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Inventory and Review of Existing PRISM Hydrogeologic Data for the Islamic Republic of Mauritania, Africa

By Michael J. Friedel

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
Volume		
ounce, fluid (fl. oz)	0.02957	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic inch (in^3)	0.01639	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
Flow rate		
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

SI to Inch/Pound

Multiply	By	To obtain
Length		
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
Volume		
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
liter (L)	61.02	cubic inch (in^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
Flow rate		
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Inventory and Review of Existing PRISM Hydrogeologic Data for the Islamic Republic of Mauritania, Africa

By Michael J. Friedel

Abstract

The USGS entered into an agreement with the Mauritania Ministry of Mines and Industry to inventory and review the quality of information collected as part of the *Project for Strengthening of the Institutions in the Mining Sector (*PRISM). Whereas the PRISM program collected geophysical, geochemical, geological, satellite, and hydrogeologic information, this report focuses on an inventory and review of available hydrogeologic data provided to the USGS in multiple folders, files, and formats. Most of the information pertained to the hydrogeologic setting and the water budget of evaporation, evapotranspiration, and precipitation in the Choum-Zouerate area in northwestern Mauritania, and the country of Mauritania itself. Other information about the quantity and quality of groundwater was found in the relational Access database. In its present form, the limited hydrogeologic information was not amenable to conducting water balance, geostatistical, and localized numerical modeling studies in support of mineral exploration and development. Suggestions are provided to remedy many of the data's shortcomings, such as performing quality assurance on all SIPPE2 data tables and sending questionnaires to appropriate agencies, mining and other companies to populate the database with additional meteorology, hydrology, and groundwater data.

Introduction

In 1996, the Islamic Republic of Mauritania requested that the U.S. Geological Survey (USGS) develop a strategic plan for the acquisition, improvement, and modernization of multidisciplinary sets of data to support the growth of the minerals sector and highlight mineral exploration potential of the country. Since development of that plan, the Ministry for Mines and Industry implemented the *Project for Strengthening of the Institutions in the Mining Sector* (PRISM) in which earth science information was acquired through financing from the World Bank, the Islamic Bank of Development, French cooperation, and the government of Mauritania (British Geological Survey, 1996). As a result of these efforts, new geological, geophysical, geochemical, hydrogeologic, and remote sensing data were provided to evaluate areas favorable to mineral exploration and development in Mauritania.

To benefit from the aggregation of new and existing data, the Mauritanian Mines and Industry called for proposals from the international geoscience community for a second project phase (PRISM-2) to synthesize and prepare these data to promote the mining sector. As part of the PRISM-2 project, the USGS agreed to provide the Mauritania Ministry of Mines and Industry with an inventory and review of their data. This first phase acquired data produced by the original PRISM study, as well as existing maps, documents, and other data on the mineral resource potential of Mauritania. This report provides an inventory and review of a subset of these data with emphasis on the available PRISM hydrogeological information (databases and related files).

Inventory and evaluation of the PRISM hydrogeologic information was conducted with four modeling components in mind: conceptualization, parameterization, boundary conditions, and calibration constraints. Conceptualization of a numerical model requires constructing data sets that describe all aspects of the groundwater system; for example, the geometry (thickness and area) of aquifers and confining units, and the location and types of boundary conditions. Parameterization involves assigning parameter values that control the flux rate of movement within the simulated groundwater basin. Examples of groundwater flow parameters include hydraulic conductivity, transmissivity, storativity (or storage coefficient), and porosity. In addition, arid regions such as Mauritania also have a comparatively large variably-saturated zone between the surface and the water table. Such a zone can include features such as dunes or alluvium in the ephemeral streams (oeuds or wadis). Whereas hydraulic parameters such as saturated hydraulic conductivity and various retention properties are easily obtainable for porous material, this information is not readily

available for fractured rock systems. Likewise, some boundary conditions (system stresses) such as precipitation, recharge, and streamflow discharge are not easily quantifiable. Other necessary information on boundary conditions include pumping, evaporation, and evapotranspiration. In many cases, either parameter values or some boundary conditions or both are not available. In these cases, their values need to be estimated using an objective inverse procedure (called model calibration or parameter estimation) that provides consistency with observed field measurements. These field measurements constrain the solution space; hence, they are called calibration constraints. Calibration constraints can include any combination of model-dependent variables, such as water levels, hydraulic head values, recharge rates, and evapotranspiration rates. In coupled mass and energy models, temperature and concentration values are often included in the estimation of related parameters. The following sections describe the findings of the hydrogeologic inventory and review.

Inventory of Hydrogeologic Information

The hydrogeologic information was provided to the USGS in multiple folders, files, and formats, in two groupings that pertained to the Choum-Zouerate area in northwestern Mauritania, and the country of Mauritania itself. A complete list of the folders (bolded), subfolders, files, and brief descriptions are provided in Appendix A.

Reports of Choum-Zouerate

Information pertaining to Choum-Zouerate are in the form of various reports and an Access database called SIPPE2**.** In the **Carte Hydro choumZte** folder (table 5), various reports provide overviews of the hydrogeology and the numerical modeling of the Zouerate area to understand the influence of mining, drilling, the regional management, the terrain, and the satellite imaging. All reports were originally published in French.

In the **Rapports** folder (table 6), a report describes the SIPPE2 (PRISM-2) database installation and use of the management graphical user interface. The executable files associated with the SIPPE2 database are found in the SIPPE2 folder. The SIPPE2 database has a management interface that was not operational because the required username and password were not provided to the USGS. Because of this, queries were set up and run to organize and retrieve data through the SIPPE2 Access database, called Tables_SIPPE2.mdb.

GIS, Excel, and Document Files of Mauritania

Hydrogeologic information for Mauritania was available as graphical information system (GIS in ArcView format), spreadsheet (EXCEL format), and document (WORD and PDF formats) files in the **Notice Hydrogeol** folder. Some of this information provides an overview of formations, groups, and geology at 1:200,000, 1:500,000, and 1:1,000,000 scales for the management areas of Hank, Zerma, Adrar, Tagant, Assaba, Affole, and Hodh. Information on drilling results are provided in a spreadsheet, with individual pages describing drilling in specific groups or areas. A limited number of well studies are provided by area (Tijirit Amsaga, Reguibat LB, Imourène Sougy Delpy LB, and Bir Moghrein TECSULT). Another well study of the AOUKER area is summarized in a separate Excel file. The last study summarized in Excel format provides an overview of drilling activities in the Tijirit, Zemmour, Noir, Amsaga, and Tiris areas. A complementary document file provides an overview by region of the economic activities, climate, and geology.

Relational Database of Choum-Zouerate and Mauritania

As part of PRISM-2, a Microsoft Access® relational database called SIPPE2 was developed and includes 30 related tables and files (fig. 1). In this database, PE and SNIM prefixes pertain to drilling, testing, and sampling across Mauritania and the Choum-Zouerate area, respectively. The most important data table is called PE_PointDEau (water point) and has 11,235 records. Using these primary tables, the primary keys were linked to other tables and queries were run to extract, summarize, and evaluate various sets of hydrogeologic information accordingly. The following section provides a summary of findings for the available GIS and SIPPE2 database information.

Review of Hydrogeologic Information

The overview of hydrogeologic information is in three sections: reports, GIS, and SIPPE2 database. Key information found in the reports includes hydrogeologic setting and the water budget components of evaporation, evapotranspiration, and precipitation. Other information about water quantity and quality are found in the relational database.

Reports

Hydrogeologic Setting

The country of Mauritania is 1,030,700 km^2, and is bounded by the Atlantic Ocean to the west, the Senegal River to the south, and the respective countries of Western Sahara, Algeria, and Mali to the northwest, north, and east. Elevation begins at sea level and rises to about 400 m. The primary rivers include the Senegal along the Senegal border, the Gorgol in the Tagant area, the Garfa and Niorda in the Assaba area, and the Karakoro along the Mali border (fig. 2). With the exception of the Senegal River, all of the rivers are ephemeral. Whereas the Senegal River used to be ephemeral, the river is now artificially maintained in a perennial state through releases of water at an upstream reservoir located in Mali. In addition to these primary rivers, there are wadis, which are smaller ephemeral tributary rivers that include: Seguelil from Atar at the confluence on plandis of Adrar and Amsaga; El Abiod from the south; Khatt depression between Adrar and Tagant; and Tayaret, which is hundreds of kilometers long and is purported to be the oldest stream network, dating back to the Holocene. There are two primary lakes and numerous sebkhas (ephemeral lakes), such as Lake Aleg, which receives water from the Ketchi wadi, and Lake R'Kiz, which receives water by the Senega River. There was no information provided on the locations of stream gage stations and/or streamflow discharge measurements (at any frequency) in any of the reports, GIS files, or databases.

Evaporation, Evapotranspiration, and Precipitation

Climate-related hydrogeologic water budget components found in various reports include evaporation, evapotranspiration, and precipitation. The combination of wind, humidity, temperature, and sun angle all contribute to the magnitude of evaporation. The climate of Mauritania is arid and hot, with annual minimum and maximum temperatures of 19.2^{0}C and 36.9^{0}C, respectively (table 1). Whereas the prevailing wind direction of northeast was given, there is no temporal or spatial information provided for local wind direction, magnitude, or humidity. Annual values of evaporation also were reported for various stations across Mauritania (tables 2-3), and values of evapotranspiration were computed for these stations using the Pennman equation.

More than 60 years of records at a limited number of stations were used to compute annual precipitation (rainfall) values. These data were sufficient to indicate a climatic shift beginning in about 1970, with an annual decrease in precipitation of 100 mm, but were inappropriate for

numerical modeling of places where the rainfall intensity varies spatially and temporally. For example, 54% of the annual rainfall for any given location in Mauritania can fall in as little as an hour. Other than the annual minimum and maximum climatic values described, no other available data sets were sampled more frequently or at additional sites.

Recharge

A third water budget component not directly discussed in the reports is ground-water recharge. The first two components, evaporation and precipitation, directly affect the ability of infiltrating water to become available to the groundwater system as recharge. The climatic shift and the extreme temporal and spatial variability in rainfall in Mauritania should have a profound affect on infiltration and therefore on ground-water recharge. Although lakes, wadis, and the artificial perennial streamflow of the Senegal River have the potential to provide recharge to the ground-water system, ground-water recharge in Mauritania has not been directly quantified (see comments in Appendix C). The only available reference quantifying recharge was an indirect estimation on an international scale by Ould and others (2006). Because the spatial and temporal magnitude of ground-water recharge is unknown, Bertone and others (2006) evaluated, as part of PRISM-2, the likely effect (sensitivity) of various hypothetical recharge scenarios on hydraulic head values in the Choum-Zouerate area, given certain mining operational conditions. One conclusion is that because so much uncertainty exists in the recharge boundary condition, future studies need to focus on quantifying recharge associated with dunes and wadis.

GIS and SIPPE2 Database

Water Quantity

Several direct and indirect methods can be used to estimate the quantity of ground-water recharge. One approach is to assume that the net change in storage is zero (mass budget, where inflows – outflow = 0). In many cases, this steady-state assumption can be used if the water balance components can be determined and are stationary (that is, the mean values do not change over time). The ability to quantify a water budget using a direct (or indirect model calibration) approach is dependent on three criteria: the conceptualization of the model (aquifer description), the supplied values of model parameters (parameterization), and boundary conditions (system stresses). To evaluate the ability to meet these criteria, relevant information from reports, spreadsheets, and the

SIPPE 2 database was tabulated. Specific hydrogeologic information that was aggregated included *conceptualization*: area, thickness, volume, productive zone, porosity, volume of water, and hit ratio; *hydraulic parameters*: permeability, transmissivity, and storativity; *boundary conditions*: production, potentiometric head values, instantaneous flows, and salinity (Appendix C).

Reviewing these tables reveals insufficient information about aquifer area and thickness to allow us to devise a traditional conceptual model. The most consistent sets of information are the hit ratio and instantaneous flows, which are interpreted as the success for producing water and the flow rate, respectively. Descriptions in several reports underscore that all but the southern Continental Terminal aquifer are characterized as fractured and/or karstic with little primary porosity and no correlation to aquifer thickness. These findings, in conjunction with the assertion by Bertone and others (2006) that pump tests are characterized by radial flow through the fractured rock, supports the notion of local equivalent porous media. With this in mind, the range of hit ratios may be viewed as a relative descriptor of heterogeneity (fracture density) in a single aquifer overlying a single impermeable base (fig. 3). In this case, the layer overlying the impermeable base might best be considered stochastic within aquifers or heterogeneous zones. The hydraulic parameters, such as transmissivity and storativity, can be described as random variables, possibly with some correlation to hit ratio and/or instantaneous flows (see table 4).

Whereas it may be possible to provide stochastic rainfall amounts at various locations using a regional downscaling approach, there are no data available on pumping or injection of wells. Several known well fields along the Atlantic coast, in the southern part of the country, and north of the Senegal River are used for public water supply; however, there do not appear to be any associated time-series pumping records in the SIPPE2 database. Historical pumping records for any mining activities also are lacking. The GIS coverages provided for potentiometric head values reveal cones of depression that presumably are located at primary pumping centers (fig. 2c). It is not clear, however, whether these data represent a synoptic study or are simply measurements collected at various times. In the SIPPE2 database, much of the water level data are associated with different years. Where these data indicate changes in water levels (fig. 2d), there is no elevation information provided from which to convert these values to values of hydraulic head.

One suggestion is to populate the SIPPE2 database with well-head elevation information in order to convert the water level data to hydraulic head values. In addition, the head values used to produce the potentiometric maps need to be included in the SIPPE2 database. This information would result in a more complete map (for example, adding missing values to the aquifer described

by the 45-65% hit ratio in south-central Mauritania, fig. 3). Additionally, a series of time-based head maps could be produced for interpreting the direction of groundwater flow, computing boundary fluxes (groundwater inflows and outflows), determining changes in storage, and constraining the calibration of any future numerical models. Other missing information includes the 624 water points (495 static water-level measurements from boreholes, dug wells, and oases) that were recorded and used in the Choum-Zouerate modeling study. After reviewing figures 3-11, we find the primary spatial deficiency in hydrogeologic measurements is in the central and east-central regions of Mauritania, where no information exists. Likewise, there are no physical measurements of infiltration, streamflow discharge, or saturated or unsaturated hydraulic information associated with wadis, sebkhas, or dunes. Anecdotal information provided in the reports indicates that water levels fluctuate both seasonally and following rain events below sebkhas, and in dug wells, domestic wells, and boreholes. More information from these regions would help calculate a more accurate water budget accounting (especially to determine groundwater recharge and sustainability) and as constraint information in numerical modeling studies.

Water Quality

As described in the companion calibration strategy report (Friedel, 2008), multiple types of measurements are required to facilitate convergence and minimize model uncertainty. Whereas flow modeling would ideally include constraint measurements such as head and flux measurements (ground-water, evaporative, and recharge), transport modeling requires additional water-quality information to constrain the estimation of transport parameters. Presently, a limited number of water-quality measurements of concentrations and aqueous physical characteristics are available in the SIPPE2 database. A summary of selected water-quality data (Ca^{2+}, HCO_3^-, Na^+, NO_3^-, SO_4^{2-}, dissolved oxygen, electrical conductivity, pH, and temperature) are provided in table 4 and as maps (figs. 6-10), all revealing their limited spatial distribution. GIS coverages (not shown here) of salinity (total dry residue) are available for the same areas.

While evaluating the SIPPE2 database, several issues came to light. First, there is too much variability in the amount, time, and location of water-quality information sampled (see table 4 and fig. 2). There are also quality assurance problems in which duplicate records and physically implausible values appear. For example, prior to removing outliers, there were impossible numerical ranges, such as those for pH: 0.8 - 737.3, conductivity: 6 – 67000 uS/cm, temperature: 3.5 – 32532.5 ^{0}C, and static water level: 2.5 – 121 m. Finally, no redox (pe or speciation pairs such

as for iron, manganese, or arsenic), dissolved inorganic carbon (DIC), or isotopic measurements are available. Water isotopes are useful in conceptualizing the system hydraulics, whereas carbon isotopes and DIC can be used as model input to NETPATH for estimating the age of water between the present and tens of thousands of years ago. This information could confirm fossil gradients and test the hypothesis of Holocene recharge of the Mauritanian aquifers (Bertone and others, 2006). Other isotopic tracers such as tritium and helium could be used with water isotopes ($^{18}O\delta$ and deuterium) and dissolved gases to understand the role of sebkhas, wadis, and dunes in recharging and discharging the groundwater system. In addition to refining the conceptual model, this information can also constrain future numerical models.

Summary and Conclusions

In 2006, the USGS entered into an agreement with the Mauritania Ministry of Mines and Industry to inventory and evaluate the quality of their PRISM data sets. These data sets were collected by outside contractors through financing from the World Bank, the Islamic Bank of Development, French cooperation, and the government of Mauritania in support of mineral exploration and development in Mauritania. Whereas the PRISM program involved collection of geophysical, geochemical, geological, satellite, and hydrological data sets, this report focuses only on assessing the quantity and quality of available hydrogeological data. The general finding is that, in the present form, the quantity and quality of the hydrogeologic data are limited in the ability to conduct water balance, geostatistical, and localized numerical modeling studies in support of mineral exploration and development. One or more of these issues may be remedied if the following data issues can be resolved.

Report Limitations

- There are no humidity measurements in reports or the SIPPE 2 data tables.
- There is no information on depth and areal extent of aquifers.
- There are no stage measurements for lakes, sebkhas, or wadis.
- There is no information on domestic, industrial, or mining pumping rates.
- There is no information on domestic, industrial, or mining pumping center locations.
- There is no information on recharge rates.

- There is no measured dissolved inorganic carbon or dissolved organic carbon.
- There is no measured redox potential (pe) or speciation pairs, iron, manganese, or arsenic.
- There are no measured isotopes.
- There are no water-level measurements associated with the wadis or sebkhas.
- There are no measurements of infiltration or discharge associated with the wadis or sebkhas.

GIS Coverages Limitations

- The available potentiometric head map is not associated with a synoptic date (or indicates the time period).
- The available potentiometric head map is limited in space.
- Some of the water-level information is not included in the SIPPE2 database.

SIPPE2 Database Limitations

- There are no humidity measurements.
- There are no wind velocity or direction measurements.
- There are no stage or streamflow discharge measurements.
- There are no stage measurements for lakes, sebkhas, or wadis.
- There are only annual rainfall measurements available in reports.
- There are only annual evaporation and evapotranspiration measurements available in reports.
- There are erroneous measurement values and dates.
- There is no information on hit ratio.
- There is no elevation information associated with drilling sites or well locations.
- There is no water level or flux information collected as part of the Choum-Zouerate numerical modeling study.
- There is no unsaturated zone retention values or saturated hydraulic conductivity values.
- There are an insufficient number of hydraulic head values to construct hydraulic gradients across the country.
- There are an insufficient number of synoptic head values to construct hydraulic regional gradients.

- There is no information on domestic, industrial, or mining pumping rates.
- There is no information on domestic, industrial, or mining pumping center locations.
- There is no information on recharge rates.
- There is no depth information for water-quality sampling parameters.
- There is no measured dissolved inorganic carbon or dissolved organic carbon.
- There is no measured redox potential (pe) or speciation pairs, iron, manganese, or arsenic.
- There are no measured isotopes or environmental tracers.
- There are no water level measurements associated with the wadis or sebkhas.
- There are no measurements of infiltration or discharge associated with the wadis or sebkhas.

Suggestions

- Perform quality assurance on all SIPPE 2 data tables.
- Send questionnaires to appropriate agencies, mining and other companies to evaluate availability of additional meteorology (Appendix D), hydrology (Appendix E), and groundwater (Appendix F) data.
- If any of the above data shortcomings can be identified, this information needs to be added to the SIPPE 2 data tables.

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Ould Baba Sy, M., and Besbes M., 2006, Holocene recharge and present recharge of the Saharan aquifers; a study by numerical modeling*, in* Proceedings International IAH Symposium - Aquifers Systems Management - Dijon, France, Mai, 2006, 12 p.

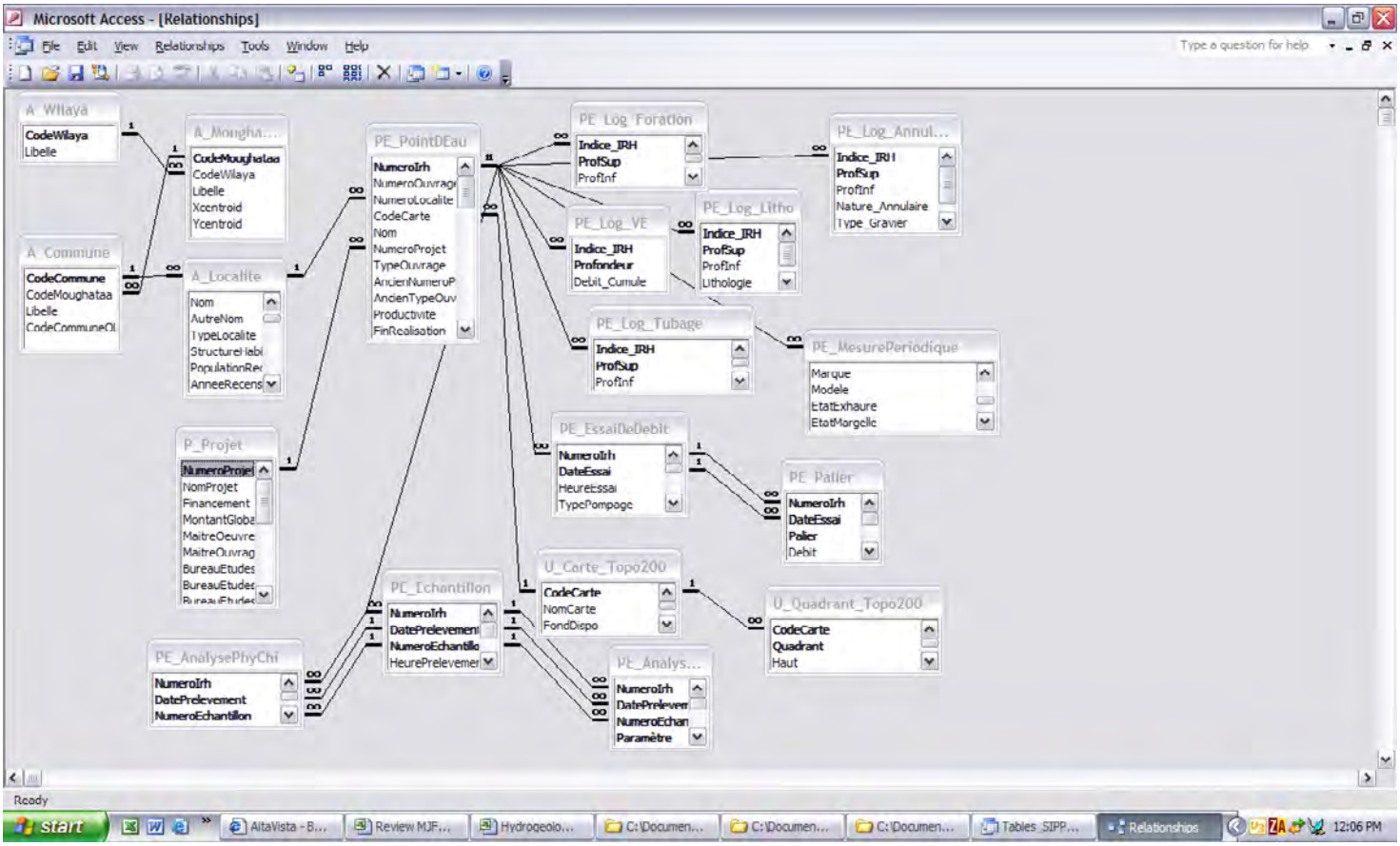

Figure 1. Schematic of relational tables in the SIPPE2 Access database.

Figure 2. Map of Mauritania, Africa, showing relief (gray), streams (light purple), sebkhas (tan), and lakes (light blue).

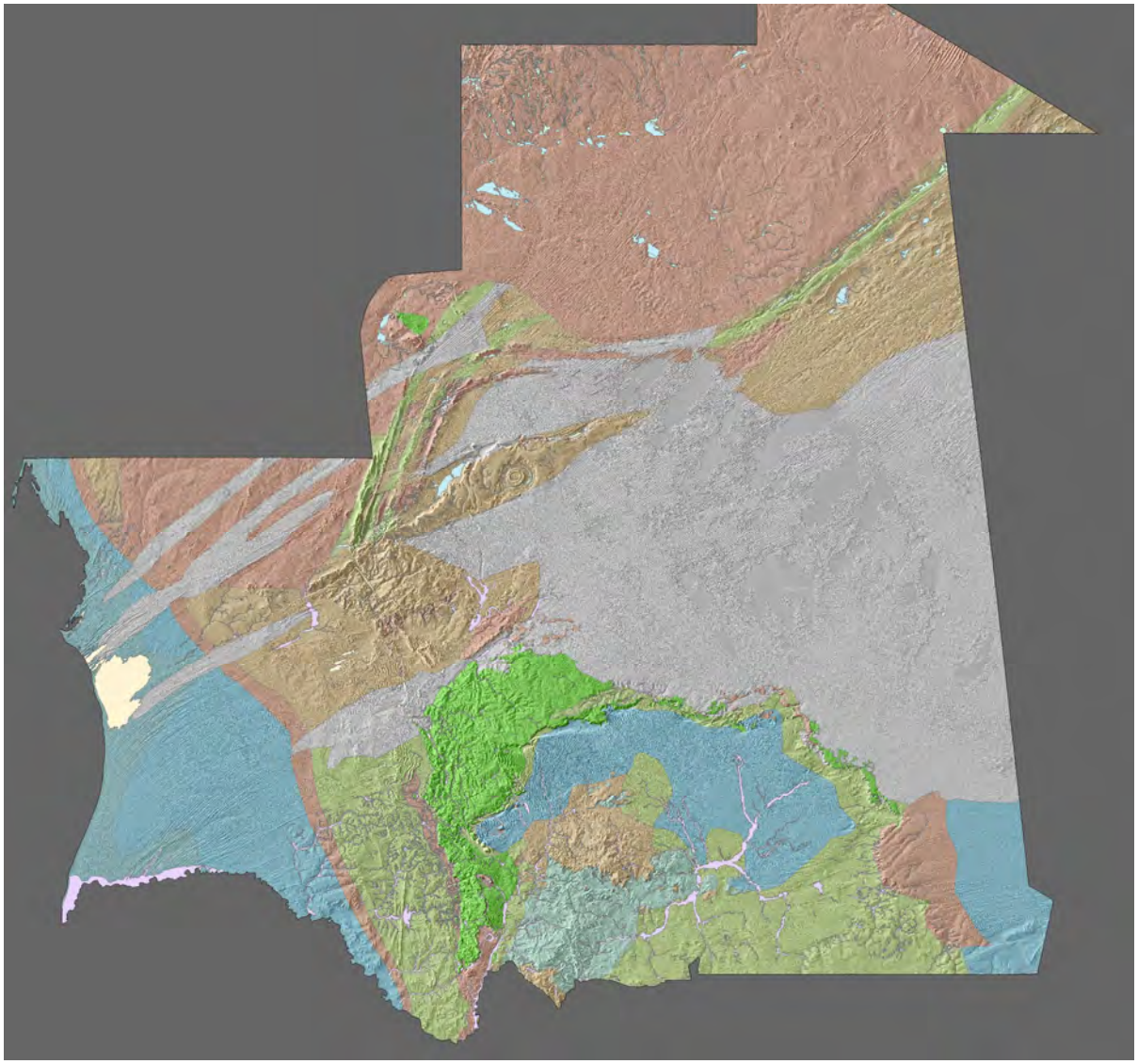

Figure 3. Distribution of aquifers based on success ratio: orange (0-5%), tan (5-45%), olive green (45-65%), light green (65-85%), blue green (80%), blue (80-90%).

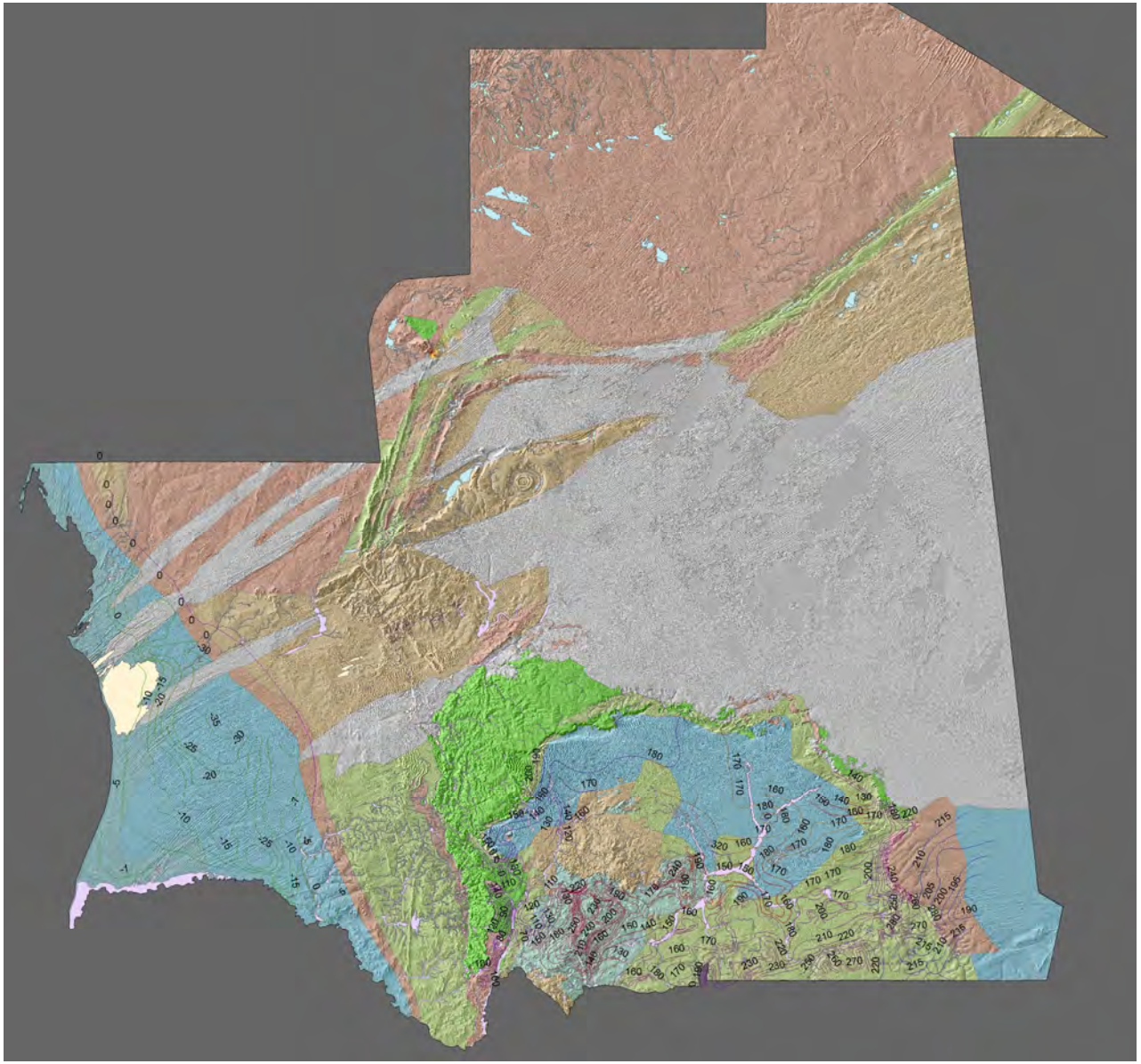

Figure 4. Distribution of hydraulic head values provided as GIS coverages.

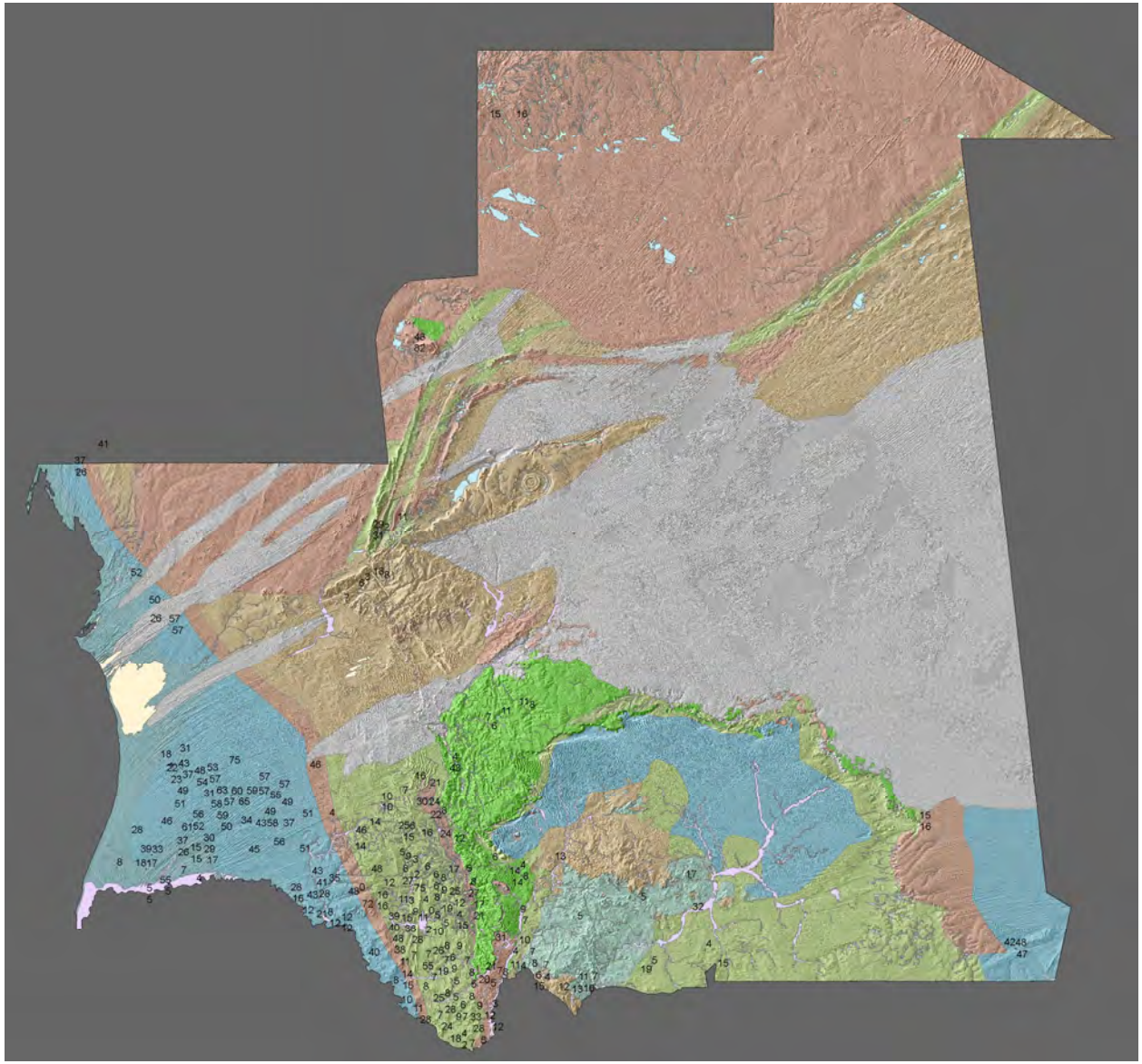

Figure 5. Distribution of measured water levels from the SIPPE2 database.

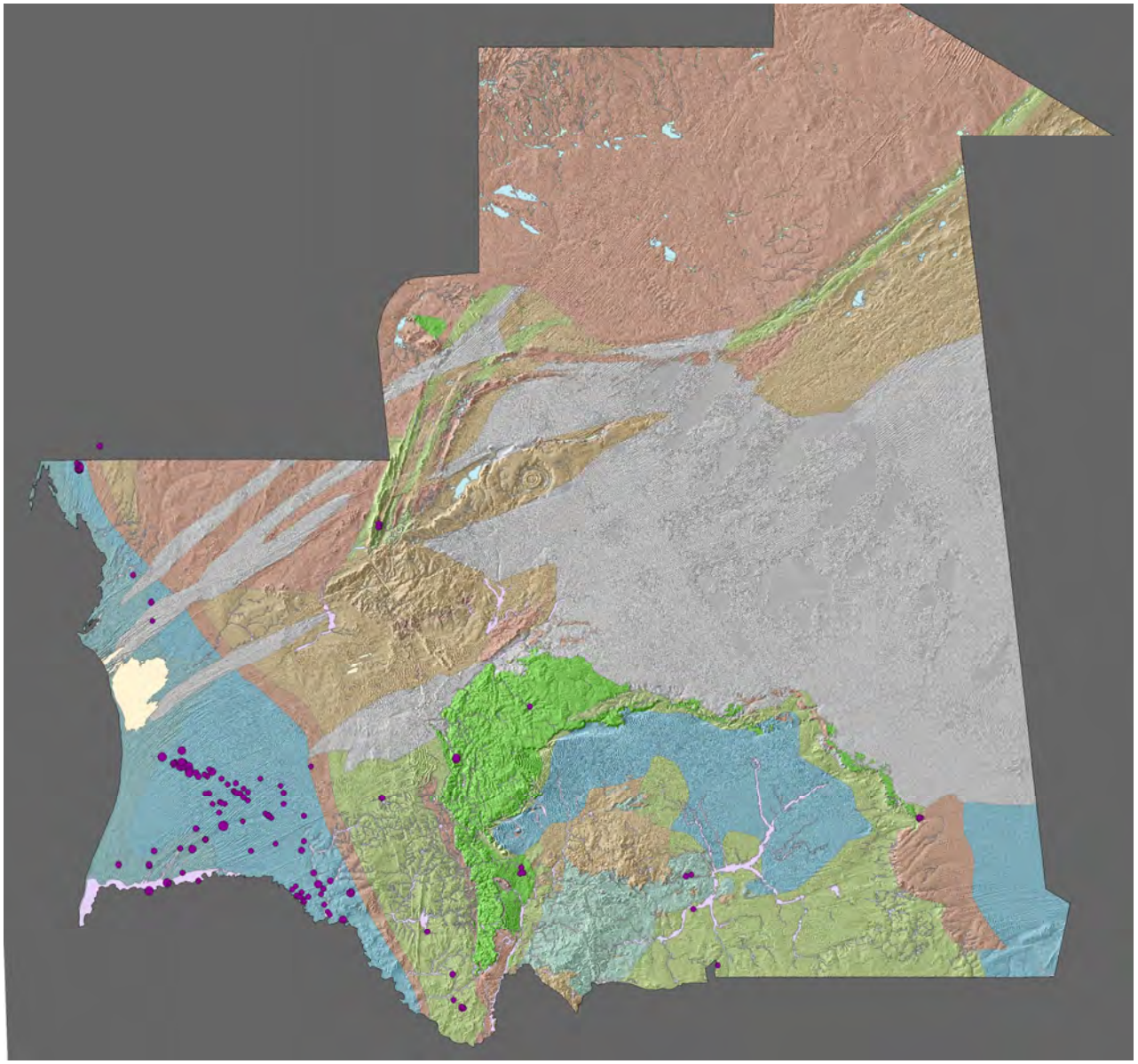

Figure 6. Distribution of aquifer transmissivity values (magenta circles) from the SIPPE2 database. Size of circle indicates relative magnitude of transmissivity.

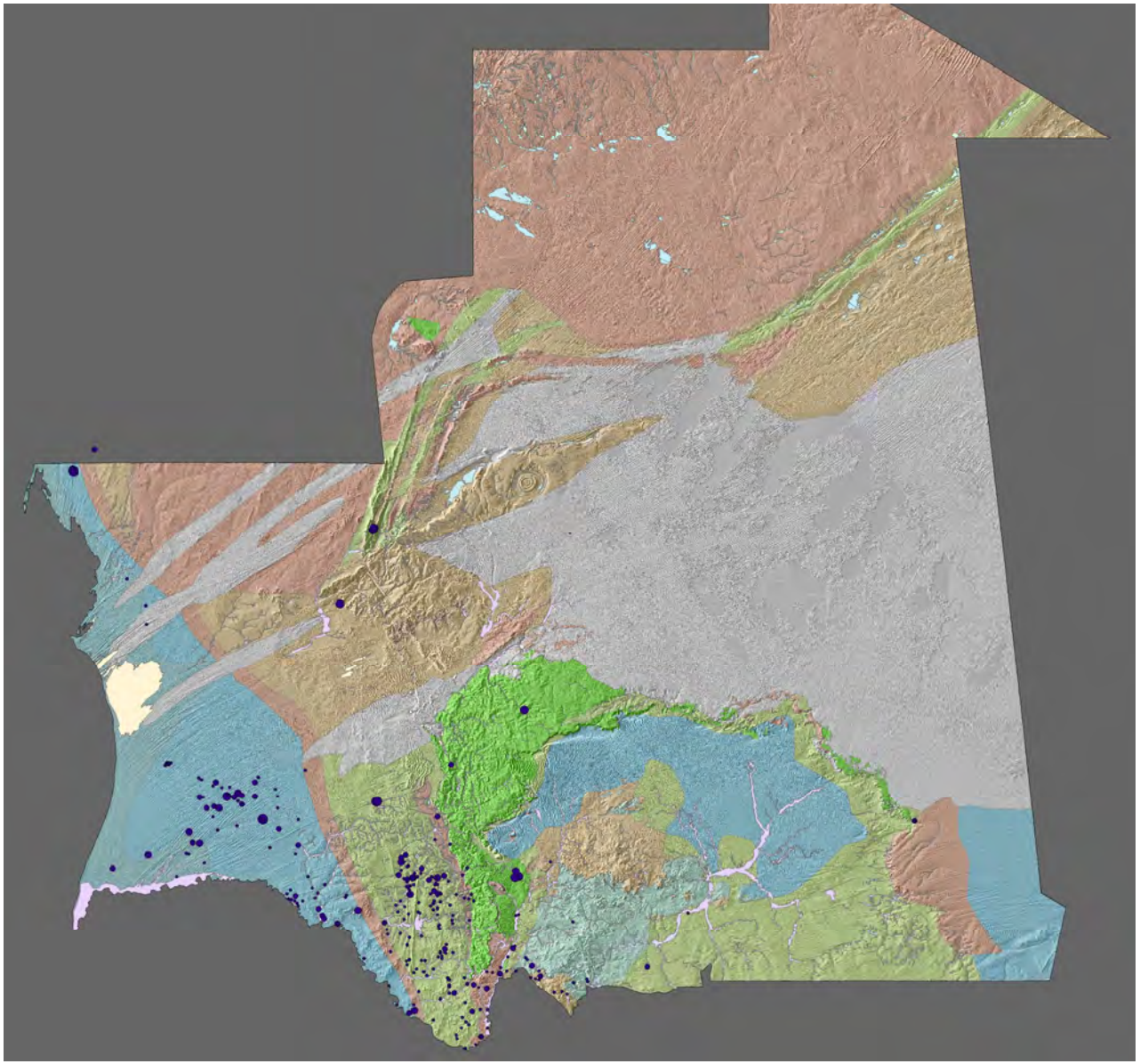

Figure 7. Distribution of dissolved nitrate (purple circles) in ground water from the SIPPE2 database. Size of circle indicates relative magnitude of nitrate concentration.

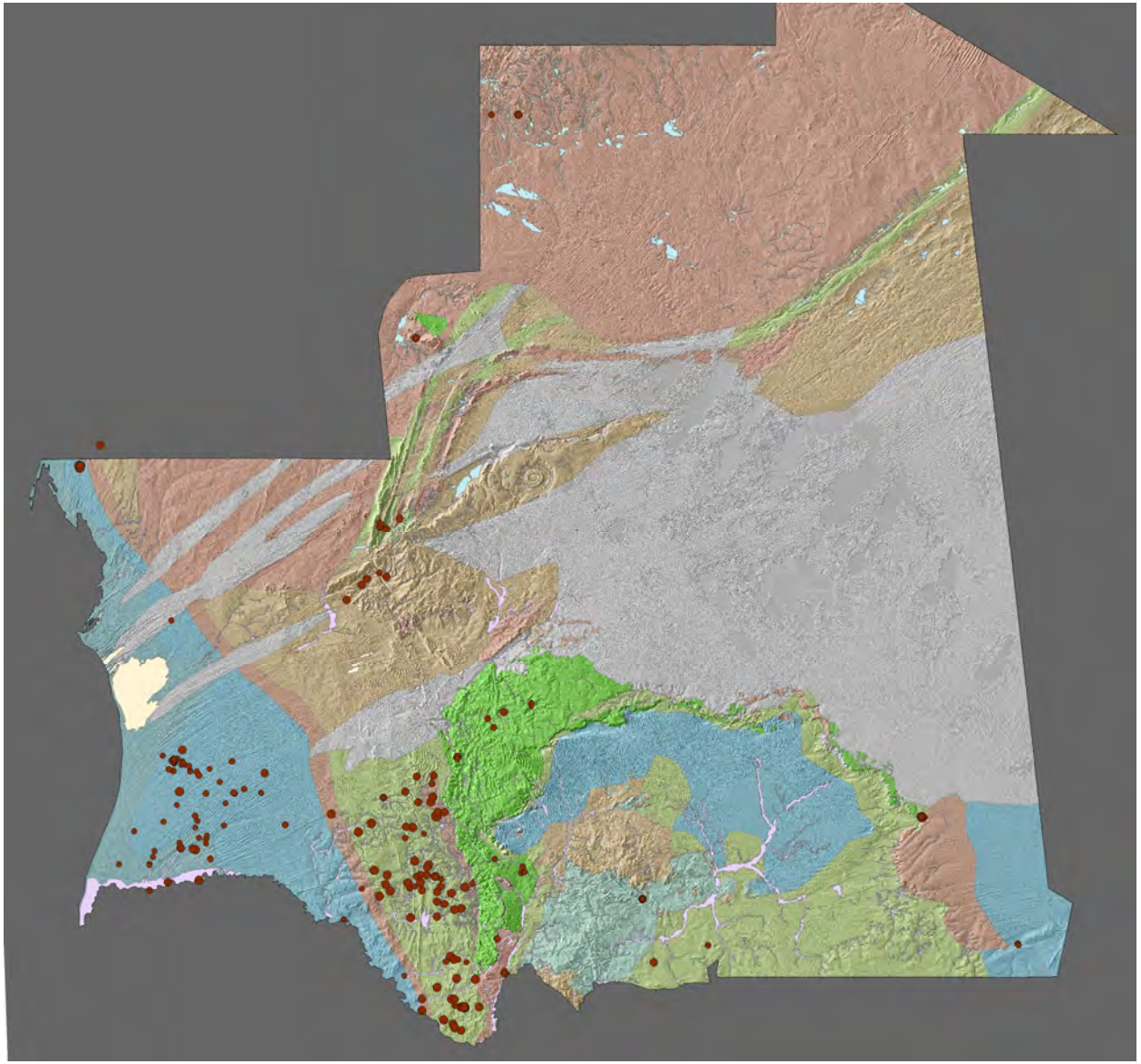

Figure 8. Distribution of dissolved bicarbonate (magenta circles) in ground water from the SIPPE2 database. Size of circle indicates relative magnitude of bicarbonate concentration.

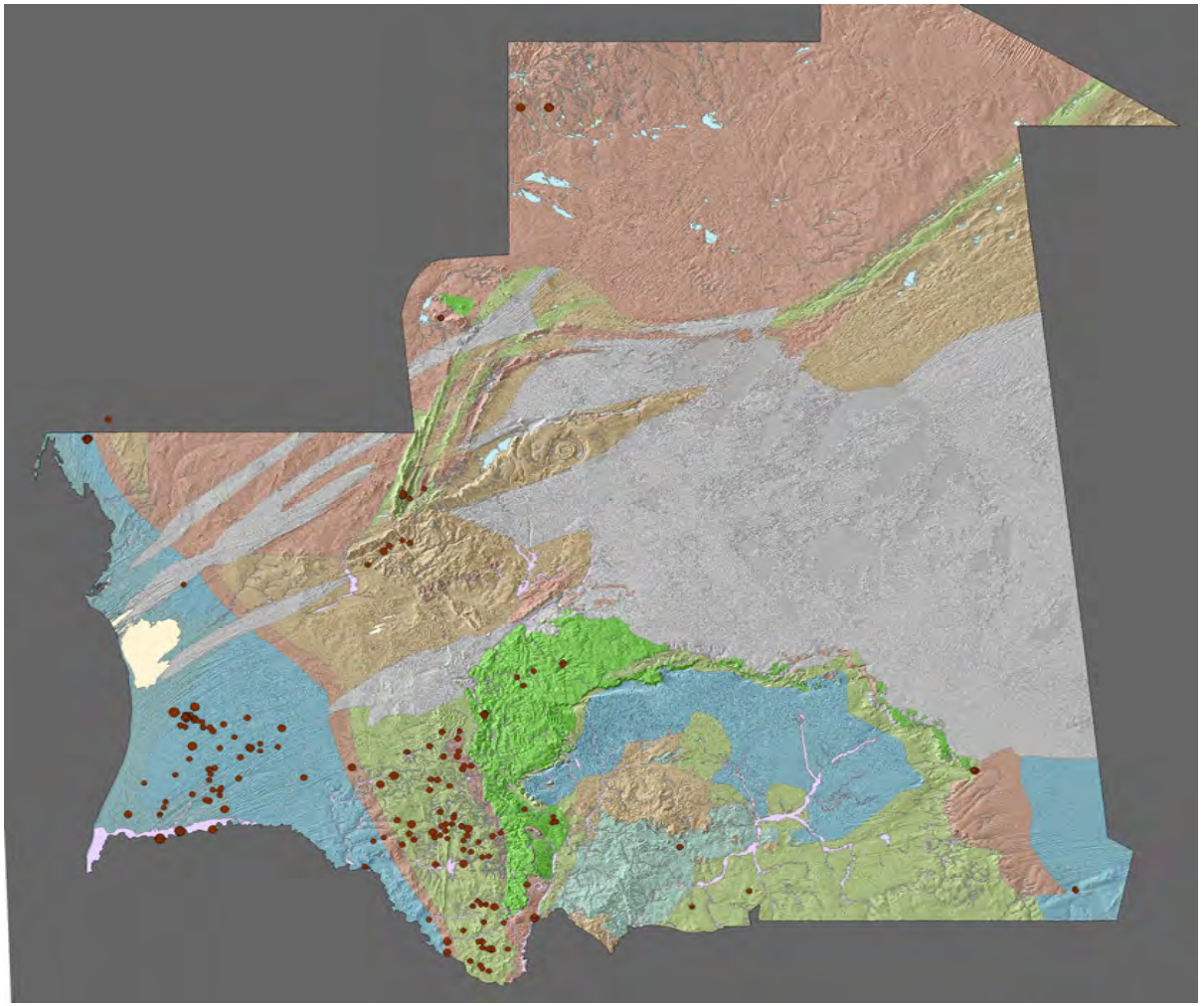

Figure 9. Distribution of dissolved sodium (magenta circles) in ground water from the SIPPE2 database. Size of circle indicates relative magnitude of sodium concentration.

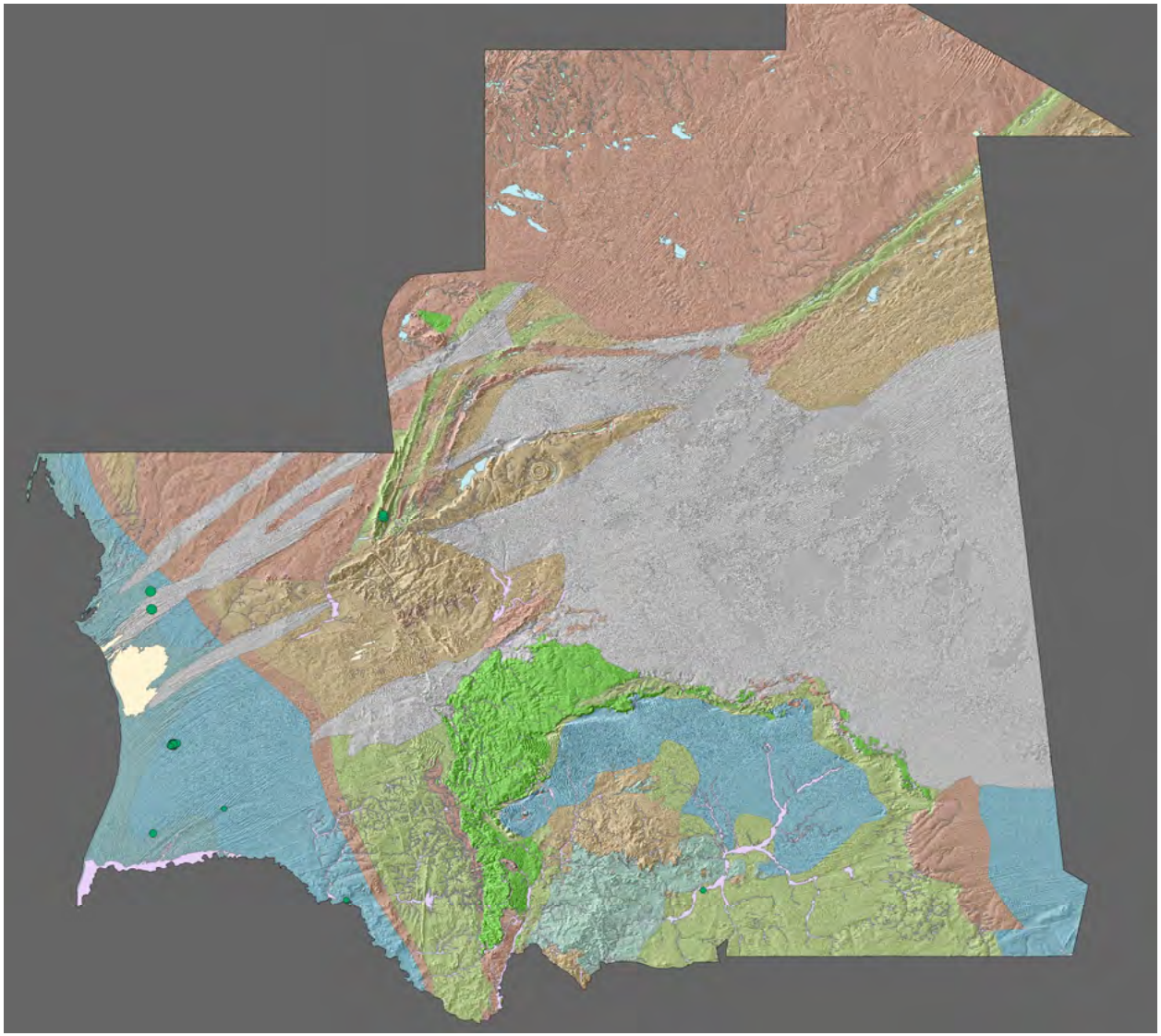

Figure 10. Distribution of dissolved oxygen (green circles) in ground water from the SIPPE2 database. Size of circle indicates relative magnitude of dissolved oxygen concentration.

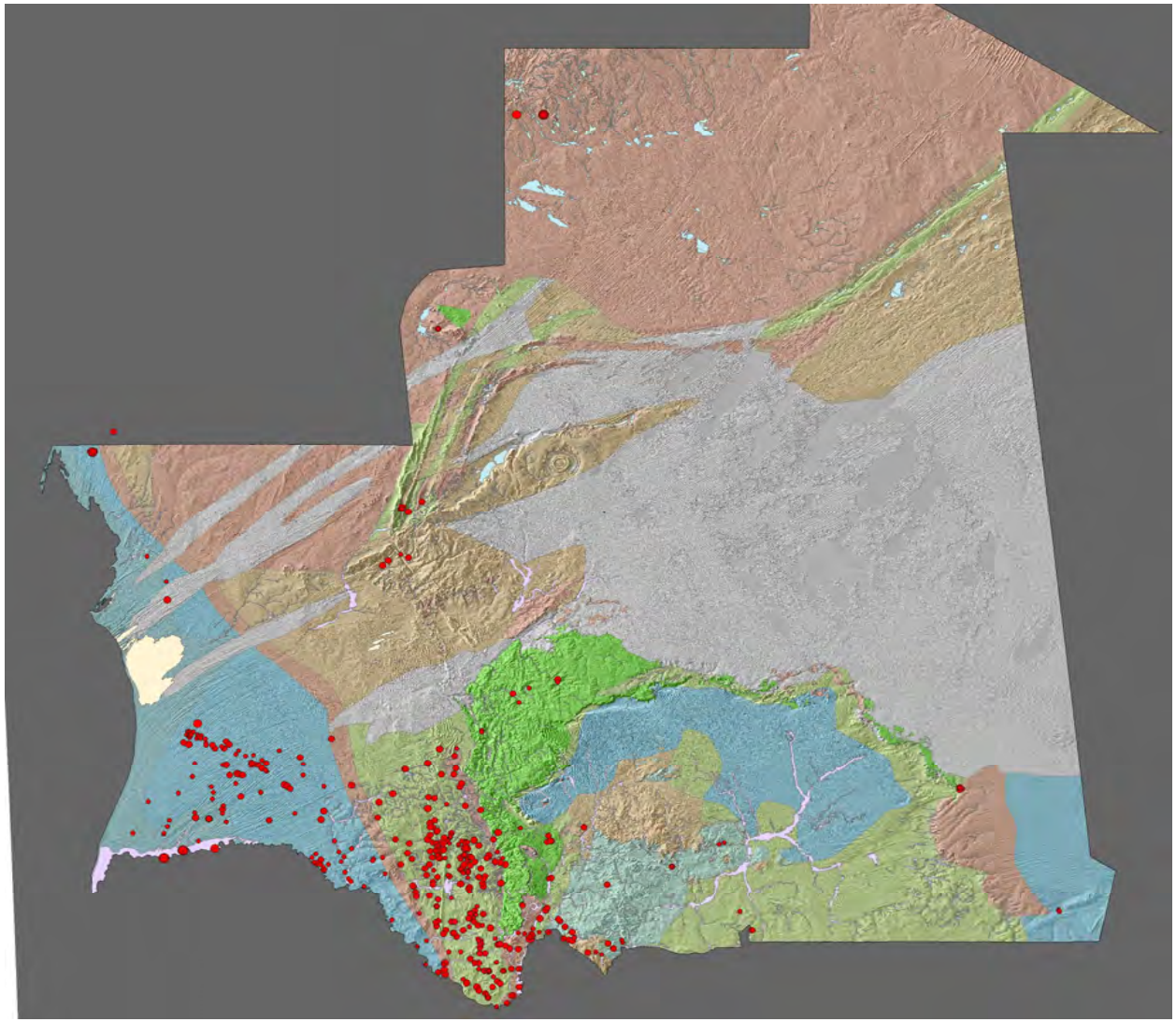

Figure 11. Distribution of electrical conductivity values (red circles) in ground water from the SIPPE2 database. Size of circle indicates relative magnitude of electrical conductivity.

Table 1. Summary of available annual climate information.

[^{0}C = degree Celsius; m = meter]

Parameter	Number of monitoring stations	Number of years monitored	Minimum	Maximum	Average	Comments
Wind	**no data**	**no data**	**No data**	**no data**	**no data**	Northeast direction
Temperatures, ^{0}C	**no data**	**no data**	19.2	36.9	**no data**	
Evaporation, m	11	50	3.2	5.2	4.5	
Potential evapotranspiration					Pennman formula	

Table 2. Annual evaporation, evapotranspiration, and humidity measurements.

[mm = millimeters]

	No. of years	Minimum	Maximum	Average	Median
Evaporation, mm	**28**	2081	5181	3893.67	4123
Potential evapotranspiration, mm	**No data**	1783	2314	2156	2263.5
ratio: E/PET	**No data**	1.07	2.31	1.91	2.12
Humidity	**No data**	**no data**	**no data**	**no data**	**no data**
Precipitation					
average (1935-1969), mm	34	31	304	152.4	138.4
average (1970-2004), mm	34	23.6	214.7	99.8	83

Table 3. Summary of evaporation at measurement stations across Mauritania.

[mm = millimeters]

	No. of years	Aioun	Tidjikja	Nema	Boutilimit	Nauadhibou	Nouakchott	Atar	Akjoujt	Bir Moghrein
Evaporation, mm		4247	4123	5181	4567	2081	2421	4541	3930	3952
Potential evapotranspiration, mm	**No data**	**no data**	1783	2314	2273	**no data**	2254	**no data**	**no data**	**no data**
Ratio: E/PET	**No data**	**no data**	2.31	2.24	2.01	**no data**	1.07	**no data**	**no data**	**no data**
Humidity	**No data**	**no data**	**no data**	**no data**	**no data**	**no data**	**no data**	**no data**	**no data**	**no data**
Precipitation										
average (1935-1969), mm	34	304	139.8	297.5	194.1	31	138.4	108.7	105.2	52.9
Average (1970-2004), mm	34	192.2	91.6	214.7	134.7	23.6	83	70.1	57	31.3
difference (avg1-avg2), mm		111.8	48.2	82.8	59.4	7.4	55.4	38.6	48.2	21.6

Notes average annual precipitation decreased about 100 mm beginning 1970

Table 4. Summary of groundwater physical parameter and chemical concentrations from SIPPE2 database.

[O2 = dissolved oxygen, Temp = temperature, Cond = electrical conductivity, S04 = sulfate, NO3 = nitrate, Na = sodium, Mg = magnesium, HCO3 = bicarbonate, IQR = interquartile range; ^{0}C = degree celsius; µS/cm = microSiemens per cm; mg/l = milligrams per liter; m = meters; m/s meters per second; m^2/s = square meters per second]

Statistic	O_2 mg/l	Salinity mg/l	Ph --	Temp ^{0}C	Cond µS/cm	SO_4 mg/l	NO_3 mg/l	Na mg/l	Mg mg/l	HCO_3 mg/l	Ca mg/l	Permeability m/s	Transmissivity m^2/s	Water Level, m
Count	27	221	569	380	571	287	391	281	293	281	296	77	150	470
Minimum	0.00	0.0	6.00	23.0	1.0	0.0	0.0	0.0	0.0	2.0	1.0	0.0000003	0.0000038	0.0
Maximum	17.59	16489.0	9.00	37.6	19040.0	1900.0	115.0	3524.0	588.0	5499.0	1214.0	0.005796	0.0694	82.2
Average	4.24	848.6	7.44	32.5	985.4	96.9	4.9	150.4	28.5	242.2	72.3	0.000332643	0.007285812	23.3
Standard deviation	3.57	1896.5	0.54	2.5	1364.7	195.3	11.9	376.5	50.1	348.3	113.5	0.000972798	0.012609859	17.3
25th percentile	3.04	252.0	7.00	31.8	457.0	12.5	0.2	30.0	8.0	94.0	25.8	0.00000856	0.000281389	9.7
50th percentile	4.00	374.5	7.47	33.0	731.0	35.0	1.2	55.0	14.0	192.1	47.5	0.00005	0.0021	17.8
75th percentile	5.00	700.0	8.00	34.0	1028.5	92.0	4.6	103.0	30.0	298.3	74.0	0.0001965	0.0081375	34.3
Inter quartile range (IQR)	1.97	448.0	1.00	2.2	571.5	79.5	4.4	73.0	16.0	204.3	48.3	0.00018794	0.007856111	24.6
1.5 * IQR =	2.95	672.0	1.50	3.3	857.3	119.3	6.6	109.5	24.0	306.4	72.4	0.00028191	0.011784167	36.9

Appendix A

Overview of Hydrogeologic Information Provided to the USGS

Table 5. Hydrogeologic information found in the Carte Hydro choumZte folder.

Folder	**\Carte Hydro choumZte**
Subfolder	\
	Zipped and picture files: rar, tiff
	Atar50k.rar, Char50k.rar, Chinguetti50k.rar, F'Derik50k.rar, OumDFeirat50k.rar, Tourine50k.rar
	Document files: pdf
	Overview of hydrogeology in the Zouerate; Hydrogeol_Notice_explicative.pdf
	Report on numerical modeling around Zouerate to understand influence of mining; Modelisation_2D_(version_provisoire).pdf
	Report on drilling; Implantation_forages(version_corrigee).pdf
	Report on regional management; Plan_de_gestion(version_provisorie).pdf
	Rapport_Terrain.pdf
	Report on satellite imaging; teledection_(version_provisoire).pdf

Table 6. Hydrogeologic information found in subfolders of the Rapports folder.

Folder	**\Rapports**
Subfolder	**\Formation**
	Document files: doc
	Training course - data bases; hydrogeologic synthesis; formation.pdf; Formation_BDD.doc
	Glossary; glossaire_extrait.doc
Subfolder	**\Notice Hydrogeol**
	Excel and document files: xls, doc
	Formation, groups, geology at 1/200k, 1/500k, 1/1000k for areas: HANK ZERMA, ADRAR. TAGANT, ASSABA / AFFOLE / HODH; Annexe 1- Annexe 1 Echelle stratigraphique.xls
	Pages includes drilling in groups/areas, success > 1m3/hr (pumping?), pages by lithology: Grès Dar Taleb El Aguer, Grès, Dolomie calcaires, granite, Mauritanides (lithology sections by wilaya - management region - no drillhole locations); Annexe 2 - Notice Analyse resultats forages.xls
	Pages by area (Tijirit Amsaga, Reguibat LB, Imourène Sougy Delpy LB, Bir Moghrein TECSULT) with various studies (wells information (deg, min, sec; quality of water, formation lithology, …) for areas Tijirit Amsaga and Bir Moghrein TECSULT (concentrations, g/l) and Bir Moghrein TECSULT ((3 dates water level - declining); Annexe 3 - Puits IMOURENE REGUIBAT TIJIRIT BIR MOGRHEIM.xls
	Pages by area (A4 Aouker Baretto), …one study PUITS AOUKER (INVENTAIRE BARRETO 1961) with information: x,y,z (ground elev), concentration g/l, some prod. Rates, 3 water levels w dates (NS/sol m?), most water levels for 1961-

62, formation lithology; Annexe 4 - Puits AOUKER.xls

Pages by area (TIJIRIT, ZEMMOUR NOIR, AMSAGA, TIRIS); each page various projects (coordinates, depth, some water levels, some concentrations, lithology described over intervals); Annexe 5 - solndages MAU67-502 TIJIRIT ZEMMOUR NOIR AMSAGAT.xls

Overview by region: economic activities (agriculture, mining, …), climate (average annual precipitation, temperature, evaporation, evapotranspiration), summary of geology (..);Noticartehdro_SR_last.doc

Subfolder **\R1- Demarrage**

Excel and document files: xls, doc

Discussion aquifers (continuous, discontinuous, others, geophysics); SIPPE, HYGES data bases and proposed structure new SIPPE2 (PRISM II) ; training; computer equipment; overview drill log software (6); Rapport R1-Evaluation-R4827a.doc

Subfolder **\R2 Notice SIPPE2**

Document files: doc

SIPPE2 (PRISM II) data base: installation, overview, and use of the management interface (gui pics); Rapport R2 - Notice SIPPE2_complet.doc

Subfolder **\R3 - Activite saise et digit**

Excel and document files: xls, doc

Annexe 1 liste projects saise coupes forgaes.xls

Annexe 2 PE avec nIRH modifie.xls

Annexe 4 Erreurs coordonnees.xls

Biblio_HC.xls

glossary of agencies; overview of drilling information including piezometers (number location; references), geological and salinity information; appendix 1 primary aquifers (1/500k), Appendix 2: reports and docs used for water points; Appendix 3: drilling amended; Appendix 4: coordinate errors for water points; Appendix 5: geological formations (hydrostratigraphic legend); R 4890 - Rapport R3 final BGP.doc

Subfolder **\ R4 Rapport final**

Document files: doc

Overview SIPPE2 (PRISM II) database, technical information (drilings, piez, etc.), gant chart, …; Rapport R4-Rapport final.doc

Subfolder **\ R4 Rapport final**

Document files: doc, pdf

Project overview; data processing examples including annual pump volume (1969-2004); changing salinity in piez (different regions) 1965-2005; average (35 years - 1970-2004) precipitation (mm) by stations (25); figures primary aquifers; Rapport T1-Activitie.doc; Rapport T1-Activitie.pdf

Table 7. Hydrogeologic information (PRISM-2) found in subfolders of the SIPPE2 folder.

Folder (PRISM II)	\SIPPE2
Subfolder	\
	Application and other files: exe, mwd,
	program used as part of management data base SIPPE2.mbd (not used in inventory); ACCES_SIPPE2.mwd
	program used to compact files when management data base SIPPE2 (PRISM II) set up properly (not used in inventory); compactcurrent.exe
	shortcut for desktop; requires setting locations for databases etc.; requires username and password (not used in inventory); Lancement de SIPPE2
	This database has management interface linked to Tables_SIPPE2.mdb; doesn't work unless shortcut is set up properly; SIPPE2.mdb primary data base used to retrieve and evaluate data sets (requires setting up and running queries); 30 tables with multiple primary keys: each described separately below; Tables_SIPPE2.mdb
Subfolder	\Add_On
	Application and other files: exe, zip
	Mapinfo6.5.exe
	WinZip.exe
	MenuTools.zip
	MenuTools_Old.zip
	MW_Fonts.zip
Subfolder	\ARCHIVE
	Text files: txt
	Liste_Zip.txt
	Liste_xZip.txt
Subfolder	\Docs
	Excel and document files: xls, doc
	Dictionary; Dictionnaire BDD.xls
	Overview of SIPPE2 database management applications ; Noitce SIPPE2_complet.doc
	Bibliography; Biblio_HC.xls
Subfolder	\Image
	Excel and picture files: xls, gif, jpg
	Various images; *.xls
	Various logos; *.gif
	Relational structure of database; Structure.jpg
Subfolder	\Dem

Digital elevation model files: img, rrd
Aster dem files: rrd, aux
Aster info files: dat, nit, 001
Aster mnt_projecte files: adf, xlm

Table 8. Hydrogeologic information found in subfolders of the Hydrology folder.

Folder	C:\Mauritania\Mauitania_work\\Hydrology
Subfolder	\decors divers
	GIS files: dbf, sbn, sbx, xhp, prj
	Arf_pays, cadre_nom_point, cadre_rectangle, commune, cote, hydro_lingne, hydro_pol, hydro_pt, mines, newhspe, orog_ligne, orog_pt, pays, physiographie_ligne, pt-eau, pt-rouge, rail, regions, routes, t_aviation, villes
Subfolder	\figuré
	Picture files: bmp
	Typical fills for geologic features
Subfolder	\Hydrogeol
Type:	GIS files: dbf, sbn, sbx, xhp, prj
Files:	aquifere, barrage, Centre_Qoueds, Centre_Sebkha_region, eau_ressource_region, Fractures_digit_yom_polyline, Fractures_digit_yom_region, Nord_Hydrogeol_Yom_polyline, Nord_Hydrogeol_yom_region, Nord_Oueds_yom_region, Nord_Sebkha_rectangle, Nord_Sebkha_region, Sud_Oueds_region
Subfolders	\piézométrie – salinité\AutresPiezos
Type:	GIS files: dbf, sbn, sbx, xhp, prj
Files:	Aouker piezo Est_polyline, Aoukerest salinite_region, Aoukerpiezo Ouest_polyline, Assabapiezo_polyline, Biceausecdhar2_polyline, Dhanemapiezo_polyline, LimiteappeAoukar_point, LimitenappeAoukar_polyline, LimitenappaoukerOuest_polyline, Piezoaoukar_polyline, PiezohodhgrresAioun_polyline, PiezopelitHodh_polyline, Pluviometriea_polyline, Pluviometrieb_polyline, Rosso_biseau_sale_polyline
Subfolders	\piézométrie – salinité\PIEZO CHINOIS
Type:	GIS files: dbf, sbn, sbx, xhp, prj
Files:	PiezoChinois_polyline

Subfolders	\piézométrie – salinité\ Piezo Nord Traza
Type:	GIS files: dbf, sbn, sbx, xhp, prj
Files:	Limitenappe_point, Limitenappe_polyline, Limitenappe_region, Limitenappe_text, PiezonordTraza_polyline, SaliniteTrarza_point, SaliniteTrarza_polyline
Subfolders	\piézométrie – salinité\SALINITE CHINOIS
Type:	GIS files: dbf, sbn, sbx, xhp, prj
Files:	Salinitechinois_polyline
Subfolders	\piézométrie – salinité\TRARAZA PIEZO
Type:	GIS files: dbf, sbn, sbx, xhp, prj
Files:	LimitenappePaloc_point, LimienappePaloc_polyline, LimitenappePaloc_region, LimitesocletrarzaCP_point, LimitesocletrarzaCP_polyline, Piezo Trarza_point, Piezo Trarza_polyline, Piezo Trarza_text
Subfolders	\piézométrie – salinité\TRARAZA SALINITE
Type:	GIS files: dbf, sbn, sbx, xhp, prj
Files:	Trarzasalinite_polyline
Subfolder	\pt_eau
Type:	GIS files: dbf, sbn, sbx, xhp, prj
Files:	Barrage_point, barrages_font_point, PE_point, sondages_point, source_font_point, SR-ListeDesPE-new_font_point, stations_hydrologiques_point
Subfolder	\SIG_Geol_500
Type:	GIS files: dbf, sbn, sbx, xhp, prj
Files:	Nord_Geol_Con_Phase1, Nord_Geol_Div_phase1, Nord_Geol_Pol_Phase1, Nord_Geol_Pol_Phase1, Nord_Geol_Pol_Phase1a, Nord_Geol_Str_Phase1, Sud_Geol_Div_Phase1, Sud_Geol_Pol_Phase1

Table 9. Hydrogeologic information found in subfolders of the SIGE folder.

Folder	\SIGE
Subfolder	\Affect_terres
	GIS files: dbf, sbn, sbx, xhp, prj
	Pot_pastoral
Subfolder	\ Cartographie de base
	GIS files: dbf, sbn, sbx, xhp, prj
	Carte des permis, commune du nord, Index_carte_topo_200k, Mauritanie_division_admin, pays voisns,
	Projet-SIGE, sans titre, SIGE, Zone_pilote_biol, Zone_pilote_carte_topo_200k,
	Zone_pilote_img_Landsat Tm_BRGM, Zone_pilote_Img_LandsatETM_01 (mxd)
Subfolder	\Cartographie thematique
	GIS files: dbf, sbn, sbx, xhp, prj
	GIS files: Carte des permis, commune du nord, Index_carte_topo_200k, Mauritanie_division_admin, pays voisns,
	Projet-SIGE, sans titre, SIGE, Zone_pilote_biol, Zone_pilote_carte_topo_200k, Zone_pilote_img_Landsat Tm_BRGM,
	Zone_pilote_Img_LandsatETM_01 (mxd)
	Figures: Con-hydro-diagr, consomation-hydrocarbure, Evoluation de la popu par regions, population selon le sexe (bmp)
	Pictures: Afrique, pays voisins, pos SIGE, Zone_pilote_carte_topo_200k (jpg)
	Maps: carte thematique, carte tehmatique de certaines composantes environementaales, communes-nord,
	Pays voisins, pop-regions, popu commune du nord, pos sige, sige (tif)
Subfolder	\Climatologie
	Excel files: xls
	Annual minimum and maximum termperatures (1995-2002); Evoluation-T°moyen annuel.xls;
	Annual maximum termperatures (1995-2002); EVOLUTION DES TEMPERATURES (MAXIMALES).xls;
	Annual minimum termperatures (1995-2002) ; EVOLUTION DES TEMPERATURES (MINIALES).xls;
	Annual minimum and maximum humidity(1995-2002); Humidité.xls;
	Annual rainfall mm (1995-2002); pluie.xls
	Annual nb-jour de pluie (1995-2002); pluie-jour.xls
	Annual vent de sable (1995-2002); vent de sable.xls
Subfolder	\Domographie
	Excel files: xls
	Com-Nord.xls

	pop NDB.xls
	pop-région.xls
	Population de la Wilaya de Dakhlet Nouadhibou.xls
	repar par age.xls
	Rép-pop-sex.xls
	Taux net de migration.xls
Subfolder	\Hydrographie
	GIS files: dbf, sbn, sbx, xhp, prj
	Cours_eau, Plan_eau_a, Plan_eau_b (dbf, prj, sbn, shp, shx)
Subfolder	\Hydrographie
	GIS files: dbf, sbn, sbx, xhp, prj
	Cours_eau, Plan_eau_a, Plan_eau_b
Subfolder	\Hydrologie
	GIS files: dbf, sbn, sbx, xhp, prj
	hydro_ligne, hydro_pol
Subfolder	\Point d'eau
	GIS files: dbf, sbn, sbx, xhp, prj
	hydro_ligne, hydro_pol, hydro_pt
Subfolder	\Textes reglementaires\ Legislation minere-Anglais
	Text files: doc, pdf
	Legal documentation
Subfolder	\Transport
	GIS files: dbf, sbn, sbx, xhp, prj
	rail, route, route_pist, t_aviation, urban_ar, Voie_ferree
Subfolder	\Villes_localites
	GIS files: dbf, sbn, sbx, xhp, prj
	cites, villes, villes_principal, schema
	Other files: DAT, ID, IND, MAP, TAB
	Belediyat

Appendix B

Overview of Tables in the PRISM-2 (SIPPE2) Relational Database

Table 10. Overview of tables and fields found in the SIPPE2 database.

[NAME_NAME = database table name; italicized codes are fields in the tables]

Table	Number Records	Comments/*Fields*
A_Commune	245	Code relationships
		CodeCommune, CodeMoughataa, Libelle, CodeCommuneOLD
A_Loc_Population	4889	Community information
		NumeroLocalite, AnneeRecensement, PopulationRecensee, Source, Code, Recensem, Observation
A_Localite	4918	Population, number of wells, latitude, longitude (hr,min,sec); Xcoor, Ycoor (dec degrees)
A_Localité absentes dans la table A_Localite	20	Codes, population, census date
		Code, NumeroLocalite, AnneeRecenser, PopulationRecente, DateRecensemente
A_Moughataa	45	City names and centroid of Wilya (regional administration)
		Libelle, Xcentroid,Ycentroid
A_Wilaya	13	Codes and names of regional management units
		CodeWilaya, Libelle
Lexique_A	23	Lexicon
Lexique_PE	639	Lexicon, codes, descriptions
		Champ, Code, Libelle *Champ (Active, Aptitude, Aquifere, Couleur, Diagnostic,Etat, Fluide, Laboratoire, Lighologie [001-165], Marque, Methode, MethodeForation, MethodInterpretation, Modele, Nature_Annulaire, Nature_Tubage, NatureAquifere, NatureCaptage, NomNappe, Odeur, OrigineCoord, Parametre_Bact, Parametre_PC, Prodcutivite, RepereMesure, Salubrite, Saveur, Stratigraphie, Turbidite, Type_Gravier, Type_Tubage, TypeAquifere, TypeExhaure, TypeOuvrage, TypePompage, Usage, Utilisation), Code, Libelle (descriptions)*
Lexique_Projet	77	Agency, code, project name
PE_AnalyseBact	734	Sample dates, parameters (coliform, e-coli, germs, streptocaucus) - 1967-2003 *Numerolrh, DatePrelevement, NumeroEchantil, Parametre, DateAnalyse, HeureAnalyse, Unite, Valeur_num, Valeur_txt*
PE_AnalysePhyChi	9450	Parametres (aluminum, ammonium, bicarbonates, calcium, fer, fluor, manganese, magnesium, nitrates, nitrites, phosphates, silice, sodium, sulfates; chlorures, aptitude, oxygeneDiss, Ph, conductivite, couleur, temperature); units: °C, uS.m, mg/l

		Numerolrh, DatePrelevement, NumerocEchantillon, Parametre, DateAnalyse, HeureAnalyse, Unite, Valeur_num, Valeur_txt, Observation
		QA problems with dates? For example, 1900-2008
		3816 records 1900-1901?
		2387 records 1900?
		1955, 1959, 1964, 67, 68, 72, 73 74, 75, 76, 80, 85, 86, 87, 89 , 90,
PE_Echantillon		Date, … laboratory, observations (cells mostly empty)
		Numerolrh, DatePrelevement, NumeroEchantil, HeurePrelevement, Preleveur, Laboratoire, Observations
PE_EssaiDeDebit	1895	Pump test information includes type of test, transmissivity, permeability (not fully populated) *Numerolrh, DateEssai, HeureEssai, TypePompage, CoteRepreeMesure, NiveauStatiqueAvantEssai, MethodInterpretation, DebitCritique, RabattlementCritique, DebitSpecifique, Transmissivite, Permeabilite, Emmagasinement, EssaiSaisi*
		QA problems - some K > T (many duplicate records (actually 77)
PE_Log_Annulaire	4048	Information for well completion
		Indie_IRH, ProfSup, Profinf, Nature_Annulair, Type_Gravier, Diametre
PE_Log_Foration	5191	Upper and lower screen/casing?, diameter of casing, drilling method, fluid
		Indice_IRH, ProfSup, Profinf, Diametre, Methode, Fluide
PE_Log_Litho		Lithology between screened interval
		Indice_IRH, ProfSup, Lithologie, Description
PE_Log_Tubage	8010	Drilling and casing information
		Indice_IRH, ProfSup, ProfInf, Type_Tubage, Nature_Tubage, Diametre
		Note: 1356 holes with no apparent casing (mixing)
PE_Log_VE	2745	No comment
PE_MesurePeriodique	7386	Depth work, depth water, level piezometrique, color, odor, turbidite, flavor, mark, models, state pumping, state margelle, state sidewalk, state cloture, state ant quagmire, abreuvior, irrigation, maitrise waters, sale water, reseau, *NumeroIrh, DateVisiteTerrain, CoteRepereMesure, ProfondeurOuvrage, ProfondeurEau, Productivite, Activite, NieveauPiezometrique, Temperature, Conductivite, Ph, Couleur, Odeur, Turbidite, Saveur, Utilisation, DebitExploite, TypeExhaure, …*
		Ph range; 0.8 - 737.3 - QA problems
		Conductivite range:6 – 67000 - QA problems
		Temperature range: 3.5 - 32532.5 - QA problems
		NieveauPiezometrique: range: 2.5 - 121 - QA problems?

PE_Palier		Pump test information? Numerolrh, DateEssai, Pailer, Debit, Duree, NieveauDynamiqueDescente, DurreRemontee, NiveauDynamiqueRemontee
PE_PointDEau	11235	Primary table with primary key for relating to other tables. Z metre, Methode foration utilisation explosif, nature captage, prof premiere venue, prof demiere venue, repere mesure, observation, formation lithologique, profondeur toit, profondeur mur, nature aquifere, type aquifere, aquifere, stratigraphie, nom nappe, coupe saisie, bibliographie, ajout hc, consolider, a verifer, date instruction, date maj
SNIM_Debit_Louly		Nocomment
SNIM_FormationCaptee	96	Well identifier, x,y,z (elevation), coordinates, formation name *ID, forage, X,Y,Z, Prof du toit, formation*
SNIM_Litho	1278	Well identifier, drill intervales, lithologies over intervals *ID, Nom de Forage, Toit, Mur, Lithologie*
SNIM_PE_Louly	268	Drilling information including total depth, and ESRI decimal degree coordinates *id, code_PE, nom,PE, Z_SNIM, propretare, Longitude, Latitude, Xcoord, Ycoord, MAPINFO_ID*
SNIM_SuiviPiezo_Louly	2173	Time series measurements for wells (years); operator *id_charge_hydro, Nom_PE, Date_mesure, mesure, operateur*
U_Carte_Topo200	115	cities, ..
U_Quadrant_Topo200	4104	No comment
U_TableFields	367	No comment
U_TableRelation	17	No comment

Appendix C

Hydrogeologic Inventory Based on Existing Reports

Table 11. Hydrogeologic inventory of aquifer area, thickness, and volume.

[km^2 = square kilometers; m = meter; m^3 = cubic meters]

Geology	Formation	Aquifers	Layers	Area, km^2	Thicknesses, m			Volume aquifer , m^3
					Minimum	Maximum	Average	
	Ridge Reguibat		Annexe 1 Echelle stratigraphique.xls					
		Tasiast		no data	12	39	no data	no data
		Tijirit		no data	47	72	no data	no data
		Amsaga		no data	21	58	no data	no data
		Tris	*Tris*	no data	15	131	31	no data
			Bir Mogrein	no data	23	31	no data	no data
			Hassi Loughar	no data	no data	no data	36	no data
		Kediat Idjill		no data	no data	no data	no data	no data
	Muaritanides							
		Inchiri	*Akjoujt mining area*	no data	23	110	58	no data
		Bakel Moudjeria	*Aleg, Selibaby*	no data	no data	no data	no data	no data
Sedimentary	Taoudenni							
	Infracambrien Adrar and Tiris Zemmour				250	750	340	
		F'Derick, Tourine		no data	no data	no data	no data	no data
		Sandstones of Agueni (Area of Atar)				533.7 (east)		
			Area of Atar	no data	109	200	150	no data
			Area of Tiris Zemmour	no data	no data	hundreds	no data	no data
		Dolomitic limestones of Zzougui						
			Area of Atar		schists -no production			
			Area of Tiris Zemmour	no data	30	400	no data	no data
		Sandstones of Foum Chor						up to 800 m unproductive sandstone toward east
			Area of Atar	no data	100	150	no data	
			Area of Tiris Zemmour	no data	no data	no data	no data	no data
		Limestones of Datar group						

		Area of Atar	no data	no data	no data	no data	no data
		Limestones of Atar	no data	no data	no data	173	no data
		Limestones of Tawaz	no data	36	54	no data	no data
		Limestones of Touiderguilt	no data	24	210	138	no data
		Area of Tiris Zemmour	no data	68	138	no data	no data
	Sandstones of Assabe El Hassian group		no data	22	138	no data	no data
Infracambrien (Assaba, Hodh, Gharbi)							
	Massive sandstones of disturbed						
		Area Kankossa	no data	400	1000	no data	no data
	Sandstones with stratifications (ss of Aioun)						
		Area Kiffa	no data	80	100	no data	no data
Cambrian			no data	35	100	no data	no data
	Lower tillite		no data	no data	no data	no data	no data
	Sandstones of Dar Teleb and El Aguer		no data	no data	no data	no data	no data
	Higher tillite		no data	no data	no data	no data	no data
Cambrian-Ordovician							
	Pilites and japers in Adrar						
		Area El Mreiti, Atar	no data	50	171	no data	no data
	Pilites and japers in Adrar						
		Area Kiffa, Kankossa, Nema, Djigueni	no data	no data	200	no data	no data
	Sandstones with patinachamois						
		Area Assaba	no data	no data	no data	no data	no data
Cambrian-Ordovician							
	Higher dolomite		no data	no data	100	no data	no data
Cambrian-Ordovician							
	Sandstones of Tagant and Assaba		no data	no data	no data	no data	no data
Diorite and dolerite intrusions			no data	no data	no data	no data	no data
Devonian			no data	no data	no data	no data	no data
Sedimentary formations in Taoudenni syncline							
	Devonian		no data	234		1492	top
	Silurian		no data	522			top
	Cambrian-Ordovician		no data	550			top
	Precambrian		no data	1726			top
Aquifers discontinuous; southern edge of Tindouf syncline							
Black Zmmour							

		Area Bir Moghrein	no data	no data	no data	no data	no data
		Area Yetin north	no data	no data	no data	no data	no data
Aquifer continuous Continental Guide (Jurassic)							
	Under Dahr de Nema						
		Areas Nema, Suina,	16,760	no data	no data	no data	no data
		Djigueni, Bassikonou	no data	no data	no data	no data	no data
	Under dunes of El Mreye and Adhafer		no data	no data	no data	no data	no data
Aquifer continuous deep Maestrichtien							
		Areas Aleg, Rosso, Nouakchott, Nouadhibou	no data	no data	no data	no data	no data
Coastal mining areas			100000				
	Trarza	Cretaceous (Masetrichtien)	no data	no data	no data	no data	no data
		Eocene	no data	no data	no data	no data	no data
		Continental Terminal	no data	30	300	east, west	no data
		Idini well field production - subphreatic layer					
	Bennichab		no data	no data	no data	no data	no data
	Tiersioum		no data	no data	no data	no data	no data
Continuous recent sedimentary							
	Alluvium of wadis						
	Adrar, Mauritanides, Tagant, Assaba, Guidimaka, Hodhs		no data	2	26	10	no data
	Alluviam of Senegal River		no data	no data	35	15	no data
	Dunes		no data	10	100	no data	no data
	Quaternary	sand dunes, wadi sands	no data	10	30	no data	no data

Table 12. Hydrogeologic inventory of aquifer production, porosity, and hit ratio.

[m = meter; % = percent; m^3 = cubic meters]

Geology	Formation	Aquifers	Layers	Productive zone, m			Porosity, %	Volume water $x10^9$ m^3	Hit Ratio, %		
				minimum	maximum	average			minimum	maximum	average
Base											
	Ridge Reguibat		Annexe 1 Echelle stratigraphique.xls								
		Tasiast		no data	no data	no data	no data	no data	no data	no data	no data
		Tijirit		no data	no data	no data	no data	no data	no data	no data	no data
		Amsaga		no data	no data	no data	no data	no data	no data	no data	21
		Tris	*Tris*	no data	no data	no data	no data	no data	no data	no data	no data
			Bir Mogrein	no data	no data	no data	no data	no data	no data	no data	no data
			Hassi Loughar	no data	no data	no data	no data	no data	no data	no data	no data
		Kediat Idjill		no data	no data	no data	no data	no data	no data	no data	no data
	Muaritanides										
		Inchiri	*Akjoujt mining area*	no data	no data	no data	no data	no data	38	50	no data
		Bakel Moudjeria	*Aleg, Selibaby*	no data	no data	no data	no data	no data	34	62	no data
Sedimentary	Taoudenni										
	Infracambrien Adrar and Tiris Zemmour										
		F'Derick, Tourine		no data	no data	no data	no data	no data	no data	no data	no data
		Sandstones of Agueni (Area of Atar)									
			Area of Atar	no data	no data	no data	no data	no data	no data	58	no data
			Area of Tiris Zemmour	no data	no data	no data	no data	no data	no data	50	no data
		Dolomitic limestones of Zzougui									
			Area of Atar	na	na	na	na	na	na	na	na
			Area of Tiris Zemmour	no data	no data	no data	no data	no data	no data	no data	70
		Sandstones of Foum Chor									
			Area of Atar				no data	no data	55	88	no data
			Area of Tiris Zemmour	no data	no data	no data	no data	no data	no data	no data	50
		Limestones of Datar group									

	Area of Atar	no data	no data	no data	no data	no data	no data	no data	no data
	Limestones of Atar	no data	no data	no data	no data	no data	no data	no data	72
	Limestones of Tawaz	no data	no data	no data	no data	no data	no data	no data	no data
	Limestones of Touiderguilt	no data	no data	no data	no data	no data	no data	no data	no data
	Area of Tiris Zemmour	no data	no data	no data	no data	no data	no data	no data	no data
Sandstones of Assabe El Hassian group		no data	no data	no data	no data	no data	no data	no data	no data
Infracambrien (Assaba, Hodh, Gharbi)									
Massive sandstones of disturbed									
	Area Kankossa	no data	no data	no data	no data	no data	no data	no data	62
Sandstones with stratifications (ss of Aioun)									
	Area Kiffa	no data	no data	no data	no data	no data	no data	no data	no data
Cambrian		no data	no data	no data	no data	no data	no data	no data	43
Lower tillite		no data	no data	no data	no data	no data	no data	no data	no data
Sandstones of Dar Teleb and El Aguer		no data	no data	no data	no data	no data	no data	no data	no data
Higher tillite		no data	no data	no data	no data	no data	no data	no data	no data
Cambrian-Ordovician									
Pilites and japers in Adrar									
	Area El Mreiti, Atar	no data	no data	no data	no data	no data	no data	no data	no data
Pilites and japers in Adrar									
	Area Kiffa, Kankossa, Nema, Djigueni	no data	no data	no data	no data	no data	41	50	no data
Sandstones with patinachamois									
	Area Assaba	no data	no data	no data	no data	no data	no data	no data	no data
Cambrian-Ordovician									
Higher dolomite		no data	no data	no data	no data	no data	no data	no data	no data
Cambrian-Ordovician									
Sandstones of Tagant and Assaba		no data	no data	no data	no data	no data	no data	no data	no data
Diorite and dolerite intrusions		no data	no data	no data	no data	no data	no data	38	no data
Devonian		no data	no data	no data	no data	no data	no data	no data	no data
Sedimentary formations in Taoudenni syncline							80		
Devonian		no data	no data	no data	no data	no data	no data	no data	no data
Silurian		no data	no data	no data	no data	no data	no data	no data	no data
Cambrian-Ordovician		no data	no data	no data	no data	no data	no data	no data	no data
Precambrian		no data	no data	no data	no data	no data	no data	no data	no data
Aquifers discontinuous; southern edge of Tindouf syncline									
Black Zmmour									

		Area Bir Moghrein	no data	no data	no data	no data	no data	no data	no data	no data
		Area Yetin north	no data	no data	no data	no data	no data	no data	no data	no data
Aquifer continuose Continental Guide (Jurassic)										
	Under Dahr de Nema									
		Areas Nema, Suina,	no data	no data	no data	5	42	no data	no data	no data
		Djigueni, Bassikonou	no data	no data	no data	no data	no data	no data	no data	no data
	Under dunes of El Mreye and Adhafer		no data	no data	no data	no data	no data	no data	no data	no data
Aquifer continuous deep Maestrichtien										
		Areas Aleg, Rosso, Nouakchott, Nouadhibou	no data	no data	no data	no data	no data	no data	no data	no data
Coastal mining areas										
	Trarza	Cretaceous (Masetrichtien)	no data	no data	no data	5	50-100	no data	no data	no data
		Eocene	no data	no data	no data	no data	no data	no data	no data	no data
		Continental Terminal	no data	no data	no data	no data	no data	no data	no data	no data
		Idini well field production - subphreatic layer								
	Bennichab		no data	no data	no data	no data	no data	no data	no data	no data
	Tiersioum		no data	no data	no data	no data	no data	no data	no data	no data
Continuous recent sedimentary										
	Alluvium of wadis									
	Adrar, Mauritanides, Tagant, Assaba, Guidimaka, Hodhs		no data	no data	no data	no data	no data	no data	no data	no data
	Alluviam of Senegal River		no data	no data	no data	no data	no data	no data	no data	no data
	Dunes		no data	no data	no data	no data	no data	no data	no data	no data
	Quaternary	sand dunes, wadi sands	no data	no data	no data	no data	no data	no data	no data	no data

Table 13. Hydrogeologic inventory of aquifer instantaneous flows and associated salinity concentrations.

[$m^3 hr^{-1}$ = cubic meters per hour; $g l^{-1}$ = grams per liter]

Geology	Formation	Aquifers	Layers	Instantaneous Flows $m^3 hr^{-1}$ Average	Minimum	Maximum	Salinity $g l^{-1}$ Average	Minimum	Maximum	Average
Base										
	Ridge Reguibat		Annexe 1 Echelle stratigraphique.xls							
		Tasiast		no data	0.6	3	no data	3	37	no data
		Tijirit		no data	no data	no data	no data	no data	no data	no data
		Amsaga		21	no data	no data	no data	no data	no data	no data
		Tris	*Tris*	no data	8	20	no data	5	60	no data
			Bir Mogrein	no data	1	3	no data	2.2	2.5	no data
			Hassi Loughar	no data	3.3	no data	no data	0.5	1.6	no data
		Kediat Idjill		no data	no data	no data	no data	0.3	1	0.45
	Muaritanides									
		Inchiri	*Akjoujt mining area*	no data	1	30	5	1	no data	no data
		Bakel Moudjeria	*Aleg, Selibaby*	no data	2.5	8.6	2.5	no data	1	no data
Sedimentary	Taoudenni									
	Infracambrien Adrar and Tiris Zemmour									
		F'Derick, Tourine		no data	no data	no data	no data	no data	no data	no data
		Sandstones of Agueni (Area of Atar)								
			Area of Atar	no data	10	80	no data	0.15	1.7	no data
			Area of Tiris Zemmour	no data	0.5	2	1.2	2	5	no data
		Dolomitic limestones of Zzougui								
			Area of Atar	no data	no data	no data	no data	no data	no data	no data
			Area of Tiris Zemmour	70	0.6	5	2.3	2	25	7
		Sandstones of Foum Chor								
			Area of Atar	no data	1	50	no data	0.5	8.4	no data

	Area of Tiris Zemmour	50	0.7	15	no data	2	7	no data
Limestones of Datar group								
	Area of Atar	no data	no data	no data	no data	no data	no data	no data
	Limestones of Atar	72	1	16	no data	no data	no data	no data
	Limestones of Tawaz	no data	no data	no data	3.5	no data	no data	no data
	Limestones of Touiderguilt	no data	10	20	no data	0.2	9	no data
	Area of Tiris Zemmour	no data	4.5	36	no data	0.7	3.7	no data
Sandstones of Assabe El Hassian group		no data	no data	no data	no data	no data	11.5	no data
Infracambrien (Assaba, Hodh, Gharbi)								
Massive sandstones of disturbed								
	Area Kankossa	62	no data	no data	2	no data	no data	0.5
Sandstones with stratifications (ss of Aioun)								
	Area Kiffa	no data	42	72	Assaba, Hodh Garbi	0.2	2	0.3
Cambrian		43	1	24	9.5	0.2	7	1
Lower tillite		no data	no data	no data	no data	no data	no data	no data
Sandstones of Dar Teleb and El Aguer		no data	no data	no data	no data	no data	no data	no data
Higher tillite		no data	no data	no data	no data	no data	no data	no data
Cambrian-Ordovician								
Pilites and japers in Adrar								
	Area El Mreiti, Atar	no data	2	14.5	no data	0.5	2.6	no data
Pilites and japers in Adrar								
	Area Kiffa, Kankossa, Nema, Djigueni	no data	no data	no data	no data	no data	no data	no data
Sandstones with patinachamois								
	Area Assaba	no data	no data	10	no data	0.3	1.8	no data
Cambrian-Ordovician								
Higher dolomite		no data	no data	no data	no data	no data	no data	no data
Cambrian-Ordovician						0.5	1	
Sandstones of Tagant and Assaba		no data	no data	no data	no data	no data	no data	no data
Diorite and dolerite intrusions		no data	1	10	no data	2	5.9	no data

Devonian		no data	no data	no data	no data	no data	no data	no data
Sedimentary formations in Taoudenni syncline								
	Devonian	no data	no data	no data	no data	no data	no data	no data
	Silurian	no data	no data	no data	no data	no data	no data	no data
	Cambrian-Ordovician	no data	no data	no data	no data	no data	no data	no data
	Precambrian	no data	no data	no data	no data	no data	no data	no data
Aquifers discontinouous; southern edge of Tindouf syncline								
Black Zmmour								
	Area Bir Moghrein	no data	no data	no data	no data	no data	no data	no data
	Area Yetin north	no data	no data	no data	no data	no data	no data	no data
Aquifer continuose Continental Guide (Jurassic)								
Under Dahr de Nema								
	Areas Nema, Suina,	no data	no data	no data	no data	no data	0.5	no data
	Djigueni, Bassikonou	no data	no data	no data	no data	no data	no data	no data
Under dunes of El Mreye and Adhafer		no data	no data	no data	no data	no data	no data	no data
Aquifer continuous deep Maestrichtien								
	Areas Aleg, Rosso, Nouakchott, Nouadhibou	no data	no data	no data	no data	1	17	east, west
Coastal mining areas								
Trarza	Cretaceous (Masetrichtien)	no data	no data	no data	no data	no data	no data	no data
	Eocene	no data	30	60		0.5	10	east, west
	Continental Terminal	no data	10	30		0.5	8	
	Idini well field production - subphreatic layer		25	80		0.01	0.5	
Bennichab		no data	no data	no data	no data	no data	no data	no data
Tiersioum		no data	no data	no data	no data	no data	no data	no data
Continuous recent sedimentary								
Alluvium of wadis								
Adrar, Mauritanides, Tagant, Assaba, Guidimaka, Hodhs		no data	no data	no data	no data	no data	no data	no data
Alluviam of Senegal River		no data	no data	no data	no data	no data	no data	no data
Dunes		no data	no data	no data	no data	no data	no data	no data
Quaternary	sand dunes, wadi sands	no data	no data	no data	no data	no data	no data	no data

Table 14. Hydrogeologic inventory of aquifer hydraulic properties.

[$m^2 s^{-1}$ = square meters per second; $m^3 d^{-1}$ = cubic meters per day]

Geology	Formation	Aquifers	Layers	Transmissivity x10^{-3}, $m^2 s^{-1}$ Minimum	Transmissivity x10^{-3}, $m^2 s^{-1}$ Maximum	Transmissivity x10^{-3}, $m^2 s^{-1}$ Average	Storativity x10^{-4} Minimum	Storativity x10^{-4} Maximum	Storativity x10^{-4} Average	Production Total pump rate, $m^3 d^{-1}$
Base										
	Ridge Reguibat		Annexe 1 Echelle stratigraphique.xls							
		Tasiast		no data	no data	no data	no data	no data	no data	no data
		Tijirit		no data	no data	no data	no data	no data	no data	no data
		Amsaga		no data	no data	no data	no data	no data	no data	no data
		Tris	*Tris*	no data	no data	no data	no data	no data	no data	no data
			Bir Mogrein	no data	no data	no data	no data	no data	no data	no data
			Hassi Loughar	no data	no data	no data	no data	no data	no data	no data
		Kediat Idjill		no data	no data	no data	no data	no data	no data	no data
	Muaritanides									
		Inchiri	*Akjoujt mining area*	2.5	6	no data	2	4.5	no data	no data
		Bakel Moudjeria	*Aleg, Selibaby*	no data	no data	no data	no data	no data	no data	no data
Sedimentary	Taoudenni									
	Infracambrien Adrar and Tiris Zemmour									
		F'Derick, Tourine		no data	no data	no data	no data	no data	no data	no data
		Sandstones of Agueni (Area of Atar)								
			Area of Atar	0.7	5	no data	1	1.5	no data	no data
			Area of Tiris Zemmour	0.2	0.8	no data	no data	no data	0.5	no data
		Dolomitic limestones of Zzougui								
			Area of Atar	no data	no data	no data	no data	no data	no data	no data

	Area of Tiris Zemmour	0.13	5.3	no data	0.01	10	no data	no data
Sandstones of Foum Chor								
	Area of Atar	no data	no data	no data	no data	no data	no data	no data
	Area of Tiris Zemmour	no data	no data	no data	no data	no data	no data	no data
Limestones of Datar group								
	Area of Atar	no data	no data	no data	no data	no data	no data	no data
	Limestones of Atar	no data	no data	no data	no data	no data	no data	no data
	Limestones of Tawaz	no data	no data	no data	no data	no data	no data	no data
	Limestones of Touiderguilt	no data	no data	no data	no data	no data	no data	no data
	Area of Tiris Zemmour	no data	no data	no data	no data	no data	no data	no data
Sandstones of Assabe El Hassian group		no data	no data	no data	no data	no data	no data	no data
Infracambrien (Assaba, Hodh, Gharbi)								
Massive sandstones of disturbed								
	Area Kankossa	no data	no data	no data	no data	no data	no data	no data
Sandstones with stratifications (ss of Aioun)								
	Area Kiffa	no data	no data	no data	no data	no data	no data	no data
Cambrian		no data	no data	no data	no data	no data	no data	no data
Lower tillite		no data	no data	no data	no data	no data	no data	no data
Sandstones of Dar Teleb and El Aguer		no data	no data	no data	no data	no data	no data	no data
Higher tillite		no data	no data	no data	no data	no data	no data	no data
Cambrian-Ordovician								
Pilites and japers in Adrar								
	Area El Mreiti, Atar	no data	no data	no data	no data	no data	no data	no data
Pilites and japers in Adrar								
	Area Kiffa, Kankossa, Nema, Djigueni	0.011	1.1	no data	0.1	1	no data	no data
Sandstones with patinachamois								
	Area Assaba	no data	no data	no data	no data	no data	no data	no data
Cambrian-Ordovician								

	Higher dolomite	no data	no data	no data	no data	no data	no data	no data
Cambrian-Ordovician								
	Sandstones of Tagant and Assaba	no data	no data	no data	no data	no data	no data	no data
Diorite and dolerite intrusions		no data	no data	no data	no data	no data	no data	no data
Devonian		no data	no data	no data	no data	no data	no data	no data
Sedimentary formations in Taoudenni syncline								
	Devonian	no data	no data	no data	no data	no data	no data	no data
	Silurian	no data	no data	no data	no data	no data	no data	no data
	Cambrian-Ordovician	no data	no data	no data	no data	no data	no data	no data
	Precambrian	no data	no data	no data	no data	no data	no data	no data
Aquifers discontinouous; southern edge of Tindouf syncline								
Black Zmmour								
	Area Bir Moghrein	no data	no data	no data	no data	no data	no data	no data
	Area Yetin north	no data	no data	no data	no data	no data	no data	no data
Aquifer continuose Continental Guide (Jurassic)								
Under Dahr de Nema								
	Areas Nema, Suina,	no data	no data	no data	no data	no data	no data	no data
	Djigueni, Bassikonou	no data	no data	no data	no data	no data	no data	no data
Under dunes of El Mreye and Adhafer		no data	no data	no data	no data	no data	no data	no data
Aquifer continuous deep Maestrichtien								
	Areas Aleg, Rosso, Nouakchott, Nouadhibou	0.1	11	west, east	no data	no data	no data	no data
Coastal mining areas								
Trarza	Cretaceous (Masetrichtien)	1	24	no data	no data	no data	no data	no data
	Eocene	3.1	9	subphreatic	2.1	11	no data	no data
	Continental Terminal	no data	no data	no data	no data	no data	no data	no data
	Idini well field production - subphreatic layer							50000
Bennichab		no data	no data	no data	no data	no data	no data	750
Tiersioum		2.1	2.1	no data	no data	no data	no data	no data
Continuous recent sedimentary								
Alluvium of wadis								
Adrar, Mauritanides, Tagant, Assaba, Guidimaka, Hodhs		no data	no data	no data	no data	no data	no data	no data
Alluvium of Senegal River		no data	no data	no data	no data	no data	no data	no data
Dunes		no data	no data	no data	no data	no data	no data	no data
Quaternary	sand dunes, wadi sands	no data	no data	no data	no data	no data	no data	no data

Table 15. Hydrogeologic inventory of aquifer piezometric head map and recharge potential.

[km^2 = square kilometers; % = percent]

Geology	Formation	Aquifers	Layers	Piezometric head map	Recharge potential	Notes
	Ridge Reguibat		Annexe 1 Echelle stratigraphique.xls			Granitic, gneissic, discontinuous fractured aquifers
		Tasiast		no data	no data	SW corner; crossed by two sand dunes; exploited by olgats in sand dunes
		Tijirit		no data	no data	
		Amsaga		no data	no data	Hit ratio 21%
		Tris	*Tris*	no data	no data	
			Bir Mogrein	no data	no data	
			Hassi Loughar	no data	no data	
		Kediat Idjill		no data	no data	Fault; quartzites (one side) good production for mining 0.5 $Mm^3 yr;^{-1}$ other side unproductive
	Muaritanides					Metamorphic rocks; schist with granitic intrusions
		Inchiri	*Akjoujt mining area*	no data	no data	
		Bakel Moudjeria	*Aleg, Selibaby*	no data	no data	760 drill holes of which half are not geologically logged; fractured schists, quartzites, and granites; exploration using air photographs and lineaments
Sedimentary	Taoudenni					
	Infracambrien Adrar and Tiris Zemmour					
		F'Derick, Tourine		no data	no data	Aquifers are sandstones, center of limestones; interbedded aquitards mudstones
		Sandstones of Agueni (Area of Atar)				
			Area of Atar	no data	yes	Recharge from sandstone outcrops and Tayaret wadi
			Area of Tiris Zemmour	no data	no data	
		Dolomitic limestones of Zzougui				
			Area of Atar			
			Area of Tiris Zemmour	no data	no data	Fractured and karstic massive dolomites

Sandstones of Foum Chor				
	Area of Atar	no data	no data	
	Area of Tiris Zemmour	no data	no data	
Limestones of Datar group				
	Area of Atar	no data	no data	
	Limestones of Atar	no data	yes	Recharge in near surface fractures may be associated with Tariofet and Amber (assumed poor) wadis
	Limestones of Tawaz	no data	yes	Recharge by dune Oum Arouaba (320 km^2); limited fractures, poor aquifer
	Limestones of Touiderguilt	no data	no data	
	Area of Tiris Zemmour	no data	no data	East of Turine, limestones under unproductive sandstone-clay 44 m; drilling sites based on Direct Current electrical surveys
Sandstones of Assabe El Hassian group		no data	no data	
Infracambrien (Assaba, Hodh, Gharbi)				
Massive sandstones of disturbed				
	Area Kankossa	no data	no data	
Sandstones with stratifications (ss of Aioun)				
	Area Kiffa	no data	yes	Small anticlinal structure is primary region of flow; piezometric head follows topography
Cambrian		no data	no data	
Lower tillite		no data	no data	
Sandstones of Dar Teleb and El Aguer		no data	no data	
Higher tillite		no data	no data	
Cambrian-Ordovician				
Pilites and japers in Adrar				
	Area El Mreiti, Atar	no data	no data	
Pilites and japers in Adrar				
	Area Kiffa, Kankossa, Nema, Djigueni	no data	no data	Siliceous rocks; fractures N70, N170, N110 devoid of primary porosity) Recharge from streambed infiltration. Piezometric head: pelites (low waters), May-July, 1986; (high waters), October-November, 1986.
Sandstones with patinachamois			yes	east-west gradient, 3.5x10-3, north-south gradient, 1.5x10-3
	Area Assaba	no data	yes	Recharged by overlying dunes
Cambrian-Ordovician				Appendix 2

		Higher dolomite	no data	no data	
	Cambrian-Ordovician				Recharged by wadis oeud El Abiod, Tidjikja, and Tamourt; many fractures - appendix 2
		Sandstones of Tagant and Assaba	no data	no data	
	Diorite and dolerite intrusions		no data	no data	
	Devonian		no data	no data	Between Adrar and Tagant; in unpopulated areas; no drilling
Sedimentary formations in Taoudenni syncline					
		Devonian	no data	no data	
		Silurian	yes no data	no data	
		Cambrian-Ordovician	no data	no data	
		Precambrian	no data	no data	
Aquifers discontinouous; southern edge of Tindouf syncline					
	Black Zmmour				
		Area Bir Moghrein	no data	no data	
		Area Yetin north	no data	no data	
Aquifer continuose Continental Guide (Jurassic)					
	Under Dahr de Nema				
		Areas Nema, Suina,	yes	no data	Piezometric head 50-80 m (2001, 1974-75, 1963)
		Djigueni, Bassikonou	no data	no data	
	Under dunes of El Mreye and Adhafer		no data	no data	
Aquifer continuous deep Maestrichtien					
		Areas Aleg, Rosso, Nouakchott, Nouadhibou	yes	no data	Piezometric head map
Coastal mining areas					
	Trarza	Cretaceous (Masetrichtien)	no data	no data	
		Eocene	no data	no data	
		Continental Terminal	no data	no data	
		Idini well field production - subphreatic layer	yes		Piezometric head 1961 (preproduction); production after 1969; time series; piezometric head map; decrease 2.5 - 5.5 m / 13 yrs (0.2 - 0.4 m/yr)
	Bennichab		yes	no data	
	Tiersioum		no data	no data	Piezometric head map; decrease 1 - 1.3 m / 30 yrs (..); salt water interface
Continuous recent sedimentary					
	Alluvium of wadis				
	Adrar, Mauritanides, Tagant, Assaba, Guidimaka, Hodhs		no data	no data	Recharged by rain; lowest in salinity; seasonal storage (?)
	Alluviam of Senegal River		no data	no data	Recharged by rain; lowest in salinity; seasonal storage (?)
	Dunes		no data	no data	Resource potential unknown; fossil water?
	Quaternary	sand dunes, wadi sands	no data	no data	

Appendix D

Meteorology Questionnaire

SPREADSHEET – Meteorology Questionnaire

Instructions: Fill out questionnaires to the best of your ability. Feel free to make copies and send to other persons that may contribute relevant information. Return completed questionnaires to Christopher Wnuk, Constella Futures International, One Thomas Circle, NW, Suite 200, Washington DC, 20005, 703-715-0847, cwnuk@resourcesfordevelopment.com [ROW 1]

Date: [ROW 2]

Institution: [ROW 3]

Contact Information: [ROW 4]

[COLUMNs shown below]

CODE for this measurement station [COLUMN A]

Owner ID [COLUMN B]

Basin Information

Basin identifier (name) [COLUMN C]

Basin measurement station (type): outlet, other [COLUMN D]

Basin location: coordinates of centroid [COLUMN E]

Measurements

Location of measurements, e.g. ____ E 2__° ____‘ ____” [COLUMN F]

Location of measurements, e.g. ____ N 4__° ____ ‘ ____” [COLUMN G]

Precipitation

Gage type, e.g., tipping bucket, other [COLUMN H]

Type of measurement, e.g. rainfall, snowfall, both [COLUMN I]

Frequency of precipitation measurements, e.g. 15-minutes, 1-hour, daily, other [COLUMN J]

Period of record, e.g. 1925-1955, 1956-present [COLUMN K]

Describe data format(s): web, digital (excel, access, other), paper [COLUMN L]
Contact information of person or place and cost to obtain these data [COLUMN M]

Evaporation

Frequency of evaporation measurements, e.g. 15-minutes, 1-hour, daily, other [COLUMN N]
Type of measurement, pan, other [COLUMN O]
Period of record, e.g. 1925-1955, 1956-present [COLUMN P]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN Q]
Contact information of person or place and cost to obtain these data [COLUMN R]

Potential Evapotranspiration

Frequency of potential evapotranspiration measurements, e.g. 15-minutes, 1-hour, daily, other [COLUMN S]
Type of measurement [COLUMN T]
Period of record, e.g. 1925-1955, 1956-present [COLUMN U]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN V]
Contact information of person or place and cost to obtain these data [COLUMN W]

Relative Humidity

Frequency of humidity measurements, e.g. 15-minutes, 1-hour, daily, other [COLUMN X]
Type of measurement [COLUMN Y]
Period of record, e.g. 1925-1955, 1956-present [COLUMN Z]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN AA]
Contact information of person or place and cost to obtain these data [COLUMN AB]

Temperatures

Frequency of temperature measurements, e.g. 15-minutes, 1-hour, daily, other
[COLUMN AC]
Type of measurement, e.g. minimum, maximum, average, others [COLUMN AD]
Period of record, e.g. 1925-1955, 1956-present [COLUMN AE]

Describe data format(s): web, digital (excel, access, other), paper [COLUMN AF]
Contact information of person or place and cost to obtain these data [COLUMN AG]

Precipitation-Quality Monitoring

Physical parameters measured, e.g. pH, dissolved oxygen, conductivity, redox potential, temperature [COLUMN AH]
Type of study: synoptic (one time) or temporal (many times) [COLUMN AI]
Quality assurance: yes, no, not sure [COLUMN AJ]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN AK]
Contact information of person or place and cost to obtain these data [COLUMN AL]
Water-quality sampled, e.g. major ions, trace elements, pesticides, isotopes or environmental tracers [COLUMN AM]
Quality assurance: yes, no [COLUMN AN]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN AO]
Contact information of person or place and cost to obtain these data [COLUMN AP]

Appendix E

Hydrology Questionnaire

SPREADSHEET – Hydrology Questionnaire

Instructions: Fill out questionnaires to the best of your ability. Feel free to make copies and send to other persons that may contribute relevant information. Return completed questionnaires to Christopher Wnuk, Constella Futures International, One Thomas Circle, NW, Suite 200, Washington DC, 20005, 703-715-0847, cwnuk@resourcesfordevelopment.com [ROW 1]

Date: [ROW 2]

Institution: [ROW 3]

Contact Information: [ROW 4]

[COLUMNs shown below]

CODE for this measurement station [COLUMN A]

Owner ID [COLUMN B]

Basin Information

Basin identifier (name) [COLUMN C]

Basin measurement station (type): outlet, other [COLUMN D]

Basin location: coordinates of centroid [COLUMN E]

Measurements

Location of measurements, e.g. ____ E 2__° ____‘ ____ ” [COLUMN F]

Location of measurements, e.g. ____ N 4__° ____ ‘ ____” [COLUMN G]

**Streamflow Discharge **

Type of measurement, e.g. direct, indirect other [COLUMN H]

Gage type, e.g., crest stage, velocity meter, pressure transducer, other [COLUMN I]

Frequency of measurements, e.g. 15-minutes, 1-hour, daily, other [COLUMN J]

Period of record available, e.g. 1925-1955, 1956-present [COLUMN K]

Year of study [COLUMN L]

Average annual discharge, in cubic metes per second [COLUMN M]
Standard deviation of annual streamflow discharge, in cubic metes per second [COLUMN N]
Minimum annual streamflow discharge (baseflow), in cubic metes per second [COLUMN O]
Maximum annual streamflow discharge (peakflow), in cubic metes per second [COLUMN P]
Baseflow index [COLUMN Q]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN R]
Contact information of person or place and cost to obtain these data [COLUMN S]

Streamflow Water Quality

Physical parameters measured, e.g. pH, dissolved oxygen, conductivity, redox potential, temperature [COLUMN T]
Type of study: synoptic (one time) or temporal (many times) [COLUMN U]
Type of probe used; e.g. YSI, Hydrolab,, other, not sure [COLUMN V]
Quality assurance: yes, no, not sure [COLUMN W]
Describe available data format(s): web, digital (excel, access, other), paper [COLUMN X]
Contact information of person or place and cost to obtain these data [COLUMN Y]
Water-quality sampled, e.g. major ions, trace elements, pesticides, isotopes or environmental tracers associated with water or bed sediment; suspended sediment [COLUMN Z]
Quality assurance: yes, no [COLUMN AA]
Describe available data format(s): web, digital (excel, access, other), paper [COLUMN AB]
Contact information of person or place and cost to obtain these data [COLUMN AC]
Aquatic biology sampled: algae, macroinvertebrates, fish [COLUMN AD]
Quality assurance: yes, no [COLUMN AE]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN AF]
Contact information of person or place and cost to obtain these data [COLUMN AG]

Return Flow Discharge

Type of measurement, e.g. direct, indirect other [COLUMN AH]
Gage type, e.g., crest stage, velocity meter, pressure transducer, other [COLUMN AI]
Frequency of measurements, e.g. 15-minutes, 1-hour, daily, other [COLUMN AJ]

Period of record, e.g. 1925-1955, 1956-present [COLUMN AK]
Year of study [COLUMN AL]
Average annual return flow, in cubic metes per second [COLUMN AM]
Standard deviation of annual return flow, in cubic metes per second [COLUMN AN]
Minimum annual return flow (baseflow), in cubic metes per second [COLUMN AO]
Maximum annual return flow (peakflow), in cubic metes per second [COLUMN AP]
Estimate total number return flow (point) sources in basin [COLUMN AQ]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN AR]
Contact information of person or place and cost to obtain these data [COLUMN AS]

Return Flow Water Quality

Physical parameters measured, e.g. pH, dissolved oxygen, conductivity, redox potential, temperature [COLUMN AT]
Type of study: synoptic (one time) or temporal (many times) [COLUMN AU]
Type of probe used; e.g. YSI, Hydrolab,, other, not sure [COLUMN AV]
Quality assurance: yes, no, not sure [COLUMN AW]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN AX]
Contact information of person or place and cost to obtain these data [COLUMN AY]
Water-quality sampled, e.g. major ions, trace elements, pesticides, isotopes or environmental tracers associated with water or bed sediment; suspended sediment [COLUMN AZ]
Quality assurance: yes, no [COLUMN BA]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN BB]
Contact information of person or place and cost to obtain these data [COLUMN BC]

Withdrawal Flow Discharge

Type of measurement, e.g. direct, indirect other [COLUMN BD]
Gage type, e.g., crest stage, velocity meter, pressure transducer, other [COLUMN BE]
Frequency of measurements, e.g. 15-minutes, 1-hour, daily, other [COLUMN BF]
Period of record, e.g. 1925-1955, 1956-present [COLUMN BG]
Year of study [COLUMN BH]
Average annual withdrawal flow discharge, in cubic metes per second [COLUMN BI]

Standard deviation of annual withdrawal flow, in cubic metes per second [COLUMN BJ]
Minimum annual withdrawal flow (baseflow), in cubic metes per second [COLUMN BK]
Maximum annual withdrawal flow (peakflow), in cubic metes per second [COLUMN BL]
Estimate total number return flow (point) sources in basin [COLUMN BM]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN BN]
Contact information of person or place and cost to obtain these data [COLUMN BO]

Withdrawal Flow Water Quality

Physical parameters measured, e.g. pH, dissolved oxygen, conductivity, redox potential, temperature [COLUMN BP]
Type of study: synoptic (one time) or temporal (many times) [COLUMN BQ]
Type of probe used; e.g. YSI, Hydrolab,, other, not sure [COLUMN BR]
Quality assurance: yes, no, not sure [COLUMN BS]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN BT]
Contact information of person or place and cost to obtain these data [COLUMN BU]
Water-quality sampled, e.g. major ions, trace elements, pesticides, isotopes or environmental tracers associated with water or bed sediment; suspended sediment [COLUMN BV]
Quality assurance: yes, no [COLUMN BW]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN BX]
Contact information of person or place and cost to obtain these data [COLUMN BY]

Appendix F

Groundwater Questionnaire

SPREADSHEET – Groundwater Questionnaire

Instructions: Fill out questionnaires to the best of your ability. Feel free to make copies and send to other persons that may contribute relevant information. Return completed questionnaires to Christopher Wnuk, Constella Futures International, One Thomas Circle, NW, Suite 200, Washington DC, 20005, 703-715-0847, cwnuk@resourcesfordevelopment.com [ROW 1]

Date: [ROW 2]

Institution: [ROW 3]

Contact Information: [ROW 4]

[COLUMNs shown below]

CODE for this borehole [COLUMN A]

Owner ID [COLUMN B]

Borehole Information

Borehole or well identifier (name) [COLUMN C]

Location borehole or well, e.g. ____ E 2__o ____‘ ____ ” [COLUMN D]

Location borehole or well, e.g. ____ N 4__o ____ ‘ ____” [COLUMN E]

Drilling method, e.g. rotary wash, flight augur, hollow stem, hand, other [COLUMN F]

Well Construction Information

Construction date, e.g. 1/1/1999 [COLUMN G]

Land surface altitude, in meters above sea level [COLUMN H]

Well depth, in meters below land surface [COLUMN I]

Casing top, in meters below land surface [COLUMN J]

Casing bottom, in meters below land surface [COLUMN K]

Casing length, in meters [COLUMN L]

Casing diameter, in centimeters [COLUMN M]

Screen top, in meters below land surface [COLUMN N]

Screen bottom, in meters below land surface [COLUMN O]

Screen length, in meters [COLUMN P]
Screen type, e.g. slotted, perforated, other [COLUMN Q]
Gravel pack around screen; e.g. yes, no [COLUMN R]
Bentonite (clay) above gravel pack, e.g. yes, no [COLUMN S]
Development method, e.g. pumped at 3 borehole volumes and until physical parameters stabilized [COLUMN T]
Contact information of person or place and cost to obtain these data [COLUMN U]

Pump Test Information

Depth of pump, in meters below surface [COLUMN V]
Type of pump, e.g. [COLUMN W]
Discharge (constant), in cubic meters per second [COLUMN X]
Pumping duration, in hours [COLUMN Y]
Water level (initial in pumping well), in meters below land surface [COLUMN Z]
Water level (final in pumping well), in meters below land surface [COLUMN AA]
Drawdown (in well), in meters [COLUMN AB]
Location observation well 1, e.g. ____ E 2__° ____‘ ____ ” [COLUMN AC]
Location observation well 1, e.g. ____ N 4__° ____‘ ____ ” [COLUMN AD]
Water level (initial in observation well 1), in meters below land surface [COLUMN AE]
Water level (final in observation well 1), in meters below land surface [COLUMN AF]
Location observation well 2, e.g. ____ E 2__° ____‘ ____ ” [COLUMN AG]
Location observation well 2, e.g. ____ N 4__° ____‘ ____ ” [COLUMN AH]
Water level (initial in observation well 2), in meters below land surface [COLUMN AI]
Water level (final in observation well 2), in meters below land surface [COLUMN AJ]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN AK]
Contact information of person or place and cost to obtain these data [COLUMN AL]

Water Level Monitoring

Date static water level measured [COLUMN AM]
Water level (static), in meters below land surface [COLUMN AN]

Describe relative accuracy of measurement [COLUMN AO]
Describe quality assurance of measurement [COLUMN AP]
List name of domestic or industrial pumping centers [COLUMN AQ]
Location of pumping well(s) in same aquifer; e.g. ____ E 2__° ____‘ ____ ” [COLUMN AR]
Location of pumping well(s) in same aquifer; e.g. ____ N 4__° ____‘ ____ ” [COLUMN AS]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN AT]
Contact information of person or place and cost to obtain these data [COLUMN AU]

Water-Quality Monitoring

Sample depth, in meters below surface [COLUMN AV]
Sample date or period, e.g. 1/1/1920 or 10/02/2000-09/31/2004 [COLUMN AW]
Physical parameter measured: pH [COLUMN AX]
Physical parameters measured: dissolved oxygen, in milligrams per liter [COLUMN AY]
Physical parameters measured: conductivity, in microSiemens per centimeter [COLUMN AZ]
Physical parameters measured: redox potential (Eh), in millivolts [COLUMN BA]
Physical parameters measured: temperature, in degrees Celsius [COLUMN BB]
Type of study: synoptic (one time) or temporal (many times) [COLUMN BC]
Type of probe used; e.g. YSI, Hydrolab, other, not sure [COLUMN BD]
Quality assurance: yes, no, not sure [COLUMN BE]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN BF]
Contact information of person or place and cost to obtain these data [COLUMN BG]
Water-quality sampled for major ions: yes, no, not sure [COLUMN BH]
Water-quality sampled for trace elements: yes, no, not sure [COLUMN BI]
Water-quality sampled for pesticides: yes, no, not sure [COLUMN BJ]
Water-quality sampled for isotopes: yes, no, not sure [COLUMN BK]
Water-quality sampled for environmental tracers: yes, no, not sure [COLUMN BL]
Water-quality sampled for dissolved organic carbon: yes, no, not sure [COLUMN BM]
Water-quality sampled for radiogenic compounds: yes, no, not sure [COLUMN BN]
Quality assurance: yes, no [COLUMN BO]

Describe data format(s): web, digital (excel, access, other), paper [COLUMN BP]
Contact information of person or place and cost to obtain these data [COLUMN BQ]

Aquifer Information

Depth interval, in meters beginning and meters ending below surface [COLUMN BR]
Age of formation [COLUMN BS]
Stratigraphic unit name: formation and group [COLUMN BT]
Lithologic description: clay, sand, silt, gravel, or bedrock [COLUMN BU]
Hydrostratigraphic description: aquifer or aquitard [COLUMN BV]
Thickness of lithologies in the open screened interval, in meters [COLUMN BW]
Thickness of aquifer-like material over entire depth of well, in meters [COLUMN BX]
Thickness of aquifer-like material in the open screened interval, in meters [COLUMN BY]
Provide contact information of person or place and cost to obtain these data [COLUMN BZ]
Specific capacity, in liter per second per meter [COLUMN CA]
Hydraulic conductivity, in meter per day [COLUMN CB]
Depth of hydraulic conductivity measurement, in meters below surface [COLUMN CC]
Transmissivity, in meter squared per day [COLUMN CD]
Depth interval over which transmissivity value pertains, in meters beginning and meters ending below surface [COLUMN CE]
Describe data format(s): web, digital (excel, access, other), paper [COLUMN CF]
Contact information of person or place and cost to obtain these data [COLUMN CG]

Geophysical Borehole Logging

Date well logged [COLUMN CH]
Electric logging: yes, no, unsure [COLUMN CI]
Induction logging: yes, no, unsure [COLUMN CJ]
Gamma logging: yes, no, unsure [COLUMN CK]
Neutron logging: yes, no, unsure [COLUMN CL]
Contact information of person or place and cost to obtain these data [COLUMN CM]

Area Surface Geophysics

Date surface geophysical surveys conducted [COLUMN CN]
Seismic reflection survey: yes, no, unsure [COLUMN CO]
Seismic refraction survey: yes, no, unsure [COLUMN CP]
Seismic tomographic survey: yes, no, unsure [COLUMN CQ]
Ground gravity survey: yes, no, unsure [COLUMN CR]
Airborne electromagnetic survey: yes, no, unsure [COLUMN CS]
Ground electromagnetic survey: yes, no, unsure [COLUMN CT]
Airborne electromagnetic survey: yes, no, unsure [COLUMN CU]
Ground magnetotelluric survey: yes, no, unsure [COLUMN CV]
Ground resistivity survey: yes, no, unsure [COLUMN CW]
Seismic tomographic survey: yes, no, unsure [COLUMN CX]
Time-domain electromagnetic survey: yes, no, unsure [COLUMN CY]
Contact information of person or place and cost to obtain these data [COLUMN CZ]