ASSESSMENT OF **GROUNDWATER RESOURCES** OF **LEBANON**

ASSESSMENT OF **GROUNDWATER RESOURCES** OF **LEBANON**

COVER IMAGE
A view of Jabal el Sheikh with the Qaroun Lake on the right of the image

PHOTOS COURTESY OF **Issam Bou Jaoude and Rena Karanouh**
DESIGN AND LAYOUT **Rena Karanouh**
PRINTED AND BOUND IN LEBANON BY

Disclaimer
The findings, interpretations and conclusions expressed in this report are those of the authors and do not necessarily represent those of the Ministry of Energy and Water or the United Nations Development Programme or the donor. The project partners do not guarantee the accuracy of the data included in this report. The boundaries, colours, denominations, and other information shown on maps and images in this work do not imply any judgment on the part of the project partners concerning the legal status of any territory or the endorsement or acceptance of such boundaries. The previously mentioned project partners do not assume responsibility of any kind for the use that may be made of the information contained in this report.

PROJECT PARTNERS:

LEBANESE REPUBLIC MINISTRY OF ENERGY AND WATER

LEBANESE CENTER FOR WATER MANAGEMENT AND CONSERVATION

Embassy of Italy COOPERAZIONE ITALIANA

UNDP Empowered lives. Resilient nations.

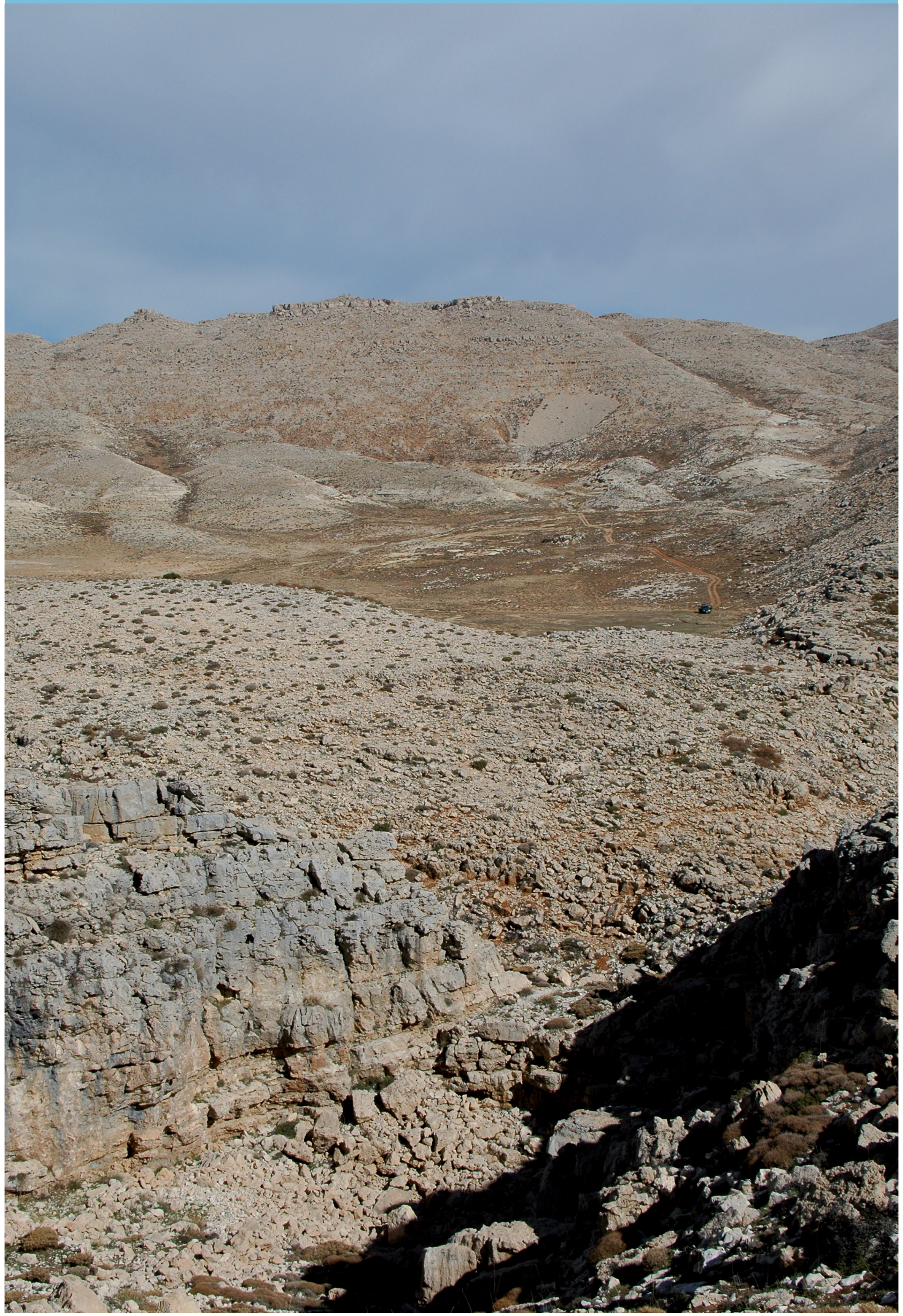
TECHNICAL CONSULTANTS:

ELARD

BURGEAP

IGIP

ribeka Groundwater and Environmental Management



The karstic plateau of Jroud Akoura showing the Sahlet el Rahwe doline

MESSAGE FROM THE **MINISTER**

It gives me great pleasure to present the National Groundwater Assessment project after more than forty years since a study of similar scope was undertaken.

The rapid global and local environmental degradations, climate change, increased desertification, population growth, and shifts in economic sectors amplify the pressure on the importance of reliable water supply. As such, a solid national database on available water resources, water reserves and corresponding consumption patterns become more and more critical.

The National Groundwater Assessment project for Lebanon has been made possible by a generous grant from the Government of the Republic of Italy through the Italian Cooperation in Beirut. The grant was managed by the United Nations Development Programme (UNDP) and implemented by the Ministry of Energy and Water. It formed a component of a larger project underway at the Ministry, which also provides technical support on water through the creation of the Lebanese Centre for Water Management and Conservation (LCWMC). An expert consortium of local and international companies worked relentlessly over a period of three years to gather, analyse, and map the data putting together this long-awaited study.

As you will read in this summary report, the scientific research carried out has resulted in redefining the watersheds, refining the hydrogeological maps and a cutting edge surveying of the groundwater wells. Such information is a valuable policy tool, not only for the Ministry of Energy and Water, but also for the Lebanese Government, Water Establishments, other Ministries, Municipalities as well as all stakeholders. The report concludes with a clear action plan to improve data collection and management of water resources.

Finally, I would like to thank everyone who has worked on this study, knowing that it has been a tedious and complicated task. As an appreciation of this work, and in order to facilitate access to the complete data and the in-depth technical analysis, a CD containing the full study is enclosed to this publication.

With this comprehensive study in hand, I am optimistic that both, decision-makers and citizens, will combine efforts to manage wisely and consume responsibly this important natural resource that our country has been blessed with.

We invite all stakeholders to continuously contribute to this report and its resulting projects.

Arthur Nazarian
Minister of Energy and Water

The Afqa spring issuing out of the entrance of Afqa cave

LIST OF **ACRONYMS**

%:	Percentage
ASR:	Storage Recovery System
AUB:	American University of Beirut
BIA:	Beirut International Airport Station
BMLWE:	Beirut Mount Lebanon Water Establishment
CDR:	Council for Development and Reconstruction
CESBIO:	Centre D'etudes Spatiale de la Biosphere
CK:	Covered Karst
CNRS:	National Council for Scientific Research
DEM:	Digital Elevation Model
E:	East
ELARD:	Earth Link & Advanced Resources Development
FAO:	Food and Agriculture Organization of the United Nations
GIS:	Geographic Information System
GW-basin:	Groundwater basins
HKE:	High Karst Exposure
Km^2:	Square Kilometers
l/s:	Liters per second
LARI:	Lebanese Agricultural Research Institute
LCWMC:	Lebanese Centre for Water Management and Conservation
LNMS:	Lebanese National Meteorological Service
LNMS:	Lebanese National Meteorological Service
LRA:	Litani River Authority
m:	meters
m^3/s:	Cubic Meter per second
MCM/year:	Million Cubic Meter per Year
MCM:	Million Cubic Meters
MKE:	Moderate Karst Exposure
mm:	Millimeter
MODIS:	Satellite Imagery
MoEW:	Ministry of Energy and Water
MSC:	Messinian Salinity Crisis
N:	North
ppm:	Parts per Million
QA/QC:	Quality Assurances / Quality Control
RKE:	Restricted Karst Exposure
S:	South
SCSCN:	Soil Conservation Service-Curve Number
TDS:	Total Dissolved Solids
UNDP:	United Nations Development Programme
USJ:	Univeristé Saint Joseph
W:	West

EXECUTIVE SUMMARY

Lebanon has always stood out for having relatively more water resources per capita than its neighboring countries. This is attributed mainly to its topography which favors moderately high rates of precipitation (rain and snow) over its territory. A large portion of this precipitation infiltrates into its aquifers to become groundwater, while the remaining portion either evaporates or flows as surface water runoff. The groundwater then either gets stored in the rock formations or flows in the subsurface until it emerges back to the surface in the form of springs or under the sea in the form of sea springs. The groundwater flow is controlled by the nature of the rocks and the geological structures.

Unsustainable water resource management practices pursued since the start of the mid seventies, coupled with weak water governance, have put a strain on the country's water resources especially on groundwater. A large number of public and private water supply wells were installed all over the country without proper planning and monitoring.

Other than the the point 4 mission from the American Bureau of Reclamation in the early 1930s, the only comprehensive national groundwater assessment study was completed in 1970 by the United Nations Development Programme (UNDP). The study was carried out in close collaboration with the Ministry of Water Resources, as it was known then, during the 1960s over a period of 9 years. One of the main outcomes of the study was the generation of a comprehensive nation-wide hydrogeological map that provides a good description and characterization of the country's groundwater resources. The study also highlighted potential areas and aquifer basins where groundwater resources were being depleted.

No other comprehensive study was conducted at a national scale since then. However, several smaller-scale studies were later carried out. These were mainly local studies targeting specific areas for groundwater development and focusing on how to maximize groundwater exploitation, without closely assessing the sustainability of the groundwater resources.

The study presented in this report is implemented by UNDP in partnership with and on behalf of the Ministry of Energy and Water (MoEW) and funded by the Government of the Republic of Italy. It aims at re-assessing the groundwater resources of the country in light of the various studies that have been conducted over the past 45 years, while taking into consideration the increased exploitation of the groundwater resources. The study was conducted by a consortium of companies lead by Earth Link & Advanced Resources Development (ELARD) and included BURGEAP, IGIP and Ribeka. It started in October 2011, and lasted for about two and a half years.

The scope of the study consisted mainly of data collection, desk studies and well surveys. The data collected was analyzed for all water life-cycle parameters and thematic maps were generated.

All existing data and available references such as gauging data, studies, reports, and published papers related to geology, hydrogeology and hydrology were collected and reviewed. This information was obtained from various stakeholders such as the MoEW, Council for Development and Reconstruction (CDR), Council of the South, Lebanese Agricultural Research Institute (LARI), Lebanese National Meteorological Service (LNMS), and Litani River Authority (LRA).

Additionally, a comprehensive well survey and a one-year groundwater monitoring program were implemented as part of this project. All primary and secondary data gathered were integrated and stored in a -first of its kind national database established at the MoEW.

The study consisted of 13 main deliverables:

- **Deliverable 1:** *Inception Report*
- **Deliverable 2:** *Technical Report on Public Wells*
- **Deliverable 3:** *Proposed Monitoring Equipment Specification Report*
- **Deliverable 4:** *Proposed One-year Monitoring Plan*
- **Deliverable 5:** *Initial Installation of a Fully Operational Database at the MoEW*
- **Deliverable 6:** *Preliminary Baseline Data Assessment Report*
- **Deliverable 7:** *Monitoring Plan Implementation Report*
- **Deliverable 8:** *Technical Report on Dedicated Database*
- **Deliverable 9:** *Data Synthesis and Basin Water Resources Characterization*
- **Deliverable 10:** *Artificial Recharge Preliminary Assessment*
- **Deliverable 11:** *Monitoring Equipment Handover Report*
- **Deliverable 12:** *3D Groundwater Flow Modeling Development for the Akkar Quaternary-Neogene Basin Report.*
- **Deliverable 13:** *Training Report.*

A summary of the main findings pertaining to each of the deliverables will be summarized in the chapters that follow. For additional details, please refer to the CD enclosed which includes the complete deliverables.

Please refer to the enclosed CD, which includes Deliverables 8, 9, 10 and 12 as these constitute the most relevant results of the monitoring and studies conducted. For additional details and information on remaining deliverables, please contact the Ministry of Energy and Water.

Geological and Hydrogeological Assessment

The geological history of Lebanon had a major role in shaping its geomorphological fabric and structural features that define the various aquifers and control the groundwater flows. Two (2) major tectonic events are documented in the geological history of Lebanon. The first event is the uplift in the late Jurassic to early Cretaceous Era, which has led to the exposure, erosion and karstification of the Jurassic limestone. The second event is the closure of the Tethyan Sea in the early Tertiary Period forming a collision zone, which has led to the first gentle uplift of Mount Lebanon and Anti-Lebanon Ranges. Another important event took place at the end of the Miocene Epoch known as the Messinian Salinity Crisis where a major drop in sea level, of about 1000 m, occurred due to the closer of the Mediterranean Sea. This event had a major impact on the development of deep karsts. Moreover, the collision of the Arabian and Asian plates during the Eocene and Oligocene Epoch led to the shaping of the North North East - South South West (NNE-SSW) trending structural features.

The hydrostratigraphic units of the country are classified into three (3) main groups: aquifers, semi-aquifers and aquicludes. The two (2) main aquifers are the Kesrouane Jurassic (J4) and the Sannine-Maameltain (C4-C5) which are mainly composed of karstic carbonate rocks. Karstic rocks are soluble rocks where voids, caverns, open fractures, and even caves have formed due to weathering by aggressive water. The two (2) aquifers are considered to be the two (2) water towers (Chateau-D'eau) of Lebanon and cover about 5590 km^2 of the Lebanese territory (i.e.,

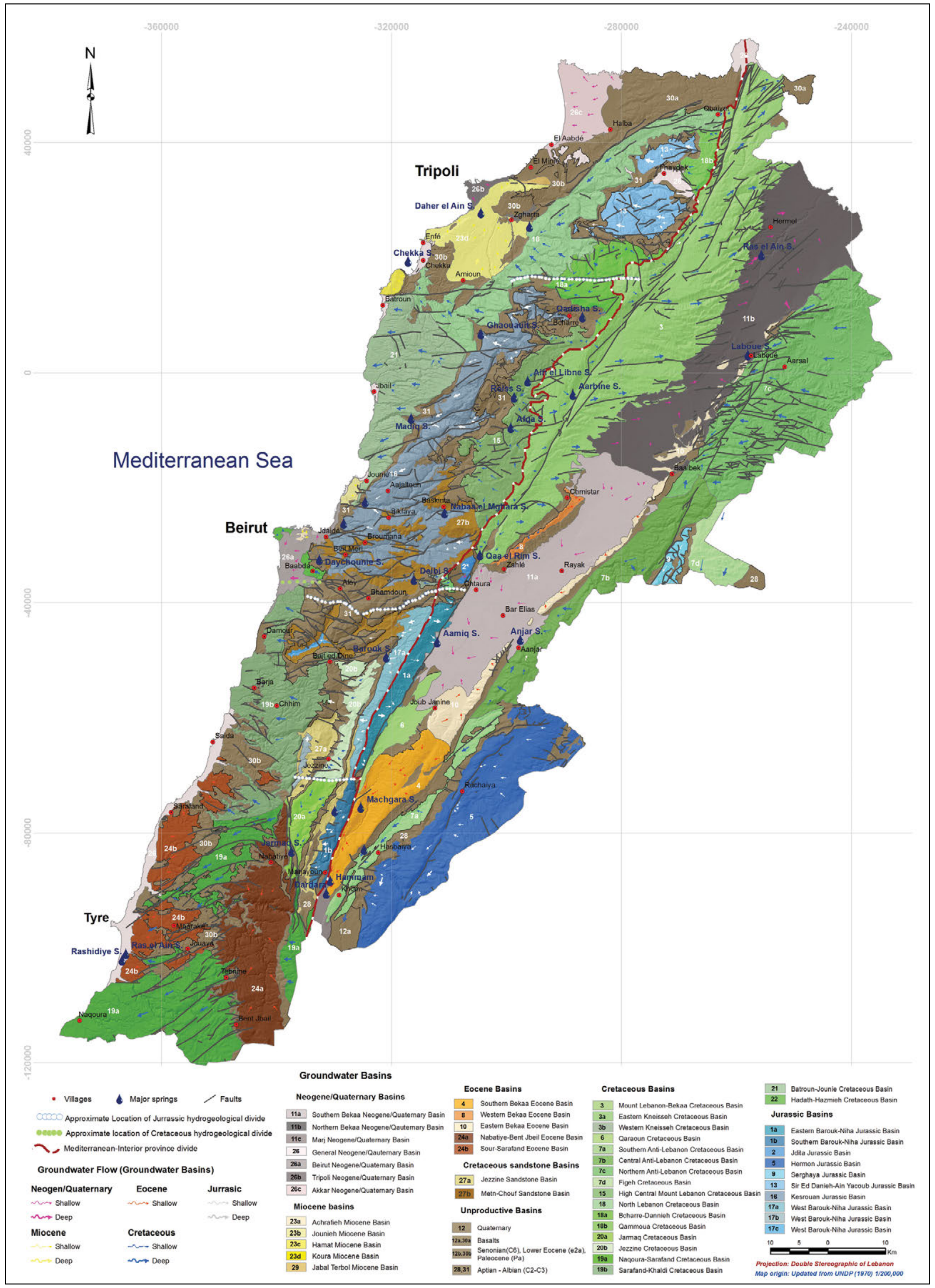


Figure 1 Map showing the updated GW-basins

more than 50% of the country's surface area).

The hydrogeological basins, called groundwater basins (GW-basins), were divided based on the various hydrostratigraphic units (i.e. aquifers, semi-aquifer and aquicludes). The major structural geological features within the GW-basin, its boundaries (whether surface or subsurface) and its interaction with neighboring basins, together control the groundwater regime of the basin. The assessment of all these factors along with the results of previous tracer tests and groundwater isotope analyses has led to some re-partitioning and re-delineation of the existing GW-basins.

In the UNDP 1970 study, 32 GW-basins (both productive and unproductive basins) were identified and divided into two (2) main hydrogeological provinces: the Mediterranean Province and the Interior Province. The dividing line between the provinces was the topographic high points of the summits of Mount Lebanon and Barouk-Niha ranges.

Based on the re-evaluation of GW-basins undertaken during this study, a total of 51 GW-basins were identified; of which 28 productive basins and three (3) unproductive basins are located in the Mediterranean Province and 17 productive basins and three (3) unproductive basins are in the Interior Province. An updated map featuring the various GW-basins is presented in Figure 1.

About 65 % of the surface area of Lebanon is covered with carbonate karstic formations. The identification, characterization and assessment of the various karstic features are important components for the overall assessment of the groundwater resources in the country. A first of its kind karstic map of Lebanon was developed as part of this study. A total of four (4) types of karstic areas were defined based on the intensity of karstification and the types of prevailing karstic features, such as doline, lapiaz, polji, sinking stream and cave. These are High Karst Exposure (HKE), Moderate Karst Exposure (MKE), Restricted Karst Exposure (RKE) and finally, the Covered Karst (CK).

Table 1 Number of springs in each class

CLASS	RANGE OF DISCHARGE	NUMBER OF SPRINGS
1	more than 10 m^3/s	-
2	(1-10 m^3/s)	7
3	(0.1-1 m^3/s)	57
4	(10-100 l/s)	101
5	(1-10 l/s)	117
6	(0.1-1 l/s)	82
7	(10-100 cm^3/s)	31
8	(Less than 10 cm^3/s)	14
	Total	409

The development of karst and the depth of karstification are also linked to the various tectonic events such as the uplift events, the volcanic activitie, and the Messinian Salinity Crisis (MSC). These events caused a drop in sea level, which may have led to deeper incisions of the water channels and consequently developed karstification as deep as 1000 m below the present coast line.

A total of about 5,050 springs are depicted in the 1:20,000 topographic maps of Lebanon. 409 springs distributed throughout the GW-basins have some reliable discharge flow data. Only nine (9) springs are currently being monitored on a regular basis.

The spring assessment is based on categorizing and classifying springs into types (based on emergence mechanism) and classes (based on discharge flow rates), in addition to analyzing hydrographs of springs with continuous data.

About 81 major springs, with sufficient reliable information, were categorized into nine (9) types. Each type is characterized by its specific emergence mechanism which includes a combination of spring hydrodynamic characteristics (i.e. draining flow, overflow, artesian, or a combination of two of these flow types) and geological controlling features (i.e. structural and stratigraphic control/barriers). The categorization of these 81 springs into types is provided in Plate 2 at the end of this report.

The classification of 409 springs with relatively reliable data is based on Meinzer (1923) which categorizes springs according to their discharge magnitude. The minimum average discharge rates of the springs were used for the classification of the. The number of springs in each class is provided in Table 1. Most likely, the majority of the remaining springs (i.e. with no data) would belong to class 5 and below.

For the hydrograph analysis, the method used to analyze the base flow relies on the assessment of the recession behavior representing saturated and non-saturated zones. A total of 45 springs were initially assessed but only 16 springs in 9 different GW-basins had reliable data. The result of these studies showed that all aquifers have similar recession coefficient ranges which, are indicative of the karstic nature of the aquifer. The lower ranges of coefficients obtained in this study are similar to those reported in the UNDP study of 1970. The higher ranges are attributed to the rapid emptying of the aquifer, mostly due to induced human factors.

The assessment of groundwater levels in the various basins, gathered during the one-year monitoring program, shows that groundwater levels rapidly respond to rainfall events, within hours or days, with a rapid increase in groundwater levels of 2 to 12m. Correlation between groundwater level data from this study and those from the UNDP study of 1970 is established in 12 of these basins. In the Mediterranean Province, most of the interior GW-basins that are not in direct contact with the sea show a decrease in groundwater level mainly due to the over-exploitation of the aquifers. In Sir ed Dannieh – Ain Yaacoub Basin (Basin 13), the drop was about 27 m. However, the coastal GW-basins show almost similar groundwater levels as in the 1970 study. The explanation is that the pumped water is being directly compensated by seawater intrusion.

With the exception of just one GW-basin, most of the basins monitored in the Interior Province show a significant decrease in the groundwater levels (from the 1970 levels). Again, this is attributed to the over exploitation from the aquifers. A drop of about 20m is observed in the Litani area in the Southern Bekaa Neogene-Quaternary Basin (Basin 11a).

The hydro-chemical characteristics of the majority of the GW-basins in the interior provinces belong to the carbonate facies with relatively low salt content. This is typical of the karstic nature of the aquifers that has a low retention time; where groundwater flows rapidly. The GW-basins of the coastal provinces that are not directly in contact with the sea show similar facies of carbonate type. Those basins that are in contact with the sea exhibit facies of Sodium-Chloride types which, are indicative of groundwater mixing with sea water. Seawater intrusion in these basins appears to be more pronounced than what it was in the 1970's.

HYDROLOGICAL ASSESSMENT

The hydrology study provides an evaluation of precipitation (rain and snow), evapotranspiration and runoff to estimate natural recharge rates for the country. Due to the limited quality and availability of data, only four (4) hydrological cycles (2008 to 2012) could be used. The data was collected from various monitoring stations distributed all over Lebanon. For these four (4) hydrological cycles, the estimated volume of rain per year ranges between 6,015 and 9,365 million cubic meters (MCM). The estimated yearly volume of evapotranspiration was estimated to fluctuate between 1,563 and 1,475 MCM.

Snow water equivalent which, was not taken into account in the UNDP 1970 study was evaluated using satellite imagery (MODIS). Variations in snow coverage combined with land measurements to determine snow thickness and density over three (3) months (January, February and March) for the four (4) hydrological cycles (2008 to 2012) was used. The yearly water equivalent volumes estimated using this technique range between 1,815 and 2,567 MCM.

The estimated yearly surface runoff for the four (4) hydrological cycles, which does not account for the portion that comes from the discharge of the various springs, varies between 2,151 and 3,807 MCM.

Recharge to groundwater is subsequently calculated as the excess of precipitation over real evapotranspiration and surface runoff. The estimated volumes, which includes both deep percolation and retention in the vadose zone for the four hydrological cycles, vary from 4,116 to 6,651 MCM with an average of about 55 % of the total precipitation.

WATER BUDGET

The groundwater balance is the difference between water recharge and discharge. The recharge (water inflow) includes natural infiltration from rainfall and snowmelt; return flows from irrigation, domestic, industrial and touristic water usages as well as from losses in the water supply network; and groundwater gains from neighboring basins/aquifer. The discharge (water outflow) includes groundwater usage for irrigation, domestic, industrial and tourism; groundwater losses to the sea; natural discharge of springs and losses to neighboring basins outside the Lebanese territories.

These components of the budget were assessed for only two hydrological cycles; a dry (2010-2011) cycle and a wet (2011-2012) cycle. They are assembled in a model that was developed to allow for updates and analyses whenever more reliable data, such as data related to groundwater gains and losses and more accurate data on spring discharge, become available.

At country level, recharge varies between 4,728 and 7,263 MCM. The discharge is estimated to be around 2,588 MCM. Therefore, the water balance in the budget is estimated to vary from 2,140 MCM for the dry year (2010/2011) to 4,675 MCM for the wet year (2011/2012). These estimates do not account for losses to the sea and deep percolation.

Although there is an overall surplus in water budgets at the national level, it is critical to note that most of the coastal GW-basins which are heavily urbanized show significant deficiencies in the water balance. In some basins such as the North Lebanon Cretaceous Basin (Basin 18), water shortages can reach more than 150 MCM per year in dry years. Other key basins showing shortages include Hadath-Hazmieh Cretaceous Basin (Basin 22) with a deficiency of 7.2 MCM, and Beirut Neogene Quaternary Basin (Basin 26a) with a deficiency of 38.4 MCM.

On the other hand, due to over exploitation for irrigation, the South Bekaa Neogene-Quaternary Basin (Basin 11a) and the North Bekaa Neogene Quaternary Basins (Basin 11b), show deficiencies in their budgets of up to 45.7 MCM and 34.2 MCM respectively.

A map showing the stressed aquifers is provided in Figure 2. A large-scale Hydrogeological map of the entire country, which is provided in Plate 1 at the end of the report, presents all the GW-basins along with some of their characteristics.

Proposed Artificial Recharge Scheme

Artificial groundwater recharge, which consists of replenishing the aquifer with surplus or reclaimed water, is an up-and-coming practice both globally and in the region. In general, an artificial aquifer recharge system is installed either

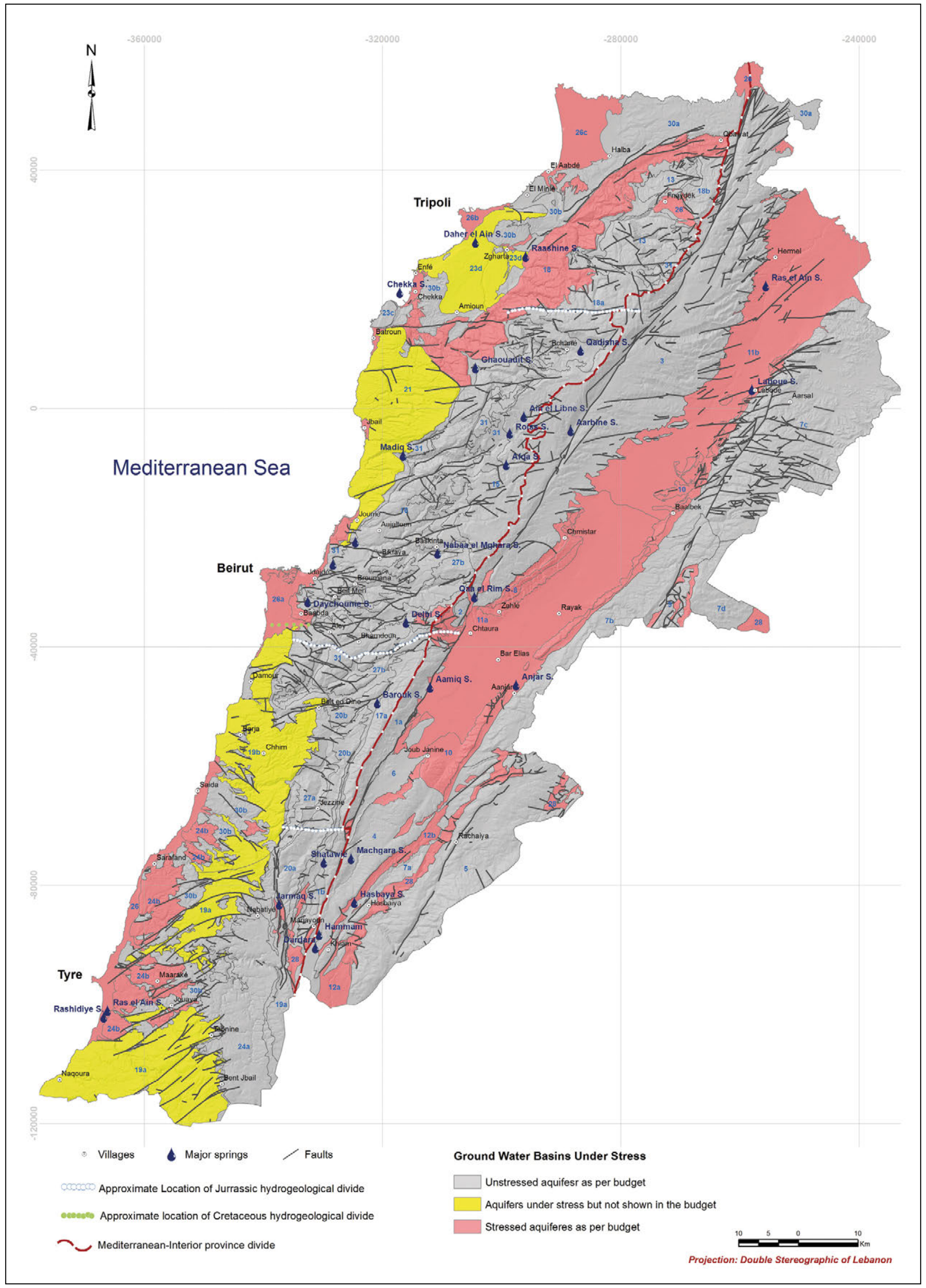


Figure 2 Map showing the stressed aquifers

to mitigate seawater intrusion in coastal aquifers that are being over-exploited or to store surplus water in the aquifer for subsequent recovery during dry seasons. The latter process is called Aquifer Storage Recovery System (ASR).

The limited storage capacity of the main aquifers in Lebanon is attributed to their karstic nature. Groundwater tends to flow along well-developed karstic underground channels at relatively high velocity, thus making storage difficult. However, artificial recharge in the up-gradient areas of the aquifer would still be beneficial. It will replenish the aquifer with a surplus of water that will delay/retard the beginning of the dry season, and shorten its period where groundwater is usually at its lowest level, and when the aquifer is subject to overexploitation, especially in the coastal areas, which are heavily urbanized.

In this study, potential areas for artificial recharge were assessed. The main sources for artificial recharge are natural sources (rivers and springs) and treated wastewater effluent. In total, 22 natural sources and ten (10) wastewater treatment plants distributed over 12 GW-basins were considered as potentially viable sources for artificial recharge. The GW-basins were selected according to the following main criteria: 1) basins under stress from depletion or saltwater intrusion; 2) basins that have the capacity to store the recharged water; and 3) areas where depth to groundwater is relatively deep to account for the potential mound (rise in groundwater level) that may result during recharge, and may potentially cause flooding if groundwater rises to the surface. The selection of these sites is preliminary. Further assessments would be required for detailed hydrogeological characterization and to confirm the adequacy of these sites for groundwater recharge.

In areas where the recharge is from the natural sources (rivers and springs), the aquifer recharge spans over a four (4) to five (5) month period during the wet season. The recharge quantities to be extracted from the source is proposed to be between 5% and 10% of the average flow of the natural source during the extraction period. The estimated volume of recharged water from natural sources is between 104 and 208 MCM/year.

In areas where the source of recharge is treated wastewater, groundwater recharge will be conducted throughout the entire year. From the ten (10) selected sites, the estimated amount of recharged water is between 103 and 118 MCM/year.

The total maximum available recharge that was estimated for the 33 sites, identified as part of this project, ranges between 207 MCM to 326 MCM/year. These estimates are in line with the figure presented in the 2010 Water Strategy of the MoEW (199 MCM/year).

In this preliminary assessment, gravity injection through wells is the proposed recharge technique. This method is considered the most suitable for recharge into karstic aquifer taking into account cost efficiency and environmental considerations. The injection wells can be installed in public property given the limited requirements of land.

RECOMMENDATION FOR THE ENHANCEMENT OF THE MONITORING NETWORK

The groundwater assessment revealed numerous deficiencies in the existing monitoring systems of the country. The proposed interventions presented below aim at improving the existing water resources monitoring system in Lebanon. An upgrade is needed to better quantify available resources - a necessity for the sustainable management of water resources in Lebanon.

Groundwater Monitoring

• Establishing a Dedicated Monitoring Well Network: The initial phase would consist of installing about 60 dedicated monitoring wells with a focus on the stressed aquifers. These wells should be equipped with continuous monitoring devices to measure the groundwater levels and in some cases, with conductivity sensors in areas that are prone to seawater intrusion. This activity should be carried by the MoEW.

• Monitoring of the Public Water Supply Wells: Out of the 842 public water supply wells, only 20 wells were equipped with continuous groundwater monitoring devices. It is proposed that water establishments equip all their wells with a discharge flow control monitoring system and continuous groundwater-level monitoring devices. Monitoring devices for those wells located in areas prone to sea water intrusion (about 250 wells), should include a conductivity sensor.

• Developing a Database for each of the Water Establishments: It is proposed that each water establishment maintains its own monitoring database. This would require the development of a formal data collection system with a quality assurance and quality control (QA/QC) program for uploading the data into the database. A proper procedure should be established for the regular reporting of information/data in digital format from the database of the various water establishments to that of the MoEW.

• Surveying the Unlicensed Private Wells: It is recommended to conduct a comprehensive survey of the unlicensed private wells and to complete the survey of private wells that have exploitation permits. Survey results can then be integrated into the existing well database that was constructed as part of this project. Due to the extensive number of wells, and the tedious investigative nature of the work, it would take approximately one (1) to two (2) years to complete.

River Monitoring

• Preparing a Detailed Plan for the Rehabilitation and Expansion of the Existing Network: This would include: 1) inspecting of all the gauging stations; 2) providing recommendations for locations of new gauging stations, and modification of existing ones if necessary; 3) preparing technical specification and guidelines for the installation of the various types of gauging stations to be installed; and 4) preparing an operational and maintenance manual to ensure the continuous acquisition of reliable data.

• Implementation of the Plan for the Rehabilitation and Expansion of the Existing Network: Preliminary assessments reveal that the minimum total number of proposed new stations needed is about 26.

• Updating and Improving the Existing Database at LRA: This would include incorporating all the existing data that is currently being gathered manually into the database and establishing a quality assurance control / quality assurance system.

Spring Monitoring

• Conducting a Nationwide Spring Survey:

Field proofing of the 5,050 springs identified in the topographic map will have to be done. For each spring the exact geographical coordinates should be taken, along with picture. The emergence mechanism should also be described. Approximate discharge flow rates should be measured and spring usage identified. Particular focus should be made on the 409 main springs that were identified in this study. This activity should be conducted by MoEW.

• Preparing a Master Plan for the Monitoring of the Major Springs in the Country: The master plan should include the identification of the major springs that would require continuous monitoring, and those that should be measured on periodical bases. It should also include technical specifications and guidelines for the installation of the gauging stations, including site preparations/ civil construction work (if any), and QA/QC procedure for data collection and data validation. This activity should be carried out by the MoEW, in collaboration with the LRA.

Meteorological Network

• Preparing a Master Plan for the Improvement of the Existing Meteorological Network: The number of stations required and their respective locations should be determined following international criteria taking into account the different microclimates and the hypsometry of the Lebanese territory. Generally, two (2) climatic stations are required for every 200 km^2. The master plan should include: 1) an assessment of existing station and the identification of the location of proposed new stations; 2) the

The karst of the Jurassic rocks of the Jaj plateau, North Lebanon (Note the human scale in the middle of the image)

preparation of technical specifications for the installation of the equipment (required civil work and instruments; and 3) Develop quality control / quality assurances (QA/QC) procedures for data acquisition, data reductions and data reporting, as wells calibration requirements.

• Installing the New Meteorological Stations: Based on a preliminary assessment, the total number of required new stations is 89 of which 20 are snow stations.

• Recovering and Processing the Historical Data: Based on the review of the hydrometrical data, historical data collected before 1975 have not been integrated into the existing database: This intervention would mainly consist of digitizing data collected before 1975; and integrating those into the existing database.

Legal and Institutional Assessment Study

The legal and institutional framework of the government services involved in the monitoring (groundwater, surface water, and meteorology) will have to be revised and their resources will have to be strengthened in order to allow these government services to properly accomplish their assigned mission. The study should include:

• Conducting a gap assessment on the existing institutional and legal framework work, of the government organisations/services involved in the specific monitoring;

• Proposing a road-map and drafting legislative texts to re-define missions and mandates, avoid overlaps and clarify attributed roles and responsibilities;

• Adjusting organisational structures, assessing staff requirements, defining and developing individual job descriptions and performance requirements for each staff category;

• Developing coordination procedures between the various stakeholders;

• Identifying training programs to strengthen the capacity of the organisations/services;

• Defining procedures for data dissemination and access control;

• Revising or developing procedures for the control of water extractions, such as drilling permits, groundwater extraction permits, and surface water allocation permits; and

• Preparing annual cost estimates for the operation and maintenance of the monitoring systems.

Snow cover in the Lebanese mountains

TABLE OF CONTENTS


The underground river of the Rahwe cave as seen in the main axis which emerges as the Rahwe spring

MESSAGE FROM THE MINISTER
LIST OF ACRONYMS

EXECUTIVE SUMMARY .... **VIII**
Hydrological Assessment........ XII
Water Budget........ XIII
Recommendation for the Enhancement of the Monitoring Network........ XV
Groundwater Monitoring........ XV
River Monitoring........ XVI
Spring Monitoring........ XVI
Meteorological Network........ XVII
Legal and Institutional Assessment Study........ XVII

TABLE OF CONTENTS **20**
LIST OF FIGURES **22**
LIST OF TABLES **24**

1. INTRODUCTION **27**
1.1 BACKGROUND 27
1.2 SCOPE OF THE STUDY 27

2. ASSESSMENT OF EXISTING DATA **29**
2.1 METEOROLOGICAL DATA 29
2.2 SURFACE WATER DATA 30
2.3 SPRING DATA 33

3. WELLS SURVEY **36**
3.1 PUBLIC WELLS 36
3.2 PRIVATE WELLS 36

4. MONITORING CAMPAIGN **39**

5. DATABASE CONSTRUCTION **41**

6. HYDROGEOLOGICAL ASSESSMENT **42**
6.1 GEOLOGICAL AND HYDROGEOLOGICAL SETTING 42
6.2 GROUNDWATER BASINS BOUNDARIES & GEOLOGY 44
6.3 KARST 48
6.4 SPRINGS ASSESSMENT 54
6.5 GROUNDWATER LEVEL 54
6.6 HYDRO-CHEMICAL CHARACTERIZATION 62
6.7 HYDROLOGY 67
6.8 WATER BUDGET 70

7. PRELIMINARY ASSESSMENT OF ARTIFICIAL RECHARGE **80**

8. RECOMMENDATIONS FOR THE ENHANCEMENT OF THE MONITORING NETWORK **80**
8.1 GROUNDWATER MONITORING RECOMMENDATIONS 85
8.2 RIVER MONITORING RECOMMENDATIONS 85
8.3 SPRING MONITORING RECOMMENDATIONS 86
8.4 METEOROLOGICAL NETWORK RECOMMENDATIONS 86
8.5 LEGAL AND INSTITUTIONAL ASSESSMENT STUDY 87

LIST OF FIGURES

The Chamsine spring

Figure 1 Map showing the updated GW-basins X
Figure 2 Map showing the stressed aquifers XIV

2. ASSESSMENT OF EXISTING DATA 29
Figure 2-1 Spatial distribution of stations and length of records 32
Figure 2-2 Map showing the UNDP (1970) springs identified on the 1:200,000 map in reference to their classes (ND: not defined)....34
Figure 2.3 Map showing the springs of Lebanon identified from the 1:20,000 topographic map 35

3. WELLS SURVEY.... 36
Figure 3-1 Map of Lebanon with statistics on public wells distribution and extraction rates 37
Figure 3-2 Pie chart that shows the distribution of private licensed wells in the different operational areas of the water establishments in Lebanon 38

4. MONITORING CAMPAIGN 39
Figure 4-1 Map showing the distribution of wells that were monitored 40

5. DATABASE CONSTRUCTION.... 41
Figure 5-1 Snapshot from GW-Base of the public wells (with locations and Information), overlaid on 1:50,000 topographic maps 41
Figure 5-2 Snapshot from GW-Base showing the station data and editing windows....42

6. HYDROGEOLOGICAL ASSESSMENT 42
Figure 6-1 Simplified stratigraphy and hydrostratigraphy of Lebanon 43
Figure 6-2 Major geological structural features of Lebanon....45
Figure 6-3 Groups of secondary faults of Lebanon 46
Figure 6-4 Groundwater basin map of Lebanon, as presented by the UNDP (1970)....47
Figure 6-5 Map showing the modified GW-basin 49
Figure 6-6 Distribution of the GW-basins and unproductive zones in Lebanon 53
Figure 6-7 Karstic map of Lebanon....51
Figure 6-8 Location of springs....57
Figure 6-9 Summary map of wells with groundwater level information 59
Figure 6-10 Groundwater table contour map for the Akkar Neogene-Quaternary Basin generated from February 2013 data set (blue) compared to February 1967 data sets (in Red), from UNDP 1970 61
Figure 6-11 Groundwater table contour map in the Akkar Neogene-Quaternary Basin for February 2013 data set (Blue), compared to February 1969 data set (in green) obtained from FAO (1970)....63
Figure 6-12 Location of the monitored wells from the "Ground Water Modelling in the Upper Litani Basin" with the generated contour lines for November 2010 (in Blue), compared to February 1967 contour lines (in Red), from UNDP 1970....64
Figure 6-13 Sub-watersheds according to Plassard's (1972) rain map 66
Figure 6-14 Average precipitation values in relation to average snow water equivalent for hydrological cycles 2008 to 2012 68
Figure 6-15 Annual precipitation 2008-2009....69
Figure 6-16 Annual precipitation 2009-2010....69
Figure 6-17 Annual precipitation 2010-2011 69
Figure 6-18 Annual precipitation 2011-2012....69
Figure 6-19 Schematic diagram of the model devised specifically for the groundwater budget of Lebanon 71
Figure 6-20 Stressed aquifers / GWB....77

7. PRELIMINARY ASSESSMENT OF ARTIFICIAL RECHARGE 80
Figure 7-1 Location of the proposed areas for artificial recharge from natural sources and from wastewater effluent overlaid over the GW-basins 89
Figure 7-2 Location of the proposed areas for artificial recharge from natural sources and from wastewater effluent overlaid over the GW-basins under stress....91

LIST OF TABLES

Karst features in the Jaj plateau

Table 1 Number of springs in each class XI

3. WELLS SURVEY 36

Table 3-1 Summary table of public wells in Lebanon 36

Table 3-2 Comparison of the number of illegal wells between Mediterranean countries 38

4. MONITORING CAMPAIGN 39

Table 4.1 Comparison of collected data between water levels of the years 2012/2013 and 2013/2014 39

6. HYDROGEOLOGICAL ASSESSMENT 42

Table 6-1 Types of karst and their distribution according to GW-basins 48

Table 6-2 Table showing the number of spring with data in each class (Meinzer Classification) compared with the UNDP 1970 with an example for each spring type 55

Table 6-3 Springs flows and recession coefficients 56

Table 6-4 Table outlining the groundwater basins with the number of samples used for the assessment of the hydrochemical facies of each basin 65

Table 6-5 Rainfall all over the Lebanese territory from 2008 to 2012 68

Table 6-6 Snow water equivalent in MCM estimated from 2008-2009 to 2011-2012 68

Table 6-7 Total precipitation (rainfall and snow) all over the Lebanese territory from 2008 to 2012 68

Table 6-8 RET from 2008 to 2012 using Turk method 70

Table 6-9 Calculated runoff from 2008 to 2012 70

Table 6-10 Estimated recharge to groundwater from 2008 to 2012 70

Table 6-11 Average precipitation, recharge to groundwater, runoff and real evapotranspiration for the Lebanese territory (2008-2012) 70

Table 6-12 Data sources of the various components of the preliminary Groundwater budget (GW-budget) 72

Table 6-13 Results and discussion of GW-basins of the Mediterranean Province 73

Table 6-14 Results and discussion of GW-basin of the Interior Province 75

Table 6-15 Preliminary GW budget of Lebanon....79

Table 6-16 Comparison of water balance estimations 79

7. PRELIMINARY ASSESSMENT OF ARTIFICIAL RECHARGE 80

Table 7-1 Proposed candidate sites utilizing surface water as a source for recharge 81

Table 7-2 Estimated ranges of volumes of water available for recharge in each candidate sites utilizing a surface water source 82

Table 7-3 Proposed candidate sites utilizing treated effluent water as a source for recharge....83

Table 7-4 Selected waste water treatment plants where effluent would be used for artificial recharge 83

Table 7-5 Volumes of potentially recharged water in each GW-basin compared to infiltrated volume 84

Balloua Baatara sinking stream in Tannourine

1. INTRODUCTION

1.1 BACKGROUND

There is a common misconception that Lebanon, with a surface area of about 10,452 km2, and moderate average rainfall, has an abundant supply of renewable water resources. Unsustainable water resource management practices that have been followed since the mid nineteen seventies, coupled with weak water governance, have put a strain on the country's water resources, specifically on its groundwater.

Growing water demand as a result of increasing population has been met by overexploitation of the country's groundwater resources. A large number of public and private water supply wells have been installed without proper planning and monitoring.

The majority of private wells are illicit; they were installed without a drilling permit. Most of the remaining private wells, although legal, do not have exploitation permits and have unreliable records. Information about these wells such as well design, well usage, and exploitation rates are missing. This uncontrolled groundwater withdrawal practice, together with the lack of adequate studies and monitoring has led to the continuous depletion of the groundwater resources in various areas of the country.

After the point four (4) mission from the American Bureau of Reclamation in the early 1930s, the only comprehensive national groundwater assessment study was completed in 1970 by UNDP. The study was carried out, in close collaboration with the Ministry of Water Resources, during the 1960s' over a period of nine (9) years.

One of the main outcomes of the study was the generation of a comprehensive nation-wide hydrogeological map that provides a good description/characterization of the country groundwater resources. The study also flagged aquifer basins where the groundwater resources were being depleted. It provided recommendations for potential basin/areas where further groundwater development could be entertained, provided proper investigation and resource assessment is conducted.

Since then, no other comprehensive studies were conducted at a national scale. However, numerous smaller-scale studies were subsequently carried out, on behalf of the MoEW and other stakeholders. Many of these studies were local, targeting specific areas for further groundwater development, and focusing on how to maximize groundwater exploitation, without considering the sustainability of groundwater resources.

Very few studies, if any, have been conducted for the purpose of a comprehensive assessment of the entire water resources of a specific region, area, or basin. Other interesting smaller-scale but valuable studies were carried out by academics and researchers. Most of these studies were carried out with limited data collection, if any. This was mostly due to time and budget constraints.

1.2 SCOPE OF THE STUDY

The current project is implemented by the United Nations Development Programme (UNDP) in partnership with and on behalf of the Ministry of Energy and Water with funding for the Government of the Republic of Italy. The project was implemented through the UNDP-led Lebanese Centre for Water Management and Conservation (LCWMC). The technical consortium of companies that executed the study was led by Earth Link & Advanced Resources Development (ELARD) and included BURGEAP, IGIP and Ribeka. The study started in middle October 2011, and, spanned for about two and a half years.

A multidisciplinary team of key experts was mobilized comprising geologists, hydrogeologists, hydrologists, integrated water resource management experts, groundwater modelers, GIS and database experts. The project technical team members are listed below:

- **Ziad Khayat (UNDP)**
  Project Manager
- **Ramez Kayal (ELARD)**
  Project Manager, Principal Hydrogeologist
- **Dominique Fougeirol (BURGEAP**
  Peer Reviewer (QA/QC)
- **Issam Bou Jaoude (ELARD)**
  Deputy Project Manager, Senior Hydrogeologist
- **Dr. Farid Karam (ELARD)**
  Co-Deputy Project Manager, Senior Hydrologist
- **Eric Berger (RIBEKA)**
  Team Leader, Senior Database Expert
- **Dr. Levant Tezcan (ELARD)**
  Senior Hydrogeologist
- **Dr. Mehmet Ekmekci (ELARD)**
  Senior Hydrogeologist
- **Fadi Merheb (BURGEAP)**
  Senior Hydrogeologist, GW Modeler
- **Dr. Wajdi Najm (ELARD Consultant)**
  Senior Hydrologist
- **Rachad Ghanem (ELARD)**
  Senior Geologist, Database Expert
- **David Balmert (RIBEKA)**
  Software Engineer, Hydrogeologist
- **Dr. Chadi Abdullah (ELARD Consultant)**
  GIS and RS Expert
- **Dr. Joanna Doummar (ELARD Consultant)**
  Senior Hydrogeologist, GW Modeler
- **Georges Makhoul (ELARD)**
  Senior Hydrogeologist
- **Dr. Marie Therese Abi Saab (ELARD**
  Consultant) Agriculture and Irrigation Expert
- **Bilal Idriss (ELARD)**
  Hydrogeologist
- **Basma Shamas, Amani Matar, Tarek el Mashtoub, Shafiq Ghraizi (ELARD)**
  Geologist
- **Mahmoud Taleb (ELARD)**
  Field Survey Coordinator
- **Stephanie Douaihy (ELARD)**
  Environmentalist

The scope of the study consisted mainly of conducting a number of keys tasks including data collection, desk studies and well surveys. The data collected was analysed for all water life-cycle parameters and thematic maps were generated.

All existing data and available references such as gauging data, studies, reports, and published papers related to geology, hydrogeology and hydrology were collected and reviewed (Deliverable 6a).

In an attempt to reduce (to the extent possible) the size of data gap, which is always a limitation when conducting comprehensive water studies, a comprehensive well survey and a one-year groundwater monitoring program were implemented as part of this project (Deliverables 2, 6b and 7).

All primary and secondary data gathered were integrated and stored in a -first of its kind- national database which was setup at the MoEW/LCWMC after running several rounds of quality assurance and consistency checks on it(Deliverables 5 and 8).

Understanding water bearing and non-bearing rock units in terms of nature and composition was crucial for initiating the overall hydrogeological assessment. A detailed review of the geological context of Lebanon is presented in Deliverable 9, Appendix 1. All geological formations are described and classified in terms of their hydrostratigraphic significance. The structural features (faults and folds) are also discussed.

Water bearing units "GW-basins" may exist in isolation or in juxtaposition with other basins. The structure of a GW-basin, its boundaries (whether surface or subsurface) and its interaction with neighboring basins as well as neighboring or cross-cutting structural features govern the groundwater flow within it and into and out of it. Such an assessment, which has been carried out, led to some re-partitioning and re-delineation of the existing GW-basins as presented in Deliverable 9, Appendix 2. Karstic features were mapped and typed. These are found in Deliverable 9, Appendix 3.

An assessment of the various springs of Lebanon is presented in Deliverable 9, Appendix 5, whereby a new classification of the springs of the country based on type of emergence, is provided. Areas and/or GW-basins that are subject to groundwater stress or depletion are highlighted in chapter Deliverable 9, Appendix 6, which tackles groundwater elevation in specific basins. Hydrochemical parameters of the GW-basins in the Mediterranean and Interior Provinces are provided in Deliverable 9, Appendix 8. Hydrological parameters are assessed individually in Deliverable 9, Appendix 9 leading to the generation of an overall, and basin-by-basin water budget which is presented in Deliverable 9, Appendix 10. Assessment of potential areas for artificial recharge is presented in Deliverable 10.

A summary of the historical tracer tests conducted throughout the country is provided in Deliverable 9, Appendix 4. The limited available groundwater isotope studies, which were assessed, and synthesized, along with the results of some groundwater isotope samples data that were collected by the consulting team during the project (at its own initiative) are presented in Deliverable 9, Appendix 7.

A 3D groundwater flow model was developed for the Akkar Quaternary-Neogen Basin and is presented in Deliverable 12.

2. ASSESSMENT OF EXISTING DATA

Throughout the first phase of the project, relevant studies, reports, maps and technical notes were gathered, compiled and reviewed by the project team. These documents were gathered from various sources mainly from the MoEW, Council for Development and Reconstruction (CDR), Council of the South, National Council for Scientific Research (CNRS), water establishments, Lebanese Agricultural Institute (LARI), Lebanese National Meteorological Service (LNMS), Litani River Authority (LRA) as well as from international organizations, universities, and engineering consulting firms. Pertinent information/data was extracted from these documents to be assessed and then used in the investigation.

One of the main requirements of the project is to assess the quality of this hydrological and metrological data being collected by various institutions as part of their existing monitoring program.

2.1 METEOROLOGICAL DATA

Several public, semi-public, academic and private establishments collect meteorological data in Lebanon, each operating one or more stations. Although the LNMS at the Civil Aviation General Directorate that belongs to the Ministry of Transportation and Public Works is officially the national agency responsible for meteorological measurements, other institutions guided by their needs for reliable climatic data to achieve their missions, have installed their own networks of stations, including LARI, which currently has the widest coverage.

Stations differ in their locations, the parameters and frequency of measurements and the quality of the data being measured. There are two (2) distinctive periods in the measurements of climatic data: the period before the Lebanese Civil War (i.e. Before 1975); and the period after the end of the Lebanese Civil War (i.e. After 1990).

The meteorological data received from the various institutions were processed to determine complete annual series only. In the first stage, the daily data series were processed to filter out the months that have missing daily data, with the exception of the three summer months, given that their contributions, if any, would be negligible, and therefore would not significantly

affect the cumulative seasonal and monthly averages. Monthly averages were then calculated. The second stage consisted of filtering out the hydrologic seasons, which have missing months, and subsequently calculating yearly cumulative precipitation values. Yearly average precipitation levels were then calculated, along with the number of years retained for each station.
In 2002, the LNMS introduced a new quality control system that was integrated into a software package called DONE. This allowed the adjustment and reproduction of precipitation average values for all available years for every station.

Adjustments were made according to the Beirut International Airport Station (BIA) averages taken for the same period by assigning adjustment coefficients, based on linear correction between the average of the BIA and the average of the station. It should be noted that these calculated averages are not completely representative given that usually data series spanning over a longer period are required to calculate reliable averages. Given that LARI's data span over a short period, yearly precipitation averages are meaningless. Therefore, cumulative yearly precipitation averages were calculated only.

The main gap in time series of meteorological data is attributed to the interruption caused by the civil war in Lebanon, (1975 and 1990), which resulted in the destruction of the majority of climatological stations and halted measurement activities all over Lebanon, especially at the historical Ksara observatory station and at the AUB station that was considered a reference station for the period preceding the war.

The relocation of stations sites has worsened the problem especially for the airport station that could have served as a reference station and filled the gap caused by the interruption of AUB and Ksara stations. The airport station was displaced several times from different places, starting with Manara (1931-1936) to the old airport location in Bir Hassan (1939-1953) and to several points in the existing airport (Terminal near tower on Terrace (1954-1963), near radio-orient to the south of the landing strip (1964-1982) and to the main terminal (1982-present)).

In addition, a lot of the data registered were either lost or disappeared from the national archive of the LNMS. A major limitation of the existing and previous meteorological networks is the lack of stations capable of collecting information on snow. The precipitation maps of the Climatic Atlas, published by the LNMS in 1972 under the management of Pere Plassard, did not account for the snow equivalent, given that no data were collected in this regard.

Snow is believed to play a crucial role in contributing to the recharge of the surface and groundwater resources of Lebanon. It is estimated that snow covers about a quarter of the Lebanese territory during the wet season. Accurate volume quantification of snow and/or its water equivalent has not been established to date. This is attributed to the limited (if not absent) field measurements of snow depth through time and the lack of studies and researches addressing the topic.

Recently (winter 2011-2012), the National Council for Scientific Research (CNRS) in cooperation with the Centre D'etudes Spatiale de la Biosphere (CESBIO) in France and Univeristé Saint Joseph (USJ), installed two (2) meteorological stations for measuring and monitoring snow depth. These two (2) stations are the first of their kind in Lebanon and are located in the region of Faraya: one at an altitude of 1,560 m above sea level (asl) and the other at 2,400 m asl. The stations' records are still unpublished and therefore are not available.

2.2 SURFACE WATER DATA

Water levels and discharges in rivers were measured in Lebanon by the point 4 mission from the American Bureau of reclamation since the early 1930s. Since 1965, these activities became the responsibility of the Litani River Authority (LRA) who managed 81 gauging stations of which 75 hydrological stations were installed and operated prior to 1970s in addition to several flow measurement sites mainly at springs (some other sources mention the existence of 87 stations). The UNDP study of 1970 included regular flow measurements of major rivers. Gauging activities stopped during the civil war. It resumed in early 1990 when 20 stations were partially rehabilitated. The number rose to 58 in 1998 with the renovation of equipment of 38 other stations.

The flow data was acquired from the Litani River Authority through the Ministry of Energy and Water. The data received do not represent all available data knowing that for the Orontos River, for example, discussions between Lebanon and Syria were based on a 50 years average of flow while data covering only 18 years was received. This created a major drawback/limitation in data analysis and extracting the averages. All major watershed basins are being gauged. However, some rivers are not measured at the right locations, such as at the confluent point of different major effluents or upstream and downstream of several major feeding sources.

Hydrological observation data are missing during a period of 15 years, between 1975 to 1990. Some basic data quality control was undertaken during the development of a computer based-archive of the pre-1974 daily mean flows, created in the early 1980's, in the context of an FAO project. Even for the initial 10-year immediate period after the civil war (between 1991 and 2000), available data are somewhat scattered depending on the stations. About one third of the area of Lebanon is not yet covered by hydrological observation system (Figure 2-1). It is therefore recommended to set-up program for the installation of hydrogeological observation stations.

By combining the data received from pre-war stations and those that are currently in operation, average flow volumes and discharge flows were calculated, first taking the pre-war data and the post-war data individually into consideration then all the data together.

In general, the main problems affecting the quality of hydrometric series values are the following:

- *Gauging series are not published leading to compromised data quality..*
- *Some rivers have several calibration curves per year for the same station and many rivers overflow their banks during flood events.*
- *Many stations are located at the mouth of rivers or downstream of tributaries and therefore do not account for irrigation intakes and inflows of water. An example is the location of the gauging station at the mouth of the Awali River. A significant flow of water, discharging into the river, is supplied from the Litani River/Quaroun Lake via a tunnel to operate three (3) hydroelectric plants located along the Awali River just upstream of the gauging station. An additional station should be located upstream of the three (3) power plants in order to estimate the inflow of water from the Quaroun Lake.*
- *No measuring stations exist at the mouth of several rivers;therefore, the recorded volumes do not represent those of the entire basin.*
- *There are hidden losses attributed to seepages, which cannot be taken into account (analyse des Strategies et Prospectives de l'Eau au Liban - rapport I: Monographies de l'eau au Liban, Katafago et Jaber).*
- *In the many steep, responsive catchments in Lebanon, the calibration of the flood range of stage-discharge relationships is made difficult by the frequent changes in bed profile, attributed to the torrential flows with high debris load, causing extensive weathering, and sediment accumulation*
- *During the dry season, the prevailing shallow water depths and very slow water velocities, together with the impact of irrigation demands and other disturbances to the natural regime, limit the accuracy and representativeness of low flow measurements.*

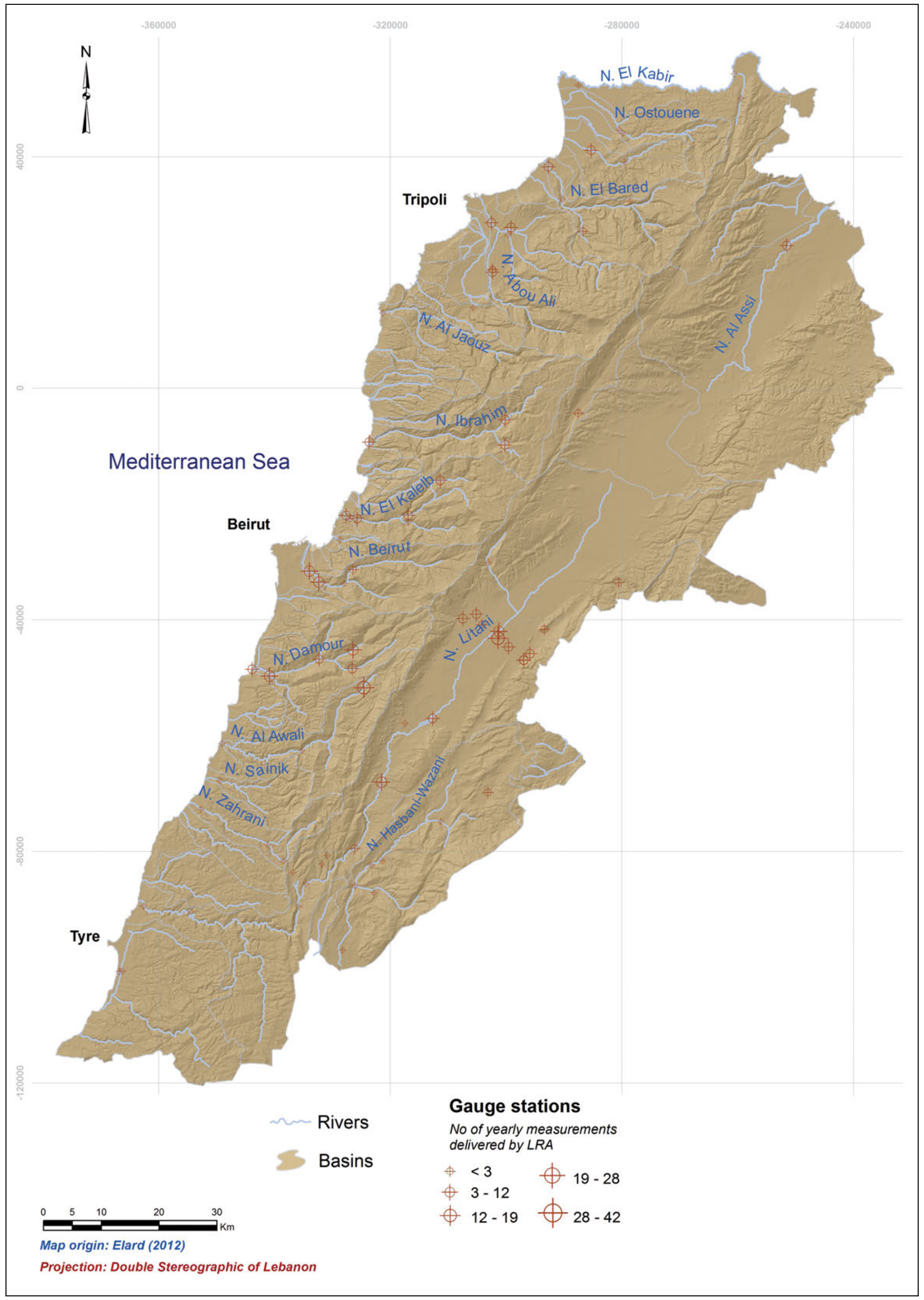


Figure 2-1 Spatial distribution of stations and length of records

2.3 SPRING DATA

The inventory of the springs was done through a comprehensive review of available information, such as topographic maps and UNDP's hydrogeological map of 1/200,000 scale (Figure 2-2). Initially the springs were depicted from the topographic maps at a scale of 1/20,000 (Figure 2-3) and supplemented by the 1/50,000. 5,050 springs were identified, out of which 2,290 have a name starting with either 'Ain" or Nabah. The LRA, responsible to maintain and operate the surface water and springs gauging stations in the country, is currently monitoring the discharge flow of nine (9) major springs, which are: 1) Nabaa el Arbaain; 2) Ain ez Zarka; 3) Ras el Ain; 4) Nabaa Al Rashidiyeh; 5) Nabaa Adonis; 6) Nabaa Chamsine; 7) Ain Aanjar; 8) Nabaa el Hasbani; and 9) Nabaa Wizeneh. Temporal discharge flow measurement series are available only for periods after the 1990s. With the exception of Nabaa Al Rashidiyeh, all these springs were part of the list of springs that were continuously monitored in the UNDP study of 1970.

One should be cautious however, that most of the spring gauging stations do not provide a true representation of the overall discharge flow, given that they are usually installed just downstream of the spring, and do not take into account the water that is being extracted for various purposes from the source, through large pipes, canals, etc. Several springs are being exploited by the water establishments; however; only scattered records of average extraction rates are reported. This average would be an indication of the spring discharge flows, in dry season when the total flow is being used. However, no measurements of the springs are made during the wet season, when the springs overflow and are releasing most of their yearly flow. Examples are: Nabaa Rachaaine, Nabaa el Hab, Chaghour Spring and Nabaa El Arbaain.

Continuous spring flow measurements are not being recorded. Discharge flow measurements of several springs have been made in the past over short periods; either on a regular or continuous basis, usually during only one hydrological cycle, and only as part of focused hydrogeological studies. These include but are not limited to: 1) Nabaa Al Daychounieh (Bureau Mounir Hajal; 1984); Nabaa Al Tasseh (ELARD-2006); Nabaa Al Safa (BTD-1999); Nabaa Four Antellias (Labaky 1998); and Chekka submarine springs (El Hajj, 2008). Last but not least, as part of regional water resources studies undertaken by several consultants, such as Dar Al Handassah Taleb, comprehensive surveys of many springs were conducted in the mid 1990's. These surveys, which were led by Mr. George Makhoul, consisted of field checking all the springs shown on the topographic map of 1/20,000, describing the hydrogeological conditions of the springs, and whenever possible, measuring the spring discharge flow. The area surveyed, included: Baalbeck, Hermel, Jbeil, Zgharta, and Sir Ed Dannieh Cazas. Approximately 550 springs were field surveyed. The field inspection sheets of these springs were provided by Mr. Makhoul. Based on the comprehensive review of all data and information gathered, it appears that the temporal series of spring discharge data are very limited. Some scattered, reliable series for few large springs, covering a very limited period (usually 1 or 2 hydrological years), are available for very few springs. Although the LRA is only continuously monitoring nine (9) major springs in the country, these measurements are generally not truly representative of the total flow of the springs, given that the extracted/exploited volumes at the spring sources are usually not accounted for. However; they represent the best available estimate. The limited availability of data constitutes a significant constrain on water balance estimations based on aquifer basins.

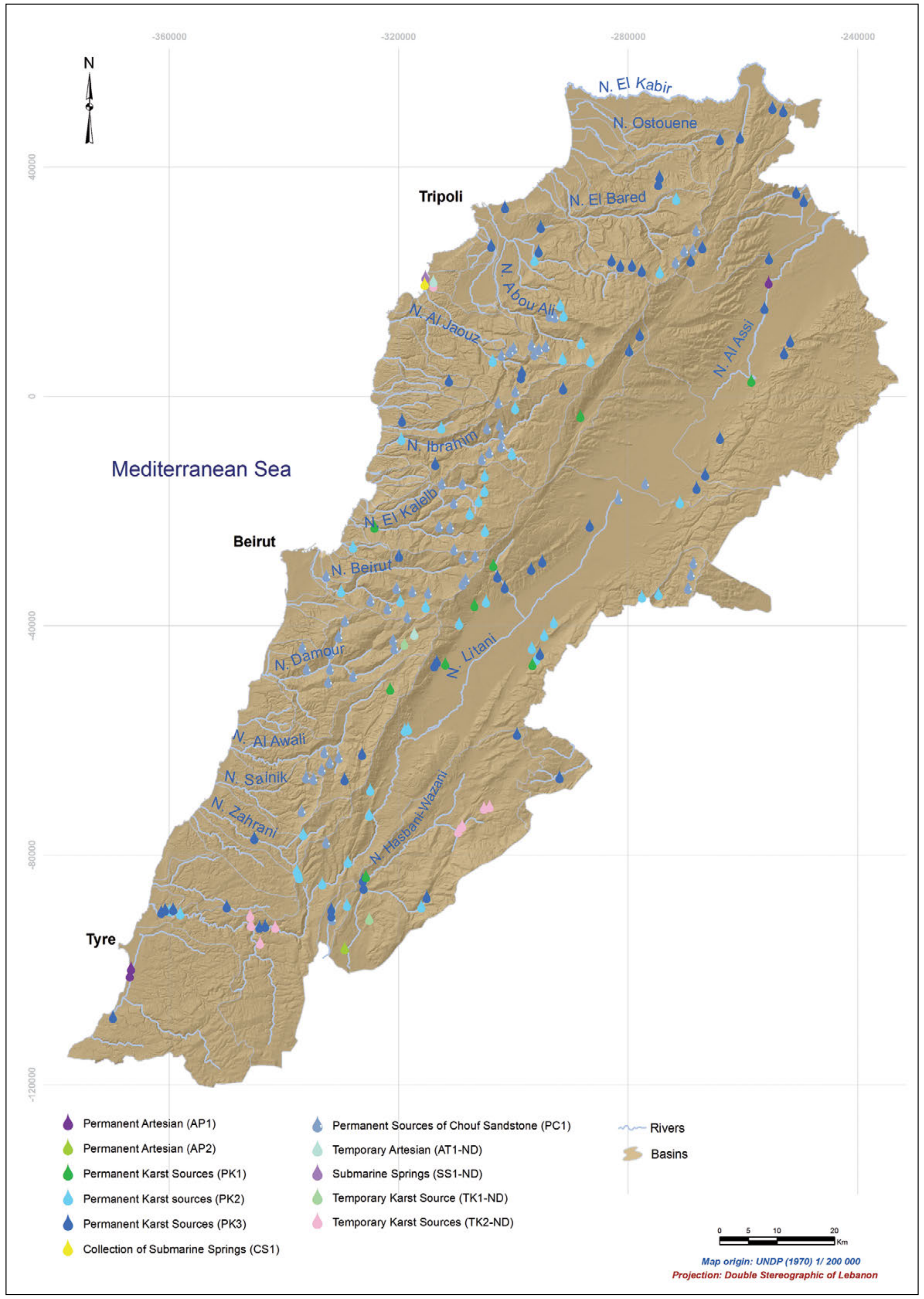


Figure 2-2 Map showing the UNDP (1970) springs identified on the 1:200,000 map in reference to their classes (ND: not defined)

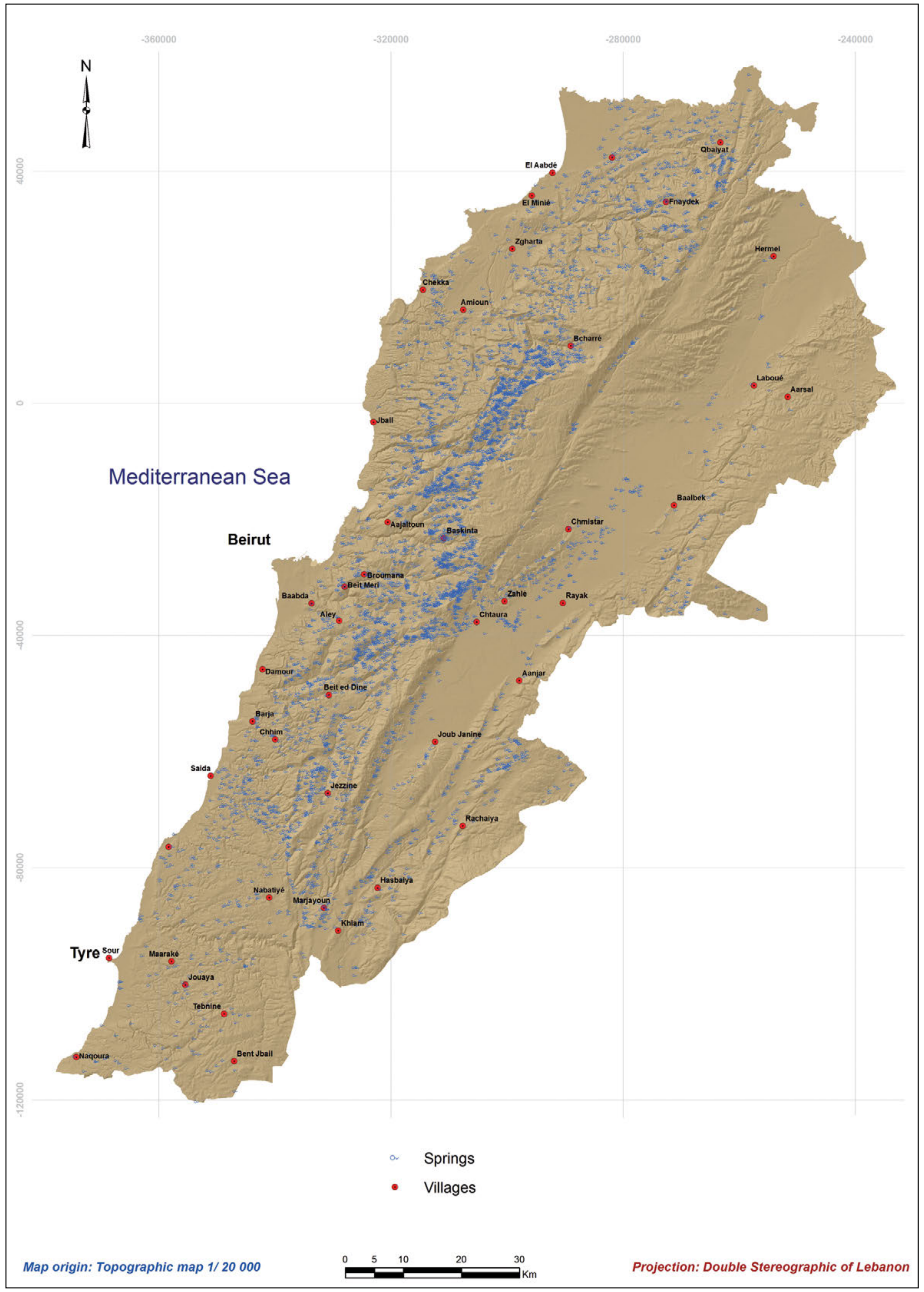


Figure 2.3 Map showing the springs of Lebanon identified from the 1:20,000 topographic map

Table 3-1 Summary table of public wells in Lebanon

ESTABLISHMENT	TOTAL NO. OF WELLS SURVEYED IN THE FIELD	TOTAL EXTRAC-TION RATE (m³/day)	TOTAL EXTRACTION RATE (Million m³/year)	TOTAL EXTRACTION RATE AS OF MOEW 2010* (Million m³/year)	TOTAL NUMBER OF PIEZOM-ETERS	TOTAL NUMBER OF FLOW METERS
BMLWE	218	193,642	71	89	38	37
BWE	209	90,422	33	53	42	59
SLWE	277	309,128	113	71	7	160
NLWE	137	88,383	32	54	25	31
Total	841**	681,576	249	267	112	287

**MoEW 2010: National Water Sector Strategy: Baseline. MoEW, 2010* ***inspection of 102 wells was not complete for varied reasons*

3. WELLS SURVEY

3.1 PUBLIC WELLS

The public well survey was conducted between November 14, 2011 and February 13, 2012. The survey area was subdivided into four (4) operational areas following the geographical coverage of the four (4) Lebanese Water Establishments.

The survey revealed the presence of 841 public wells in the country, out of which 44 wells are abandoned and 68 are non-operational. Data collection on 102 wells was not completed due to inaccessibility. In addition to the general information collected on each public well (well depth, pump depth, type of casing, depth to groundwater, operating hours, etc.), information on the aquifer tapped and estimates of the discharge rates were also integrated in the survey sheets and databases.

Flow meters or flow totalizers were installed in 287 public wells. The survey showed that the operational public wells are exploiting the various aquifers at an estimated rate of about 248.7 million m³/year (Table 3-1 & Figure 3-1 Only 112 wells were equipped with piezometers. In the South Lebanon Water Establishment (SLWE), six (6) wells were identified with pseudo-piezometers, which is a short black polyethylene hose of 1.5-inch ID and one (1) to two (2) m length installed only on top of the well head.

Water level was measured in 118 public wells, which are the wells equipped with piezometers and few extra wells where groundwater levels were shallow. The ones where groundwater levels could not be measured were mainly because the electric water level meter could not be lowered to the level of the groundwater.

Knowing the importance of monitoring extraction rates and the level of groundwater in public wells, it is highly recommended that the water establishments install flow meters and piezometers in newly constructed wells and in wells that are being rehabilitated.

3.2 PRIVATE WELLS

The private wells assessment was conducted for two (2) categories of wells: one relates to the private licensed wells; and the other relates to the private unlicensed wells.

The official data base of private licensed wells was obtained from the MoEW; approximately 20,537 are officially registered (up until January 2012). Among the officially registed private wells, 2,888 have exploitation permits and about 17,649 have drilling licenses but no exploitation permits. The methodology used to survey such a large number of wells involved dividing the country into operational areas in line with the geographical coverage of the four (4) Lebanese water establishments and subdividing these areas according to Cazas. The pie chart in Figure 3-2

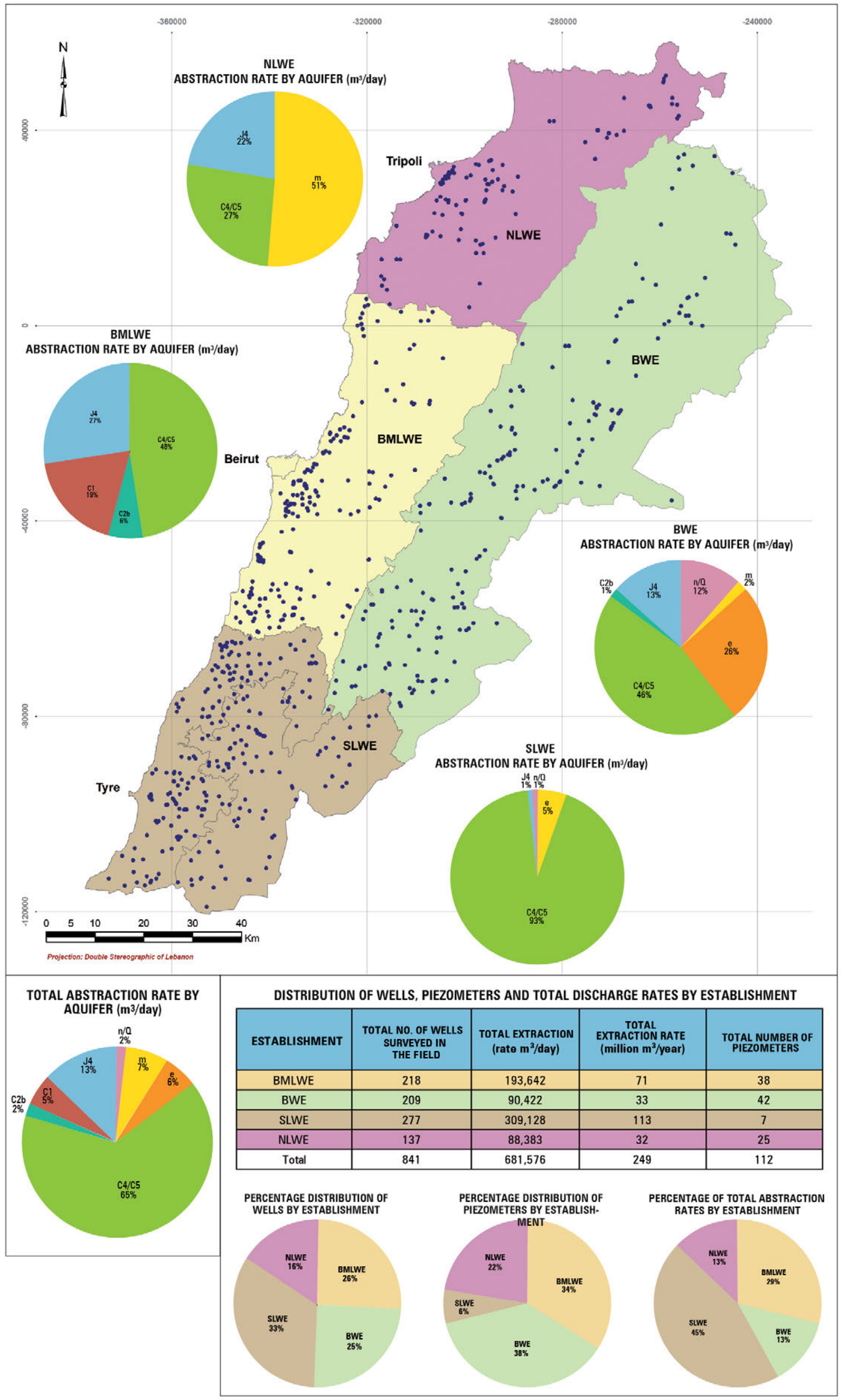


Figure 3-1 Map of Lebanon with statistics on public wells distribution and extraction rates

outlines the distribution of wells in the each operational area. More than 50% of the private licensed wells are located in the BMLWE. The field survey for private wells took about seven (7) months to complete.

The number of unlicensed private wells, was approximated from interviews and discussions with representatives from local authorities, municipalities, residents, pilot areas and in some cases with local drillers. The estimated number of unlicensed private wells is almost three (3) times higher than the number of licensed private wells (about 55,000 to 60,000 wells).

In heavily urbanized areas, most of the unlicensed wells are suspected to be used for domestic purposes and may therefore most likely have relatively low daily extraction rates. As an example, considering the 180 l/day/capita (MoEW, 2010) and an average of 5 persons per household, the average extraction rate for each private well is approximately 1 m^3/day if no other source of water is available for that household. In rural areas, especially in the Bekaa and Hermel, most of these wells are suspected to be used for irrigation purposes, and would therefore have higher extraction rates. Consider for example that the net irrigation needs is 4,500 to 5,000 m^3/hectare/irrigation season. Knowing that the irrigation season is approximately 6 months; therefore the net irrigation needs are 25m^3/day/hectare. This volume will be considered as the approximate groundwater extraction volume if no other source of water is available for irrigation. Finally Table 3-2 compares the number of illegal wells in four (4) Mediterranean countries. The ratio of the number of illegal wells to the surface area, which is approximately five (5), is quite comparable between Lebanon, Cyprus and Italy but much higher than Spain.

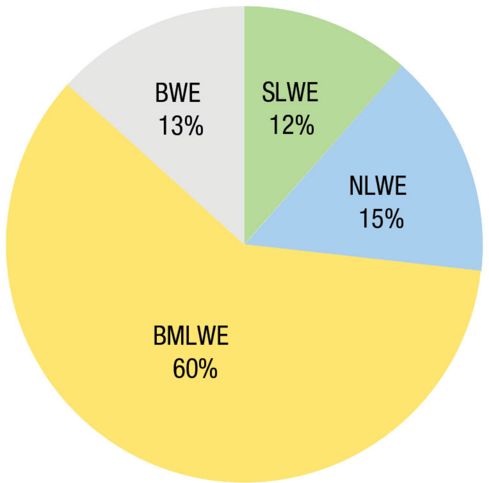


Figure 3-2 Pie chart that shows the distribution of private licensed wells in the different operational areas of the water establishments in Lebanon

Table 3-2 Comparison of the number of illegal wells between Mediterranean countries

COUNTRY	SURFACE AREA (Km^2)	NO. OF ILLEGAL WELLS	NO. ILLEGAL WELLS (Km^2)	ESTIMATION PROCESSES
Lebanon	10,452	54,246 to 59,124	5.6	• Interviews with representatives from local authorities and local municipalities • Interviews with local residents • Interviews with and discussion with local drillers • Pilot area surveys
Cyprus	9,251	50,000*	5.4	-
Spain	505,992	510,000**	1	• Estimation figure from the increase in irrigated land • Estimated figure from local authorities
Italy	301,338	1,500,000*	5	-

4. MONITORING CAMPAIGN

As part of this project, a total of 109 wells were selected as observation wells (based on information available from the public and private wells survey task) for the one-year groundwater monitoring program (between years 2012-2013). Initially the wells were chosen to be in close proximity to wells monitored by the UNDP 1970 study. They were also distributed within most of the GW-basins in Lebanon (Figure 4-1). As specified in this study's terms of reference, only 20 wells were equipped with continuous monitoring devices for the measurement of temperature, conductivity, and depth to groundwater every 15 minutes. Aqua Troll 200 level probes manufactured by In-Situ inc., of Fort Collins, in Colorado, USA were used. These probes are equipped with three (3) sensors (temperature, pressure, and water conductivity) and a built-in data logger. The probes were also equipped with a telemetry unit manufactured by ANT-Group, of Garvado, Italy, and conceptualized by ELARD. This allowed for the data to be directly transmitted to UNDP personnel and the database at the MoEW.

The remaining 89 wells were designated for monthly measurements using hand-held pH meters on the third week of each month for the same parameters as those of the continuous monitoring wells.

Once received, the data was checked for quality and purged for any inconsistency and anomaly that could have resulted from unusual and unpredictable factors. The UNDP project staff has continued with the retrieval of data from the continuous monitoring probes in the 20 wells that were part of the one-year monitoring program. The collected data, even though over a brief period, allowed comparison between water levels of the years 2012/2013 (a normal rainfall year) and 2013/2014 (a dry year). This only stresses the need for a national dedicated groundwater monitoring network that would help significantly in the management of the groundwater resources and record the effects of climate and exploitation on the groundwater levels. Table 4-13-3 illustrates how the dry year resulted in a drop in groundwater levels in most areas to varying degrees, combined with a rise in Total Dissolved Solids (TDS) in coastal areas.

Table 4.1 Comparison of collected data between water levels of the years 2012/2013 and 2013/2014

WELL AREA		END OF APRIL 2013		END OF APRIL 2014		CHANGE	
		DEPTH TO WATER LEVEL (m)	TDS (ppm)	DEPTH TO WATER LEVEL (m)	TDS (ppm)	DEPTH TO WATER LEVEL (m)	TDS (ppm)
Zahle, Central Bekaa		15.78	359	27.43	340	-11.65	-19
Labweh, North Bekaa		114.5	260	121.6	261	-7.1	1
Behsas, Tripoli		31.3	446	51.3	453	-20	9
Nabaa El Tasse, Habouche		5.7	263	11.1	272	-5.4	9
Hazmieh	Beirut	31.9	2705	36.6	5974	-4.7	3269
Damour	South Of Beirut	85.1	608	85.1	630	-0.5	22
Mechref	South Of Beirut	131.7	980	139.3	2270	-7.6	1290
Hariri	Saida	11.9	452	17.2	431	-5.3	-21

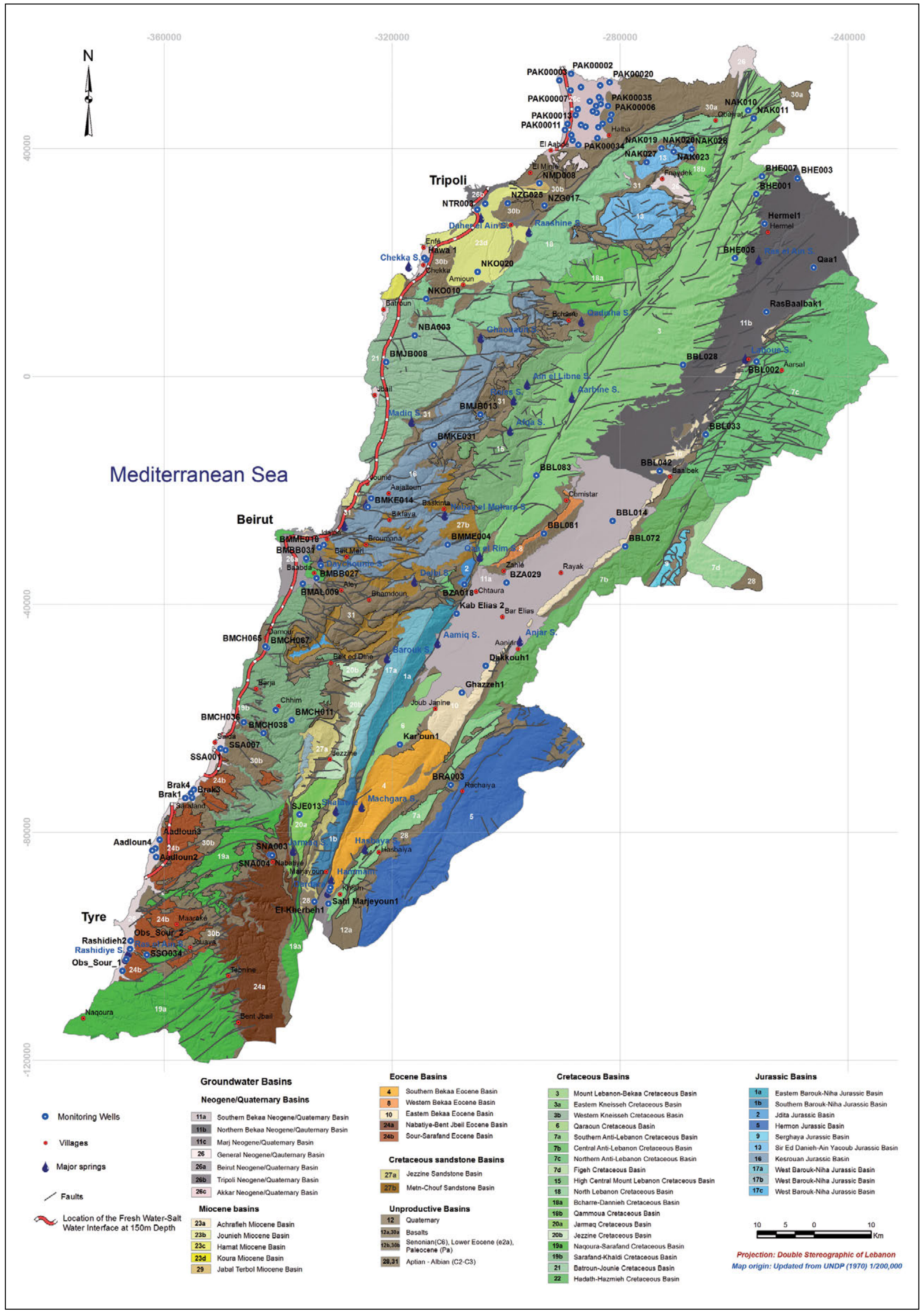


Figure 4-1 Map showing the distribution of wells that were monitored

5. DATABASE CONSTRUCTION

A professional and efficient groundwater resource management GW-Base software was used for building, managing and storing the comprehensive database at the MoEW. The software has been developed by Ribeka of Germany. A total of 22,945 stations of various types were loaded into the main 'GW Assessment Lebanon' Project in GW-Base. Seven (sub-projects were created within this project. The sub-projects are:

- *Public wells (841 Stations)*
- *Private Licensed Wells (20,529 Stations)*
- *Private Unlicensed Wells (809 Stations) (from the pilot areas)*
- *Private Wells (Monitored Unlicensed) (49 Stations, used in manual monitoring)*
- *Automated monitoring (20 Stations, used in automated monitoring)*
- *River Gauges (121 Stations)*
- *Springs (490 Stations)*
- *Meteorological Stations (106 Stations)*

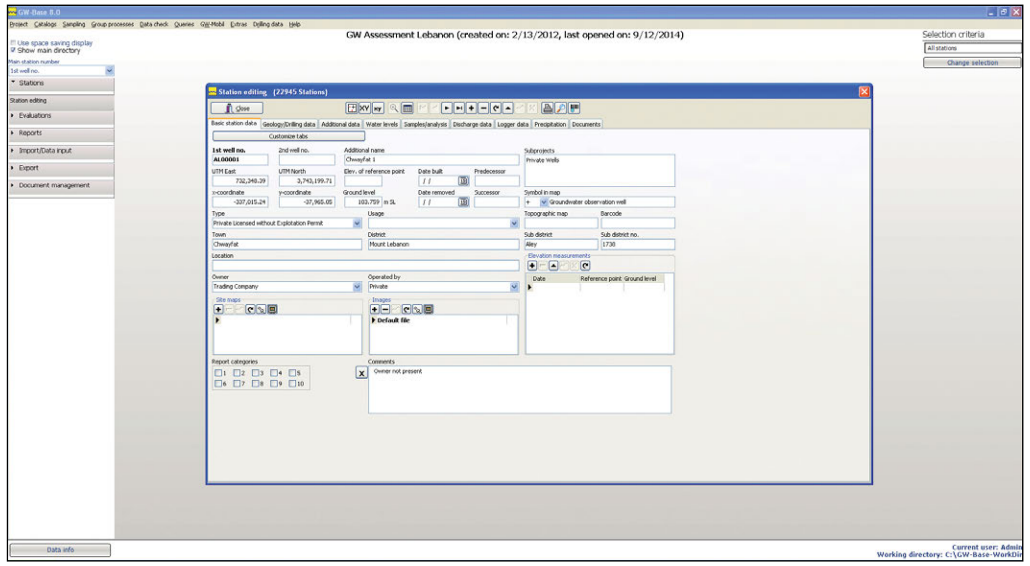
An Arabic interface of the GW-Base Solution was loaded and activated. One can easily switch between interface languages by selecting the desired language. Snap-shots of the Software interface are provided in Figure 5-1 and Figure 5-2.

In addition to the above, a geo-database, including multiple thematic maps, were constructed in GIS. Accordingly, the GIS database was built using ArcGIS 9.3 geo-database in 8-feature datasets, a standalone feature classes, raster data, three (3) object classes and relationships between feature and object classes. The main feature datasets are administrative, geology, hydrogeology, hydrology, karst and soil. The stand-alone feature class is the land cover/use and objects classes, which are tables covering information of the daily and monthly discharge records of the streams, as well as related studies that were gathered for each spring. The raster data were the DEM and the related geological cross-section. All data stored in GW-base can be viewed and combined with any of the above-mentioned maps using the GW-ARC extension.

It is believed that the database is a first of its kind in terms of data variety, size, integration, quality and comprehensiveness in Lebanon. The database will serve as a strong tool for future projects at the MoEW, as well as for improving the management of the water sector.

It is therefore highly recommended to maintain and keep updating the database by loading data gathered at the various stations from subsequent projects. Future assessment projects can make use of the timely completed database.

Figure 5-1 Snapshot from GW-Base of the public wells (with locations and Information), overlaid on 1:50,000 topographic maps



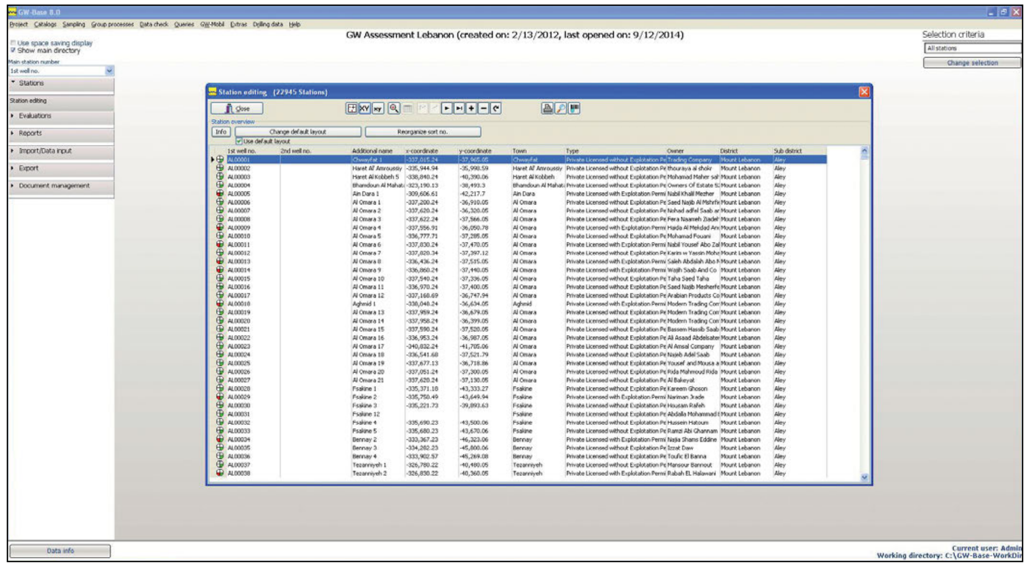


Figure 5-2 Snapshot from GW-Base showing the station data and editing windows

6. HYDROGEOLOGICAL ASSESSMENT

6.1 GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The geological history of Lebanon had a major role in shaping the country's main geomorphological fabric. Appendix 1 in Deliverable 9 provides details on the geological history, hydrogeological setting and the main structural features that make up the geology of Lebanon. Various tectonic events of uplift, collision and changes in sea level were main factors in determining the structural features and depositional environments.

Two (2) major tectonic events are documented in the geological history of Lebanon. The first event is the uplift in the late Jurassic to early Cretaceous Eras, which led to the exposure, erosion and karstification of the Jurassic Limestone. The second event is the closure of the Tethyan Sea in the early Tertiary Period forming a collision zone, which has led to the first gentle uplift of Mount Lebanon and Anti-Lebanon Ranges. These events were separated by times of rise in sea level, which has caused

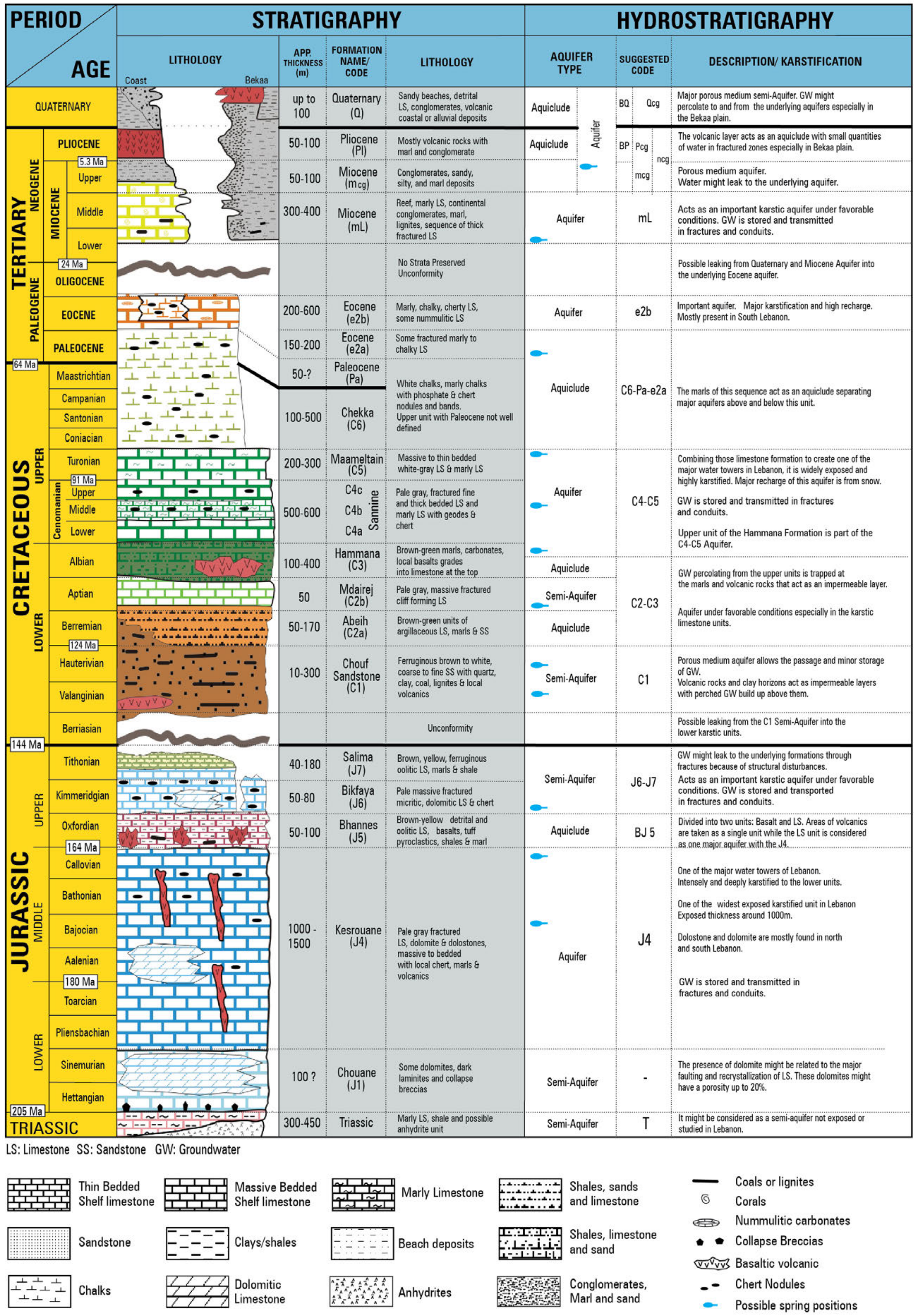


Figure 6-1 Simplified stratigraphy and hydrostratigraphy of Lebanon, (adapted from Walley (1995) and Abbud and Aker (1986))

the deposition of thick limestone units mainly in the early Jurassic, late Jurassic and middle Cretaceous periods. The early Cretaceous period was characterized by the delta river deposits that were mainly sands and clay and that reach a thickness of 300 m in central Lebanon.

A major regional event also took place at the end of the Miocene epoch known as the Messinian Salinity Crisis where a major drop in sea level, by about 1000 m, occurred due to the closer of the Mediterranean Sea. This event led to the deposition of thick salt layers and had a major impact on the development of karstification.

Moreover, the collision of the Arabian and Asian plates, during the Eocene and Oligocene epoch, led to the shaping the NNE-SSW trending features.

The stratigraphic formations, for the purpose of this study, were grouped according to their hydrostratigraphic classification and are divided into three (3) main groups: Aquifers, Semi-Aquifers and Aquicludes. The two (2) main aquifers are the Kesrouane Jurassic (J4) and the Sannine-Maameltain (C4-C5) which are lithologically composed mainly of karstic limestone. They are the two (2) water towers (Chateau-D'eau) of Lebanon and cover about 5590 km2, which is about 54% of the country surface area.

The main structural features are shaped by the major tectonic events that are recorded in the geological history of Lebanon. These structures have an impact on controlling the groundwater flow directions; they can serve either as a preferential pathway or as a flow-restricting boundary. They are divided into primary and secondary structures. The Primary structures are divided into: 1) primary faults (Yammouneh, Rashaya, Hasbaya, Roum and Serghaya) 2) primary folds (North Mount Lebanon Anticline, Barouk-Niha Anticline, Bekaa Syncline/garben, North Anti-Lebanon Anticline and Mount Hermon Anticline) and 3) platforms (Akkar, Tyr and Saida-Damour). The secondary structures are divided in to secondary faults, which are trending in a NW-SE, NE-SW, ENE-WSW and E-W and secondary folds, mainly trending in a NNE-SSW direction parallel to the primary faults.

6.2 GROUNDWATER BASINS BOUNDARIES & GEOLOGY

In the UNDP 1970 study, 32 groundwater basins were identified and divided into two (2) main hydrogeological provinces: the Mediterranean Province and the Interior Province (Figure 6-4). The dividing line between the provinces was the topographic high points of the summits of Mount Lebanon and Barouk-Niha ranges.

A three-step methodology was adopted for redefining the GW-basin boundaries: the first and second steps consisted of digitizing the UNDP 1970 hydrogeological map and refining the aquifer boundaries according to the 1:50,000 geological maps respectively. The third step involved redefining some of the GW-basins identified in the 1970 study, and revisiting/shifting of some aquifer boundaries based on recent geological, hydrogeological information gathered during the project and on topographical highs when no other reliable method could be applied. The details of the re-evaluation of the groundwater basin can be found in Appendix 2 of Deliverable 9.

Based on the re-evaluation of GW-basins, 51 GW-basins were identified of which 28 productive basins and three (3) unproductive basins are located in the Mediterranean Province, and 16 productive basins and three (3) unproductive basins are in the Interior Province. An updated map showing the various GW-basins was generated (Figure 6-5 and Figure 6-6)).

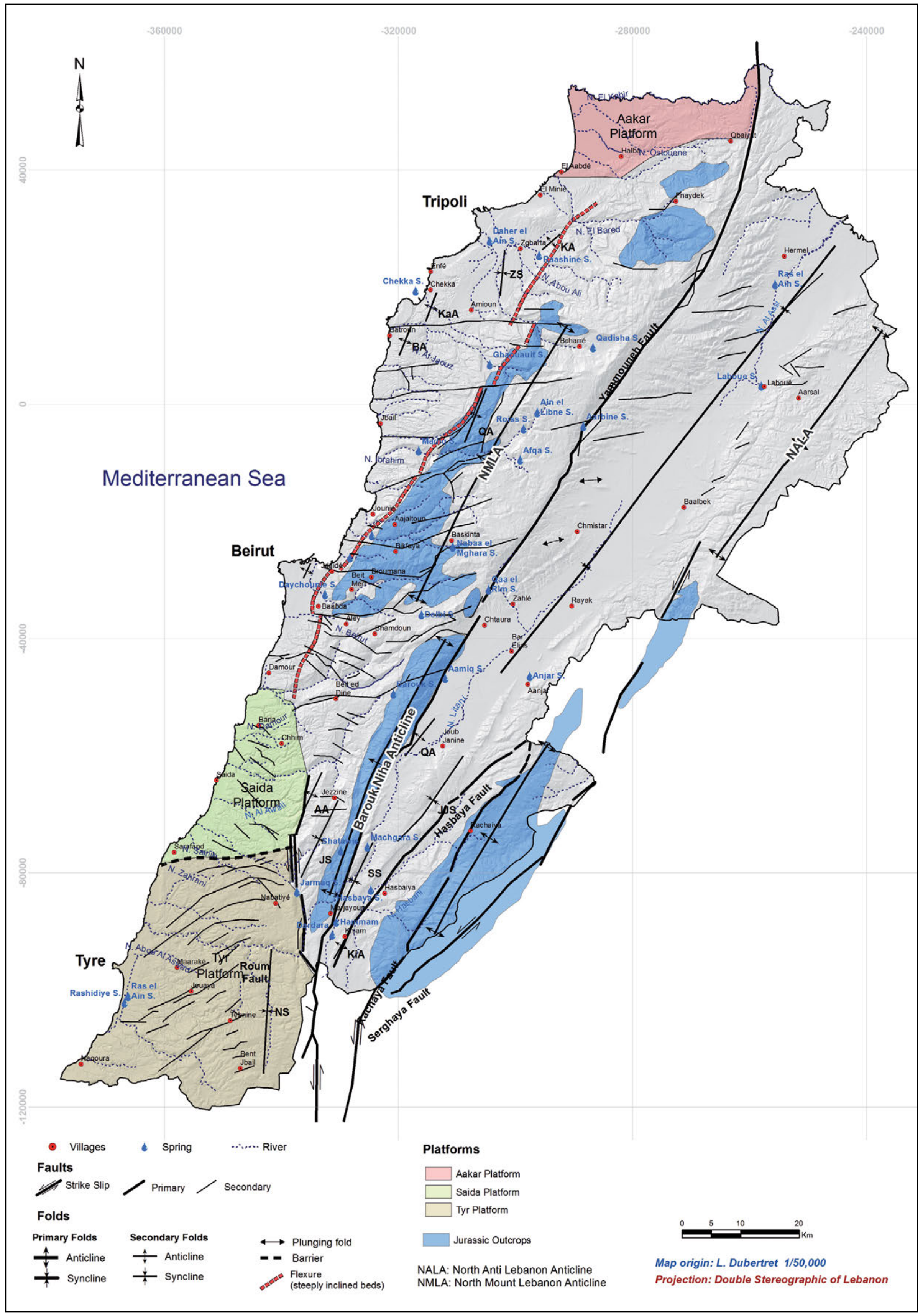


Figure 6-2 Major geological structural features of Lebanon

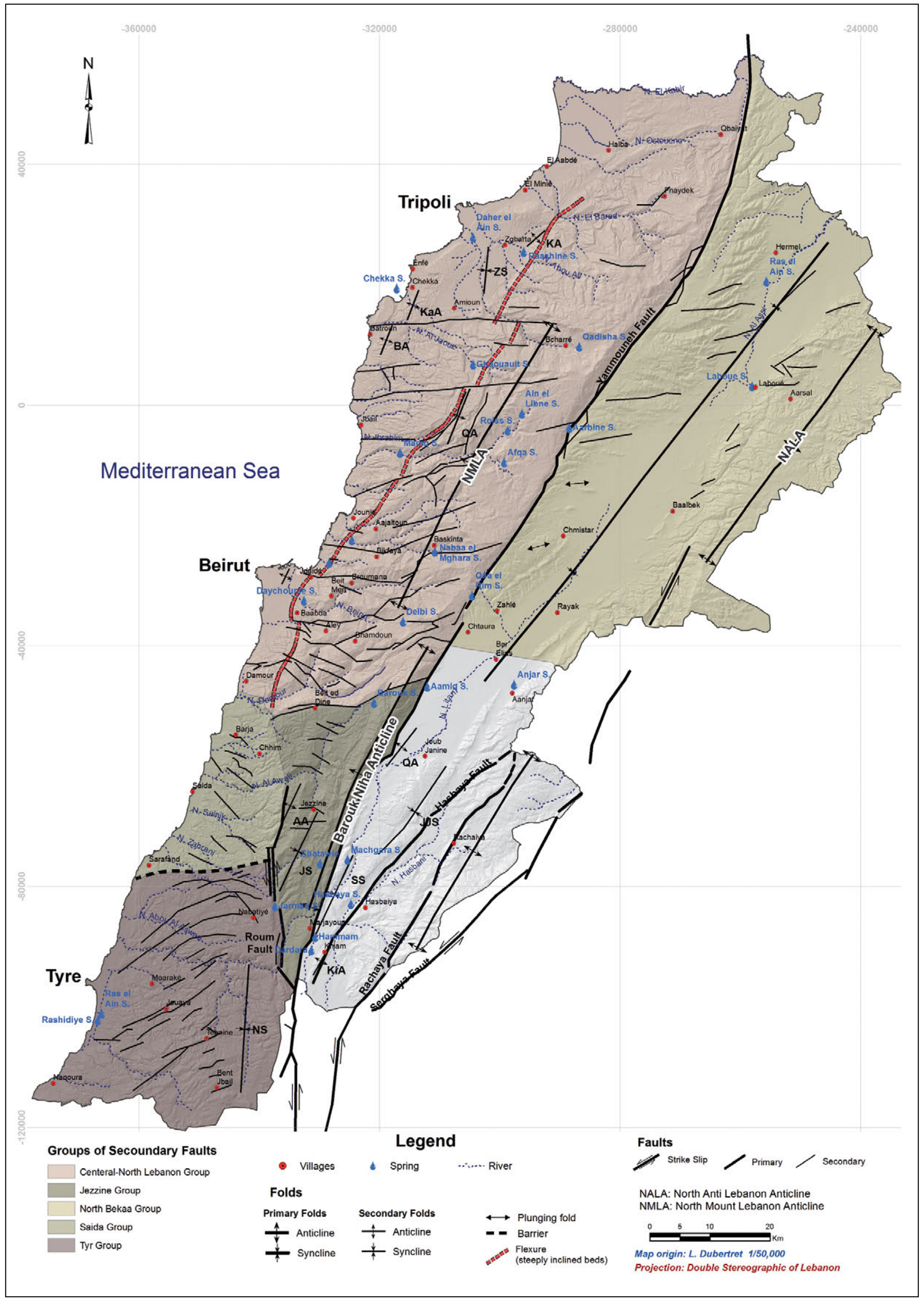


Figure 6-3 Groups of secondary faults of Lebanon

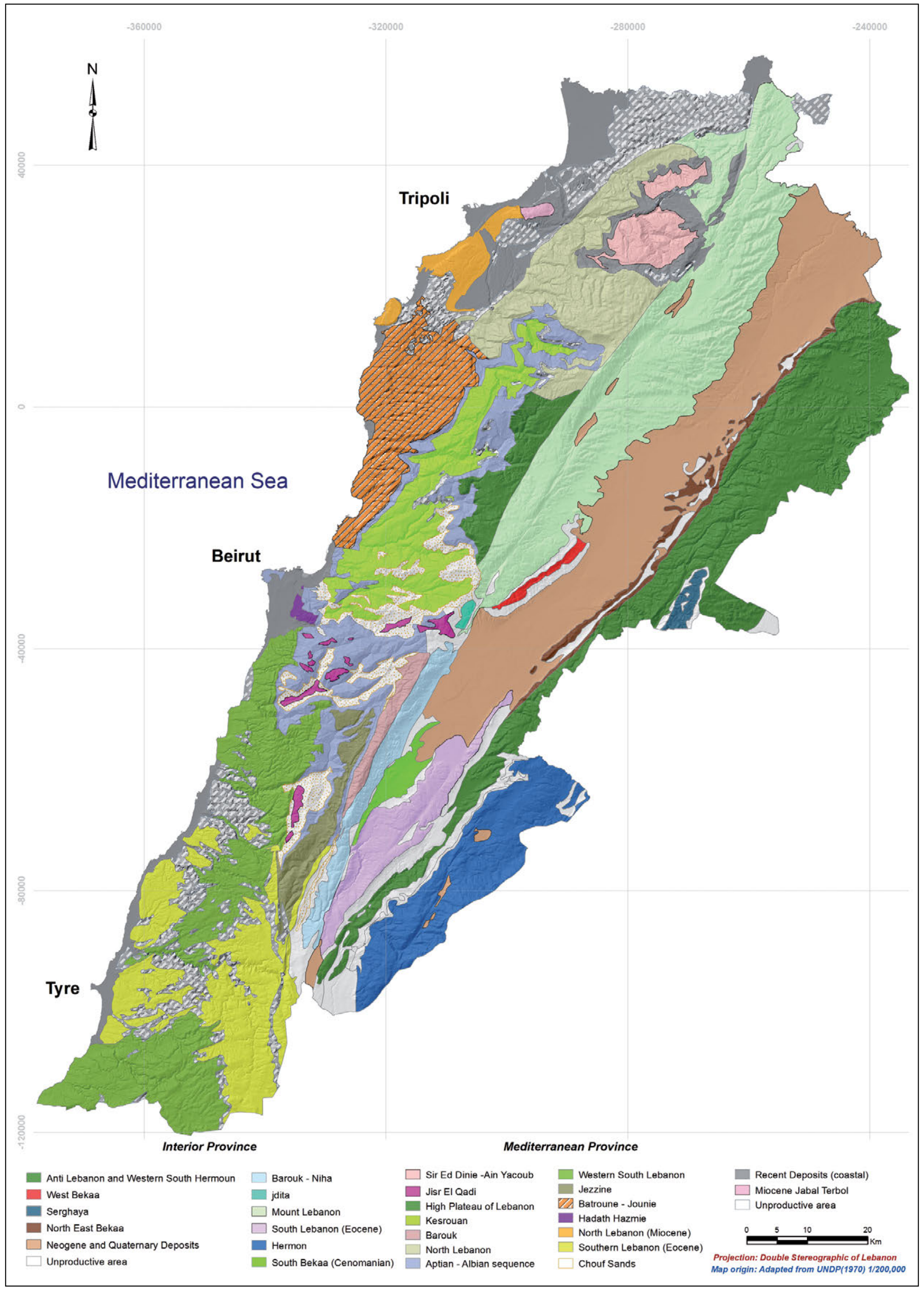


Figure 6-4 Groundwater basin map of Lebanon, as presented by the UNDP (1970)

6.3 KARST

About 65 % of the surface of Lebanon is covered with carbonates karstic formations. The identification, characterization and assessment of the various karstic features are important components of the overall assessment of the groundwater resources of the country. Karstic features tend to constitute preferential pathways for groundwater flow. A first of its kind karstic map of Lebanon was developed as part of this study. Four (4) types of karstic areas were defined, based on the intensity of karstification, and the types of prevailing karstic features, such as doline, lapiaz, polji, sinking stream, and cave. These are High Karst Exposure (HKE), Moderate Karst Exposure (MKE), Restricted Karst Exposure (RKE) and finally the Covered Karst (CK (Refer to Table 6-1 and Figure 6-7)).

The development of karst and depth of karstification were also studied and linked to the various uplift events that are documented in the stratigraphic column of Lebanon, the volcanic activities, the Messinian Salinity Crisis (MSC) with the drop of sea level and to the glacial-interglacial periods during the Pleistocene. These events and the drop of sea level might have led to the deeper incision of the water channels and developed the karstification to about 1000m below the present coast line. Another proof of the deep karstification in Lebanon is the submarine springs that have vents at 40m below sea level in Chekka area. A description of the types, density and distribution of karstification in the various groundwater basins of the major Karstic is provided in Appendix 3 of Deliverable 9.

Table 6-1 Types of karst and their distribution according to GW-basins

TYPE OF KARST AREA MAJOR KARSTIC FEATURE	DEFINITION OF KARST TYPE	GW-BASIN	EFFECT ON SURFACE WATER AND GW-BASIN
Area 1 - High Karst Exposure (HKE) *(Doline (D), Lapies (L), Poljie (P), cockpit (C), Natural bridges, DLC (combination))* *DLCJ-Jurassic (J4)* *DLCC-Cretaceous (C4-C5)* *DJ- Jurassic (J4)* *DC- Cretaceous (C4-C5)* *LJ- Jurassic (J4)* *LC- Cretaceous (C4-C5)*	• Karstified formation • Karst well developed visible and easily identified. • High infiltration rate with isolated drainages	Basin 1a, 3, 17a ,17c, 15, 16, 18, 21	• High infiltration rate • High groundwater flow velocity • No major surface runoff • Sinking streams
Area 2 - Moderate Karst Exposure (MKE) *MKEJ-Jurassic (J4)* *MKEC-Cretaceous (C4-C5)* *MKEE-Eocene (e2b)* *MKEM-Miocene (ml)*	• Karstified formation. • Karst well developed but not easily identified. • Relatively high diffused infiltration.	Basin 1, 3, 4, 5, 7a,b,c,d, 9, 10, 13, 16, 18, 19a, 20a, 21, 26a,b,c and unproductive areas	• Relatively high infiltration rate • Groundwater flow present • Normal surface runoff with diffused losses
Area 3 - Restricted Karst Exposure (RKE) *RKEJ- Jurassic (J5-J7)* *RKEC- Cretaceous (C2-3)*	• Non karstic formation • Relatively thin Limestone units • Karst restricted to thin Limestone units • Karst might be well developed	Basin 19a, 28, 30b, 31	• No major effect on the infiltration rate unless passing over those karstic units • Groundwater might be present • No major loss from surface runoff unless drainage passing over karstic units
Area 4 - Covered Karst (CK) *CKQN by Recent deposit (Q and mcg)* *CKB by Basalt (p)* *CKCS (Cretaceous Sandstone C1)* *CKCE (C6-e2a)*	• Karstified formations that is covered either by other formations such as recent deposits, basalt, sand, and marls.	Distributed over small part in all the GW-basins. Basins 11a, b, 26a b, c, 30a, 27a & b	• Interaction between the permeable top layers and the underlying

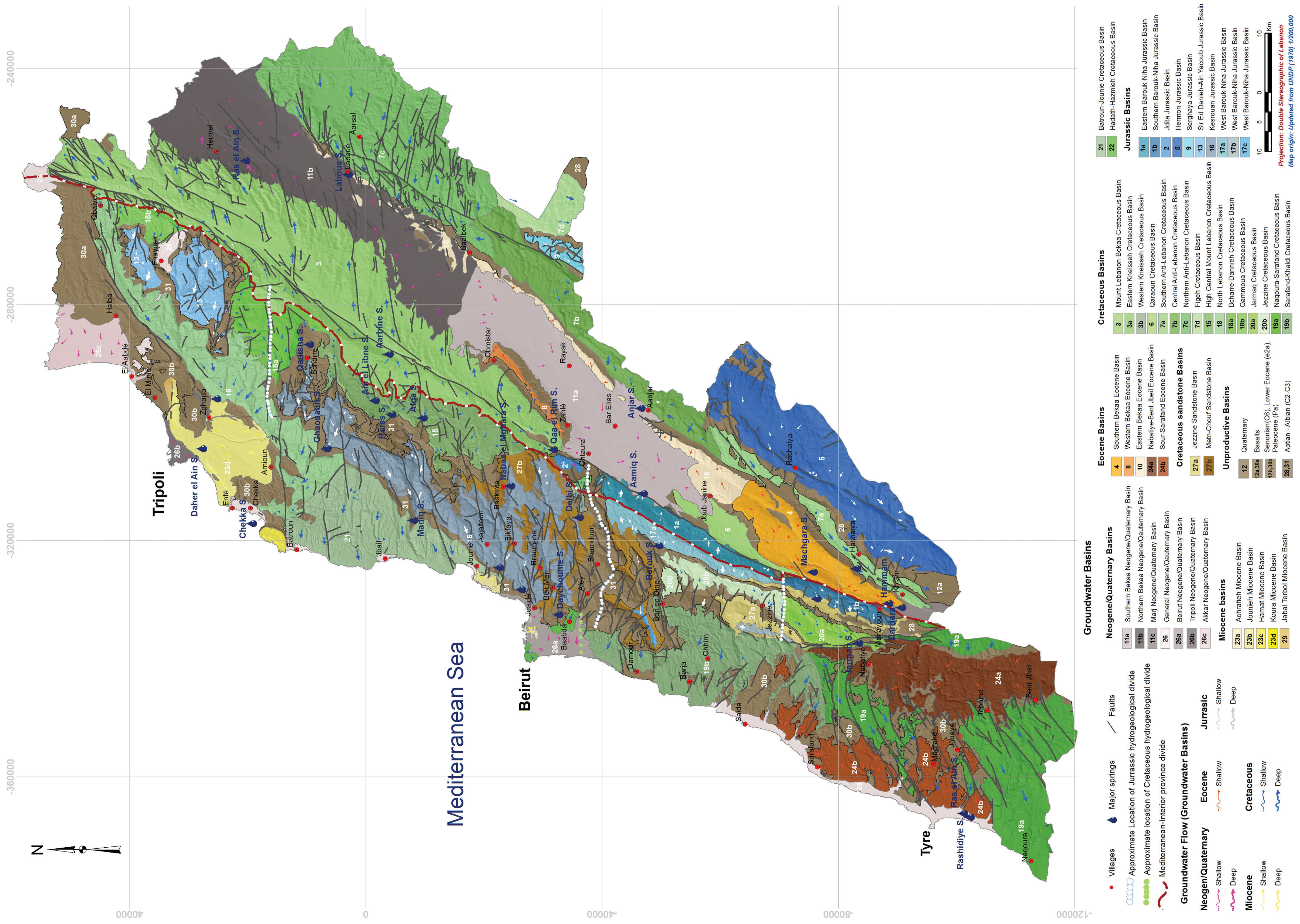


Figure 6-5 Map showing the modified GW-basin

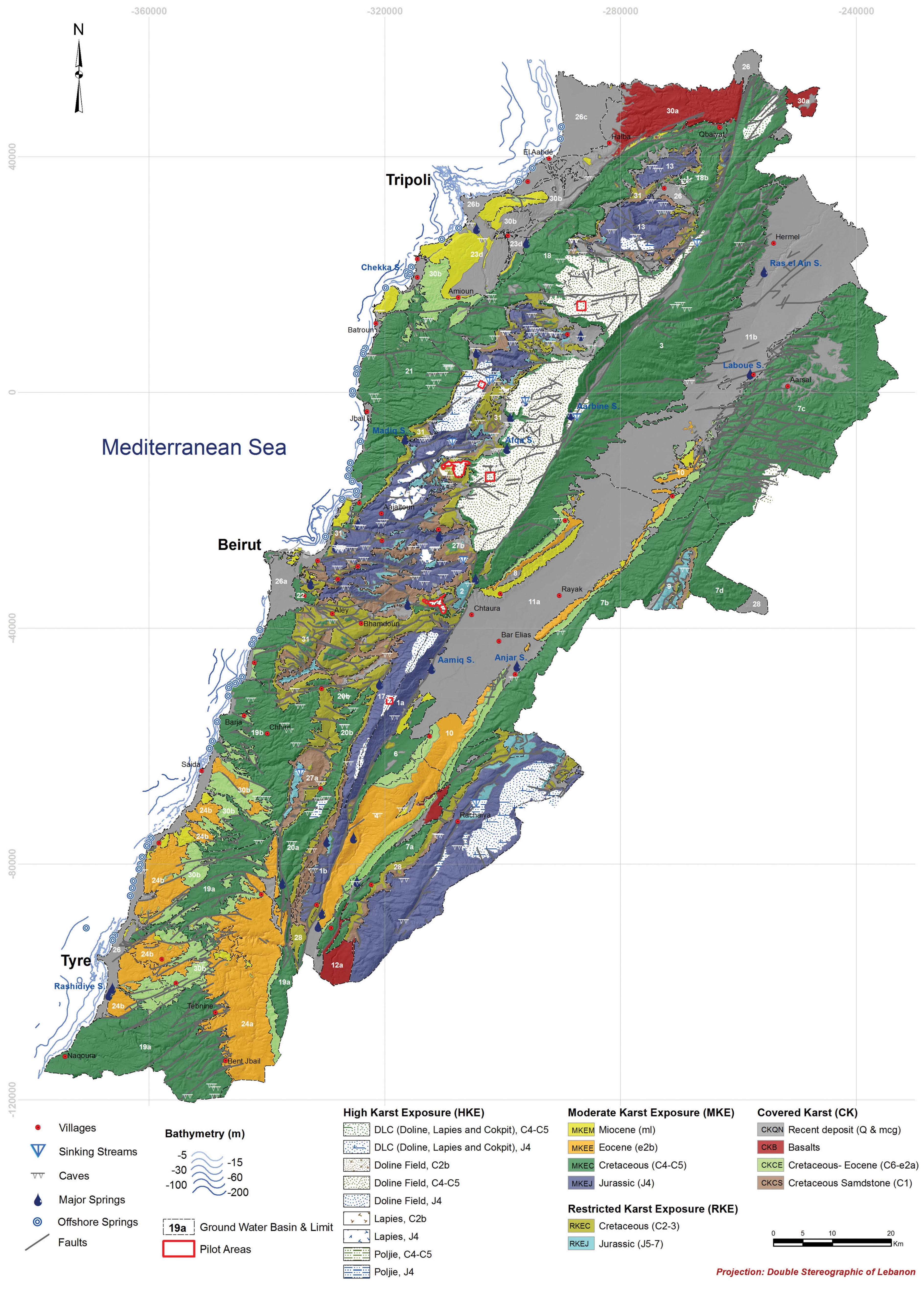


Figure 6-7 Karstic map of Lebanon

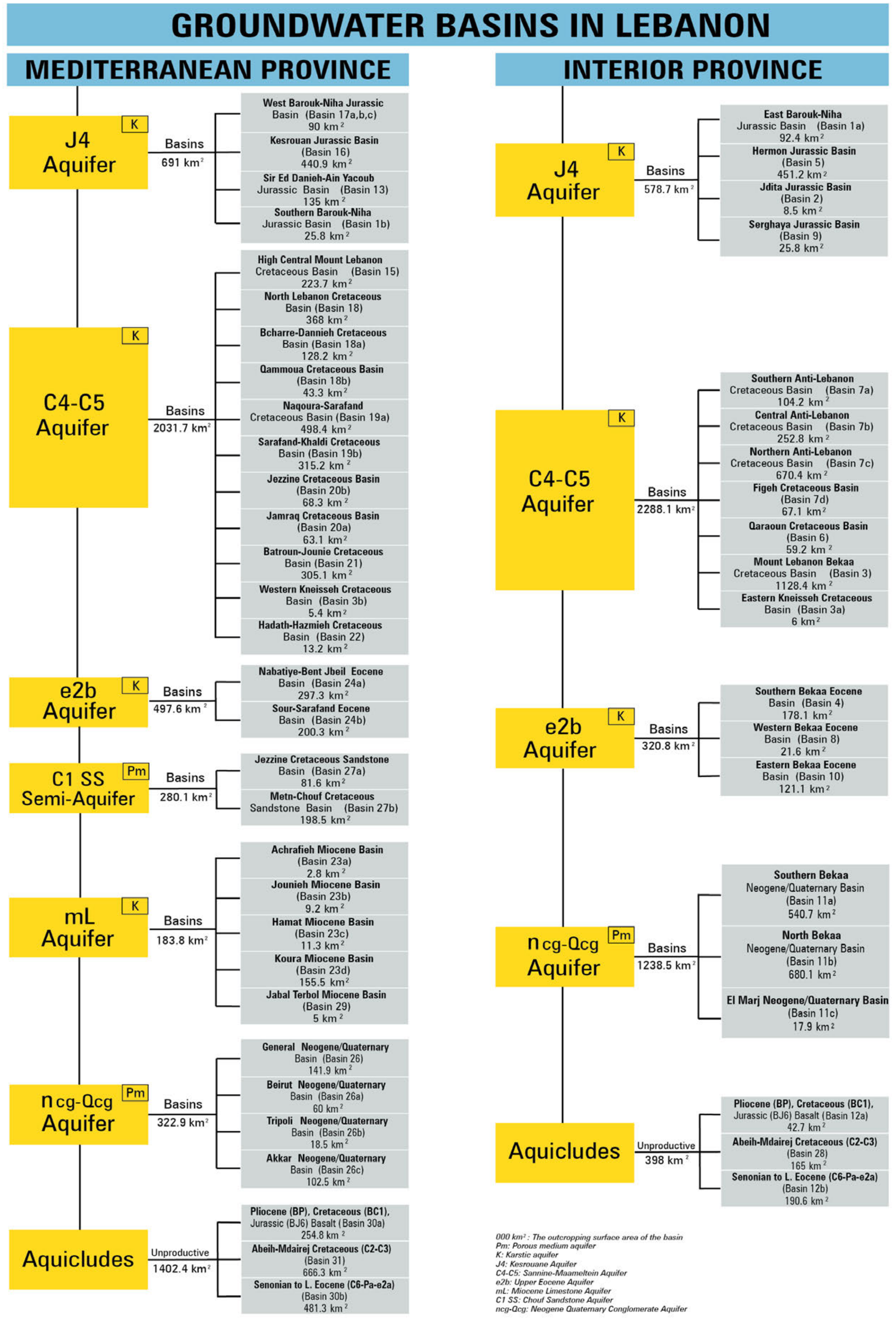


Figure 6-6 Distribution of the GW-basins and unproductive zones in Lebanon

6.4 SPRINGS ASSESSMENT

The spring characterization (Appendix 5 of Deliverable 9) of the various GW-basins is an essential component of the overall assessment of the groundwater resources of the country. 5,050 springs were depicted from the available topographic maps (refer to Figure 6-8). About 409 springs distributed over most of the GW-basins were identified as having some reliable discharge flow data. Only nine (9) springs are being monitored on a regular basis.

The spring assessment was based on categorizing and classifying springs into types (based on emergence mechanism) and classes (based on discharge flow rates) as well as on analyzing hydrographs of springs with continuous data.

About 81 springs were categorized into nine (9) types of springs, developed specifically in this study. Each type is characterized by its specific emergence mechanism which includes a combination of spring hydrodynamic characteristics (i.e. Drainage flow, overflow, artesian, or a combination of two (2) of these flow types) and geological controlling features (i.e. Structural and stratigraphic control/barriers). The categorization of these 81 springs into types is provided in Plate 2 at the end of this report.

The classification of 409 springs with relatively reliable data was based on Meinzer (1923) which categorizes springs according to their discharge magnitude (refer to Table 6-2). The minimum average discharge rates of the springs were used for the classification of the springs of Lebanon. Only five (5) springs were found to belong to class 2, which is characterized by a discharge rate ranging between 1 to 10 m^3/s. 57 springs belong to class 3 with a discharge rate ranging 0.1 to 1 m^3/s, and on 101 springs belongs to class 4 of discharge flow ranging between 10 to 100 l/s. The remaining springs have discharge rates less than 10 l/s, out of which 107 springs belong to class 5 with a discharge rate ranging from 1 to 10 l/s. The majority of the springs of class 5 and below are found in the major aquifers of karstic nature.

For the hydro-graph analysis the method used to analyze the base flow relies on the assessment of the recession behavior representing saturated and non-saturated zones. A total of 45 springs were initially assessed but only 16 springs in nine (9) different GW-basins had reliable data (refer to Table 6-3). The result of these studies showed that all aquifers have similar recession coefficient ranges, which are indicative of the karstic nature of the aquifer. The lower ranges of coefficients obtained in this study are similar to those reported in the UNDP 1970 study. The higher ranges are attributed to the rapid emptying of the aquifer which is mostly due to induced human factors.

6.5 GROUNDWATER LEVEL

A detailed description of the evaluation of the groundwater level in various GW-basins is provided in Appendix 6 of Deliverable 9. The evaluation of the groundwater level trends in Lebanon and in specific GW-basins was made using primarily the data collected during the 1-year monitoring program (2012-2013).

This analysis comprised the generation of hydrographs overlain with rainfall data to assess the response of groundwater levels to rainfall events. Additionally, whenever possible, these groundwater levels were compared to the levels presented in the 1970 study. The purpose of this task was to assess the overall drop in water levels and to estimate the general ground water flow directions in various basins. The assessment has revealed that the groundwater levels in the wells that were continuously monitored showed a relatively rapid response (of hours or even day) to rainfall events with a rapid increase in groundwater levels of two (2) to 12m. This response to rainfall events was mainly attributed to the rapid recharge from precipitation.

Table 6-2 Table showing the number of spring with data in each class (Meinzer Classification) compared with the UNDP 1970 with an example for each spring type

CLASS / DISCHARGE RANGE	NUMBER OF SPRINGS	UNDP 1970 (CLASSIFICATION OF 194 SPRINGS)*	EXAMPLES			
			NAME	AV. MIN. DISCHARGE RATE (m^3/s)	BASIN	TYPE OF SPRING
Second (1-10 m^3/s)	7	12	Chekka Submarine	6	18	8
			Nabaa el Aassi (Ain el Zarka)	5.2	3	6
			Nabaa Jeita	1.55	16	6
			Ain ez Zarq	1.2	4	4
			Nabaa Yammouneh	1.1	3	5
Third (0.1-1 m^3/s)	57	46	Nabaa Fouar Antelias	0.2	16	6
			Nabaa Adonis (Afqa)	0.2	15	1
			Nabaa el Aassal	0.16	15	1
			Nabaa Chtaura	0.15	11a&2	9
			Nabaa el Hasbani	0.227	7a	7
			Nabaa er Roueis	0.144	15	1
Fourth (10-100 l/s)	101	59	Nabaa el Hadid	0.02	16	1
			Nabaa ed Dardara	0.02	4	5
			Nabaa Jezzine	0.05	20b	1
			Nabaa Ebel	0.02	4	-
Fifth (1-10 l/s)	117	62	Nabaa el Madik	0.002	16	6
			Nabaa Safsaf	0.002	3	3
			Nabaa Naas	0.001	27b	1
			Nabaa Kesrouane	0.008	3a	1
			Nabaa Niha	0.002	17a	2
Sixth (0.1-1 l/s)	82	-	Nabaa Sir	$4*10^{-4}$	9	-
			Nabaa Sawkah	$2*10^{-4}$	27b	1
			Nabaa Ouweinat	$5*10^{-4}$	30a	1
			Ain el Aassafir	$2*10^{-4}$	18a	-
			Ain el Kazzabi	$3*10^{-4}$	3	-
Seventh (10-100 cm^3/s)	31	-	Ain el Triq	$6*10^{-5}$	13	-
			Ain Oum Hassane	$5*10^{-5}$	18a	-
			Ain Adde	$3*10^{-5}$	18	-
			Ain el Mehle	$4*10^{-5}$	13	-
			Ain Saader	$2*10^{-5}$	31	-
Eighth (Less than 10 cm^3/s)	14	-	Nabaa Jouaat	0	18a	-
			Ain Hochbai	$6*10^{-6}$	8	9
			Nabaa Sreid	0	5	-
			Nabaa Qatra	0	21	-
			Nabaa el Hammam	$6*10^{-8}$	4	-
Total	409	179				

** About 15 springs from the UNDP 1970 didn't have a range of discharge and could not be classified. These springs were related to the submarine springs or the Temporary karstic or artesian springs.*

Table 6-3 Springs flows and recession coefficients

GWB NO.	GWB	SPRING	NO. YEARS	YEARS (dis-continuous)	AV. RECESSION COEFFICIENT α1(10⁻²)	AV. RECESSION COEFFICIENT α2(10⁻²)		TOTAL FLOW	BASE FLOW	MAX	MIN	UNDP 1970 TOTAL FLOW	UNDP 1970 RECES-SION COEF. (102)
1a	E. Barouk-Niha Jurassic	Ain ed Daiaa	5	[2001…2010]	1.2	0.38	m³/s	0.14		0.21	0.1		
							MCM	4.49	4.32	0.55	0.26		
		Ain et Tannour	5	[2001…2010]	1.1	0.57	m³/s	0.27		0.45	0.16		
							MCM	8.58	5.78	1.17	42		
		Nabaa el Khraizat	6	[1993…2011]	1	0.68	m³/s	0.22		0.37	0.11		0.7
							MCM	6.79	4.05	0.98	0.3	9.45	
11a & 2	S. Bekaa Neogene-Quaternary Basin and Jdita Jurassic Basin	Nabaa Chtaura	6	[1994…2005]	1.3	1	m³/s	0.42		0.81	0.17	14.5	0.57
							MCM	13.19	5.46	2.12	0.45		
16	Kesrouane Jurassic	Nabaa Fouar Antelias	6	[2002…2010]	1.9	1.6	m³/s	2.4		7.69	0.3		1.2
							MCM	75.7	26.04	18.6	0.77		
17a	W. Barouk-Niha Jurassic	Nabaa el Safa (Azzounieh)	2	[2009-2011]	3.3	1.86	m³/s	1.78		7.57	0.39		1
							MCM	56.21	28.04	18.32	1.04	45	
3	Mount Lebanon-Bekaa Cretaceous	Nabaa el Berdaouni	16	[1990…2010]	2.1	1.79	m³/s	1.16		2.77	0.04		0.94
							MCM	36.62	8.49	7.42	0.11	44.5	
7a	S. Anti-Lebanon Cretaceous	Nabaa el Hasbani	5	[2005-2010]	1.5	0.95	m³/s	1.33		4.05	0.38		1.94
							MCM	41.8	21.18	9.81	1	31	
		Nabaa el Wazzani	2	[2008-2010]	3.2	0.64	m³/s	2.55		5.74	1.24		1.5
							MCM	80.56	49.66	15.38	3.32	60	
7b	Central Anti-Lebanon Cretaceous	Ain Aanjar (Ghayzayel Aanjar)	12	[1996-2007]	1.4	0.65	m³/s	1.51		3.12	0.67		0.22
							MCM	47.74	29.24	8.37	1.73	63.5	
		Nabaa Chamsine	10	[2001-2011]	1.7	1	m³/s	0.21		0.3	0.01		0.39
							MCM	6.65	3.02	0.77	0.27	14.7	
		Nabaa Yahfoufa - Ain es sikeh	11	[1998-2009]	2	1.9	m³/s	1.37		3.71	0.35		
							MCM	43.06	9.09	9.94	0.94		
20a	Jarmaq Cretaceous	Nabaa el Maidane	6	[2000…2010]	1.3	0.65	m³/s	0.07		0.18	0.04		
							MCM	2.17	1.37	0.43	0.1	5	
4	S. Bekaa Eocene	Ain ez Zarqa	6	[2000…2011]	0.9	0.63	m³/s	1.98		3.51	0.99		
							MCM	62.43	50.87	9.39	2.66	77	

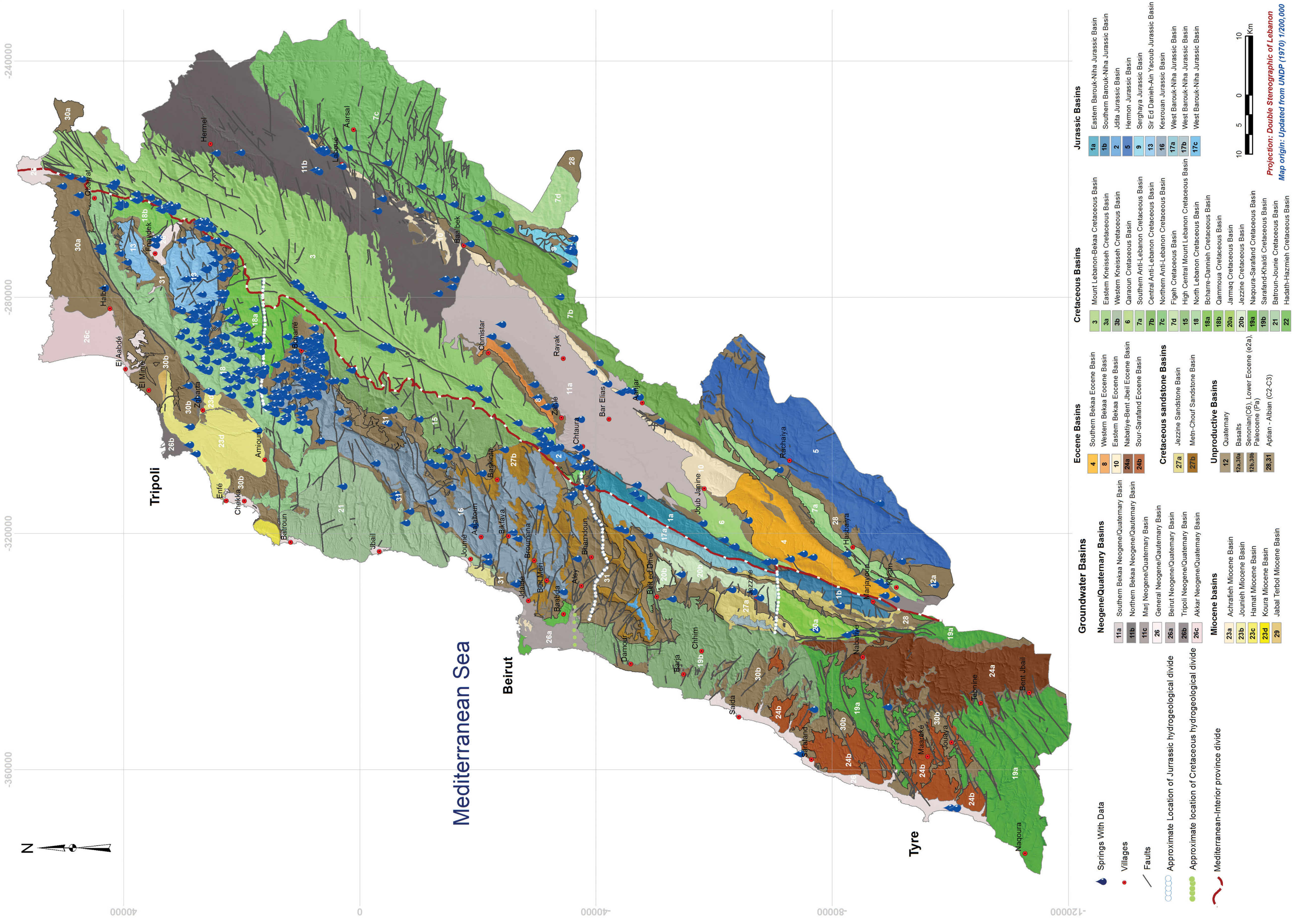


Figure 6-8 Location of springs

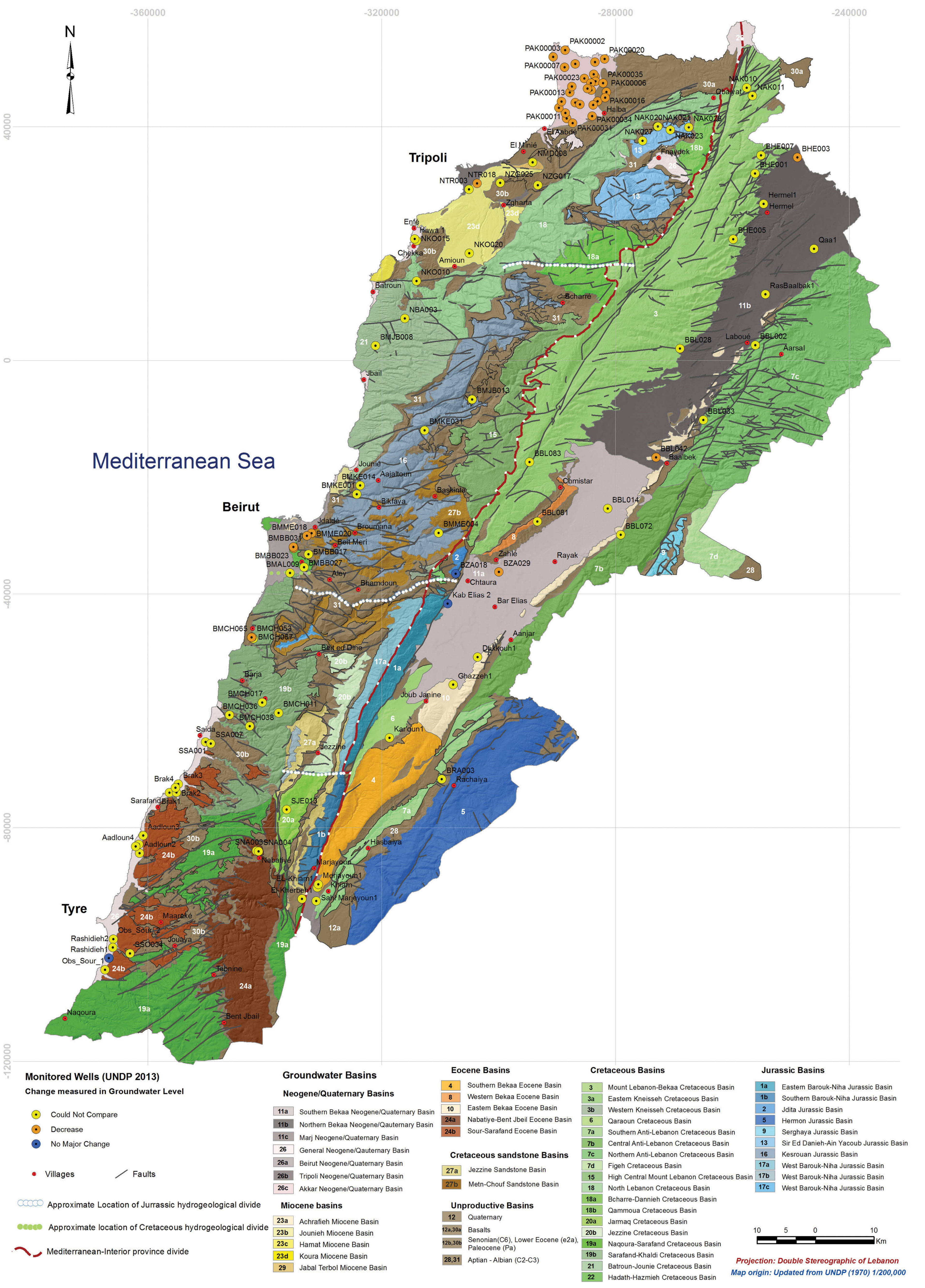


Figure 6-9 Summary map of wells with groundwater level information

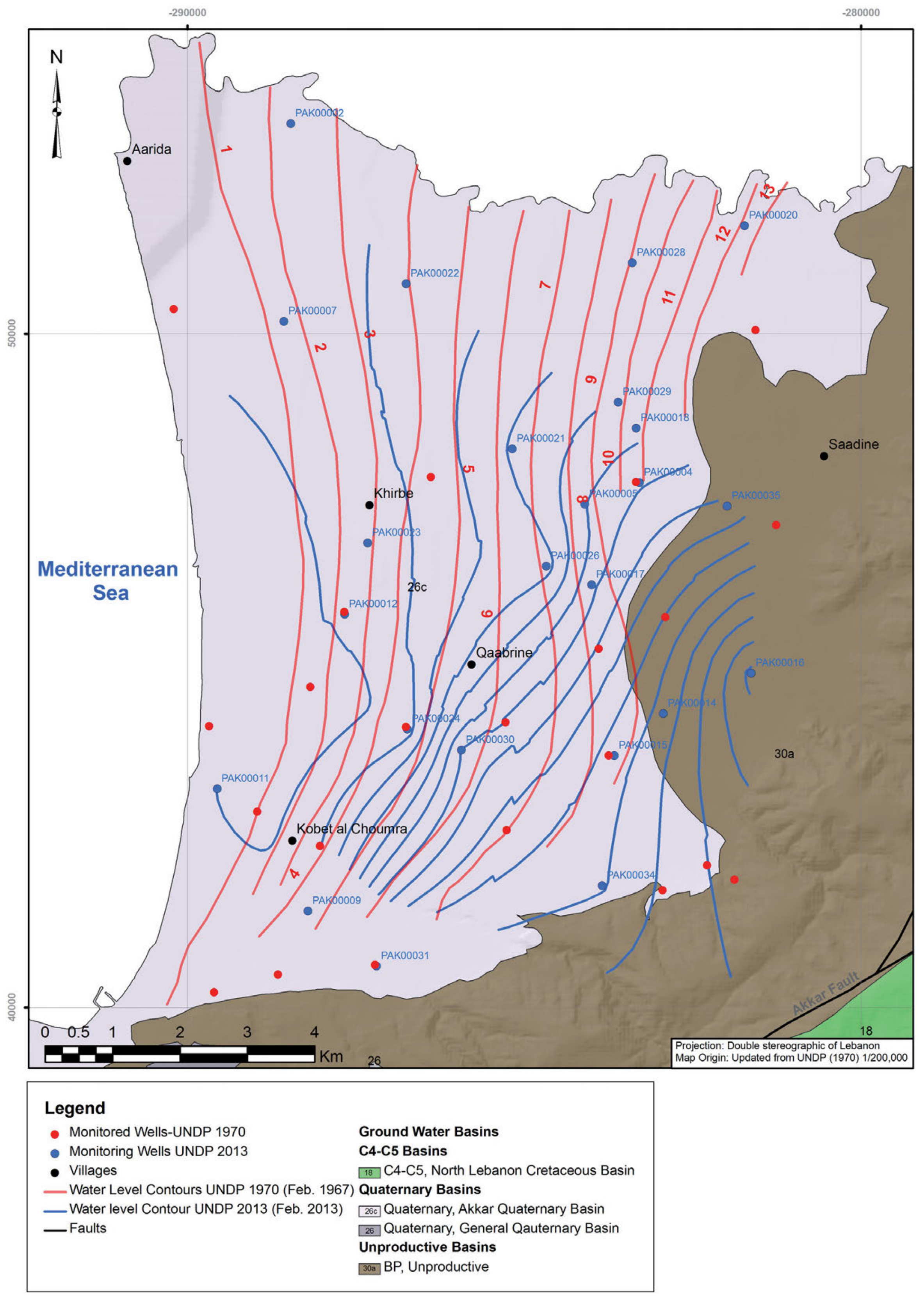


Figure 6-10 Groundwater table contour map for the Akkar Neogene-Quaternary Basin generated from February 2013 data set (blue) compared to February 1967 data sets (in Red), from UNDP 1970

Correlation between groundwater level data from this study and those from the UNDP 1970 study was established in 12 of these basins. The Mediterranean Province and most of the interior GW-basins, which are not in direct contact with the sea, have shown a decrease in groundwater levels which was mainly attributed to the over-exploitation of the aquifers. In Sir ed Dannieh-Ain Yaacoub Basin (Basin 13), the drop was about 27m. The coastal GW-basins showed almost similar groundwater level to those of the UNDP 1970 study because the exploited water is being directly compensated by sea water intrusion. Groundwater table contour map for the Akkar Neogene-Quaternary Basin generated from February 2013 d ata set is compared to February 1967 data sets from UNDP 1970 and data sets from FAO (1970) in Figure 6-10 and Figure 6-11 respectively.

With the exception of one (1) GW-basin, most of the basins that were monitored in the Interior Province showed a significant decrease in groundwater levels (from the 1970 levels) which is also attributed to the over exploitation of the aquifers. A decrease of about 20m was observed in the Litani area in the Southern Bekaa Neogene-Quaternary Basin (Basin 11a) (refer to Figure 6-12). In the Jdita Jurassic Basin (Basin 2), the groundwater levels do not appear to have decreased from the 1970 levels indicating that groundwater in this basin has not been overexploited.

6.6 HYDRO-CHEMICAL CHARACTERIZATION

This section aims at characterizing the hydro-chemistry of the various GW-basins of the country and assessing the conditions of the coastal aquifers with respect to sea water intrusions. For more details, please refer to Appendix 8 of Deliverable 9. Hydro-chemical data that were gathered from various sources such as the water establishments, and previous studies, were processed and assessed. A total of 307 samples were deemed to be reliable, and were retained for the evaluation of the hydro-chemical characteristics of the various GW-basin of the country. Number of samples used for the assessment of the hydrochemical facies of each basin is presented in Table 6-4.

Piper diagrams were generated for various GW-basins. In the Interior provinces, the majority of these basins belonged to the carbonate facies, and more specifically to the Ca-Mg-HCO3 facies, which is typical of the karstic nature of the aquifers of Lebanon and is consistent with the results of the UNDP 1970 study.

The conductivity values tend to increase with the increase in the aquifer retention time. In general, the groundwater conductivity values in karstic aquifers tend to be higher than those in the porous medium aquifers. Also, the closer to the recharge area, the lower the conductivity is. Last but not least, the conductivity values tend to be directly impacted by precipitation. They generally tend to slightly increase immediately after rainfall events. This is a clear indication of the instant recharge caused by rain infiltration and the well-developed karstic nature of most of the aquifers of the country.

In the Mediterranean provinces, two (2) types of facies were identified: 1) The Ca-Mg-HCO_3 facies, which is typical of the karstic nature of the aquifer, are found in the inland basins that are usually not in contact with the sea; and 2) The Na-K-CI-SO_4 facies reflecting the influence of sea water intrusion is dominant in most of the coastal aquifers that are in direct contact with the sea. The salt water encroachment in the GW-basins of these coastal basins is currently much more extensive than what it was in the 1970's. The current location and depth of the fresh water salt water interface is shallower than in 1970 and has shifted further inland.

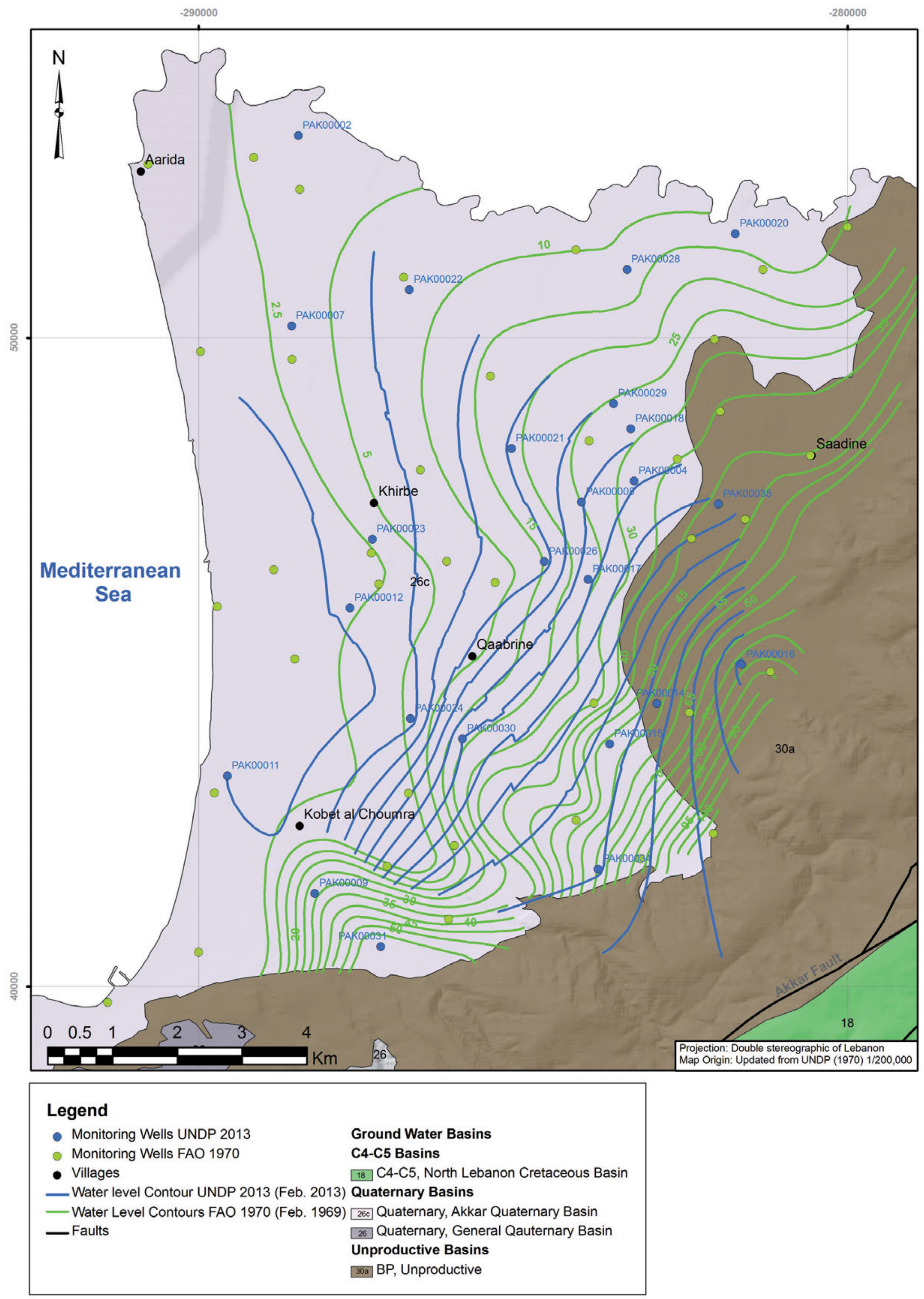


Figure 6-11 Groundwater table contour map in the Akkar Neogene-Quaternary Basin for February 2013 data set (Blue), compared to February 1969 data set (in green) obtained from FAO (1970)

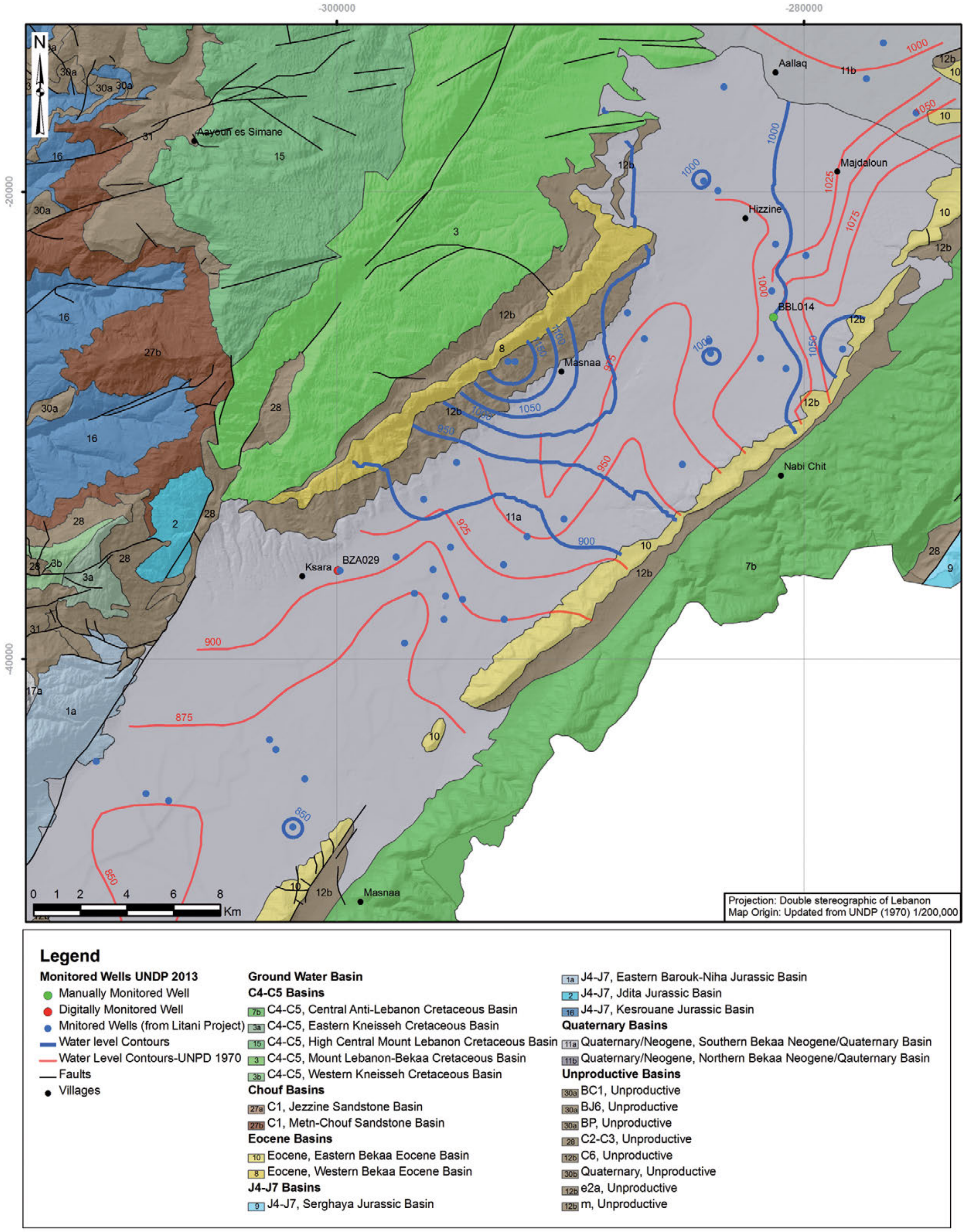


Figure 6-12 Location of the monitored wells from the "Ground Water Modelling in the Upper Litani Basin" with the generated contour lines for November 2010 (in Blue), compared to February 1967 contour lines (in Red), from UNDP 1970

Table 6-4 Table outlining the groundwater basins with the number of samples used for the assessment of the hydrochemical facies of each basin

GW BASIN NO	NO. OF SAMPLES	FACIES FROM PIPER	GW BASIN NO.	NO. OF SAMPLES	FACIES FROM PIPER
INTERIOR PROVINCE					
1a	16	Ca-Mg-HCO_3	2	5	Ca-Mg-HCO_3
1b	1	Ca-Mg-HCO_3	3	36	Ca-Mg-HCO_3
3b	1	Ca-Mg-HCO_3	4	8	Ca-Mg-HCO_3
5	5	Ca-Mg-HCO_3	6	9	Ca-Mg-HCO_3
7a	8	Ca-Mg-HCO_3	7b	17	Ca-Mg-HCO_3
7c	29	Ca-Mg-HCO_3	8	20	Ca-Mg-HCO_3
9	1	Ca-Mg-HCO_3	10	23	Ca-Mg-HCO_3
10-11a	1	Ca-Mg-HCO_3	11a	2	Ca-Mg-HCO_3
11b	3	Ca-Mg-HCO_3	3-11b	2	Ca-Mg-HCO_3
12	1	Ca-Mg-HCO_3			
Mediterranean Province					
15	2	Ca-Mg-HCO_3	16	14	Ca-Mg-HCO_3
17b	1	Ca-Mg-HCO_3	17c	1	Ca-Mg-HCO_3
18	3	Ca-Mg-HCO_3 With shift towards salt water intrusion for SS2 values	19a	6	Ca-Mg-HCO_3
19a-24a	1	Ca-Mg-HCO_3	19a-24b	3	Ca-Mg-HCO_3
19b	23	The scatter deviating towards $Na^+K^+Cl^-SO_4$ facies is a troublesome fact that could indicate seawater intrusion	20a	5	Ca-Mg-HCO_3
20b	6	Ca-Mg-HCO_3	21	10	Most of the samples fall in Ca-Mg-HCO3 facies except for sample GH005 which is of the $Na^+K^+Cl^-SO_4$, a troublesome fact that could indicate seawater intrusion
22	4	Most of the samples fall in Ca-Mg-HCO3 Except for LU001 which is of the $Na^+K^+Cl^-SO_4$, a troublesome fact that could indicate seawater intrusion	23d	16	Most of the samples fall in Ca-Mg-HCO_3 facies except for sample NTR023 taken in winter which is of the $Na^+K^+Cl^-SO_4$, a troublesome fact that could indicate seawater intrusion.
24a	2	Ca-Mg-HCO_3	24b-26a	1	Ca-Mg-HCO_3
26a	1	Ca-Mg-HCO_3	27a	1	Ca-Mg-HCO_3
28	11	Most of the samples fall in Ca-Mg-HCO3 facies except for the sample obtained from GH004 which is of the $Na^+K^+Cl^-SO_4$, a troublesome fact that could indicate seawater intrusion			

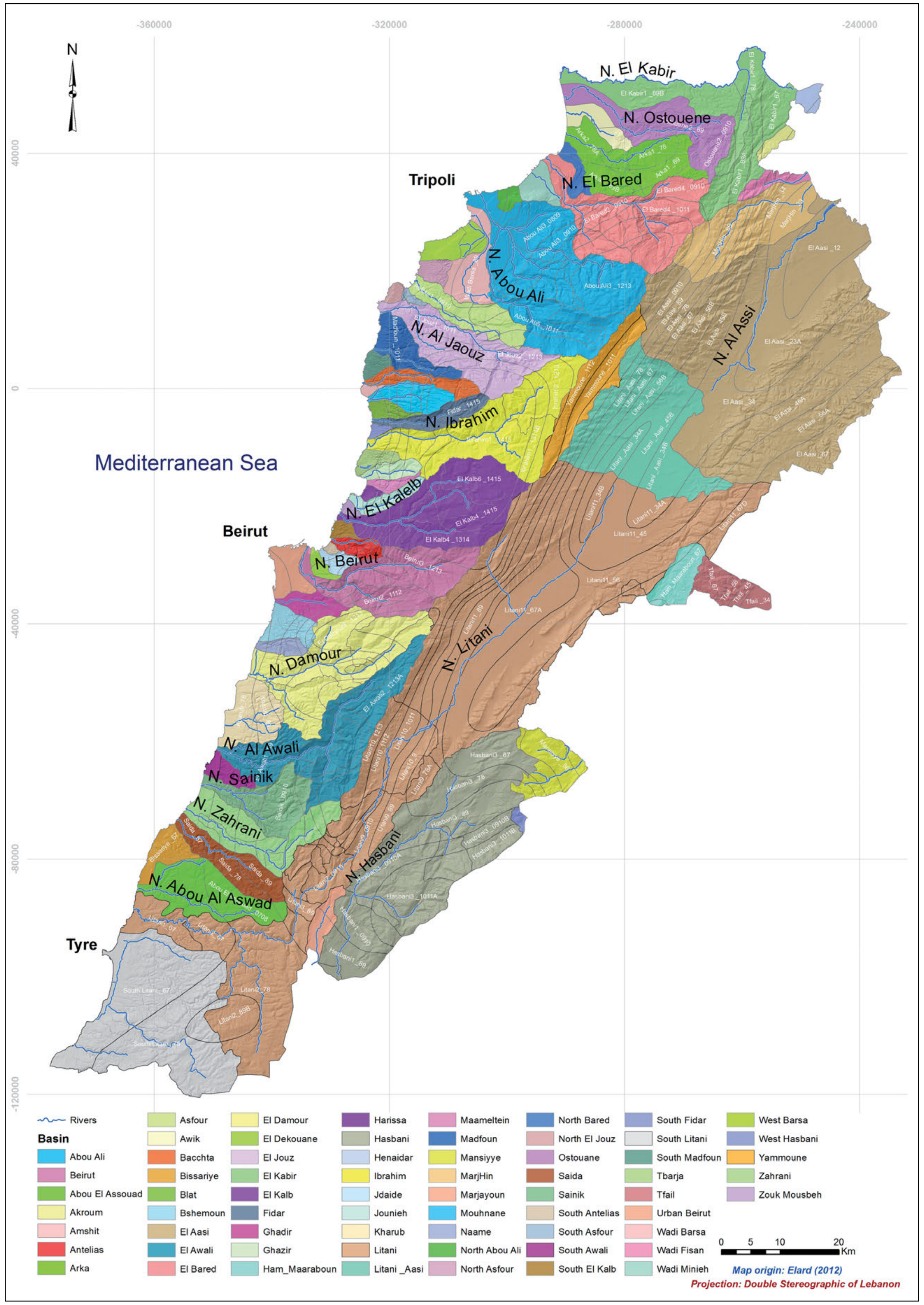


Figure 6-13 Sub-watersheds according to Plassard's (1972) rain map

6.7 HYDROLOGY

The hydrological study (Appendix 9 in Deliverable 9) provides an evaluation of precipitation (rain and snow), evapotranspiration, and runoff for the country to properly assess the natural recharge by infiltration. Surface watersheds were initially considered as the basin unit in the assessment of the different parameters. They were further divided into sub-watersheds according to their location within the rain map of 1972 and to their elevation (Figure 6-13). Results obtained from the analysis performed based on the sub-watersheds were then propagated to the intersecting GW-basins to evaluate the groundwater recharge of each groundwater aquifer basin.

Due to the limited quality and availability of data, only four (4) hydrological cycles (2008 to 2012) were retained for analysis. The data gathered from various stations fairly distributed over the Lebanese territory that were deemed of acceptable quality were used to calculate rain and the evapotranspiration amounts. For these four (4) hydrological cycles, the estimated volume of rain per year ranges between 6,015 and 9,365 MCM (Table 6-5).

Snow water equivalent, which had not been taken into account in the UNDP 1970 study, was evaluated using satellite imagery (MODIS) for the four (4) hydrological cycles (2008 to 2012). The yearly water equivalent volumes of snow water estimated using this technique range between 1,815 and 2567 MCM (Table 6-6).

The maximal estimated total precipitation is the sum of the rainfall and the snow water equivalent averaged on every surface watershed. Figure 6-14 shows the average precipitation values in relation to average snow water equivalent and table 6-7 summarizes the total yearly precipitation values for the retained four (4) hydrological cycles, which vary between 7830 MCM to 11932 MCM. Total yearly average precipitation maps were generated for these (4) four hydrological cycles and are provided in Figure 6-15, Figure 6-16, Figure 6-17 and Figure 6-18.

The yearly volumes of real evapotranspiration (RET) that were estimated for the four (4) hydrological cycles using the Turk method (Turk,1961) vary between 1,563 and 1,475 MCM (Table 6-8).

In the UNDP 1970 study, the hydrogeological budget of spring discharges was lumped with the surface runoff. In the current study, a different approach was adopted; the runoff was calculated using the United States Soil Conservation Service-Curve Number (SCS-CN) method which is recommended for semi-arid areas. The estimated yearly surface runoff for the four (4) hydrological cycles, which does not account for the portion that comes from the discharge of the various springs, varies between 2,151 and 3,807 MCM (table 6-9).

Recharge to groundwater was subsequently calculated as the excess of precipitation over real evapotranspiration and surface runoff. The estimated volumes which includes both deep percolation and retention in the vadose zone for the four (4) hydrological cycles varies vary from 4,116 to 6,651 MCM (Table 6-10), with an average of about 55 % (±2%) of the total precipitation.

Out of the four (4) hydrological cycles, one wet cycle (2011-2012) and one dry cycle (2010-2011), were retained, for detailed analysis, and water budget estimation. For these two (2) years, the four (4) parameters (precipitation, recharge to groundwater, runoff and evapotranspiration) were estimated for the various groundwater basins of the country. Table 6-11 presents the estimated average precipitation, recharge to groundwater, runoff and real evapotranspiration for the entire country.

Table 6-5 Rainfall all over the Lebanese territory from 2008 to 2012

	2008-2009	2009-2010	2010-2011	2011-2012	4 YEARS AVERAGE	STANDARD DEVIATION (σ)
Runoff (MCM)	6978	7268	6015	9365	7407	1222
Runoff (mm)	681	709	587	913	722	119

Table 6-6 Snow water equivalent in MCM estimated from 2008-2009 to 2011-2012

	2008-2009	2009-2010	2010-2011	2011-2012	4 YEARS AVERAGE	STANDARD DEVIATION (σ)
I(MCM)	2497	2300	1815	2567	2295	294
I(mm)	244	224	177	250	224	29

Table 6-7 Total precipitation (rainfall and snow) all over the Lebanese territory from 2008 to 2012

	2008-2009	2009-2010	2010-2011	2011-2012	4 YEARS AVERAGE	STANDARD DEVIATION (σ)
Total Precipitation (MCM)	9476	9568	7830	11932	9702	1462
Total Precipitation (mm)	924	933	764	1164	946	143

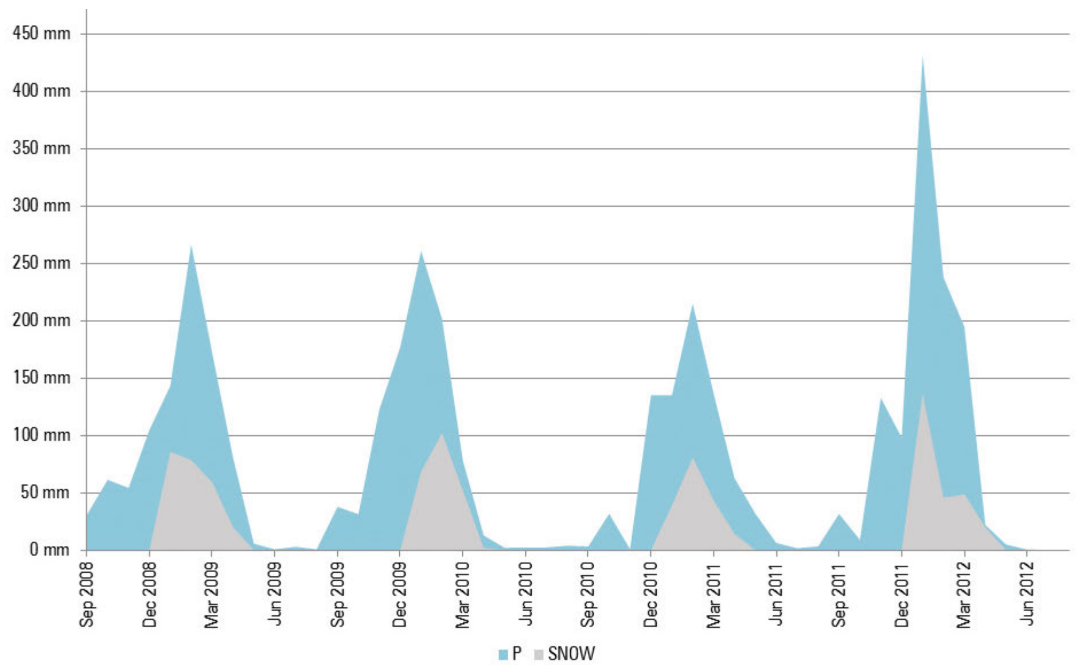


Figure 6-14 Average precipitation values in relation to average snow water equivalent for hydrological cycles 2008 to 2012

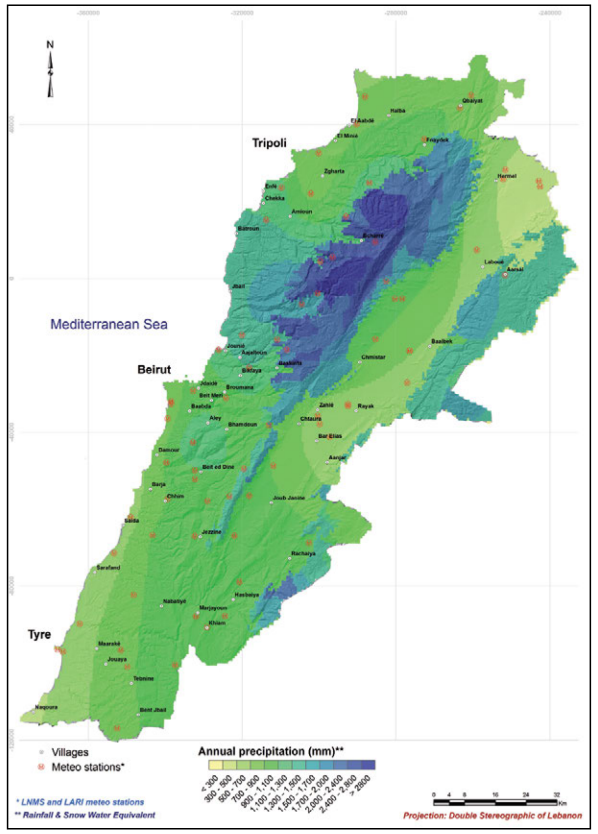


Figure 6-15 Annual precipitation 2008-2009

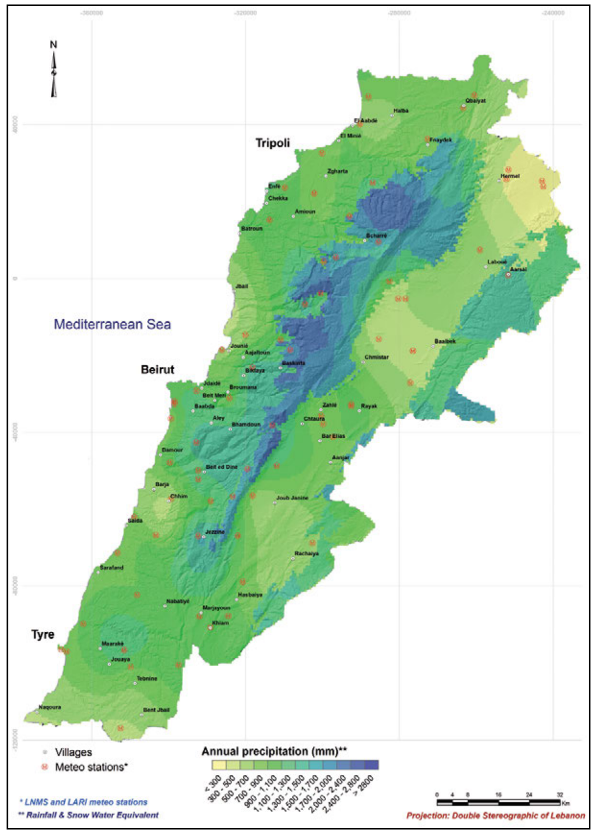


Figure 6-16 Annual precipitation 2009-2010

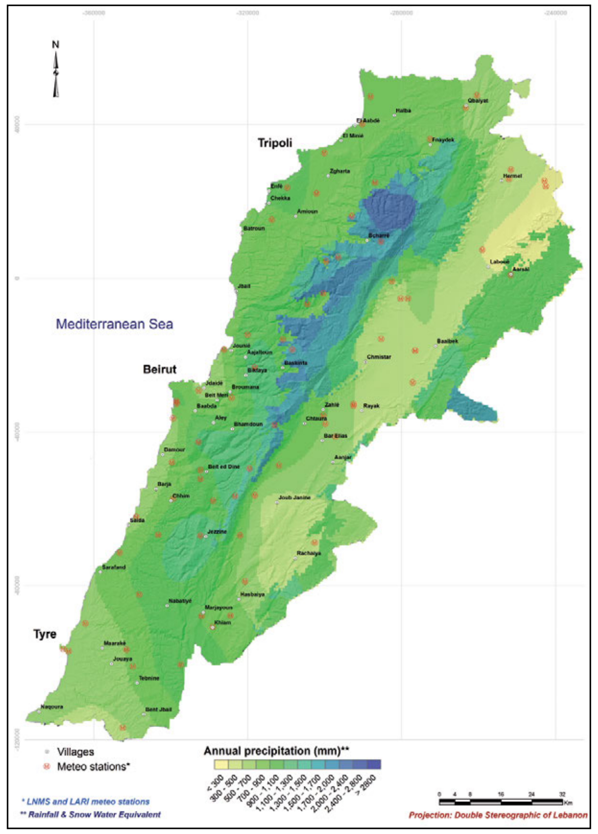


Figure 6-17 Annual precipitation 2010-2011

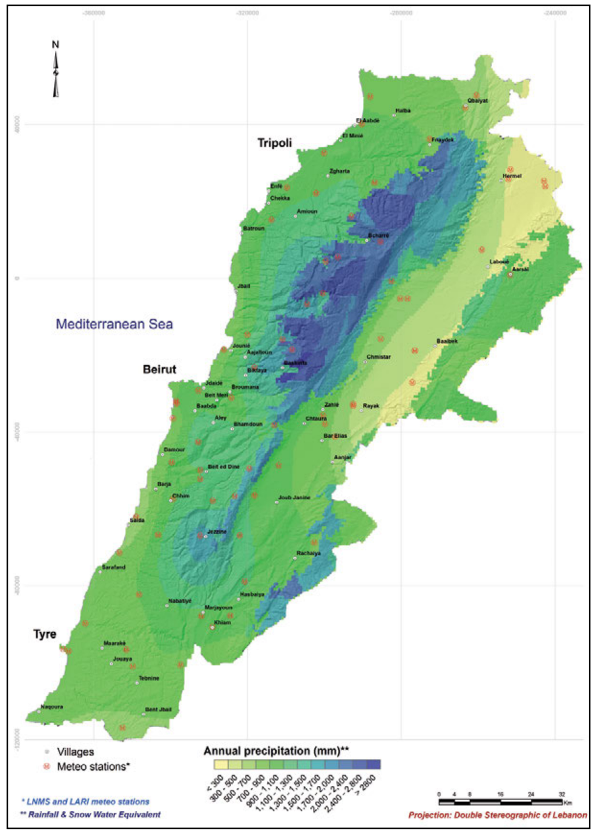


Figure 6-18 Annual precipitation 2011-2012

Table 6-8 RET from 2008 to 2012 using Turk method

	2008-2009	2009-2010	2010-2011	2011-2012	4 YEARS AVERAGE	STANDARD DEVIATION (σ)
(MCM)	1554	1834	1563	1475	1607	136
(mm)	152	179	152	144	157	13
% from Rainfall	22%	25%	26%	16%		
% from Prec.	16%	19%	20%	12%		
% from Prec.	16%	17%	18%	13%		

Table 6-9 Calculated runoff from 2008 to 2012

	2008-2009	2009-2010	2010-2011	2011-2012	4 YEARS AVERAGE	STANDARD DEVIATION (σ)
Runoff (MCM)	2517	3068	2151	3807	2886	721
Runoff (mm)	246	299	210	371	281	70

Table 6-10 Estimated recharge to groundwater from 2008 to 2012

	2008-2009	2009-2010	2010-2011	2011-2012	4 YEARS AVERAGE	STANDARD DEVIATION (σ)
I(MCM)	5404	4666	4116	6651	5209	1096
I(mm)	527	455	401	649	508	107

Table 6-11 Average precipitation, recharge to groundwater, runoff and real evapotranspiration for the Lebanese territory (2008-2012)

GROUNDWATER BASIN		DRY (2010-2011)			WET (2011-2012)			UNDP 1970*	
		MCM	mm	%	MCM	mm	%	MCM	%
Total Lebanon	Precipitation	7830	764	100	11932	1164	100	9378	100
	Recharge to GW	4116	401	53	6651	649	56	3246	35
	Runoff	2151	210	27	3807	371	32	1090	12
	ETR	1563	152	20	1475	144	12	5040	54*

** Losses reported by the UNDP 1970 include, but not only restricted to RET, extraction wells; return flows (from domestic and irrigation use); and shallow subsurface flow in soils. The UNDP 1970 did not report the RET alone.*

6.8 WATER BUDGET

This section brings together the information collected in the various deliverables of this study in an attempt to estimate Lebanon's groundwater budget. The assessment undertaken in this section indicates the behavior and conditions of each GW-basin and the identification of the strained aquifers. More details can be found in Appendix 10 of Deliverable 9.

The groundwater balance is the difference between the recharge and discharge that comprise the water budget. The recharge (water inflow) includes natural infiltration from rainfall and snowmelt; return flows from irrigation, domestic, industrial and touristic water usages as well as from losses in the water supply network; groundwater gains from other basins/aquifer. The discharge includes groundwater usage for irrigation, domestic, industrial and tourism; groundwater losses to the sea; natural discharge of springs and losses to other basins/aquifers (Table 6-12).

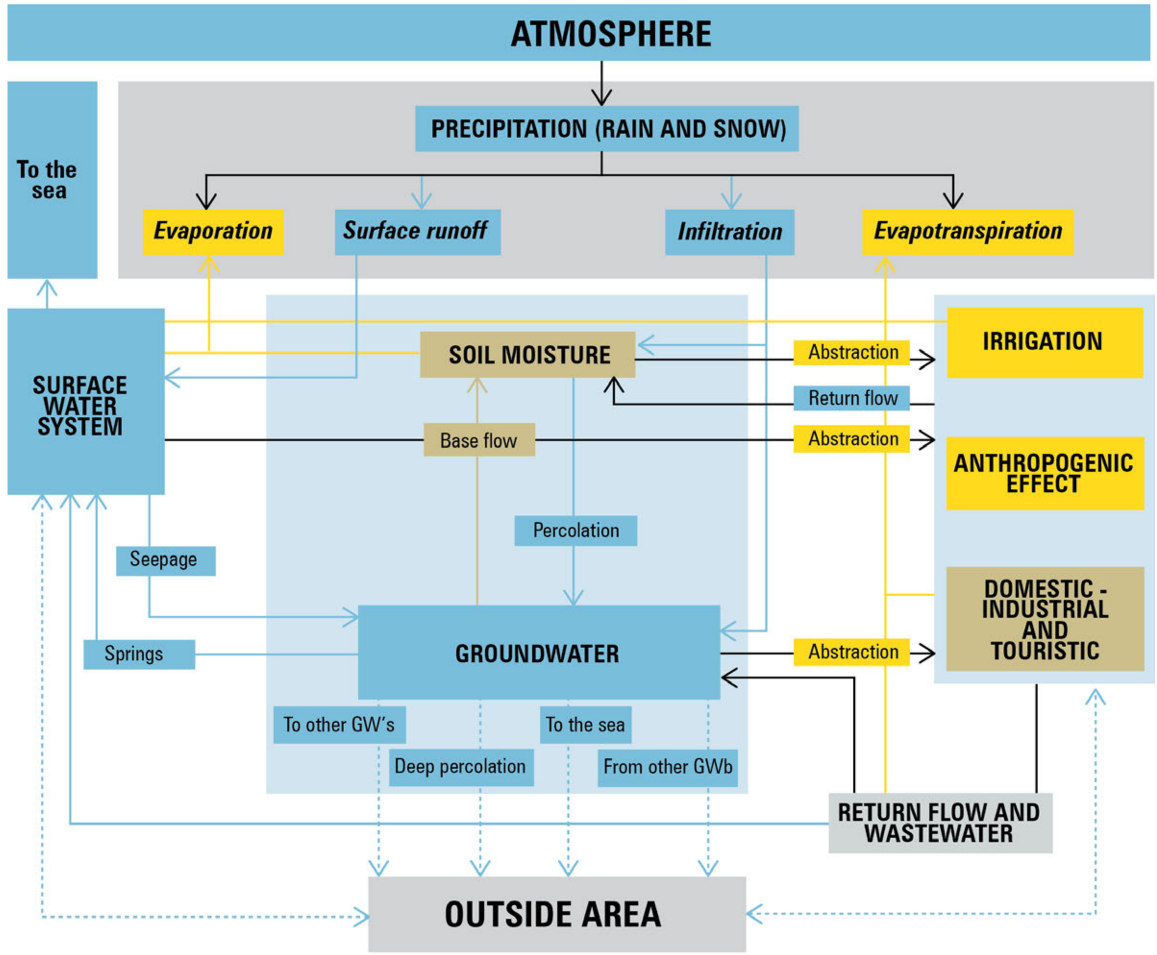


Figure 6-19 Schematic diagram of the model devised specifically for the groundwater budget of Lebanon

These components of the budget were assessed for two (2) hydrological cycles, a dry (2010-2011) cycle and a wet (2011-2012) cycle, mainly because of the availability and reliability data for those two (2) cycles. They were assembled in a simple Excel model (Figure 6-19) that could be easily updated in the future whenever new or more reliable data become available.

The estimated values presented in the model are only indicators rather than real values; they provide information on the mechanisms of exchange rather than on precise quantities. Some data were not available such as those related to groundwater gains and losses from one basin to another, deep percolation and losses to the sea. Other pertinent data were either not exhaustive or inaccurate such as those of spring discharge. Nevertheless, the model that was developed allows for future updates and analyses on basin levels when more data becomes available.

Results of GW-basins of the Mediterranean province and the Interior Province are presented in Table 6-13 and Table 6-14 respectively.

At the national level, the recharge for the two (2) retained hydrological cycles varies between 4,728 and 7,263 MCM. The discharge was estimated to be around 2588 MCM. The water balance in the budget was estimated to vary from 2,140 MCM for the dry year (2010/2011) to 4,675 MCM for the wet year (2011/2012) (Figure 6-15). These values do not account for the losses to the sea and for the deep percolation. A comparison between estimates made in the UNDP study of 1970 are is provided in Table 6-16).

Generally, with the exception of the coastal basins and some interior basins of the Bekaa region, the majority of the GW-basin, show a surplus in the budget. Many of the coastal GW-basins, which are heavily urbanized, show significant deficiencies in the water balance. Deficiencies reaching more than 150 MCM per year in the dry year were observed, such as in the North Lebanon Cretaceous Basin (Basin 18) which showed a deficiency of 157 MCM (equivalent to 427 mm); the Hadath-Hazmieh Cretaceous Basin (Basin 22) with a deficiency of 7.2 MCM (equivalent to 544 mm); and the Beirut Neogene-Quaternary Basin (Basin 26a) with a deficiency of 38.4 MCM (equivalent to 648 mm). The South Bekaa Neogene-Quaternary Basin (Basin 11a) and North Bekaa Neogene-Quaternary Basins (Basin 11b) show deficiencies in their budgets of up to 45.7 MCM and 34.2 MCM respectively (equivalent to 84 mm and 50 mm), mostly due to intense exploitation for irrigation purpose. Stressed aquifers are presented in Figure 6-20.

Table 6-12 Data sources of the various components of the preliminary Groundwater budget (GW-budget)

ABBREVIATION	DATA	SOURCES
GW BALANCE		
St	Groundwater storage in the aquifer	Was not possible to estimate each one separately. St, LS and DP were jointly estimated from the difference between Recharge and Discharge
DP	Deep percolation	
RECHARGE		
I	Infiltration	Discharge to Groundwater component (Hydrology Report)
RF	Return flow from domestic, industrial and touristic usages and	Domestic, Industrial and Touristic Water Usage
	Irrigation practices	Irrigation Water Usage
	Return flow from Losses in the Domestic Supply Network	Domestic, Industrial and Touristic Water Usage
GA	Groundwater gains from other basins/ aquifers	Was not possible to estimate in this project
DISCHARGE		
Dom	Domestic, Industrial and Touristic Supply	Calculate in the (Domestic, Industrial and Touristic Water Usage)
Irr	Irrigation water Usage from wells and from springs	Calculated in the (Irrigation Water Usage)
SD	Springs discharge from GW-basins	Partly estimated in the Springs assessment
GL	Loss to other basins/ aquifers	Was not possible to estimate in this project
LS	Losses to the Sea (point and/or diffused)	Was not possible to estimate for individual basins; however the total expected volume was estimated from literature.

Table 6-13 Results and discussion of GW-basins of the Mediterranean Province

GW BASIN NO.	GW BASIN NAME	BUDGET MCM (BUDGET / AREA mm) DRY YEAR 2010/11	BUDGET MCM (BUDGET / AREA mm) WET YEAR 2011/12	DISCUSSION AND COMMENTS
1b	S. Barouk-Niha Jurassic	21.4 (446)	40.7 (848)	• Possible percolation to deeper parts of the aquifer/Basin. • Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined.
17a,b,c	W. Barouk-Niha Jurassic	23.4 (261)	64.2 (713)	• Retention and storage not well defined.
16	Kesrouane Jurassic	288.3 (654)	501.4 (1137)	• Possible lateral loss to E. Barouk-Niha Jurassic Basin.
13	Sir Ed Danieh-Ain Yacoub Jurassic	73.9 (547)	145.6 (1078)	• Possible percolation to deeper parts of the aquifer/Basin. • Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Retention and storage not well defined.
20a	Jarmaq Cretaceous	18.3 (290)	45.7 (724)	• Possible lateral loss to Jezzine Cretaceous Basin. • Spring discharges not well measured and might be underestimated. Retention and storage not well defined.
20b	Jezzine Cretaceous	38.4 (562)	68.7 (1005)	• Possible lateral loss to Jarmaq Cretaceous Basin. • Spring discharges not well measured and might be underestimated. Retention and storage not well defined.
3b	W. Kniesseh Cretaceous	4 (741)	6.3 (1159)	• Possible lateral loss to E. Kniesseh Cretaceous Basin. • Spring discharges not well measured and might be underestimated. Retention and storage not well defined.
15	High Central Mount Lebanon Cretaceous	262.7 (1174)	451 (2015)	• Possible lateral loss to Mount Lebanon-Bekaa Cretaceous Basin. • Spring discharges not well measured and might be underestimated. Retention and storage not well defined.
18a	Bcharre-Dannieh Cretaceous	119.2 (930)	184.4 (1438)	• Possible lateral lose to North Lebanon and Mount Lebanon-Bekaa Cretaceous Basins.
18b	Qammoua Cretaceous	17.5 (404)	39.6 (914)	• Spring discharges not well measured and might be underestimated. Retention and storage not well defined.
21	Batorun-Jounie Cretaceous	140.9 (462)	262.3 (860)	• Possible percolation to deeper parts of the aquifer/Basin. • Losses to the sea in the form of diffused and points discharges. • Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Retention and storage not well defined. • Lateral exchange (gain or losses) between this basin and North Lebanon Cretaceous Basin is not well defined. • Exposed to salt water intrusion.
18	North Lebanon Cretaceous	-157.1 (-427)	-1.4 (-4)	• Possible percolation to deeper parts of the aquifer/Basin. • Losses to the sea in the form of diffused and points discharges. • Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Retention and storage not well defined. • Possible lateral exchange (gains or losses) between this basin and Batorun-Jounie, Bcharre-Dannieh and Qammoua Cretaceous Basins is not well defined. • Exposed to salt water intrusion.
19a	Naqoura-Sarafand Cretaceous	118 (241)	255.6 (522)	• Possible percolation to deeper parts of the aquifer/Basin. • Losses to the sea in the form of diffused and points discharges. • Spring discharges not well measured and might be underestimate. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined.
19b	Sarafand-Khaldi Cretaceous	108.4 (344)	221.3 (702)	• Retention and storage not well defined.

Table 6-13 Results and discussion of GW-basins of the Mediterranean Province (Cont'd)

GW BASIN NO.	GW BASIN NAME	BALANCE / DEFICIENCY IN BUDGET/AREA mm		DISCUSSION AND COMMENTS
		DRY 11-OCT	WET 12-NOV	
22	Hadath-Hazmieh Cretaceous	-7.2 (-544)	-3.9 (-291)	• Exposed to salt water intrusion.
27a	Jezzine Sandstone Cretaceous	11.7 (143)	27.8 (341)	• Possible percolation to deeper parts of the aquifer/Basin especially in coastal areas. • Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined.
27b	Metn-Chouf Sandstone Cretaceous	42.5 (214)	75.1 (378)	• Retention and storage not well defined.
24a	Nabatiye-Bent Jbeil Eocene	43.1 (145)	87.4 (294)	• Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Retention and storage not well defined.
24b	Sour-Sarafand Eocene	-8.2 (-41)	13.6 (68)	• Spring discharges not well measured and might be underestimate. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Possible losses to the sea in the form of diffused and points discharges
23a	Ashrafieh Miocene	-0.5 (-174)	-0.2 (-86)	• Negative budget might be due to loss of infiltration because of high rate of urbanization and possible overexploitation.
23b	Jounieh Miocene	-0.2 (-26)	0.5 (59)	• Exposed to salt water intrusion.
23c	Hamat Miocene	1.9 (167)	3.6 (317)	• Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined.
23d	Koura Miocene	26.2 (168)	50.6 (325)	• Possible losses to the sea in the form of diffused and points discharges
29	Jabal Terbol Miocene	0.8 (163)	1.5 (293)	• Exposed to salt water intrusion.
26a	Beirut Neogene-Quaternary	-38.4 (-648)	-34.6 (-584)	• Spring discharges not well measured and might be underestimate. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined.
26b	Tripoli Neogene-Quaternary	-5.3 (-288)	-3.9 (-212)	• Possible losses to the sea in the form of diffused and points discharges
26c	Akkar Neogene-Quaternary	-8.1 (-79)	-1.5 (-15)	• Negative budget might be due to loss of infiltration because of high rate of urbanization and possible overexploitation.
26	General Neogene-Quaternary	-35.6 (-251)	-27.9 (-197)	• Exposed to salt water intrusion.
28	Unproductive (Aptian-Albian sequence)	-13.2 (-77)	-4.4 (-26)	-
30,31	Unproductive	74.1 (53)	148.2 (106)	-

Table 6-14 Results and discussion of GW-basin of the Interior Province

GW BASIN NO.	GW BASIN NAME	BALANCE / DEFICIENCY IN BUDGET/AREA mm		DISCUSSION AND COMMENTS
		DRY 11-OCT	WET 12-NOV	
1a	E. Barouk-Niha Jurassic	15.7 (170)	55.8 (603)	• Possible percolation to deeper parts of the aquifer/Basin. • Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Retention and storage not well defined. • Possible lateral loss to W. Barouk-Niha Jurassic Basin.
2	Jdita Jurassic	3.3 (382)	6.4 (751)	• Possible percolation to deeper parts of the aquifer/Basin. • Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Retention and storage not well defined. • Possible lateral losses to E. Barouk-Niha Jurassic Basin and Kesrouan Basin.
5	Hermon Jurassic	241.2 (535)	454.8 (1008)	• Possible percolation to deeper parts of the aquifer/Basin. • Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Retention and storage not well defined.
9	Serghaya Jurassic	8.4 (327)	16.8 (649)	• Possible lateral losses to areas outside Lebanon.
6	Qaraoun Cretaceous	21.5 (363)	46.1 (779)	• Possible percolation to deeper parts of the aquifer/Basin. • Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Retention and storage not well defined. • Possible lateral losses to S. Bekaa Eocene, E. Bekaa Jurassic and Southern Bekaa Neogene-Quaternary Basins.
3a	E. Kniesseh Cretaceous	-0.8 (-134)	1.9 -313	• Possible lateral loss to W. Kniesseh Cretaceous Basin. • Spring discharges not well measured and might be underestimated. • Retention and storage not well defined.
3	Mount Lebanon-Bekaa Cretaceous	495.7 (439)	939.5 (833)	• Possible percolation to deeper parts of the aquifer/Basin. • Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Retention and storage not well defined. • Possible lateral loss to northern Bekaa Neogene-Quaternary Basins

Table 6-14 Results and discussion of GW-basin of the Interior Province (Cont'd)

GW BASIN NO.	GW BASIN NAME	BALANCE / DEFICIENCY IN BUDGET/AREA mm DRY 11-OCT	WET 12-NOV	DISCUSSION AND COMMENTS
7a	S. Anti-Lebanon Cretaceous	11.6 (111)	56.7 (544)	• Possible percolation to deeper parts of the aquifer/ Basin. • Spring discharges not well measured and might be underestimated.
7b	C. Anti-Lebanon Cretaceous	5.6 (22)	43.5 (172)	• Number of private wells is not well defined and the extraction rates from private and public wells is not well defined.
7c	N. Anti-Lebanon Cretaceous	199.1 (297)	313.2 (467)	• Retention and storage not well defined.
7d	Figeh Cretaceous	50 (744)	53.2 (792)	• Possible lateral losses to northern Bekaa Neogene-Quaternary Basins and basins outside Lebanon.
4	S. Bekaa Eocene	19.2 (108)	76.3 (428)	• Spring discharges not well measured and might be underestimate. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Possible losses to deeper parts of the aquifer. • Possible lateral losses to northern Barouk-Niha Jurassic Basins and basins outside Lebanon. • Retention and storage not well defined.
10	E. Bekaa Eocene	4.8 (39)	23.4 (190)	• Spring discharges not well measured and might be underestimate. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Possible losses to deeper parts of the aquifer.
8	W. Bekaa Eocene	-2.1 (-96)	-0.5 (-22)	• Negative budget might be due to possible overexploitation.
11a	S. Bekaa Neogene-Quaternary	-45.7 (-84)	-25.3 (-47)	• Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Possible losses underlying aquifers.
11b	N. Bekaa Neogene-Quaternary	-34.2 (-50)	-4.7 (-7)	• Negative budget might be due to loss of infiltration because of urbanization and possible overexploitation.
11c	El Marj Neogene-Quaternary	0.8 (45)	2 (111)	• Possible percolation to deeper parts of the aquifer/ Basin. • Spring discharges not well measured and might be underestimated. • Number of private wells is not well defined and the extraction rates from private and public wells is not well defined. • Retention and storage not well defined. • Possible lateral losses to deeper aquifers
12	Unproductive Senonian-L Eocene	-14.7 (-62)	-1.5 (-6)	-

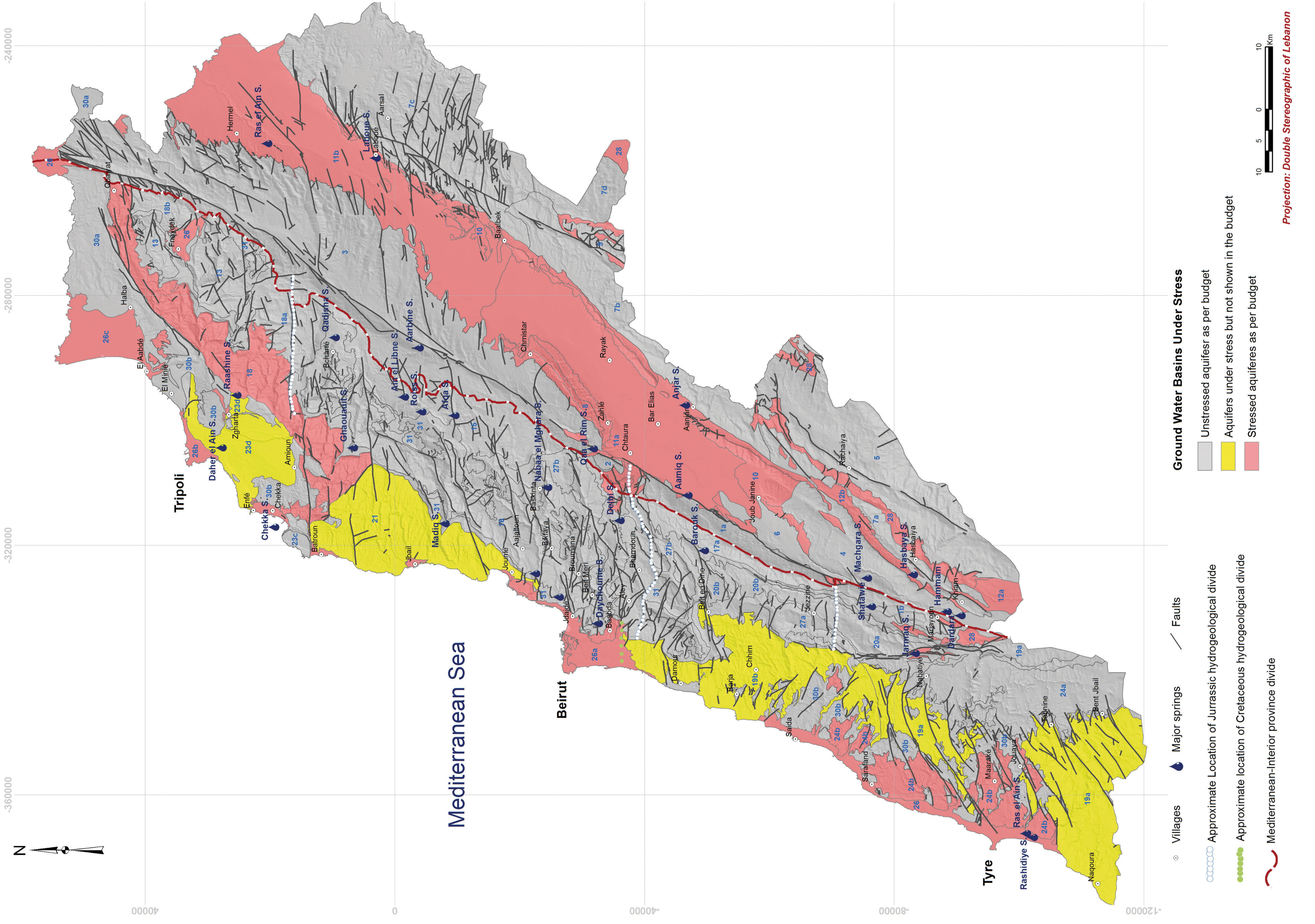


Figure 6-20 Stressed aquifers / GWB

Table 6-15 Preliminary GW budget of Lebanon

SHEET	NAMES/DESCRIPTION	DRY 11-OCT	WET 12-NOV	EXPLANATION
		MCM		
RECHARGE				
I	Infiltration	4116	6651	Values obtained from the Hydrology Chapter
RF	Return Flow	612		Return Flow from Domestic, Irrigation and Losses in the Network
GA	Addition from other basins/ aquifers	ND	ND	Not Defined
DISCHARGE				
Dom	Domestic, Industrial and Touristic Usage	818		Values obtained from Domestic, Industrial and Touristic Water Consumption
Irr	Volume of Irrigation Usage	728		Values obtained from Irrigation Water Consumption
SD	Natural Springs Discharge	1042		Values obtained from Springs Chapter
GL	Losses to other basins/aquifers	ND	ND	Not Defined
DP	Deep percolation	ND	ND	Not Defined
LS	Losses to the Sea	600-1000		From FAO (1973)
BALANCE / DEFICIENCY IN BUDGET				
Balance / Deficiency in Budget		2140	4675	Which includes LS, DP, GL, & St for they are not estimated and con not be extracted from the values obtained.
				Care should be considered when using those values.

Table 6-16 Comparison of water balance estimations

DESCRIPTION	UNDP (1970)	UNDP 2013	
		DRY 10-11	WET 11-12
Precipitation (MCM)	9,700[a]	7,830	11,933
Evapotranspiration (MCM)	ND	2,110[b]	2,022[b]
Deficiency in Runoff (MCM)	5,400	ND	ND
Surface Runoff (MCM)	1,300	2,150	3,806
Estimated Total inflow to Groundwater (MCM)	3,000	3,570[c]	6,105[c]

[a] *According to an estimated surface area of Lebanon of 10,200 km^2*
[b] *Values extracted from Table in hydrological model, (part of the project deliverables to MoEW)*
[c] *Values extracted from Table in hydrological model, (part of the project deliverables to MoEW), which includes return flows from various sources*
ND: Not Defined

7. PRELIMINARY ASSESSMENT OF ARTIFICIAL RECHARGE

Deliverable 10 presents an assessment of the potential areas for artificial recharge in the different GW-basins of Lebanon. The main purpose for artificial recharge is to replenish some the stressed aquifers of Lebanon and combat salt water in the coastal aquifers. The main sources for artificial recharge are natural sources (rivers and springs) and treated wastewater effluent. In total, 22 natural sources (Table 7-1 and Table 7-2)) and ten (10) wastewater treatment plants (Table 7-3 and Table 7-4) were selected as potential sources for artificial recharge in Lebanon covering over 12 GW-basins. The GW-basins were selected according to the following criteria: 1) basins that are under stress from depletion or saltwater intrusion; 2) basins that have the capacity to store the recharged water; and 3) areas where depth to groundwater is relatively deep to account for the potential mound (i.e. Groundwater level rise) during recharge that may reach the surface. Locations of the potential sites are presented on Figure 7-1 and Figure 7-2).

In areas were the recharge is from natural sources (rivers and springs), the aquifer recharge will span over a four (4) to five (5) month period in the wet season (starting in November/ December) when there is sufficient surplus of water to be used as a source. The recharge quantities to be extracted from the source are proposed to be between 5% and 10% of the average flow during the extraction period. The total estimated volume of recharged water from the natural sources is between 104 and 208 MCM/year.

The artificial recharge activities from the wastewater treatment plants were proposed to use most of the treated wastewater effluent. From the ten (10) selected sites, the estimated amount of recharged water is between 103 and 118 MCM/year.

In this preliminary assessment and site identification, the proposed technique for recharge is gravity injection mainly through wells. This method, which is considered the most suitable for recharge into karstic aquifer, was proposed for cost efficiency and environmental considerations. Given that large surface areas of land are not need, the injection wells can most likely be installed in public property.

A feasibility study should be conducted for each candidate site. The feasibility study should include a detailed hydrogeological study to assess the exact characteristics of the aquifer, the residence time, the exact volume to be recharged, the method of extracting water from the source, the mitigating measures for reducing turbidity of the recharge water, the compatibility between the quality of the recharged water and the groundwater, the blending conditions, the recharge techniques, the depth and the zone of injection (saturated/unsaturated), as well as the number of recharge units.
From the ten (10) selected sites, the estimated amount of recharged water is between 103 and 118 MCM/year.

In this preliminary assessment and site identification, the proposed technique for recharge is gravity injection mainly through wells. This method which is considered the most suitable for recharge into karstic aquifer was proposed for cost efficiency and environmental considerations. The injection wells can most likely be installed in public property, given the limited requirements of land.

8. RECOMMENDATIONS FOR THE ENHANCEMENT OF THE MONITORING NETWORK

The groundwater assessment revealed numerous deficiencies in the existing monitoring systems of the country. The proposed

Table 7-1 Proposed candidate sites utilizing surface water as a source for recharge

GW BASIN	CODE	WATER SOURCE	DEPTH TO GROUNDWATER (m BG)	DISTANCE BETWEEN INJECTION POINT AND EXIST POINT	DISTANCE BETWEEN WATER SOURCE AND INJECTION POINT	STRESSED AQUIFER
				(km)	(km)	Type
Kesrouan Jurassic Basin (16)	N-A1	Abou Ali River	200-400	26 - 27	<0.05	Salt W. In.
	N-A2	Al Jaouz River	100-200	20 - 21	<0.05	Salt W. In.
	N-A3	Beirut River	100 - 300	11 - 12	<0.05	Salt W. In.
North Lebanon Cretaceous Basin (18)	N-A4	Al Jaouz River	200-250	8.5 - 10	<0.05	Salt W. In.
	N-A5	Abou Ali River	200-250	14 - 16	<0.05	Salt W. In.
	N-A6	Abou Ali River	300-350	16.8 - 18	<0.05	Salt W. In.
	N-A7	El Bared River	150-250	19 - 23	<0.05	Salt W. In.
Batroun Jounieh Cretaceous Basin (21)	N-A8	Madfoun River	200-300	11.5 - 12	<0.05	Salt W. In.
	N-A9	Ibrahim River	40-60	3.5 - 5	<0.05	Salt W. In.
Mount Lebanon-Bekaa Cretaceous Basin (3)	N-A10	Berdouni River	120	26 - 28	<0.05	Depletion
Central Anti-Lebanon Cretaceous Basin (7b)	N-A11	Hala River	200-400	15 - 20	<0.05	Depletion
Hadath-Hazmeih Cretaceous Basin (22)	N-A12	Daychounieh spring (Beirut Canal)	100 - 300	5 - 6	6-May	Salt W. In.
Sarafand-Khaldi Cretaceous Basin (19b)	N-A13	Awali River	300-400	10 - 12	<0.05	Salt W. In.
	N-A14	Damour River	250-350	4 - 6	<0.05	Salt W. In.
	N-A15	Ghadir River	70-100	4 - 6	<0.05	Salt W. In.
Naqoura-Sarafand Cretaceous Basin (19a)	N-A16	Litani River	100-150	14 - 17	<0.05	Salt W. In.
	N-A17	Zahrani River	300-400	20 - 23	<0.05	Salt W. In.
	N-A18	Abo Assouad River	100-200	3 - 4	<0.05	Salt W. In.
Southern Bekaa Eocene Basin (4)	N-A19	Litani River	200-350	12 - 14	<0.05	Depletion
Eastern Bekaa Eocene Basin (10)	N-A20	Litani River	200-300	23 - 26	6-May	Depletion
Koura Miocene Basin (23d)	N-A21	Barsa River	120 - 130	4 - 6	<0.05	Salt W. In.
	N-A22	Abo Ali River	120 - 130	4 - 6	<0.05	Salt W. In.

Table 7-2 Estimated ranges of volumes of water available for recharge in each candidate sites utilizing a surface water source

PROPOSED GW BASIN TO BE RECHARGED	CODE	WATER SOURCE	RIVER DISCHARGE 2011-2012 CYCLE			AVAILABLE VOLUME FOR RECHARGE
			Min (m^3/s)	Max (m^3/s)	Winter Av. (m^3/s)	MCM/Year
Kesrouan Jurassic Basin (16)	N-A1	Abou Ali River	0.54	19.51	12.14	2.4 - 4.8
	N-A2	Al Jaouz River	0	10.68	5.88	1.5 - 3.0
	N-A3	Beirut River	0.05	24.8	5.68	2.9 - 5.9
North Lebanon Cretaceous Basin (18)	N-A4	Al Jaouz River	0	10.68	5.88	1.5-3.0
	N-A5	Abou Ali River	0.54	19.51	12.14	2.4-4.8
	N-A6	Abou Ali River	0.54	19.51	12.14	2.4-4.8
	N-A7	El Bared River	0.39	12.37	8	4.1-8.3
Batroun Jounieh Cretaceous Basin (21)	N-A8	Madfoun River	0.1	20	14	7.3-14.5
	N-A9	Ibrahim River	0.3	63.9	26.9	13.9-27.9
Mount Lebanon-Bekaa Cretaceous Basin (3)	N-A10	Berdouni River	0.1	66.1	3.3	1.7-3.4
Central Anti-Lebanon Cretaceous Basin (7b)	N-A11	Hala River	0.1	4.56	1.2	0.6-1.2
Hadath-Hazmeih Cretaceous Basin (22)	N-A12	Daychounieh spring (Beirut Canal)	-	-	228	1.8-3.5
Sarafand-Khaldi Cretaceous Basin (19b)	N-A13	Awali River	14.53	84.7	39.12	20.3-40.6
	N-A14	Damour River	0	68.9	17.47	9.1-18.1
	N-A15	Ghadir River	0.02	1.65	0.83	0.4-0.9
Naqoura-Sarafand Cretaceous Basin (19a)	N-A16	Litani River	0.15	55.9	20.9	10.8-21.7
	N-A17	Zahrani River	0.09	4.04	2.3	1.2-2.4
	N-A18	Abo Assouad River	-	-	3	1.6-3.1
Southern Bekaa Eocene Basin (4)	N-A19	Litani River	0.15	35.7	18.13	4.7-9.4
Eastern Bekaa Eocene Basin (10)	N-A20	Litani River	0.15	35.7	18.13	4.7-9.4
Koura Miocene Basin (23d)	N-A21	Barsa River	0.83	19.5	12.17	6.3-12.6
	N-A22	Abo Ali River	0.54	19.51	12.14	2.4-4.8
Total						104-208

Table 7-3 Proposed candidate sites utilizing treated effluent water as a source for recharge

GW BASIN	CODE	WASTE WATER TREATMENT PLANT	DEPTH TO GROUNDWATER (m BG)	DISTANCE BETWEEN INJECTION POINT AND EXIST POINT (km)	DISTANCE BETWEEN WATER SOURCE AND INJECTION POINT (km)	STRESSED AQUIFER TYPE
North Lebanon Cretaceous Basin (Basin 18)	W-A1	Chekka	10 - 35	1.2-1.4	2 - 3	Salt W. In.
Batroun Jounieh Cretaceous Basin (Basin 21)	W-A2	Jbeil	10 - 30	0.2-0.6	0.1 - 0.5	Salt W. In.
	W-A3	Tabarja	10 - 30	0.8-1.2	0.2 - 0.5	Salt W. In.
Sarafand-Khaldi Cretaceous Basin (Basin 19b)	W-A4	Ghadir	40	1.7-3.8	2 - 4	Salt W. In.
	W-A5	Jeyyeh	10 - 20	0.5-2	0.1 - 0.5	Salt W. In.
	W-A6	Saida	16.06	5.3-5.6	5	Salt W. In.
Naqoura-Sarafand Cretaceous Basin (Basin 19a)	W-A7	Nabatiye	20-30	15-16	0.1 - 0.5	Salt W. In.
Eastern Bekaa Eocene Basin (Basin 10)	W-A8	Joub Jannine	20-32	5.3 - 5.6	0.1 - 0.5	Depletion
	W-A9	Aanjar	40-50	15 - 16	0.1 - 0.5	Depletion
Southern Bekaa Neogene/ Quaternary Basin (Basin 11a)	W-A10	Zahle	20-30	9 - 12	0.1 - 0.5	Depletion

Table 7-4 Selected waste water treatment plants where effluent would be used for artificial recharge

PROPOSED GW BASIN TO BE RECHARGED	CODE	WASTE WATER TREATMENT PLANT	ESTIMATED OR ANTICIPATED EFFLUENT CAPACITY (m^3/day)	AVAILABLE VOLUME FOR RECHARGE (MCM/Year)	REMARKS
North Lebanon Cretaceous Basin (Basin 18)	W-A1	Chekka	2,100	0.5 - 0.6	• Secondary treatment. Completed but not yet in operation
Batroun Jounieh Cretaceous Basin (Basin 21)	W-A2	Jbeil	4,600	1.2 - 1.3	• Secondary treatment. Completed but not yet in operation
	W-A3	Tabarja	70,000	17.9 - 20.4	• Secondary Treatment (Conventional T. Not Constructed Yet. Construction is anticipated to begin in 2014
Sarafand-Khaldi Cretaceous Basin (Basin 19b)	W-A4	Ghadir	138,000	35.3 - 40.3	• Secondary treatment. Not constructed yet. Feasibility Study completed. Construction is not anticipated to begin before 2015
	W-A5	Jeyyeh	12,000	3.1 -3.5	• Secondary treatment. Completed for first phase capacity of 6000 m^3/day. Not yet in operation
	W-A6	Saida	55,000	14.1 - 16.1	• Design for secondary Treatment. Presently, it is only primary treatment
Naqoura-Sarafand Cretaceous Basin (Basin 19a)	W-A7	Nabatiye	12,000	3.1 - 3.5	• Tertiary Treatment (only with disinfection and no filtration). In operation
Eastern Bekaa Eocene Basin (Basin 10)	W-A8	Joub Jannine	14,000	3.6 - 4.1	• Tertiary treatment (only with disinfection and filtration). In operation
	W-A9	Aanjar	50,000	12.8 - 14.6	• Tertiary treatment. Not yet Constructed
Southern Bekaa Neogene/Quaternary Basin (Basin 11a)	W-A10	Zahle	45,000	11.5 -13.1	• Tertiary treatment (disinfection and filtration). In Construction for first phase of 18,000 m^3/day capacity
Total				103 - 118	

Table 7-5 Volumes of potentially recharged water in each GW-basin compared to infiltrated volume

GW-BASIN	VOLUME OF POTENTIAL RECHARGE (MCM/YEAR)		TOTAL VOLUME OF POTENTIAL RECHARGE (MCM)	% OF ARTIFICIAL RECHARGE TO NATURAL RECHARGE	% OF ARTIFICIAL RECHARGE TO NATURAL RECHARGE
	NATURAL SOURCES	WASTE-WATER EFFLUENT		(2010-2011)*	(2011-2012)*
Kesrouan Jurassic Basin (Basin 16)	6.9 - 13.7	-	6.9 - 13.7	1.7-3.4	1.1 - 2.25
North Lebanon Cretaceous Basin (Basin 18)	10.5 - 20.9	0.5 - 0.6	11 - 21.5	4.1 - 8.1	2.6 - 5.1
Batroun Jounieh Cretaceous Basin (Basin 21)	21.2 - 42.4	19.1 - 21.7	40.3 - 64.1	24.5 - 39.1	14.1 - 22.4
Mount Lebanon-Bekaa Cretaceous Basin (Basin 3)	1.7 - 3.4	-	1.7 - 3.4	0.2-0.4	0.1-0.27
Central Anti-Lebanon Cretaceous Basin (Basin 7b)	0.6 - 1.2	-	0.6 - 1.2	0.5 - 1	0.3 - 0.78
Hadath-Hazmeih Cretaceous Basin (Basin 22)	1.8 - 3.5	-	1.8 - 3.5	23.6-46	16.3-31
Sarafand-Khaldi Cretaceous Basin (Basin 19b)	29.8 - 59.5	52.5 - 59.9	82.3 - 119.4	52.5 - 76.1	27.7 - 40.2
Naqoura-Sarafand Cretaceous Basin (Basin 19a)	13.6 - 27.2	3.1-3.5	16.7 - 30.7	7.1 - 13.1	4.5 - 8.2
Eastern Bekaa Eocene Basin (Basin 10)	4.7 - 9.4	16.4 - 18.7	21.1 - 28.1	32 - 43	25 - 33
Southern Bekaa Eocene Basin (Basin 4)	4.7 - 9.4	-	4.7 - 9.4	5.6-11.3	3.3-6.7
Koura Miocene Basin (Basin 23d)	8.7 - 17.4	-	8.7 - 17.4	20-40	12.7-25.5
Southern Bekaa Neogene / Quaternary Basin (Basin 11a)	-	11.5 - 13.1	11.5 - 13.1	13.7 - 15.6	8.1 - 9.2
Total	104 - 208	103 - 118	207 -326	-	-

* *The volume of natural recharge was obtained (total recharges) from the hydrology and budget and safe yield report and calculations are shown in table in Appendix XI.*

interventions presented below aim at improving the existing water resources monitoring system in Lebanon. An upgrade is needed to better quantify available resources – a necessity for the sustainable management of water resources in Lebanon.

8.1 GROUNDWATER MONITORING RECOMMENDATIONS

Lebanon is one of the few countries in the world that does not have a network of monitoring wells. The only dedicated monitoring wells are 13 wells installed in the Upper Litani River basin. It is therefore necessary to install dedicated monitoring wells in a phased approach, focusing on the stressed aquifers, then expanding over the rest of the country.

Moreover, it is necessary to monitor the quantity of groundwater that is being extracted from both public and private wells. In theory, all the public wells should be equipped with continuous recording devices to monitor groundwater extraction volumes and to measure the groundwater levels.

In addition, better control of the estimated 55,000 to 60,000 unlicensed wells is required. These wells will eventually need to be properly surveyed. Ultimately, on the long term, a control/monitoring system should be established to compel the owners of the private wells to install discharge flow monitoring devices on their wells and to report the groundwater extraction volumes to the regulatory agency on a regular basis. This would however require a complete revision of the regulation pertaining to well drilling permits, and groundwater extraction permits procedures and requirements. In drafting these regulations, the current context should be taken into account, especially the limited alternative options available to the private sector given the current limitation of the various water establishments in meeting water supply demands.

In light of these findings the following intervention would be recommended:

- *Establishing a Dedicated Monitoring Well Network: The initial phase would consist of installing about 60 dedicated monitoring wells with a focus on the stressed aquifers. These wells should be equipped with continuous monitoring devices to measure the groundwater levels and in some cases, with conductivity sensors in areas that are prone to seawater intrusion. This activity should be carried by the MoEW.*

- *Monitoring of the Public Water Supply Wells: Out of the 842 public water supply wells, only 20 wells were equipped with continuous groundwater monitoring devices. It is proposed that water establishments equip all their wells with a discharge flow control monitoring system and continuous groundwater-level monitoring devices. Monitoring devices for those wells located in areas prone to sea water intrusion (about 250 wells), should include a conductivity sensor.*

- *Developing a Database for each of the Water Establishments: It is proposed that each water establishment maintains its own monitoring database. This would require the development of a formal data collection system with a quality assurance and quality control (QA/QC) program for uploading the data into the database. A proper procedure should be established for the regular reporting of information/data in digital format from the database of the various water establishments to that of the MoEW.*

- *Surveying the Unlicensed Private Wells: It is recommended to conduct a comprehensive survey of the unlicensed private wells and to complete the survey of private wells that have exploitation permits. Survey results can then be integrated into the existing well database that was constructed as part of this project. Due to the extensive number of wells, and the tedious investigative nature of the work, it would take approximately one (1) to two (2) years to complete.*

8.2 RIVER MONITORING RECOMMENDATIONS

The LRA is responsible for the gauging of all the surface water courses and the major springs of the country. There are many significant deficiencies in the existing network due to the limited resources (financial and human resources) within the LRA. About one third of the area of Lebanon is not yet covered by hydrological observation system. Additionally, some of the existing stations need to be relocated, and rehabilitated to allow for accurate and reliable measurements.

The existing network of river gauging and spring discharge flow monitoring will have to be rehabilitated and expanded to ensure proper coverage of the entire territory. The following interventions are proposed:

- *Preparing a Detailed Plan for the Rehabilitation and Expansion of the Existing Network: This would include: 1) inspecting of all the gauging stations; 2) providing recommendations for locations of new gauging stations, and modification of existing ones if necessary; 3) preparing technical specification and guidelines for the installation of the various types of gauging stations to be installed; and 4) preparing an operational and maintenance manual to ensure the continuous acquisition of reliable data.*

- *Implementation of the Plan for the Rehabilitation and Expansion of the Existing Network: Preliminary assessments reveal that the minimum total number of proposed new stations needed is about 26.*

- *Updating and Improving the Existing Database at LRA: This would include incorporating all the existing data that is currently being gathered manually into the database and establishing a quality assurance control / quality assurance system.*

8.3 SPRING MONITORING RECOMMENDATIONS

Most of the major springs of Lebanon are not being monitored. Only nine (9) major springs are being monitored by the LRA. These measurements are not truly representative of the total flow of the springs given that the extracted/exploited volumes at the spring sources are usually not accounted for. The following interventions are proposed:

- *Conducting a Nationwide Spring Survey: Field proofing of the 5,050 springs identified in the topographic map will have to be done. For each spring, the exact geographical coordinates should be taken, along with picture. The emergence mechanism should also be described. Approximate discharge flow rates should be measured and spring usage identified. Particular focus should be made on the 409 main springs that were identified in this study. This activity should be conducted by MoEW.*

- *Preparing a Master Plan for the Monitoring of the Major Springs in the Country: The master plan should include the identification of the major springs that would require continuous monitoring, and those that should be measured on periodical bases. It should also include technical specifications and guidelines for the installation of the gauging stations, including site preparations/civil construction work (if any), and QA/QC procedure for data collection and data validation. This activity should be carried out by the MoEW, in collaboration with the LRA.*

8.4 METEOROLOGICAL NETWORK RECOMMENDATIONS

The Lebanese National Meteorological Service (LNMS) is responsible for establishing, operating and maintaining the national meteorological network of the country. The meteorological network that was initially established was destroyed during the Civil War. Starting in the mid 1990's, the LNMS has re-initiated its climatic monitoring activities.

There is major shortcoming in the current meteorological network with respect to data quality and network coverage. The existing stations do not adequately cover all the Lebanese territories. Additionally, another major limitation of the existing network and the past network that was destroyed during the civil work is the lack of stations capable of collecting information on snow.

Thus, there is a need to improve the quality of data acquisition, data reduction, and data reporting, and to improve national network coverage over all the country. The proposed interventions presented below should be carried by the LNMS.

- *Preparing a Master Plan for the Improvement of the Existing Meteorological Network: The number of stations required and their respective locations should be determined following international criteria taking into account the different microclimates and the hypsometry of the Lebanese territory. Generally, two (2) climatic stations are required for every 200 km^2. The master plan should include: 1) an assessment of existing station and the identification of the location of proposed new stations; 2) the preparation of technical specifications for the installation of the equipment (required civil work and instruments; and 3) Develop quality control / quality assurances (QA/QC) procedures for data acquisition, data reductions and data reporting, as wells calibration requirements.*

- *Installing the New Meteorological Stations: Based on a preliminary assessment, the total number of required new stations is 89 of which 20 are snow stations.*

- *Recovering and Processing the Historical Data: Based on the review of the hydrometrical data, historical data collected before 1975 have not been integrated into the existing database: This intervention would mainly consist of digitizing data collected before 1975; and integrating those into the existing database.*

8.5 LEGAL AND INSTITUTIONAL ASSESSMENT STUDY

The legal and institutional framework of the government services involved in the monitoring (groundwater, surface water, and meteorology) will have to be revised and their resources will have to be strengthened in order to allow these government services to properly accomplish their assigned mission. The study should include:

- *Conducting a gap assessment on the existing institutional and legal framework work, of the government organisations/services involved in the specific monitoring;*

- *Proposing a road-map and drafting legislative texts to re-define missions and mandates, avoid overlaps and clarify attributed roles and responsibilities;*

- *Adjusting organizational structures, assessing staff requirements, defining and developing individual job descriptions and performance requirements for each staff category;*

- *Developing coordination procedures between the various stakeholders;*

- *Identifying training programs to strengthen the capacity of the organisations/services;*

- *Defining procedures for data dissemination and access control;*

- *Revising or developing procedures for the control of water extractions, such as drilling permits, groundwater extraction permits, and surface water allocation permits; and*

- *Preparing annual cost estimates for the operation and maintenance of the monitoring systems.*

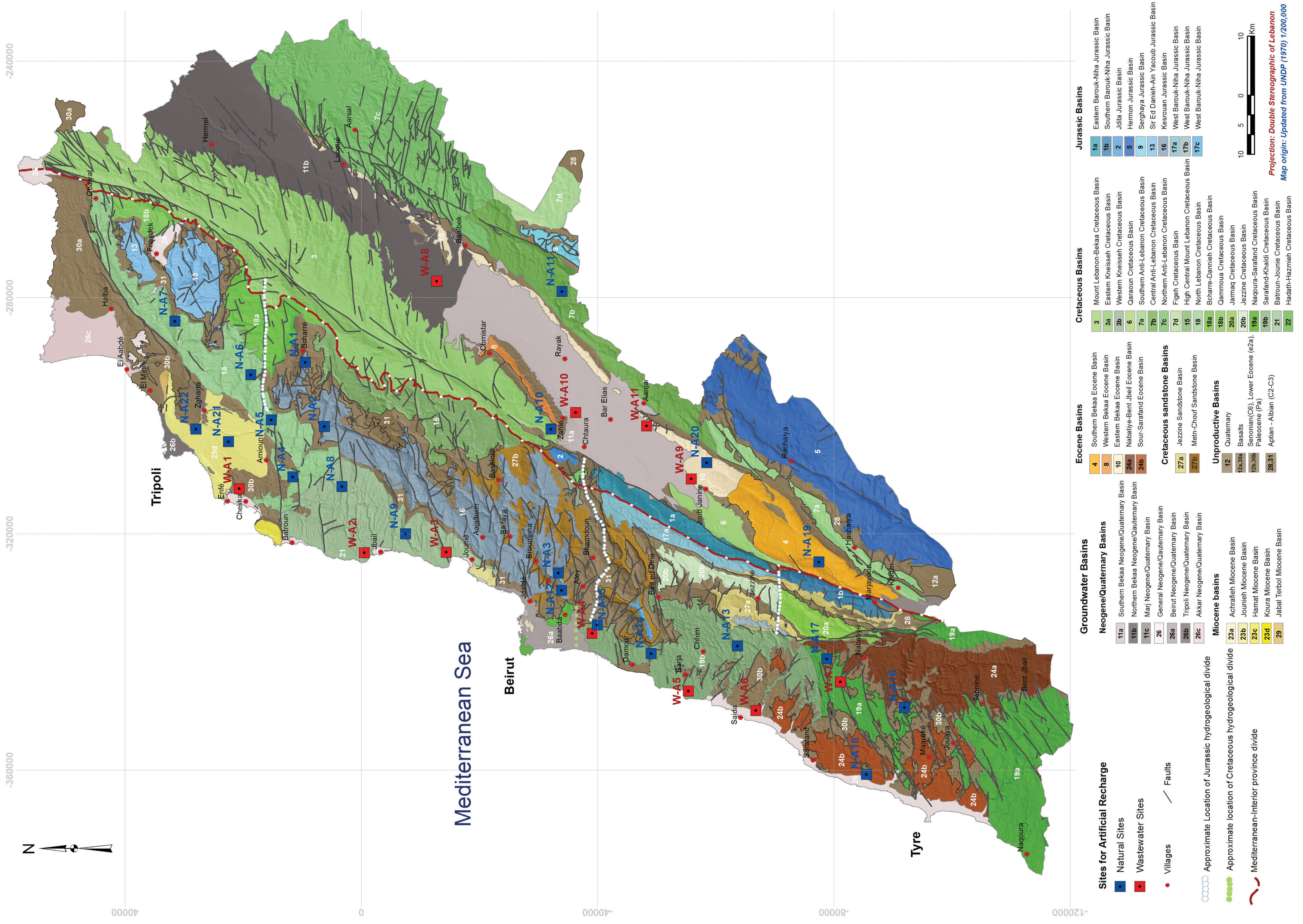


Figure 7-1 Location of the proposed areas for artificial recharge from natural sources and from wastewater effluent overlaid over the GW-basins

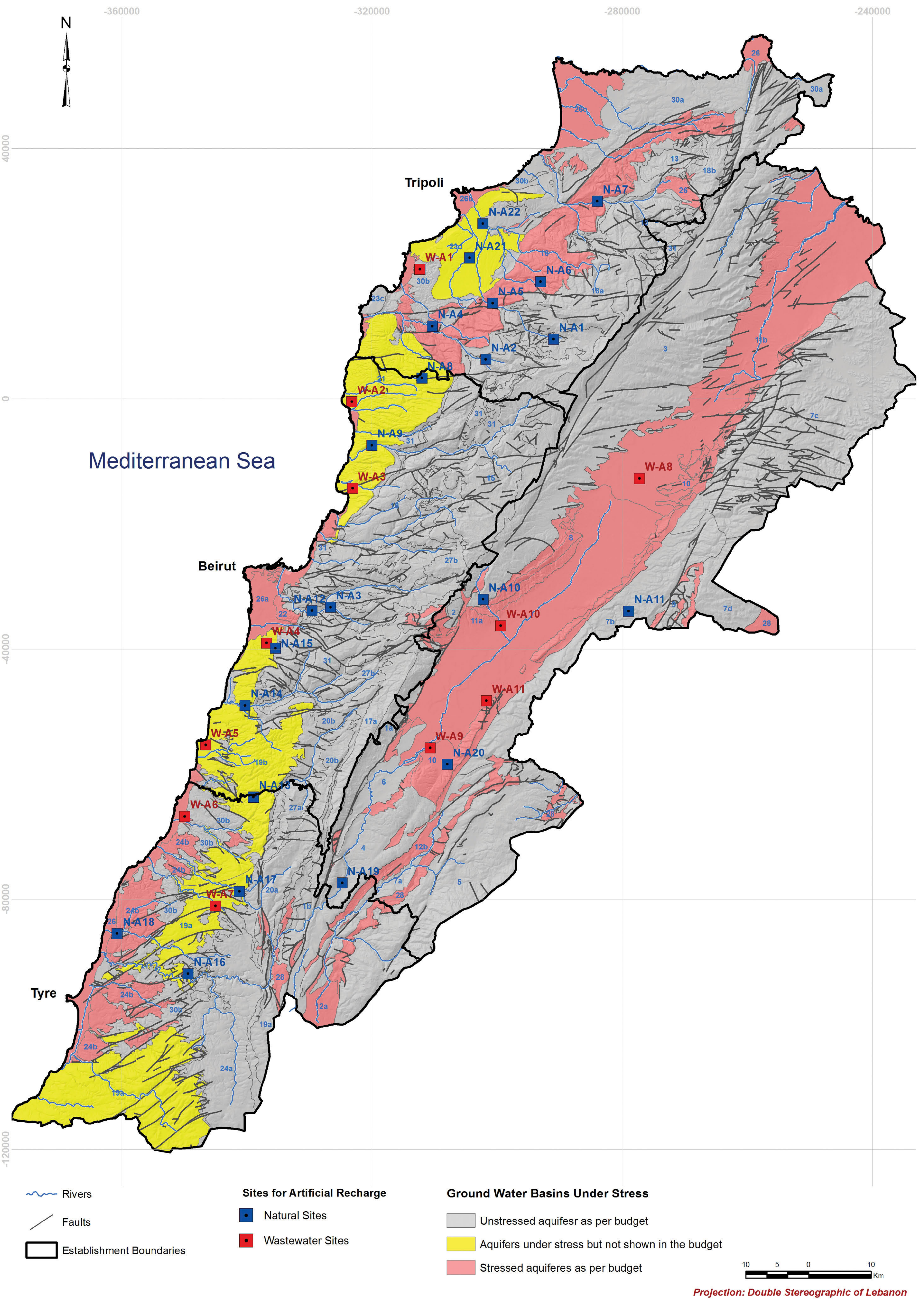


Figure 7-2 Location of the proposed areas for artificial recharge from natural sources and from wastewater effluent overlaid over the GW-basins under stress