso	-498336.2	-614305.6	175				
	26645	Dosso	-487649.8	-580102.8	203.4				
	26661	Dosso	-481962.6	-575151.7	217				
	26768	Dosso	-496151	-614360.7	174				
	3.505	Dosso	-497854	-552061.8	204.8				
	3111005	ALFA MABEYE KOARA	Dosso	-566173.4	-531570.9		1992		
	3111010	ALZANA FANDOU	Dosso	-562619.3	-523649.4		1992		
	3111015	BARBE DJERMA	Dosso	-564955.9	-526051		1992		

Total 0 dans le CT 1191

One can choose to sort data:

- by country and administrative unit
- by aquifer and water point type

This is done by scrolling the choice list of the browsing key to select one of the two criteria.

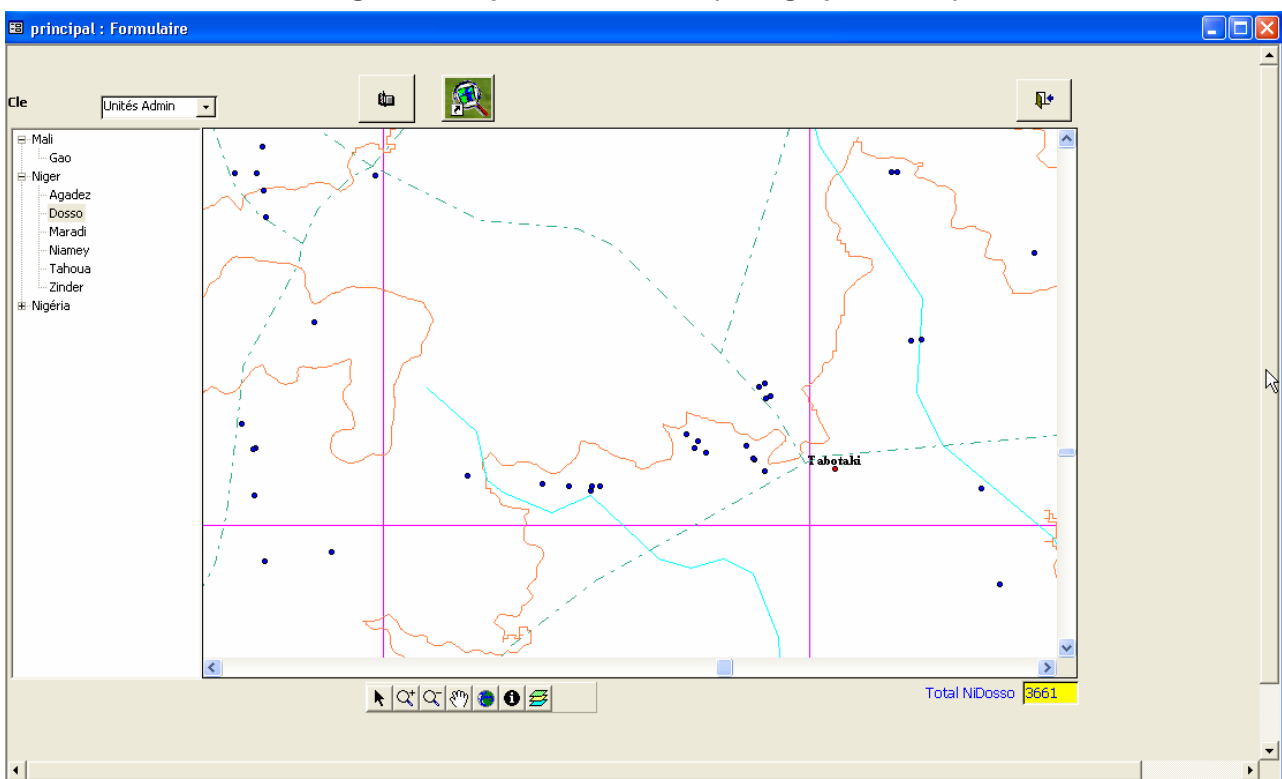


The by-default display is done by administrative unit.

### 3.2.2.1.2- Cartographic mode

In this mode, the listview is replaced by a cartographic window which displays the GIS ground layers on which the water points are superposed. The data representation of the latter is done from the '**points**' table; that is to say, the potential modifications of the water point coordinates automatically affect the window card.

Figure 16: Exploration window (cartographic mode)





The toolbar allows for performing the following basic GIS software tasks:








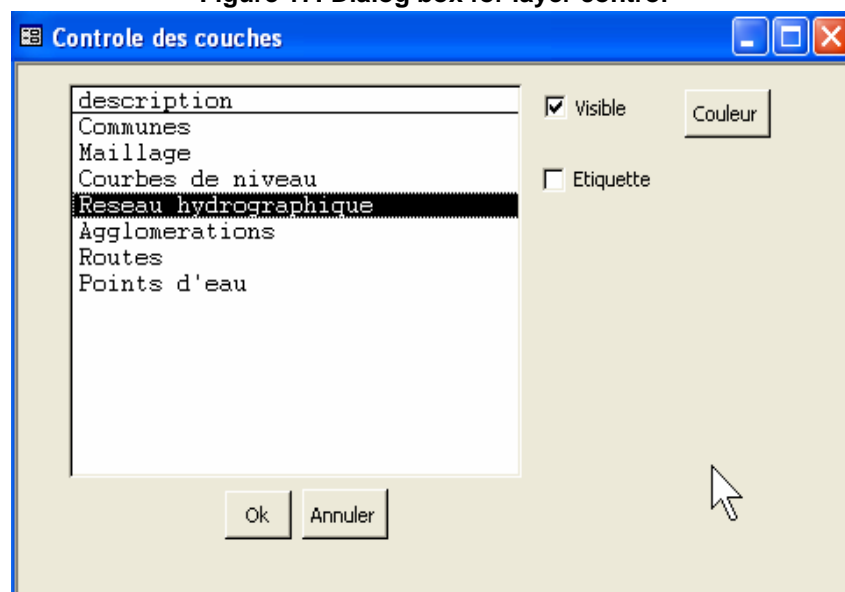
-  Customized zoom (rectangle with the help of the mouse)
-  1.5 highlighted zoom. Select the key and click once on the card window.
-  0.5 highlighted zoom. Select the key and click once on the card window.
-  Panning (moving and re-centring on a zone). Works when a zoom-in has been made
-  Full extension: 100% zoom (display of all the layers in the card window)
-  Water point identification. By clicking on a water point, the '**General Data**' form is loaded with information on the selected water point.
-  Control of layers (change the layer display attributes). By clicking on this key, the following form is displayed:

Figure 17: Dialog box for layer control



The '**Visible**' box to tick allows for displaying the selected layer or not.

The '**Label**' box to tick is used to display or not the labels concerning the selected layer. The displayed text depends on the configuration (see table 'GIS layers'). To change the text which appears as a label, this table should be opened and the 'chp-label' value should be modified.


**Caution: The field should first be available in the allotted table linked to the layer.**

The 'colour' key allows for modifying the display colour of the selected layer. By clicking on the key, the dialog box of colour choice prompts and one can choose the display colour of the selected layer.



**Important: These changes are valid only during the session and are not then saved.**

#### 3.2.2.2- ArcView Project

The key  allows for loading ArcView and the main project containing the set of layers in order to possibly modify them or do layouts.

#### 3.2.3- Links with the PM5 simulation model

This option is used to perform the data preparation tasks for the PM5 hydro-geological simulation model:

- Allocating a grid number to all the water points inside the zone.
- Recharge entry.
- Creation of PM5 documents for keying and simulations.

##### 3.2.3.1- DB – GIS – Model interface

The advantage of resorting to specific databases in the case of aquifer systems shared by two or more countries is to use this tool as an elementary means to harmonise and homogenise data. Through the links established between this database and the models, the required data for model setting and operation are directly channelled from the DB to the model. In addition, the model processing results can be directly restored to the DB without any risk of alteration or distortion. On the other hand, the links between the DB and GIS make it possible to recover data from the database as well as the model results to secure exits and graphic or cartographic representations. The elaboration of these links is the shared task of the IASIS computer

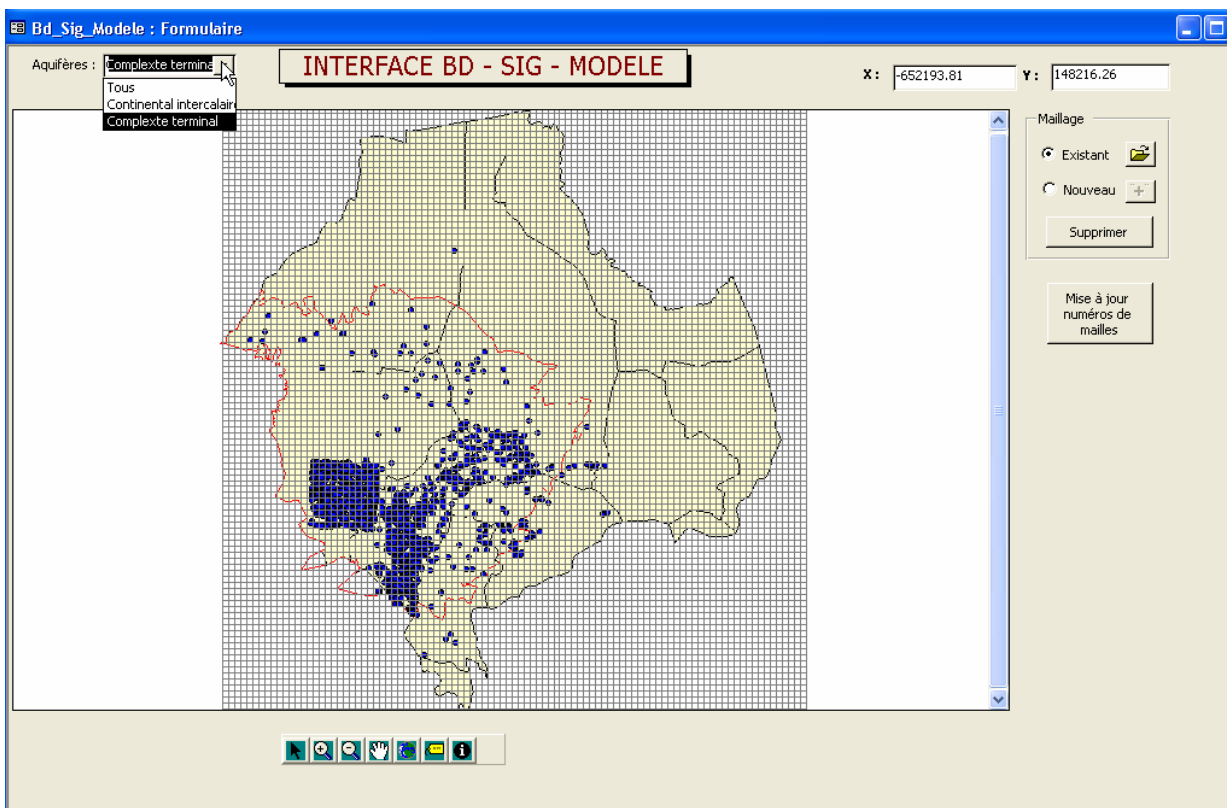
manager and the aquifer system modelling engineer. These links meet the requirements of the different functionalities in both digital systems and facilitate establishing an integrated data processing and management system, leading to the development of decision aid products for aquifer system managers.

### 3.2.3.1.1- Gridding generation

The module (Fig.18) is used to make the following processing operations:

- generate a gridding.
- allot a gridding number to the water point.
- check withdrawals per gridding.

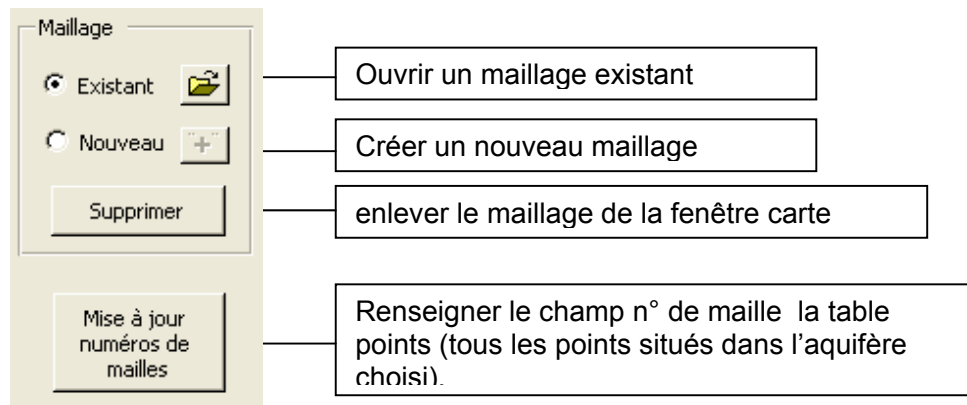
**Figure 18: Form for generating gridding and 'points'-'model' link**



### Procedure

When we select an aquifer, the programme displays the corresponding GIS layer, followed by the set of points belonging to the aquifer.

Secondly, we display the model gridding. We can open an existent gridding (search for it in the \\ullemeden\GIS\ document) or create a new one.



If we click on the '**New gridding**' option, the key is activated. This key is used to load a dialog box in order to enter the new parameters for the gridding to be created.

**Figure 19: Form for entering the parameters of a new gridding**


The dialog box is titled 'param\_maillage : Formulaire' and contains the following fields and controls:

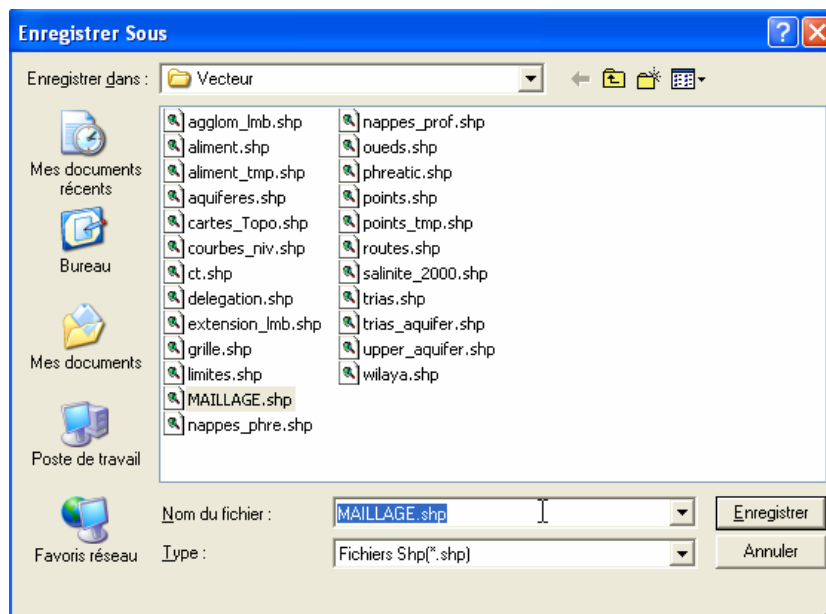
- X 'origine :** Text box with value 807553.9
- Y origine:** Text box with value -844786.3
- Nombre de mailles ex X :** Text box with value 97
- Nombre de mailles ex Y :** Text box with value 100
- Angle en °**: Text box with value 0
- Taille des mailles en mètres**: Text box with value 10000
- Limites du maillage :** Dropdown menu
- Nom du fichier SHP :** Text box with a folder icon button next to it
- Buttons:** 'Lancer' and 'Annuler'

### Significance of the form fields

X origin:	X of the origin of gridding in the Lambert south coordinate system.
Y origin:	Y of the origin of gridding in the Lambert south coordinate system.
X nb of griddings:	Gridding number by X axes (lines)
Y nb of	

griddings: Gridding number by Y axes (columns)  
 Angle: Gridding orientation angle  
 Size: Gridding size in meters  
 Gridding limits: Polygon-type extension if we want to cut off the gridding (optional).  
 SHP file: SHP file access path and name which will be developed ('**grd\_map**' by default). We can, however, provide another name). Note that the name used in the programmes is 'gridding'.

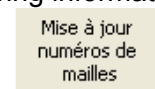
We can enter the file access path and name in the text zone or click on the key  which displays the file saving dialog box.



The 'Start' key triggers the gridding generation module execution.

### 3.2.3.1.2- Allocation of gridding numbers


This functionality is used to update the 'points' table by entering information in the 'grid' column. This is done by clicking on the key 'Updating grid numbers'.

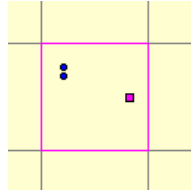


A geographical processing is therefore launched which affects at each water point the grid number in which it is located.

### 3.2.3.1.3- Checking tasks


In addition to the usual functionalities of the GIS software (Zoom, Pan,), the toolbar has additional keys whose task is to help the user with data control during the model keying stage.

The  key activates the grid selection on the drawing. By clicking on a grid, its colour changes.



Its grid number and the corresponding PM5 number are displayed at the same time as the water point list located in the grid:

Maille :

Num. PM5 :  

XNG\_25


XNG\_26

XNG\_31

XNG\_32

Grid sequential number. This is the value that identifies the grid.

List of water points belonging to the selected grid. By double-clicking on a point, the 'General Data' prompts and one can consult or edit the data.

One can also select a grid if one knows its PM5 number by clicking on the  key.

The following dialog box prompts:

Recherche maille PM5

Entrer Ligne et colonne séparées par '-'

OK

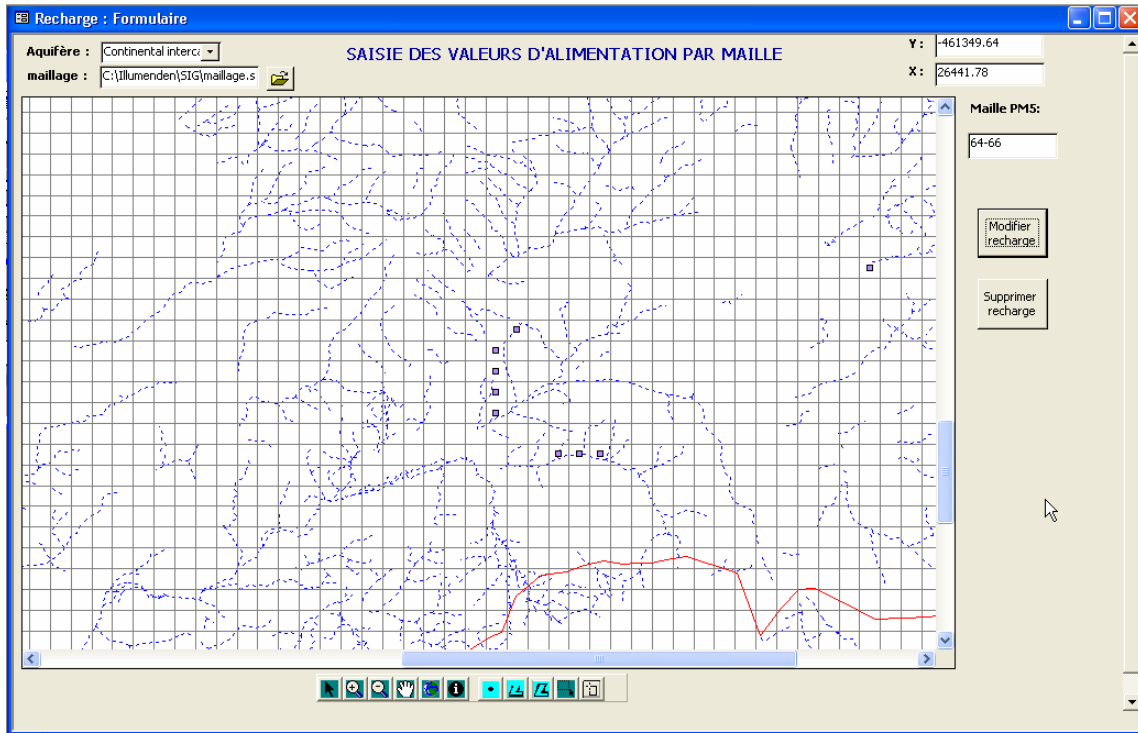
Annuler

By clicking on 'OK', one obtains the same result as a selection on the card window (grid colour change and list of the included points).

### 3.2.3.2- Recharge entry

The 'Recharge Entry' option launches the following form (Fig. 20):

Figure 20: Form for recharge graphic entry




At the launch of the form, the zone hydrographical stream is displayed.

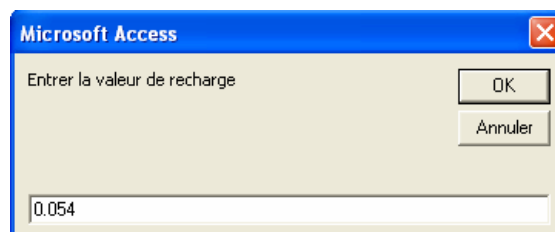
#### Procedure:

- Choose an aquifer. At this moment, the corresponding layer is loaded then added to the card window.
- Open the gridding.
- Enter the values:
  - By point (one single grid).
  - By line (set of cell intersecting with the line).
  - By polygon (set of grids touching the polygon).
- 


#### Toolbar


 Displays the selected cell number (PM5 number)


 Creates a point. The cell is highlighted. To enter its recharge value, click right. A dialog box prompts.




Enter the recharge value in the text zone and click on '**OK**' to validate or '**cancel**'.  
This value is allocated to the grid that was clicked. The point is also added to the GIS layer.

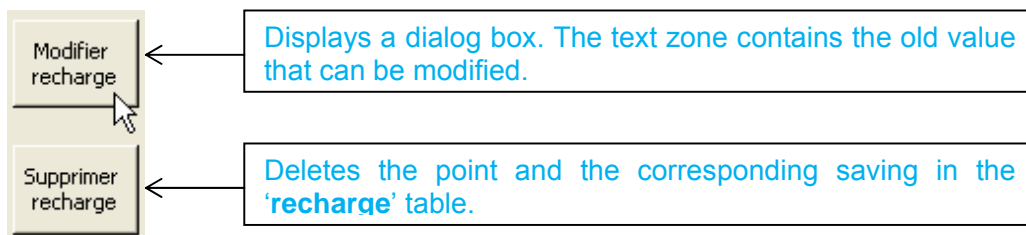
 Creates a line by moving the mouse and clicking to add a vertex. To end, double click.  
At this moment, all the grids which intersect with this line are highlighted (magenta colour)

 Draws a polygon: each click adds a vertex. To end, double click.

 Allows for selecting a set of points by drawing a polygon. Once the polygon is drawn with the help of some vertexes, all the recharge points are highlighted (in magenta.)

 Allows for selecting a recharge point. This point is displayed in magenta.

In performing one of these selections, two keys are displayed in the right part of the form:



#### 3.2.3.3- Transfer to PM5

This last option allows for automatically generating the WEL and OBS documents in order to start PM5 by using the information stored in the DB (Fig. 21).



Figure 21: PM5 data transfer form

PM5

Transfert des données vers PM-5

Noclas	Nom	Type	X_Lamb	Y_Lamb	aquifere	NOBS
18782	Gao	1	-534296.8	-410105	CI	2
343015	SABON BIRNI	1	-490510.8	-673421.1	CI	2
42600	Digdiga	1	-444024.8	-266365.8	CI	2
8457	Abala	1	-506354.7	-334339.6	CI	2
Ibeceten	Ibeceten 1	1	-238645.5	-304626.7	CI	2
Tassara	Tassara	1	-262519.3	-127290.1	CI	2
XNG_1	ISA-DUGWELL	1	-181872.3	-529339.1	CI	2
XNG_10	GORONYO	1	-261919.4	-503743.9	CI	2
XNG_11	GADA	1	-317775.2	-467153.8	CI	2
XNG_12	RAFIN DUNA	1	-274227.6	-455791.3	CI	2
XNG_13	GIDAN CIWAKE	1	-287952.1	-467615	CI	2
XNG_14	ILLELA	1	-301536.6	-469259.9	CI	2
XNG_15	NAMMAN SU...	1	-300049.7	-490246.8	CI	2
XNG_17	KWARE	1	-304246.7	-527499.6	CI	2
XNG_2	ISA	1	-182482.3	-530550.3	CI	2
XNG_21	SOKOTO YAU...	1	-310618.8	-548225.7	CI	2
XNG_22	SOKOTO YAU...	1	-310618.8	-548225.7	CI	2
XNG_24	BARAN ZAKI	1	-273598.4	-518696.6	CI	2
XNG_25	WURNO N*3	1	-289173.5	-519861.4	CI	2
XNG_26	WURNO N*1	1	-289173.5	-519861.4	CI	2
XNG_27	GIDAN TUDU	1	-278864.3	-527876.4	CI	2
XNG_28	G.G.S.S. RAB...	1	-280520.4	-538033.2	CI	2
XNG_29	ACIDA	1	-291326.5	-532631.3	CI	2
XNG_3	SHINKAFE B...	1	-171121.7	-544843.4	CI	2
XNG_30	KANDAN	1	-298032.1	-536232.9	CI	2
XNG_31	CHINOLA N*1	1	-295486.3	-517762.6	CI	2
XNG_32	CHINOLA N*2	1	-295474.7	-516991.6	CI	2
XNG_34	LAMBA BAKU...	1	-239832.8	-598757.8	CI	2

Débits par maille (PM5)

Boreholes

Observations

Quitter

Période Historique

An début :  Ok

An fin :

The form displays the list of water points having at least two-level values, so that they can ultimately be transferred to the 'PMWIN5000\_BOR\_FILE' file' (This will make it possible to compare the two observed levels and those quantified by PM5).

#### Displayed columns

NoClass: Water point identification number.  
 Name: Water point names.  
 X Lamb: X Lambert in meters.  
 Y Lamb: Y Lambert in meters.  
 Aquifer: Aquifer code where the water point is located.  
 Nobs: Number of measure levels made on the water point.

Débits par maille (PM5)

By clicking on the key the application launches a request which allows for listing the model grids and the set of water point flows which they contain.

PM5

## Transfert des données vers PM-5

Année	Couche	Ligne	Colonne	debit
1956	1	33	25	5.37211177676901E-02
1956	1	34	32	8.05816766515352E-02
1956	1	35	8	0.026860558883845
1956	1	37	34	5.37211177676901E-02
1956	1	38	8	0.026860558883845
1956	1	38	16	0.026860558883845
1956	1	38	20	0.21488447107076
1956	1	39	5	0.026860558883845
1956	1	39	7	5.37211177676901E-02
1956	1	39	14	8.05816766515352E-02
1956	1	40	31	0.026860558883845
1956	1	40	34	0.026860558883845
1956	1	41	22	0.026860558883845
1956	1	41	26	8.05816766515352E-02
1956	1	41	30	0.026860558883845
1956	1	41	32	5.37211177676901E-02
1956	1	42	26	8.05816766515352E-02
1956	1	44	17	5.37211177676901E-02
1956	2	9	38	6.97042251346923E-03
1956	2	24	39	1.39408450269385E-02
1956	2	30	13	6.97042251346923E-03
1956	2	32	19	6.97042251346923E-03
1956	2	32	38	6.97042251346923E-03
1956	2	34	17	1.39408450269385E-02
1956	2	34	21	6.97042251346923E-03
1956	2	34	29	6.97042251346923E-03
1956	2	35	38	6.97042251346923E-03
1957	1	33	25	5.55892510803625E-02

Débits par maille (PMS)

Boreholes

Observations

Quitter

Période Historique

An début :

An fin:  Ok

### Signification des colonnes affichées :

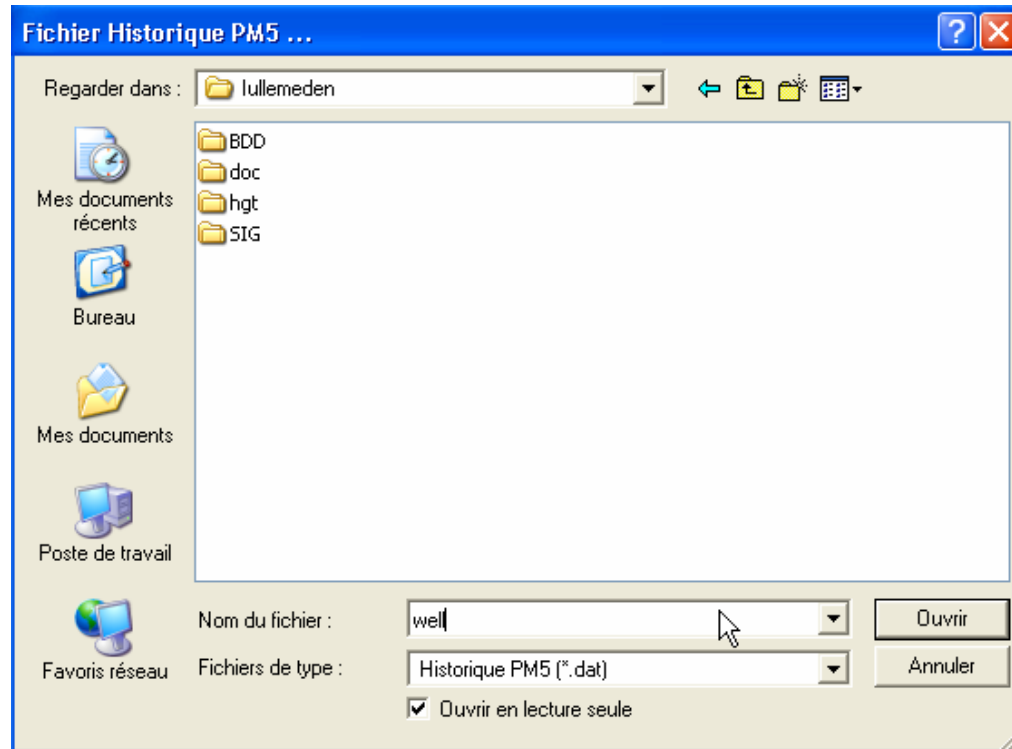
Année : Année de la mesure  
Couche : numéro de couche (CT = 1 ; CI = 2)  
Ligne : numéro de ligne de la maille  
Colonne : numéro de colonne de la maille  
Débit : valeur du débit (somme des débits des points d'eau)

Dès que la liste est affichée, les zones de texte « **Année début** » et « **An fin** » sont activées. Une fois renseignée la période (années début et fin) et en cliquant sur Ok, l'application fait apparaître la boîte de dialogue d'enregistrement de fichier

### Significance of the displayed columns

**Year:** Year of measurement  
**Layer:** Layer number (TC=1; IC=2)  
**Line:** Grid line number  
**Column:** Grid column number  
**Flow:** Flow value (sum of water point flows)

As soon as the list is displayed, the 'Starting year' and 'Ending year' text zones are activated. Once informed about the period (starting and ending years) and by clicking on 'OK', the application shows a file saving dialog box.



The user enters a new file name or selects an existing file (Caution: the one which is going to be crashed). By clicking on 'Open', the application starts to generate a file containing the flow values by grid. These values constitute the algebraic sum 'Recharge-Withdrawal'.

#### 4- CONTENT SYNTHESIS (DB AND GIS)

The project has made it possible to collect, format and homogenise the set of existing IAS information. In fact, a relational, coherent, and scalable database structure allowing for an easy data processing was set up at the level of the three countries.

Among the most important benefits of the established system, one can cite:

- A common database for the whole basin: structure, codification, processing procedures.
- The country experts properly master the operational tools, thus facilitating the continuous system updating and modernising.
- A common geographic reference shared by the three countries: projection system, basic layers, DEM, ....

For once, the set of information specific to the IAS aquifer is harmonised and shared by the three administrations managing the basin water resources. This information is accessible in forms facilitating direct exploitation and is adapted to modelling. This information is thus used to help with decision making on basin water resource development planning. Its adaptation to

mapping at the catchment area scale, as well as the possibilities of its processing for the IAS aquifer hydrodynamic operation simulation, provides it with an added value in relation to its status in the three countries' national databases.




#### **4.1- The common database**

The IAS common database is the central element of the information system of this hydrogeological entity. Thus, it is a link in the components of the decision aid system for consultations between the three countries with a view to securing the best management and planning of the basin water resources. After describing in detail the structure in the previous chapter, we shall now deal with the contents, i.e. the set of data collected either by the country teams or the OSS team.

##### **4.1.1- Water point characteristics**

The building up of a common IAS database structure on the 'water point' is justified by the importance and the information diversity to which it is attached. The 'water point' in its most general sense (climatologic station, gauging sites, catchment area or groundwater exploitation) is an essential key in accessing information in its spatiotemporal reference. Special significance is given, according to data tables, to the water points related to underground water, given that the IAS aquifers are the subject matter of a major analysis targeted by hydrogeological risks. These water points (wells, drillings, boreholes, sources, etc.) are the access point to the physical and hydraulic knowledge on these aquifers. The other water points specific to the identification of climate or hydrologic data enable us to better grasp the water exchanges between the aquifer system and its environment.

The total number of water points collected and included in the '**points**' table of the IAS common DB is **17171**. This number mainly deals with:

-  Drillings and wells collected by the three administrations managing basin water resources.
-  Drillings having served for geological treatment whose major part is gathered in the countries and the additional part is drawn from the available studies.
-  Other developed water points, such as oil boreholes, because they provide useful information to aquifer knowledge like transmissivity, water quality data, data on the piezometric level of water tables and water points...


The accumulation of such information does not miss reflecting some redundancies resulting from the diverse data collection sources. This is the price to pay to have all the available data and useful information in the DB. One of the tasks of information updating, implemented within the project's framework, is to analyse and process data with the aim of avoiding redundancies and harmonising the proper presentation formats.

**Tableau 7: Filling rates of key fields**

Field	Informed recordings	%		Field	Informed recordings	%
<b>Name</b>	16151	94.06		<b>State</b>	0	0
<b>Type</b>	17171	100		<b>Artesian</b>	17171	100
<b>Aquifer</b>	2671	15.56		<b>Equip.</b>	17171	100
<b>Admin</b>	17135	99.79		<b>Drilled_depth</b>	14898	86.76
<b>Longitude</b>	17170	99.99		<b>Equip_depth</b>	13782	80.26
<b>Latitude</b>	17170	99.99		<b>QEX</b>	13302	77.47
<b>Altitude</b>	7860	45.77		<b>NS</b>	14855	86.51
<b>Usage</b>	12572	73.22		<b>Grid</b>	2609	15.19
<b>Year</b>	5089	29.64				

The entry systematisation and data harmonisation meant that several common DB fields were informed:

 Automatically: administrative unit (by GIS), grid...

 By request: usage code, country, sce\_year

This resulted in duplicating identified water points under different codes while referring to the same geographical areas. It is only through an extended information analysis that it becomes possible to identify such duplication and limit the attached errors.

#### *4.1.1.1- Distribution by administrative unit*

The geographical information distribution is a basic option which allows its subsequent identification given that this approach is the one used by the administration to classify water points and follow up water resources in these aquifers. The choice of the basic administrative unit is dictated by the country's adopted administrative classification, while bearing in mind the need for scale harmonisation among countries to avoid providing too many details or lacking accuracy in the data restitution for the different applications used within the project's framework. Given the basin size, it was decided to use the department as a basic administrative subdivision.

Table 4, below, provides the water point numbers, all types included, by administrative unit, for the three countries.

**Tableau 8: Water points by administrative unit**

Country	Administrative Unit	Number of points
Non-identified	Non-identified	36
Mali	Gao	734
Niger	Agadez	95
	Dosso	3635
	Maradi	4039
	Niamey	4138
	Tahoua	3046
	Zinder	1148
Nigeria	Katsina	26
	Kebbi	95
	Sokoto	179
<b>IAS Total</b>		<b>17171</b>

This situation shows only one state of the database at a given date (January 2007). It is scalable depending on the countries teams' new data contribution. This state is considered as the culmination of an effort made over a period of more than two years to collect data in these countries. Such data have been used for elaborating the hydrogeological simulation model.

The number of water points not attached to a given country among the three IAS sharing countries is relatively reduced in relation to the total number of water points (2‰). It translates the effort to identify these water points whose number is relatively high. The distribution of these water points among the three countries should be taken with great care given that the basin area proper to each country and the significance of aquifers varies from one country to another. It is not, then, expected that a certain correlation between the number of water points and the geographical extension of the basin by country exists. Similarly, the three countries are not expected to have relatively comparable water point density. But it is evident that Niger, where more than 80% of the IAS basin is located, includes the largest number of identified water points (93.7%).

### **Distribution by aquifer**

Water point aquifer codes were allocated by OSS in the presence of experts from the countries because some work was done to homogenise the local litho-stratigraphic formations. This field is essential for water points with a withdrawal history.

The following table shows that about 85% of the basin water points are not attached to a given aquifer. This is because the entry of water points included in the database was systematically done (water resource card) on the basis of sources not taking into account the key significance of this specification. For modelling purposes, the allocation of water points by aquifer was done on the basis of geographical location, intersecting formations and the reached depth.

**Tableau 9: Water point by aquifer**

<b>Aquifer Code</b>	<b>Aquifer name</b>	<b>Number of points</b>
CI	Continental Intercalaire	275
CT	Continental Terminal	2396
Unknown		14500
<b>IAS Total</b>		<b>17171</b>

#### 4.1.1.2- Distribution by type

The water point type is a characteristic essentially used for purely statistical purposes to qualify the hydraulic infrastructure of the IAS groundwater mobilisation. In this case, we note the absence of springs which are natural appearances in underground water. This can be explained by the confined aquifer feature and the reduced role of tectonic accidents in the emergence of water of the basin different aquifers.

The predominance of surface wells (60.1%) in the number of identified points (Table 8) is due to the fact that they constitute the hydraulic infrastructure that is best adapted to the basin's operating conditions. In fact, since drillings are more costly and less mastered as a water mobilization technique in a good part of the basin, their percentage is relatively low (25.3%). The drilling groups are a device used when it is hard to have a representation of a large number of drillings and to the extent that these water points are not properly identifiable on the map. This was the case with drillings in Nigeria where the specific relevant information does not include the geographical details to locate them. It is for this reason that they were included in the form of drilling groups linked to the local area whose name they bear (usage destination).

**Tableau 10: Water points by type**

<b>Point Type</b>	<b>Number of points</b>
Non-identified (14%)	2463
Drilling	4346
Drilling group	12
Piezometer	20
Wells (60.1%)	10330
<b>IAS Total</b>	<b>17171</b>

#### 4.3.1.3- Water points with a history

The historical data (series) on piezometry, operation and water chemical quality are basic information for the setting of the hydrogeological simulation models. It is then important to identify the water points with some history in relation to these three variables. The historical background relevant to the hydrodynamic features underlines the hydraulic test frequency of these water points.

Table 7, below, provides, for each aquifer, the number of points having at least one recording in each of the tables. If we take the example of piezometry levels, we have:

- 42 water points, whose aquifer code is not available, and which have at least one level observation.
- 200 water points in CI and 296 in CT, which have at least one level measurement.

**Tableau 11: Number of water points with at least a history**

Aquifer	Operation	Piezometry	Hydrodynamics	Quality
Unknown	0	42	2	24
CI	162	200	81	0
CT	629	296	15	0

We note that as far water quality is concerned, none of the 24 water points with measures is informed by the 'aquif \_ code' field.

The data in this table show a main gap in the implementation of the IAS common database. In fact, out of the 17,171 identified water points, only 8% are likely to serve in following up the historical backgrounds of piezometric levels or the required implementation for levelling the hydrodynamic simulation in transitory mode. This big gap suggests that the information collected in this way can only be used for levelling the model in permanent mode. The quantitative indicators on the operation development or the piezometric decline of the different aquifer levels are reduced and show that hypotheses referring to variables indirectly related to water usage (population, livestock, and irrigated areas) are required to trace exploitation evolution or the piezometric decline over time.

#### 4.3.2- Withdrawals

The withdrawals from the aquifers reserves or operation are a key element of the required information for operating the hydrogeological simulation model of the IAS dynamic operation. The relevant data are complex and require an accurate identification of the exploited water points, type of exploitation (by artesian pressure or pumping), and operation duration (by day, season, or during the works lifetime). Such identification can only be secured with the help of a well-structured management, which allots the necessary means for a proper follow-up in order to make regular or periodic measurements - which is not the case in the three IAS-sharing countries. In fact, the information relevant to exploitation evaluation in the IAS framework has never been the subject of a detailed and exhaustive quantitative analysis. It has always been superficial and partial. The obtained specific data are rudimentary, fragmentary and insufficient to ensure a satisfactory evaluation. Thus, the common database suffers from specific gaps and



requires a better analysis of the existing data in the three countries to deduce information capable of partially overcoming the flagrant measurement gaps.

The database structure requires that withdrawals are attached to water points. However, the little available information on this variable is rather provided in a synthetic way (annual volume by usage sector) and differs from one country to another.

- For Nigeria, the global withdrawals are provided by province and usage (domestic usage, animal husbandry)
- For Mali, the global withdrawals are given by usage (livestock, nomads, sedentary)
- For Niger, the operation volumes are provided by water point, but it is not necessarily the instant withdrawal flow. In many cases, the filing numbers as well as the captured aquifers have not been sufficiently informed to identify the operation unitary flows.

The aim of this processing is to establish an operation history file (1970-2004) by water point on the basis of the collected information. For such reason, the following approach was adopted:

- Distribute the total withdrawals by water point for Mali and Nigeria, thus supposing that the 'aquifer' and 'unite\_admin' fields 'are informed.
- Allocate an annual withdrawal value to the water points in Niger on the basis of the operation flow and an average uniform operation duration of 4 hours per day.

The 'Operation' table was produced according to the following approach:

- Acquisition of the 'Code\_Admin' field from the GIS.
- Allocation of the aquifer code (CI or CT) to the water points, according to the field value 'Aquif\_CI-CT:

- If 'Quat',

- If the points are inside the intersection **CI-CT**, the value of CODE\_AQUIF=CT

- Otherwise,

- If the holes are in CI, the value of CODE\_AQUIF=CI
- Otherwise the value of the CODE\_AQUIF=TC

If 'Palz' or 'BASE' or 'Aquitard', the value of the CODE\_AQUIF=Null

- Distribution of total withdrawals by water point with the help of an ACCESS request, for the Nigerian and Malian parties.
- For Niger, we applied the following rule:
  - A request calculating the annual withdrawal from the operation rate on the basis of usage duration of 8 hours per day. This calculation only affected the water points whose realisation year is known. In the absence of the unit, we considered that the flow is expressed in litres/seconds.
  - Filling up the 'operation' table from an 'Addition' request after conversion in m3/year.

After processing, the 'operation' table is filled in the manner required by the DB structure

#### 4.3.2.1- Withdrawal distribution per aquifer and administrative unit

The request aimed at presenting the withdrawals on the IAS water reserves per country and aquifer shows an identification gap of some water points which could not be allocated to a given aquifer level. The withdrawals amounting to 1.55 hm<sup>3</sup>/year (1.4% of total withdrawals) are relatively negligible and the indeterminacy of their allocation to one of the three countries does not seem to alter the significance of the findings especially that this volume was allocated to the TC aquifers.

On the whole, CI operation (65.31 hm<sup>3</sup>/year) in the three countries is only 62% of CT operation (105 hm<sup>3</sup>/year). Such observation confirms a greater accessibility of the TC aquifers to operation than the CI ones, which is in relation with the most extended type of mobilization works (wells).

The CI water table operation is more extended in Nigeria (57.39 hm<sup>3</sup>/year) than in the other two countries. Here, the required groundwater mobilisation works are less deep (drillings of less than 100 m depth). The same applies to the CT groundwater (Nigeria: 60.21 hm<sup>3</sup>/year). But in this case, the Niger operation is equally important (42.68 hm<sup>3</sup>/year). The IAS operation in Mali is relatively negligible and needs to be further checked.

The percentages included in Table 8, below, on IAS aquifer operation in the three countries can be explained by two parameters:

- Greater accessibility of CT aquifers in Niger and CI aquifers in Nigeria, given that the depth of catchment works is relatively weak.
- Demographic density and various usages (Water supply, irrigation, livestock and industry) are more developed in Nigeria and Niger.

**Tableau 12: Samples per aquifer and administrative unit**

Aquifer	Country	Administrative unit	Vol (hm <sup>3</sup> /year)
CI	Mali	Gao	0.03
	Nigeria	Katsina	7.67
		Kebbi	19.14
		Sokoto	30.58
		<b>Total Nigeria</b>	<b>57.39</b>
	Niger	Dosso	0.57
		Maradi	0.21
		Tahoua	7.10
		Zinder	0.01
		<b>Total Niger</b>	<b>7.89</b>
CT	<b>IC Total</b>		<b>65.31</b>
	Inconnu	Inconnue	1.55
	Mali	Gao	0.56
	Nigeria	Kebbi	24.17
		Sokoto	36.04
		<b>Total Nigeria</b>	<b>60.21</b>
	Niger	Dosso	29.34

	Niamey	1.84
	Tahoua	11.53
	<b>Total Niger</b>	<b>42.68</b>
<b>Total CT</b>		<b>105.0</b>
<b>Total CI+CT (hm<sup>3</sup>/year)</b>		<b>170.31</b>

We note that some water points totalling up a withdrawal of 1.55 hm<sup>3</sup> do not belong to any administrative unit.

#### 4.3.2.2- Total withdrawals per administrative unit

These are total CI and CT withdrawals per administrative unit in each country. The number of points providing this volume is equally displayed, as well as the ratio of 'withdrawals/number of points'. This ratio is deduced from withdrawal distribution and the number of water points and shows a significant variation from one country to another and from one administrative subdivision to another (Table 11). The ratio values range from 0.01 hm<sup>3</sup>/year and per point in Mali, to 0.50 hm<sup>3</sup>/year and by water point in Nigeria, and to 0.103 hm<sup>3</sup>/year and by water point in Niger. These values can be used as checking 'standards' for the water point withdrawals in the three countries insofar as we consider the sample of 781 identified water points representative of the withdrawals distribution within the IAS.

**Tableau 13: Total withdrawals per administrative unit (year 2000)**

Country	Administrative Unit	Nb points	Withdrawals Hm <sup>3</sup> /year	Ratio
Mali	Gao	54	0.60	0.01
Nigeria	Sokoto	122	66.61	0.55
	Kebbi	86	43.31	0.50
	Katsina	26	7.67	0.30
	<b>Total Nigeria</b>	<b>234</b>	<b>117.59</b>	<b>0.50</b>
Niger	Dosso	343	29.91	0.09
	Tahoua	135	18.62	0.14
	Niamey	11	1.84	0.17
	Maradi	3	0.21	0.07
	Zinder	1	0.01	0.01
	<b>Total Niger</b>	<b>493</b>	<b>50.59</b>	<b>0.103</b>
<b>Total IAS (CI+CT))</b>		<b>781</b>	<b>168.78</b>	<b>0.216</b>

As far as Mali is concerned, and given that one administrative subdivision is considered (Gao with 54 water points), we have no reference enabling us to deduce the spatial variation of this ratio. We consider the **0.01 hm<sup>3</sup>/year** value per water point as representative of this part of the basin

In the case of Nigeria, we have three values of this ratio relating to the three administrative subdivisions (Sokoto, Kebbi and Katsina). These values range from 0.30 to 0.55 hm<sup>3</sup>/year and by water point. They provide an average value representative of this portion of the basin, which is **0.5 hm<sup>3</sup>/year** and by water point.

In the case of Niger, the department where the number of water points is relatively weak (one water point in Zinder) is excluded. For the remaining departments, the ratio varies between 0.07 and 0.17 hm<sup>3</sup>/year and by water point. The average value is 0.10 hm<sup>3</sup>/year.

By considering all the departments in the basin in the three countries and the sample of 781 water points, the average operation ratio per water point is 0.22 hm<sup>3</sup>/year (6.8l/s in a continuous fictitious flow). It results that the unitary operation per work is the strongest in Nigeria (0.5 hm<sup>3</sup>/year) and the weakest in Mali (0.01 hm<sup>3</sup>/year)

#### 4.3.2.3- Withdrawals history per water point

This crossed request is meant to check the withdrawals data:

- Data availability period
- Evolution of values in time

**Tableau 14: Operation history per water point (in m<sup>3</sup>)**

Noclas	1956	...	1988	1999	2000	2001	2002	2003	2004
Oulit Erajoun	219.819	...	1048.147	3091.056	3226.209	3399.933	3462.902	3429.897	3678.123
321282		...	1051.2	1051.2	1051.2	1051.2	1051.2	1051.2	1051.2
321283			168192	168192	168192	168192	168192	168192	168192
321284			4204.8	4204.8	4204.8	4204.8	4204.8	4204.8	4204.8
321296		...	5256	5256	5256	5256	5256	5256	5256

#### 4.3.2.4- Withdrawals by type of usage

The two-way frequency table provides the volumes in hm<sup>3</sup>/year by administrative unit and usage. If the sum of volumes does not correspond to the global IAS volume, it is because the 'code\_usage' field is not informed for all the water points. ('points' table)

**Table 11: Withdrawals by administrative unit and usage (year 2000)**

Country	Administrative unit	Urban AEP	Rural AEP	Unused	Irrigation	Pastoralism
Niger	Dosso	0.67	28.96			0.18
	Maradi		0.02			
	Niamey		1.28			0.56
	Tahoua	1.23	16.87		0.53	
	Zinder		0.01			
Nigéria	Katsina	3.24	4.42			
	Kebbi	8.56		1.01		
	Sokoto	11.47		8.19		

### 4.3.3- Piezometry

In the absence of a network of piezometric follow up, the information on the levels was collected from diverse sources:

- Country teams during the workshops.
- Use of existent study documents.

#### 4.3.3.1- Distribution by data origin

The origin of piezometric level information is very important during the data control and validation stage.

**Tableau 15: Distribution of measurement levels by data source**

Source	Mali	Nigeria	Niger	Total per source
Non-informed	6	10	133	149
FAO Project, 1970	4	18	44	66
Workshop-November 2006	5		53	58
BCEOM-EC, 1988 and 2000			34	34
Greigert, 1978			8	8
K.F. SAAD, 1971	17		28	45
MHE-1983			5	5
JICA_Sokoto_Report 1990 and 1991		242	4	246
<b>Total per pays</b>	<b>32</b>	<b>270</b>	<b>309</b>	<b>611</b>

#### 4.3.3.2- Level series

No spatiotemporal follow-up of the IAS different aquifer piezometry is secured in the three concerned countries. The piezometric measurements collected and exploited for the purposes of the study emanate from the water point characteristics identified during the establishment of the reconnaissance or operation works, or other accompanying measures made when the synthesis studies were made by the countries. It is also found out that no piezometric history is available and that the few validated measurements represent very insufficient distant milestones in their spatial distribution to ensure a clear vision of piezometry over time.

The water points having at least two measurement levels are not many (68 for the two aquifers). The gap between these measurements is, for the majority, 1 year (which is insufficient to analyse the level variations). No single point has three measurements at least.

**Tableau 16: Points with at least two-level measurements: series length and distribution by administrative unit**

Pays	Administrative Unit	The longest period (years)	Number of points with more than two measurements	MAX Number
Mali	Gao	0	0	2
Nigeria	Kebbi	1	19	2
	Sokoto	1	36	2
Niger	Dosso	28	7	2
	Maradi	1	1	2
	Niamey	13	1	2

Pays	Administrative Unit	The longest period (years)	Number of points with more than two measurements	MAX Number
	Tahoua	8	4	2

We notice that no water point in Mali benefits from two level measurements or more.

If we examine the distribution of these series by aquifer (Table 16), we notice that for the TC the number of water points with two measurements is only 12.

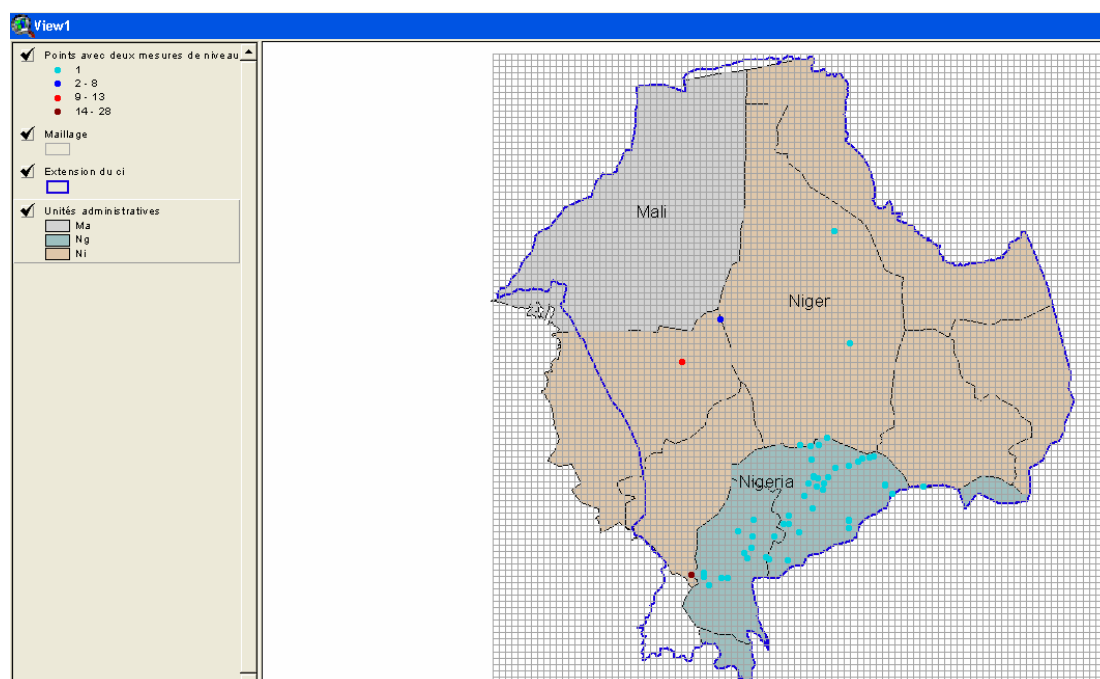
**Tableau 17: Points with at least two level measurements: Series length and distribution per aquifer**

Aquifer	The longest period (years)	Number of points with more than two measurements
Unknown	1	3
IC	28	53
TC	12	12

The spatial CI point distribution shows that (Fig. 22):

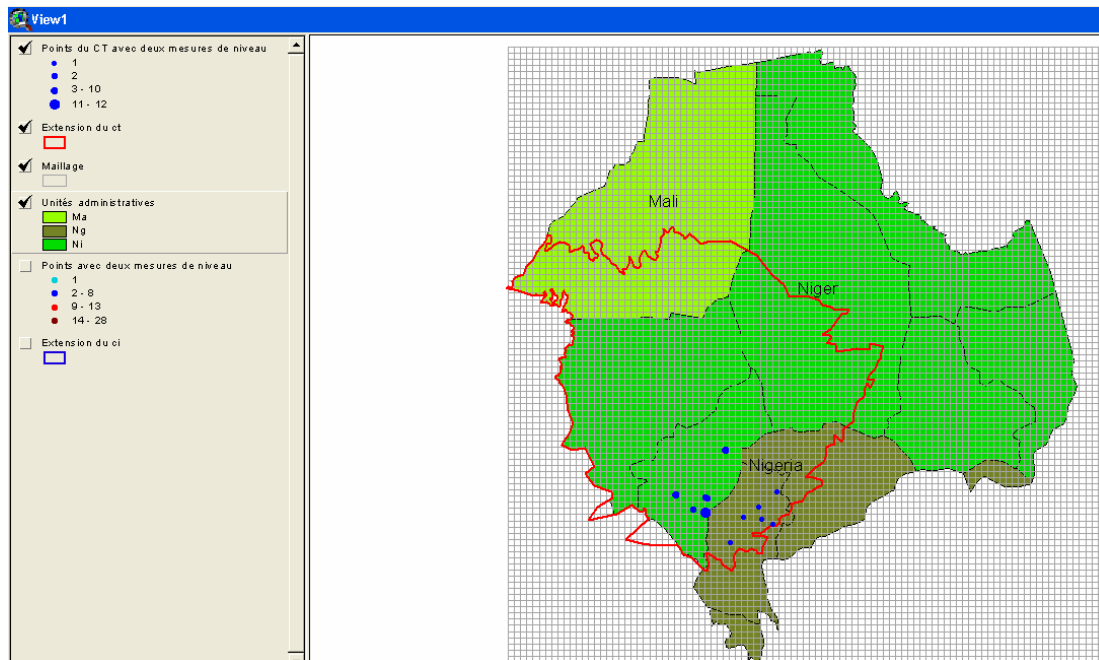
- Their number is high in Nigeria, but the longest period is only 1 year.
- There are no points in Mali.
- Only 3 points have a period longer than 3 years. They are all in Niger.

**Figure 22: Spatial CI point distribution with two or more level measurements**



The spatial CT point distribution is illustrated in the map, below (Fig.23)

**Figure 23: Spatial CT point distribution with two or more level measurements**



There are three CT points with a period  $\geq 10$  years. They are located in the Dosso zone, as shown in the following table:

Shape	Nomenclature	Code_Aquif	Nom_Admin	Xcoord	Ycoord	NR_Mes	PremierDeDate	DernierDeDate	Long_periode
Point	26598	CT	Dosso	-486016.062500	-602379.687500	2	1988	2000	12
Point	323252	CT	Dosso	-453538.156250	-499637.906250	2	1988	1998	10
Point	331508	CT	Dosso	-534328.562500	-572905.437500	2	1988	1998	10
Point	344050	CT	Dosso	-485413.562500	-577934.812500	2	1998	2000	2
Point	344079	CT	Dosso	-483259.625000	-579099.375000	2	1998	2000	2
Point	26595	CT	Dosso	-505556.937500	-597440.375000	2	1998	2000	2
Point	XNG_40	CT	Kebbi	-398052.187500	-592492.187500	2	1988	1989	1
Point	XNG_41	CT	Kebbi	-369370.687500	-567116.687500	2	1988	1989	1
Point	XNG_42	CT	Kebbi	-393001.031250	-612977.875000	2	1988	1989	1
Point	XNG_54	CT	Kebbi	-444860.437500	-650812.312500	2	1988	1989	1
Point	XNG_56	CT	Kebbi	-423876.093750	-608631.875000	2	1988	1989	1
Point	XNG_58	CT	Kebbi	-374932.687500	-620743.312500	2	1988	1989	1

### Conclusion on piezometry

The basin-shaped IAS made the interpretation of the piezometric data on the different aquifers relatively easy, particularly that the main part of the aquifer system is located in Niger and secondarily in Nigeria. The previous hydrogeological studies carried out in Mali (K.F Saad, 1971), Niger (FAO, 1970; BCEM, 1978; MHE, 1983) and Nigeria (JICA, 1991) put forward some basic hypotheses for the interpretation of the whole piezometric outlook. As the operation of the aquifer system has recently evolved in a relatively balanced manner in Mali and Niger, and as the strongest operation was witnessed in Nigeria (an IAS outlet), the general outlook of the pressure-surface contours does not seem to be too distorted by such operation. Levelling the system in permanent mode was obtained on the basis of the available data that was judged to be acceptable.

Levelling the model in transitory mode is judged to be more random with the absence of a viable and representative peizometric file history. The few well-spaced measurements are precious yardsticks which made it possible to guide model levelling, knowing that the evolution of the aquifer system operation has more or less remained within the limits of its unsustainable resources. It is only during the recent years that the operation seems to overtake the annual recharge.

#### 4.3.4- Geology

The geological data introduced in the IAS common DB correspond to the drilling data from the basin. These are presented in the form of a lithostratigraphic description of the drilled layers. Stratigraphic subdivisions were adopted before securing the processing of this information with the help of '**Rockworks**', a software used for establishing correlations between drillings according to preferential directions making it possible to highlight the peculiarities of the geological structure associated with each correlation.

With the help of this information, mapping the walls, ceilings and thickness of each aquifer formation was made with maximum accuracy, given the good density of the considered points and the refined adopted stratigraphic division.

Through this work of geological analysis, the conceptualisation of the IAS structural configuration was made with more accuracy and harmonisation. This approach has much helped the representatives of the three countries to:

- Opt for a shared conception of the IAS structure in each part of the basin.
- Adopt harmonised subdivisions to draw the major IAS aquifer levels and share the decision on the number of layers to adopt in the model,
- Adopt layer thickness (aquifer or aquiclude) by referring to the harmonised data of the three countries.

Thus, the geological data were at the origin of the information which made it possible to come up with the conceptual schema of the aquifer structure. It is the elaboration of structural maps (ceiling, wall and thickness) for the considered formation which largely facilitated this operation. The thickness maps constitute a vital element in model levelling through transmissivity distribution<sup>4</sup>. In light of such maps, the physical data relating to each layer's thickness were better grasped and the structure of the aquifer system simulated with much accuracy.

The 'geology' table consists of 690 points, but only 89 have the informed '**code\_aquif**' (CI or CT). Attaching a water point to one of the two IAS aquifers is an accessory operation in this data use framework, given that most of the points, which have not been attached, integrate the information relating to the two aquifers.

Aquifer	Number of points
Uninformed	509
IC	31
TC	58

<sup>4</sup>  $T=K \cdot E$  ; T : Transmissivité, K: Perméabilité et E : épaisseur de la couche aquifère ou aquiclude



#### 4.3.5- Hydrodynamic parameters

The '**Hydrodynamic**' table brings together the data relating to the hydrodynamic characteristics of the IAS aquifers (transmissivity and storage coefficient) in particular the transmissivity values deduced from the interpretation of the pumping test. These values, coupled with those of the aquifers submerged thickness, allow us to assess the total aquifer system's reserves. Adopted in the hydrodynamic model, they served to put the aquifer system in a balanced state.

The absence of data on the hydrodynamic characteristics of the two aquifers in Mali and Nigeria, in January 2007, meant that this collected information for the sake of the model could not be integrated in time in the database (Table 17).

**Tableau 18: Distribution of points with a transmissivity value**

Aquifer	Country	Admin	Number of points
CI	Niger	Dosso	11
		Maradi	7
		Niamey	3
		Tahoua	24
		Zinder	3
CT	Niger	Dosso	12
		Niamey	2
		Tahoua	1

We notice that there are no data on the hydrodynamic parameters of Mali and Nigeria.

### Quality

The hydrochemical and isotopic data were very useful in guiding the conceptualisation of the IAS hydrodynamic functioning. The data on these two aspects were only secondarily considered during the data collection for the common database, given that the national teams did not have time to take care of it. In fact, this aspect is not accounted for in the elaboration of the IAS hydrodynamic model, the reason for which it could not be developed on time in the database.

The existing '**quality**' table in the IAS common DB includes only 24 recordings – all of them from Mali.

**Tableau 19: Distribution of points with chemical analytical values**

Country	Name_Admin	Number of points
Mali	Gao	24
Nigeria	Katsina	0
	Kebbi	0
	Sokoto	0
Niger	Agadez	0
	Dosso	0
	Maradi	0
	Niamey	0
	Tahoua	0
	Zinder	0

The set of points with quality data is found in Mali.

#### 4.4- Geographical Information System (GIS)

The IAS geographical information system is a set of software to produce a cartographic representation of existing data in the common database. The support for the required digitized maps for this representation was developed as a separate activity in the project framework.

The GIS used to represent the IAS is designed as an integrated part of the overall Information System (designed for very large needs), insofar as all the descriptive information of geographical objects is planned in the database structure. The primary aim is to store each piece of information in one area (no redundancy).

The second objective concerns the links between the Database and the model, on the one hand, and GIS and the model, on the other. The links must be established automatically and transparently for the user. These links can be set up at a later stage, after establishing the database, but before feeding the model with specific data. The IAS Information System consists of two major parts: the Database and GIS. This set is coupled with a model grid, which is at the same time a DB table and a GIS layer, thus securing the link between the DB model and GIS.

#### 4.4.1- Projection system

To have a common cartographic reference in the three countries and automatically produce the grid of the hydrodynamic model, which requires a system of projected coordinates, the Lambert projection was adopted.

In the IAS region, Niger, which occupies most of the basin, is covered by three Lambert zones, as shown in the following table:

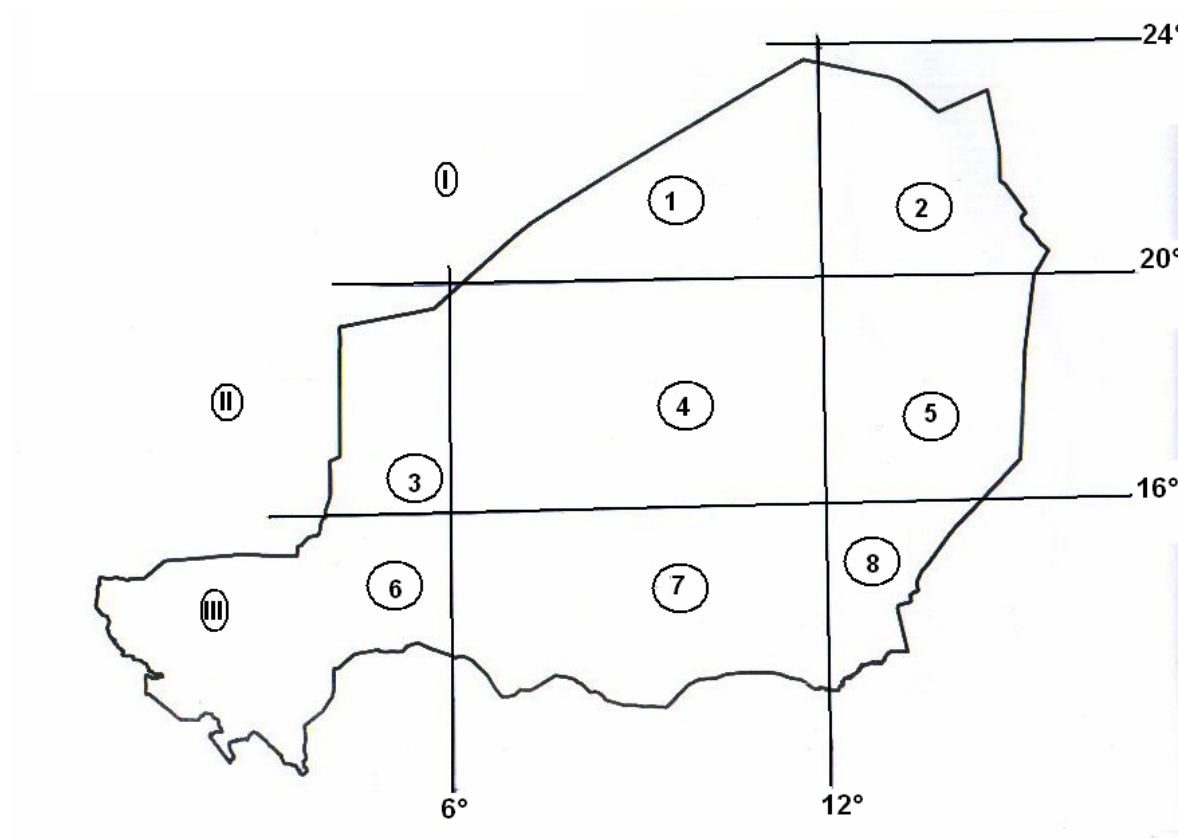
**Tableau 20: Parameters of the three Lambert zones covering Niger**

Name	Zone N°		
	I	II	III
Ellipsoid	Clarke 1880	Clarke 1880	Clarke 1880
Reference spheroid	<u>International 1900</u>	<u>International 1900</u>	<u>International 1900</u>
central meridian	8.08	8.08	8.08
Reference parallel (latitude reference)	22.00	18.00	14.00
South latitude (Standard parallel 1)	20.66	16.66	12.66
North Latitude (Standard parallel 2)	23.33	20.33	16.33
False easting	0	0	0
False northing	0	0	0

The three concerned zones are (Fig. 24):

- North, latitude > 20°
- Centre, latitude ranging between 16° and 20°
- The south, latitude < 16°

Figure 24: The three Lambert zones of the Niger territory



The common system chosen for the IAS corresponds to zone II whose parameters are:

- Central meridian: 8.08
- Latitude ref.: 18
- Parallel 1: 16.66
- Parallel 2: 20.33
- False Easting: 0
- False Northing: 0

In order to facilitate the process of converting geographic layers to Lambert, the abovementioned parameters were integrated in ArcView 'Default.prj' file. The set of layers mentioned in Chapter 2 were converted to Lambert.

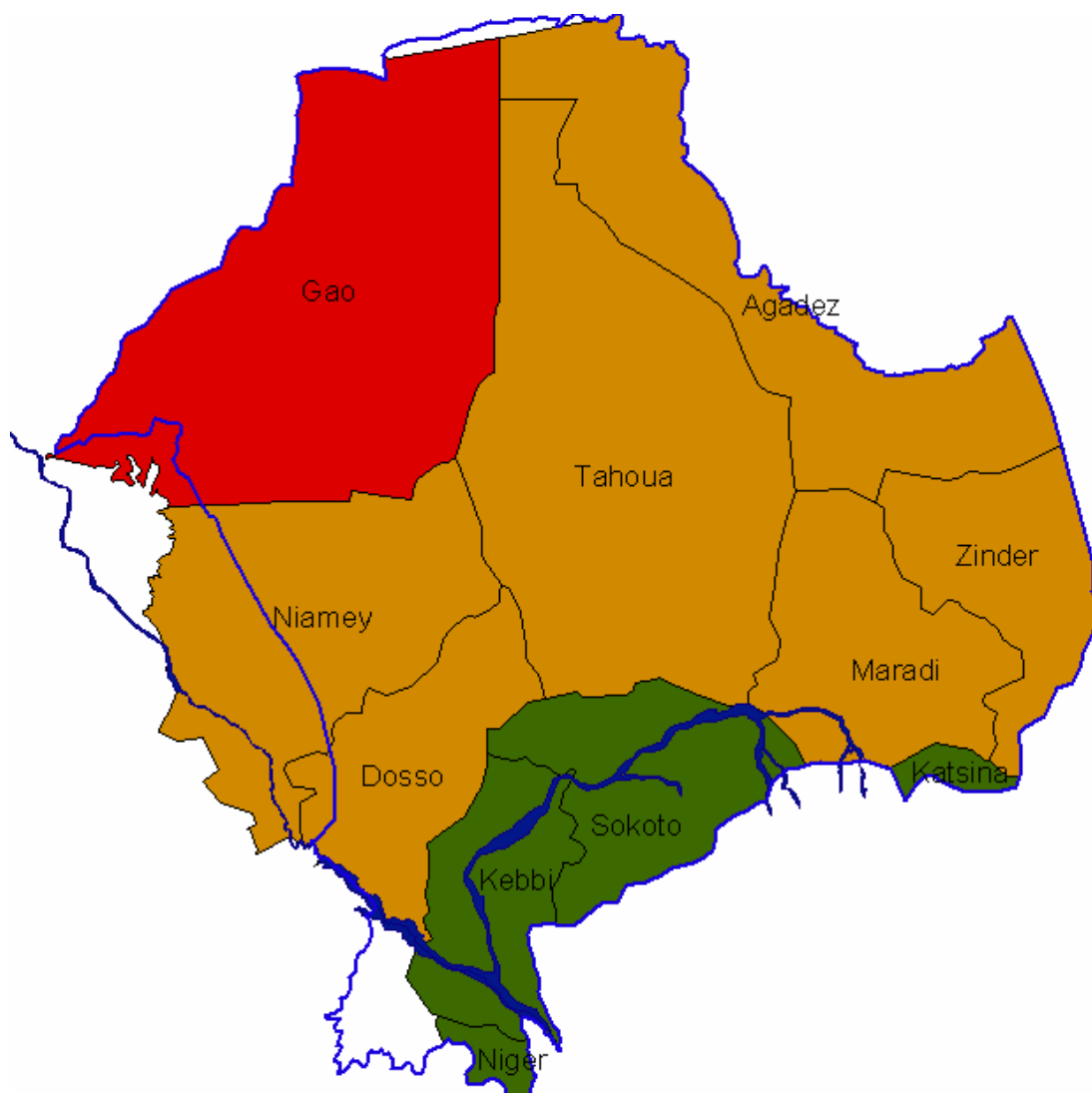
#### **4.4.2- Layers added for the purposes of the study**

At the time of devising the links between the IAS common database and GIS, the following layers were added:

##### **4.4.2.1- Administrative limits**

It is a layer used in GIS and DB: see statistical requests on the number of water points and withdrawals. It was extracted from the ESRI data.

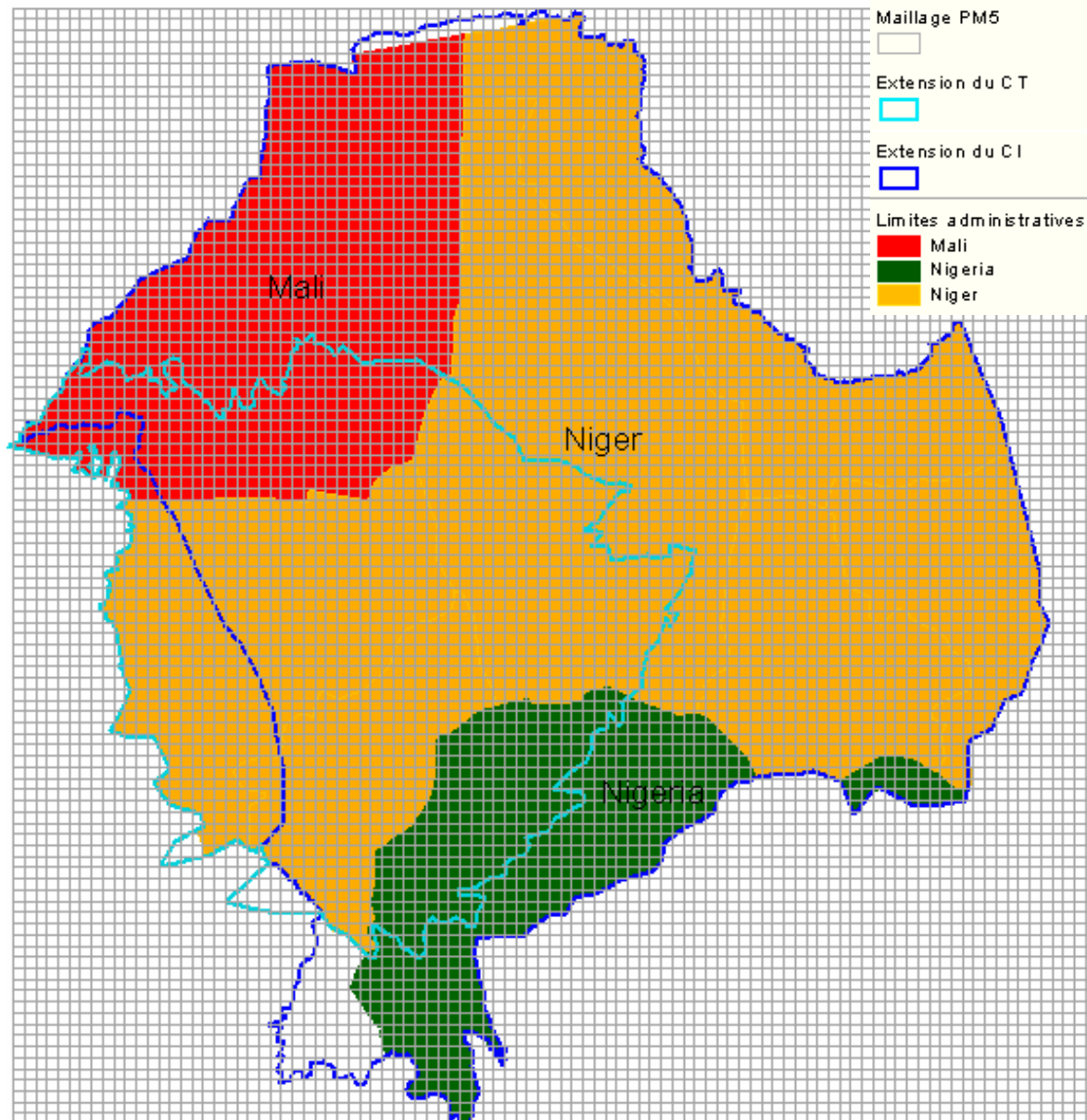
**Figure 25: Layers of administrative units**



#### 4.4.2.2- Gridding

Gridding is generated from the DB by automatic processing ('Db\_Sig\_model' form), but this processing generates the 'gridding' layer in the same projection system as the others. This layer is required for the hydrodynamic model. It ensures the link between the DB and the model.

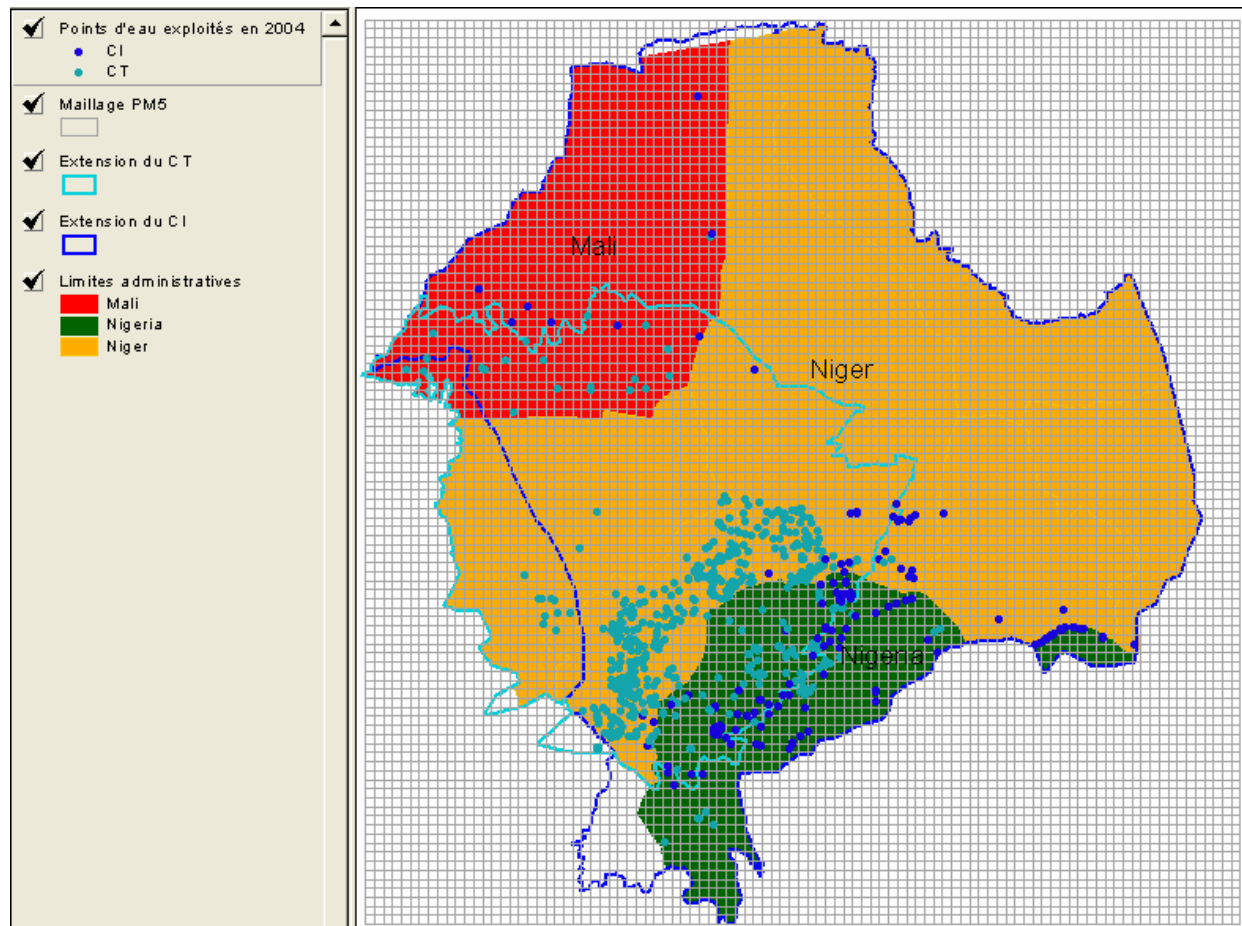
**Figure 26: PM5 gridding**



The allotted table of the 'gridding' layer and the 'gridding' table of the database have a common field which is the grid number. This allotted table is automatically attached to the DB.

#### 4.4.2.3- The water point layer

The water point layer is not static. It is automatically generated from the 'points' table when the explorer is started. Thus, any change in the coordinates impacts on this layer without any manual intervention.



We can, on the basis of ArcView, display the water points layer by using SQL Connect. The procedure is as follows:

- Make a request at the level of the 'IASIS database, using the 'points' table with possibly another related table. This request must include at least these fields 'NoClas', 'Xcoord' and 'Ycoord'. Save the request.
- Under ArcView, make 'Project', 'SQL Connect'. Choose the 'MS access database' driver, then click on 'connect' to locate 'IASIS.MDB' which should be found by default in the 'C:\nullemeden\DB\' file
- Select the request which has just been made and finish by clicking on 'Query'
- In a view, make 'View', 'Add event theme' and give the name of the 'Xcoord' and 'Ycoord' fields.

### Digital Elevation Model (DEM) 90 meters

Ce MNT a été constitué au mois de Septembre 2007. Il a une résolution de 90 mètres et il est issu d'un traitement sur des fichiers téléchargés gratuitement à l'adresse suivante : (<ftp://e0mss21u.ecs.nasa.gov/srtm/Africa/>). Contrairement à la première version, la version 2 propose des données corrigées exploitables.

The DTM was established in September 2007. It has a 90-meter resolution and it is the outcome of processing free-downloaded files from the following address: <ftp://e0mss21u.ecs.nasa.gov/srtm/Africa/>). Contrary to the first version, Version 2 proposes operational corrected data.

**Figure 27: Digital Elevation Model at 90-meters**





These are SRTM format files covering 1 square degree whose name has the following structure: NxxExx.hgt, where xx represents the longitude and the latitude in degrees.

The IAS zone is covered by 60 files, as shown in the following table:

	File number
N10E02 to N10E04	03
N11E02 to N11E04	03
N12E01 to N12E08	08
N13E01 to N13E08	08
N14E01 to N14E09	09
N15E00 to N15E09	10
N16E00 to N16E08	09
N17E01 to N17E06	06
N18E02 to N18E05	04
N19E03 to N19E05	03
<b>TOTAL</b>	<b>60</b>

The processing took place as follows:

- Reading of hgt files by an avenue programme and conversion to ESRI grid.
- Gridding mosaic (Grid Analyst extension).
- Partitioning with the IAS extension.
- Lambert grid projection, with the help of Grid Analyst.

## CONCLUSION AND RECOMMENDATIONS

The setting up of an IAS common database made it possible to bring in the set of available hydrogeological data on the system aquifers together and to make them more homogeneous and coherent at the levels of:

- Codification
- Format
- Processing mode

However, given that it is the first time that the contents of the different DB files are issued from diverse sources before adapting them to a common structure, these should be subjected to a more thorough test, be validated and directly made amenable to processing. This will be the most urgent task of the national teams, assisted by OSS at first.

The major project contribution at this level lies in the fact that the common database as well as the accompanying tools are capable of updates (corrections, new data additions...) in a standard format shared by the three country teams. This will facilitate a periodic updating of the common base and data exchange among the different partners.

At the level of contents, many things were done, but certain faults still persist:

- A good number of water points are still without an identifier or without coordinates.
- There is much duplication which needs to be deleted.
- For all the water points, the withdrawals have been estimated because the information was not available.
- There are still many uninformed fields.

The establishment of the DB and GIS within the three countries, the training of the teams in operation, including the administration of tools developed for the project, have to be anticipated so as to allow for the system's regular updating.

This will facilitate the establishment of an information system which will secure regular updating and the gradual development of a decision aid system. This system should be accompanied by an exchange mechanism between the countries and the establishment of the data administration function in these countries and within the IAS concerted management organ.

The two workshops organised within the project framework for the benefit of the experts of the three countries who will be in charge of the DB common management are considered as a step to facilitate management responsibility and the countries' involvement in content conceptualisation and selection. These workshops have also served for accommodating these teams to GIS during the gradual elaboration of the hydrodynamic model.

Feeding the database with the new information that the national teams keep collecting, with the perspective of updating its history, is planned until the end of the project (March 2008). The establishment of the database in the countries is the last stage which should crown the IASIS establishment.

This database is designed according to a gradual and extendable scheme to secure its sustainability in the management of IAS water resources data. If, at this stage, the information

which is stored there is mainly oriented towards the hydrogeological aspect, it is necessary to pay attention to:

- Completing the IAS hydrogeology data entry, adding the recently collected data, and allowing for history updating.
- Completing the hydrogeological data with hydrological, climatological and hydro-agricultural data to further consolidate the model's hydrodynamic results, make them more capable of forecast simulations (medium and short terms), and secure the IAS water resources management.
- Enriching the database structure and content with other aspects to make it a monitoring tool for the IAS water resources within the framework of a cooperation structure between the three countries for the optimal planning of the basin water resources, hence reducing the hydrogeological risks and ensuring development.

For this purpose, it is recommended to make the specialists feel more responsible so that they own the common DB and the IASIS. This ownership cannot be realised without an additional training of the designated technicians and a reinforcement of the computing abilities of the concerned structures.

In its current state, the database includes a precious piece of information which could not have been collected before. This information requires more specific processing for validating, processing and generating further results. Such effort is the responsibility of the national teams in the first place, but it can also be used with other OSS applications in the framework of monitoring member countries' water resources. Similarly, the methodology developed by the project team for validating and harmonising data can be an example for developing similar activities for other aquifer systems.

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## APPENDIX: DETAILED STRUCTURE OF THE DATABASE TABLES

Database : C:\Iullemeden\BDD\SAI\_DATA.mdb

**Table: Admin (administrative units)**

**Propriety**

Date of creation:	05/03/2007 09:41:49	last update:	05/03/2007 12:39:24
GUID:	Binary data	NameMap:	Donnée binaire
Orientation:	0	RecordCount:	10
TriActif:	False	Updatable:	true

**Columns**

Name	Type	Description	Size
Code_Pays	Texte	Code pays (Ma = Mali, Ni = Niger, Ng = Nigeria)	2
Nom_Admin	Texte	Complete name of the country	20

**Table: agglomerations (principal agglomerations )**

**Proprety**

Date of creation:	05/03/2007 09:42:01	Last update:	03/04/2007 20:35:07
NameMap:	Binary data	Orientation:	0
RecordCount:	249	TriActif:	False
Updatable:	true		

**Columns**

Nom	Type	Description	size
AGGLOM_ID	Réel double	Agglomeration Identifiant	8
NOM	Texte	Nom de l'agglomération	30
CODE_ADMIN	Texte	Code de l'unité administrative où se situe l'agglomération	30

**Table: aliment (valeurs d'alimentation par maille)**

**Proprety**

Date of creation:	06/03/2007 16:17:20	last update:	06/03/2007 16:17:23
GUID:	Binary data	NameMap:	Binary data
RecordCount:	9	TriActif:	true
Updatable:	true		

**Colums**

Nom	Type	Description	size
NOCLAS	Texte	identification number (similar to that of water points	22
couche	Texte	Number of the layer in PM5 software	1
aquif	Texte	aquifer name	30
X	Réel double	X of the cell center	8
Y	Réel double	Y of the cell center	8
Alim	Réel double	recharge value l/s	8
MAILLE	Texte	Cell Identifiant	10
NOM	Texte	Name of the recharge point	100

**Table: Aquifer (list of IAS aquifers)****Propriety**

Date of creation: 05/03/2007 10:01:25      last update: 05/03/2007 10:20:58  
 GUID: Binary data      NameMap: Binary data  
 Orientation: 0      RecordCount: 2  
 TriActif: False      Updatable: True

**Colums**

Nom	Type	Description	Size
Code_Aquif	Texte	aquifer Code (CT = Complexe terminal, CI = continental intercalaire	2
Nom	Texte	Aquifer Name	30
Couche_modele	Texte	Number of the layer in PM5 software	1
Shape_file	Texte	Nom du fichier Shp correspondant	30

**Table: etats (list of states of the water point)****Propriety**

Date of creation: 06/03/2007 10:01:59      Last update: 06/03/2007 10:02:24  
 GUID: Binary data      NameMap: Binary data  
 Orientation: 0      RecordCount: 4  
 TriActif: False      Updatable: True

**Colums**

Nom	Type	Description	Size
Code_Etat	Texte	State Code of a water point	2
Description	Texte	Wording of the state	30

**Table: Exploitation (Time series of the annual abstractions)****Propriety**

Date of creation: 06/03/2007 08:48:04      last update: 27/03/2007 22:47:24  
 GUID: Binary Data      NameMap: Binary data  
 Orientation: 0      RecordCount: 20242  
 TriActif: False      Updatable: True

### Columns

Nom	Type	Description	Size
Noclas	Texte	identification number of the water point	22
Annee	Entier	Year of measurement	2
Prelevement	Simple Real	Abstraction value in m3	4
Origine	Text	Source of the information	50
Date_Maj	Date/Hour	Record update date	8

**Table: GEOLOGIE (Geological description of the water point)**

### Propriétés

AffichParDéfaut:	Data sheet	Date of creation:	07/10/2006 09:42:00
Last update :	03/04/2007 21:54:22	GUID:	Binary data
NameMap:	Binary data	Orientation:	0
RecordCount:	598	TriActif:	False
Updatable:	True		

### Columns

Nom	Type	Description	Size
NoClas	Texte	identification number of the water point	22
Quat	double real	Altitude in meter of the Quaternary	8
Plioc	double real	Altitude in meter of Pliocene	8
Mioc	double real	Altitude in meter of Miocene	8
Olig	double real	Altitude in meter of l'Oligocene	8
Eoc	double real	Altitude in meter of l'Eocène	8
Pal	double real	Altitude in meter of Paléocene	8
Sen	double real	Altitude in meter of Senonian	8
Tur	double real	Altitude in meter of Turonien	8
Cen	double real	Altitude in meter of Cenomanian	8
CI	double real	Altitude in meter of CI	8
Jur	double real	Altitude in meter of Jurassic	8
Trias	double real	Altitude in meter of Triassic	8
Palz	double real	Altitude in meter of Paleozoic	8
TD	double real	Total depth in meter	8
Date_Maj	Date/Hour	Record update date	8

**Table: hydrodynamic (hydrodynamic parameters)**

### Propriety

AffichParDéfaut:	Data sheet	Date of creation:	19/07/2006 11:06:02
last update:	08/03/2007 16:07:15	GUID:	Binary data
NameMap:	Binary data	Orientation:	0
RecordCount:	98	TriActif:	False
Updatable:	True		

### Coloums

<b>Nom</b>	<b>Type</b>	<b>Description</b>	<b>Size</b>
Noclas	Text	identification number of the water point	14
Date_mesure	Date/Hour	Pumping test date	8
Duree	Octet	Pumping test duration in hours	1
NS	simple real	Static level in meter	4
Debit	simple real	Pumping test yield in l/s	4
Rabattement	simple real	Drawdown in meter	4
Méthod_interp	Octet	interpretation Method of the pumping test	1
Type_essai	Octet	Type of pumping test	1
Transmis	double real	Transmissivity m2/s	8
Permeab	double real	permeability	8
Coeff_emmag	double real	Storage Coefficient	8
Source	Text	Origine of the informations	50
Fichier	Text	Name of the file used to import data	50
date_maj	Date/Hour	Record update date	8
Observations	Text	Observations (comment)	50

**Table: Grid (cells of the model)**

#### Propriety

Date of creation:	06/03/2007 15:38:32	last update:	06/03/2007 15:58:16
GUID:	Binary data	NameMap:	Binary data
Orientation:	0	RecordCount:	9700
TriActif:	False	Updatable:	false

#### Colums

<b>Nom</b>	<b>Type</b>	<b>Description</b>	<b>Size</b>
MAILLE	Texte	Number of the cell	10
NUM_PM5	Texte	corresponding PM5 number (line – Colum)	16

**Table: Objets\_Ouvrage**

#### Propriety

Date of creation:	02/03/2007 16:30:05	last update:	05/03/2007 12:24:33
NameMap:	Binary data	Orientation:	0
RecordCount:	5	TriActif:	False
Updatable:	True		

#### Colums

<b>Nom</b>	<b>Type</b>	<b>Description</b>	<b>Size</b>
Code_Obj	Octet		1
Description	Text		30

**Table: Pays**



**Propriety**

Date of creation: 02/03/2007 12:23:48      Dernier mis à jour: 05/03/2007 18:16:59  
 GUID: Donnée binaire      NameMap: Donnée binaire  
 Orientation: 0      RecordCount: 3  
 TriActif: Faux      Updatable: Vrai

**Columns**

Nom	Type	Description	Size
Code_Pays	Text		2
Nom	Text		255

**Table: PIEZOMETRIE (Piezometric time series des niveaux)****Propriety**

AffichParDéfaut: Data sheet      date of creation: 08/10/2006 16:06:22  
 Last updating: 06/03/2007 15:23:42      GUID: Binary data  
 NameMap: Binary data      Orientation: 0  
 RecordCount: 611      TriActif: False  
 Updatable: True

**Columns**

Nom	Type	Description	Size
NoClas	Text	identification number of the water point	22
Date	Entier	Measurement date	2
NS	Entier long	Static level in meter	4
NP	Entier long	piezometric level	4
Observations	Text	comment	50
Source	Text	Origine of the information	50
Fichier	Text	Name of the file used to import data	50
Date_maj	Date/hour	record updating date	8

**Table: QUALITE****Proprety**

Date of creation: 03/03/2007 17:40:12      last update: 08/03/2007 14:27:19  
 GUID: Binary data      NameMap: Binary data  
 Orientation: 0      RecordCount: 24  
 TriActif: False      Updatable: True

### Columns

Nom	Type	Description	Size
Noclas	Texte	identification number of the water point	22
Date_mes	Date/Hour	Measurement date	8
Ph	simple real		4
EC	simple real		4
TEMP	simple real		4
Ca2+	simple real		4
Mg2+	simple real		4
K+	simple real		4
Fe2+	simple real		4
Mn	simple real		4
Na+	simple real		4
HCO32-	simple real		4
CO32-	simple real		4
Cl-	simple real		4
NO3-	simple real		4
SO42-	simple real		4
d18O	simple real		4
d2H	simple real		4
d3HTU	simple real		4
14C	simple real		4
13C	simple real		4
Nom_Fichier_ Source	Text	Name of the file used to import data	50

**Table: POINTS (Water point characteristics)**

### Proprety

AffichParDéfaut:	Data sheet	Date of creation:	11/07/2005 12:28:36
Last update:	03/04/2007 21:25:28	GUID:	Binary data
NameMap:	Binary data	Orientation:	0
RecordCount:	17171	TriActif:	True
Updatable:	True		

### Columns

Nom	Type	Description	Size
Noclas	Text	identification name of the water point	22
Nom	Text	Name of the water point	50
Indice_Village	Text	Village (for the malian water points)	7
Localite	Text	locality name of the water point	50
Code_Type	Octet	Type of point	1
Artesien	Oui/Non	Artésien (yes ou no)	1
Equipe	Oui/Non	taped (yes ou no)	1
Code_Aquif	Text	Code of the taped aquifer (see table « aquifere »)	2
Nom_Admin	Text	administrative Unit	20
Long	Text	longitude	20
Lat	Text	latitude	20

Long_dec	simple real	Longitude in decimal degrees	4
Lat_dec	simple real	Latitude in decimal degrees	4
Xcoord	simple real	X lambert	4
Ycoord	simple real	Y lambert	4
Alt	simple real	Altitude	4
Nom_Formation_Geol	Text	Name of the taped formation	50
Code_Usage	Octet	Use Code of the water points (table "usages")	1
Prof_foree	simple real	total depth in m	4
Prof_equippee	simple real	taping depth	4
QEX	simple real	exploitation yield at the creation	4
NS	simple real	static level at the creation	4
GPH	Text		1
Date_debut	simple real	starting date of the work	8
Date_fin	simple real	date of the end of the work	8
Annee_sce	Entier	Starting date	2
Code_Objet	Octet	object Code of the water point (objective)	1
Code_Etat	Entier long	Water point state Code (table « etats »)	4
Observations	Text	comment	60
Source_Info	Text	Origine of the information	50
Nom_Fichier_Origine	Text	Name of origine file	50
Date_maj	Date/Hour	record update date	8
Maille	Text	cell number	10

**Table: Types\_Ouvrage (list of the water point type)**

**Proprety**

Date of creation:	02/03/2007 11:52:48	Last update:	05/03/2007 12:22:16
GUID:	Binary data	NameMap:	Binary data
Orientation:	0	RecordCount:	6
TriActif:	False	Updatable:	True

**Colums**

Nom	Type	Description	Size
Code_Type	Octet	Type of water point Code	1
Description	Texte	working type	30

**Table: Usages (list of functions of the water point)**

**Proprety**

Date of creation:	02/03/2007 12:18:34	last update:	05/03/2007 12:22:34
GUID:	Binary data	NameMap:	Binary data
Orientation:	0	RecordCount:	6
TriActif:	False	Updatable:	True

**Columns**

<b>Nom</b>	<b>Type</b>	<b>Description</b>	<b>Size</b>
Code_Usage	Octet	Use Code	1
Lib_Usage	Text	Working use	30
Categorie	Text	Category (AEP, IRR, ...)	3