REPUBLIC OF LEBANON
MINISTRY OF ENERGY AND WATER

UPDATED NATIONAL WATER SECTOR STRATEGY - 2020

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FOREWORD

The present volume is part of the ***Updated National Water Sector Strategy 2022***, which includes the following volumes:

The Updated National Water Sector Strategy 2022 (the core volume of the Strategy)

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- C Human Resources of the WEs
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Annex II : Water resources management *(this volume)*

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LIST OF ACRONYMS

Bm^3	Billion cubic meter
BMLWE	Beirut and Mount Lebanon Water Establishment
BWE	Bekaa Water Establishment
CDR	Council for Development and Reconstruction
CM	Customer Management
EIB	European Investment Bank
EU	European Union
HR	Human resources
IFRS	International Financial Reporting Standards
IWMI	International Water Management Institute
l/c/d	Litres per capita per day
l/sec	Litres per second
LBP	Lebanese Pound
LRA	Litani River Authority
m^3/d	Cubic meter per day
m^3/h	Cubic meter per hour
masl	Meters above sea level
MCM	Million cubic meter
MENA	Middle East and North Africa region
Mm^3	Million cubic meter
MoA	Ministry of Agriculture
MoE	Ministry of Environment
MoEW	Ministry of Energy and Water
NGO	Non-Governmental Organization
NLWE	North Lebanon Water Establishment
NRW	Non-Revenue Water (unaccounted-for water)
NWSS	National Water Sector Strategy

ONL	Office National du Litani
PPP	Private Public Partnership
SLWE	South Lebanon Water Establishment
UFW	Unaccounted for Water
UN	United Nations
WE	Water Establishment
WEs	Water Establishments
WES	Water Establishments

SECTION A
Available water resources
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A.1 WATER RESOURCES

A.1.1 AVAILABLE WATER RESOURCES

Lebanese water resources consist of surface water directly discharged into rivers and groundwater from direct infiltration and snowmelt over karstic and highly permeable geological layers either stored in aquifers or emerging from mountainous and coastal springs. Several reports have described the historical and actual status of the Lebanese water resources, however only *AQUASTAT Country Profile* of Lebanon carried out by FAO[1] in 2008 using long term precipitation data and the Assessment of Groundwater Resources of Lebanon report of 2014 carried out by the MEW and UNDP[2] will be described and adopted. The hydrology study of 2014 (UNDP, 2014) provided an evaluation of precipitation (rain and snow), evapotranspiration and runoff to estimate natural recharge rates for the country but only four hydrological cycles (2008 to 2012) were used.

A.1.1.1 Groundwater resources

The presence of karstic formation, fissures and fractures, depression and sinkholes encourage rainwater and snowmelt to percolate and infiltrate deep into the ground and feed the aquifers or emerge at lower elevations as springs that flow into rivers. In the assessment of groundwater resources (UNDP, 2014), the 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 hydrological cycles, vary from 4,116 Mm^3 to 6,651 Mm^3 with an average of about 55 % of the total precipitation. In this report and based on historical measurements mainly from LRA, BTD, UNDP 1970, UNDP 2014 and other reports, it was estimated that the 275 tapped springs were generating a total annual flow of 2,050 Mm^3/year and that 700 Mm^3 were feeding the dynamic reserves of the aquifers. The total groundwater outflow leaving Lebanon is estimated at about 1,020 Mm^3/year of which 740 Mm^3 to the sea, 150 Mm^3 to Hulah Lake and 130 Mm^3 to Dan Springs in the Syrian Arab Republic.

Major Springs

Table A 1 shows the list of the major springs yielding an average of more than 100 l/s tapped for drinking water purposes by each WE, sorted by caza. The situation may be summarized as follows:

- The total number of springs reaches 2000 with only 275 tapped one. However, small local springs are subject to a progressive drought due to increasing urbanisation and groundwater misuse.
- The yearly average yield of all tapped springs exceeds 2,050 Mm3. However, the maximum available yield in dry months is approximately 200 Mm3.
- The WEs are currently tapping almost 90% of the water resources available from springs. Therefore, little future optimisation is expected (less than 10 %)
- It should be noted that over extraction from groundwater through unlicensed wells affects the flows available from springs. Public and licensed private wells are subject, prior to development, to a hydrogeological study that identifies their potential impact on springs flow.

[1] FAO, (2008)
[2] UNDP, (2014)

A.1.1.2 Surface water resources

In the Assessment of Groundwater Resources report (UNDP, 2014), the average annual precipitation including snow contribution was estimated at 946 mm ranging between 764 mm and 1164 mm, hence an equivalent amount of 9,702 Mm^3 (7,830 Mm^3 and 11,932 Mm^3) between 2008 and 2012. The estimated yearly surface flow for the four hydrological cycles, which does not account for the portion that comes from the discharge of the various springs, varies between 2,151 Mm^3 and 3,807 Mm^3. The estimated yearly volume of real evapotranspiration was estimated using Turc (1961) method over 71 meteorological stations across Lebanon ranging between 1,563 Mm^3 (26%) and 1,475 Mm^3 (16%) of the total precipitation. In this report, the average annual precipitation will be adopted from FAO 2008 *AQUASTAT Country Profile* report estimated at 823 mm, with high variability across the country, hence a total amount of 8,559 Mm^3.

Lebanon comprises 17 perennial and 23 seasonal rivers or wadis with an average annual flow estimated at 4,260 Mm^3 including groundwater discharge from 2,000 springs. The total surface water outflow outside Lebanon was estimated at 735 Mm^3/year, of which 160 Mm^3 to the sea, an outflow to the Syrian Arab Republic estimated at 415 Mm^3 through the Asi-Orontes river and an outflow into the north of the occupied territories from the Hasbani/Wazani complex estimated at 160 Mm^3/year (Plassard, 1971; FAO, 2008).

Major Rivers

Table A 2 shows the list of major rivers used for either irrigation or potable water. The yields and volumes shown are those measured at the reference gauging stations (where available) by the hydrological service at LRA. It has to be noted that when the gauging station is on the sea mouth, the volumes extracted upstream are not measured and it also includes the discharged volumes from springs. Thus, due to missing data and lack of measurements, it is almost impossible to assess the total yield that would be available from those rivers for various uses. The yield of main and secondary seasonal rivers, wadis and in-between streams are those measured by LRA in addition to estimated yields from adjacent rivers specific average flows. The total area of Lebanon was considered 10400 km^2 same as of FAO 2008 report to ease calculation estimation. Based on available measurements, the estimated yield from rivers is 4,260 Mm^3/year including 2,210 Mm^3/year of surface water either remaining or leaving the country, and 2,050 Mm^3/year the estimated springs flows discharged into rivers.

A.1 water resources

Table A 1 List of major springs in use for potable water

Spring Name	Average Flow (m³/d)	Exploited Flow for Domestic Usage (m³/d)
BMLWE	**1,998,000**	**226,000**
Baabda		
Ain El Delbé	20,000	6,000
Daychounieh	39,000	6,000
Chouf		
Ain Dara before safa	47,000	
Barouk	83,000	9,000
Qah	20,000	9,000
Raayan	120,000	17,000
Safa	83,000	6,000
Jbeil		
Afqa	300,000	3,000
Rouaiss	265,000	1,000
Kesserwan		
Jeita	370,000	120,000
Nabaa El Aassal	75,000	7,000
Nabaa El Laban	89,000	
Nabaa El Madiq	86,000	10,000
Metn		
Fouar Antelias'	207,000	19,000
Kashkoush	176,000	13,000
Saltaneh	18,000	
BWE	**1,507,000**	**337,000**
Baalbeck		
Laboue	77,000	1,000
Nabaa Yahfoufa - Es Sike	69,000	
Nabaa Yahfoufa - Bustan El Mirr	47,000	
Ras el Ain (Baalbeck)	17,000	
Yammouneh	97,000	
Yammouneh - El Arbaain	67,000	
Yammouneh - El Bawalih	28,000	
Yammouneh - El Mahkan	10,000	
Hermel		
Ain Ez Zarka	224,000	86,000
Ras El Mal	25,000	25,000
West Bekaa		
Ain el Hajar	22,000	22,000
Ain El Zarqa (West El beqaa)	228,000	1,000
Ana spring	32,000	32,000
Nabaa el Khraizat	19,000	
Nabaa es Saalouk	20,000	20,000
Zahle		
Ain el Baida Spring - Kfarzabad	17,000	
Ammiq Spring	26,000	
Anjar Spring	164,000	58,000
Berdaouni Spring	156,000	2,000
Chamsine	18,000	18,000
Chtaura spring	37,000	
Qabb Elias - Ouadi El Delem	56,000	56,000
Ras El Ain (Chtaura)	51,000	16,000

Spring Name	Average Flow (m³/d)	Exploited Flow for Domestic Usage (m³/d)
NLWE	**724,000**	**151,000**
Akkar		
Ain Aamas	11,000	
Bebnine Spring	13,000	
Nabaa es Safa	75,000	11,000
Batroun		
Dalle and Ghouaouit	43,000	12,000
Bcharre		
Mar Challita	24,000	3,000
Nabaa El Haddad	9,000	1,000
Qadisha	89,000	3,000
Ras En Nabaa (Mashour)	10,000	1,000
Koura		
Abou Halka	25,000	35,000
Nabaa el Haab	35,000	35,000
Miniyeh-Daniyeh		
Ain el Arbaain	35,000	
Ain el Bire	22,000	
El Sekkar	62,000	5,000
Nabaa El Breissa	27,000	1,000
Nabaa El Qseim	17,000	3,000
Nabaa Ez Zahlane	30,000	1,000
Oyoun El Samak	11,000	10,000
Ras El Ain	18,000	1,000
Zgharta		
El Kadi	25,000	2,000
Rachiine	143,000	27,000
SLWE	**1,042,000**	**100,000**
Hasbaiya		
Hasbani	169,000	5,000
Sreid - El Mairi Bridge	59,000	
Wazzeni	180,000	6,000
Jezzine		
Aazibi Springs	27,000	
Ain al Kabire spring	12,000	7,000
Jarmak Spring	26,000	
Jesr el Habayeb Spring	28,000	
Jezzine Spring	63,000	8,000
Joun Spring	25,000	
Nabatieh		
Aalman Spring	22,000	10,000
Nabaa el Tasse Spring	31,000	30,000
Ghelle	230,000	
Saida		
Qasmiye - Ain Abou Abdallah	86,000	
Sour		
Rachidiye springs	17,000	12,000
Ras El Ain springs	67,000	22,000
Total of 275 tapped springs	**5,500,000**	**814,000**

Table A 2 List of major Lebanese rivers and streams

River	Watershed Area (km²)	Average Annual Volume (1990 – 2013) (Mm³)	Specific Average Flow (l/s/km²)	Reference Gauging Station
Abou Ali	481	218	14.4	Abou Samra
Arka	121	49	12.7	Hakour
Assi	1764	390	7.0	Sea Mouth
Awali	302	433	45.5	Saida
Bared	281	127	14.3	Sea Mouth
Beirut	222	78	11.2	Daychounieh
Damour	293	183	19.8	Sea Mouth
El Ghadir	52	9	5.6	Sea Mouth
El Jouz	180	57	10.0	Sea Mouth
El Kabir	300	432	45.7	Sea Mouth
El Kalb	258	190	23.4	Sea Mouth
Hasbani	526	151	9.1	DS Wazzani Spring
Ibrahim	336	335	31.7	Sea Mouth
Litani	1288	223	5.5	Joub Jannine
Litani	2163	215	3.2	Sea Mouth
Ostouane	161	71	14.0	Sea Mouth
Sainiq	108	11	3.3	Sea Mouth
Zahrani	109	18	5.1	Sea Mouth
Perennial rivers	7,656	3,189	13.2	
Main wadis*	1,223	448	11.6	
In-between and secondary seasonal rivers	1,522	623	13.0	
Grand Total	10,400	4,260		

A.1.1.3 Snow cover

Snow cover is the main source of groundwater recharge which is enhanced by fractures, sinkholes and depressions of a heavily dissected karstified limestone across Mount Lebanon and Anti Lebanon mountain chain. Mount Lebanon is yearly covered by snow during 3 months between 1,700 m and 3,000 m, with an average yearly precipitation of around 3,000 Mm^3 in the form of snow, with the snowpack reaching its peak in March. Starting February, temperatures are sufficiently high to cause snowmelt at altitudes lower than 2,000 m (Najem, 2007).

Two snow observatories were established in Lebanon jointly with the French National Research Institute for Development (IRD). The first observatory between 2000 and 2003 with the Regional Center for Water and Environment of Saint Joseph University (CREEN-USJ) with one station installed at the mountain top of Mzar - Faraya and another in Oyoun el Simane. The project included snow sample collection and snow cover monitoring across Nahr el Kalb watershed over 2 years and resulted with an extensive finding on snowfall, snowcover and snowmelt characteristics in Lebanon and an estimation of the Snow Water Equivalent.

The snow that covered Mount Lebanon during the 2000 - 2001 winter contributed an equivalent of 1,250 Mm^3 (± 10%), compared to a total rainfall volume of 1,875 Mm^3 (CREEN, 2001). Using satellite imagery, the amount of water derived from snowmelt over Mount Lebanon for the years 2001–2002 was estimated to be around 1,100 Mm^3, which suggests that about two thirds of the precipitation is derived from snowfall and not directly from rain, as snowmelt infiltrates the limestone and discharges at several karst springs (Aouad et al., 2005; Hreiche et al., 2006)

The second observatory established under SudMed scientific and technical cooperation signed in 2010 in a joint project between Centre d'Etudes Spatiales de la Biosphère CESBIO-IRD, the Lebanese National Council for Scientific Research/Remote Sensing Center (CNRS-NRCS) and Remote sensing Lab at Saint Joseph University (USJ). Three Snow monitoring stations were installed in Faraya at 2300 m, Laqlouq at 1850m and Cedars at 2850 m. The mean snow density for the three stations over the two snow seasons (2014–2016) ranged between 440 kg/m^3 and 489 kg/m^3. These high seasonal density values are common in Mediterranean regions (Fayad et al., 2017).

The Assessment of Groundwater Resources report evaluated the snow water equivalent using satellite imagery (MODIS). To consider the variations in snow coverage the satellite imagery was combined with land measurements to determine snow thickness and density over January, February and March for the hydrological cycles of 2008 to 2012. The yearly water equivalent volumes using this technique was estimated between 1,815 Mm^3 and 2,567 Mm^3 hence an average of 224 mm and 2295 Mm^3 (UNDP, 2014), an average close to the estimated springs discharge estimated in the previous paragraph.

A.1.2 WATER BALANCE

Several studies and projects have tried to develop an annual water balance of the Lebanese water resources but failed to deliver a long term estimation which considered all the components. In ex. UNDP 1970 study of Lebanese groundwater missed to include snow contribution as no monitoring stations were installed above 2000 m altitude back in that time; FAO 2008 *AQUASTAT country profile* report didn't calculate the evapotranspiration however, was adopted by the 2010 NWSS with an unjustified estimation of the evapotranspiration at 50% of the total precipitation; UNDP 2014 assessment of groundwater resources in Lebanon estimated the water balance components for only two hydrological cycles (2010-2011) and (2011-2012) without estimating the surface and groundwater flows to adjacent countries and the flow of submarine sources. Nevertheless, UNDP (2014) advanced a serious calculation of the real evapotranspiration using Turc (1961) method over 71 meteorological stations across Lebanon with an estimation ranging between 16% and 26% of the total precipitation.

Despite all these estimations, a complete and inclusive long term annual average water balance is still missing for Lebanon and requires further knowledge and studies especially regarding real evapotranspiration estimation, groundwater resources leaving Lebanon either to adjacent countries or to the sea through submarine springs with estimations dating back to 1970's. In addition, with the new information collected on snow cover contribution during last decade, it should be seriously integrated into the annual water balance.

The 2020 NWSS annual water balance updated the 2010 NWSS based on the review of FAO 2008 components to include the total losses as deficit of runoff (evapotranspiration and other losses) estimated at a ratio of 30% equivalent to 2,579 Mm^3 closer to UNDP 2014 real evapotranspiration figures between 16% and 26% of the total precipitation. The same figures as of FAO 2008 were adopted for the water outflow leaving Lebanon, with the total surface water outflow estimated at 735 Mm^3/year, of which 160 Mm^3 to the sea and the total groundwater outflow leaving Lebanon estimated at about 1,020 Mm^3/year of which 740 Mm^3 to the sea. Hence, the water resources remaining in Lebanon are 4,225 Mm^3/year of which 700 Mm^3 as dynamic reserves, 2,050 Mm^3 as springs discharge and 1,475 Mm^3 as surface runoff, estimated from the average flows measured by LRA hydrometric service between 1990 and 2013 and other private hydrometric records. In summary, the real evapotranspiration is estimated at 30% of total precipitation, total surface runoff inside and outside Lebanon about 25% and groundwater infiltration about 45%.

The difference of 115 Mm^3 (equivalent to 3%) between the rivers measured flows of 4,260 Mm^3 from Table A 2 and the theoretical rivers flow of 4,260 Mm^3 (sum of springs discharge 2,050 Mm^3, surface runoff 1,475 Mm^3 and the surface outflow 735 Mm^3) is an acceptable error with all the measurements uncertainties.

It should be noted that the annual water balance was included for information and should not be adopted for water management plans at national scale. Rather, water management plans should be based on water balance estimated at the watershed scale as part of the IWRM approach. The updated water balance is presented in Figure A 1 below and the components advanced by the collected studies are summarized in Table A 3 below.

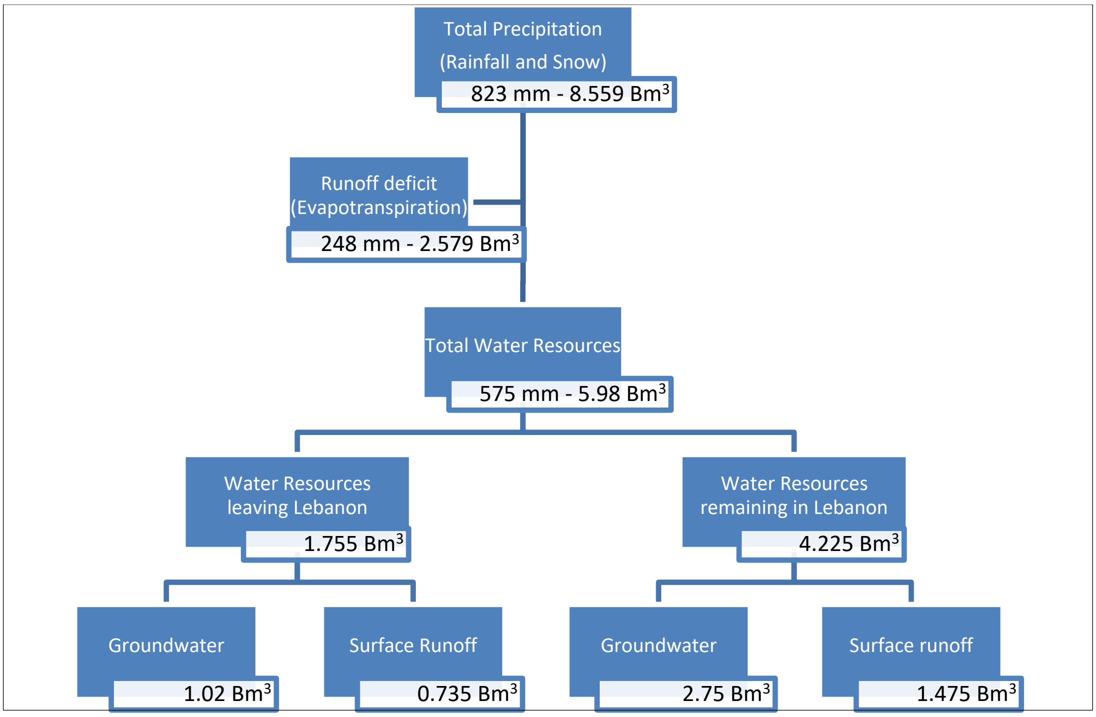

Figure A 1 Simplified annual water balance diagram

(Developed based on MEW 2010, FAO 2008 and UNDP 2014 reports)

In fact, Figure A 1 is a simplified diagram. The annual water balance distribution should be detailed furthermore to show each component distribution especially groundwater resources and the resources leaving Lebanon to adjacent countries or to the sea. Exploited water resources by different water establishments and authorities could also be added to the diagram. A detailed diagram is suggested in Figure A 2 which shows empty cases that must be filled for an adequate water resources management, which requires:

- Implementing adequate and comprehensive coverage of the Lebanese territory with meteorological and hydrometric networks, which would provide reliable data about surface water. Surface water management is addressed in detail in *Annex II Section B*.
- Carrying out required comprehensive geological and hydrogeological studies all over the Lebanese territory, in order to properly assess the groundwater capacity (static reserves), and also to properly assess how the volumes lost by "*groundwater seepage to the sea*" are affected by the exploitation of the sea cost aquifers. Groundwater management is addressed in detail in *Annex II Section C*.
- Conducting studies to set up Watershed management schemes.

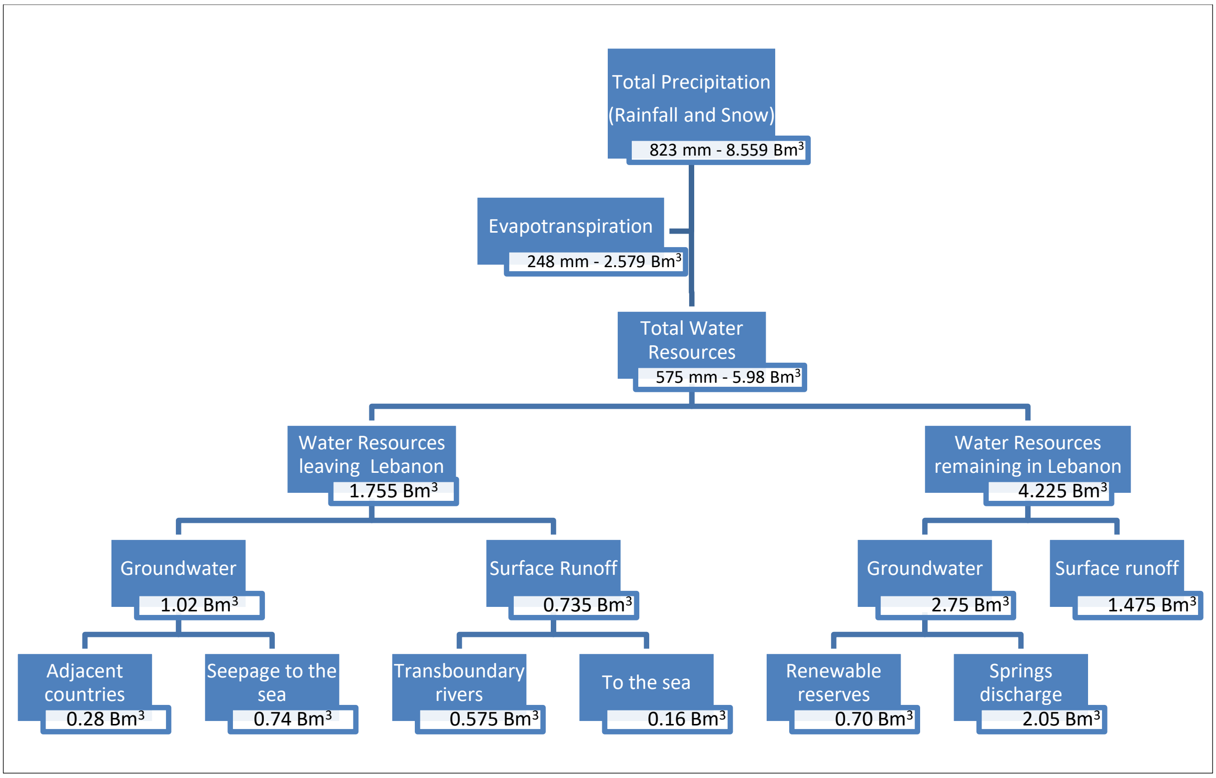

Figure A 2 Suggested detailed annual water balance diagram

Table A 3 Summary table of water balance estimation

Description	UNDP (1970)	Plassard (1971)	Geadah (2002)	World Bank (2003)	MoEW (2004)	FAO (2008)	MED EUWI (2009)	MoEW (2010)	UNDP * (2014)	MoEW (2020)
Precipitation (mm)	940	-	-	820	820	823	800 - 1000	823	764 - 1164	823
Evapotranspiration (mm)	-	-	-	380	430	-	500 - 600	433	206 - 197	248
Precipitation (Mm^3)	9800	8600	8600	8600	8600	8559	8320 - 10400	8559	7830 - 11932	8559
Snow (Mm^3)	-	-	-	-	-	-	-	-	1815 - 2567	-
Evapotranspiration (Mm^3)	-	4300	4300	4000	4500	-	4300 - 6240	4500	2110 - 2020	2579
Total flow of the 40 major streams (Mm^3)	4300	1800	1774	3800	3680	4100	3673 - 4800	2200	2151 - 3807	4260
Flow to adjacent countries (Mm^3)										
Surface flow	680	160 (Palestine) 510 (Syria)	670	700	945	575	300 - 670	700	-	575
Groundwater flow		150 (Palestine)	300	200		280	310	300	-	280
Flow of submarine sources (Mm^3)	711	880	880	700	385	-	385 - 1000	-	-	-
Total internal resources (Mm^3)										
Average year	-	-	-	-	-	4800	2600 - 4800	4800	2140 - 4675	4225
Dry year	-	-	-	-	-	-	1400 - 2200	-	2140	-
Exploitable resources (Mm^3)										
Surface water	-	-	-	-	-	1580	1500	-	-	1475
Groundwater	-	1800	-	-	-	500	700 - 1165	-	-	2750
Total exploitable resources	**-**	**-**	**2000**	**-**	**-**	**2080**	**1400 - 2200**	**-**	**-**	**4225**

* The NWSS 2010 – 2020 water balance was based on MEW and FAO 2008 reports with an estimation of the real evapotranspiration at 50% of the total precipitation

** UNDP 2014 annual water balance was assessed for only two hydrological cycles a dry cycle (2010-2011) and a wet cycle (2011-2012)

*** The NWSS 2020 – 2035 adopted FAO (2008) report with an estimation of the runoff deficit at 30% including the real evapotranspiration from UNDP 2014 report

A.2 IMPACT OF CLIMATE CHANGE

A.2.1 LEBANON CLIMATE

Lebanon is characterized by a Mediterranean climate with precipitation mainly occurring between October and March while June, July and August are always dry hence affecting water availability due to low water storage capacity and the shortcomings of the existing water supply system.

Mediterranean climate is a result of a complicated global cyclonic system swiping a large evaporative basin. The distribution of marine and continental air masses creates an alternation of low-pressure zones coming over from Iceland and the Persian Gulf or high-pressure zones from Siberia and Azores (Clerget, 1937). The seasonal shifts of these zones are magnified by the North Atlantic Oscillation (NAO) that plays an important role in shaping Mediterranean climate and influencing the evolution of farming and social activities on the long-term (Rodwell and Hoskins, 1996). During the positive phases of the NAO, oceanic disturbances bring the most humid to northern Europe and less humid to North Africa and the Middle East (Douguédroit & Lionello, 2015). This continuous alternation of high and low pressure, cold and humid winters followed by a hot and dry summers, marks the Mediterranean seasonality which makes the region attractive to social activities, thus its sensitivity to climate change and anthropogenic pressures (PlanBleu, 2012).

The Lebanese Meteorological Service (LMS) has divided the Lebanese territory for climatic and orographic considerations into three zones (Coastal, Mountainous, Internal) and each zone to North, Central and South region giving in total 8 climatic regions sharing specific climatic and landform characteristics, each covered by a number of stations (see Annex II Section B.2.1). Historical records over 50 years have registered a yearly average of 600 mm to 1,100 mm in the coastal zone, 1,210 mm over Mount Lebanon and 700 mm in the Beqaa. Qaa and Hermel region can record as low as 80 mm/year while top mountains can record as high as 3,010 mm/year, hence showing the high precipitation variability across the Lebanese territory.

The average annual temperature of the coastal zone is above 20°C, ranging from 13 °C in winter to 27°C in summer, whereas in Bekaa valley it's lower at 16 °C, ranging from 5°C in winter to 26°C in summer; nevertheless, at higher elevations located between 1,100 m and 1,200 m it's 15°C and in the mountain located above 1,800 m altitude the average annual temperature is below 10°C, ranging from 0°C in winter (with daily averages reaching -10°C during specific storm events) to 18°C in summer.

A.2.2 FUTURE CLIMATE CHANGE IN THE MEDITERRANEAN REGION

The Mediterranean basin has been identified as one of the most vulnerable regions to climatic and anthropogenic changes. Currently, the southern and eastern rims are experiencing high to severe water stress. Climate change is expected to have severe consequences on Mediterranean river flows with a serious risk of freshwater availability decrease of 2% to 15% for 2°C of warming and significant increase of droughts period particularly in the South and East (Hreiche et al., 2007; Cudennec et al., 2007; Garcia-Ruiz et al., 2011; Verdier and Viollet, 2015; Allam et al., 2020).

A.2.2.1 Analytical assessment of available timeseries

A climate change research program carried out at CREEN-USJ clearly demonstrated that precipitations over the Eastern Mediterranean Basin have not experienced any particular increasing or decreasing trends or a major shift in the rainy season over the past century (Najem et al., 2006; Zeinoun, 2004), however, long-term rainfall series do reveal wide multiannual variations, where lengthy humid periods follow lengthy dryer periods (Bakalowicz, 2009).

A.2.2.2 PRECIS Simulations projections

Climate change simulations were performed on the Eastern Mediterranean and Middle East driven by the IPCC Special Report on Emission Scenarios (SRES) A1B emissions scenario of the Third Assessment Report using PRECIS RCM (Providing Regional Climates for Impact Studies), based on the United Kingdom (UK) Met Office Hadley Centre HadRM3P model run over the period 1950–2099 at about 25 km resolution. PRECIS consists of the dynamic downscaling of the Atmosphere-Ocean General Circulation Models (AOGCM). SRES A1B emission scenario describes a future world of very rapid economic growth relying in a balanced manner on all energy sources (Zittis, 2013).

Future climate projections from PRECIS model shows that mean summer maximum temperature warming ranges between 3.5°C and 7°C by the end of the century while mean winter minimum temperature warming is less with a maximum between 3°C to 4°C by the end of the century. This warming is more spatially uniform for winter, while for summer it is most pronounced at north (6°C to 7°C) and weaker in the south (3.5 °C). The simulated changes in precipitation exhibit a large variability in space with –25% to –35% decrease around the South eastern Mediterranean projected by the end of the century and without a change in the North eastern region. The annual number of dry days of less than 1 mm precipitation may increase (10-20 days/year) in the East Mediterranean region while the number of days with heavy precipitation (>10 mm/day) is expected to decrease in the high- elevation areas.

A.2.2.3 MED-CORDEX RCM models

More recently, the CMIP5 simulations expected a mean precipitation decrease of -4%/°C and temperature increase of 20% more than the global average with maximum precipitation reduction reaching -7%/°C in winter in the southern Mediterranean region and -9%/°C in the summer in the Northern region (Lionello & Scarascia, 2018). At 1.5 °C global warming, some Mediterranean areas are under aridification while moving to drier state due to the decrease in precipitation combined with evapotranspiration increase leading to an expansion of drylands, hence affecting more people (Koutroulis, 2019).

The COordinated Regional Downscaling EXperiment specific for the Mediterranean Med-CORDEX aims at improving our understanding of climate change through high resolution Atmosphere Regional Climate Models (RCM). The primary application of RCM has been in the development of climate change scenarios of which ALADIN RCM (Aire Limitée Adaptation dynamique Développement InterNational) developed by Météo France and CCLM (Cosmo Climate Limited-area Model) developed by the German Weather Service (DWD) both applied for Med-CORDEX projects (Rockel et al., 2008; Tramblay et al., 2013).

The MED-CORDEX RCM models historical and projected data simulated using ALADIN at 12-km resolution and CCLM at 50-km resolution under Radiative Concentration Pathway RCP 4.5 and 8.5 scenarios for the 2070-2100 period served to assess the climate change impact on the Mediterranean region and have demonstrated an evolution towards arid climate. RCP is a greenhouse gas (GHG) concentration trajectory adopted by the International Panel for Climate Change (IPCC) for its fifth Assessment Report (AR5) in 2014 (Giorgi et al., 2009; IPCC, 2013; Ruti et al., 2016).

A.2.2.4 ALADIN simulations projections

Under RCP 4.5 scenario, temperature is increasing by 1.4 to 3.5°C (average 2.2°C), with the lowest rates during winter and the highest during summer. In the South, on average, precipitation is increasing by 25% during winter and 70% during summer and decreasing by 15% during spring and 5% during fall. In the North it is increasing by 10% during winter, spring and fall while staying stable along the year in the central region.

Under RCP 8.5 scenario, the case is accentuated for temperature which is increasing evenly across the Mediterranean by 2.5 to 5.6°C (average 3.8°C) with the lowest rates during winter and the highest during summer. In the South, on average, precipitation is increasing by 60% during summer and decreasing by 10% during winter. In the North it is increasing by 5% during spring and summer while staying almost stable along the year in the central region.

A.2.2.5 CCLM simulations projections

Under RCP 4.5 scenario, temperature is increasing by 1.9°C to 3.5°C (average 2.9°C), with the lowest rates in the South during winter and the highest in the North during summer. In the South, on average, precipitation is increasing by 20% during winter and 10% during fall and decreasing by 10% during summer but stable during spring. In the North it is increasing up to 10% during fall and winter and decreasing down to 30% during spring and summer.

Under RCP 8.5 scenario, temperature is increasing by 3.6°C to 6.4°C (average 5.1°C), with the lowest rates in the South during winter and the highest in the North during summer. In the South, on average, precipitation is increasing by 30% during winter and 10% during fall and decreasing down to 25% during summer but stable during spring. In the North it is increasing up to 10% during fall and winter and decreasing down to 60% during spring and summer.

A.2.3 FUTURE CLIMATE CHANGE IN LEBANON

The Second and Third National Communication (SNC[3] and TNC[4]) to the United Nations Framework Convention on Climate Change (UNFCCC) developed by the MoE in 2011 and 2016 presented the expected climate change effects in Lebanon obtained from university research programs and scenarios that have been developed for Lebanon through the application of the PRECIS RCM model (SNC) and MENA CORDEX RCM (TNC).

A.2.3.1 Statistical analysis

The analysis of precipitation timeseries have shown a stable trend without any clear variation in the past decades.Figure A 3 shows the precipitation in four Lebanese regions.

[3] MoE/UNDP/GEF, (2011)
[4] MoE/UNDP/GEF, (2016)

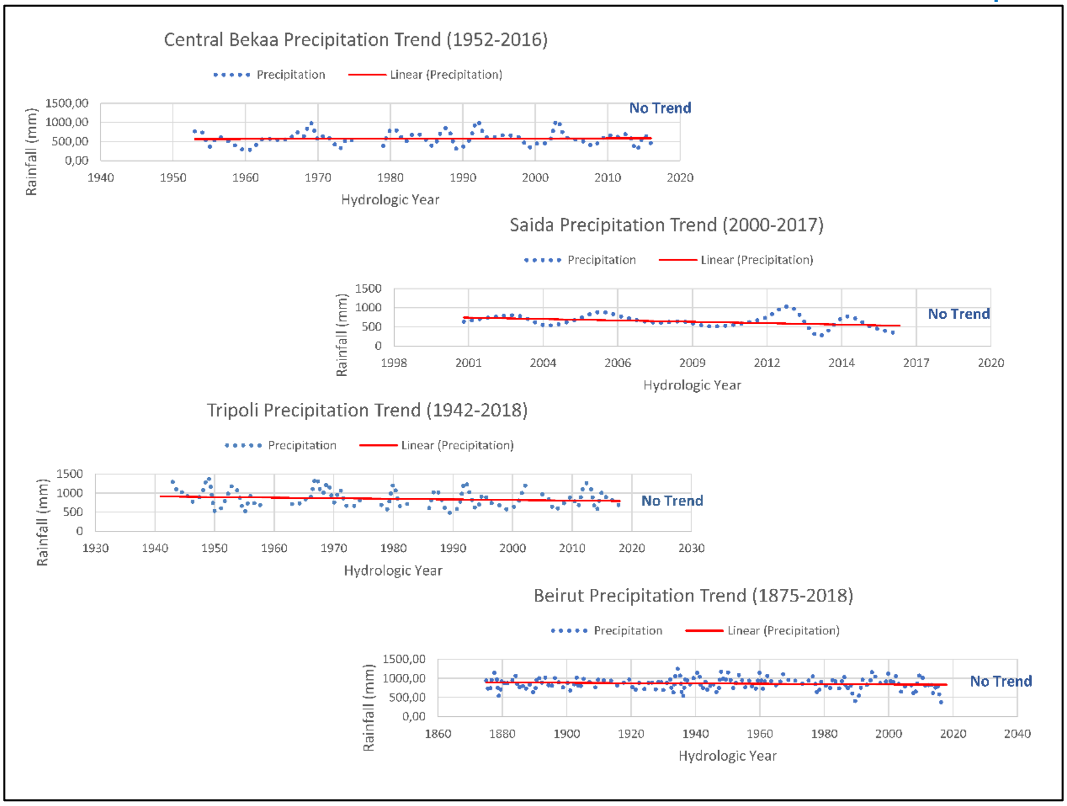

Figure A 3 Rainfall trend[5]

On the other hand, Figure A 4 clearly shows a confirmed increasing trend of minimum temperatures in Beirut with an estimated 3°C over the past 140 years

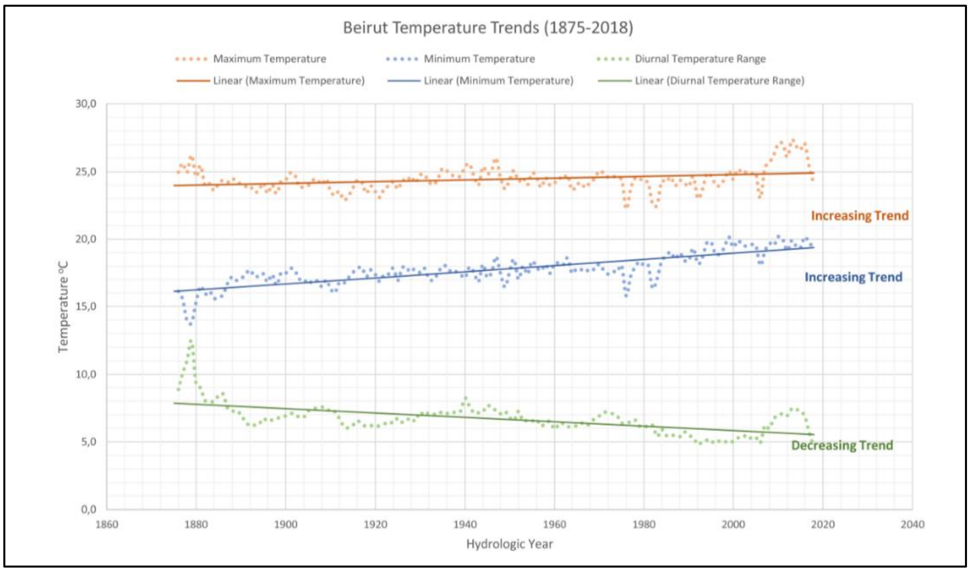

Figure A 4 Temperatures trend[6]

[5] Issam Fares Institute for Public Policy and International Affairs - AUB
[6] Issam Fares Institute for Public Policy and International Affairs - AUB

A.2.3.2 PRECIS Simulations projections

The main results of key climate variables in Lebanon as simulated by PRECIS were presented as changes of the respective periods of the near and distant future compared to the "control" period the last 20-30 years or the "recent past/ present". According to PRECIS model and in relation to the present climate, by 2040 temperatures will increase from around 1°C on the coast to 2°C in the mainland, and by 2090 they will be 3.5°C to 5°C higher. Comparison with Lebanese Meteorological System LMS historical temperature records from the early 20th century indicates that the expected warming has no precedent. Rainfall is also projected to decrease by 10% to 20% by 2040, and by 25% to 45% by the year 2090. This combination of significantly less wet and substantially warmer conditions will result in an extended hot and dry climate. Temperature and precipitation extremes will also intensify. In Beirut, hot summer days (T_{max} > 35°C) and tropical nights (T_{min} > 25°C) will last, respectively, 50 and 34 days more by the end of the century. The drought periods, over the whole country, will become 9 days longer by 2040 and 18 days longer by 2090.

In terms of seasonal changes, temperatures will increase more in summer and precipitation will decrease more in winter, while positive changes are predicted for autumn.

While the actual considered resolution is 25 km, the SNC authors pointed out the need for a finer modeling resolution to help decision makers defining Lebanon's optimal commitments on mitigation and adaptation measures facing Climate Change. Hence the importance of the application of recent RCM models considering new CMIP5 scenarios similar to the ones applied in the Med-CORDEX project which do not rely on downscaling the GCM.

The TNC included the analysis results of the projected climatic changes in Lebanon and their impacts on natural resources based on the generation of dynamically downscaled regional climate modelling projection covering the Arab/Middle East North Africa (MENA) domain in accordance with the CORDEX program under RCP4.5 and RCP8.5 scenarios. These projections were carried out through the Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources in the Arab Region (RICCAR) led by the United Nations Economic and Social commission for Western Asia (ESCWA). The projections were then linked to two regional hydrological models to specifically analyze the impact of climate change on the region's freshwater resources.

In Lebanon, the projections by the end of the century compared to the baseline period of 1986-2005 results showed an increase in temperature by up to 3.2°C with an increasing warming trend reaching up to 43 additional days with maximum daily temperature higher than 35°C. It also showed a decrease in precipitation by 4% under RCP 4.5 and 11% under RCP8.5 with trends towards drier conditions with an increase in number of consecutive dry days (when precipitation < 1.0 mm) which indicates the extension of dry summer season. This combination of significantly less wet and substantially warmer conditions will result in hotter and drier climate[7].

[7] ESCWA, (2015)

A.2.4 CLIMATE CHANGE IMPACT ON WATER RESOURCES

In what follows, we discuss the impact of climate change on water resources and consequently on SDG 6, SDG 2, and SDG 15.

A.2.4.1 Impact on SDG 6: Ensure availability and sustainable management of water and sanitation for all

The SNC and TNC included a climate change impact assessment on Lebanese water resources taking into consideration the effect of precipitation and temperature variation on surface water and groundwater availability from direct runoff, infiltration, and snowmelt. The assessment covered the variation of precipitation during wet season including snow cover, and losses through ETP increased by temperature increases during dry season. This assessment faces multiple challenges mainly the limited recorded data and lack of meteorological and hydrometric stations.

The expected increase in temperature as described in previous section has a considerable impact on the snow cover, main source of freshwater resources in Lebanon. It was estimated that a 2°C increase in temperature would cause a decrease of 50% in snow depth in addition to a significant reduction in the maximum volume of snowpack from 1,200 Mm^3 to 700 Mm^3; a 4°C warming would further reduce it to 350 Mm3. The altitude of sustained snow cover would also shift upwards from 1,500 m to 1,700 m for a 2°C warming, and to 1,900 m for a 4°C warming (Najem, 2007).

These findings were confirmed by the analysis of satellite images that have shown a noticeable spatial and temporal decrease between 1990's and 2000’s of the dense snow cover surface by 350 km^2 and residence time by 20 days (Shaban, 2009).

This has consequently major impact on the stream flow regimes of major rivers and springs. Drought periods would occur 2 to 3 weeks or even a month earlier for a 2°C and 4°C temperature increase, and peak flows would shift from the end of April to the end of March and river flows would increase during winter months while demand is low. Upon the recharge of most springs’ aquifers, early snowmelt will reduce the available water supply for irrigation during summer and increase floods by up to 30%. This will have adverse impacts on rivers and groundwater recharge and will affect water availability during summer season and drought periods.

The main consequence would consist in a decrease in spring and stream discharges towards the end of the dry season. Aquifer recharge conditions, however, remain less predictable, as one cannot easily forecast whether early precipitations would efficiently recharge the aquifers or simply contribute to fast runoff. In the absence of proper water storage structures, a considerable proportion of this water would be lost. From April to June, while the demand for irrigation water for agriculture is higher, the reduction in snowpack will not allow to sustain river flows.

These results highlight the increasingly difficult challenges that water sector is actually and will be facing in the future, particularly with respect to water supply, as a result of the expected increase in population and demand per capita, coupled with longer periods of water shortage. Drought’s impacts on groundwater usage for agriculture are considerable. It increases irrigation demand, which is met almost entirely by groundwater abstraction during dry seasons. Also, large agricultural areas depend on spring systems, while the discharge of these springs fluctuates in response to climate affecting changing snow cover and precipitation. While autonomous adaptation through changing of sowing dates is possible in the agriculture sector, the shortening of the season when aquifers and springs recharge will necessitate the construction of surface and underground storage reservoirs that can store enough water for the longer dry season (Hreiche et al., 2007; Najem, 2007).

A.2.4.2 Impact on SDG 2: End hunger, achieve food security and promote sustainable agriculture

The impact of climate change not only affects the flow regime of water, but also menaces Lebanon's food security if lower quantities of water are available for agriculture. Therefore, it is primordial that: i) the Government of Lebanon identifies the crops it considers important for the country's food security, and ii) the Ministry of Agriculture identifies the lands dedicated for these crops, so that MoEW and the WE's can properly plan their resource allocation and their infrastructure plans to cater for food security needs.

A.2.4.3 Impact on SDG 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

Changes in water availability directly and negatively impact biodiversity. Increase in temperatures and extreme hot weather events increase risks of forest fires, cause desertification and impact the water cycle in general, resulting in further changes to the climate. Forest fires also require water points be made available in proximity of forests, which requires planning and capital expenditures that should be decided on at a national level.

A.2.5 CLIMATE CHANGE IMPACT ON LAND

Soil erosion is a direct impact of extended drought seasons induced by climate change. Increased erosion might increase desertification, defined as "the degradation of land in arid, semi-arid, and other areas with a dry season caused primarily by over-exploitation and inappropriate [land] use interacting with climate variance" (FAO and NDMC 2008). Land degradation is defined as the "reduction or loss of the biological or economic productivity and complexity" (UNCCD, 1994). It is an underlying cause for reduction in ecosystem productivity and has ripple effect that can reduce the country's abilities to meet its needs of clean and safe water, food and liveable and environments. Lebanon's vulnerability to climate change is expected to hasten land degradation processes; therefore, the country has committed to the Land Degradation Neutrality (LDN) framework that is proving to be one of the most effective mechanisms of the United Nations Convention to Combat Desertification (UNCCD).[8]

Conservation agriculture, which consists of no-tillage, permanent soil cover through crop residues or cover crops and crop rotation, has strong mitigation and adaptation synergies. Conservation tillage has been shown to enhance soil structure and thus water holding capacity, making agriculture more resilient to extreme weather events such as heavy rains and drought. In addition, the increase in soil water content in dry climates can limit soil erosion, decrease desertification, and make agricultural lands more resilient to climate change.[9]

[8] MoA/UNCCD/LDN, (2018)
[9] MoE/UNDP/GEF, (2016)

A.2.6 NWSS IMPACT ON CLIMATE CHANGE

This chapter has discussed till now the impact of climate change on water resources and their availability. In this section it will discuss the probable impact of the strategy on local and global climate including the adopted objectives and proposed projects (dams, infrastructure, etc.) and actions.

The strategy is developed in the context of the Sustainable Development Goal 6, in particular target 6.4 "By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity." It also implicitly takes into consideration the SDG 13 "Take urgent action to combat climate change and its impacts" through the adoption of the IWRM as main background framework with all the proposed governance measures, sector reform and projects.

The adoption of the IWRM at the river basin level as main approach with all its implementation principles in particular the principle of sustainable development will optimize the water resources distribution according to its availability now and in the future taking into consideration the climate change scenarios discussed previously (Principle of sustainable development : According to which water resources management must meet the environmental needs of the present without compromising the ability of future generations to meet their own needs). The potable water balance estimation at the distribution system level in each district has detected the deficit and surplus of available water resources and suggested corresponding development projects accordingly. This exercise could be considered as first step towards complete IWRM at the river basin level once necessary data will be collected and water balance models developed using appropriate software (WEAP software detailed in Annex II Section B). The optimized water balance shall ensure sustainable withdrawals and address water scarcity issues.

The suggested projects are diverse and range between municipal, district and national level. Their impacts are also diverse some are local like wells and springs intake and can only affect the concerned aquifers and streams and other have larger impacts like dams that can affect the microclimate and the ecosystem.

Dams and corresponding lakes can induce altered microclimate due to increased humidity and cooling in the area, they will also induce greenhouse gas emissions because of decomposing matter submerged by the flooding. To mitigate those effects, every removed tree, can be compensated by another and the ecosystem restored in an adjacent area of the dam.

A.2.7 CLIMATE CHANGE ADAPTATION

Lebanon faces significant challenges in meeting the country's water demand in terms of quantity and quality. Unsustainable water management practices, environmental risks and water governance shortcomings are among the main obstacles facing the sector. Water demand has increased excessively the last decade which multiplied the challenges in ensuring the required quantity and quality. Water governance, unsustainable water management practices and environmental risks are among the main obstacles facing the sector.

One of the limits to the climate change adaptation and mitigation is the absence of a wholistic climate monitoring mechanism. Monitoring systems act as information sources to trigger action. This dearth of climatological data and the non-centralized nature of water resource data management are major stumbling blocks hence the importance of implementing an Integrated Hydrological Information System (IHIS) within the Ministry of Energy and Water.

Acknowledging that climate change impacts (drought, floods, etc.) is a major challenge in Lebanon is the first step towards a long term risk management plan, hence awareness campaigns shall be carried out by different stakeholders to raise awareness level especially in the poorest communities that have limited resilience and adaptation capacity to manage climate change risks while being the most affected.

In Lebanon, drought management is not centralized, but managed by individual institutions through their own frameworks. There is not a guiding national strategy for drought management and efforts are not coordinated and institutional roles in drought management are not clear and support is limited to only one institution, the Higher Relief Fund effort.

Successful drought risk management requires both immediate emergency assistance and longer-term policy, structural, and institutional interventions, with a focus on water resource management, agricultural technology improvements, and water-related infrastructure developments.

Lebanon's adaptive capacity to the impact of climate change on water resources is low due to its limited capacity to store surface water and groundwater, to face seawater intrusion, to reduce the losses in the distribution network, to promote best irrigation methods and water conservation practices through the implementation of metering systems, tiered pricing, awareness efforts, etc.

SNC and TNC promoted for a national adaptation framework for the water sector, needed to restructure water governance, implement measures for water resources and infrastructure, improve surface and groundwater quality, improve equitable access to sustainable water supply and enhance knowledge and capacity for climate change adaptation.

Potential adaptation measures include:

- Reducing the likelihood that coastal freshwater aquifers will experience from saltwater intrusion as sea level rises;
- Increasing the water-use efficiency of domestic, industrial, and agricultural sectors;
- Developing watershed-managed plans appropriate for expected changes in climate;
- Investigating the feasibility of alternative sources of water supply;
- Improving the available information about Lebanon's water resources and water systems.

The Technology Needs Assessment (TNA)[10] developed in 2012 identified potential adaptation technologies that would enhance adaptation to climate change for the several prioritized sectors including water and agriculture. These potential efforts generally aim to reduce the vulnerability of Lebanon's capital resources to climate change and increase their resilience.

According to an assessment on updating the national adaptation plan to climate change in the water sector conducted under CapWater project (funded by the World Bank and implemented by the CNRS in 2015), several obstacles have been identified that prevented the implementation of previous adaptation measures within the water sector and that will influence any current or future attempts to adapt to climate change effects within the water sector.

[10] MoE/URC/GEF, (2012)

The assessment proposes an action plan for the period 2016-2021 to consolidate the national adaptation framework in the water sector. Main areas of work identified in the action plan are:

- Restructure the water governance towards a climate responsive water sector
- Implement climate change adaptation and vulnerability reduction measures for water resources and infrastructure
- Improve surface and groundwater quality
- Improve equitable access to sustainable water supply
- Enhance knowledge and capacity for climate change adaptation in the water sector.

During the 21st Conference of the Parties in Paris in December 2015, a strong broad coalition of 290 nations, river basin organisations (including cross-border), business and civil society and funding agencies announced the creation of the Paris Pact on Water and Climate Change Adaptation. The objective of the pact is to make water systems – the very foundation of sustainable human development - more resilient to climate impacts. Lebanon is one of the countries that joined the initiative, which is led by the International Network of Basins Organisations (INBO).

The pact encompasses individual commitments to implement adaptation plans, strengthening water monitoring and measurement systems in river basins and promoting financial sustainability and new investment in water systems management. The project Lebanon is involved in under the Pact is the Mediterranean Water Knowledge Platform, a 7-year commitment to assess the state and trends of water resources.

A.2.8 NATIONALLY DETERMINED CONTRIBUTION

In December 1994, Lebanon ratified the UNFCCC and has since been involved in various activities aimed at spreading climate change awareness in the country, reducing national GHG emissions, developing measures to reduce adverse impacts on environmental, economic and social systems, building institutional capacity and mainstreaming climate change into the different policies. These activities were undertaken and monitored through a platform, the Climate Change Coordinating Committee (CCCC), led by the Ministry of Environment and in cooperation with its various focal points located at the line ministries, government agencies, private sector and academic institutions.

In the context of UNFCCC - COP 21 in Paris in December 2015, Lebanon presented its Intended Nationally Determined Contribution (INDC) to the Paris Climate Agreement built on the development of low-carbon and adaptation strategies[11]. In 2016, an official NDC committee was established with the objective of following up the NDC implementation and reporting (Council of Ministers' decision 185/2016, dated 7/10/2016) and in 2017, the Council of Minister's decision 33-2017 mandated the MoE to coordinate the NDC's implementation. In 2019, the government issued Law 115 for the ratification of the Paris Agreement. In accordance with article 4.9 of the Paris Agreement (and Law 115/2019) the republic of Lebanon submitted an update to its 2015 NDC.

[11] MoE, CCCC, (2015)

Given the projected decrease in precipitation, there is an immediate need to increase water resources through the designing and commissioning of dams and hill lakes as well as artificially re-charging the groundwater. In addition, there is a need to optimize the use of current water resources through the rehabilitation of the existing network and the installation of water meters. Lebanon is already undertaking major initiatives to ensure the availability of affordable water for domestic, industrial and agricultural use, in line with the NWSS. However, more technical, financial and capacity building support and technology transfer is needed to optimize water storage, water use efficiency, improve irrigation systems and demonstrate reuse of wastewater.

With this NDC, the Lebanese government strived to both build resilience and improve adaptation as it lowers emissions, and therefore take advantage of the synergies between adaptation and mitigation. Regarding mitigation, the NDC has two targets: the first representing the country's own contribution "unconditional target", the second offering a wider mitigation "conditional target" conditional on receiving international support. The water sector adaptation measures objective consists of increasing water availability and improving water usage to decrease the sector's vulnerability to climate change impacts by:

- Implement the Beirut Water Declaration[12];
- Enhance the efficient use of irrigation water and expand the supply of surface water sources for irrigation;
- Encourage and support the use of renewable energy in agricultural irrigation and in drinking water supply;
- Build an operational and sustainable legal and institutional framework to ensure a proper management of the water sector allowing the development of sustainable and efficient services;
- Develop financing tools for the sector to set-up financial mechanisms allowing the sustainability and the financial balance of the services;
- Involve all actors in the service chain and establish sustainable mechanisms for collaboration and coordination to improve the sector monitoring and transparency.

[12] https://www.riob.org/en/file/280436/download?token=pIghIHCp

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SECTION B
Surface water resources management

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EXECUTIVE SUMMARY

General

Within the NWSS update for 2020-2035 an assessment of the Lebanese meteorological and hydrological information networks constituted a main component of the data collection and the basis of any National Surface Water Management. In this report, a survey and assessment of the existing meteorological and hydrological information systems were carried out in their actual status; it included a detailed list of all 137 meteorological stations and 138 hydrometric stations, regardless of their operational situation, located on all catchments, rivers, springs and channels across Lebanon showing their locations and eventually their specifications when available. The assessment also identified the actual gaps of the existing networks mainly the proper coverage of hydrogeological aquifers and mountainous areas; and suggested a methodology for the implementation of new stations based on WMO recommendations and Lebanese climatic and landform characteristics.

The association and combination of the LMS's climatic zoning approach, LRA's catchment scale distribution approach and completed by LARI's agrometeorological network for agricultural areas ensures that catchment microclimates are well covered (coastal areas, plains, lowlands and mountains), rivers specific hydrological regimes are taken into consideration (snow influence, spring contribution, etc.) and landcover characteristics are covered by LARI's network for evapotranspiration estimation. This integrated network could be achieved without any institutional merge or tasks overlap but requires a very developed technical assistances focusing on staff training for performing and following up hydrologic measurements and an elaborate inter-institutional coordination within the Integrated Hydrological Information System (IHIS) centre.

In fact, the primary function of a hydrological service is to provide essential information to decision makers on the status and trends of the water resources from systematic data collection, archiving and dissemination. A reliable hydrological monitoring system is the basis of any assessment, management and planning of a National Water Sector Strategy that aims to overcome the challenges related to Integrated Water Resources Management (IWRM) and achieve Sustainable Development Goals (SDG).

Upgrade of meteorological and hydrometrics networks

The implementation of complete meteorological and hydrometric networks, constituted by LMS, LRA, LARI's and MoE networks, requires reinforcing the networks with 113 additional meteorological stations and 135 additional hydrometric stations, in order to reach an average density of 50 km²/station. The implementation plan shall take into consideration the available budget and could be divided into several phases either by gradually expanding the basic network to reach a complete network or by fully equipping one catchment at a time and then moving on to another catchment.

Implementation of an Integrated Hydrological Information System

On the other hand, Lebanon has not yet established an IHIS which shall provide public and private stakeholders an access to reliable information and management services to build this management approach. An IHIS will allow all information providers to manage, publish, share their data, products and services and will allow all users to develop value-added services and new products.

For these reasons, a strategy for the IHIS implementation is recommended with a focus on supporting Lebanese decision regarding the United Nations SDGs, the United Nations Framework Convention on Climate Change (UNFCCC), the Global Framework for Climate Services (GFCS), etc. An Implementation Coordination Team of the IHIS shall be formed to elaborate and maintain a strategic plan for developing the IHIS over the next period.

The proposed studies for IHIS implementation are:

- Assessment studies for the meteorological and hydrometric networks including an assessment of the Institutional framework and working teams (skills, knowledge, expertise, trainings, etc…), an assessment of the data management centre and quality of measurements, etc…
- Update and analysis of the National Land Use Master Plan Geodatabase (NLUMP) in order to include the latest and most precise maps describing the Lebanese landscape, geology, hydrogeology, land use, morphology, water and land resources with the contribution of both public and private sectors especially academic and research institutions.
- Lebanese Data Rescue Project to preserve all data at risk of being lost due to deterioration of the medium and digitizing current and past data into computer compatible form for easy access as most of climatic data are still on paper.
- Design studies of the IHIS implementation upon the achievement of all assessment studies of existing meteorological and hydrological networks and based on the resulting comprehensive analysis report of the NLUMP. The proposed studies are:
    - Institutional and capacity building of all administrations involved in the IHIS.
    - Design of the LMS, LRA, LARI and MoEW meteorological and LRA hydrometric networks.
    - Design of data management centre including server specifications, data collection, dissemination and archiving protocol.
    - Benefit cost analysis of the implementation of the IHIS.
    - Preparations of the terms of reference for IHIS implementation
    - Integrated water resources management for major Lebanese rivers using WEAP software over a time period of 5 years.

Cost estimates

The estimated cost for the required works is as follows :

• MH-A: Meteorologic and Hydrologic Networks upgrade and expansion:	6,066,000 USD
• MH-B: Integrated Hydrological Information System	9,548,000 USD
	15,614,000 USD

B.1 INTRODUCTION

The water sector in Lebanon faces several challenges that stand between its current situation and the sustainable sector that the MoEW and all stakeholders tends towards it. Among these challenges are the limited capacities for an Integrated Water Resources Management (IWRM) and incomplete monitoring actions of the entire sector showing discrepancies in data.

IWRM is the main background framework of the strategy. It has several implementation principles that are included as core principles of the Water Code (law 77/2018) and its anticipated revision. It is a process that promotes the coordinated development and management of water, in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment. This means that infrastructure must be re-positioned as part of a more comprehensive system and not as an objective in itself.

A Bottom - Up IWRM approach could be the best fit for Lebanon starting at the distribution schemes level and up to river basin level then national level. This updated NWSS has tried in *Annex III Section B.3* to cover the potable water balance deficit for each distribution scheme for the 2020-2035 horizon by proposing the construction or rehabilitation of local projects like wells, tapped springs, pumping stations, treatment plants, and regional projects like dams. The validation of the proposed development projects at the river basin and national levels was not carried out as it requires first, accurate monitoring data of available surface water and groundwater resources and infrastructure, unavailable at the present time, see Sub Section B.2.3, and second, an extensive work of water balance estimation with the support of WEAP software and the development of all suggested studies out of this NWSS scope, see Sub Sections B.2.4B.2.5, and B.4.2. However, the estimation of the water demand for each distribution scheme and irrigation plan along with the extensive data gathering and listing of all available resources and infrastructure, are considered as initial steps towards IWRM at the river basin level, see Annex III.

The main objective of the National Policy Dialogue on IWRM planning in Lebanon was to assist the country in review the national 10-year strategy plan and to launch and advance the process of complementing the strategy with an IWRM plan. The review using the IWRM framework tackled issues of water balance, water management, supply and sanitation, irrigation and capacity building while achievements, gaps and deficiencies were identified.

The Lebanese government endorsed legally this national strategy with the newly ratified Water Code aiming to regulate, develop, rationalize and exploit water resources, protect them from depletion and pollution and improve the efficiency of transport, distribution and maintenance systems for the operation of water installations in order to ensure the sustainable management of the natural water resources of the Lebanese State. On the International level, Lebanon has joined the Paris Pact on Water and adaptation to Climate Change in the basins of rivers, lakes and aquifers, led by the International Network of Basins Organisations (INBO) at the COP21 in Paris in 12th December 2015. Previously in 1995 Lebanon has adopted Barcelona Convention the action plan for the protection of marine environment and the sustainable development of the coastal areas of the Mediterranean Sea which rivers consist the main component. These commitments are translated by strengthening the IWRM and improve governance at the river basin level.

IWRM is the hub of the 6 strategic components and their specific objectives and proposed actions. The upgrade of the hydrometeorological networks and the implementation of the IHIS with the recommended studies fall within the reporting and monitoring objective and specifically C.1 Enhance sector monitoring. A reliable hydrological monitoring system is the basis of any assessment, management and planification of a National Water Sector Strategy that aims to overcome the challenges related to IWRM and achieve Sustainable Development Goals (SDG). The primary function of a hydrometeorological service is to provide essential information to decision makers on the status and trends of the water resources from systematic data collection, archiving and dissemination.

Several international conferences, the United Nations Water Conference (UNWC) of Mar Del Plata in 1977 and subsequent related conference of 1991; the International Conference on Water and the Environment (ICWE) held in Dublin in 1992; highlighted that "*all efforts should be undertaken at the national level to increase substantially financial resources for activities related to water-resources assessment and to strengthen related institutions and operational services as necessary and appropriate at the national and regional levels*"[1].

The World Meteorological Organization (WMO) and United Nations Educational, Scientific and Cultural Organization (UNESCO) report on the Progress in the Implementation of the Mar del Plata Action Plan stressed on the need for an international, regional and national Water Resources Assessment for the following purposes.[2]

- Assessing a country's water resources (quantity, quality, distribution in time and space), the potential for water-related development and the ability of the supply to meet actual or foreseeable demand;
- Planning, designing and operating water projects;
- Assessing the environmental, economic and social impacts of existing and proposed water resources management practices and planning sound management strategies;
- Providing security for people and property against water-related hazards, particularly floods and droughts;
- Allocating water among competing uses, both within the country and cross-border;
- Meeting regulatory requirements.

The Dublin statement on water and sustainable development within the ICWE also highlighted very effectively the achieving goals related to sustainable development; (United Nations, 1992)

- The ICWE addressed the following issues:
- Integrated water resources development and management;
- Water resources assessment and impacts of climate change;
- Protection of water resources, water quality and aquatic ecosystems;
- Water and sustainable urban development and drinking water supply and sanitation in the urban context;

[1] Mar Del Plata Action Plan. (UNWC, 1977); Resolution № 1
[2] UNESCO, 1991

- Water for sustainable food production and rural development, and drinking water supply and sanitation in the rural context;
- Mechanisms for implementation and coordination at the global, national, regional and local levels.

In 2012, the EMWIS technical unit (Euro-Mediterranean Information System on Know-How in the Water Sector) within the Ministry of Energy and Water started working on a pilot project for a National Water Information System (NWIS), which guarantees data sharing among national key-institutions working in the water sector to ensure Integrated Water Resources Planning and Water Regulation. The status report presented the actual status of water data management and proposed a pilot development of a NWIS to be shared among the main stakeholders in the country and, in harmony with other Mediterranean countries systems. The focus of the foreseen NWIS is to provide reliable data for water resources planning as well as to enforce the water legislation.

The EMWIS 2012 report “Pilot development in Lebanon; status report and proposed action plan” has listed the public institutions involved in water related data monitoring with a brief description of existing datasets, monitoring networks and information systems. It has also addressed the inter-institutional cooperation and tackled on the challenges that each institution is actually facing in matter of data collection, network monitoring and information management. The EMWIS technical unit has proposed its vision for the implementation of a NWIS within the MOEW and suggested a 3 phases action plan over 30 months with a provisional implementation budget. However, the NWIS has not been established yet, however it shall be organized within a formal framework to involve all public and private stakeholders working in the water sector and clarify the roles and responsibilities of each stakeholder. The NWIS provisional budget was estimated at 3,128,600 Euros equivalent to 4,000,000 USD and the "Strengthening monitoring networks" item at 865,000 USD.

The Ministry of Energy and Water (MOEW) prepared in 2010 a National Water Sector Strategy (NWSS) which was approved by the Council of Ministers in 2012. This strategy presented a detailed road map for improving water conditions and service delivery in the country and included 7 objectives consisting on improving the management, the potential and quality of surface and groundwater water resources while fulfilling deficits. In 2018, the Lebanese government endorsed legally this national strategy with the newly ratified Water Code aiming to regulate, develop, rationalize and exploit water resources, protect them from depletion and pollution and improve the efficiency of transport, distribution and maintenance systems for the operation of water installations in order to ensure the sustainable management of the natural water resources of the Lebanese State. These commitments are translated by strengthening the IWRM and improve governance.

The updated NWSS for 2020-2035 includes completed projects and revise the planned projects to be in line with the Capital Investment Plan prepared by the Government of Lebanon for the CEDRE conference (April 2018) and which this section constitute a main component in the data collection.

B.2 SURFACE WATER RESOURCES MANAGEMENT

B.2.1 STUDY AREA

Lebanon is located in the temperate zone, at the limit of the arid zone. It has a typical Mediterranean climate characterized by a short, cold and wet winter season resulting in annual rainfall ranging between 600 mm and 2000 mm/year and by a practically total drought during summer months.

The Lebanese landscape is characterized by two long mountain chains dividing the country from North to South. The high mountains act as a barrier to the prevailing southwest winds carrying humid air masses across the Mediterranean. Due to its mountainous morphology, much of this precipitation falls in form of snow that accumulates throughout the winter over the mountains top.

The Lebanese littoral is rich in coastal rivers with the major rivers starting from North are, Nahr Al Kabir Al Janoubi, Ostouene, Arka, Al Bared, Abou Ali, Al Jaouz, Ibrahim, Al Kalb, Beirut, Al Damour, Al Awali, Sainiq, Al Zahrani, and Hasbani, Litani, Al Assi in the internal region. During winter these rivers are mainly fed by the rain falling over their watersheds. During spring they drain the melted snow accumulated at high altitude and discharged by the springs. This annual cycle is keeping on sustained flows in rivers by extending the low flow season and allowing the regulation of river regime. This phenomenon is mainly due to high contribution of the snow cover when melt, feeding up to 50% of the Lebanese coastal rivers' flows.

B.2.2 APPROACH AND METHODOLOGY

Management of surface water resources comprehends the management of rivers, springs, storage infrastructure like dams, hill lakes, reservoirs, and infrastructures like water and wastewater treatment plants, pumping stations, supply networks, stormwater etc. It also includes the risk management of disasters related to the water sector, such as floods, droughts, forest fires, contamination along with nonconventional resources like aquifer recharge, wastewater reuse and rainwater harvesting. Groundwater management, elaborated in Annex III Section C, is directly linked to surface water management as tapped springs and wells are the main supply of potable water and irrigation and shall be monitored in an integrated way along with surface water management.

It is imperative for an optimized management, that every component is well monitored, and resources are well assessed, hence the need for a complete monitoring service allowing the follow up of resources' availability and sustainable usage. Several hydrometeorological services are operational in Lebanon but with different status. This section will tackle the surface water resources management, presents an overview of the hydrometeorological services in Lebanon and propose the implementation of an Integrated Hydrological Information System (IHIS) within the MoEW for better management.

In brief, Annex II Section B will develop the surface water management with the following steps:

- Status of the hydrometeorological services in Lebanon with the review of the previous and actual monitoring services, description of the data management methodology and recommendation for their upgrade with design studies.

- The Integrated Hydrological Information System implementation methodology, design, and complementary studies.
- Disaster risk management.
- Nonconventional water resources.
- Cost Estimates and time schedule of IHIS implementation with all related studies.

B.2.3 DATA AVAILABILITY AND QUALITY

Effective management is based on sound decision-making based on accurate information. Data collection, verification and dissemination are therefore essential steps for the production of such information.

Ideally, for a water balance equation, all input and output parameters are directly measurable. In reality number of these components have to be estimated, because of:

- Difficulty of measurement: for example, groundwater inflows and outflows are often difficult to measure; as well as irrigation volumes used by agriculture. These can be estimated based on standard evapotranspiration values and estimates regarding cropped areas and cropping patterns;
- Insufficient or unreliable data: measurements exist only for the periods when a monitoring device was in place thus reducing the completeness of the dataset, and the accuracy of the resulting data. Although Lebanon used to have a reasonable network of gauging stations recording river flows, the civil war between 1975 and early 90s severely affected this monitoring process. Efforts have resumed since, but the lack of equipment and staff has not ensured routine collection of accurate data as it used to be. Focused efforts to improve both collection and quality control of hydrologic data are sorely needed.
- Access to existing data: data collected by various stakeholders is commonly considered with secrecy. Sharing of public data is limited within or among administrations and rarely if ever made accessible to the public at large.

In spite the limitations, experience has shown that water accounting, even based on estimates, can be quite useful to managers, farmers, and most importantly decision makers.

B.2 Surface Water Resources Management

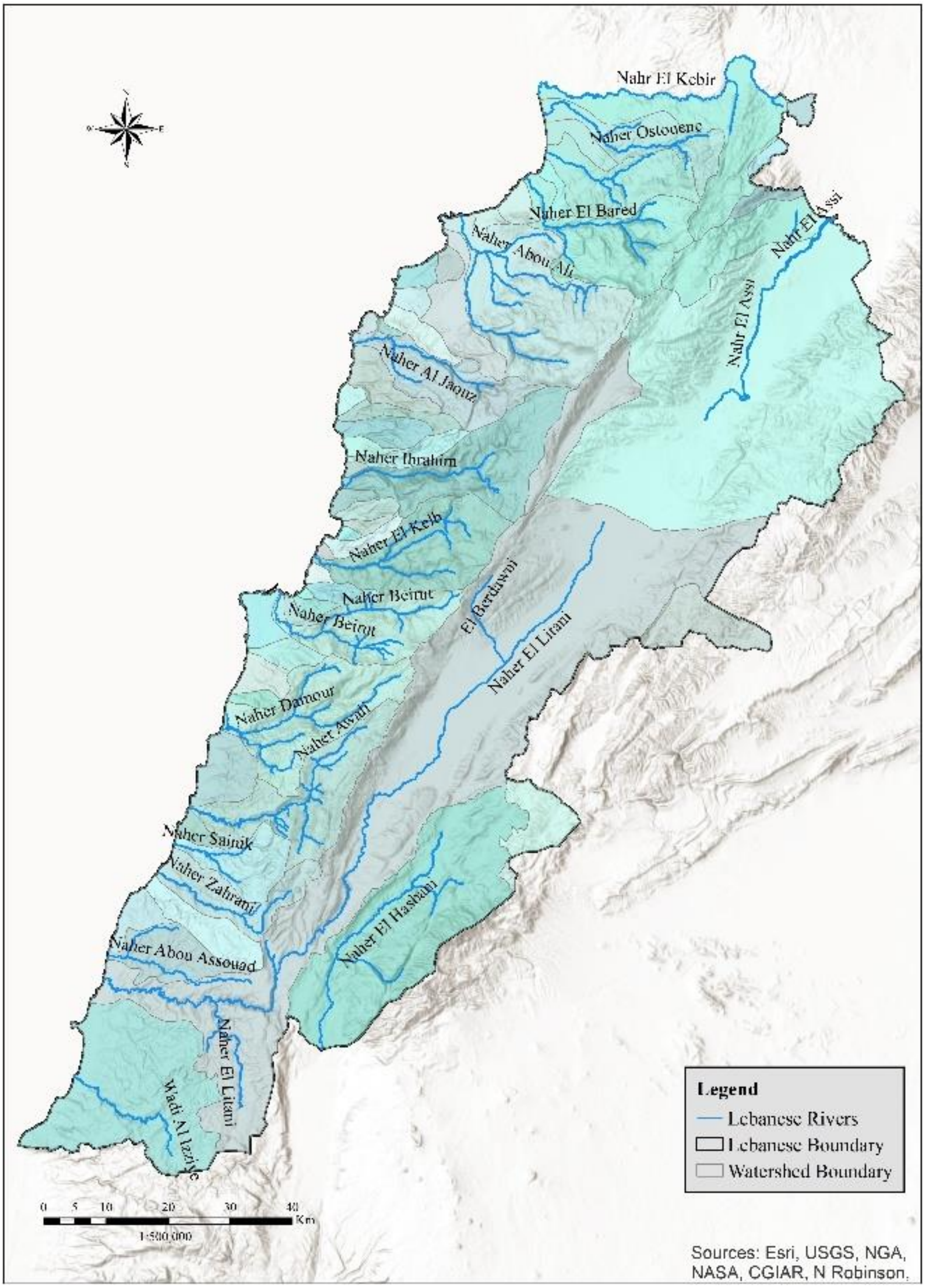

Figure B 1 Lebanese Rivers.

B.2.4 WATER BALANCE COMPONENTS

Building water balances helps to combine and structure the key components of the natural hydrological cycle and the relevant inputs and outputs due to human interventions (e.g. abstractions, returns, etc.) into a coherent framework. The following section explains these different components, identifying the type of information that is required for describing each component and developing water balances.

The first step in developing water balances requires the assessment of the freshwater resources, accomplished through the quantification of the components of the hydrological cycle. The hydrological balance equation is based on the principles of conservation of mass in a closed system: any change in the water content of a given watershed during a specified period must equal the difference between the amount of water added to the watershed and the amount of water withdrawn from it.

In a system with no external inflows from adjacent catchments and territories, the water is entering the system via precipitation (P), converted into evaporation (E) and/or runoff (R) (surface, subsurface or groundwater) and associated storage (S) or change in storage ΔS during the time period investigated, as expressed in the following general equation:

$$P = R + E \pm \Delta S \qquad [Eq.\ 1]$$

In detail, looking at the functioning of the hydrological cycle and the dynamics of its different components during a given time period, (P) reaches the soil surface and the vegetation where water can be intercepted and evaporate directly (Ei) or stored for domestic, industrial or agricultural uses (ΔS). Water can also infiltrate the soil or directly runoff (Rs) if the amount of rainfall exceeds the infiltration rate capacity (rainfall excess). The water infiltrating the soil goes to the unsaturated zone and recharges the ground water. Groundwater (Rgw) and unsaturated zone water (Rsub) can also contribute to river flows as subsurface runoff. Roots from vegetation cover absorb water that is transported to the stomata of the leaves, where it goes back to the atmosphere as transpiration (Et). Water can also evaporate directly from the soil or from the river (Es). Capillary rise brings water to the soil surface and then water evaporates.

Estimating the different storage capacities of a water system or catchment is key to understanding and analyzing the overall hydrological process. Water storage can occur in soil, groundwater, lakes, rivers, snow and glaciers or vegetation.

In some cases, there might be some amount of water that is lost or gained due to naturally occurring groundwater outflow or inflow (Ex_{InOut}) and from neighboring watersheds. This is common in karstic systems or coastal areas both widespread across Lebanon. This amount should be then incorporated in the water balance equation.

Thus, in a natural hydrological system with external outflows and inflows the water balance can be further formulated as follows:

$$P + Ex_{InOut} = R_s + R_{sub} + R_{gw} + E_s + E_i + E_t \pm \Delta S \qquad [Eq.\ 2]$$

With P: Precipitation measured by weather stations

R: Runoff measured by available hydrometric gauging stations or estimated based on surface flow data, and hydrogeological assessments (s: surface, sub: subsurface, gw: groundwater)

E: Evaporation measured or estimated as a percentage of precipitation according to land cover types (s: surface, i: interception, t: transpiration)

ΔS: Change in storage over time due to domestic, industrial or agricultural practices.

Ex_{InOut}: External Inflow or Outflow is the total volume of actual flow of rivers and groundwater entering or exiting the watershed from or to adjacent watershed or systems.

The quantification of the components of Eq. 2 at a given watershed in a given time period requires information from monitoring stations. Hydrometeorological networks provide information on water flows into, and losses from, rivers, soils, lakes and aquifers, as well as on precipitation and evaporation, in selected sites, depending on the design and density of the network. However, estimations are always needed since it is impossible to monitor every component at every place. Irrigation, domestic and industrial flows are usually estimated from both surface and groundwater withdrawals or using collected information from different water establishments[3].

Until now, the existing meteorological and hydrological information networks do not allow the estimation of the water balance at high resolution. However, it is possible to estimate the water balance at the catchment and sub-catchment scale based on the existing stations. The accuracy of the water balance estimation shall improve with the networks upgrade until a high resolution precipitation grid of 1km x 1km could be established for Lebanon.

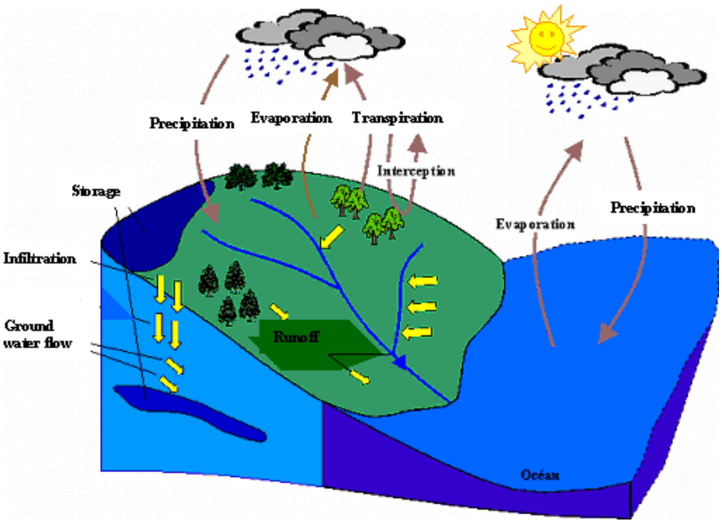

Figure B 2 Sketch showing different components of the hydrological cycle.

[3] Source: WMO Guide for hydrological practices Vol. I

B.2.5 WEAP MODEL AND SOFTWARE

WEAP (Water Evaluation And Planning) is an integrated water resources management system developed by the non-profit research and policy institute Stockholm Environment Institute (SEI). It has a GIS-based graphical user interface that permits a physical simulation of water demands, supplies and scenario management. it helps with high level planning and strategic analysis at local and regional scales. WEAP is acknowledged as a Decision Support System (DSS) tool for water management in Lebanon and other MENA countries.

WEAP model will help in assessing the actual status of water resources and simulate several future technical, institutional, socioeconomic and climatic scenarios with the purpose of improving the conservation and management of the river basin and optimize the economic, environmental and social benefits of the river. This model is addressed to different stakeholders and water management experts, Ministry of Energy and Water (MoEW), Ministry of Environment (MoE), Water Establishments, local municipalities and communities. This model shall serve as a decision support system (DSS).

The model shall include river runoff data, all major spring discharges, dams and reservoirs, major groundwater outflows and/or inflows, demand sites corresponding to irrigation projects, wastewater treatment plants, quality monitoring sites, etc… The model shall also include climate data consisting of precipitation (P), reference evapotranspiration (ET_0), relative humidity and temperature (T).

The general approach of developing a WEAP model includes several steps, rivers, boundaries of study area and the sectorial scale of the system's modeling process have to be defined. Boundaries are represented by river catchments. Based on this definition, demand and supply elements of the system are identified, integrated into the model and connected to each other via natural or manmade conduits. This built up structure is called schematic.

Data is attributed to the elements of the system. After data input, assessment of quantification of flows and calibration of the model can be conducted. In this stadium, the model represents a conceptual representation of the real hydrological system that is called Current Accounts. It is the best available estimate of the current system in the present. Based on the Current Accounts, a reference or business-as-usual scenario is established. The reference scenario may include a variety of additional economic, demographic, hydrological and technological trends. After definition of this, simulations of the model lead to the assessment and interpretations concerning water distribution, supported by visualized output, through diagrams, maps or through data tables.

For the working process, WEAP contains five different views:

I. Schematic View. This graphical window represents the physical structure of the supply- and demand system that can be easily modified through drag and drop.
II. Data View. This shows a hierarchical tree in which relationships between the system's elements are represented. Hierarchy can be modified, and element's data can be accessed.
III. Results View. It displays charts and tables referring to supply and demand sites.
IV. Overview View. This can show a group of charts simultaneously.
V. Notes View. This is a simple word processing tool for documentation and references for each branch of the hierarchical tree (Data View).

WEAP includes some additional features, such as the water year method, a tool that takes into consideration the temporal variability of input of the hydrological system. This is done through scenario analysis. Seasonal variation of streamflow, precipitation or groundwater recharge can be established and defined as different climate regimes (dry-wet, hot-cold), relative to the Current Accounts. Another important tool is the Rainfall Runoff Method (simplified coefficient) that is based on the methodology of FAO, taking into account the variability of rainfall. The Rainfall Runoff Method (soil moisture) integrates a one dimensional, two-layer soil model for advanced surface water/groundwater modeling. By using this method, the user can specify soil properties and advanced climate data (temperature, humidity, wind speed, etc.). Based on these data, WEAP calculates interflow, deep water percolation and ET_0. In turn, the disadvantage is the need for relatively complex data, especially to specify soil properties.

In addition to the water balance monitoring at the catchment scale using WEAP software, natural disaster risks shall be monitored using real-time climatological and hydrological models and software at high resolution. These models shall be developed progressively with the IHIS implementation and the meteorological and hydrometric networks upgrade.

B.3 STATUS OF THE LEBANESE HYDROMETEOROLOGICAL INFORMATION NETWORKS

B.3.1 LEBANESE METEOROLOGICAL SERVICE

B.3.1.1 Networks before 1975

Several academic, private and public services have been monitoring meteorological variables in Lebanon since 1875, when the first weather station was installed by the meteorological service of the American University of Beirut. The number of weather stations started to increase when the Observatory of Ksara was founded as part of Saint Joseph University on the 4th of November of 1906, which started publishing monthly weather data summaries named "Bulletin". The meteorological network reached 56 stations in 1940's covering Lebanon and Syria, (Figure 1-1) all monitored by the "Central Meteorological Service of Levantine states under the French mandate", established on the 4th of July in 1921. The Central Meteorological Service with the help of the Observatory of Ksara also published the "Bulletin Climatologique".

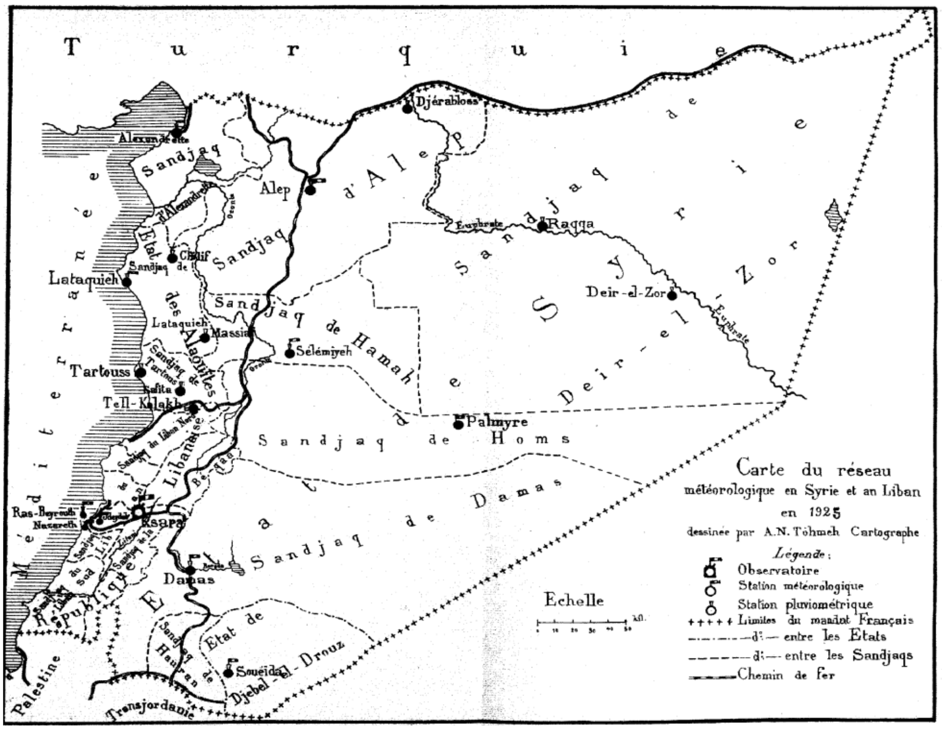

Figure B 3 Map of the meteorological network in Syria and Lebanon in 1925[4]

Upon its independence, the Lebanese state created the Lebanese Meteorological Service (LMS) as part of the Directorate General of Civil Aviation (DGCA) within the Ministry of Public Works. The number of stations peaked in the 1970's at 139 stations within Lebanon at the same time; In total 187 different stations were installed and monitored by the service from 1875 to 1975 between Lebanon and Syria. The network included 6 Synoptic Meteorological Stations, 1 radiosonde station, and wind radar, all

[4] Source ; Notice historique sur l'Observatoire de Ksara

located inside Lebanon. The LMS, always with the help of the Observatory of Ksara continued to publish the "Bulletin Climatologique" until the start of the conflict in 1975 which ceased all monitoring operations and data collection except for the three main synoptic stations of Tripoli, Zahle and Beirut International Airport, used to assist air navigation monitoring. Two editions of the "Atlas Climatique du Liban" were published in 1967 and 1977, and included an extensive statistical summaries and maps of all recorded parameters (precipitation, temperature, wind, pressure, nebulosity, humidity, etc.)

The Meteorological service has divided the Lebanese territory for climatic and orographic considerations into three zones (Coastal, Mountainous, Interior) and each zone to North, Central and South region giving in total 8 climatic regions sharing the same climatic and landform characteristics, each covered by a number of stations, detailed here below (see Figure B 5 below).

- Coastal Zone: from the shore to the 800 meters altitude contour line;
  - Coast North (15 stations)
  - Coast Centre (31 stations)
  - Coast South (12 stations)
- Mountainous Zone: from the 800 meters altitude contour line to the top of Mount Lebanon
  - Mountain North (8 stations)
  - Mountain Centre (34 stations)
- Interior Zone: from the top of Mount Lebanon to the Syrian border
  - Interior Orontes (10 stations)
  - Interior Litani (22 stations)
  - Interior Hasbani (7 stations)

Figure B 4 shows two hydrographs used to measure humidity. On the left, an old French made *Jules Richard* hydrograph installed in Qartaba station till 1975; On the right the *SIAP Bologna*, Italian made hydrograph installed till the 1990’s

Figure B 4 Two hydrographs used to measure humidity

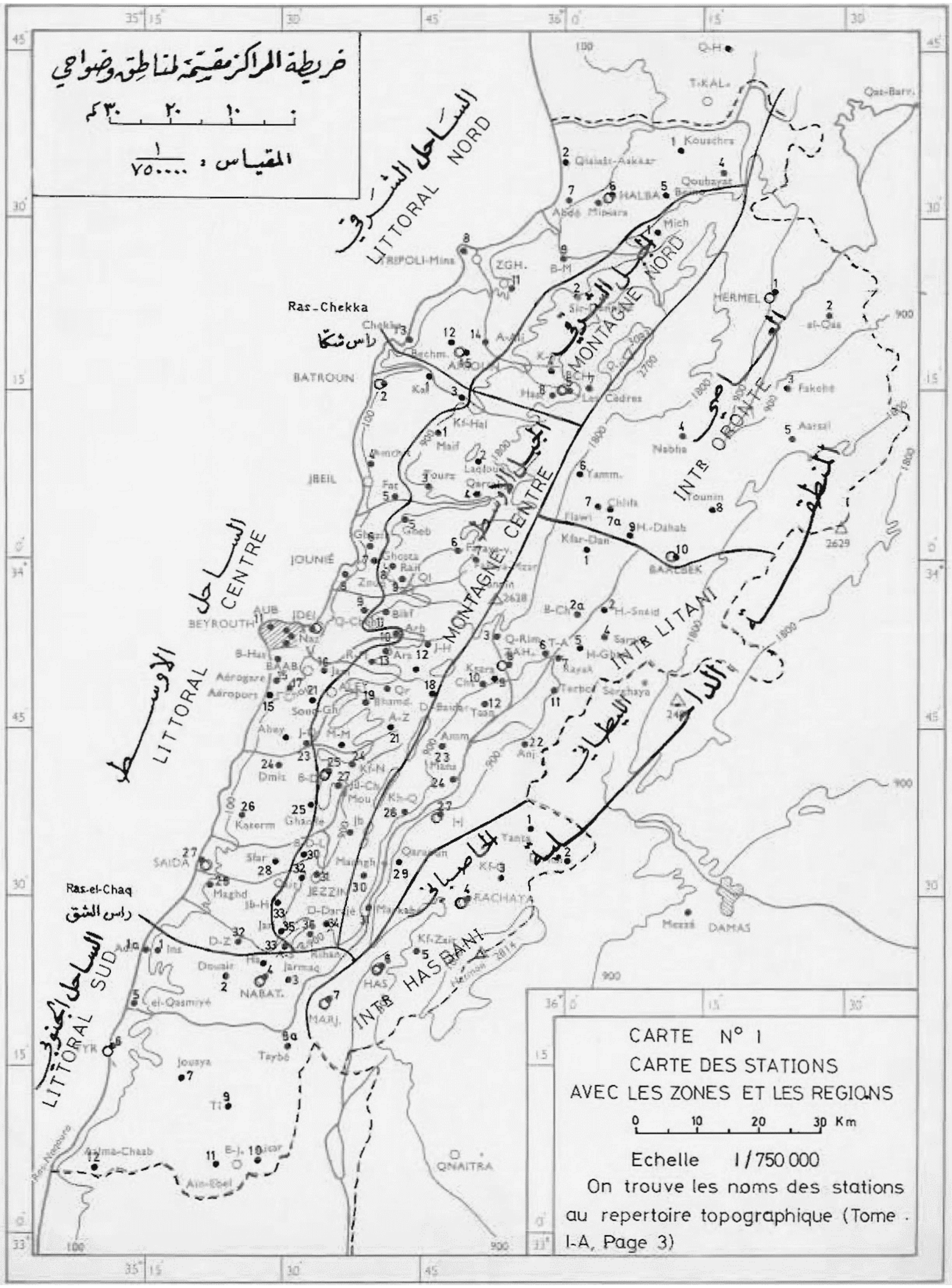

Figure B 5 Map of the meteorological network in Lebanon in 1970[5]

[5]Source : Atlas Climatique du Liban, Tome 1, 1977

B.3.1.2 Networks after 1990

Lebanese Meteorological Service - LMS network

At the end of the conflict in 1990, the meteorological service has lost all its stations and data collection was ceased except for three synoptic stations needed for air traffic monitoring, Beirut airport, Tripoli and Zahle. The meteorological service progressively restored his previous tasks, as for the observatory of Ksara it closed its doors in 1977 after the publishing the second edition of the "Atlas Climatique du Liban".

With the help of WMO and METEO France, the LMS started the network restauration in August 1994 with two new Automated Weather Observation Stations (AWOS) Milos 500 - Vaisala station, installed at Beirut International Airport and Tripoli. The network modernization was completed after the signature of the Lebanese - French financial protocol agreement in 1997. The new meteorological network includes a total of 37 stations divided between 7 synoptic stations, 3 agro-meteorological stations, 9 climatological stations remotely connected to the data centre and 18 other stations relying on memory card for data collection, in addition to 3 buoys, 1 radiosonde and 1 weather radar installed at the Golf club course. The stations' locations are listed in appendix 2 and the map in appendix 4 shows the geographical distribution of all meteorological stations of LMS, LARI, LRA and NAQMS.

Two types of stations were installed; the AUREA 6 which measure the 6 usual parameters (Temperature, Relative Humidity, Evaporation, Precipitations, Wind, Solar Radiation) and AUREA 12 to measure, in addition to the usual climatic parameters, the Air Quality and Environmental parameters (CO, CO3, CH4, NOX, O3), Aerosols, and Sea Swell. Since then, no new weather station was installed, however, a new radar was recently purchased in 2019 and a team from the meteorological department is getting trained to the newest technology.

Figure B 6 Typical weather station with wind tower

National Air Quality Management System

In 2005, the Ministry of Environment (MoE) prepared the Draft Law on the Protection of Air Quality, which was approved by the Council of Ministers (Decree 8075 of 05/05/2012). In result a National Strategy for Air Quality Management for 2030 was adopted, (NAQMS/MoE, 2017).

Accordingly, MoE has initiated the development of the National Strategy for Air Quality Management in Lebanon in 2015 with the support of the European Union (EU) funded programme Support to Reforms on Environmental Governance (StREG), in collaboration with the United Nations Development Programme (UNDP) project of the Environmental Resources Monitoring in Lebanon (ERML).

An existing Air Quality Monitoring Network (AQMN) has been installed and activated by MoE over two phases. In 2013, MoE launched Phase 1 of the national AQMN with real time air quality monitoring through 5 stations in Lebanon, with the support of the United Nations Environment Programme (UNEP) and UNDP. These stations used online analyzers connected to a supervisory control and Data Acquisition System (DAS) located at MoE. Phase 2 of the AQMN was launched in 2017 with the support of the EU and covered the installation of 10 additional stations to monitor criteria pollutants, in addition to 8 weather stations, 3 particulate matter analysers and 1 calibration station. Those are also directly connected to the DAS at MoE. The AQMN stations monitor the following parameters: PM2.5 - PM10 - CO - SO2 - NOx - O3 in addition to weather data. The measurement through these stations is continuous.

In addition to these stations, several other institutions have acquired air quality monitoring facilities:

The Urban Community of Al-Fayhaa (UCF) that installed in 2017 three air quality monitoring stations in Tripoli (including a meteorological station), Mina, and Beddawi under the European Union's Gouv'AIRnance project. UCF's stations were connected to a DAS within its premises. Data generated from the UCF's stations will be communicated to the MoE's DAS to centralize all air quality parameters.

Some universities, local authorities, and companies have few instruments for the measurements of the airborne pollutants, these include Saint Joseph University (USJ), American University of Beirut (AUB), University of Balamand (UoB), etc.

LARI agro-meteorological Network

The Lebanese Agricultural Research Institute (LARI) previously known as the Department of Agricultural Scientific Research is an autonomous public institution established in 1964 and working under the supervision of the Minister of Agriculture. LARI headquarter is located at Tel Amara Station in the Bekaa Valley in addition to other stations across Lebanon (Tourbol, Abde, Fanar, Kfarchakhna) each for different agricultural practice.

For 10 years, LARI has established an agro-meteorological network of over 60 stations from which only 30 are highly reliable (DAVIS® and PESSL® Instruments) distributed across Lebanon for weather forecasting and agricultural research. The institution has also developed a mobile application called LARI-LEB which gives daily weather forecasts to assist landowners and farmers in irrigation monitoring and other practices. The location of the stations is listed in the appendix 2.

LRA meteorological network

Upon the end of the Jeita Spring Protection Project - JSPP, 6 THIES® weather stations installed in 2013, were transferred to Litani River Authority - LRA. These stations are all located within Nahr el Kalb watershed and mainly used for its water balance estimation. One snow monitoring station was also installed in 2017 on top of Faraya Mzar, however it has never operated yet.

Military meteorological networks

- United Nations Interim Force in Lebanon - UNIFIL

  The UNIFIL have installed 6 VAISALA® AWOS for their military aviation monitoring within their operation zone in the South of Lebanon.

Academic and research institutions meteorological networks

Several universities and research institutions preferred to install their private meteorological stations for scientific research purposes. Several reasons fall behind these private networks' development mainly:

- Lack of data reliability and poor data quality of public institutions stations.
- Lack of data publication in addition to expensive fees requested by LMS for data acquisition.
- Difference/divergence between research projects objectives (hydrology, hydrogeology, agriculture, environment, risk and emergency assessment, etc.) and the installed stations objectives (weather forecast, agricultural monitoring, air traffic assisting, etc.)
- Poor spatial and temporal coverage of the existing networks

a. National Council for Scientific Research NCSR

The National Council for Scientific Research (NCSR) has installed one station on the roof of it headquarter in Jnah (DAVIS® instrument).

Recently a snow observatory was established under SudMed scientific and technical cooperation signed in 21/01/2010 in a joint project between CESBIO-IRD, NRCS and USJ Remote Sensing departments. Three Snow monitoring stations were installed in Faraya in 2012 (2300 m), Laqlouq (1850m) in 2014 and Cedars in 2014 (2850 m)

b. Saint Joseph University - USJ

The Regional Centre of Water and Environment (Centre Regional de l'Eau et l'Environnemnt - CREEN) at the faculty of engineering of the Saint Joseph University- USJ, was established in 1996 in the aim of training experts in the field of water and environment research as it welcome Masters and PhD students. Since then, CREEN has implemented his own meteorological network with 5 Campbell stations. CREEN has developed and was part of several national and regional research projects from which the first snow observatory in Lebanon established in 2000 jointly with the French Research Institute for Development (IRD). The project aimed to improve the knowledge on the snow contribution into Lebanese water resources as no info was previously acquired on the snow in Lebanon. One station was installed at the mountain top of Mzar - Faraya and another in

Oyoun el Simane. The project included snow sample collection and snow cover monitoring across Nahr el Kalb watershed over 2 years and resulted with an extensive finding on the snowfall, snowcover and snowmelt characteristics in Lebanon and an estimation of the Snow Water Equivalent.

c. American University of Beirut - AUB

Although AUB's meteorological service was shut down in 1975, AUB Farm in heart of the Beqaa valley, within Advancing Research Enabling Communities Centre (AREC) kept monitoring its station but with some interruption. AREC was established in 1953 as an extension of the AUB campus, it serves the faculty of Agriculture and Food Sciences (FAFS) faculty members, students, and other AUB faculties interested in agriculture, health, environment and sustainable rural livelihoods.

Several other research labs have installed their private stations for research purposes mainly the department of geology for hydrogeology projects and recently 2 stations were installed in Nahr el Kalb watershed.

d. University of Balamand - UoB

The University of Balamand has installed 2 weather stations, the first within its campus and the second in Kaftoun within Farid and Daad Karam Reserve (FDKR).

The first weather station comprises the following sensors; Wind Speed, Wind Direction, Temperature, Relative Humidity, Rainfall Precipitation, Radiation, and Pressure. The ELO105 Data Logger, is connected to the central unit/Server via RS 232 advanced cables to ensure data is being transferred without interference. As for the software, the installed unit is equipped with a double software system; the first is programmed to retrieve data from the logger and to give online reading; the second is high-end e-SAM software with unlimited data storage capabilities, enabling the continuous storage of data in two formats, Excel and PDF with user-defined intervals.

e. Holy Spirit University of Kaslik - USEK

Private meteorological networks

With the development of new technologies, several weather stations manufacturers have developed new compact stations with supporting software and mobile applications with easier data management systems and which could be directly connected to internet permitting free access for any user. These personal weather stations have become widespread across the globe. At least 9 brands of private weather stations could be found in Lebanon, some are high end professional stations used for agriculture, weather forecast or private research with their own web platform or private servers, others are of lower quality installed by users as a hobby. It is worth mentioning that for the last few years, amateur meteorologist, has relied on these stations and other forecast software and web applications to give the weather forecasting bulletin on tv channel and social media platforms like (Lebanese Weather Forecast, or Weather of Lebanon).

Some of these stations were duplicates between platforms, others were not continuously connected and couldn't be detected, thus the difficulty of counting all these stations. Despite that, 125 stations could be counted, however, the real number exceeds that by far. These stations are privately owned therefore they were not listed in this report. In summary the existing stations are divided into the following networks:

- Weatherlink developed by DAVIS® Instruments https://www.weatherlink.com/map
- Fieldclimate for PESSL® Instruments mostly used for agricultural monitoring and research https://ng.fieldclimate.com/
- MyAcuRite for ACURITE® stations https://www.myacurite.com
- CAMPBELL® stations are usually connected to private server mostly used for research
- Weather Underground, an integrated platform that connects several types and brands of stations (DAVIS®, AMBIENT WEATHER®, ACURITE®, LACROSSE®, NETATMO®, WEATHERFLOW® AND RAINWISE®) https://www.wunderground.com/

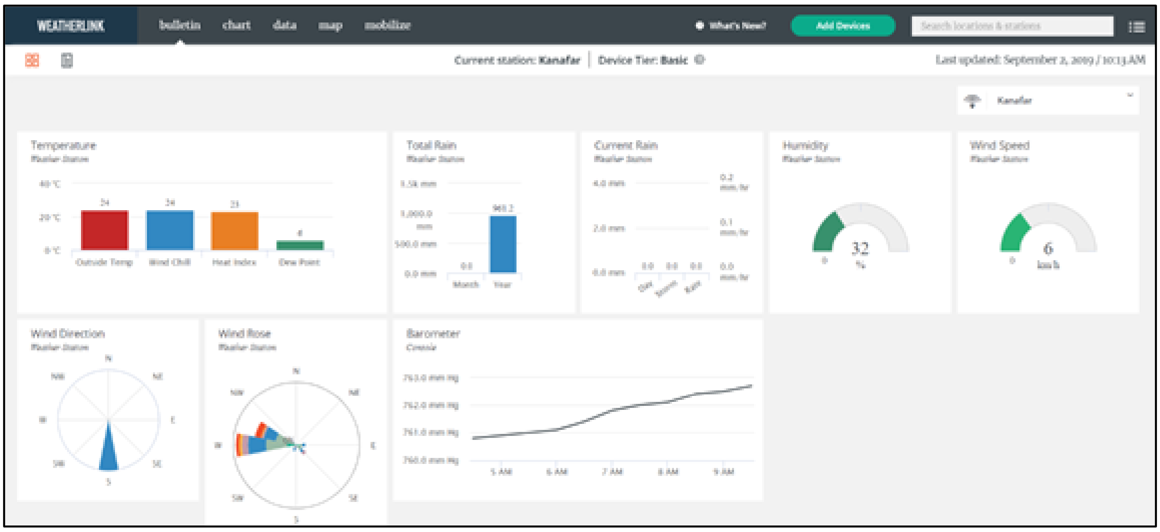

Figure B 7 Weatherlink web interface for Davis instruments

B.3.2 LEBANESE HYDROLOGICAL SERVICE

B.3.2.1 Hydrometric network before 1975

The first surface water gauging station dates back to 1931 when Ibrahim Abd el Aal, previous chief hydrologist and General Director of the Ministry of Public Works from 1949 to 1959, installed the first stations on Litani river at Mansoura, Qelia and Qaraoun villages, thus launching the planning for Litani project. Another station was also installed on Assi river at Hermel the same year. The hydraulic department of the Ministry of Public back then, was responsible of monitoring the installed hydrometric stations and carrying out hydrological studies when needed such as the hydrological studies of Litani and Nahr Ibrahim achieved by Ibrahim Abd el Aal.

Several projects have contributed to the extension of the Lebanese hydrometric network. Mainly the United States Bureau of Reclamation (USBR) "Point 4 program" of 1954 and the UNDP Groundwater assessment study of 1970.

The USBR "Point 4 program" has studied the water resources development opportunities on 10 main rivers (Nahr Ostouane, Nahr Arka, Nahr el Bared, Nahr Abou Ali, Nahr Ibrahim, Nahr el Kaleb, Nahr Beirut, Nahr el Damour, Nahr el Assi and Nahr el Litani) and produced in 1958 a detailed report for each river which included Hydrometric study, water budget estimation, development plans and economical assessment of the potential projects. This project included hydrometric stations installation and gauging monitoring on these rivers, some were for the project period and other were permanent and kept after the project.

The Government of Lebanon, with the assistance of the United Nations and UNDP, carried out from October 1962 to July 1969 an extensive study of Lebanese groundwater. The final report on this project, published the results of this collective work in 1970. The operations consisted mainly of inventorying existing water points, carrying out drilling and geophysical work, establishing a water balance of the country and providing technical training to personnel. The investigations were carried out on a regional basis determined by hydrogeological criteria. Two hydrogeological regions were considered, one coastal and another interior, divided into 30 hydrogeological units of which the aquifers were identified, the hydrodynamic conditions defined, and the groundwater resources evaluated.

The inventory included 1481 wells, 1031 boreholes and 1121 springs, and was completed by a hydro-chemical study. Finally, it resulted in the establishment of a groundwater monitoring network covering 327 wells or control boreholes in addition to hydrometric stations to monitor the main springs.

The study recommended that a routine water monitoring and control tasks should be continued on the existing monitoring network and systematically extended to the aquifers that will be studied in detail in the future. The study stated that the water budget of certain basins was partly hypothetical for lack of flow measurements and that if one wishes to specify the water resources of Lebanon, it is essential to increase the density of gauging stations as well as the frequency of measurements on as many watercourses as possible, and the knowledge of snow contribution into total precipitation.

Upon the completion of the USBR study which gave a particular attention to Litani, the Lebanese government established the Litani River Authority (LRA) under the Law of August 14, 1954 in order to implement the Litani project. In 1962, a Hydrometric service was established within the Water Resources Department at LRA whose task was to monitor the hydrometric stations within Litani basin only. However, the monitoring responsibilities of all hydrometric stations on all Lebanese rivers were transferred to this Hydrometric service in 1965. The network density increased to reach in 1975 a total of 150 hydrometric stations distributed between principal hydrometric stations (permanent stations), secondary hydrometric stations (installed for a certain period of a project) and point data gauging stations covering main Lebanese rivers and distributed on 84 streams, 35 springs and 33 irrigation channels; See Appendix B.4 for the distribution of previous and actual hydrometric stations.

B.3.2.2 Hydrometric network after 1990

The Hydrometric service has lost most of the installed hydrometric stations between 1975 and 1990 but kept collecting some interrupted data from few hydrometric stations mostly outside the conflict zones. The service started progressively restoring its tasks and network in 1990. The stations were distributed between point data gauging stations, principal and secondary hydrometric stations, however starting 2016, all 138 working hydrometric stations were rehabilitated and restarted recording continuous daily data. In addition to surface water monitoring, LRA monitors on a monthly basis 35 wells within Litani basin. It is worth noting that each of the four water establishments monitors the wells within its territory. The complete list of hydrometric stations and location maps are given in the Appendices.

The Hydrological service in the water resources department at LRA has profited from the installation of 13 hydrometric stations under the Litani River Basin Management Support project (LRBMS), a USAID-funded program which consisted of a 4-year program to improve water management in the Litani River Basin in the Bekaa; (LRBMS/USAID, 2012). The program began in October 2009 and had four components: (1) Building institutional capacity; (2) Water monitoring, (3) Irrigation management; and (4) Risk management.

The location of these stations was defined as to cover Litani River and its tributaries (for the surface stations), and the main aquifers (for the groundwater stations) distributed as follow

- 5 surface water stations (installed in September 2011)
- 8 groundwater stations. (installed in June 2012)

Each monitoring station was equipped with a multi-parameters probe and a built-in data logger to continuously record the main water quality indicators parameters: Dissolved Oxygen, temperature, pH, and conductivity, in addition to the water level for river flow monitoring. Groundwater stations recorded groundwater level, conductivity and temperature. In addition to the installation, a technical assistance was provided to enhance the existing surface water monitoring system and initiate a groundwater monitoring system.

The LRA have recently received

- A modern " River Surveyor ", an ADCP profiler (Acoustic Doppler Current Profiler: a device from oceanography, based on the Doppler effect) which measures automatically the water depth and speed, hence reducing the on-site measurement time.
- An ADCP machine which was installed at Laban spring.
- 9 Paratronic hydrometers as part of a telemetry pilot project in Nahr el Damour.
- Equipment for 30 in situ stations from UNICEF

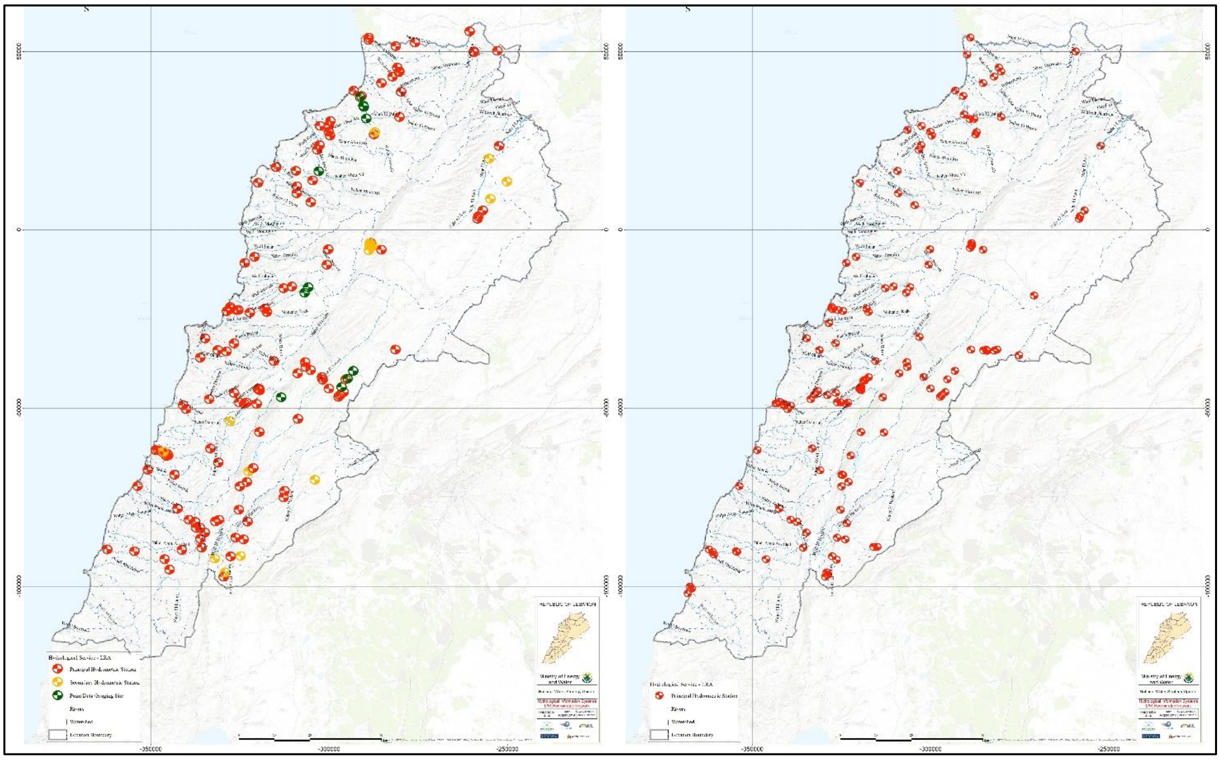

Figure B 8 Maps of the Lebanese hydrometric network before 1975 (left) and in 2016 (right), from Litani River Authority (LRA)

Figure B 9 Hydrometric stations on Awali river located at Marj Bisri Bridge

B.3.3 DATA MANAGEMENT

B.3.3.1 Meteorological data management

We will limit our description to the LMS data management system, being the oldest and most elaborate management system. Meteorological data management has gone through several phases starting with manual paperwork back in 1920's to semi or full automated digital data collection in present time.

Phase 1: Manual records and data collection

In its early years, the meteorological service relied on citizens and village residents, wherever the station was installed, to manually register on paper daily observations (some were hourly) of precipitation amounts, snowfall, temperature, pressure, humidity and other parameters. The service, with the help of Ksara observatory, used to collect the records from across Lebanon, check the data in reports and the recording instruments when available, then prepare and publish monthly statistical bulletin, with comparison charts. The hard copies and files (on papers and by microfilm) are still in archive at the LMS and still rely till now on hard copies and paper forms to record some parameters.

Phase 2: Digital Era

In the 1960's a digitizing operation of meteorological data was performed on perforated cards but resulted with too much errors as digitizing operation was achieved without quality control and by employees who are not experimented in meteorology or times series data collection. The errors were detected by two PhD students while working on their thesis who were obliged to revisit the original drum recorders of the stations and helped the observatory of Ksara, under the direction of Jacques Plassard S.J. back then in the correction of the data series to produce the a correct second edition of the "Atlas Climatique du Liban".

The LMS started a two phase digitizing operation within a data rescue project, the first consisted of digitizing the monthly averages temperature and rainfall amount for the period 1931- 2007, in order to develop long and homogenized time series and estimate long-term trends; the second consisted of digitizing the daily records of temperature, rainfall, sunshine duration, wind frequency and air pressure, in order to estimate long term normal and address the changes trends over the periods 1960 - 1990 and 1970 - 2000.

With the modernization of the meteorological network, data from remotely connected synoptic stations were automatically sent to the data center in the LMS. Daily and monthly statistics were generated from synoptic stations in 1994 with monthly backups. In 1995, data from all stations were saved to a special workstation and statistics and reports were generated using CLImate COMputing (CLICOM) system.

CLICOM is a CDMS that was initiated in 1985 by the WMO, with the assistance of the National Oceanic and Atmospheric Administration (NOAA) to help small countries with climate data management. CLICOM was developed as a PC based database running under the Disk Operating System (DOS). The LMS began digital data management by means of CLICOM in 1996, provided by the World Meteorological Organization (WMO). Starting 2000, CLICOM began to lose reliability on newer Microsoft Windows operating systems with the last official upgrade being Version 3.1 released in January 2000; (Martin, Howard, Hutchinson, McGree, & Jones, 2015). By the end of February 2002, the LMS stopped using CLICOM as it faced many problems due to inhomogeneity between CLICOM and other software for its low capacity to generate reports with long climate timeseries in addition to problems with maintenance, backup, restore and merged data.

Upon the renovation of the meteorological information system in 1997 based on SOFREAVIA study, a central server was installed at LMS headquarter at the airport (see Figure 1-9 and 1-10) with two secondary servers in Tripoli and Zahle, both monitored by resident teams connected by phone line to the central information system located at the offices of the Meteorological service at the airport. The system consists of an Automatic Message Switching System (AMSS) which is a standard ICAO ground-to-ground communication system for the exchange of air traffic control messages within the Aeronautical Fixed Telecommunication Network (AFTN) between airports. It receives the data from the synoptic stations and dispatch it to other airports.

The LMS is currently relying on CATRA V3.2 and CAOBS software to monitor the stations connected by AMSS. CATRA software permits the visualization of hourly data received from the synoptic and other connected stations. CAOBS is another software specific to VAISALA weather station located in Tripoli. These software permits the management of:

- Daily and monthly loading, and record treatment from SYNOP, agrometeorological and non-connected meteorological stations.
- Long terms statistics, means, normal, frequencies, quintiles, monthly records and wind roses.
- Data quality control: Homogeneity testing of meteorological series; Verification for missing observations, missing values of a certain meteorological element or parameter, permissible values and intervals of variation, correspondence with the code tables, etc.; Expert control on the basis of annual reports and comparison with meteorological stations - analogs.

The LMS also relies on SYNERGIE V3.7.i for weather forecast. SYNERGIE stands for " SYstème Numérisé d'Exploitation Rationnelle et de Gestion Interactive et Evolutive des informations météorologiques " is an integrated forecasting tool for decision support, capable of managing all types of data relevant for forecasting: surface observation (soil and oceans), satellites (images or point data), radar, lightning, atmospheric or wave model outputs, dispersion of pollutants, Alphanumeric messages, T4 documents, and maps or objects generated by other forecasters or forecasting centres. The main feature of SYNERGIE is the integration of all these types of data at the heart of a single system, allowing quick access, and especially a wealth of combinations by the forecaster throughout his work: monitoring, analysis, understanding, forecasting, model tracking, graphic design work, and final production. The user interface is based on a multi-window graphic, a dedicated interface for selecting and displaying each type of data and a multi-screen management.

B.3.3.2 Hydrometric data management

Hydrometric data are only monitored and managed by LRA, which centralizes the data management hence reducing diversity and management errors. Hydrometric data management has also gone through manual and digital phases.

For the old hydrometric network installed before 1975, the principle stations were equipped by SIAP® floaters connected to drum recorders which record the water depth (stages) of the river. LRA teams used to visit these stations on weekly basis to change the drum papers, fill the ink, and measure the channel section and speed using propeller-type current meter instruments. The recovered drum papers will then be converted into flows using the correspondent taring curves and record the values on specific forms.

With the new network installed after 1990, drum recording floaters were gradually converted into OTT® or SEBA® reel instruments, automatic floaters which digitally recorded the water depth and speed. These stations are still visited periodically to check on its status and recover the data. The teams still measure the river section periodically and measure the speed when and where needed to correct the taring curves or for point data gauging sites. The conversion of stages into flows have been digitized through HYDATA and HYDRAS software used for hydraulic analysis. After that, the measurements and analyzed results are archived, graphs are drawn, tables are prepared, and saved.

B.3.1 ASSESSMENT OF THE EXISTING NETWORKS

A detailed assessment of the existing Hydrometric networks and supporting institutions is necessary and required before any future design study of networks expansion or renovation. Such assessment shall tackle the institutional framework of all stakeholders working in the water sector and conduct a full analysis of the existing networks. The figure 4-1 below, from WMO Guide for Hydrological practices Vol. I, (WMO, 2008) lays out the steps that should be taken in conducting a review and redesign of an existing Hydrometric network. Such reviews should be conducted periodically to take advantage of the reduction in Hydrometric uncertainty brought about by the added data since the last network analysis and to tune the network to any natural or human induced changes in the environment that may have transpired. In this chapter, the assessment is limited to the main problems encountered in the institutional framework, network design and data management, without covering every network.

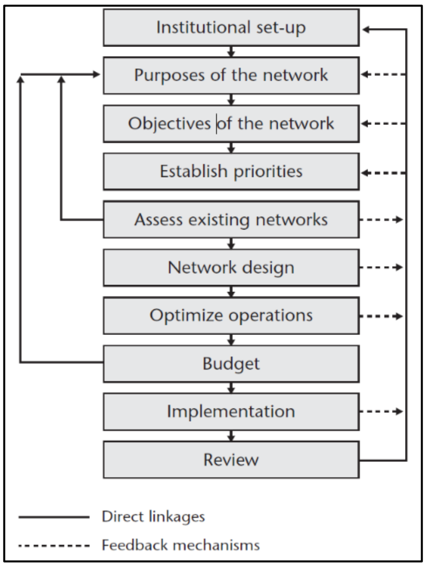

Figure B 10 A framework for network analysis and redesign[6]

B.3.1.1 Institutional Framework

Based on the belief that information, if well collected, managed and distributed, is the best mean for decision makers to plan water strategies and projects for sustainable development, a NWIS as planned by the MoEW require a collaboration between all public and private institutions and universities that are directly or indirectly involved in the water sector. An inter-institutional coordination, on technical and operational level, improves the quality of the outcome and optimize the decisions. For the time

[6] Source : WMO Guide for Hydrological Practices Vol. I

being there are no clear framework that rules the relation between all these institutions. The main challenge lies in the institutional diversity and could be summarized as follow:

1. Technical diversity: there is a wide range of equipment and data management systems and software within the same institution and from institution to another even for the measurement of the same parameter; this variety increases data errors and uncertainties. Ex: LMS stations are mainly AUREA® and VAISALA® while LARI agro-meteorological stations are PESSL® and DAVIS® instruments.

2. Operational diversity: each institution operates according to its own methodology and corresponding to its needs knowing that the collected data from one institution fulfils the needs of other institutions. Another challenge between institutions is that they rely on different teams for data collection, maintenance and management while each team was trained differently according to the needs and without any communication between the teams of different institutions.

B.3.1.2 Meteorological and Hydrometric networks

Climatic and geographical coverage

There are around 150 meteorological stations installed by 11 different public and academic institutions from which only 85 stations are working properly, in addition to the privately-owned stations (at least 125 counted stations); and 138 operating hydrometric stations monitored by LRA installed on different rivers, springs and channels.

Such number of stations might suggest that the Lebanese territory is well covered and answers the needs for an accurate estimation of the Lebanese water resources and water balance at the catchment scale, however several technical and operational challenges inhibits it:

- Despite that the LMS has always adopted a correct climatic zoning with an identification of coastal, mountainous and interior zones, with each including northern, central and southern region, these zones are only covered by 3 stations each, except for the central coastal and central mountainous by 18 stations both. Knowing that the Lebanese landform is highly accented, there are only 3 stations located between 1500 and 2000 m altitude and none above 2000 m where snow lasts for at least 3 months per year, reaching easily 7 months. (Only a joint IRD - USJ - CNRS research project has installed 3 snow monitoring stations above 2000 m).

- The new LMS meteorological network includes a total of 37 stations divided to 16 stations in the coastal regions (210 km^2/station), 12 in the mountainous region (350 km^2/station) and 9 in the internal plains (320 km^2/station). The network density respects the recommended minimum densities of stations by WMO except for mountainous area, as high mountains and eastern mountain chain are not covered. However, only half of the stations are functioning properly, therefore, the existing network is not sufficient for accurate precipitation estimate nor for the estimation of the water balance at the catchment scale.

- LARI's network is very discipline-oriented covering only the agricultural areas without any consideration of a geographical or climatic distribution.

- The AQMS-MOE network is also discipline oriented, mostly covering the coastal urbanized area and major cities, with very few stations located in natural reserves and only 2 stations in the interior located in Zahle and Baalbeck.
- LRA, being a hydrology-oriented institution, has adopted a catchment scale instrumentalization, with 6 meteorological stations in Nahr el Kalb and 4 stations in Nahr el Damour with a good coverage of climatic zones, however, these stations were recently installed and cover 2 catchments only.
- Academic and research institutions have always installed their stations according to the research project they have been working on.

Teams, equipment and data quality

The assessment of Lebanese water resources and water balance on which the NWSS have been developed upon, was left until now, for consultants and engineering companies to estimate, leaving for each consultant the task of data collection and methodology of work as he sees it appropriate. These consultants usually collect data from different stations and networks to estimate the monthly average precipitation and evapotranspiration, but this approach is way far from being perfect for the following reasons:

- Wide range of types and brands of stations within the institution or inter-institution.
- Frequent station crashes and malfunctioning requiring expensive maintenance usually neglected.
- Discontinuity of data time series as few stations have records that exceed 10 continuous years, while concomitant years between all stations are very limited.
- Data management and quality check differ between institutions leaving each consultant with its judgement of the data quality usually of poor quality and not well organized and archived.
- Institutions are understaffed as recruitment is limited, with lack of continuous capacity building and trainings leading to tasks neglect.
- Small budgets are usually left for network expansion, upgrade, operation and maintenance, relying usually on international funds to purchase new equipment.

Recently, a GIS database has been set up within the MOEW as part of the MED EUWI WEAP Project, including hydrologic data (flow, discharge…), water resources demand, climate data (precipitation, temperature, humidity) over the entire Lebanese territories with an average time series ranging over a period of 10-30 years. This database also includes the assimilated land use/cover, hydrogeology, geology, and soil available as spatial GIS layers.

B.3.1.3 Assessment of river gauging stations and measurement locations in Lebanon

To assist LRA in its water management, a contract funded by LWP/USAID was signed on May 18, 2016 between DAI and ELARD to assess the status of LRA's existing Gauging Stations (GSs) and Measurement

Locations (MLs) and provide recommendations for improvement. A summary of the report is provided in *ANNEX III B*.

The overall objective was to obtain a clear baseline about the quality of the flow measurements and to estimate the funding required to improve the quality of the data collected. The assessment tasks were the following:

- Assessed the status of installed surface GSs and predefined MLs.
- Evaluated GSs equipment and conditions of operation.
- Assessed the quality of the measurement data.
- Proposed new locations for additional GSs at predefined MLs or at new sites along Lebanese rivers and their main tributaries.
- Estimated the costs of interventions that are needed and that should be done within 3 months and recommended improvements to be implemented within 3 months to 3 years.

The work methodology to conduct the assessment for LRA included the following activities:

- Desk review of all relevant data for GSs and MLs provided by LRA.
- Field survey of the 71 GS and 90 MLs.
- Creation of GIS geodatabase and watershed delineation.
- Analysis to verify the accuracy of LRA data based on comparing.

The assessment findings were divided into administrative and technical. Administratively, it was found that LRA's water resources department is under-staffed and that incentives and capacity building opportunities should be provided to motivate the existing team and improve their data management skills especially that new data management and analysis software are needed. Technically, the number of gauging stations should be increased to cover catchments interactions, measure all river flows at sea mouth, cover all major springs and public wells, however the recommendations didn't cover groundwater considerations. The assessment mentioned a list of equipment and accessories that shall be procured to improve the existing network and provided a detailed cost estimate of interventions per district consisting of US$ 426,400 which only cover the rehabilitation of existing permanent gauging stations.

In result, LRA started immediately the implementation of the assessment recommendations which improved the data acquisition to reach a total of 128 principal stations for the 2016-2017 hydrological year after it was 87 in 2015-2016. It was assumed that LRA already had some of the needed equipment and no specific fund was provided to improve its network.

B.3.2 RECOMMENDATIONS FOR THE UPGRADE OF EXISTING NETWORKS

B.3.2.1 General recommendations

WMO has always promoted the application of best practices in hydrology, adapted to the different needs. The efforts towards this aim has led to the first edition of "the Guide to Hydrological Practices" in 1965. The Guide is a major output of the activities of the WMO Commission for Hydrology (CHy) published as a comprehensive guide, providing practicing hydrologists with handy access to state of the art and reliable information on Hydrometric practices, from simple discharge measurement to modelling complex Hydrometric systems. The most recent 6th edition was published in 2008, which was made to ensure that the various needs, emerging from different hydrologic regimes as well as environmental and socio-economic conditions in which hydrologists are working, could be addressed by the practices depicted in the Guide.

We are not in the process of drafting a new methodology for the design of a Lebanese hydrological network in this report, for WMO Guide include extensive description of the methodology and the design requires a specific and elaborate separate study. However, the main specificities that should be taken into consideration for the re-design and or upgrade of Lebanese hydrological networks are cited.

The best design of an integrated network in Lebanon resides in the combination between LMS's climatic zoning, LRA's distribution on catchment scale and completed by LARI's agrometeorological network for agricultural areas. This way ensures that each catchment microclimates are well covered (coastal areas, plains, lowlands and mountains), rivers specific hydrological regimes are taken into consideration (snow influence, spring contribution, etc.) and landcover characteristics are covered by LARI's network for evapotranspiration estimation. This integrated network could be achieved without any institutional merge or tasks overlap but requires an elaborate inter-institutional coordination within a central IHIS unit located in the MEW.

Nevertheless, some gaps are still to be covered in this integrated network by the proper institution and according to a detailed design; the main gaps in the existing networks are briefed here below.

- Hydrogeological aquifers are main contributors to river flow regimes and especially karstic formation (cave and submarine springs); they should be well monitored by expanding both meteorological and hydrometric networks to detect each aquifer contribution from and into surface flows.
- Expansion of hydrometric network to cover more streams connections and sub-catchments;
- Snow cover makes up to 25% of Lebanese water resources. Autonomous snow monitoring stations should be installed to cover the mountainous regions above 1500 m and estimate correctly the snow contribution into river flows.
- All the natural reserves and forests should be covered by expanding MoE network and include it in the integrated network;
- Expansion of all networks for a better flood risk prediction and early warning systems;

In addition to infrastructure upgrade and networks expansion, data management and valorization also needs improvements, in particular:

- Setting up of the IHIS data centre to record, check, analyse and archive all the collected measurements; which improve the quality and reduce the time for water balance estimation, water allocation simulations, prediction and planning;
- Activation of the Geographical Information System (GIS) platform for an interactive and dynamic assessment and follow-up of all existing networks;
- Improve the knowledge of global change impact on Lebanese water resources for better adaptation strategies;
- Setting up a data management protocol which unify the data sharing methodology and reliability.
- Establishing a unit for the monitoring, prediction and management of natural disasters, in particular floods and droughts;

B.3.3 OVERVIEW OF PREVIOUS STUDIES ON HYDROLOGICAL NETWORKS

B.3.3.1 Context

Historically, the Lebanese hydrological networks were developed since before its independence. The meteorological network was first launched by universities' observatories of AUB in 1875 and USJ in 1906 and then supported by the "Central Meteorological Service of Levantine states under the French mandate" in 1921 before the National Meteorological Service was established in 1940's.

The hydrometric network was first established in 1931 by Ibrahim Abd El Aal. previous chief hydrologist and General Director of the Ministry of Public Works (MoPW) from 1949 to 1959, who installed the first stations on Litani river. The hydraulic department of the MoPW was responsible of monitoring the installed hydrometric stations back then and carrying out hydrological studies when needed. After the establishment of the Litani River Authority (LRA) under the Law of 14 August 1954, in order to implement the Litani project, the monitoring responsibilities of all hydrometric stations on all Lebanese rivers were transferred from the MoPW to LRA hydrological service in 1965.

This section will describe the few studies that was undertaken for the development of current hydrological networks.

B.3.3.2 Meteorological Networks Design Studies

The meteorological network that existed till 1975, consisted of 14 stations in 1921 and reached 56 stations in 1940's covering Lebanon and Syria. It was established by Ksara Observatory starting 1906 based on personal expertise of the Jesuit priests who headed the observatory; Berloty S.J. till 1934 and Jean Rey S.J. till 1975 who published several studies on Lebanese climatology and mainly the first pluviometric map of Lebanon in 1951 (Udías, 2014).

Upon its independence, the Lebanese state created the Lebanese Meteorological Service (LMS) as part of the Directorate General of Civil Aviation (DGCA) within the MoPW. The number of stations peaked in the 1970's at 139 stations in the same time. The LMS, always with the help of the Observatory of Ksara continued to publish the "Bulletin Climatologique" until the start of the conflict in 1975 which ceased almost all monitoring operations and data collection except for air traffic control. Two editions of the "Atlas Climatique du Liban" were published in 1967 and 1977, and included an extensive statistical summaries and maps of all recorded parameters (precipitation, temperature, wind, pressure, nebulosity, humidity, etc.)

The Meteorological service has divided the Lebanese territory for climatic and orographic considerations into three zones (Coastal, Mountainous, Interior) and each zone to North, Central and South region giving in total 8 climatic regions sharing the same climatic and landform characteristics, each covered by a number of stations(See Figure B 11 below).

- Coastal Zone: from the shore to the 800 meters altitude contour line;
    - Coast North
    - Coast Centre
    - Coast South
- Mountainous Zone: from the 800 meters altitude contour line to the top of Mount Lebanon
    - Mountain North
    - Mountain Centre
- Interior Zone: from the top of Mount Lebanon to the Syrian border

Interior Orontes

- Interior Litani
- Interior Hasbani

B.3 Status of the Lebanese Hydrometeorological information networks

Figure B 11 Pluviometric map of Lebanon, Published by the LMS with the help of Ksara Observatory in 1971 showing different climatic regions and main weather stations

Since the establishment of the LMS in 1940's only one official study included a detail design for the modernization of the previous network. This network modernization study was carried on by SOFREAVIA within the Lebanese - French financial protocol agreement in 1997.

The modernization study of the meteorological network included the implementation design of new stations and the design of a new digital data management system.

The designed network consisted of 37 stations divided between synoptic, agro-meteorological, remote and non-remote climatological stations, in addition to buoys, radiosonde and weather radar which was installed at the Golf Club.

The data management design consisting of a central server with corresponding software. The central sever is an Automatic Message Switching System (AMSS) which was installed at LMS headquarter at the airport (Figure B 12) with two secondary servers in Tripoli and Zahle, both monitored by resident teams connected by phone line to the central information system located at the offices of the Meteorological service at the airport. The LMS is currently relying on CATRA V3.2 and CAOBS software to monitor the stations connected by AMSS. CATRA software permits the visualization of hourly data received from the synoptic and other connected stations. CAOBS is another software specific to VAISALA weather station located in Tripoli. The LMS also relies on SYNERGIE V3.7.i for weather forecast.

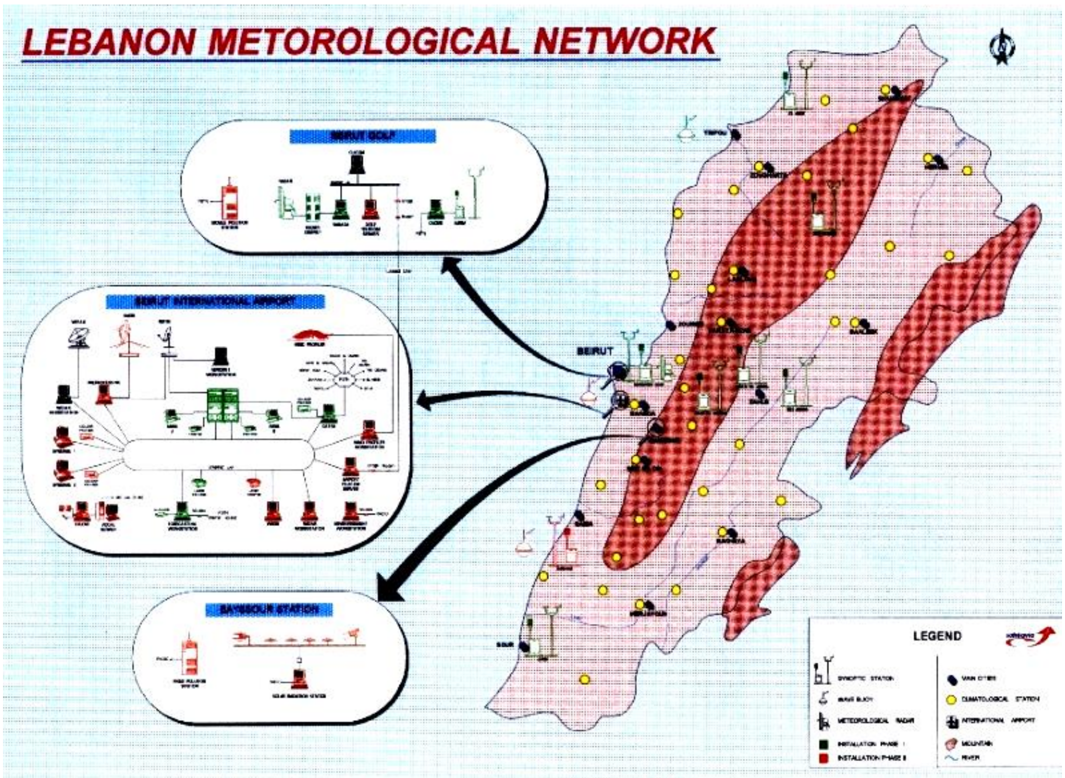

Figure B 12 Modernization of the Lebanese Meteorological Information System - SOFREAVIA 1996

B.3.3.3 Hydrometric Networks Design and Assessment Studies

Several projects have contributed to the extension of the Lebanese hydrometric network. Mainly the United States Bureau of Reclamation (USBR) "Point 4 program" of 1954 and the UNDP Groundwater assessment study of 1970. These studies didn't include a detailed design for the implementation of the hydrometric station, they were mainly installed at the sea mouth and some tributaries, in addition to few stations which were installed to monitor main springs and public wells but to our knowledge no hydrometric station was installed to monitor other groundwater aquifers, instead the study resulted with some recommendations for monitoring in future phase.

The USBR "Point 4 program" has studied the water resources development opportunities on 10 Lebanese rivers (Nahr Ostouane, Nahr Arka, Nahr el Bared, Nahr Abou Ali, Nahr Ibrahim, Nahr el Kaleb, Nahr Beirut, Nahr el Damour, Nahr el Assi and Nahr el Litani) and produced in 1958 a detailed report for each river which included hydrological study, water budget estimation, development plans and economical assessment of the potential projects. This project included hydrometric stations installation and gauging monitoring on these rivers, some were for the project period and other were permanent and kept after the project.

The Lebanese government, with the assistance of the United Nations and UNDP, carried out from October 1962 to July 1969 an extensive study of Lebanese groundwater. The final report on this project, published the results of this collective work in 1970. The operations consisted mainly of inventorying existing water points, carrying out drilling and geophysical work, establishing a water balance of the country and providing technical training to personnel. The investigations were carried out on a regional basis determined by hydrogeological criteria. Two hydrogeological regions were considered, one coastal and another interior, divided into 30 hydrogeological units of which the aquifers were identified, the hydrodynamic conditions defined, and the groundwater resources evaluated.

The inventory included 1481 wells, 1031 boreholes and 1121 springs, and was completed by a hydro-chemical study. Finally, it resulted in the establishment of a groundwater monitoring network covering 327 wells or control boreholes in addition to hydrometric stations to monitor the main springs.

The study recommended that a routine water monitoring and control tasks should be continued on the existing monitoring network and systematically extended to the aquifers that will be studied in detail in the future. The study stated that the water budget of certain basins was partly hypothetical for lack of flow measurements and that if one wishes to specify the water resources of Lebanon, it is essential to increase the density of gauging stations as well as the frequency of measurements on as many watercourses as possible, and the knowledge of snow contribution into total precipitation.

Since then, no national scale studies were carried on for the rehabilitation of the existing network or its optimization despite few catchment-scale studies that resulted with the implementation of additional stations mainly in Litani and Damour rivers.

The hydrological service in the water resources department at LRA has profited from the installation of 13 hydrometric stations under the Litani River Basin Management Support project (LRBMS), a United States Agency for International Development (USAID)-funded program which consisted of a 4-year program to improve water management in the Litani River Basin in the Bekaa; (LRBMS/USAID, 2012).

The program began in October 2009 and had four components: (1) Building institutional capacity; (2) Water monitoring, (3) Irrigation management; and (4) Risk management.

The location of these stations was defined as to cover Litani River and its tributaries (for the surface stations), and the main aquifers (for the groundwater stations) distributed as follow

- 5 surface water stations (installed in September 2011)
- 8 groundwater stations (installed on June 2012)

Another catchment scale study was recently achieved by LRA supported by the "mission économique" of the French ministry of Economy with the fund of NATIXIS and carried on by HYDRATEC and several other partners. The project consisted of an integrated telemetry pilot project for an optimal knowledge of Damour river water resources. The study resulted with the implementation of 9 Paratronic hydrometers. The study included four components starting with:

- Component 1
  - Preliminary investigation of Damour catchment
  - Implementation and methodological transfer of hydrological data security, controlling and validation
- Component 2
  - Design, purchase and implementation of a telemetry system to monitor different water resources;
  - Training of ONL staff on equipment and maintenance requirements
- Component 3
  - Operation and maintenance of the telemetry system.
  - Hydrological data management, analysis and validation.
- Component 4
  - Organizational, technical and financial modelling of the necessary equipment, staff and financial resources for the extension of Damour catchment telemetry pilot project at the national scale.

To assist LRA in its water management, an assessment project was carried out by DAI and ELARD within Lebanese Water Project (LWP) funded by the USAID to assess the status of existing gauging stations and provide recommendations for hydrometric network improvement. The overall objective was to obtain a clear baseline about the quality of the flow measurements and to estimate the funding required to improve the quality of the data collected. The assessment tasks also comprised an assessment of the quality of the measurement data.

The assessment findings were divided into administrative and technical. Administratively, it was found that LRA's water resources department is under-staffed and that incentives and capacity building opportunities should be provided to motivate the existing team and improve their data management skills especially that new data management and analysis software are needed. Technically, the number of gauging stations should be increased to cover catchments interactions, measure all river flows at sea mouth, cover all major springs and public wells, however the recommendations didn't cover groundwater considerations. The assessment mentioned a list of equipment and accessories that shall be procured to improve the existing network and provided a detailed cost estimate of interventions per district which only cover the rehabilitation of existing permanent gauging stations.

In result, LRA started immediately the implementation of the assessment recommendations which improved the data acquisition to reach a total of 128 principle stations for the 2016-2017 hydrological year after it was 87 in 2015-2016. It was assumed that LRA already had some of the needed equipment and no specific fund was provided to LRA to improve its network.

B.4 IMPLEMENTING AN INTEGRATED HYDROLOGICAL INFORMATION SYSTEM

B.4.1 METHODOLOGY

B.4.1.1 General

Global change of anthropological or natural sources is influencing water management. This change includes growing competition for water, economic pressures, increased focus on water conservation and reuse, environmental legislation, legal measures to ensure that users and water managers justify their needs, uses and management practices, emphasis on basin and regional water planning.

These trends indicate that greater coordination of data-collection efforts is required to meet the needs of water managers. Water management is becoming more integrated across disciplines and specialties; therefore, compatible data on quantity and quality of surface water and groundwater, and on specific basins and regions will be required. Current problems related to data accessibility, compatibility and reliability will have to be resolved to meet these needs. In addition, water management challenges are closely linked to those of environmental management or ecosystem management.

Therefore, an increasingly holistic management approach is required. While many users will still need data for design and analysis purposes, increased attention must be paid for comprehensive regional surface and groundwater information that can be applied to many different kinds of water issues and problems. This means that overview information, fact sheets and summaries, surface-water and precipitation mapping, hydrological assessments of basins and regions, and water information relevant to the assessment of water quality and groundwater problems must be available. The use of real-time water data will continue to grow to serve many needs.

Lebanon has not yet established an Integrated Hydrological Information System (IHIS) which shall provide public and private stakeholders an access to reliable information and management services to build this holistic management approach. An IHIS will allow all information providers to manage, publish, share their data, products and services and will allow all users to develop value-added services and new products.

This section suggests a design and a strategy for the implementation of this IHIS with a focus on supporting Lebanese decision regarding the United Nations SDGs, the United Nations Framework Convention on Climate Change (UNFCCC), the Global Framework for Climate Services (GFCS), etc. An Implementation Coordination Team of the IHIS shall be formed to elaborate and maintain a strategic plan for developing the IHIS over the next period.

B.4.1.2 IHIS Design

One of the most successful designs of an IHIS in Lebanon resides in the combination between LMS's climatic zoning, LRA's distribution on catchment scale and completed by Lebanese Agricultural Research Institute LARI's agrometeorological network for agricultural areas, as described in report 1. Each network monitored by its corresponding institution but in coordination with the IHIS office. This distribution ensures that each catchment microclimates are well covered (coastal areas, plains, lowlands and mountains), rivers specific hydrological regimes are taken into consideration (snow influence, spring contribution, etc.) and land cover characteristics are covered by LARI's network for evapotranspiration estimation. However, groundwater aquifers need to be monitored based on aquifer delimitation of 1970 and the findings of other relevant hydrogeological and geological studies. The cost estimation of a complete and integrated hydrological network (upgrade and expansion) amounts to **6,066,000 USD** according to the holistic approach described in *Annex III Section C*.

Nevertheless, some gaps are still to be covered by the corresponding institution to complete this integrated system. It shall be completed according to the suggested detailed design. The main gaps in the existing networks are briefed here below.

- Hydrogeological aquifers are main contributors to river flow regimes and especially karstic formation (cave and submarine springs); they should be well monitored by expanding both meteorological and hydrometric networks to detect each aquifer contribution from and into surface flows.
- Expansion of hydrometric network to cover more streams connections and sub-catchments;
- Snow cover makes up to 25% of Lebanese water resources. Autonomous snow monitoring stations should be installed to cover the mountainous regions above 1500 m and estimate correctly the snow contribution into river flows.
- All the natural reserves and forests should be covered by expanding MoE network and include it in the integrated network;
- Expansion of all networks for a better flood risk prediction and early warning systems;

In addition to infrastructure upgrade and networks expansion, data management and valorisation also needs improvements, in particular:

- Setting up of the IHIS data centre to record, check, analyse and archive all the collected measurements; which improve the quality and reduce the time for water balance estimation, water allocation simulations, prediction and planning;
- Activation of the Geographical Information System (GIS) platform for an interactive and dynamic assessment and follow-up of all existing networks;
- Improve the knowledge of global change impact on Lebanese water resources for better adaptation strategies;
- Setting up a data management protocol which unify the data sharing methodology and reliability.

B.4.1.3 Strategy

The IHIS office shall be operated by a team of trained experts, and will be built on industry standards, incorporating existing services and solutions provided by the public and private sectors. It aims to establish a national information management, processing and sharing platform that will provide the following benefits:

1. Accessibility:
   A platform enhancing the collection of data and allowing applications and services to be developed, capable of working with high-volume and archived data, and operated and managed without the complexity of building and maintaining infrastructure or managing local repositories of data;
2. Interoperability:
   Software components interact with the platform using industry-accepted approaches and open standards;
3. Visibility:
   Authoritative data shall be visible to government, commerce and citizens;
4. Utility:
   A focus on meeting the needs of users to exploit hydrological data in context with data from other domains;
5. Reliability:
   Data and services are safe and accessible with guaranteed performance at any time;
6. Cost-effectiveness:
   Avoidance of duplication through use of shared components built on the infrastructure of organizations that can leverage economies of scale;
7. Capacity-building:
   Training to enable all existing services to use the infrastructure and services of the IHIS platform.

B.4.1.4 Challenges

Key changes in the world of information technology are taking place which require the traditional approach of information delivery to be amended. In its design, the IHIS shall evolve into a dynamic platform while managing the increasing volume of data where end users can pull selected information into areas of their choice.

Users expect an effective use of information, including combining data from multiple areas of benefit to society, such as biology, earth sciences and disaster-risk management, which consist a main factor of economic growth. It is increasingly important that information becomes available in a way that maximizes uptake and business opportunities. Users also expect to access weather, water and climate information and services easily, with familiar interfaces and applications through more social interaction and mobile delivery.

Lebanese meteorological and hydrological services are facing continuous pressure on budgets. It is important to remove duplication of effort, to facilitate the use of existing solutions and to make the infrastructure more cost-effective through simplification.

B.4.1.5 Governance

A governance regime supporting a financially sustainable IHIS platform shall be developed alongside the technical aspects. Existing systems (LMS, LARI, LRA or MoE) remain the primary centres as these collect data, generate content and deliver services. However, data sharing with private and public sectors shall be reserved to the IHIS office. IHIS governance will need to address issues such as:

- Data life-cycle management;
- Data licensing and access;
- Information security;
- Relation to existing institutions and data centres;
- Cost sharing and contract management with commercial infrastructure suppliers;
- Resource allocation (e.g. computing, storage) within shared components;
- Private sector participation.

Considering the operational aspects and both institutional and technical complexity, the IHIS shall be implemented step by step with defined and manageable phases according to an implementation plan describing the transition from independent networks into an integrated system taking into consideration the risks involved.

B.4.1.6 Risks

The implementation of the IHIS is ambitious, involving many contributors, new technologies and standards. Hardware, systems, development and ongoing support must be integrated into strategic planning and system replacement processes. There is also a critical requirement for the evolution of existing information systems to meet with the new IHIS platform requirements. The successful implementation of the IHIS will require the participation of experts and to reduce the exposure to the risks and to ensure prompt delivery of the IHIS, it is recommended that a full-time project manager is appointed to guide implementation of the strategy, to maintain a comprehensive risk assessment and to act as the focal point for all significant issues.

B.4.2 RECOMMENDED STUDIES FOR IHIS IMPLEMENTATION

B.4.2.1 General

This section gives a description of the various studies that need to be carried out in order to design and implement the IHIS. These studies shall include first:

- A set of assessment studies to evaluate the actual status of hydrological services;
- An update and analysis of the National Land Use Master Plan Geodatabase;
- A Lebanese data rescue project;

- A set of design studies;

To guarantee the best implementation and well operation standards, these studies shall be in line with different WMO technical guidelines, reports and manuals listed below. WMO has always promoted the application of best practices in hydrology, adapted to the different needs. It has also supported the national hydrological services in meeting international commitments in different areas through the establishment of observational networks and data management centres, creation of standards for observation and monitoring; application of science and technology in operational meteorology and hydrology and the coordination of research and training in hydrology.

The efforts towards this aim has led to the publication of several guidelines and reports, in particular "the Guide to Hydrological Practices". The Guide is a major output of the activities of the WMO Commission for Hydrology (CHy) published as a comprehensive guide, providing practicing hydrologists with handy access to state of the art and reliable information on hydrological practices, from simple discharge measurement to modelling complex hydrological systems. The list of WMO that the studies should be based on are the following:

- WMO strategic plan for 2020-2023 (WMO-No. 1225);
- Guidelines on the Role, Operation and Management of National Meteorological and Hydrological Services (WMO-No. 1195);
- Step-by-step Guidelines for Establishing a National Framework for Climate Services (WMO-No. 1206);
- Guidance on Good Practices for Climate Services User Engagement, Expert Team on User Interface for Climate Services, Commission for Climatology (WMO-No. 1214);
- Guidance on Integrated Urban Hydrometeorological, Climate and Environmental Services Concept and Methodology (WMO-No. 1234);
- Guide to Meteorological Instruments and methods of Observation (WMO-No. 8);
- Technical regulations (WMO-No. 49); Vol. I - General Meteorological Standards and Recommended Practices; Vol. II - Meteorological service for International air Navigation; Vol. III - Hydrology;
- Guide to Climatological Practices (WMO-No. 100);
- Guide to Hydrological Practices (WMO-No. 168); Vol. I - From Measurement to Hydrological Information; Vol. II - Management of Water Resources and application of Hydrological Practices;
- Manual on the Global Data-Processing and Forecasting System (WMO-No. 485);
- Cost-benefit assessment techniques and user requirements for hydrological data (WMO-No. 717);
- Manual on stream gauging (WMO-No. 1044); Vol. I - Fieldwork; Vol. II - Computation of Discharge;
- Manual on Flood Forecasting and Warning (WMO-No. 1072);
- Guidelines for the Assessment of Uncertainty for Hydrometric Measurement (WMO-No. 1097);
- Guide to the Implementation of Quality Management Systems for National Meteorological and Hydrological Services and Other Relevant Service Providers (WMO-No. 1100);
- Climate Data Management System Specifications (WMO-No. 1131);
- Guidelines for Hydrological Data Rescue (WMO-No. 1146);

- Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services (WMO-No. 1153);
- Guidelines on Best Practices for Climate Data Rescue (WMO-No. 1182);
- Guidelines on Generating a Defined Set of National Climate Monitoring Products (WMO-No. 1204);
- An International Agenda for Education and Training in Meteorology and Hydrology (WMO-No. 1219);
- Guidelines on Quality Management in Climate Services (WMO-No. 1221);

B.4.2.2 Assessment studies

A detailed assessment of the existing hydrological networks and supporting institutions is necessary and required before any future design study of networks expansion or renovation. Such assessment shall tackle the institutional framework of all hydrological services and conduct a full analysis of the existing networks. The Figure 3-1 below, from WMO Guide for hydrological practices, WMO-No. 168 Vol. I (WMO, 2008), lays out the steps that should be taken in conducting a review and redesign of an existing hydrological network. Such reviews should be conducted periodically to take advantage of the reduction in hydrological uncertainty brought about by the added data since the last network analysis and to tune the network to any natural or human induced changes in the environment that may have transpired.

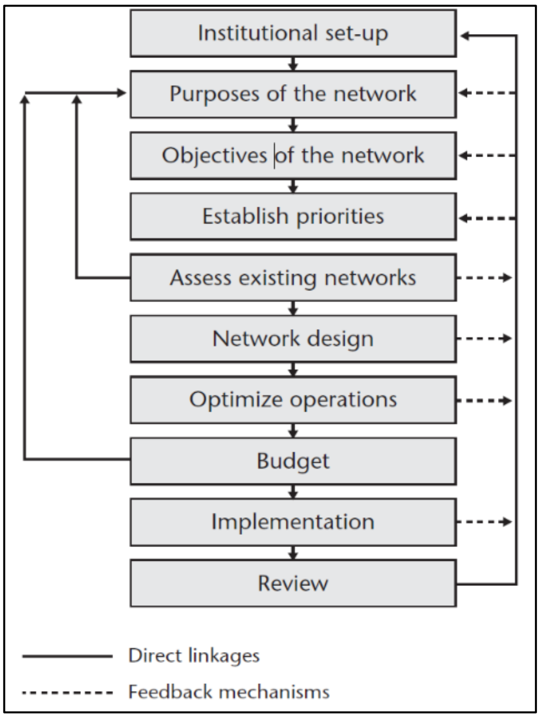

Figure B 13 A framework for network analysis and redesign[7]

[7] Source : MO Guide for hydrological practices Vol. I

Meteorological Networks Assessment

The objective of the assessment study is to obtain a clear baseline about the installed weather stations, about the quality of the climate measurements and to estimate the funding required to complete the existing network and improve the quality of the collected data. This baseline will increase the accuracy of climatic measurements and provide LMS, LRA, MoE and future IHIS centre with high quality data. The assessment studies shall include:

- Assessment of the institutional framework and working teams (skills, knowledge, expertise, trainings…);
- Identification of Lebanon needs and priorities in meteorology to guide the activities and projects (weather and risk forecasting, water resources assessment, climate change, etc.)
- Assessment of the existing network design (location, coverage, density, distribution) and suggestion of complementary locations;
- Assessment of the installed weather stations based on a field survey (specifications, instrumentations, date of installation, status, condition of operation);
- Assessment of the data management centre and quality of measurements;
- Assessment of the financial resources and estimation of the cost of interventions to redesign and complete the existing network.

LRA Hydrological Network Assessment

Based on the recent assessment study carried out by DAI in 2017, this study shall be updated and completed with:

- Following up on the implementation of the previous study recommendations and suggested interventions;
- Assessment of new hydrological design studies;
- Status update of existing gauging stations and cover any newly installed ones;

B.4.2.3 Update and Analysis of the National Land Use Master Plan Geodatabase

The National Land Use Master Plan (NLUMP) developed in 2004 a national geodatabase designed to store, query, and manipulate geographic information and spatial data using ArcGIS software (MOE/UNDP/ECODIT, 2011). Many institutions supplied data to buttress and consolidate the database, including:

- Directorate General of Geographic Affairs provided the topographic maps;
- NCSR, in cooperation with the MoE, provided the Land Use/Land Cover Map;
- Central Administration of Statistics, provided socio-economic and housing data at the cadastral level;
- Ministry of Public Works and Transport (MoPWT), provided the road network;
- Directorate General of Urban Planning (MoPWT) provided decreed and approved urban master plans;

An update of this geodatabase should be carried out to include the latest and most precise maps describing the Lebanese landscape, geology, hydrogeology, Landuse, morphology, water and land resources with the contribution of both public and private sector especially academic and research institutions.

A comprehensive analysis of this geodatabase should be carried out to homogenise the knowledge on Lebanese environment and to provide a common vision for the design of meteorological and hydrological networks.

B.4.2.4 Lebanese Data Rescue Project

Data Rescue is the ongoing process of preserving all data at risk of being lost due to deterioration of the medium and digitizing current and past data into computer compatible form for easy access

Access to historical data is essential to understand the context of changes in climate and its extremes, and to frame the sensitivity of man-made and natural systems to hydrological variability as a guide to future adaptation. However, in Lebanon these historical data are not easily accessible, being locked up in paper records which are at risk of loss and damage. Even when secured, the data remain inherently inaccessible unless they can be digitised or imaged into an accessible database. The recovery of climate records from paper and obsolete electronic media was achieved at LRA but partly done in LMS as only temperature and rainfall time series of four stations were digitized.

The historical observations could bolster the climate record and allow a greater understanding of climate. Lebanon must identify, appraise, archive and migrate these records to new technologies to make them available for research. The conversion of observation data to common electronic formats is vital to preserving and enhancing the global climate record. Creating homogeneous, complete data sets from disparate collections is a fundamental challenge facing the climate research community. This is best achieved by leveraging partnerships with academic institutions to share resources and areas of expertise. The goal is to bring more information into the hands of scientists who seek to understand the global climate system in order to anticipate changes to the climate. Long time series of the past weather are useful for many parts of our society, such as agriculture, water resource management, human health, disaster risk reduction, energy, construction, transport, and insurance.

It is the purpose of a DAta REscue (DARE) project to recognize, rescue, preserve and digitize historical data. WMO has collaborated and still with several DARE initiatives such as MEDARE, which Lebanon was present at its first workshop in Spain back in 2007 but abstained later, the International Environmental Data Rescue Organization (IEDRO) data rescue programme, it also developed the International Data Rescue Portal (I-DARE) and other initiatives which are currently underway to preserve and digitize climate data into computer compatible form.

A Lebanese DARE project should be carried out, as most of climatic data are still on paper. Lebanese climatic reports were first published by the meteorological service of the American University Observatory back in 1875 and the Observatory of Ksara in 1910 in addition to all LMS reports "Climat du Liban - Bulletin Statistique Mensuel" and "Atlas Climatique du Liban" which were never digitized. Paper records were still in use at LMS till 2000's to register air navigation parameters, hence the importance of this project. The data rescue project shall be based on WMO following reports:

- Guidelines for Hydrological Data Rescue (WMO-No. 1146);

- Guidelines on Best Practices for Climate Data Rescue (WMO-No. 1182);
- Report of the meeting of the Commission for Climatology Expert Team on the Rescue, Preservation and Digitization of Climate Records (WMO-TD No.1480).

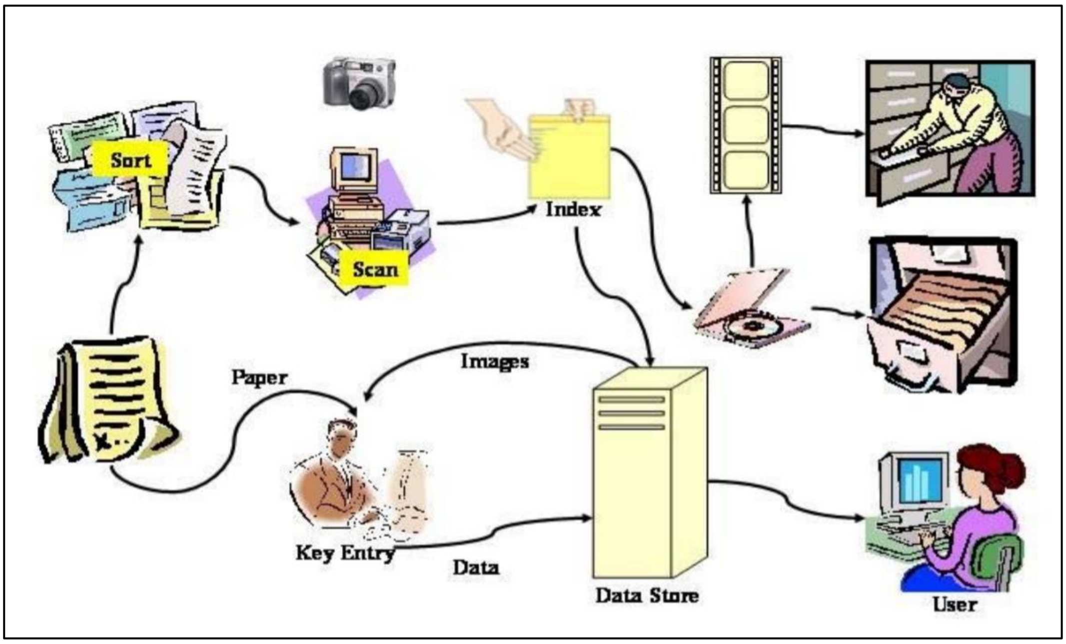

Figure B 14 The data rescue and digitization process from WMO/TD No. 1210

The aims of a data rescue project will generally, but not always or exclusively, include:

- Creation of an inventory of data holdings;
- Rationalization and indexing of physical records/data holdings;
- Identification of data holdings of genuine importance;
- Improving storage conditions for physical data holdings and storage media;
- Digitization of time series data;
- Extraction of data from obsolete storage media (physical and digital);
- Storage of digital data in future-proof formats and storage media;
- Storage of time series data within a hydrological database;
- Establishing procedures for the ongoing use of data archives; database systems and digital archives such as electronic backups.

B.4.2.5 Design studies

Upon the achievement of all assessment studies of existing meteorological and hydrological networks and based on the resulting comprehensive analysis report of the NLUMP, a set of design studies should be carried out for the implementation of the IHIS. This study shall comprise but not limited to:

- Institutional design and capacity building;

- Design or redesign of LMS, LRA, LARI and MoE meteorological networks and LRA hydrometric network to cover surface and groundwater water resources including station specifications, location, detailed cost estimation, implementation timetable, platform design;
- Data management design including server specifications, data collection, dissemination and archiving protocol
- Benefit - cost analysis of the implementation of the IHIS;

Institutional Design and Capacity Building

In order to obtain accurate information, meteorological and hydrological services require proper institutional development to meet the new water management challenges and develop appropriate capabilities and establish partnerships or strategic alliances with complementary services. Once its vision is established, the institutional design of a hydrological service shall include:

- The formal and informal mix of values, rules, organizational structures and cultures, mechanisms, processes and actions that give credibility or legitimacy to the IHIS.
- The roles, aims, management functions and legislative responsibilities of all the services;
- Communication links between all services to improve coordination, collaboration and coherence among different services;
- The proper policy to maintain effective relationships and good communication with clients to ensure that they be made aware of the service capabilities and work;
- Code of ethics and organizational cultures to foster collaboration and cooperation, rather than competition between staff members;
- Capacity building to improve the management, leadership, communication and advocacy skills of the personnel. These trainings need to be introduced into initial and continuous professional development programmes for meteorological and hydrological professionals.

Network Design

A complete network design answers the following questions:

- What hydrological variables need to be observed?
- Where do they need to be observed? Density?
- How often do they need to be observed?
- What is the duration of the observation programme?
- How accurate should the observations be?

To answer these questions, a network design can be conceptualized as shown in Figure 3-3. The base of the pyramid is the science of hydrology. The right-hand side of the pyramid (probability, sampling theory, correlation and regression analyses, Bayesian analysis) deals with quantitative methods for coping with hydrological uncertainty. The column in the middle of the structure, optimization theory, is often used in hydrological network design. The left-hand side of the pyramid represents a rather amorphous group of technologies under the heading of socio-economic analysis. Atop the pyramid is decision theory, which is a formal mechanism for integrating all the underlying components. Refer to the Guide to Hydrological Practices (WMO-No. 168); Vol. I - From Measurement to Hydrological Information page I.2-19 for a detailed explanation of each component.

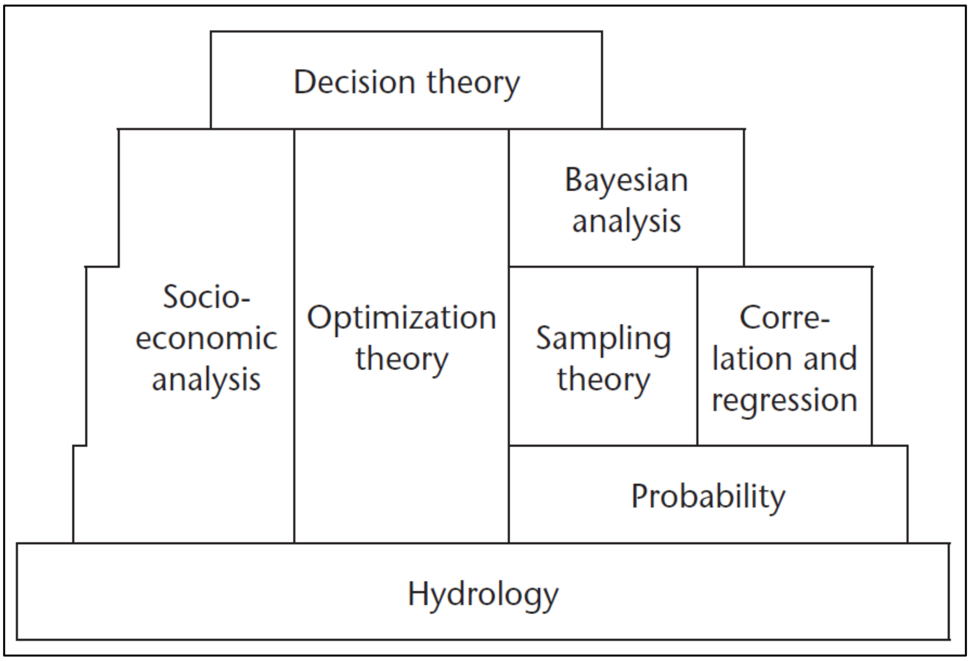

Figure B 15 The basic building blocks of network design[8]

Nevertheless, hydrological data-collection sites are often installed to meet pressing social needs and economic constraints with relatively little thought to meeting long-term hydrological information needs. Aside from meeting scientific needs, data-collection sites may be installed to assist water managers in responding to extreme events such as floods or droughts, allocating water supplies among competing uses, or meeting regulatory requirements. Sites operated for these latter purposes may also lead to increased hydrological understanding, but the resulting network is by no means optimized for that purpose.

When designing an integrated network, one should consider that the hydrological cycle is a continuum, and its interconnections permit the partial transfer of information obtained in one part of the cycle to another. The efficiency of such transfers is proportional to the degree of hydrological understanding that is captured in the models that are used to route the water (and the information) between the parts of the cycle. For example, precipitation records on or near a gauged drainage basin permit the reconstruction of streamflow records during periods when the stream-gauge malfunctions if a valid precipitation-runoff model has been calibrated during times when all gauges were functioning properly. A groundwater observation well may perform a similar role for malfunctions of the stream gauge if the well is monitoring the water table of an aquifer that is directly connected to the stream.

To date, little has been done in Lebanon to include these interactions in network designs. Ideally, the complementarity between the rain gauges and the stream gauges that are operated in a flood-forecasting network could be used in designing a network for water resources assessment, this

[8] Source : WMO Guide for hydrological practices Vol. I

example could be extended to other fields. However, networks should be designed iteratively, and the outcomes of an existing design should become starting points for subsequent designs.

Data Management Design

The availability of sufficient good quality data underpins all aspects of hydrology, from research, to water resources assessment through to a wide range of operational applications. A data set is clearly of great value as it is inevitably collected through a huge commitment of time and money. However, no discussion of information systems is complete without mention of an available robust data management system. The management of these data is therefore important work in itself and this work must be performed effectively in order to maximize the results of this investment. A well-established and well-managed hydrological archive should consolidate the work put into data collection to provide a source of high-quality and reliable data for tens or hundreds of years into the future. A poor-quality archive, due to lack of forethought in its foundation or poor management, can lead to years of excess data collection or modelling work, and subsequent poor decision-making.

There is a definite flow path that hydrological data must follow from the point of collection, as input into the system, through validation to dissemination and use in decision-making processes. This path is essentially the same regardless of the scale of operation and the level of technology used for data management and is demonstrated by the schematic diagram below.

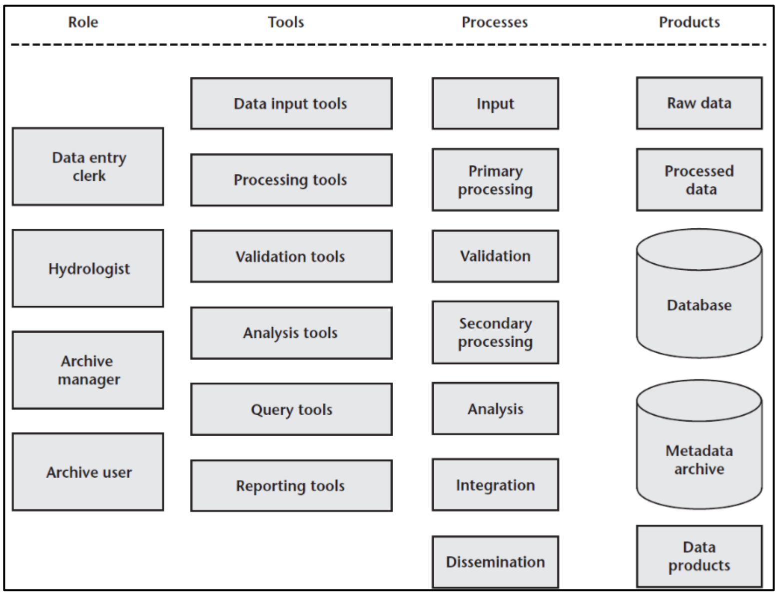

Figure B 16 The Data management scheme

The data management processes are the following:

- Input:
  Data are obtained from the source or instrument, via manual recording, data logging, digitization or other method, and transformed to the appropriate format for storage;
- Processing of raw data:
  Data stored in manual and digital forms;

- Validation:
  Raw data are checked for erroneous values and edited to produce a corrected raw data series;
- Secondary processing:
  This stage includes infilling of missing data where appropriate, conversion to secondary intervals (for example, calculations of mean and total series), creating rating curves from new discharge measurements and conversion of raw stage data to flows or reservoir storage;
- Security and archiving:
  Data must be archived in such a way as to be accessible but secure, and well documented and indexed;
- Integration with other data:
  Allowing display of data with other sources of data such as GIS data sets;
- Data dissemination:
  Data are distributed as required and in appropriate forms to modellers, decision makers, public bodies, etc.

A data management design should be carried out taking in consideration the above flow path and recommendations in the guide for hydrological practices Vol. I chapters 9 and 10 (WMO-No. 168).

Benefit-Cost Analysis

Benefit-Cost Analysis (BCA) is a method for comparing the benefits and costs of a project, programme or investment over time and determining whether or not it improves or diminishes societal well-being. This economic information can then be considered as one of several factors that will help hydrological services or funding authorities take funding decisions on met/hydro services. Benefit-cost analysis involves a systematic appraisal of a programme (whole of services or specific met/hydro services) in order to quantify the full range of social, economic and environmental benefits and costs in monetary terms. The analysis can also be used for choosing among alternative approaches to achieving programme goals. (WMO-No. 1153)

The primary reason for undertaking a BCA is to implement an accepted and unbiased economic analysis that considers all of the positive and negative impacts (characterized as benefits and costs) of a planned or potential investment or planned expenditure to support decision making.

A network design could be based on a maximization of the economic worth of the data that are to be collected. However, such has not been the case in the real world or in Lebanon. Generally, in water resources decision making, the economic impacts of hydrological data are never considered. Decisions are made based on the available data as the option of delaying the decision to collect more data is not explored or deemed unacceptable.

A minimum level of data collection is desirable in a nation-wide basic hydrometric network, regardless of present or prospective economic development. Hydrometric data are time bound. This means that they are mainly dependent on records which can be collected only as the phenomena unfold with the passage of time. It has been estimated that at least 25 to 50 years of hydrometric data are desirable to give an adequate picture of conditions for design of water-resource projects (Canada. 1981). This is obviously an ideal situation which is rarely realized before development commences. However, it indicates the necessity of setting up at least a minimum network in undeveloped areas well in advance of the actual need for the data. (WMO-No. 717)

Once a development plan is under consideration. the need for the data is immediate. It is of course difficult to determine ahead of time what data will be required and impossible to put a station on every stream in a country. Hence. it is necessary to plan the station network very carefully to achieve the maximum return from available resources.

The operation of networks of hydrological information networks, including handling of data, can be made more meaningful if some assessment is made of the related economic factors. It is generally recognized that the use of hydrological information generates considerable benefits; there are, however, few known practical methods of applying cost-benefit criteria for determining these benefits (Reynolds, 1979). In the past few years considerable information has appeared on this subject.

Appendix I of (WMO-No. 717) contains a series of nine matrices, each of which summarizes the hydrological information required for a particular type of water-resource activity. These matrices were prepared by the rapporteurs of the Working Group on Users' Requirements for Hydrological Information.

B.5 DISASTER RISK MANAGEMENT

As part of surface water management, it is necessary for the MoEW to put in place management plans for disasters related to the water sector in coordination with the Disaster Risk Management (DRM) unit of the Presidency of the Council of Ministers (PMC). Floods, drought and forest fires are the main threats that require the ministry's intervention and preparation.

B.5.1 FLOOD RISK MANAGEMENT

A flood risk management plan for each of the 20 major Lebanese rivers which watershed area exceeds 100 km² would include a conceptual and legal framework, a program of measures, early warning protocol and organizational frameworks.

The preparation of such study includes the following tasks:

- Topographical and urban surveys of the river and its floodplains.
- Hydrological study
- Hydraulic study and flood mapping
- Risk analysis
- Social risks management plan including conceptual and legal frameworks, a program of measures, early warning protocol, organizational framework.

B.5.2 DROUGHT MITIGATION PLAN

A Drought Mitigation Plan must be put in place at a national scale level.

The study of such a plan would include the following tasks:

- Define the conceptual and legal framework, methodology,
- Data collection including historical drought events
- Establish indicators and thresholds for drought classification based on climate change scenarios
- Develop a program of measures, mitigations and recommendations for a nation scale strategy
- Establish drought early warning protocol
- Establish organizational framework for the production, implementation and update of the drought mitigation plan.

B.5.3 FOREST FIRES

The MoEW shall be included in the inter-ministerial committee, responsible for the implementation of Lebanon's National Strategy for Forest Fire Management which establishes a comprehensive Risk Management Framework for forest fire management known as the 5Rs, Research, Risk modification, Readiness, Response and Recovery. It shall be more involved in Research with the help of the meteorological monitoring network and the IHIS functioning as early warning service and in Readiness through locating water reservoirs and increasing water availability near forests.

B.6 NON CONVENTIONAL WATER RESOURCES

With the increasing challenges facing water availability continuously along the year starting from climate change and seasonal variability, anthropogenic activities and not ending at lifestyle evolution, it is actually crucial to rely on nonconventional resources to fill the deficit gap of the water balance where possible and ensure sustainable sector management. Artificial Aquifer Recharge, Wastewater reuse and Rainwater harvesting has been found the most efficient non-conventional resources needed in Lebanon.

B.6.1 ARTIFICIAL AQUIFER RECHARGE

There are significant unexploited runoffs during the rainy season and especially during snowmelt. Injecting part of it in the aquifers would have a positive impact on the potential groundwater availability and would reduce seawater intrusion into the coastal aquifers. AAR has a great potential to increase the renewable resources and ease the water stress in Lebanon. *Refer to Annex II Section C.3.8 for more details* on the advances of AAR and the still needed steps.

B.6.2 WASTEWATER REUSE

The reuse of treated wastewater was one of the main nonconventional resources that the NWSS 2010 has assessed and set to increase to 50% in 2020. However, only Ablah WWTP in Bekaa was equipped with a reuse system for the irrigation of 20ha of grapes that replaced irrigation from individual wells.

The list of all available wastewater facilities in Annex III Section A shows that the majority of treated wastewater are discharged to the sea, while the actual annual flow of treated wastewater suitable for irrigation was estimated to only 17.5 Mm^3/year from 28 WWTP, a small volume in comparison with the available freshwater resources. The reuse of treated wastewater in Lebanon also faces legal constraints as there is no legal basis no regulations, guidelines and standards for reuse of wastewater for different purposes. Hence wastewater reuse will be dropped from being a priority target for nonconventional resources in this NWSS for the horizon 2035. *Refer to Annex II Section E.2 for more details.*

B.6.3 RAINWATER HARVESTING PROGRAM

A Rainwater Harvesting Program and strategy must be put in place at a national scale level.

The study of such a program would include the following tasks:

- Define the conceptual and legal framework, methodology
- Data collection
- Hydrological assessment of the rainwater harvesting potential
- Determination of the harvesting methods and potential implementation sites
- Development of an implementation strategy and program considering climate change scenarios.

B.7 COST ESTIMATES AND TIME SCHEDULES

B.7.1 COST ESTIMATE FOR NETWORKS UPGRADE AND IHIS IMPLEMENTATION

Decisions are made based on available information; hence networks expansion with better data management systems lead to improved data which provides the decision makers with a clear vision to set adequate planning and strategies.

A review of the hydrometric network in one Canadian province indicated that the cost-benefit ratio of the existing provincial network was very high and that the network could be tripled in size to maximize economic benefits (Azar, 2003). Even in nations with very dense hydrometric networks, such as the United Kingdom, economic analysis inevitably demonstrates that benefits of hydrometric networks exceed the cost (CNS, 1991).

This study estimates the total cost for the IHIS implementation and the LMS, LRA, LARI's and MoE networks expansion at **6,066,000 USD** according to the combinatory approach described previously and the following considerations.

B.7.2 TIME SCHEDULE AND COST ESTIMATE FOR IHIS IMPLEMENTATION

Based on the above recommended studies for IHIS implementation, Table B 1 below gives the Cost Estimate of each study

- The integrated approach was adopted for cost estimation assuming that: LMS and LRA networks shall cover each catchment by 5 meteorological stations on average with an additional snow monitoring station if the catchment exceeds 2000m altitude and additional agrometeorological stations to LARI's network if a catchment contains cultivated lands and additional stations belonging to the MoE network if the catchment contains natural reserves or main forests; An uncovered catchments include maximum 1 station, a semi covered catchment includes 2 or 3 meteorological station.
- In general, the network expansion has aimed to increase the density and exceed the total number of 140 stations that was previously installed in the 1970's. The complete integrated network constituted by LMS, LRA, LARI's and MoE networks reaches a total number of 200 stations and an average density of 50 km^2/station;
- The price of a meteorological station was adopted based on a quotation received from 2 different high-end weather stations manufacturers. The price ranged between \$7000 and \$9000 and was rounded to \$10,000. The snow monitoring stations require the installation of a GEONOR® which usually costs \$ 5,000 alone; (prices do not include spare parts);
- It is assumed that LARI has well covered all agricultural lands, however, some stations need continuous maintenance therefore the instrumentation for 10 stations is needed;

- The installation of complementary hydrometric stations requires the construction of a threshold (taking into consideration streams connections and hydrogeological basins), hence increasing the unit price as access to these locations are not always available;
- Three catchments are already meteorologically fully covered taking part of a research or a pilot project (Nahr el Awali, Nahr el Kalb and Nahr el Damour).

It should be noted that this cost estimate covers an ultimate Hydrometric network. If the available budget was limited, the implementation plan should be divided into several phases according to one of the following approaches:

- Basic network gradually expanded to complete network: This implementation approach starts by adding meteorological stations progressively all over Lebanon according to the available budget while considering at first a minimum network to cover all climatic regions and catchments starting with at least one station by region.
- Catchment by catchment: This approach aims to reach ultimate Hydrometric network starting by fully equipping one catchment at a time, and then moving on to another catchment.

B.7.3 COST ESTIMATE OF THE RECOMMENDED STUDIES FOR IHIS IMPLEMENTATION

This study estimates the total cost for the recommended studies for IHIS implementation at 3,457,000 USD based on the description in the previous section, on the working team and project duration as summarized hereafter. The detailed cost estimate is given in Table B 1 below

- The assessment studies shall comprehend the assessment of institutional framework shall involve the LMS, LARI, LRA and MoE. It shall identify Lebanon needs and priorities, the assessment of new and old network design, installed weather stations based on field survey, data management and the financial resources.
  - Duration : 12 months
  - Estimated cost : 250,000 USD
- The update and analysis of the NLUMP and annexed geodatabase shall involve the MoE, CDR, Higher Council for Urban Planning.
  - Duration : 12 months
  - Estimated cost : 625,000 USD
- The Lebanese Data Rescue Project shall involve the MOEW, MoTPW, LMS, LARI, LRA, MoE.
  - Duration : 24 months
  - Estimated cost : 625,000 USD
- The required design studies for IHIS implementation shall involve the MEW, MoTPW, LMS, LARI, LRA and MoE. It shall include an institutional design, capacity building, meteorological and hydrometric

networks design, data management design, Benefit-cost analysis and the preparation of the terms of references.

  - Duration : 16 months
  - Estimated cost : 425,000 USD

- The IWRM studies of main Lebanese rivers shall involve the MEW and LRA.
  - Duration : 60 months
  - Estimated cost : 2,100,000 USD

- Flood risk management plan study (*see Sub Section B.5.1*)
  - Duration : 7 months for each river
  - Estimated cost : 142,000 USD per river

- Drought mitigation plan study (*see Sub Section B.5.2*)
  - Duration : 9 months for each river
  - Estimated cost : 140,000 USD per river

- Rainwater harvesting plan
  - Duration : 9 months for each river
  - Estimated cost : 125,000 USD per river

B.7.4 TIME SCHEDULE AND COST ESTIMATE OF THE RECOMMENDED STUDIES FOR IHIS IMPLEMENTATION

Based on the above recommended studies for IHIS implementation, Table B 1 below gives the Cost Estimate of each study

Table B 1
Detailed cost estimate of the recommended studies, networks expansion and IHIS implementation

(Based on the combinatory approach; spare parts not included)

Priority	Project code	Description	Estimated cost (USD)
MH A. Meteorological and Hydrometric network expansions and improvements			
1	MH-A.1	LMS + LRA Meteorological Network Expansion Coastal Catchments: 9 Uncovered Catchments (+5 stations) 6 Semi-covered Catchments (+3 stations) Snow monitoring stations (+1 station per catchment above 2000m)	790,000
1	MH-A.2	LMS + LRA Meteorological Network Expansion Interior Catchments: 1 Uncovered Catchments (+5 stations) 3 Semi-covered Catchments (+3 stations) Snow monitoring stations (+1 station per catchment above 2000m)	200,000
1	MH-A.3	LARI Meteorological Network Expansion Maintenance instruments for 10 stations	100,000
1	MH-A.4	MoEW Meteorological Network Expansion Natural reserves and Forests	250,000
1	MH-A.5	LRA Hydrometric Network Expansion: Improvement of hydrometric stations as per LWP assessment report Hydrometric monitoring stations for stream connections coverage Hydrometric monitoring stations for hydrogeology coverage Main springs ADCP Installation Groundwater wells monitoring	4,726,000
		Total	**6,066,000**
		Out of which : Priority 1	6,066,000
		Priority 2	-
		Priority 3	-
MH-B. Integrated Hydrological Information System			
1	MH-B.1	Required studies for IHIS implementation: Assessment studies Update and Analysis of the NLUMP and annexed geodatabase Lebanese Data Rescue Project Design studies for the IHIS implementation Integrated water resources management studies Flood Risk Management plan Drought Mitigation plan Rainwater Harvesting plan	7,180,000
1	MH-B.2	IHIS implementation	2,000,000
1	MH-B.3	IHIS Operation for 24 months	288,000
1	MH-B.4	WEAP Operation and Implementation	80,000
		Total	**9,548,000**
		Out of which : Priority 1	9,548,000
		Priority 2	-
		Priority 3	-

The implementation timescale shall take into consideration the available budget and divides it into phases as follows

1. Recommended studies based on their priority and following a chronological order.
2. Gradually expanding the basic meteorological and hydrometric networks to reach a complete coverage.
3. Design and implementation of the IHIS center within the MoEW.

The chart below gives the proposed timescale of the three phases.

	Duration (months)	YEARS 1	2	3	4	5	6	7	8	9
A- Recommended studies for IHIS implementation	**84**									
Assessment studies	12									
Update and Analysis of the NLUMP	12									
Lebanese Data Rescue Project	24									
Design studies for IHIS implementation	16									
Integrated water resources management studies	60									
Flood risk Management Plan	84									
B- Networks Expansion	**60**									
LMS + LRA Meteorological Network	40									
LARI Meteorological Netwokr	12									
MoE Metworological Network	24									
LRA Hydrometric Network	60									
C- IHIS implementation	**36**									
IHIS Implementation	12									
IHIS Operation and Supervision	24									
WEAP Implementation	6									

Figure B 17 Recommended studies, networks expansion and IHIS implementation timescale

	Duration (months)	MONTHS 1	2	3	4	5	6	7	8	8
Drought Mitigation (Nation scale drought mitigation plan)	**9**									
Define the conceptual and legal framework, methodology,	2									
Data collection including historical drought events	1									
Establish indicators and thresholds for drought classification	3									
Develop a program of measures, mitigations and recommendations fdor a nation scale strategy	6									
Establish drought early warning protocol	2									
Establish organizatioinal framework for the production, implementation and update of the drought mitigation plan	1									
Rainwater harvesting program (Nation scale rainwater harve	**9**									
Define the conceptual and legal framework, methodology,	2									
Data collection	1									
Hydrogical assessment of the rainwater harvesting potential	2									
Determination of the harvesting methods and potential implementation sites	3									
Development of an implementation strategy and program	6									

Figure B 18 Time scale for preparing drought mitigation and rainwater harvesting studies.

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APPENDIX B.1 LIST OF INSTITUTIONS

Table B 2 List of Institutions

Institution	Hydrometric network (streams, springs, channels)	Groundwater quantity (wells and water levels)	Meteorological Network	Types of Stations
LMS			40	VAISALA, AUREA
LARI			64	PESSL, DAVIS
AQMS - MoE			23	LUFFT
LRA	138	35	10	SIAP, OTT, SEBATHIES, PARATRONIC
UNIFIL			6	VAISALA
CNRS			1	DAVIS
USJ			5	CEIS-ELTA
AUB			3	-
UoB			2	-
AEC			1	DAVIS
Private			125	DAVIS, PESSL, AMBIENTWEATHER, ACURITE, CAMPBELL, LACROSSE, NETATMO, WEATHERFLOW, RAINWISE

APPENDIX B.2 LIST OF METEOROLOGICAL STATIONS

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Table B 3
Meteorological stations under Lebanese Meteorological Service - LMS

Station	District	Long	Lat	Altitude	Notes
Al Arz / Les Cedres	North Lebanon	36.07	34.25	1916	
Balamand	North Lebanon	35.77	34.37	359	
Barouk Faraidis	Mount Lebanon	35.67	33.71	1114	
Bayssour	Mount Lebanon	35.57	33.76	978	
Beyrouth Airport	Beirut	35.49	33.83	12	
Beyrouth buoy	Beirut			0	
Beyrouth Golf	Beirut	35.49	33.85	14	Non-Operating
Dahr El Baidar	Bekaa	35.77	33.82	1516	
Deir El Ahmar	Bekaa	36.13	34.12	943	
Deir El Kamar	Mount Lebanon	35.56	33.70	794	
Douris	Bekaa	36.17	33.99	1009	Non-Operating
El Abdeh	North Lebanon	35.98	34.52	37	
El Hermel	Bekaa	36.39	34.40	605	
El Qaa	Bekaa	36.48	34.34	513	Non-Operating
El Qoubayat	North Lebanon	36.28	34.57	497	
El Qoussaibah	Mount Lebanon	35.65	33.87	584	Non-Operating
El Quassmieh	South Lebanon	35.25	33.32	9	
El-Mechref	Mount Lebanon	35.46	33.71	395	
Faqra	Mount Lebanon	35.81	33.99	1655	Discontinuous
Hemlaya	Mount Lebanon	35.71	33.94	805	
Jezzine	South Lebanon	35.59	33.54	1070	
Kafar Dounine	South Lebanon	35.40	33.22	560	
Kafar Qouq-Rachaya	Bekaa	35.89	33.53	1205	
Kaslik Jounieh	Mount Lebanon	35.62	33.98	41	
Kfar Chakhna	North Lebanon	35.86	34.36	260	
Lebaa	South Lebanon	35.45	33.55	331	
Marjayoun	South Lebanon	35.59	33.36	827	
Qartaba	North Lebanon	35.85	34.10	1222	
Qlaiaat-Akkar	North Lebanon	35.99	34.59	5	
Quaraoun-Barrage	Bekaa	35.69	33.55	843	
Rayak Amara	Bekaa	36.01	33.85	852	
Saida	South Lebanon	35.37	33.56	14	
Sir el Dinnieh	North Lebanon	36.03	34.38	926	
Sour	South Lebanon	35.21	33.27	4	
Tannourine	North Lebanon	35.93	34.21	1838	
Tripoli buoy	North Lebanon			0	Non-Operating

Table B 3
Meteorological stations under Lebanese Meteorological Service - LMS

Station	District	Long	Lat	Altitude	Notes
Tripoli IPC	North Lebanon	35.81	34.45	6	
Zahle - Haouch Oumara	Bekaa	35.85	33.82	926	
Zahrani	South Lebanon	35.46	33.43	10	
Zahrani buoy	South Lebanon			0	Non-Operating

Table B 4
Meteorological stations under Lebanese Agricultural Research Institute - LARI

Station	District	Long	Lat	Altitude	Notes
Aakar al atika	Akkar	36.24	34.53	827	Reliable
Aamatour	Mount Lebanon	35.60	33.63	702	Reliable
Aandket	Akkar	36.31	34.60	640	
Aarsal	Baalbak-Hermel	36.42	34.18	1424	
Ain al abou	Mount Lebanon	35.78	34.01	1200	
Ain zhalta	Mount Lebanon	35.71	33.74	1205	
Al abdeh	Akkar	35.99	34.52	15	Reliable
Al akoura	Mount Lebanon	35.89	34.12	1461	
Aley	Mount Lebanon	35.61	33.81	885	Reliable
Ammik	Beqaa	35.78	33.71	876	
Baakline	Mount Lebanon	35.57	33.68	885	Reliable
Balaa - tannourine	North Lebanon	35.88	34.17	1547	Reliable
Bar elias	Beqaa	35.94	33.79	882	Reliable
Barouk	Mount Lebanon	35.70	33.71	1340	
Bayno - aakar	Akkar	36.18	34.54	521	Reliable
Bcharri	North Lebanon	36.02	34.25	1440	Reliable
Berbara-akar	Akkar	36.18	34.58	396	Reliable
Bir hasan	Mount Lebanon	35.49	33.86	40	
Btedii	Baalbak-Hermel	36.11	34.11	1049	
Chhim	Mount Lebanon	35.49	33.63	854	
Deir nbouh	North Lebanon	34.93	34.37	278	Reliable
Derdghaya	South Lebanon	35.37	33.28		Reliable
Doures	Baalbak-Hermel	36.16	33.99	1066	
Ehden	North Lebanon	35.97	34.30	1480	
El kaa	Baalbak-Hermel	36.51	34.39	583	Reliable
El khyem	Nabatieh	35.61	33.33	714	
El nabatiyeh	Nabatieh	35.41	33.40	345	Reliable
Fanar	Mount Lebanon	35.55	33.88	90	Reliable
Fneidek	Akkar	36.18	34.49	1212	Reliable
Ghazir	Mount Lebanon	35.68	34.02	550	

Table B 4
Meteorological stations under Lebanese Agricultural Research Institute - LARI

Station	District	Long	Lat	Altitude	Notes
Haouch oumara	Beqaa	35.91	33.82	884	
Hasbaya	South Lebanon	35.69	33.40	740	Reliable
Hawsh ammik	Beqaa	35.76	33.71	867	Reliable
Jabbouleh	Baalbak-Hermel	36.34	34.23	847	
Kfarchakhna	North Lebanon	35.87	34.35	233	Reliable
Kfardan	Baalbak-Hermel	36.06	34.02	1049	Reliable
Kfarhata-al koura	North Lebanon	35.74	34.29	325	
Khorbet char-akar	Akkar	36.18	34.60	366	
Khorbet kanafar	Beqaa	35.72	33.64	1005	Reliable
Lebaa	South Lebanon	35.45	33.54	351	Reliable
Maaser el chouf	Mount Lebanon	35.67	33.67	1154	
Machghara	Mount Lebanon	35.66	33.64	936	
Mansoura-hermel	Baalbak-Hermel	36.41	34.42	682	
Markaba	Nabatieh	35.53	33.24	520	
Mayrouba	Mount Lebanon	35.78	34.01	1183	
Mcheitiyeh	Baalbak-Hermel	36.08	34.16	1470	
Michmich	North Lebanon	36.25	34.45	1100	Reliable
Mimes	Nabatieh	35.70	33.44	820	
Niha - el chouf	Mount Lebanon	35.63	33.60	1153	
Qlaiaat	Mount Lebanon	35.71	33.97	1063	Reliable
Rachaya el fakhar	Nabatieh	35.66	33.36	797	
Ras baalbeck	Baalbak-Hermel	36.42	34.26	1060	Reliable
Rmeich	Nabatieh	35.37	33.09	627	
Saida	South Lebanon	35.38	33.55	31	Reliable
Sfireh	North Lebanon	36.06	34.40	1250	Reliable
Shheem	Mount Lebanon	35.49	33.63	580	Reliable
Syr el douniyeh	North Lebanon	36.17	34.39	936	
Tal amara	Beqaa	35.99	33.86	915	Reliable
Talia	Baalbak-Hermel	36.15	33.92	1185	
Tarchich	Mount Lebanon	35.82	33.88	1622	
Terbol	Beqaa	35.99	33.81	905	
Tyr	South Lebanon	35.22	33.26	4	Reliable
Wata houb	North Lebanon	35.90	34.20	1363	
Zaaroureyi	Mount Lebanon	35.52	33.62	663	Reliable

Table B 5
Meteorological stations under Ministry of Environment - NAQMS

Station	District	Long	Lat	Altitude	Notes
Lebanese University - Hadath	Mount Lebanon	35.52	33.83	45	+weather data
Pine Forest - Beirut	Beirut	35.51	33.87	47	
Zahle – Public Garden	Bekaa	35.90	33.85	985	+weather data
Saida – Rafic Hariri Secondary School	South Lebanon	35.39	33.58	15	
Baalbeck – مكي محمد تكنة	Baalbak-Hermel	36.21	34.00	1220	
Tyre - Tair Debba Municipality	South Lebanon	35.28	33.27	200	+weather data
Chouf - Nature Reserve	Mount Lebanon	35.70	33.69	1790	+weather data
Nabatieh - Asdak Parc	Nabatieh	35.48	33.38	410	+weather data
Tripoli - Deir Ammar	North Lebanon	35.90	34.46	25	+weather data
Zouk - USEK	Mount Lebanon	35.62	33.98	45	+weather data
Fiaa -Chekka	North Lebanon	35.79	34.35	415	+weather data
Beirut - Lebanese American University	Beirut	35.48	33.89	82	+weather data
Sabtieh - Middle East University	Mount Lebanon	35.57	33.87	163	+weather data
Pine Forest - Main entrance -Tayouneh side	Mount Lebanon	35.51	33.87	50	+weather data
Barja - Iman High School	Mount Lebanon	35.44	33.64	342	+weather data
Chekka - Hamat	North Lebanon	35.68	34.28	203	
University of Balamand	North Lebanon	35.78	34.37	317	
Kfarhazir Municipality	North Lebanon	35.77	34.31	327	
Andkit – AFDC ecolodge	Akkar	36.30	34.55	730	
Minyeh - Btormaz	North Lebanon	36.04	34.42	655	
Bentael – Reserve committee headquarter	Mount Lebanon	35.69	34.15	502	
Bsalim – Daher El Bachek public hospital	Mount Lebanon	35.60	33.88	473	
Dmit- AFDC ecolodge	Mount Lebanon	35.50	33.70	64	
Bkassine Firefighters center in Bkassine Public School	South Lebanon	35.58	33.57	833	
Wadi Al Houjeir- Kabrikha municipality	Nabatieh	35.46	33.25	496	
Naqoura- public school	South Lebanon	35.14	33.12	79	

Table B 6
Meteorological stations under Litani River Authority - LRA

Station	District	Long	Lat	Altitude	Notes
Aajaltoun AIS	Mount Lebanon	35.68	33.96	821	
Baqeesh reservoir	Mount Lebanon	35.79	33.95	1416	
Kfar Debbiane municipality	Mount Lebanon	35.77	33.98	1307	
Shaile reservoir	Mount Lebanon	35.65	33.96	463	
Chabrouh dam	Mount Lebanon	35.83	34.03	1596	
Dome du Mzaar	Mount Lebanon	35.84	33.97	2425	Non-Operating
Damour SeaMouth	Mount Lebanon	35.45	33.71	10	
Jisr el Adi	Mount Lebanon	35.56	33.73	259	
Silfaya Church	Mount Lebanon	35.57	33.74	342	
Azzounieh	Mount Lebanon	35.71	33.77	1160	

Table B 7
Meteorological stations under National Council of Scientific Research - NCRS

Station	District	Long	Lat	Altitude	Notes
Jnah	Beirut	35.49	33.87	50	

Table B 8
Meteorological stations under Academic and Private Institutions

Station	District	Long	Lat	Altitude	Notes
American University of Beirut - AUB					
AREC AUB Farm	Bekaa	36.08	33.92	998	
Chabrouh	Mount Lebanon	35.83	34.03	1560	
Aajaltoun	Mount Lebanon			950	
Institut de Recherche pour le Developpement - Projet SudMed IRD - NRCS - USJ					
Cedres	North Lebanon	36.09	34.26	2830	
Mzar	Mount Lebanon	35.86	33.98	2300	
Laqlouq	Mount Lebanon	35.88	34.14	1850	
Saint Joseph University - Centre Regional de l'Eau et l'Environnement - CREEN - USJ					
Mar Roukoz - ESIB	Mount Lebanon	35.56	33.86	249	
Ainata	Bekaa	36.07	34.17	1567	
Faraya	Mount Lebanon	35.84	33.99	1846	
Saida	South Lebanon	35.36	33.52	38	Non-Operating
Ballouneh	Mount Lebanon	35.67	33.95	715	

Table B 8
Meteorological stations under Academic and Private Institutions

Station	District	Long	Lat	Altitude	Notes
University of Balamand - Institute of the Environment IOE-UoB					
Kaftoun - FDK Reserve	North Lebanon	35.77	34.27	310	
Balamand	North Lebanon	35.78	34.37	300	
Arc En Ciel - AEC					
Taanayel	Bekaa	35.87	33.80	880	

APPENDIX B.3 LIST OF HYDROMETRIC STATIONS

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Table B 9
Hydrometric stations (all under LRA)

Station	Bassin	District	Long	Lat	Alt	Years in service
Kousba	Nahr Abou Ali	North Lebanon	35.85	34.36	270	58
Daraya	Nahr Abou Ali	North Lebanon	35.86	34.37	174	32
Racheine stream - Zgharta Bridge	Nahr Abou Ali	North Lebanon	35.89	34.40	80	42
Joueit stream - Zgharta	Nahr Abou Ali	North Lebanon	35.89	34.39	133	9
Abou Samra	Nahr Abou Ali	North Lebanon	35.86	34.42	46	43
Abou Halka Spring	Nahr Abou Ali	North Lebanon	35.82	34.41	3	14
Fawar Antelias	Nahr Antelias	Mount Lebanon	35.60	33.91	15	16
Hakour	Nahr Arqa	North Lebanon	36.04	34.53	77	51
El Jaamani stream - Ras el Metn Bridge	Nahr Beyrouth	Mount Lebanon	35.62	33.86	270	22
Dachounieh	Nahr Beyrouth	Mount Lebanon	35.57	33.84	73	36
Jisr el Basha	Nahr Beyrouth	Mount Lebanon	35.53	33.87	22	43
Chagour Hammana	Nahr Beyrouth	Mount Lebanon	35.74	33.82	1207	23
Bziza Bridge	Nahr el Asfour	North Lebanon	35.79	34.30	320	21
Hermel	Nahr el Assi	Bekaa	36.41	34.38	590	58
Canal - ElQaa - Laboue	Nahr el Assi	Bekaa	36.36	34.22	877	28
Canal - ElRoueiss - Laboue	Nahr el Assi	Bekaa	36.35	34.20	893	32
Canal - Matrafe - Laboue	Nahr el Assi	Bekaa	36.35	34.20	899	32
Ras el Ain Baalbeck	Nahr el Assi	Bekaa	36.22	34.00	1161	23
Marj Bisri	Nahr el Awali	South Lebanon	35.56	33.59	398	45
Saida	Nahr el Awali	South Lebanon	35.39	33.58	6	60
Jezzine Spring - Entree S	Nahr el Awali	South Lebanon	35.59	33.54	924	11
Mechmech - Qobayat	Nahr el Bared	North Lebanon	36.10	34.45	390	21
Tirane	Nahr el Bared	North Lebanon	36.02	34.40	510	20

Table B 9
Hydrometric stations (all under LRA)

Station	Bassin	District	Long	Lat	Alt	Years in service
Sea Mouth	Nahr el Bared	North Lebanon	35.96	34.51	29	36
Tirane - Downstream plant	Nahr el Bared	North Lebanon	36.02	34.44	239	9
Tirane - Upstream plant	Nahr el Bared	North Lebanon	36.03	34.41	239	14
Pont Adwe	Nahr el Bared	North Lebanon	35.99	34.45		7
Canal - Bebine	Nahr el Bared	North Lebanon	35.98	34.50		21
Tirane - Downstream Abou Moussa	Nahr el Bared	North Lebanon	36.00	34.44		12
Es Safa - Wadi es Sitt	Nahr el Damour	Mount Lebanon	35.64	33.71	536	28
Abou Zebli - Rachmaya Plant	Nahr el Damour	Mount Lebanon	35.62	33.74	447	41
Jisr el Kadi	Nahr el Damour	Mount Lebanon	35.55	33.72	254	51
el Hammam stream - Upstream Connection	Nahr el Damour	Mount Lebanon	35.48	33.69	19	36
Sea Mouth	Nahr el Damour	Mount Lebanon	35.44	33.70	9	25
Ain Dara - Pont Bmehray	Nahr el Damour	Mount Lebanon	35.71	33.77	1060	2
Canal - Es Safa - BeitedDine-Qaa	Nahr el Damour	Mount Lebanon	35.70	33.75	1042	23
Canal - Es Safa - Principale	Nahr el Damour	Mount Lebanon	35.70	33.75	968	23
Canal - Raayen - Es Safa (داخل المعمل)	Nahr el Damour	Mount Lebanon	35.70	33.75	979	15
Canal - Barouk Rive Droite	Nahr el Damour	Mount Lebanon	35.66	33.71		23
Canal - Barouk Rive Gauche	Nahr el Damour	Mount Lebanon	35.66	33.71		23
Canal - Upper Damour	Nahr el Damour	Mount Lebanon	35.47	33.70	36	20
Canal - Lower Damour	Nahr el Damour	Mount Lebanon	35.46	33.71	32	20
Canal - El Hammam	Nahr el Damour	Mount Lebanon	35.47	33.70		8
Es Safa Spring	Nahr el Damour	Mount Lebanon	35.70	33.75	949	21
Ain Darah Spring - Upstream Es Safa	Nahr el Damour	Mount Lebanon	35.72	33.78	1260	17
Es Safa - Upstream usine - Azzouniyeh	Nahr el Damour	Mount Lebanon	35.71	33.77	1086	15
Damour Sea Mouth	Nahr el Damour	Mount Lebanon	35.45	33.71	5	1

Table B 9
Hydrometric stations (all under LRA)

Station	Bassin	District	Long	Lat	Alt	Years in service
El Hammam	Nahr el Damour	Mount Lebanon	35.47	33.70	19	1
Demit	Nahr el Damour	Mount Lebanon	35.49	33.70	65	1
Jisr el Kadi	Nahr el Damour	Mount Lebanon	35.56	33.73	254	1
Silfaya Church	Nahr el Damour	Mount Lebanon	35.57	33.74	286	1
Rechmaya	Nahr el Damour	Mount Lebanon	35.60	33.73	447	1
Ouadi El Sitt	Nahr el Damour	Mount Lebanon	35.63	33.71	536	1
Azzounieh	Nahr el Damour	Mount Lebanon	35.71	33.77	1086	1
Nabaa el Safa	Nahr el Damour	Mount Lebanon	35.70	33.75	949	1
Wadi Fardis - Upstream	Nahr el Hasbani	South Lebanon	35.67	33.37	497	25
Jisr Fardis	Nahr el Hasbani	South Lebanon	35.64	33.37	482	29
Downstream Wazzani Spring	Nahr el Hasbani	South Lebanon	35.61	33.27	281	20
Sreid spring - el Mari Bridge	Nahr el Hasbani	South Lebanon	35.63	33.32	370	20
Wazzani Spring	Nahr el Hasbani	South Lebanon	35.62	33.28	287	18
Canal - Hasbani	Nahr el Hasbani	South Lebanon	35.64	33.32	370	7
Upstream Wazzani Spring	Nahr el Hasbani	South Lebanon	35.62	33.28	300	15
Hasbani Spring	Nahr el Hasbani	South Lebanon	35.67	33.41	567	13
El Joz Spring - Chebaa	Nahr el Hasbani	South Lebanon	35.77	33.35	1357	5
El Moughara Spring	Nahr el Hasbani	South Lebanon	35.75	33.35	1252	5
Beit Chlala	Nahr el Jaouz	North Lebanon	35.79	34.25	609	25
Sea Mouth	Nahr el Jaouz	North Lebanon	35.68	34.27	9	44
Dalleh	Nahr el Jaouz	North Lebanon	35.85	34.22	650	12
Wadi Chadra	Nahr el Kabir	North Lebanon	36.32	34.62	373	41
Sea Mouth	Nahr el Kabir	North Lebanon	36.00	34.65	0	21
el Mougharah stream - Hrajel	Nahr el Kalb	Mount Lebanon	35.76	34.01	1178	27

Table B 9
Hydrometric stations (all under LRA)

Station	Bassin	District	Long	Lat	Alt	Years in service
Daraya - El Hardoum stream	Nahr el Kalb	Mount Lebanon	35.72	33.94	600	36
Daraya	Nahr el Kalb	Mount Lebanon	35.71	33.95	557	41
Sea Mouth	Nahr el Kalb	Mount Lebanon	35.60	33.95	12	57
Canal - Dbayeh - Upstream Tunnel	Nahr el Kalb	Mount Lebanon	35.60	33.95	16	36
Canal - Wata - After Dam	Nahr el Kalb	Mount Lebanon	35.62	33.95	16	35
Canal - Hrajel Irrigation	Nahr el Kalb	Mount Lebanon	35.79	34.01		22
Canal - Dbayee part (right - left) part 1-2-3 same	Nahr el Kalb	Mount Lebanon	35.61	33.95	16	4
El Aassal Spring	Nahr el Kalb	Mount Lebanon	35.83	34.00	1535	17
El Laban Spring	Nahr el Kalb	Mount Lebanon	35.84	34.01	1629	21
Kachkouch Spring	Nahr el Kalb	Mount Lebanon	35.64	33.94	50	4
Chamsine Spring - Downstream The Spring	Nahr el Litani	Bekaa	35.96	33.75	871	29
Ghzayel - Anjar	Nahr el Litani	Bekaa	35.94	33.74	891	40
Canal - Anjar	Nahr el Litani	Bekaa	35.94	33.73	879.3	56
Ghzayel - Damascus Road	Nahr el Litani	Bekaa	35.91	33.76	883	54
Berdaouni - Damascus Road	Nahr el Litani	Bekaa	35.89	33.78	866	59
Wadi Chtoura - Damascus Road	Nahr el Litani	Bekaa	35.84	33.81	910	24
Wadi ed Delem - Kabb Elias	Nahr el Litani	Bekaa	35.81	33.79	924	35
Joub Janine	Nahr el Litani	Bekaa	35.77	33.64	859.7	20
Yahfoufa - Ain el Sikeh	Nahr el Litani	Bekaa	36.18	33.85		20
Qillaya	Nahr el Litani	Bekaa	35.65	33.44	851	57
Khardali	Nahr el Litani	South Lebanon	35.54	33.34	240	55
Litani - Downstream Wadi Ghandourieh	Nahr el Litani	South Lebanon	35.43	33.31	105	31
Canal - Mathaneh - Qasmiyeh - Downstream Inlet	Nahr el Litani	South Lebanon	35.34	33.33	12	32
Sea Mouth - Qasmieh	Nahr el Litani	South Lebanon	35.26	33.33	3	43

Table B 9
Hydrometric stations (all under LRA)

Station	Bassin	District	Long	Lat	Alt	Years in service
Zghir stream - Downstream Faour Spring	Nahr el Litani	Bekaa	35.96	33.78	863	21
Ras el Ain Spring - Turbol	Nahr el Litani	Bekaa	35.98	33.80		22
Ghelle Spring - Wazzaaeih	Nahr el Litani	South Lebanon	35.55	33.38		12
el Maydani Spring - Wadi el Maydani	Nahr el Litani	South Lebanon	35.52	33.41		29
Khraizate Spring	Nahr el Litani	Bekaa	35.70	33.64	967	51
Ammik Spring	Nahr el Litani	Bekaa	35.77	33.73	875	28
Chtoura Spring - Downstream	Nahr el Litani	Bekaa	35.84	33.82		36
Ain ez Zarka Spring	Nahr el Litani	Bekaa	35.67	33.51	674	35
Canal - Tunnel Markabi-Jezzine	Nahr el Litani	Bekaa	35.65	33.50	641	20
Ain El Dob - Aytanit	Nahr el Litani	Bekaa	35.68	33.58	1050	8
El Dayaa Spring - Machgharah	Nahr el Litani	Bekaa	35.65	33.53	1033	17
Abou Zeid Spring - Machgharah	Nahr el Litani	Bekaa	35.65	33.53	1012	16
El Tannour + Abou Zeid - Machgharah	Nahr el Litani	Bekaa	35.65	33.53	995	17
Zangil janta	Nahr el Litani	Bekaa	36.10	33.86	1070	6
Canal - Al Nasrieh - Yahfoufa	Nahr el Litani	Bekaa	36.11	33.86	1112	20
Bostan El Meer Beginning - Yahfoufa	Nahr el Litani	Bekaa	36.08	33.86	1112	17
Bostan El Meer End - Yahfoufa	Nahr el Litani	Bekaa	36.07	33.86	1034	17
el Sahour - Ali el Nahri - Yahfoufa	Nahr el Litani	Bekaa	36.03	33.86		8
Canal Irrigation - Yahfoufa	Nahr el Litani	Bekaa	36.08	33.86		8
Terfelsay	Nahr el Litani	South Lebanon	35.34	33.33	40	5
Canal - Borj Rahal - Qasmiye	Nahr el Litani	South Lebanon	35.27	33.32	27	31
Canal - el Tekhchiba - Qasmiye	Nahr el Litani	South Lebanon	35.27	33.32	19	0
Berdaouni - Qaa el Rim	Nahr el Litani	Bekaa	35.87	33.88	1243	10
Beit el Hajj	Nahr el Oustouane	North Lebanon	36.10	34.56	109	27

Table B 9
Hydrometric stations (all under LRA)

Station	Bassin	District	Long	Lat	Alt	Years in service
Halba Bridge	Nahr el Oustouane	North Lebanon	36.09	34.57	89	51
Sea Mouth	Nahr el Oustouane	North Lebanon	35.99	34.60	7	11
Canal - Halba Bridge - (1-2-3-4)	Nahr el Oustouane	North Lebanon	36.07	34.55	89	37
Wadi El Akhdar	Nahr el Zahrani	South Lebanon	35.50	33.41	445	27
Deir el Zahrani	Nahr el Zahrani	South Lebanon	35.47	33.44	301	22
Sea Mouth	Nahr el Zahrani	South Lebanon	35.34	33.49	3	36
Canal - Main	Nahr Ibrahim	Mount Lebanon	35.67	34.08	3	40
Afqa Spring	Nahr Ibrahim	Mount Lebanon	35.89	34.07	1113	41
El Rouaiss - Majdel Bridge	Nahr Ibrahim	Mount Lebanon	35.90	34.11	1073	40
Sea Mouth	Nahr Ibrahim	Mount Lebanon	35.64	34.07	3	44
Canal - North	Ras el Ain	South Lebanon	35.21	33.23	1	20
Sea Mouth	Ras el Ain	South Lebanon	35.20	33.22	1	20
Borak Ras el Ain Fuite	Ras el Ain	South Lebanon	35.21	33.23	1	18
Tunnel Entrance	Yammouneh	Bekaa	36.06	34.11	1361	34
El Arbain Spring	Yammouneh	Bekaa	36.02	34.13	1363	24
El Kazzaib Spring	Yammouneh	Bekaa	36.02	34.11	1366	14
El Mahkan Spring	Yammouneh	Bekaa	36.02	34.12	1364	19
El Mghr Spring	Yammouneh	Bekaa	36.02	34.12	1368	19
El Tefaha Spring	Yammouneh	Bekaa	36.02	34.12	1358	19

APPENDIX B.4 MAPS OF EXISTING NETWORKS

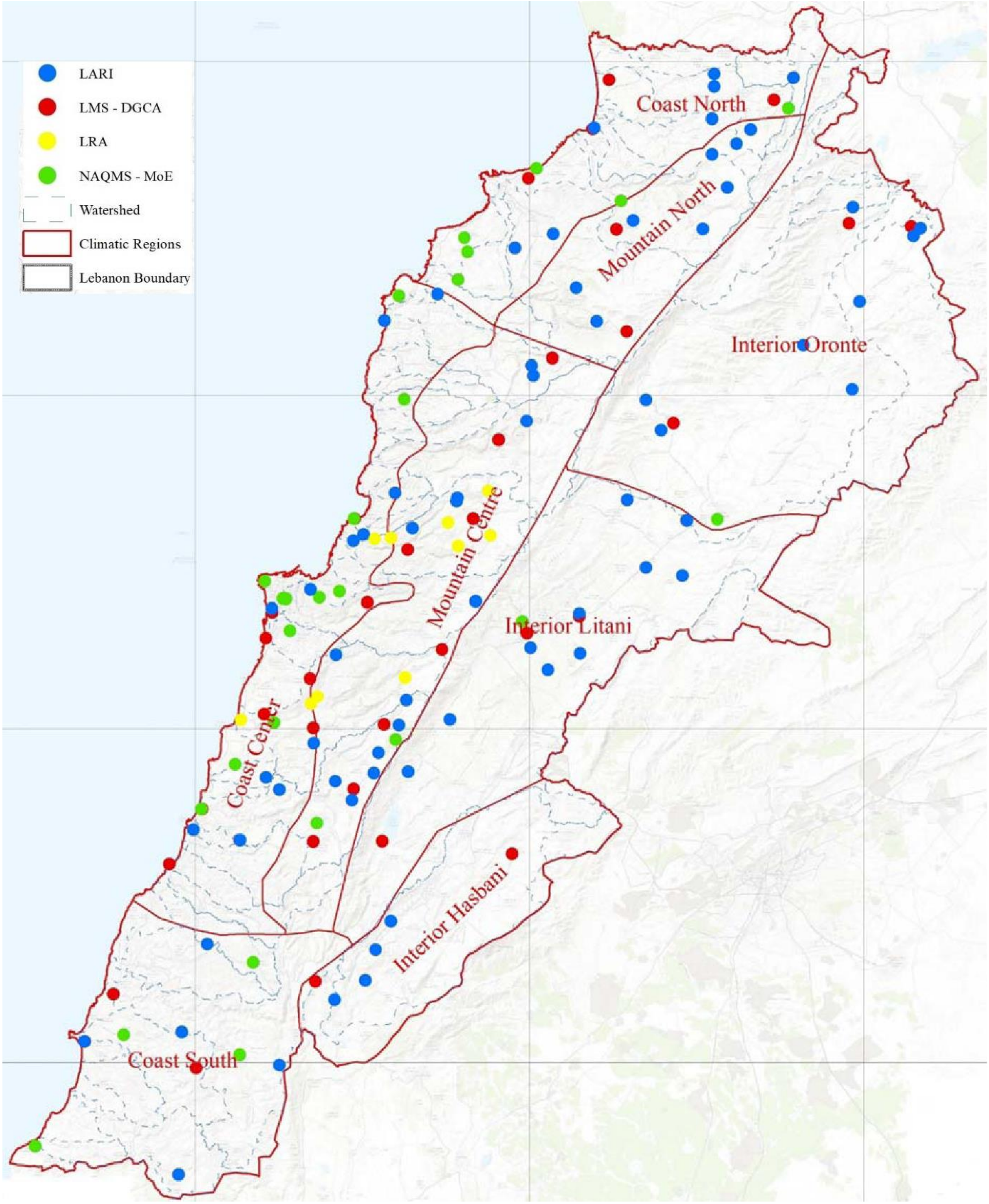

Figure B 19
Meteorological stations of all public institutions

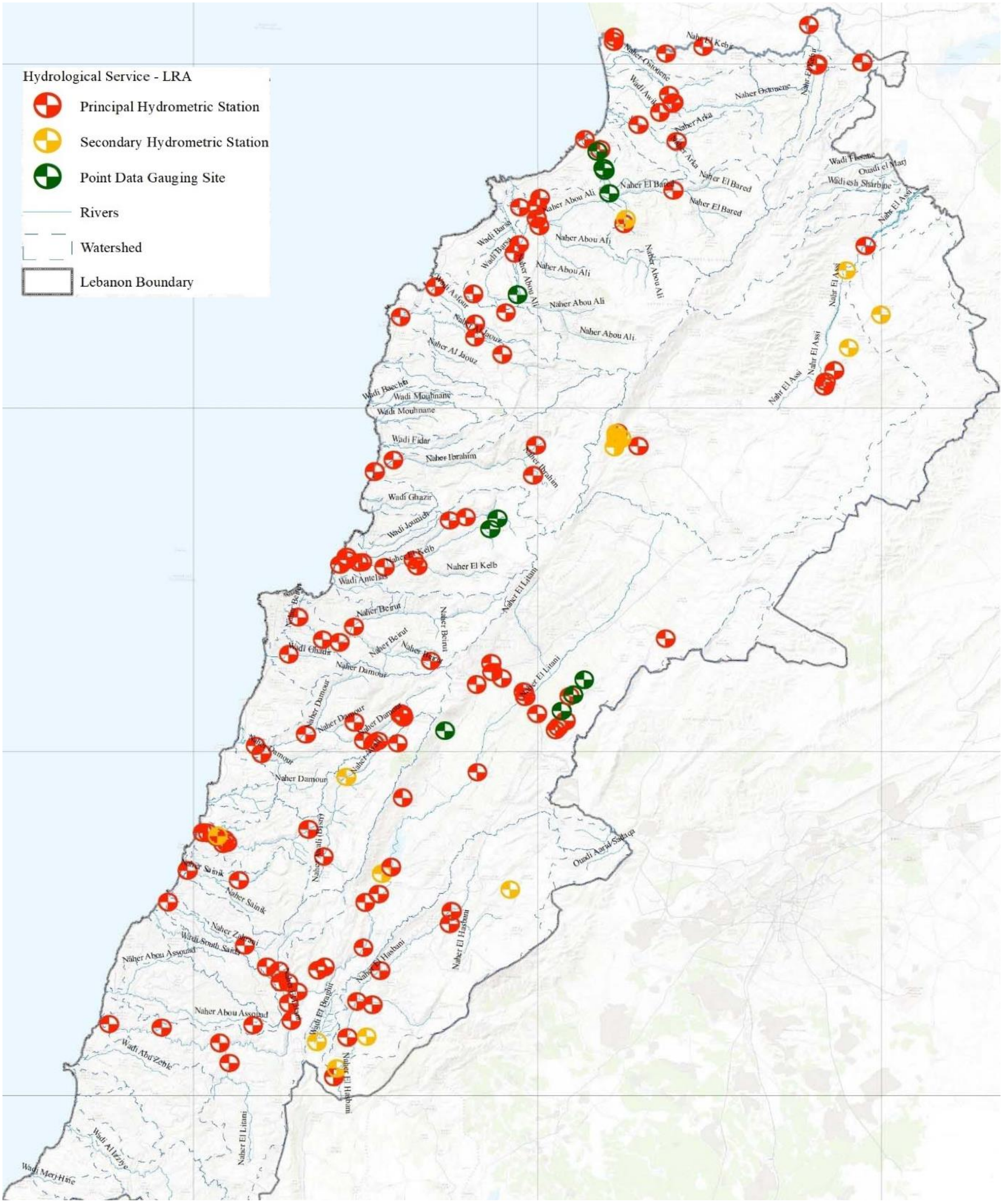

Figure B 20
Hydrometric stations of the Lebanese Hydrological Service at the LRA before 1975

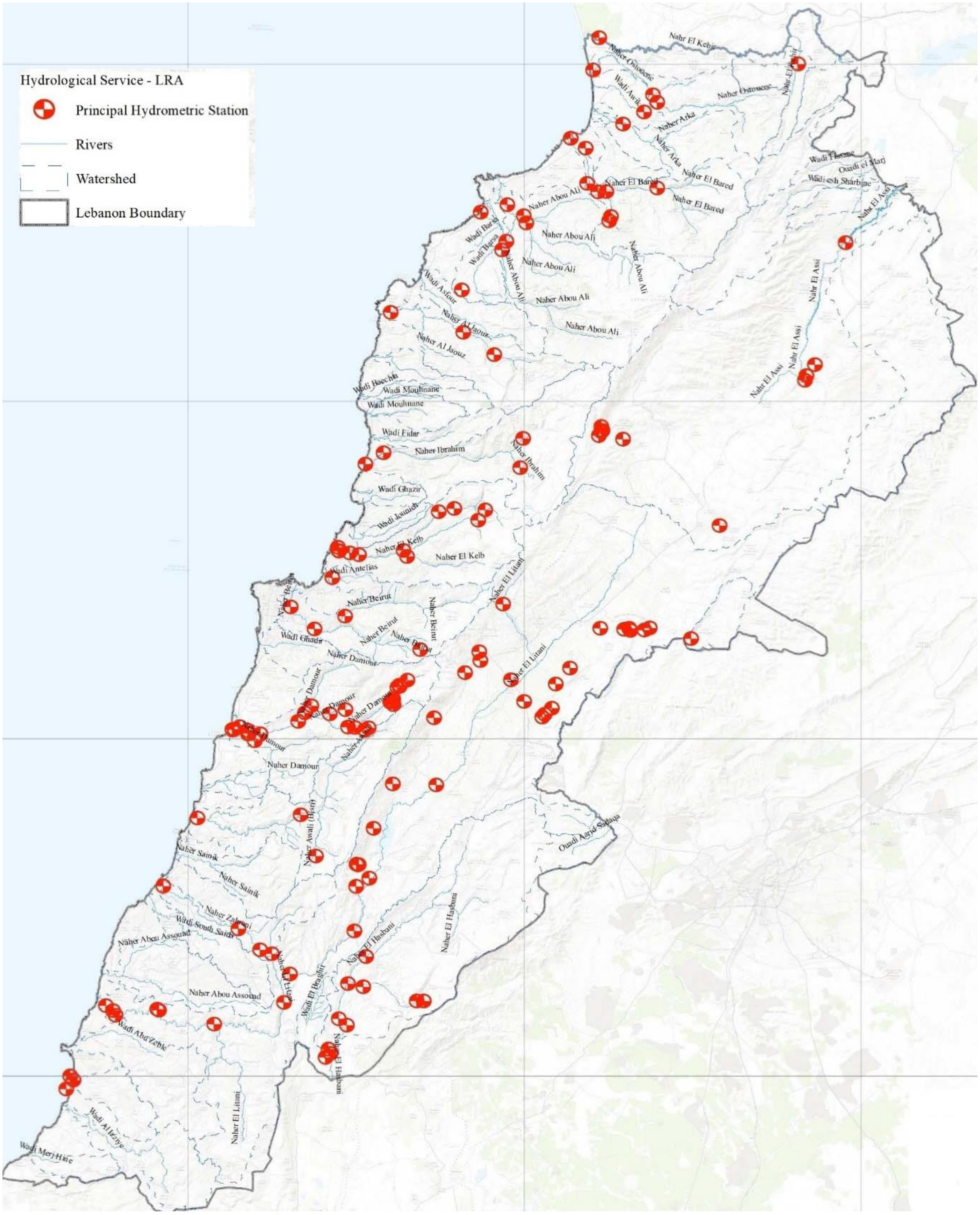

Figure B 21
Hydrometric stations of the Lebanese Hydrological Service at the LRA in 2016

SECTION C
Groundwater resources management

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C.1 INTRODUCTION

Water scarcity has been a redundant problem in Lebanon for the past decades due to the mismanagement of water resources which has been causing the imbalance between supply and demand. The difficulty of balancing between supply and demand requires the need for a sustainable Water Resources Management (WRM), especially with the growing population. The World Bank defines WRM as the “process of planning, developing, and managing water resources in terms of both water quantity and quality, across all water uses”. It includes the institutions, infrastructure, incentives and information systems that support and guide water management.

This document of the strategy exposes the problems related to groundwater resources management then, gives recommendations for developing a sustainable groundwater resources management within the Ministry of Energy and Water (MoEW). This approach starts with developing a proper database management system in order to support the optimum use of water resources and ultimately reach water security. It has to be stated that the groundwater resources management proposed strategy should be implemented simultaneously with the surface water management strategy.

Groundwater resources are 53.4% of the water resources in Lebanon (IFI, 2014). For a sustainable use of water resources, an improved and forward-thinking groundwater management is necessary. Therefore, valid and accurate information on groundwater quantity and quality, its renewability and the hydrogeological structure of the underground are necessary (BGR, n.d.).

The continuous increase in population since the 50s (Figure C 1) leads to a continuously increasing water demand. This results in an overexploitation of underground resources, not only by the public sector, but by the private sector as well, without proper planning nor monitoring.

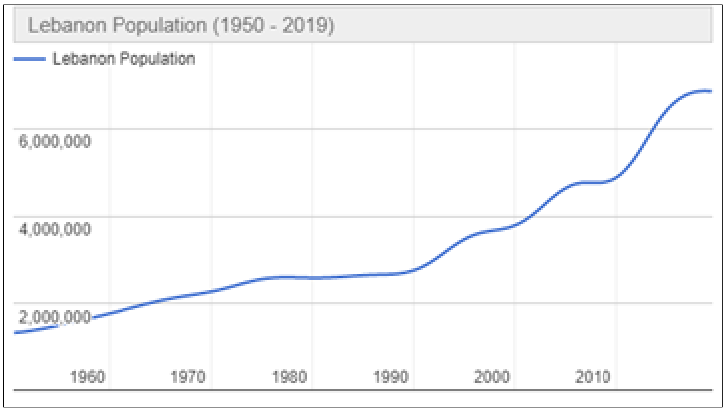


Figure C 1 Population growth in Lebanon between 1950 and 2019. (Worldometers, 2019)

Figure C 2 shows the location of the major stressed aquifers in Lebanon. It appears that they are located underneath populated urban areas (coastal area) and in areas where overexploitation is due to the demand for irrigation (Beqaa, Akkar plain).

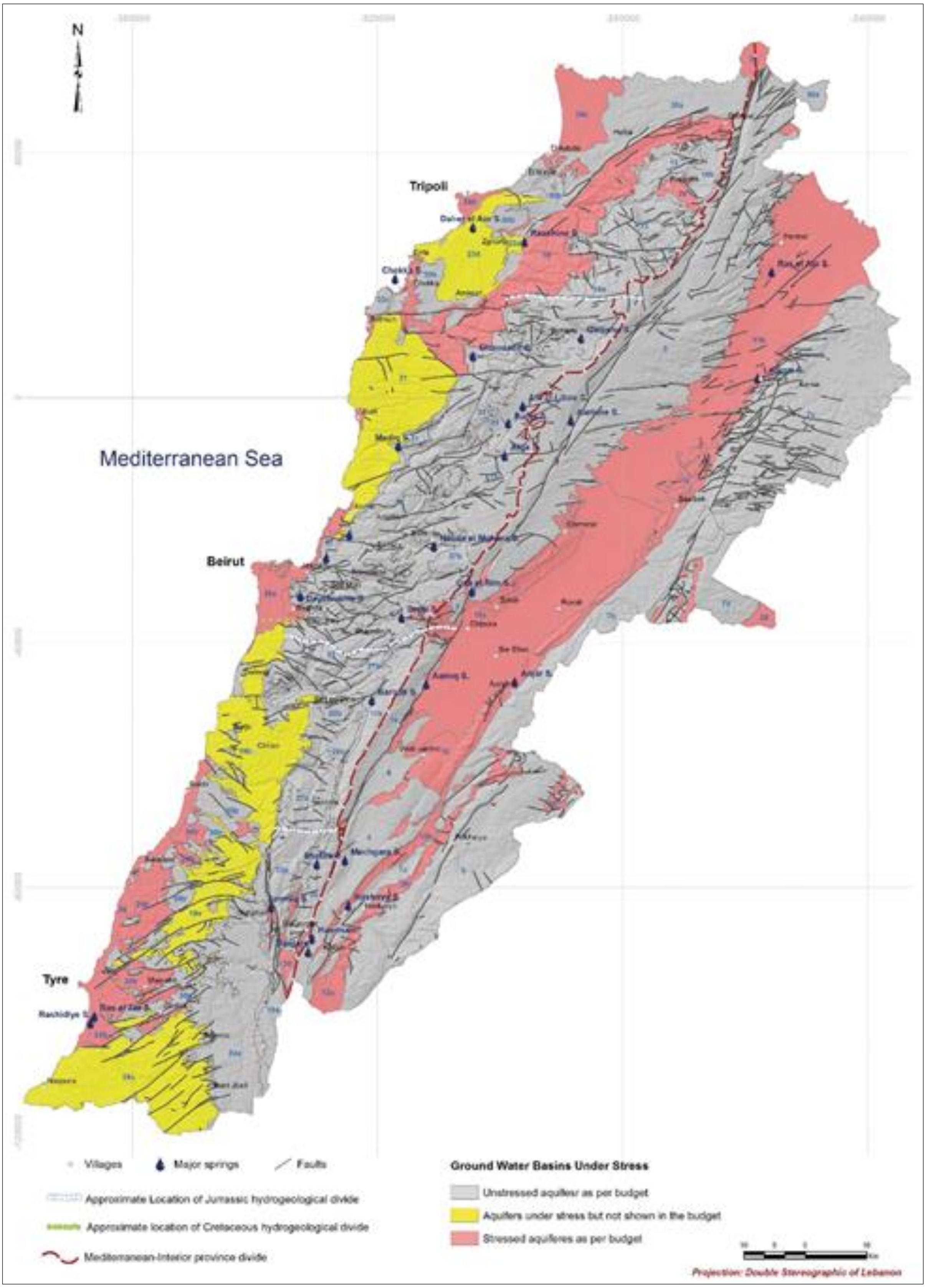


Figure C 2 The stressed groundwater basins in Lebanon (UNDP, 2014)

C.2 GROUNDWATER MANAGEMENT PRESENT SITUATION

C.2.1 BACKGROUND

Lebanon is currently going through a critical phase in managing its natural resources. Particularly in the water sector, the socio-economic evolution of the population on one side and the Syrian refugees' crisis on the other, greatly add to the stress on available resources and will exacerbate the expected 10-20% decrease in precipitation volumes by 2040, related to climate change (SNC - MoE 2011).

Due to its topography and geographic location along the Eastern Mediterranean shore, Lebanon has enjoyed a relative abundance of water from rainfall and snowfall origins continuously renewed every year or every climatic cycle. The receptacle of this resource is the geology. Suitable geological conditions favour the infiltration and storage of the water in its subterranean layers before emerging onto the surface again in springs and rivers. A multitude of rock units have the required characteristics to act as impervious zones holding back the water and preventing its further infiltration or emergence while others have the needed properties making them adequate storage zones. The result is an organized and defined sequence of sub-surface reservoirs that contain the wealth in water resources and control its flow.

Few comprehensive studies have addressed the issue of water resources in Lebanon. In 1970 the United Nations Development Program (UNDP) published results of their study of underground water resources in Lebanon, conducted for the Lebanese Government. The study which was part of a larger project, aimed also towards the capacity building and institutional development of the public water management sector in Lebanon. It led to the first definitions of groundwater basins (GWB) in Lebanon and produced a first assessment of the geographic extent, hydrodynamic parameters, hydraulic balance and potential resources for 30 major GWB over the entire country (See *ANNEX III C.1*).

A number of wells drilled to an average depth of around 150mbgl were used for exploring the sub-surface geology and testing the aquifers in terms of yields, hydrodynamic properties and water quality. Shallow geophysical exploration (electrical resistivity profiling and seismic refraction surveys) were used to better delineate the extent of some major aquifers. The geological model (constructed with structural and stratigraphic data) used for the GWB studies was adopted from the previous work of L. Dubertret.

In addition, geological maps were published by prominent geologists who worked in the UNDP project (1970) and by geologists preparing their PhD theses. These maps are the ones of the Koura - Zgharta (1/20,000), the coastal area of Akkar (1/20,000), the Baalbeck - Hermel area (1/50,000), and the whole South Lebanon (1/20,000). In addition, 2 hydrogeologic maps at a scale of 1/20,000 were published: these are those of the Akkar plain and the Koura-Zgharta area.

Results from these studies were left largely unexploited nor improved during the subsequent long years of civil war. The chaotic development of the country during this period resulted in shuffling of many parameters such as the estimates on population growth and water needs in different localities. Internally displaced population during this period increased the water demand in some areas and lessened it in others.

In the years extending between 1993 and 2005, many water resources studies were launched by the CDR to supply localities in different areas of Lebanon.

During the preparation of these water resources studies, many detailed geological surveys and hydrogeological studies were performed and many detailed geological maps at a scale of 1/20,000 were prepared and many public water wells were drilled, equipped and operated.

These studies covered several regional areas such as:

- Koura - Tripoli
- Miniye.
- North Metn.
- Northern, Middle and Western Beqaa.
- Kesrouane.
- Batroun.
- Baabda - Aaley.
- Syr el Deniye.
- South Lebanon.
- Marjayoun.

These geological and hydrogeological studies at a scale of 1/20,000, allowed to select sites for drilling public wells tapping potential aquifers to extract groundwater resources to supply the areas listed above with water and their results contributed in acquiring additional data and knowledge of the Lebanese karst in general and the aquifers potentialities in particular.

However, the data collected from these studies remained only in the hands of the administration which managed these studies and the implementation of the works but were never gathered by a specialized administration working on entering into a database system the already available data neither to exploit it (existing geological and groundwater service).

Between 2010 and 2013, a very detailed study was made by BGR on the protection of Jiita spring, through a financing from the German Government.

The study included the following (See *ANNEX III C.2*):

- Geology and hydrogeology of the area contributing in the recharge of Jiita aquifer.
- The tracer tests results.
- The monitoring of groundwater discharge and abstraction.
- The assessment of the groundwater recharge.
- The groundwater aquifer balance results.
- The water Isotope analysis results.
- The groundwater vulnerability and protection zones of Jiita spring.
- The recommendations.

In 2011, a water balance (between available resources and water needs) was conducted in the Upper Litani River basin which covers about 1500 km2 in the Central and South Bekaa valley through a financing from the USAID. The objectives of this assessment were to:

- Provide an overview of the current state of knowledge of the water balance for the Upper Litani River basin.
- Document how the water balance was established, what available data was used and what renewable hypotheses were made and also to guide future water data collection.
- Alert water users and decision makers as to the current and future water deficits that jeopardize sustainable water use in the Litani River basin.

The conclusions of this study showed that no water balance of the Middle Litani River basin could be made because of lack of sufficient and reliable data (See *ANNEX III C.3*).

In addition, the CDR launched in 2011, through a financing from the Kuwait Fund, a very detailed water resources study of the same above-mentioned area to supply all its localities with water.

Extensive geological and hydrogeological surveys at a scale of 1/20,000 were made and locations for drilling new public water wells have been identified and cost estimated.

The selected works have been implemented partly between 2013 and 2016 and the remaining ones are being presently implemented.

Simultaneously, the UNDP launched in 2011 a study at the national level to assess the National Groundwater Resources through data collection and field campaign assessment of groundwater resources across Lebanon. 13 deliverables were submitted through that study and a fully operational database system was installed in the Ministry of Energy and Water. In fact, an existing software (GW-Base) developed by RIBEKA (Germany) was selected to serve for groundwater database management with capabilities to store and manage various information (Geological, drilling, logging and well construction) needed for the assessment of wells. Groundwater levels can also be interpreted and analysed, as well as pumping tests and discharge rates data and physico-chemical quality data.

On February 15 and February 16, 2012, the software package was installed by RIBEKA personnel on a dedicated PC located at the offices of the Lebanese Center for Water Management and Conservation at the MoEW and leaded with various datasets on public wells, topographic and geologic maps (From UNDP, 1970) as well.

The deliverables of the 2014 UNDP study are the following (See *ANNEX III C.4*):

1. Del 01 Inception Report
2. Del 02 Technical Report on Public wells
3. Del 03 Proposed Monitoring Equipment Specifications
4. Del 04 Proposed one-year Monitoring Plan
5. Del 05 Initial Installation of a Fully Operational Database at t
6. Del 06A Preliminary Baseline Data Assessment Report
7. Del 06B Private well Survey Report

8. Del 07 Monitoring Plan Implementation
9. Del 08 Technical Report on Dedicated Database
10. Del 09 Data Synthesis and Basin Water Resources Characterization
11. Del 10 Artificial Recharge Preliminary Assessment
12. Del 11 Monitoring Equipment Handover Report
13. Del 12 3D GW modelling Akkar
14. Del 13 Training Completion Report

The results of the re-assessment study of groundwater resources of Lebanon funded by the Government of the Republic of Italy was published in 2014 by the Ministry of Energy and Water (MoEW) of Lebanon.

Between 2013 and 2016, several detailed hydrogeologic studies were launched, at the request of the MoEW, by UNICEF and UNHCR in the cazas of Akkar, Jezzine, Koura, Syr el Denniye, Minie and Rachaya to survey the existing public and private wells in the different identified aquifers and to designate sites for drilling new public water wells in the privilege cazas.

These studies were not unfortunately detailed but were very general and were mostly extracted from the 2014 UNDP study without suggesting or proposing detailed sites for drilling new wells (only broad areas for drilling wells have been identified) (See *ANNEX III C.5*).

In 2016-2017, the UNICEF, at the request of the Ministry of Energy and Water awarded a contract to BTD to assess, out of the selected 33 potential sites for artificial recharge in the UNDP 2014 study, 22 sites where artificial recharge could be made using natural water sources.

A total of 26 selection criteria falling under five main categories were used to prioritize the candidate sites. The 5 categories cover the quality and quantity of the recharge water, the environmental hazards at the sites, the aquifer/storage zone characteristics, the aquitard/confining zone(s) characteristics in addition to socio-economic factors. Each one of the 26 selection criteria was attributed a score range for its qualifiers and a weighting actor depending on the impact of the criterion on the success of the artificial recharge process. A special consideration was paid towards aquifers already under stress. The total score for each site was tallied up by multiplying the individual parameter scores by their corresponding weighting factor and summing up the result. The four sites that were retained for the feasibility assessment phase were Wadi El Aarayesh - El Berdawni River (Site A10), Damour (Site A14), Middle Zahrani River (Site A17) and Majdlaya - Nahr Abou Ali (Site A22) (See *ANNEX III C.6*).

In 2017 and 2018, the Ministry of Energy and Water, through a financing from UNICEF< managed the preparation of a feasibility study to select the springs which catchment structure need to be rehabilitated and to estimate the cost of the rehabilitation works.

A total of 36 springs all over Lebanon have been visited by the assigned consultant (BTD) and the current condition of their catchment works have been assessed. The assessment tasks that were conducted consisted in:

- Surveying and assessing the hydraulic accessories suitability and condition.
- Surveying and assessing the protection systems such as fences, doors, access, etc…

- Assessing of the number of water users from these springs.
- Estimating the overall cost of the rehabilitation works.
- Evaluating the benefit gained from the implementation of the rehabilitation works (increase in flow, less pollution, better protection, etc…).

The assessment results were compared and criteria for selecting the ones to be rehabilitated have been selected such as the least cost for the maximum of benefits.

The final decision was to rehabilitate a total number of 18 springs out of 36.

The second stage of the study was to prepare the detailed designs of the rehabilitation works and the detailed BOQ and costs estimates. Designs were accomplished in 2018. Works started in 2019 and will be completed in July 2020.

Lately in 2020 the UNICEF, at the request of the Ministry of Energy and Water and in line with the recommendations of the UNDP 2014 study, awarded BTD consultant a study to monitor and assess over a period of 1 year, the impact of sea-water intrusion in the coastal aquifers of Lebanon. The requested study includes the execution of the following tasks:

- Collect all available data on private and public wells tapping the coastal aquifers and sort them in operational and non-operational and in licensed and not licensed.
- Collect available data on the quality of the water extracted from the public wells and the private wells (if possible).
- Identify the tapped coastal areas aquifers.
- Refresh and edit the geology of the coastal area that covers the coastal aquifers, as hard and digital copies of 1/50,000 and 1/20,000 geologic maps, on the basis of geological surveys to be conducted and new mapping methods.
- Undertake several tracer tests between identified sinkholes or selected areas in the existing rivers upstream and the springs that burst out close to the coast, downstream.
- Monitor the flows and the water qualities of the coastal springs by collecting samples on monthly basis and analysing their physico-chemical and bacteriological characteristics.
- Prepare a hydrogeologic study and hydrogeologic maps at a scale of 1/50,000 covering the coastal parts of 3 areas which water distribution (domestic and irrigation) is managed by the Water Establishments (North Lebanon, Beirut and Mount Lebanon, South Lebanon Water Establishments). The hydrogeologic study will include the accomplishment of the following tasks:
    - Select among the surveyed coastal water wells a total number of 80 to 100 public and private water wells tapping the identified aquifers to monitor continuously over a period of one year, through the installation of sensors, their water levels fluctuations and their water conductivity and temperature. The selection of these wells has been made in a way to select in each aquifer a minimum of 4 wells where the first two wells are located close to the coast and the two others at a certain distance from the coast, inland.
    - Assess the seawater intrusion in each of the identified coastal aquifers by interpreting the measurements that will be done during one full year.

- Set up a methodology to be applied later on (after 5 years of monitoring) for the budgeting and the water modelling of the karst, saline and porous aquifers.
- Recommend for each water establishment, the safe yields that can be extracted from each public water well to supply the localities.
- Prepare detailed geological and hydrogeological studies for selecting the sites to drill the water wells that have been proposed in the strategy and prepare their detailed designs.

- Assess the possibilities of recharging artificially the coastal aquifers (characterization studies) which could be the following:
  - The porous aquifer of Akkar plain in North Lebanon.
  - The conglomerates aquifer in North Lebanon.
  - The Pliocene deposits of Minieh in North Lebanon.
  - The Beddaoui Miocene limestones of Minieh in North Lebanon.
  - The Miocene limestones in Minieh (North Lebanon).
  - The Miocene limestones of Chekka - Ras El Seqaa - Enfe in North Lebanon.
  - The Miocene limestones, which front extends along the sea coast from Dbaiye to Kaslik in Mount Lebanon.
  - The Cenomanian limestones aquifer which front extends along the sea coast from Batroun to Jounieh.
  - The Cenomanian limestones aquifer which front along the sea coast extends from Hadath-Hazmieh - Khaldeh down to Nahr el Awali.
  - The semi-porous alluvial aquifer that extends along the coast from Saida to Ras el Chaq.
  - The Cenomanian limestones aquifer that extends from Awali river to Maghdouche.
  - The Eocene limestones aquifer that extend from Maghdouche to Nahr El Litani
  - The Cenomanian limestones aquifer of Ras Nabaa Mheibib.
  - The Eocene limestones aquifer which front extends along the coast from Tyr to Ras El Biyyada.
  - The Cenomanian limestones coastal aquifer that outcrops in the extreme part of South Lebanon.

The study is on-going and is expected to be completed in May 2021.

C.2.2 PRESENT SITUATION

The present situation of groundwater extraction can be described as follows:

- In coastal and urban areas, the number of existing drilled water wells is extremely high putting the tapped aquifers under stress and consequently preventing a full material replenishment. This uncontrolled situation has led to the draining of the groundwater resources and to their contamination by seawater intrusion.
- In the remaining areas, most of the groundwater aquifers are being overexploited by private wells which are extracting large volumes of water without any restrictions nor monitoring made by the

Ministry of Energy and Water. As an example a total number of 25000 licenses for drilling private wells were issued in 2017-2018 by the Ministry of Interior without the knowledge of the Ministry of Energy and Water and no data on the locations of these wells could be obtained.

- The uncontrolled number of private wells and the uncontrolled extraction of groundwater from these wells decreased dramatically the flows discharged by many springs, which water is primarily used for domestic supply and irrigation.
- No detailed groundwater balance studies have been made on the identified aquifers since 1970.
- No monitoring on the extracted water volumes from public and private wells is made.
- No monitoring of the fluctuations of the water levels in the wells is being made.
- No monitoring of the quality of the extracted water from the wells is being made.
- There is therefore a big necessity to sustain a serious groundwater resources management.
- The coastal area that will be geologically surveyed by April 2021 within the UNICEF contract of 2020, is about 1430 km2 and represents 33 topographic sheets at 1/20,000 out of 120 sheets that cover the full territory.:

Existing springs

The number of existing springs (as per Meinzer classification) is:

- Q > 2800 l/sec 7 springs
- 2800 > N > 280l /sec 47 springs
- 280 > N > 28 l/sec 56 springs

Existing wells

1. Existing public wells :

Areas	Equipped	Recently drilled but not yet equipped	Dry or shallow & not operational
NLWE	234	4	21
BMLWE	340	9	83
SLWE	492	5	27
BWE	274	7	28
Total	**1340**	**25**	**159**

2. Existing private wells :

A number of private wells are licenced by the MoEW and the Ministry of Interior as follows :

- MoEW 21800
- Min of Interior 25000

46800

In addition, there is a high number of unlicensed private wells that is impossible to estimate

C.2.3 ISSUES

The resulting issues from the assessment of the present situation in groundwater management reveals the following:

- Mismanagement or decentralization of groundwater data due to the large number of participants resulting in data loss and data inconsistency between the different establishments and the MoEW.
- Reliability of the collected groundwater data is uncertain due to data redundancy and inaccuracy.
- Existing groundwater data exchange procedures are not based on a uniform format.
- Insufficient staff to cover all the duties of the geology and underground water service in the MoEW.
- Damaged or insufficient meteorological and hydrometric stations spread on the groundwater and river basins.
- Overexploitation of groundwater resulting in seawater intrusion in the coastal aquifers.
- Huge number of unlicensed private wells.
- Wastewater mismanagement leading to groundwater contamination.
- No studies of springs protection zones
- Absence of monitoring systems for groundwater quantity and quality.
- Absence of detailed wells and springs inventory.
- No control of groundwater extracted from wells for drinking and irrigation purposes.

If the above constraints are not taken care of in the near future, the situation will get worse leading to a water crisis. Therefore, it is crucial to start adapting a sustainable groundwater resources management.

C.3 STRATEGIC RECOMMENDATIONS FOR GROUNDWATER RESOURCES MANAGEMENT

C.3.1 GENERAL

The increased fluctuations in precipitation and extreme weather events will directly affect the availability of groundwater and our depending on it. For example, during long periods of droughts, rivers and springs will become almost dry to the point where people will increasingly rely on wells to secure their water needs, resulting in a higher risk of aquifers depletion or contamination by seawater intrusion. In other cases, such as flooding events, the rate of surface run-off will be very high resulting in a lower infiltration rate which leads to a lower recharge rate and eventually a higher risk of aquifers depletion.

There is therefore a necessity to build up a strategy which target is to enforce the management capacities of the MoEW by:

- Recruiting a specialized staff in the fields of geology, hydrogeology and water resources.
- Implementing simultaneously with the recruitment of staff a Project Management Unit (PMU) to assist the Ministry and the newly recruited staff to:
  - Recommission the database centre installed in 2014 in the Ministry of Energy and Water and enter all collected data such as geological and hydrogeological studies and reports, theses prepared in the field of hydrogeology and water resources, publications related to these fields, all information on public and private wells, lists of licensed wells, etc…
  - Follow up the geological, hydrogeological and water resources, etc… studies launched either by the Ministry of Energy and Water, the CDR, the Water Establishments, etc…
  - Assist the Ministry in improving the licensing procedures for drilling and operating private wells.
  - Monitoring the yields of the public and private wells, the springs and their water quality.
  - Assist the Ministry of Energy and Water in providing advises and respond to urgent requests in relation with the Ministry of Energy and Water.
  - Assist the Water Monitoring Department in the Ministry of Energy and Water to monitor the flows of all the rivers in Lebanon with the exception of the Litani river which flow monitoring will be performed by the LRA.
- Refreshing and completing the detailed geologic mapping of Lebanon at scales of 1/20,000. This will help tremendously in selecting the sites for drilling the water wells suggested in the strategy and in facilitating licensing of private wells drilling and exploitation.
- Refreshing the 2014 UNDP water resources study by performing in stages hydrogeological studies and producing hydrogeological reports on the identified hydrogeological basins in the North, Central, South, North Bekaa valley, South Bekaa valley and Eastern Lebanon mountain chain area.
- Drill deep reconnaissance water wells to detect the presence of new potential aquifers in some specific areas and proceed with their water testing.
- Proceed with the second phase of the rehabilitation of the springs catchment structures.

- Enhancing the Artificial Recharge of some selected aquifers.
- Enhancing the vulnerability studies in relation with the springs and the definition of their protection perimeters.
- Refresh the water budgeting of all aquifers progressively.
- Perform progressively the modelling of the karstic, saline and porous aquifers.

The above recommendations are described in details hereafter.

C.3.2 RECRUITMENT OF ADEQUATE STAFF

Adequate staff must be recruited for the department of geology and groundwater resources within the MoEW.

The monitoring, protection, development and exploitation management of groundwater resources requires the presence of qualified, well trained and experienced staff in the fields of geology and hydrogeology as well as of the availability of tools and equipment in the Ministry of Energy and Water, and more precisely in the Department of Geology and Groundwater.

However, the number of experienced senior geologists, hydrogeologists and associated experienced staff such as groundwater modellers, GIS engineers, karst hydrogeologists, water resources engineers is null. Therefore, a campaign should be launched to recruit expert and senior staff in the field of geology and hydrogeology. According to the present organization chart of the Ministry of Energy and Water, the groundwater and geology department should include the following staff:

- 11 geologists.
- 9 engineers.
- 20 technicians.
- 2 laboratory assistants.
- 1 chemical engineer
- 4 secretaries.
- 2 draftsmen.

Under the present situation, there are no geologists or hydrogeologists working in the MoEW and the department of groundwater and geology is under staffed. Therefore it is recommended to relocate the existing staff who is not qualified and recruit the following staff:

- 4 senior hydrogeologists of more than 10 years experience.

4 senior geologists of more than 10 years experience.

- 8 geologists, hydrogeologists and water resources engineers of 3 to 5 years experience.
- 1 senior GIS engineer of more than 10 years experience.
- 2 junior GIS engineers of 3 to 5 years experience.
- 1 senior groundwater modeller.
- 1 chemical engineer.

- 2 laboratory assistants.
- 2 draftsmen.
- 4 secretaries.
- 20 technicians.

The recruitment of this staff could be made through the Public Service Council (Conseil de la Fonction Publique). The chances to find such specialized staff are high knowing that the American University of Beirut as well as the Lebanese University are graduating students in the fields of geology, hydrogeology and petroleum geology and many Lebanese students follow their higher educations (Master Degree and PhD) in the fields of geology, hydrogeology, groundwater modelling, etc… abroad in international universities and would be interested to come back and work in Lebanon.

In case of impossibility, due to the government decision forbidding any recruitments of new staff, it is recommended to involve the donors in creating technical assistance program through which the requested staff would be recruited to work in the Ministry with a firm promise to hire them later.

C.3.3 PROJECT MANAGEMENT UNIT

A PMU should be implemented within the MoEW before mid-2021 to train the recruited staff and assist the Ministry of Energy and Water for a period of 5 to 7 years in the management of the groundwater resources in line with the strategy recommendations

The training of the recruited permanent or temporary staff would be made by implementing within the Ministry a Project Management Unit (PMU) financed through a technical assistance program. The tasks of the PMU are to help the newly recruited staff in their daily tasks, to follow up the on-going studies or projects prepared either by the Ministry, the CDR, or the Water Establishments through loans or grants, and to perform the below mentioned tasks. It would be a kind of long term training of the newly recruited staff and a serious assistance to the Ministry of Energy and Water in the field of Groundwater Resources Management.

The implementation of the PMU would require a period of 6 months and its activities would extend over a period of 5 to 7 years. The main tasks that the PMU should perform are:

- Review, sort and classify all existing data in the database center of the Ministry of Energy and Water.
- Define the logistic needs and equipment needs of the Department of Geology and Groundwater.
- Prepare tender documents for the procurement of equipment, vehicles, working tools, etc… for the Department of Energy and Water staff and purchase this equipment.
- Follow up, manage and control the on-going studies and future studies in the field of geology, groundwater and hydrogeology that would be requested by the MoEW and financed by different stakeholders.
- Assist the Ministry in reviewing and improving the licensing procedures for drilling and operating private wells taking into consideration the geological and hydrogeological conditions, the potentialities of the aquifers, the nature of the aquifers, the proximity of nearby springs, public

and private wells, the hydrodynamic characteristics of the aquifers, the future use of the water that will be extracted and its quality.

- Gather and classify all data related to geology, hydrogeology, water resources, publications, theses, studies performed in the past by Water Establishments, Ministry of Energy and Water, the CDR and eventually other Ministries such as the Ministry of Environment, etc…
- Recommission the groundwater data center provided by the UNDP in 2012 and implemented in the Ministry of Energy and Water to store and continuously update all data relevant to geological and hydrogeological studies, geological and hydrogeological maps, private and public wells, springs, groundwater and springs water quality, etc… This data center would be connected to the Water Resources Center (Integrated Hydrological information Center) which is planned to be implemented also in the Ministry of Energy and Water.
- Enter all collected data in the database system already installed in the Ministry of Energy and Water.
- Prepare the terms of reference for a study to select the sites for implementing hydrometric stations along the Lebanese rivers and follow up the preparation of this study and making available, to the selected consultant, all geologic and hydrogeologic data.
- Coordinate with the water establishments to perform the monitoring on regular basis, of the extracted yields from the public water wells, the fluctuations of their dynamic water levels, their water qualities, etc...
- Select the springs to monitor their yields by giving priorities to the major ones (those which flows exceed 100 l/sec).
- Prepare for the Ministry all administrative and technical measures, studies and projects that should be planned and realized in a gradual sequence with clearly described activities gathered in a coherent project(s) framework with adequate tasks and objectives, staff, budget, specified timeframe, particularly for specific sectorial activities that need long-term strategic focus that may span a 5 or 7 years time horizon.
- Encourage and develop the cooperation with universities and research centers by listing topics which master program students or researchers or PhD students would select as theses. The purpose is to encourage further comprehensive researches on some specific karst environments. These studies could include groundwater modelling of the major karstic springs aquifers.
- Involve the Ministry of Energy and Water in cooperating with small to medium stakeholders (NGOs, etc…) to implement small scale projects such as equipping public wells and springs with flow monitoring devices (watermeters), monitor the water quality of the water extracted from some medium to small scale aquifers, perform the feasibility studies and detailed studies for the rehabilitation of some springs catchment works, perform feasibility studies for the artificial recharge of some selected aquifers, or groundwater modelling of some small scale aquifers, or performing tracer tests in some specific areas or design in detail some selected AAR works or performing any other tasks contributing in improving the knowledge of the hydrogeology of Lebanon.

C.3.4 SURFACE WATER RESOURCES FLOW MONITORING

Assign the flow monitoring tasks of rivers and springs to the existing "Water Monitoring Department" in the Ministry of Energy and Water with the exception of the Litani River which flows, and water quality will be monitored by the Litani River Authority. The same Authority will also have to monitor the yields and, the water quality of all wells drilled in the Litani river watershed as well as their water levels fluctuations.

The collected data should be shared with the geology and underground water department.

C.3.5 GEOLOGICAL MAPPING

C.3.5.1 General

Refresh and complete the geological mapping of Lebanon at a scale of 1/20,000

The objective is to prepare new geological maps with higher resolution and more lithostratigraphic and structural details than the only existing national geological map coverage at the scale of 1/50.000 completed more than 50 years ago by the French geologists under the supervision of Louis Dubertret.

Geological mapping is always an interpretative exercise that conveys an important component of subjectivity. It is a representation of many sort of inferences made by the surveyor according to the state of the art of the time. In fact, during the past 5 decades large advances in the understanding and interpretation of the geological outcrops and exposures have took place, with the onset of game-changing theories and concepts such as the theory of Plate Tectonics and the application of sequence stratigraphy concepts as well as the new technological facilities that opened the way to unprecedented applications in geochemical, geophysical, petrological and paleontological analysis. Many research outputs and academic studies conducted throughout Lebanon in the past two decades have significantly modified the geological understanding of Lebanon and the region and questioned the mapping done in the past. Geological mapping suggested in the frame of this project will not only integrate and apply all these new findings and concepts in geosciences for analyzing and interpreting the outcrops and exposures but will benefit from the major advances in geological survey technologies with the introduction of modern remote sensing techniques and computer facilities.

Mapping starts by preparing and interpreting available stereographic photos, maps and satellite images. The existing geological maps, essentially those established by Dubertret, will serve as a base for a primary interpretation and to design the surveys. This is followed by field visits to the surveyed areas to check for the outcrops and geological boundaries (on maps and through localized detailed cross-sections) and to take structural measurements. In fact the first important decision a geologist should do when surveying new areas is to set the basis for subdividing the rock layers into units. This necessitates undertaking detailed lithologic and lithostratigraphic sections of the main identified geologic formations. Previous geological studies in Lebanon have resulted in the identification of the major subdivisions with differing levels of detail and accuracy over the country. Therefore, it is important to review all existing literature dealing with the lithostratigraphy of Lebanon and to undertake careful sampling of the major stratigraphic units within each of the large mapped zones for the purpose of dating the geological formations using paleontological content. Nannofossils will be the main target for the dating process in the essentially marine rocks of Lebanon. However, many continental sediments outcropping in Lebanon would require using microfossils and entomofauna for dating them. The dating of various volcanic units on another hand requires petrographical and radiometric analysis for the different sampled sites.

With the careful mapping of set geological boundaries from field survey and through remote sensing the outcrop patterns will take shape reflecting the geology of the area. Measurement of the exposures' attitude done over the field will complete the surface mapping of the area and the identification of the geological structures such as folds, faults, unconformities or other. In addition to the survey of exposed surfaces the geological mapping will be completed using lithologic logs and electrical resistivity logs, where available from public and private wells, whenever obtained during the data collection.

For each map, a detailed stratigraphy including the period, age, lithology, thickness and the formation code of the main identified geologic formations will be also prepared The maps should show:

- Topographic contour lines
- The geological formation with the related code
- The structural features
- The geomorphological features which allow to identify recharge areas such as dolines, lapiaz, karst polji, ponors, etc,
- The surface water bodies and the springs,
- The urban and rural, location and other anthropogenic activities.

The new geological dataset conducted at a scale of 1/20,000 following the existing grid of topographic basemaps of the same scale, will have significant implications in many domains such as for natural hazards mapping and urban planning for example. It will enable refined subdivisions of the geological formations in terms of their lithology and stratigraphy as well as a more precise and acceptable interpretation of the spatial extent of the different rock units and their structural relationships. All of which will significantly improve the geological understanding leading to better identification and delineation of the aquifers and estimation of their volumes and physical characteristics.

In order to achieve the tasks of producing geological maps, the following guidelines need to be applied.

1. Collection of available geological data from all previously published sources as maps, papers, thesis and studies from available sources (governmental, academic, NGOs, or from private companies).
2. Referencing all previously produced maps in one geographic database in order to assess the existing overlap and gaps at the different scales.
3. Reviewing the stratigraphic definitions of the different lithological units of Lebanon and adopting a uniformized nomenclature.
4. Identifying the important parts of the stratigraphic sections that need to be further investigated and refined,
5. Sampling the key outcrops for petrographic and paleontological analysis.
6. Establishing key lithologic sections and definitions for each of the adopted stratigraphic units.

7. Undertake a detailed analysis of remote sending data including digital elevation models (DEMs) and stereographic images and plan the field survey.
8. Undertake field survey for mapping the outcrop and the geological boundaries and structures (and undertaking detailed stratigraphic logging at specific key locations) as well as the geomorphological features.
9. Measure the real structural values over the mapped area at number of places that significantly reproduce the variability in the structures and geology.
10. Identify the different type of faults encountered on the field.
11. Reproduce the mapped geology on updated individual topographic maps at the scale of 1/20,000 with the proper legend, the structural measurement and at least one cross-section showing the major structural style of the area.
12. Prepare geological booklets describing in detail the geology of the areas served by each Water Establishment. As a whole, 5 booklets should be prepared.

C.3.5.2 Mapping procedure

The study area cover all Lebanon (10,450 km²). It is divided into 4 mapping areas (Coastal, Central, Bekaa, and Eastern areas)as shown on Figure C 3 . It covers all of the 120 sheets of Lebanon's national topographic grid at 1/20,000 scale

Louis Dubertret and his team mapped the geology of the entire area, mostly at a scale of 1/50,000 back in 1950-1970. Some geological maps at a scale of 1/20,000 also exist. Other unpublished geological maps sparsely distributed within Lebanon also exist, including a set of around sixteen (16) unpublished geological maps of south Lebanon prepared by the UNDP-FAO at a scale of 1/20,000. Other geological maps established by different consultants to the benefit of the Ministry of Energy and Water or other groups or mapped in the framework of academic or research activities in Lebanon, also exist. Although all of these maps have been strongly inspired by the pioneering work of Dubertret, they do not necessarily show internal coherence and their mapped geological boundaries, formations and structures seldom coincide between adjacent maps.

Table C 2 below shows, for each mapping area, the list of the covered maps from the national topographical grid at 1/20,000 together with the surface covered by each sheet and the percentage of geological mapping at 1/20,000 scale already achieved to date. It is summarised in Table C 1 below.

Table C 1 Mapping areas surfaces

	Total Area Km²	Mapped Area Km²	% Mapped
Total Coastal Area	**1 677.3**	**1 257.2**	**75%**
Total Central Area	**4 384.4**	**2 025.1**	**46%**
Total Beqa Area	**2 638.7**	**114.8**	**4%**
Total Eastern Area	**1 749.6**	**27.2**	**2%**
	10 450 km²	**3 424 km²**	**33%**

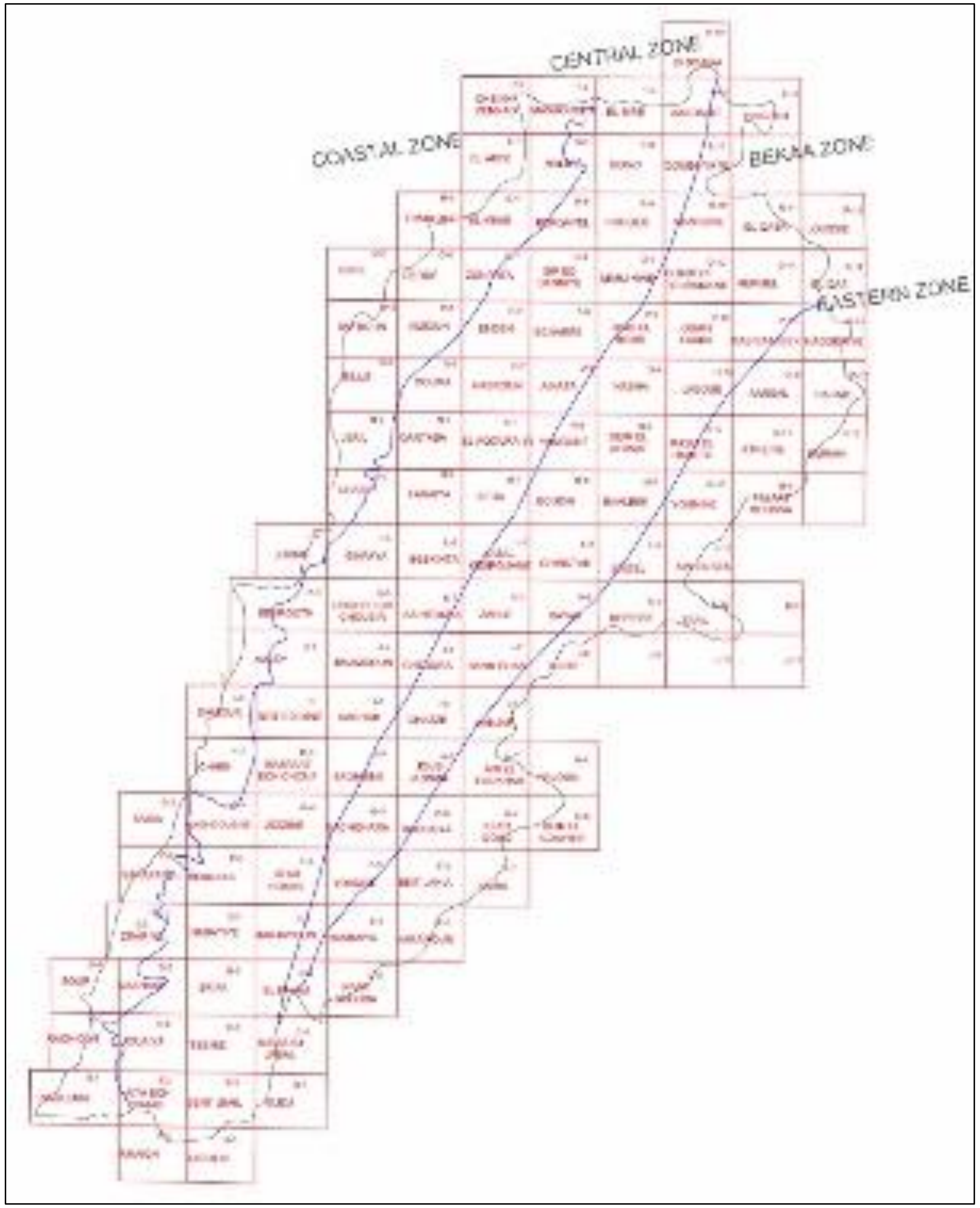


Figure C 3 Geological mapping areas and 1/20,000 national topographical grid

Table C 2 Mapping areas with the corresponding topographic sheets at 1/20,000 scale

COASTAL AREA

Total area : 1 677.3 km² **Mapped : 1 257.2 Km² (75 %)**

Map Code	Map Name	Total Area Km²	Mapped Area Km²	% Mapped
T-7	Cheikh Zennad	11.6	11.6	100%
T-8	Masaoudiye	40.6	40.6	100%
S-7	Al Abde	18.9	15.0	80%
S-8	Halba	70.7	65.4	92%
R-6	Trablous	27.4	27.4	100%
R-7	El Minieh	90.9	90.9	100%
R-8	Berqayel	24.3	13.5	55%
Q-5	Enfe	10.2	1.8	18%
Q-6	Dedde	85.0	74.6	88%
Q-7	Zgharta	50.4	50.4	100%
P-5	Batroun	68.0	2.6	4%
P-6	Amioun	95.4	55.2	58%
P-5	Ehden	6.6	6.6	100%
O-5	Bejje	95.7	24.9	26%
O-6	Douma	16.9	16.9	100%
N-5	Jbail	92.5	92.5	100%
M-5	Ghazir	55.6	55.6	100%
L-4	Jounieh	21.3	21.3	100%
L-5	Bikfaya	9.5	9.5	100%
K-5	Beyrouth	58.3	58.3	100%
J-4	Aaley	63.7	63.7	100%
I-3	Damour	60.2	56.0	93%
I-4	Beit Ed Dine	4.3	0.0	0%
H-3	Chhim	96.0	69.5	72%
H-4	Mazraat Ech Chouf	4.2	0.0	0%
G-2	Saida	16.9	11.8	70%
G-3	Maghdoushe	31.4	30.1	96%
F-2	Sarafand	68.0	69.1	102%
F-3	Jernaya	10.7	10.8	102%
E-2	Zrariye	91.2	84.6	93%
D-1	Sour	39.8	6.3	16%
D-2	Maarake	61.3	53.3	87%
C-1	Rachidiye	56.8	52.5	92%
C-2	Jouaiya	15.5	15.0	97%
B-1	Naqoura	90.3	0.0	0%
B2	Aita Ech Chaab	17.2	0.0	0%
	Total Coastal Area	**1 677.3**	**1 257.2**	**75%**

CENTRAL AREA

Total area : 4 384.4 km² **Mapped : 2 025.1 Km² (46 %)**

Map Code	Map Name	Total Area Km²	Mapped Area Km²	% Mapped
U-10	El Bqaiaa	6.5	0.0	0%
T-8	Masaoudiye	18.8	18.8	100%
T-9	El Bire	61.3	3.9	6%
T-10	Aandaqit	57.0	20.5	36%
S-8	Halba	42.4	40.0	94%
S-9	Beino	114.8	7.8	7%
S-10	Qoubaiyate	55.3	31.6	57%
R-8	Berqayel	83.9	9.9	12%
R-9	Fnaideq	110.8	22.4	20%
R-10	Charbine	23.1	0.0	0%
Q-7	Zgharta	54.5	7.3	13%
Q-8	Sir Ed Danniye	106.7	10.5	10%
Q-9	Marj Hine	94.2	0.0	0%
Q-10	Ouadi Et Tourkmane	0.5	0.0	0%
P-7	Ehden	103.6	85.6	83%
P-8	Bcharre	110.8	49.1	44%
P-9	Jbab El Homr	36.9	0.0	0%
O-6	Douma	86.8	86.8	100%
O-7	Hasroun	106.7	106.7	100%
O-8	Ainata	84.6	45.3	53%
N-5	Jbail	12.4	12.4	100%
N-6	Qartaba	107.7	107.7	100%
N-7	El Aqoura	111.8	111.8	100%
N-8	El Yamoune	34.7	12.3	35%
M-5	Ghazir	49.7	49.7	100%
M-6	Faraiya	103.6	103.6	100%
M-7	Afqa	95.7	95.7	100%
L-5	Bikfaya	102.6	102.6	100%
L-6	Beskinta	105.7	105.7	100%
L-7	Jabal Kesrouane	42.4	0.0	0%
K-4	Beyrouth	58.2	58.2	100%
K-5	Dhour Ech Choueir	107.7	107.7	100%
K-6	Aaintoura	91.3	7.8	8%
K-7	Zahle	1.9	0.0	0%
J-4	Aaley	78.2	78.2	100%
J-5	Bhamdoun	111.8	111.8	100%
J-6	Chtoura	52.7	52.7	100%
I-4	Beit Ed Dine	106.7	0.0	0%
I-5	Barouk	104.7	0.0	0%
I-6	Ghazze	9.8	0.0	0%
H-4	Mazraat Ech Chouf	112.8	0.0	0%
H-5	Saghbine	73.2	0.0	0%
G-3	Maghgoushe	78.2	17.5	22%
G-4	Jezzine	111.8	0.0	0%
G-5	Machghara	29.1	0.0	0%
F-3	Jernaya	102.6	81.9	80%
F-4	Kfar Houne	116.8	18.0	15%
F-5	Yohmor	2.4	0.0	0%
E-2	Ez Zrariye	28.3	4.4	16%
E-3	Nabatiye	110.8	108.1	98%
E-4	Marjayoun	90.6	7.7	9%
D-2	Maarake	50.5	41.6	82%
D-3	Srifa	112.8	0.0	0%
D-4	El Khiam	61.7	0.0	0%
C-2	Jouaiya	100.5	81.8	81%
C-3	Tebnine	115.8	0.0	0%
C-4	Meiss Ej Jabal	36.7	0.0	0%
B-2	Aita Ech Chaab	77.2	0.0	0%
B-3	Bent Jbail	102.6	0.0	0%
A-2	Rmaich	11.4	0.0	0%
A-3	Yaroun	10.1	0.0	0%
	Total Central Area	**4 384.4**	**2 025.1**	**46%**

BEQAA AREA

Total area : 2 638.7 km² **Mapped : 114.8 Km² (4 %)**

Map Code	Map Name	Total Area Km²	Mapped Area Km²	% Mapped
T-10	Aandaqit	28.2	0.0	0%
T-11	Hnaider	30.8	0.0	0%
S-10	Qoubaiyate	44.2	5.2	12%
R-10	Charbine	84.5	0.0	0%
R-11	El Qasr	84.0	0.0	0%
R-12	Joussie	4.1	0.0	0%
Q-9	Marj Hine	14.2	0.0	0%
Q-10	Ouadi Et Tourkmane	105.7	0.0	0%
Q-11	Hermel	112.8	0.0	0%
Q-12	El Qaa	33.8	0.0	0%
P-9	Jbab El Homr	74.9	0.0	0%
P-10	Ouadi Faara	110.8	0.0	0%
P-11	Ras Baalbek	78.9	0.0	0%
O-8	Ainata	23.3	0.0	0%
O-9	Nabha	105.7	0.0	0%
O-10	Laboue	100.3	28.9	29%
O-11	Aarsal	9.8	4.7	49%
N-8	El Yamoune	77.2	0.0	0%
N-9	Deir El Ahmar	111.8	0.0	0%
N-10	Rasm El Hadeth	51.7	0.0	0%
M-7	Afqa	12.0	0.0	0%
M-8	Boudai	106.7	8.9	8%
M-9	Baalbek	101.4	0.0	0%
M-10	Younine	7.0	0.0	0%
L-7	Jabal Kesrouane	66.0	8.5	13%
L-8	Chmistar	109.7	11.1	10%
L-9	Britel	53.9	0.0	0%
K-7	Zahle	101.1	0.0	0%
K-8	Rayak	85.6	7.1	8%
K-9	Khreibe	3.3	3.3	100%
J-6	Chtoura	50.6	17.5	35%
J-7	Barr Elias	101.0	0.0	0%
J-8	Raite	15.4	0.0	0%
I-6	Ghazze	91.9	0.0	0%
I-7	Aanjar	43.6	0.0	0%
H-5	Saghbine	40.6	0.0	0%
H-6	Joub Jannine	90.2	0.0	0%
H-7	Ain El Foukhar	1.4	0.0	0%
G-5	Machghara	81.8	0.0	0%
G-6	Rachaiya	38.6	0.0	0%
F-4	Kfar Houne	4.1	0.0	0%
F-5	Yohmor	85.8	0.0	0%
F-6	Beit Lahia	1.6	0.0	0%
E-4	Marjayoun	26.4	11.5	43%
E-5	Hasbaiya	15.3	8.1	53%
D-4	El Khiam	17.2	0.0	0%
	Total Beqa Area	**2 638.7**	**114.8**	**4%**

EASTERN AREA

Total area : 1 749.6 km² **Mapped : 27.2 Km² (2 %)**

Map Code	Map Name	Total Area Km²	Mapped Area Km²	% Mapped
Q-12	El Qaa	1.4	0.0	0%
P-11	Ras Baalbek	35.6	0.0	0%
P-12	Haoueriye	63.5	0.0	0%
O-11	Aarsal	105.7	13.8	13%
O-12	Halime	81.0	0.0	0%
N-10	Rasm El Hadeth	59.5	0.0	0%
N-11	Atneine	116.8	0.0	0%
N-12	Emrani	33.5	0.0	0%
M-9	Baalbek	6.1	0.0	0%
M-10	Younine	98.8	0.0	0%
M-11	Talaat Moussa	57.7	0.0	0%
L-9	Britel	56.9	0.0	0%
L-10	Ain Es Sea	65.7	0.0	0%
K-8	Rayak	19.1	0.0	0%
K-9	Khreibe	96.5	0.0	0%
K-10	Tfail	65.4	0.0	0%
J-8	Raite	32.4	0.0	0%
I-7	Aanjar	43.2	0.0	0%
H-6	Joub Jannine	16.6	0.0	0%
H-7	Ain El Foukhar	84.8	0.0	0%
H-8	Haloua	14.2	0.0	0%
G-6	Rachaiya	65.5	0.0	0%
G-7	Kfar Qouq	91.4	0.0	0%
G-8	Deir El Achayer	22.7	0.0	0%
F-5	Yohmor	28.3	0.0	0%
F-6	Beit Lahia	108.7	0.0	0%
F-7	Aaiha	45.5	0.0	0%
E-5	Hasbaya	98.6	13.4	14%
E-6	Haramoun	58.7	0.0	0%
D-4	El Khiam	26.0	0.0	0%
D-5	Kfar Chouba	48.5	0.0	0%
C-4	Meiss Ej Jabal	1.1	0.0	0%
	Total Eastern Area	**1 749.6**	**27.2**	**2%**

Consequently, the target, is to:

- Review the geological maps prepared by the FAO and UNDP.
- Review the geological maps prepared by several consultants to the benefit of the Ministry of Energy and Water, the CDR, and other Lebanese Administrations.
- Review the geological maps prepared at Universities and research institutes.

All the new geological maps that will be produced shall be normalized to the same standards of stratigraphy and geological mapping aligned with international standards such as those set by the International Union of Geological Sciences (IUGS) or the Commission for the Geological Map of the World (CGMW).

The geological mapping will proceed gradually from west to east. The coastal area is being mapped presently along the geological boundaries of the major coastal aquifers. After completing the mapping of the coastal area (expected to occur in 2021), the mapping will move inland to the northern, central and southern Lebanon, before shifting to the Bekaa valley and after to the eastern area of Lebanon. This subdivision will allow a build-up in the geological understanding of the area serving a better final mapping result. The distribution of the mapping activity in space and time is presented in the figures and tables below

C.3.5.3 Reporting:

The produced reports will be geological booklets that will explain the main geological features of the mapped areas in terms of structures, stratigraphy, geomorphology and that will discuss their spatial organization and significance within the geological framework of Lebanon and the region.

C.3.5.4 Geological Mapping Time Schedule

The proposed time schedule for mapping the whole Lebanon at a scale of /20,000 is as shown below:

Years 2020-2021

Production of geological maps at a scale of 1/20,000 covering the coastal area which encompasses the aquifers within the Coastal Area The geological mapping is currently on-going.

Years 2022 to year 2023 (2 years)

Production of geological maps at a scale of 1/20,000 covering the Central Area extending from South to North. Bound easterly by the Yammouneh fault.

Year 2024 to 2025 (2 years)

Production of geological maps at a scale of 1/20,000 covering the whole Bekaa Area extending from North to South. Bound westerly by the Yammouneh fault and easterly by the foot line of the Eastern Lebanon mountain chain.

Year 2026 to 2027 (2 years)

The geological maps of this area will cover the Eastern Lebanon Mountain chain. Bound easterly by the Syrian border.

C.3.6 HYDROGEOLOGICAL STUDIES OF THE IDENTIFIED AQUIFERS

C.3.6.1 General

The ultimate target of this recommendation is the preparation of hydrogeologic maps at scales of 1/50,000 using the national 1/50,000 scale topographic sheets and using the geologic maps and the refreshed geologic maps that will be made at scale of 1/20,000.

The ultimate goal of the hydrogeological studies is to:

- Refresh the UNDP studies of 1970 and 2014.
- Define the major productive hydrogeological basins/aquifers such as depths, specific yields of wells, thicknesses, aquifers transmissivity values, aquifer storativity values, types of basins, etc…
- Define the locations and the specifications of the new wells to be drilled (depths, yields, construction details, etc…).
- Define the groundwater balances of the hydrogeological basins.

The hydrogeological maps will be prepared based on:

- The hydrogeological studies previously made at the national level and
- The specific hydrogeologic studies made in different parts of the country.
- The data that will be collected by the PMU and the newly recruited staff in relation with the springs, and water wells, flows, yields, water quality monitoring, etc… and on the results of tracer tests that will be performed. Each map will provide the local hydrostratigraphy with the type of aquifer and their characterizations (hydraulic conductivities/transmissivity, thickness, specific storage/storativity, specific yield) the location of the main springs, the hydrogeological code, etc… These maps should show:
  - Topographic contour lines,
  - The limits of the aquifers, and the type of boundaries,
  - The limit of the effective catchment area (hydrogeological basin),
  - The main hydrogeological formations with their related code,
  - The main structural features playing a significant role for the hydrogeology,
  - The location of springs and their classification on basis of their annual yields,
  - The location of the surface water bodies,
  - The location, operating rate (yields)static/dynamic water level and taped aquifers of the public wells,
  - The location of identified private wells, operating rate, static/dynamic water level and taped aquifers,
  - The locations of hydrometric stations on streams and rivers,

- The locations of the climatological stations,
- The flow directions of underground water,
- The limits of the seawater - freshwater front in the coastal aquifers,
- The location of the recharge area based on the geomorphological features,
- The locations where tracing tests were made,
- The locations where new potential wells could be drilled, showing their depths, the tapped aquifers and their expected yields.
- The urban and rural, location and other anthropogenic activities.

Figure C 4 below shows the geological map of Lebanon, with the extent of the area to be mapped , with the limits of the coastal aquifers and each of the five inland mapping areas.

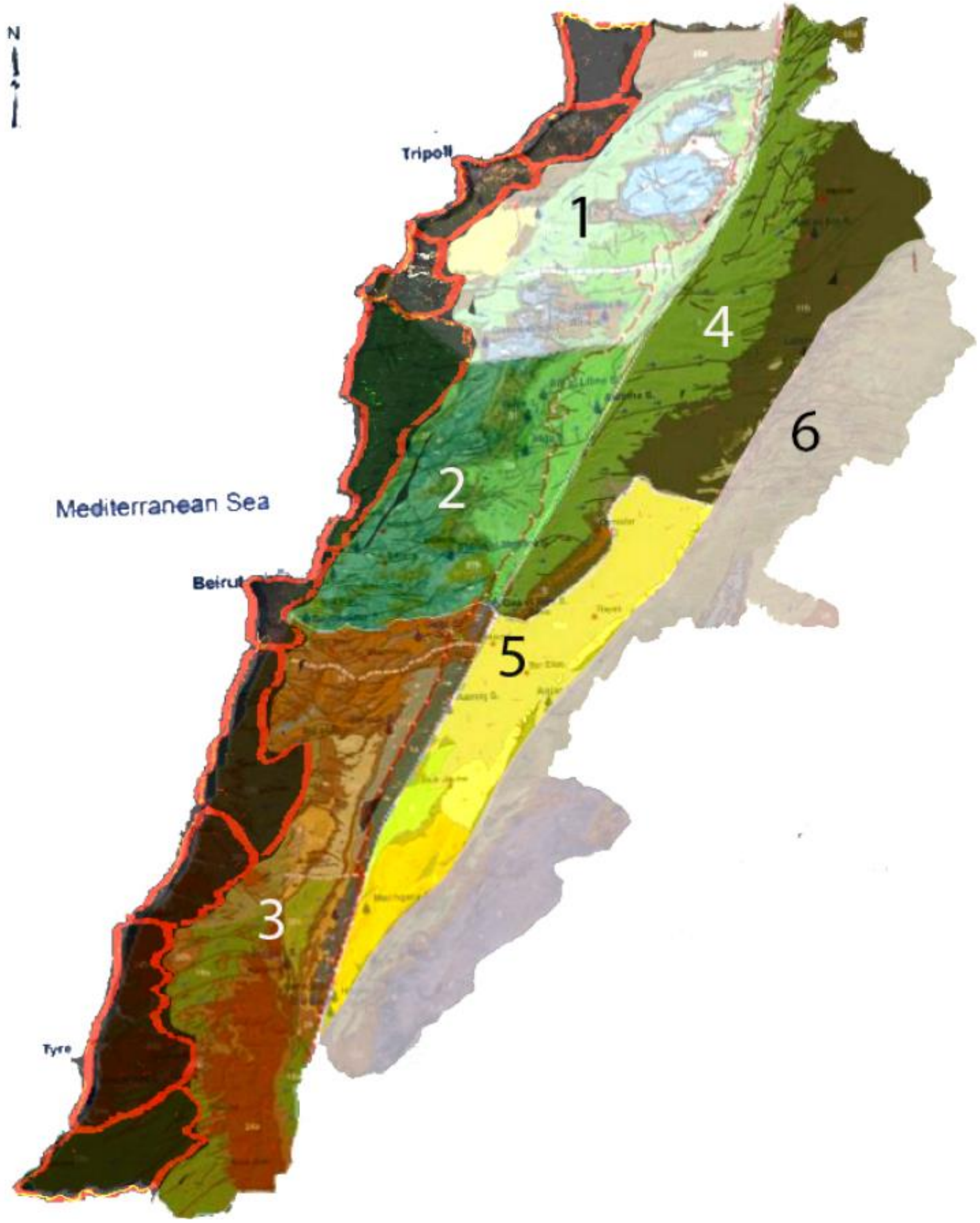


Figure C 4 Coastal aquifers and the five inland areas to be mapped.

C.3.6.2 Hydrogeological mapping coverage

The hydrogeological study will cover six different areas defined here above in Fig. III.C.5.1.1, a knowing that a preliminary assessment of the salinity of the coastal aquifers of areas 1, 2 and 3 is presently being performed by the Ministry of Energy and Water.

1. North area

   The first area extends from Nahr Al Kabir Al Janoubi in the north, down to Nahr Al Jaouz-Douma-Hasroun limit in the south. It includes the Akkar plain aquifer, the Akkar basaltic aquifer, the Miocene aquifer of Tripoli-Koura, the Jurassic aquifers of Qobayyat - Beino and Fnaideq - Sir Ed Danniye (Ain Yacoub), the Turonian-Cenomanian aquifers of Amioun, Zgharta, Bcharre- Cedars, the Jurassic aquifer of Nabaa Dalle spring.

2. Central Lebanon area

   The second area extends from Nahr Al Jaouz - Douma - Hasroun limit in the north to Beirut - Baabda Aintoura limit in the south.

   It will include the Jurassic hydrogeologic aquifer that extends from Qartaba in the north to Daichouniyeh in the south, the Cenomanian coastal aquifers extending from Batroun in the north to Beirut in the south, the eastern Cenomanian aquifers from the Cedars in the North to Sannine and Jabal Knaisse in the south, the Miocene aquifer in Nahr Al Kalb.

3. Southern area

   The third area extends from Beirut-Baabda-Aintoura limit in the north to the southern border of Lebanon with Palestine in the South.

   It will mainly include the coastal Cenomanian aquifers which extend from Hadath-Hazmieh to Ras an Nabi Younes, the coastal Eocene aquifers between Saida and Rachidiyeh, the eastern Cretaceous aquifers which extend from Beit ed Dine to Marjayoun, the Central Cenomanian aquifers which extend from Zahrani River to Maarake, the southern Cenomanian aquifers which extend from Jouaiy to the southern border of Lebanon with Palestine and finally the Jurassic aquifers from Barouk to Ghalle (Aichiyeh - Marjayoun), the eastern Eocene aquifers between Nabatiye and Jabal Amel.

4. North Bekaa area

   The fourth area extends from the northeastern border of Lebanon with Syria down to Chmistar in the south.

   It includes aquifers lying to the east of Yammouneh fault and aquifers in the Bekaa plain extending from Hermel to Baalbeck.

5. South Bekaa area

   The fifth area extends from Chmistar in the north to the Lebanon border with Palestine in the South.

It includes the Quaternary aquifers of the central plain, the Eocene aquifer that extends from Haouch el Harim to the south.

Each identified aquifer in these five areas will be studied and its water balance of the catchment zones will be prepared taking into consideration the data collected from different water wells tests, the precipitation data, the natural and the artificial discharges of these aquifers and the geological characteristics of the aquifer such as nature, thickness, hydraulic conductivity/transmissivity, specific storage/storativity, specific yield, etc…

6. Eastern Bekaa area

The sixth above areas encompasses:

- The Cenomanian-Turonian hydrogeologic basins that extend from Qaa Northern to Baalbeck Southward and from Baalbeck to Aita el Fokhar and from Aita El Fokhar to El Khyam Southward.
- The Jabal esh Sheikh Jurassic limestones aquifer

C.3.6.3 Saline Water Intrusion Preliminary Assessment in Major Coastal Aquifers

Some of the major coastal aquifers identified in previous hydrogeological studies of Lebanon show significant levels of saline water intrusion. These levels have very likely evolved since the earliest salinity assessment done in UNDP 1970, and no assessment of the salinity waterfront at the national scale has been undertaken since. Some aquifers around Beirut and Damour area, or along the coastal agricultural plain of Akkar, Sarafand, Sour, etc… have been closely studied for the evident social and economical importance of the issue. Results from the UNDP 2014 groundwater assessment study confirmed the deterioration of the water quality due to an increase in the amplitude of the seawater intrusion.

The new geological mapping of the coastal area will serve as a basis for a reassessment of the groundwater resources and the impact of saline water intrusions on each of the major coastal aquifers. With the updated geological maps the existing wells can be better classified in terms of their tapped aquifers and a better assessment of the quality and extent of the seawater intrusion, if any, can be done. Moreover, a careful mapping will be able to identify the effect of the impervious surface geology, or even the surface recharge areas, on the water quality at depth, leading to a better assessment of the quality and vulnerability of the potential groundwater resources.

The assessment of the quality of each of the major aquifers relative to seawater intrusion will proceed as follow:

- Gathering existing well data
- Identifying tapped aquifers
- Water sampling from selected wells at different times during the year to measure the temperature, conductivity, Na+, K+, SO4--, TDS.
- Monitoring water conductivity, temperature and level in 80 selected wells tapping the identified coastal aquifers using (TCL) sensors and data loggers.
- Analyzing water samples for the needed chemical and physical properties
- Classifying the aquifers' water quality and its variation in space and time

- Producing new global maps of the salinity level at the scale of 1/50000 using the new geological maps
- Later on and after a first water salinity report issued during the on-going project which will end in May 2021, continued monitoring and analysis during the life of the project will result in a second yearly report on the seawater intrusions combining the results of the continuous water wells monitoring that will be made by the Ministry of Energy and Water.

C.3.6.4 Hydrogeological Mapping and Reporting

Six hydrogeological maps at a scale of 1/50,000 for each of the six areas (including their coastal extents) will be prepared with the production of 6 hydrogeological booklets.

- The identification of the major hydrogeologic basins and aquifers,
- The definition of the lithologic nature and thickness of the major aquifers,
- The results of the updated surveys of the water wells,
- The results of the updated studies of the springs (classifications, yields, recession, coefficients, etc…),
- The results of already made detailed studies on the aquifers,
- The results of the updated data of the hydrodynamic characteristics of the aquifers,
- The results of the dye tests that have been made in the recent years,
- The results of the tracer tests,
- The results of the continuous monitoring of selected wells in the identified aquifers,
- The results of the salinity monitoring of the coastal aquifers,
- The underground water quality assessment results,
- The assessment of the recharge zones of the aquifers,
- The results of the pumping tests made on wells tapping different aquifers (if available).

As a result, the major hydrogeological basins will be identified geographically and geologically, their borders will be drawn, their nature will be described, their hydrodynamic characteristics and hydraulic properties will be defined based on the assessment of the collected pumping tests performed on wells tapping the aquifers, their thicknesses will be defined based on the assessment of field observation and geological review of surveyed water wells, their potentiality will be classified and assessed, the quality of their water will be characterized based on the assessment of the collected data, and on the water analyses results.

Hydrogeological reports will be produced for the six areas along with the hydrogeological maps at the scale of 1/50,000. Moreover, they include a presentation and recommendations for further enhancement of the hydrogeological results of water yield with suggestions for potential resources that could be exploited.

In fact, the final hydrogeological reports should include conclusions drawn from the evaluation of the obtained information.

It is axiomatic that the conclusions and recommendations must be effectively and clearly stated, for there is little possibility that the recommendations will be followed and implemented if they are obscure or the report is poorly written. The amount and form of basic data to be included with the report vary with the type of the report, and with the type of reader for which it is primarily written. Even the general public should be given sufficient basic data to support adequately the conclusions and recommendations of the report.

The evaluations presented in a study report for water supply generally will describe the various areas and depth zones within the region with regard to their potential for development of a water supply. This type of evaluation is particularly valuable if it is supported by hydrogeologic maps showing and describing area and aquifer characteristics.

Therefore, the Consultant will have to prepare a hydrogeological report for each of the 5 areas summarizing his findings and giving his recommendations on the suggested methods to manage the monitoring of the hydrogeologic basins and the underground water use in order to avoid the exhaustion of the aquifers and their contamination by sea water intrusion (mainly for the coastal aquifers).

The ultimate aims of the hydrogeological reports and maps are to:

- Show the limits and extents of the hydrogeological basins/aquifers.
- Show the locations of the springs and their relation with the identified hydrogeological basins/aquifers.
- Define the types and nature of these springs on basis of their geologic bursting conditions and yields,
- Show the locations of the public, licensed, monitored and unlicensed wells and their relation with the identified hydrogeologic basins/aquifers.
- Define the depths and yields of the wells and identify their taping aquifers.
- Show the gaps in the flow monitoring of the surface water courses on basis of the geological conditions.
- Show the gaps in the monitoring of the climatological data on basis of topographic, hydrologic and hydrogeological conditions.
- Define the underground water flows in each of the identified hydrogeological basins.
- Show the contaminated coastal aquifers by seawater intrusion and show the extent of the seawater intrusion in the coastal aquifers.
- Show the locations of suggested potential wells and giving their characteristics such as aquifer(s) tapped, yields, depths, etc…
- Propose plans for managing the exploitation of the underground water in the hydrogeological basins.

C.3.6.5 Hydrogeological Mapping Time Schedule

The proposed time schedule for the preparation of the hydrogeological maps and the production of 6 hydrogeological reports is:

Year 2020-2021

Preliminary assessment of the salinity in the identified coastal aquifers.

Year 2022 to year 2023 (2 years)

Production of hydrogeological maps at a scale of 1/50,000 and hydrogeological report on the identified hydrogeological basins/aquifers of the Central area of Lebanon.

Year 2023 to year 2024 (2 years)

Production of hydrogeological maps at a scale of 1/50,000 and hydrogeological report on the identified hydrogeological basins/aquifers of the North Lebanon.

Year 2024 to year 2025 (2 years)

Production of hydrogeological maps at a scale of 1/50,000 and hydrogeological report on the identified hydrogeological basins/aquifers of the South Lebanon.

Year 2025 to year 2027 (3 years)

Production of hydrogeological maps at a scale of 1/50,000 and hydrogeological report on the identified hydrogeological basins/aquifers of the Beqaa (North Bekaa and South Bekaa).

Year 2026 to year 2027 (2 years)

Production of hydrogeological maps at a scale of 1/50,000 and hydrogeological report on the identified hydrogeologic basins/aquifers of the Eastern Lebanon.

C.3.7 REHABILITATION OF THE EXISTING SPRINGS CATCHMENT WORKS

C.3.7.1 General

UNICEF, through a KFW fund and upon the request of the MoEW, rehabilitated the catchment works of 22 springs in order to reduce their leaks and protection the tapped water from any pollution. The rehabilitation and construction works are expected to be done by May 2020.

It is recommended to extend this program in order to rehabilitate the remaining springs catchment works which their waters are used for domestic supply.

The major important springs in Lebanon are listed below. Table C 3 emphasises which springs are currently undergoing rehabilitation and which ones their catchments were only assessed.

Table C 3 Lebanon's major springs and catchment specifications

	Catchment		Rehabilitation works ongoing
	Assessed	Designed	
North Lebanon:			
Nabaa el Jaouz (Qobayat)	X		
Nabaa Hamde (Qobayat)	X		
Nabaa Oyoun es Samak (Miniyeh)	X	X	X
Nabaa Markebta (Miniyeh)			

Table C 3 Lebanon's major springs and catchment specifications

	Catchment		Rehabilitation works ongoing
	Assessed	Designed	
Nabaa el Qseym	X	X	X
Nabaa Sukkar (Syr el Daniye)	X	X	X
Nabaa el Arbaiin (Syr el Daniye)			
Nabaa es Safa (Wadi Khaled)			
Nabaa es Sabaa (Akroum)	X		
Nabaa ech Chouh (Chaqdouf- Dawra- Qaws-Aiyat)			
Nabaa el Jaouz (Akkar atiqa)			
Nabaa Mar Sarkis (Ehden)	X	X	X
Nabaa Mar Semaan (Becharre)			
Nabaa el Mashour (Bcharre)	X		
Nabaa Qadisha (Bcharre)	X	X	X
Ain Daher (Becharre)	X	X	X
Nabaa Iskandar (Bcharre)	X		
Nabaa Rachaaine (Zgharta)	X	X	X
Nabaa el Qadi (Zgharta)	X	X	X
Nabaa Ziret el Tine (Zgharta)			
Nabaa el Hab (Tripoli)			
Nabaa Abou Halqa (Tripoli)			
Nabaa el Ghar (Koura)	X		
Nabaa el Hab (Koura)	X	X	X
Nabaa Tourza (Koura)			
Nabaa Dalle (Batroun)	X	X	X
Nabaa el Rahoue (Batroun)	X		
Mount Lebanon: Nabaa el Jouaizat (Metn)			
Nabaa Antelias (Metn)			
Nabaa el Mamboukh (Metn)	X		
Nabaa Abou Azem (Metn)			
Nabaa Ain el Delbe (Metn)	X	X	X
Nabaa Jamajem (Metn)			
Nabaa Afqa (Jbeil)	X	X	X
Nabaa el Aassal (Keserwan)			
Nabaa el Mghara (Jbeil)	X		
Ain el Sfayat (Aley)	X		
Nabaa el Ayoun (Aley)	X	X	X
Nabaa el Baradaii (Aley)	X		

Table C 3 Lebanon's major springs and catchment specifications

	Catchment		Rehabilitation works ongoing
	Assessed	Designed	
Nabaa el Daychouniye (Baabda)	X		
Nabb Raayan and Safa (Chouf)	X		
Nabaa el Barouk (Chouf)			
Bekaa: Nabaa Oyoun Orghoch (North Bekaa)			
Nabaa Ras Baalbeck (Baalbeck)	X		
Nabaa Marj Hine (Nabaa el Haour) (North Bekaa)			
Nabaa Yammouneh (North Bekaa)			
Nabaa el Aassi (North Bekaa)			
Nabaa Nahle (North Bekaa)			
Nabaa Laboue (North Bekaa)			
Nabaa Ras el Ain (Qab Elias)	X		
Nabaa el Berdawni and Nabaa Zahle (Zahle)			
Nabaa Jdita (Zahle)			
Ain Ez Zerke (Zahle)	X		
Nabaa Chamsine (West Bekaa)			
Nabaa Chtaura (South Bekaa)			
Nabaa Chebaa (South Bekaa)			
Nabaa Ain El Zarka (West Bekaa)	X	X	X
Nabaa el Khrayzat (West Bekaa)	X		
Nabaa Borghos (South Bekaa)			
South Lebanon: Nabaa Ras el Ain (Tyr)	X		
Nabaa Qasmiye (Tyr)			
Nabaa Rachidiyeh (5 springs-Tyr)	X	X	X
Nabaa Aalman (Tyr)			
Ain el Tine (Nabatiyeh)	X	X	X
Ain Rkeiz (Nabatiyeh)	X	X	X
Nabaa Qbay (Nabatiyeh)	X	X	X

C.3.7.2 Assessment procedures

With the aim of implementing necessary rehabilitation works, the current conditions of a spring catchment structure (civil works) should be assessed. The following tasks should be conducted to determine the rehabilitation works needed :

- Detailed Geological survey

  The geology of the close catchment area of each spring should be surveyed on a scale of 1:2000 or 1:5000 depending on the size of the area. A detailed description is needed to depict all the geological structures that contribute to the bursting of the spring.

- Spring flow measurement

  Flow can be directly reported if flow-measuring devices are installed. If not, the volumetric method or the current meter method can be applied. It should be noted that the flow changes with seasons, being the lowest at the end of the dry season. Therefore, precise flow measurements should be done three or four times per month over the span of at least one year.

- Survey of catchment structures and assessment of condition

  Catchment works (where existing) should be described and reported as follows:
  - Age of existing catchment structure.
  - Height, length, thickness of catchment walls.
  - Configuration of chamber: length, height (if roofed), thickness, material (stone, concrete) of tunnel and channel when present.
  - Description of the entrance to catchment structure (ex: gate)
  - Diameter and type of pipelines
  - Condition of the structures: Inspection of concrete works, leakages, clogging, collapse, pipeline connection functionality, or any pattern of defect that should be considered for rehabilitation works.

- Survey of hydraulic accessories and assessment of condition

  The presence of hydraulic accessories such as valves, flow devices, hydraulic pumps, transmission lines, and their usages should be reported. An inspection of their condition and functionality should be carried.

- Survey of protection system and assessment of condition

  Check if any protection system, such as a fence, is installed to protect the water source from unauthorized access. If present, its efficiency should be inspected (high vegetation inside, deteriorated structure…).

- Identification of spring water users

  The number of beneficiaries should be collected from the respective water authority. A survey should be run in order to classify the use of water by each beneficiary (drinking, domestic, irrigation…). Water use should be measured for each beneficiary in order to evaluate the water balance.

The expected output of the study would be :

1. Rehabilitation of the existing catchment works;
2. Equipping the new catchment works with flow monitoring devices.

C.3.8 ARTIFICIAL RECHARGE OF SELECTED AQUIFERS

There are significant unexploited runoffs during the rainy season and especially during snowmelt. Injecting part of it in the aquifers would have a positive impact on the potential groundwater availability and would reduce seawater intrusion into the coastal aquifers.

To quantify this potential and to contribute to the global experience with AAR in karst and in porous permeable aquifers (alluvial or others), it is therefore recommended to:

a. Carry out Detail Design and implement AAR scheme in Berdaouni. The implementation of this project will create less stress on the exploitation of groundwater from already newly drilled and equipped public wells tapping the Cenomanian limestones aquifer for the supply of Zahle city.

b. Carry out Detailed Design and implement the AAR exploitation scheme of Mejdlaya - Abou Ali. The implementation of this project will create less stress on the exploitation of groundwater from the public wells tapping the Miocene Vindobonian limestones aquifer which contribute in supplying water to Tripoli city.

c. Carry out Detailed Design and implement the AAR exploitation scheme of Damour site. The implementation of this project will contribute in improving the water supply of the area extending from Damour to Choueifat by reducing the salinity and providing good quality of water

d. Prepare prefeasibility and feasibility studies and later on detailed design studies for the AAR project (1 & 2 locations) in the porous permeable aquifer of Akkar which is impacted by a high seawater intrusion due to overexploitation. The implementation of this project will create less stress on the exploitation of groundwater from this aquifer to supply many localities in Akkar plan.

e. Review the feasibility study of the artificial recharge of the Hadath-Hazmieh aquifer but by exploring first the possibilities of recharging the Lower Cenomanian limestones aquifer (C4a) instead of the Upper Cenomanian limestones one (C4c) which artificial recharge, according to the latest study performed by the AUB, Dr. Mutassem Fadel, in 2015, seems to be not feasible, because the uncontrolled extracted volume of water by private wells is much higher than the available water resources that could be used for recharge.

   The implementation of this project will contribute positively in the water supply of the Southern area of Beirut.

   In fact, Based on field observations and review of available studies, the geographic boundary of the study area was extended beyond the boundaries of the Hazmieh area originally set under the Terms of Reference (TOR) of the study in an attempt to cover the geological extent of relevant aquifers while still focusing the analysis on the Hazmieh area to provide possible MAR-based mitigation strategies to control seawater intrusion and stabilize the water table.

   Groundwater quality data further confirmed seawater intrusion with most wells showing high levels of TDS coupled with an evident seasonality in salinity levels. While a temporal trend of increased salinity can be established, spatial correlations were weak due to the karstic nature of the aquifers and the lack of information about the tapped zones from where samples were collected. Most wells in the area were not accessible although water levels in the Sannine Formation showed a large variability.

The available surface water quantities (including the Beirut river) may be sufficient for potential groundwater recharge activities, but water in its various forms (river, runoff, and groundwater) is contaminated and therefore calls for pre-treatment. Even if treated, the lack of storage areas, along the Beirut river in particular, will hinder the effectiveness of MAR. Hence, the imbalance between demand and supply will continue to grow with increased population and development and thus aggravate seawater intrusion.

Potential MAR alternatives may contribute to reversing seawater intrusion in the coastal aquifer but the combined volume of water that can be collected from various sources appears to be less when compared to the continuously growing deficit pumped from the aquifers of the Beirut area. Besides the physical constraints associated with karstic aquifers, until the extracted volumes from private wells are reduced, to sustainable levels or completely ceased, MAR efforts in the Hazmieh area and its surrounding may fall short of stopping the progression or the reversal of seawater intrusion. As such, the success of MAR alternatives may be dependent on the success of governmental projects (Awali Conveyor and Bisri dam) that are aiming to provide new water sources to Greater Beirut in order to relieve mounting pressures on groundwater.

While the current study provided a strong basis towards the feasibility of MAR alternatives, more work is needed to better quantify the dynamics of seawater intrusion and assess the impacts of MAR on reversing the salinization of the coastal aquifer. For that purpose, a multi-objective 3D variable-density flow and solute transport model needs to be developed for the GBA to shed light on the impacts of anthropogenic activities, potential climate change, and the spatial heterogeneities and anisotropies in the aquifers. Such models can help in:

- Simulating seawater intrusion into the Beirut coastal aquifer;
- Understanding the impacts of aquifer heterogeneities in the evolution of seawater intrusion;
- Assessing the impact of continuous abstraction on the future spread of the seawater interface;
- Quantifying the volumes needed to reverse the landward propagation of the salt wedge;
- Determining the time needed to achieve a given improvement in the aquifer; and
- Locating suitable locations for the implementation of MAR in the context of reversing seawater.

A major limitation towards developing such models is the scarcity of available data needed for calibration and validation to reduce uncertainties associated in a complex karstic system. As such, intensive data collection continues to be a top priority to fill the main data gaps that are currently lengthening development efforts. Additionally, the following is needed:

- Climatic stations within the catchment area (Cenomanian; Baabda (300 m asl); and a station in the upper reaches of the Beirut River (>1500 m)). These stations will help measure the variability in the climatic parameters and determine precipitation (rainfall and snowfall) and reference evapotranspiration in the basin. A minimum of 2 stations are needed in this context.
- Long term well monitoring with automated multi-parameter data loggers (water level and salinity indicators) in the entire area. A minimum of 20 wells are needed in this context.
- River flow gauges on the Beirut River (downstream in Hazmieh, as well as upstream in the headwaters). A minimum of 3 stations are needed in this context.

- Systematic surface water quality monitoring program needs to be established along the Beirut River (a minimum of 10 locations) and the groundwater wells (a minimum of 50 wells).

The need to secure larger volumes of better quality water to counterbalance the pumping in the GBA will encourage expanding the study area towards less developed regions in the vicinity of the GBA. The study recommends expanding any future MAR plan beyond the area of Hazmieh that encompasses only 3 km2, most of which are ineffective for MAR in comparison to other areas because:

1. it is not connected to the quaternary aquifer, where most of the seawater intrusion is occurring;
2. There is no evidence where the recharge volume will flow with the continuous pumping downstream, although flow towards Cheyah or towards the sea are the most likely path; and
3. The area is rapidly urbanizing.

Although beyond the scope of work of the study, additional recommendations that can indirectly help in the success of MAR strategies and the reversal of saltwater intrusion include:

- Demand side management by introducing smart meters coupled with tariff restructuring and economic incentives such as tax breaks or low interest loans for efficient water appliances or rainwater harvesting applications;
- Improve the efficiency of the water supply network in general and at the building scale;
- Eliminate wastewater discharge into the Beirut River by ensuring connection to the existing sewage network in Beirut leading to planned wastewater treatment facilities;
- Install gauging and meteorological monitoring stations along the Beirut River;
- Set standards for recharge water and implement a periodic monitoring program for surface and groundwater quality;
- Raise awareness on the importance of water conservation and reuse particularly for basic water uses in the household.

Finally, the most important implementation plan should target the deployment of a combination of methods as there is no one approach that can stop or reverse the seawater intrusion alone. Implementing a combination of these recommendations within a framework of close collaboration and coordination between various stakeholders (i.e. MoEW, MoPW, MOE, MoIM, local municipalities, academic and research institutions, NGOs) is imperative towards the protection and sustainable management of groundwater resources.

C.3.9 VULNERABILITY MAPPING - SPRINGS PROTECTION ZONES

In order to enhance legislative protection measures for springs with more than 10 l/s yield, it is required to define their catchment areas and their immediate protection zones

Spring contamination is directly related to groundwater vulnerability and contamination as well as human practices, such as agriculture and industry, producing contaminants. In porous aquifers, delineating protection zones is simple and depends only on the travel time of potential contaminant release from the land surface to the spring outlet. Karst systems, which constitute most of the Lebanese groundwater systems, are much more complicated. In fact, the groundwater flow is non-uniform with matrix flow, fracture flow and conduit flow being possible. To deal with this intricacy, a combination of groundwater vulnerability assessment and travel time of potential contaminant is needed to delineate protection zones. The following methodology describes the tasks that should be followed to determine the geometry and extent of the different protection zones around each spring, especially in karstic systems.

- Delineation of spring catchment area
  The first fundamental step is to delineate the catchment area of the spring. A combination of topographical, geological, and hydrogeological data is needed. In fact, topography limits the areas located at higher altitude rather than the spring itself, forming its actual catchment area. Additionally, the stratigraphy and hydrogeology of the area should be studied in detail to define the aquifer draining towards that spring. For better accuracy, tracer tests can be used to confirm the catchment area limits.
- Groundwater vulnerability mapping
  - Data required
    The intrinsic vulnerability of the aquifer is considered, which is only related to the geological and hydrogeological properties of the area. Therefore, the data required for the vulnerability assessment are:
    - Topography (SRTM DEM)
    - Geology of the area
    - Depth to groundwater (thickness of unsaturated zone)
    - Precipitation
    - Vegetation cover
    - Karst features (swallow holes)
    - Soil cover
  - Methodology
    The vulnerability map is obtained by combining several maps representing different parameters essential for groundwater protection. The European approach suggests the COP method that stands for Concentration of flow, Overlying layers and Precipitation. The O factor is used to assess the natural protection of groundwater determined by the properties of overlying soils and the unsaturated zone. The C factor estimates how this protection can be modified by diffused or concentrated infiltration process, while the P factor takes into consideration the climatic conditions (Daly et al., 2002).
  - Advantages of Using the COP method
    Vulnerability assessment for contamination is based on an origin-pathway-target model, which includes all the components of the natural system through which the potential contaminant travels from origin to target. Different indexing methods, including COP, are based on this conceptual model. For example: PI method is a preliminary method that only considers the Protective cover and the Infiltration conditions; EPIK method (stands for Epikarst, Protective cover, Infiltration conditions and Karst network development) was developed specifically for Karst systems. The advantages of the COP method over the other ones is that it includes the precipitation factors and can be applied in karst systems as well as porous ones. In addition,

COP was previously applied in a major karstic spring in Jeita to assess its vulnerability and delineate the respective protection zones.

- Tracers travel time
  Some tracers can be used to confirm the vulnerability assessment results and record their travel time for the delineation of protection zones later on.

- Pollution Hazard mapping
  Aims at mapping the distribution of the main pollution sources in the catchment area such as agriculture, general farming, industrial activities and other sources as landfills, waste disposal, etc, and classifying them based on the level of contamination danger they present (Figure C 5 below).
- Pollution Risk mapping

It is the product of a groundwater vulnerability map combined with a hazard map that results in the risk map. This map describes the actual threat of polluting activities to groundwater quality and shows the necessity to act.

- Delineation of protection zones
  There are national guidelines for the delineation of protection zones dating back to 1926, therefore, international standards are considered instead (Zhu and Balke, 2008):
  - Protection Zone III: Protection of the entire catchment.
    The following is forbidden: (1) seepage of wastewater, (2) factories such as oil refineries, metal plants and chemical plants without sufficient protection measures, (3) nuclear power plants, (4) storage or disposal of water endangering substances, (5) long-distance pipelines for water endangering substances, (6) large-scale animal husbandry, (7) settlements, hospitals, plants without safe waste water removal, (8) reloading and trading of fuel oil, diesel and other water endangering and radioactive substances, (9) airfields, (10) exercises of armed forces, (11) refuse dumps and garbage deposits, (12) sewage and waste water treatment plants, (13) transport of manure and feces, (14) drillings for exploration or exploitation of crude oil, natural gas, carbonic acid, mineral water, salt and radioactive substances.
  - Protection Zone II:
    10-days travel time from land surface to spring, and zones of very high groundwater vulnerability (as mapped by COP method); To reduce risk of microbiological contamination.
    Protection zone II is situated within Protection zone III and protects especially against noxious microorganisms. Besides the restrictions suggested for Protection zone III, Protection zone II also has the following additional prohibitions: (1) buildings for commercial and agricultural use, (2) roads and railway, (3) parking places and petrol stations, (4) camping and sports grounds, (5) cemeteries, (6) open pits, cuts and quarries, (7) blastings, (8) intensive grazing and crowds of cattle, (9) over-fertilizing, (10) open storage and improper use of mineral fertilizers, (11) private gardens and commercial horticulture, (12) storage of fuel oil and diesel, (13) drain ditches, (14) fishponds.
  - Protection zone I:
    50 meters at least in the upstream direction, 10 meters in the downstream direction and 15 meters at each side. The area should be surrounded by a stable fence.
    The restrictions of Protection zones III and II are also applied. In addition, the following is not allowed in Protection zone I: (1) unauthorized entry, (2) any kind of agricultural or other usages.

- Water quality Monitoring
  Past water quality analysis and actual water samples should be examined for chemicals (Nitrate, Nitrite, pH…) and bacteria (Coliform, E.Coli…) to relate the effect of potential pollution sources in the catchment area to water quality.
  A monitoring system for water quality should be implemented after establishing the protection zones in order to assess their effectiveness.
- Summary of data collection tasks
  - Geological survey and karst feature mapping
  - Aquifer characterization
  - Vegetation mapping
  - Slope variations (DEM acquisition)
  - Precipitation data acquisition
  - Tracer test to estimate travel time
  - Mapping of pollution sources
  - Water sampling+ results of previous water analyses

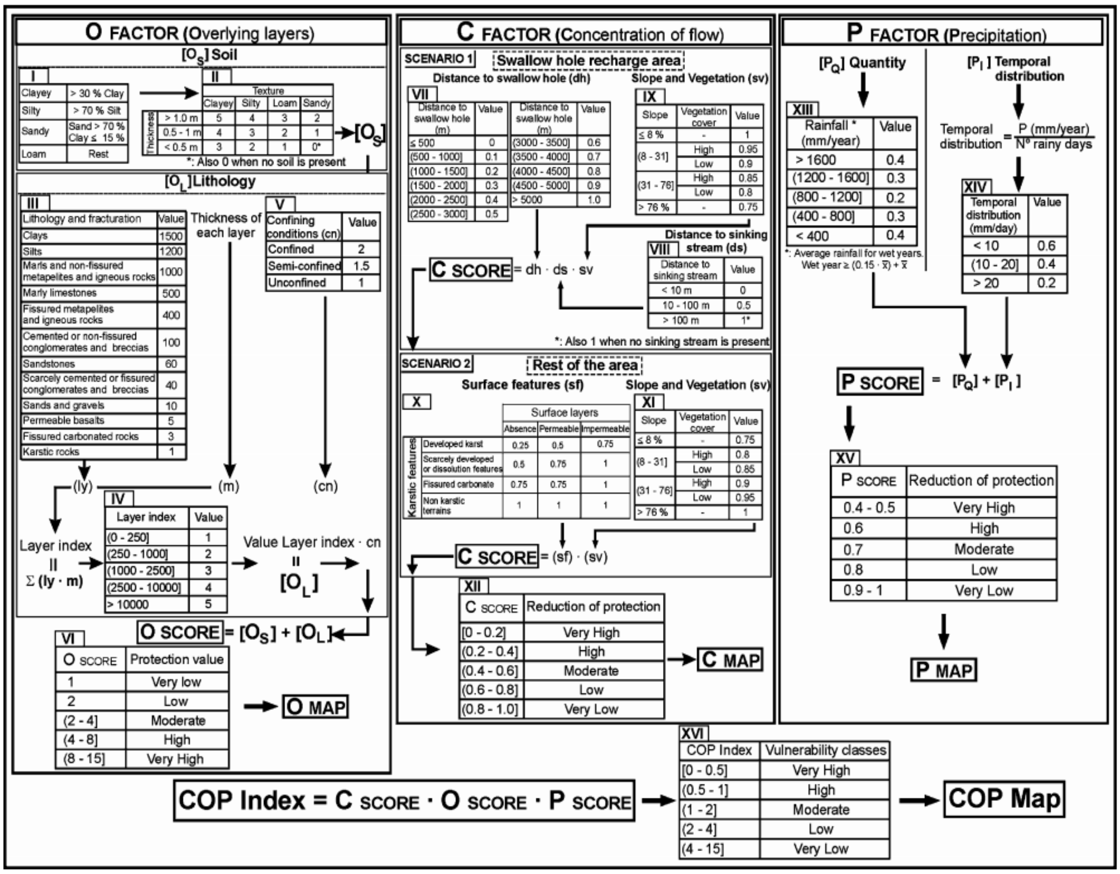


Figure C 5 Summary of steps for COP index calculation
(VIAS & al. 2002, 20)

C.3.10 POTENTIAL DEEP AQUIFERS

There are some deep aquifers, such as in Akkar (North Lebanon), Hadath/Hazmieh and Daichouniye (Southern Beirut), and Brak (Zahrani – South Lebanon), which are suspected to be artesian once tapped, with a high yield; and therefore worth assessing their groundwater potentiality.

C.3.10.1 The Hadath-Hazmieh Lower Cenomanian limestones aquifer

The Upper Cenomanian limestones aquifer (C4c) in the area of Hazmieh - Hadath is contaminated by seawater intrusion. Investigations showed the presence of thousands of private wells extracting very high volumes of water exceeding the natural fresh water replenishment of the aquifer. Artificial recharge attempts of this aquifer were not successful due to the uncontrolled and very high volumes of water extracted by private wells.

It is therefore suggested to drill reconnaissance wells in some selected areas in Hadath-Hazmieh to assess first the presence of groundwater in the Lower Cenomanian limestones aquifer (C4a), and second test the potential of these wells and proceed later on to the artificial reacharge of the aquifer to act as profitable resources on the long term.

C.3.10.2 The Kesrwan limestones aquifer in Daichouniye area

All the public wells drilled by BMLWE in Daichouniye area to supply part of Beirut city (Baabda area) are tapping and exploiting the groundwater of the Bekfaya limestones aquifer (J6).

Due to the shortage of good quality water in the Southern suburb of Beirut, it is suggested to drill deep reconnaissance wells to assess the presence and potentiality of the Keserwan limestones aquifer (J4), which is located stratigraphically beneath the Bikfaya limestones aquifer (J6) but separated from the latter by the impervious marl layers of the Bhannes formation (J5).

It is suggested to drill reconnaissance wells in Daichouniye area to assess the potential of the Kserwan limestones aquifer (J4) to act as a profitable resource on the long term and envisage simultaneously its artificial recharge in winter times using the Beirut river waters.

C.3.10.3 The deep unconsolidated Miocene deposits aquifer in Akkar plain.

Akkar plain is considered as one of the most important agricultural areas in Lebanon, relying on groundwater as the main source for irrigation. In 1970,a study by FAO estimated discharges to the sea from the aquifer in Akkar to be around 9 MCM. This value decreased to 7.5 MCM in 2013 in the latest study assessing the water balance in Akkar plain, due to increased abstraction rates from private wells. The aquifer exploited in Akkar is mainly the Pliocene-Quaternary aquifer which compromise volcano-sedimentary units with significant lateral variations. However, due to the lack of management, the water quantity and quality in this aquifer has deteriorated significantly over the years due to a number of reasons summarized below:

- Seawater intrusion has affected a great part of the exploited aquifer due to uncontrolled pumping especially from private wells close to the coastal line;
- Numerous operations routinely applying chemical and organic fertilizers and pesticides;

- Sewage infiltration due to the lack of sewage networks and their deterioration in large areas of Akkar plain;
- Landuse change where more areas are being used for agriculture and more urbanized areas are contributing to sewage infiltration;
- Usage of wastewater for irrigation purposes.

Therefore, the currently exploited Quaternary-Pliocene aquifer can no longer be used for water supplies in Akkar area.

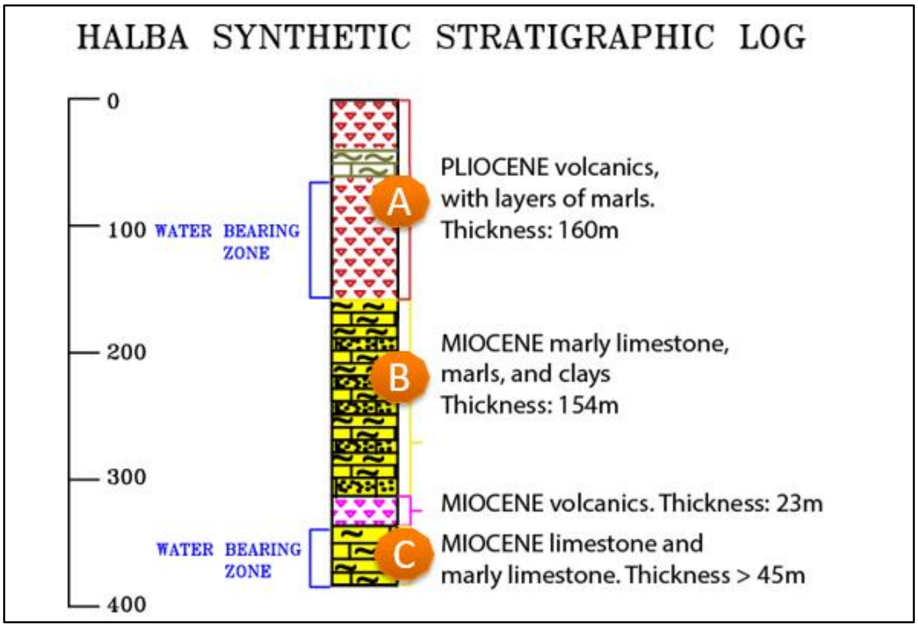
Based on the conceptual model developed by FAO (1970), UDPD funded the study[1] and implementation of the drilling of a series of exploratory wells to understand the stratigraphical changes in Akkar plain. A summary of the lithostratigraphy is presented in the table below along with geological cross section in the E-W and N-S direction showing the well lithology.

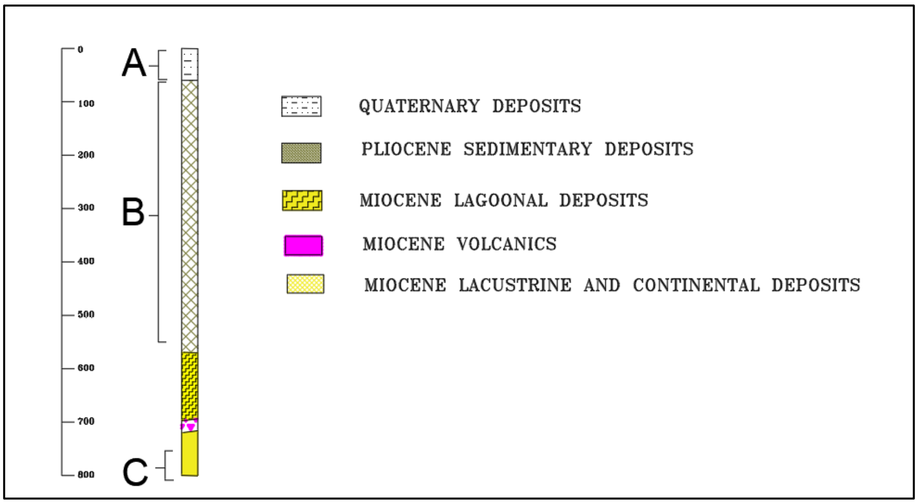
Table C 4 Summary of Akkar plain lithostratigraphy

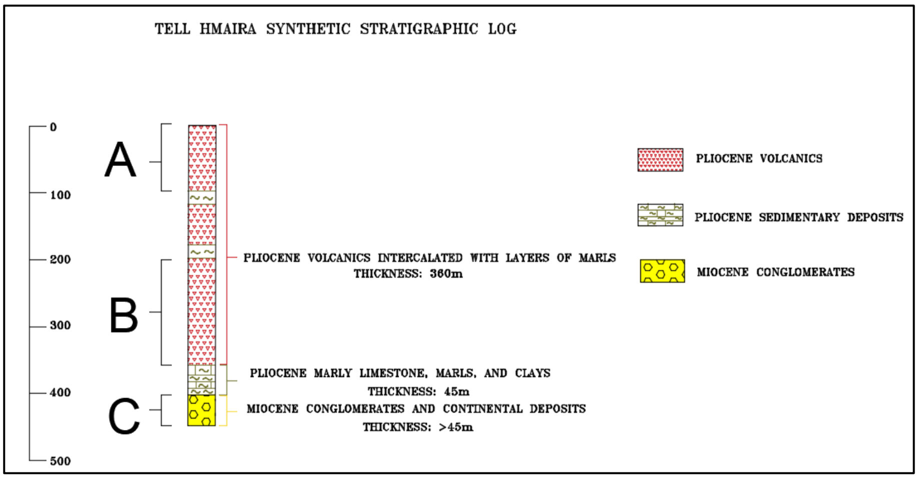
	Formation	Lithology	Thickness (m)
Akkar plain	*Pliocene*	Marls, marly and clayey limestone	*180*
	Upper Miocene	Gypsum and anhydrite intercalated with marls	*60-83*
	Lower/Middle Miocene	Continental clays and calcareous concretions	*70*
East of Akkar plain	*Pliocene*	Intercalations between sedimentary marine marls and marly limestone deposits with basaltic flows	*>300*
	Upper Miocene	Continental conglomerate and sandy marls	*unknown*
	Lower/Middle Miocene	Unknown	*unknown*
South East of Akkar plain	*Pliocene*	Intercalations between sedimentary marine marls and marly limestone with basaltic flows	*427*
	Upper Miocene	Lacustrine marls and marly limestone	*155*
	Lower/Middle Miocene	Conglomerates, marls, and marly limestone	*unknown*

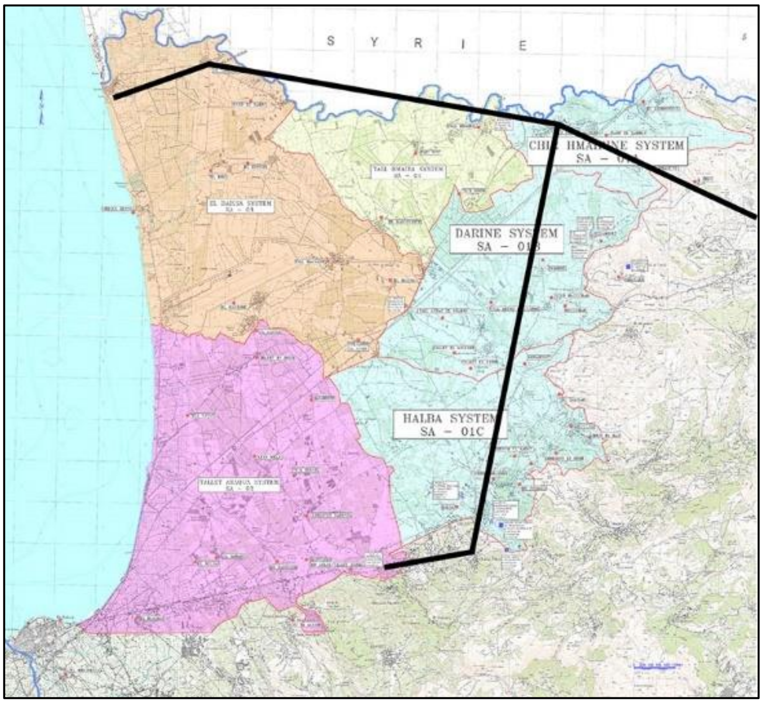
The geological investigations reveal the presence of deeper aquifer units that might be a substitute for the heavily exploited Quaternary-Pliocene aquifer. In North Akkar (Tell Hmaira area), the Miocene conglomerates encountered by Aamaret el Beikat well proved to be a highly productive aquifer that could be exploited. The thick clays at the bottom of the Pliocene sequence presents a confining unit and isolates the Miocene aquifer from the contaminated Pliocene-Quaternary aquifer overlying it. In the southern part of Akkar plain (Halba Area), the Miocene limestones and marly limestone units underlying the Miocene volcanic unit could also present a target aquifer to be exploited. The Miocene volcanics are massive and are less fractured than the outcropping Pliocene volcanic units, which isolates the underlying Miocene unit. In the central area of Akkar plain (El Haissa and Tell Meeian), the Miocene lacustrine and continental units can be exploited, given that they are protected from the agricultural contamination and seawater intrusion by the thick clays overlying it.

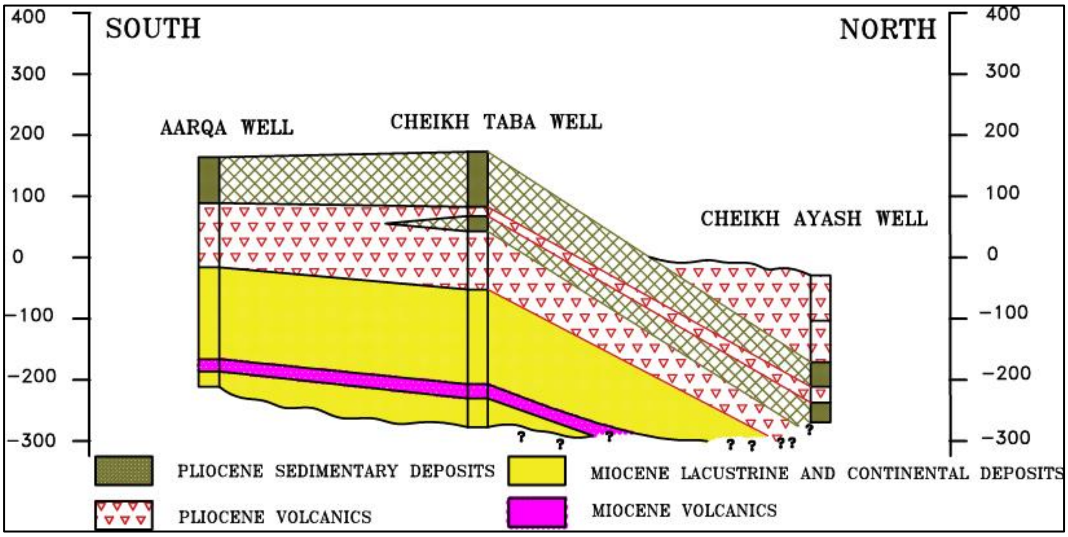
[1] BTD - 2014


HALBA SYNTHETIC STRATIGRAPHIC LOG
0
100
200
300
400
WATER BEARING ZONE
WATER BEARING ZONE
A
PLIOCENE volcanics, with layers of marls. Thickness: 160m
B
MIOCENE marly limestone, marls, and clays Thickness: 154m
MIOCENE volcanics. Thickness: 23m
C
MIOCENE limestone and marly limestone. Thickness > 45m


0
100
200
300
400
500
600
700
800
A
B
C
QUATERNARY DEPOSITS
PLIOCENE SEDIMENTARY DEPOSITS
MIOCENE LAGOONAL DEPOSITS
MIOCENE VOLCANICS
MIOCENE LACUSTRINE AND CONTINENTAL DEPOSITS


TELL HMAIRA SYNTHETIC STRATIGRAPHIC LOG
0
100
200
300
400
500
A
B
C
PLIOCENE VOLCANICS INTERCALATED WITH LAYERS OF MARLS
THICKNESS: 360m
PLIOCENE MARLY LIMESTONE, MARLS, AND CLAYS
THICKNESS: 45m
MIOCENE CONGLOMERATES AND CONTINENTAL DEPOSITS
THICKNESS: >45m
PLIOCENE VOLCANICS
PLIOCENE SEDIMENTARY DEPOSITS
MIOCENE CONGLOMERATES


S Y R I E
HALBA SYSTEM
SA – 01C


SOUTH
NORTH
400
300
200
100
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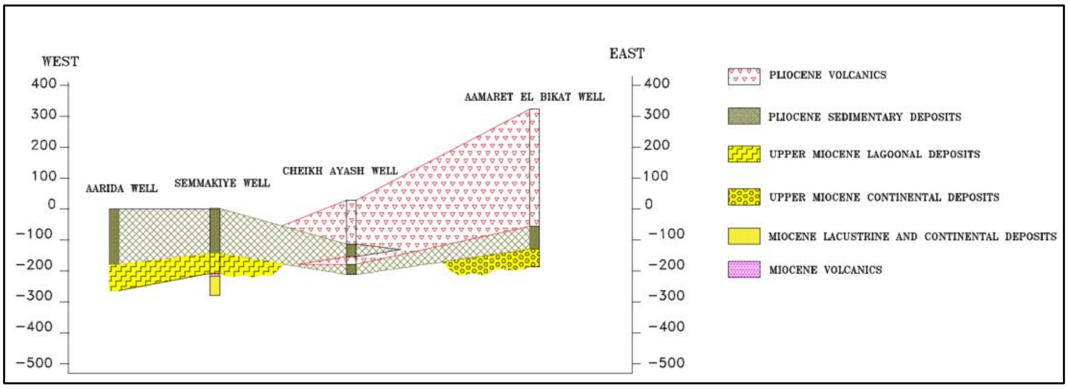
−100
−200
−300
AARQA WELL
CHEIKH TABA WELL
CHEIKH AYASH WELL
PLIOCENE SEDIMENTARY DEPOSITS
MIOCENE LACUSTRINE AND CONTINENTAL DEPOSITS
PLIOCENE VOLCANICS
MIOCENE VOLCANICS


WEST
EAST
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−400
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AARIDA WELL
SEMMAKIYE WELL
CHEIKH AYASH WELL
AAMARET EL BIKAT WELL
PLIOCENE VOLCANICS
PLIOCENE SEDIMENTARY DEPOSITS
UPPER MIOCENE LAGOONAL DEPOSITS
UPPER MIOCENE CONTINENTAL DEPOSITS
MIOCENE LACUSTRINE AND CONTINENTAL DEPOSITS
MIOCENE VOLCANICS

The Council for Development and Reconstruction and Reconstruction through a financing from the Islamic Bank will very soon start, drilling 5 deep water wells in the Akkar plain to test the potentiality in groundwater of the Lower/Middle Miocene aquifer which is made of conglomerates, marls and marly limestones. The drilling and testing of these wells will help in selecting the location of 5 remaining deep wells. These wells are:

Package number	Well name	Depth (m)	Expected yield (l/s)
Package I – Under execution	Chir Hmayrine	550	50
	Darine 1	550	50
	Darine 2	550	50
	Halba 1	500	50
	Halba 2	500	50
Package II – Proposed	Aarqa	600	30
	El Haissa	800	50
	Massoudiye	800	50
	Qoubbet Chamra	800	50
	Tell Hmaira	800	50

C.3.10.4 The Turonian – Upper Cenomanian limestones aquifer in Brak

The Cenomanian-Turonian aquifer is very important in the Brak area Zahrani – South Lebanon), having a significant recharge area to the east where these formations are outcropping (Figure 1), and with a considerable thickness. In fact, the minimum thickness of the aquifer is 300m, while the maximum thickness cannot be determined in the area due to the absence of a lower boundary but can be assumed to be no less than 500m.

Transmissivity values according to UNDP (1970) are in the order of 10-2 • This shows the importance of this aquifer and its high ability to conduct water. Moreover, the piezometric surface gradient is high in the region. It can be seen from the piezometric contours on the hydrogeological map of UNDP (1970) that the piezometric level of the confined Cenomanian-Turonian aquifer is less than 5 m depth in El Brak area. Consequently, wells reaching the Cenomanian-Turonian aquifer in this area are expected to have an artesian flow. It is thus suggested to drill a well reaching the deep Cenomanian aquifer. This aquifer is still not affected by sea water intrusion due to the overlay of the Senonian impervious formation delaying the seawater intrusion and contamination.

Such a reconnaissance well will not only improve the quality of the water but most importantly will bring reliable and precise information about the subsurface hydrogeology of the area, much needed for a better understanding of the characteristic and potential of the water resources in the area, and for securing a sustainable management of the aquifer.

The well should have a depth of 700 m, grouted for at least 200 m (from the surface to the bottom of the Eocene formation), and cased to prevent water mixing and seawater contamination from the shallow aquifers (Quaternary and Miocene).

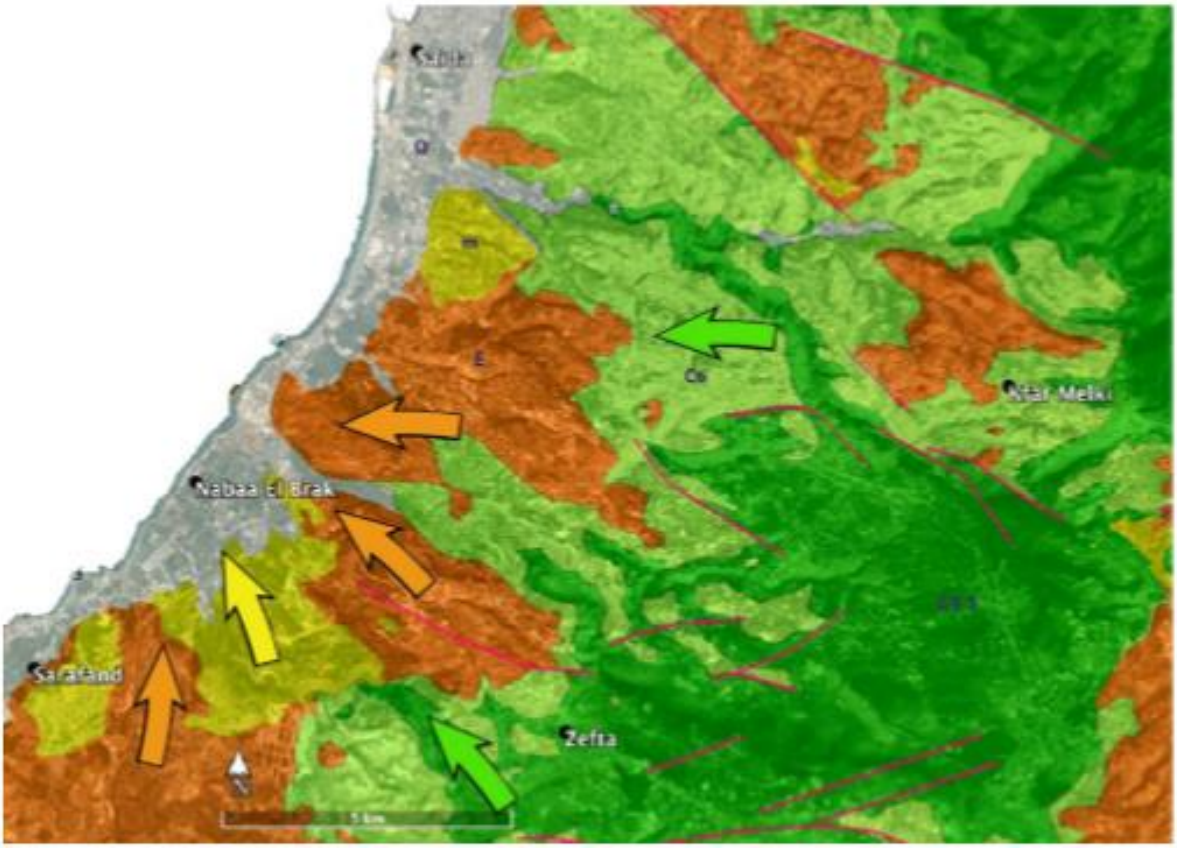

Figure C 6 Cenomanian-Turonian limestones extent to the east in Brak, contributing to the recharge of the aquifer.

C.3.10.5 The Miocene and Eocene limestones aquifer in el Brak area (Zahrani – South Lebanon)

The Eocene aquifer has the Miocene pervious formation as its upper boundary and the Senonian impervious formation as its lower boundary. The permeable zone is made of massive limestone and marly limestone. The recharge of this aquifer is done by infiltration from precipitation and from the Quaternary and Miocene permeable formations. According to the UNDP (1970), transmissivity values range between 10-4 and 10-2 m2/s. Currently, a well is being drilled near Nabaa el Brak to reach the deep Eocene aquifer at approximately 300 m. This well will test the hydraulic properties of the deep Eocene aquifer. Works are on-going.

C.3.11 GROUNDWATER BALANCES OF THE MAJOR HYDROGEOLOGICAL BASINS

The groundwater balances of the major hydrogeologic basins will be prepared according to the following:

C.3.11.1 Data availability and quality

Effective management is based on sound decision-making based on accurate information. Data collection, verification and dissemination are therefore essential steps for the production of such information.

Ideally, for a water balance equation, all input and output parameters are directly measurable. In reality number of these components have to be estimated, because of:

- Difficulty of measurement: for example, groundwater inflows and outflows are often difficult to measure; as well as irrigation volumes used by agriculture. These can be estimated based on standard evapotranspiration values and estimates regarding cropped areas and cropping patterns;
- Insufficient or unreliable data: measurements exist only for the periods when a monitoring device was in place thus reducing the completeness of the dataset, and the accuracy of the resulting data. Although Lebanon used to have a reasonable network of gauging stations recording river flows, the civil war between 1975 and early 90s severely affected this monitoring process. Efforts have resumed since, but the lack of equipment and staff has not ensured routine collection of accurate data as it used to be. Focused efforts to improve both collection and quality control of hydrologic data are sorely needed.
- Access to existing data: data collected by various stakeholders is commonly considered with secrecy. Sharing of public data is limited within or among administrations and rarely if ever made accessible to the public at large.

In spite the limitations, experience has shown that water accounting, even based on estimates, can be quite useful for decision makers.

C.3.11.2 Methodology

Water balances components

Building water balances helps to combine and structure the key components of the natural water cycle and the relevant inputs and outputs due to human interventions (e.g. abstractions, returns, etc.) into a coherent framework. The following section explains these different components, identifying the type of information that is required for describing each component and developing water balances.

The first step in developing water balances requires the assessment of the freshwater resources, accomplished through the quantification of the components of the water cycle. The hydrological balance equation is based on the principles of conservation of mass in a closed system: any change in the water content of a given catchment during a specified period must equal the difference between the amount of water added to the system and the amount of water withdrawn from it. Estimation of the water balance is performed for a catchment area delineated on the basis of clear structural or hydraulic boundaries. This is generally the situation of spring. In the case of a pumping well and particularly in the case of competitive abstractions between several wells implemented in the same aquifer, it is more appropriate to consider the hydrogeological basin of the aquifer.

In a system with no external inflows from adjacent catchments and territories, the water is entering the system via precipitation (P), converted into evaporation (E) and/or runoff (R) (surface, subsurface or groundwater) and associated storage (S) or change in storage ?S during the time period investigated, as expressed in the following general equation:

P = R + E ± ?S [Eq. 1]

In detail, looking at the functioning of the hydrological cycle and the dynamics of its different components during a given time period, (P) reaches the soil surface and the vegetation where water can be intercepted and evaporate directly (Ei) or stored for domestic, industrial or agricultural uses (?S). Water can also infiltrate the soil or directly runoff (Rs) if the amount of rainfall exceeds the infiltration rate capacity (rainfall excess). The water infiltrating the soil goes to the unsaturated zone and recharges the ground water. Groundwater (Rgw) and unsaturated zone water (Rsub) can also contribute to river flows as subsurface runoff. Roots from vegetation cover absorb water that is transported to the stomata of the leaves, where it goes back to the atmosphere as transpiration (Et). Water can also evaporate directly from the soil or from the river (Es). Capillary rise brings water to the soil surface and then water evaporates.

Estimating the different storage capacities of a water system or catchment is key to understanding and analyzing the overall hydrological process. Water storage can occur in soil, groundwater, lakes, rivers, snow and glaciers or vegetation.

In some cases, there might be some amount of water that is lost or gained due to naturally occurring groundwater outflow or inflow (ExInOut) and from neighboring watersheds. This is common in karstic systems or coastal areas both widespread across Lebanon. This amount should be then incorporated in the water balance equation.

Thus, in a natural hydrological system with external outflows and inflows the water balance can be further formulated as follows:

$$P + Ex_{InOut} = R_s + R_{sub} + R_{gw} + E_s + E_i + E_t \pm \Delta S \qquad [Eq.\ 2]$$

With P : Precipitation measured by weather stations

R : Runoff measured by available hydrometric gauging stations or estimated based on surface flow data, and hydrogeological assessments (s: surface, sub: subsurface, gw: groundwater)

E : Evaporation measured or estimated as a percentage of precipitation according to land cover types (s: surface, i: interception, t: transpiration)

ΔS : Change in storage over time due to domestic, industrial or agricultural practices.

ExInOut : External Inflow or Outflow is the total volume of actual flow of rivers and groundwater entering or exiting the watershed from or to adjacent watershed or systems.

The quantification of the components of Eq. 2 at a given watershed in a given time period requires information from monitoring stations. Hydrometeorological networks provide information on water flows into, and losses from, rivers, soils, lakes and aquifers, as well as on precipitation and evaporation, in selected sites, depending on the design and density of the network. However, estimations are always needed since it is impossible to monitor every component at every place. Irrigation, domestic and industrial flows are usually estimated from both surface and groundwater withdrawals or using collected information from different water establishments.

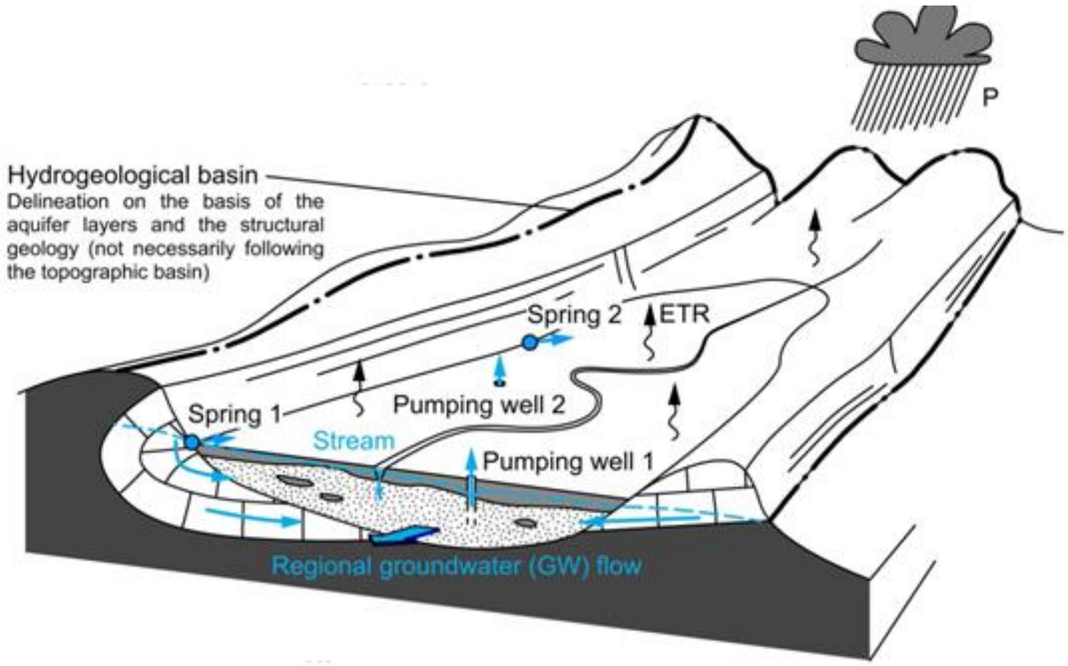

Figure C 7 Example of water balance components at hydrogeological basin scale (T. Bussard, SDC guidelines 2016)

C.3.12 GROUNDWATER FLOW MODELLING

The Groundwater Flow Modelling of the major potential hydrogeological basins will be made for:

- Evaluating the impact of saltwater intrusion along coastal regions.
- Delineating groundwater wellhead protection areas.
- Providing estimates of sustainable future pumping rates for aquifers or indicating if not suitable for pumping.
- Evaluating groundwater remediation systems and investigating the possibility of artificial recharge of suitable coastal aquifers for the purposes of both water resource storage and mitigation of saline intrusion.
- Determining the groundwater balance in the major hydrogeologic basins based on current abstraction regimes.
- Providing the groundwater modellers with suitable training/user manuals etc. as a tool for future use in aquifer management.

C.3.12.1 Model description

Groundwater modelling involves building, calibrating and running the 3D groundwater flow models where required for the most sensitive aquifers in particular.

Some aquifer systems will likely be too complicated for a spreadsheet water balance to adequately address the study objective of assessing water availability. Even for simple aquifer systems a 3D model will be able to help reduce the range of error in the predictions made compared to a simple spreadsheet, to incorporate any 3D effects of interactions between various stresses and boundaries, as well as 3D variations in the geology. 3D models can also help produce maps of the uncertainty of parameters in different regions of the model, particularly emphasizing uncertainties most relevant to the types of prediction you are making and thus help define areas and parameters for further investigation and field data collection/testing. A 3D model is also able to incorporate locally significant karstic features that control groundwater flow. This would not be possible in a simple spreadsheet model.

C.3.12.2 Conceptual modelling

Once all existing data has been gathered and prepared (early on year 1) conceptual modelling could be approached through a workshop involving input from geologists, hydrogeologists and hydrologists who have been on the field and those who worked on the data collection, as well as the groundwater modeller.

This work would focus mainly on the most critical aquifers with careful and focused consideration of each aquifer system in turn, bearing in mind possible interactions between adjacent aquifers.

The objective of the workshop will be, for each aquifer, to better understand the key system components:

- Recharge inputs (areal/rivers/GW inflow),
- Discharge boundaries (rivers, springs, sea, abstractions),
- Groundwater flow mechanisms
- Hydrostratigraphical layering
- Significant structures controlling flow.
- Natural hydrogeological boundaries that can define limits of the system.

The workshop will enable, based on the conceptual model, the complexity of each system and the available data, as well as time and work-capacity constraints, the determination of appropriate type of modelling approach for each aquifer system.

For some aquifers, a simplified spreadsheet water balance can be undertaken first, followed by more detailed 3D flow modelling.

Another aim of the conceptual modelling will be to determine if and how to combine any of the aquifers into a single model for groundwater flow, which relates to the task of determining which hydraulic boundaries are the most appropriate for delineating model edges.

The workshop would also be a suitable time to determine whether to undertake hydrostratigraphic geological modelling for each aquifer individually or whether to produce a combined geology model, bearing in mind that the geological model will not be detailed in terms of stratigraphy, but will comprise the significant hydrostratigraphic units and/or structures inferred to control groundwater flow.

During this conceptual modelling workshop we should also determine which aquifers are the most suitable candidates for the simple saline intrusion and artificial recharge simulations, within budget and time constraints

During the workshop, areas for further data collection will be identified and recommendations made regarding further field data collection in preparation for the more detailed groundwater flow modelling.

Other similar workshop should take place at a later stage during the project (2nd and 3rd year) in order to update initial models along with the newly gathered data and observations.

C.3.12.3 Preliminary water balance modelling

A preliminary water balance modelling should be undertaken for aquifers where this type of model has been deemed appropriate during the conceptual modelling workshop. This will at least provide some initial, first pass estimated ranges of water availability and sustainable overall pumping rates. These can serve as a starting point or reality check for more detailed, 3D modelling in the later modelling processes.

C.3.12.4 Model Input Features

Recharge model

A fundamental input to any groundwater modelling is the recharge. Some models may already exist or can be extracted from existing data such as FAO 1970s publications, Other data can be generated with SWAc (surface water accounting) tools. It may be more efficient and useful to produce a country-wide recharge model which can then feed into all the individual GW models.

Geological modelling

Needed for the purpose of hydrogeological modelling, including the layers and structures significant to groundwater flow. Modelling can be done with the Leapfrog (Works) package, a very user-friendly software which output feeds easily into MODFLOW model build.

Groundwater flow modelling in MODFLOW-USG

MODFLOW-USG is the recommended groundwater flow modelling code for the following reasons:

- Unstructured grids allows for local refinement, allowing increased accuracy around hydrogeological features of interest while remaining computationally efficient.
- New solvers and methods for handling model cell drying and resaturation give more numerically stable models.

- MODFLOW is open source allowing user to adapt to project-specific needs.
- MODFLOW is transparent in its outputs, allowing convergence or mass balance issues to be easily identified and solved.
- Recent MODFLOW versions are updated and have efficient support.

Groundwater Vistas 7 (pro) is the user interface of choice, for the majority of the pre and post-processing of the MODFLOW-USG model, combined with a number of bespoke tools created to handle any inputs or outputs specific to this project, which cannot currently be processed within GWV7. This user interface is industry standard software used for groundwater models in many varied applications. It is constantly being updated to incorporate the latest features of MODFLOW as it evolves.

Model calibration to historical data

Each model should be calibrated to groundwater head and flow data where available. This is the history-matching process during which model hydraulic parameters and boundary conditions are derived. Further calibration data can be incorporated to improve confidence in the models during the model updates towards the end of the project.

Modelling of karst features

Such features can be simulated in MODFLOW-USG as discrete features - CLN (connected linear network) package. These can be incorporated where justified by geological and hydrogeological data.

Predictive scenario modelling

Scenario modelling should be used to look at impacts on groundwater levels of likely future pumping. The first outputs of this task should be limited and these models will be updated and refined in later stages of the project.

C.3.12.5 Saline intrusion modelling

A detailed assessment of the likely migration of the saline interface in the coastal aquifer will be undertaken starting from the conceptual models and at a later stage from their groundwater flow model as previously explained. The modelling approach will be set based on inputs from different fields (geology, hydrology, hydrogeology and modelling) as discussed and confirmed during the conceptual modelling workshops. Based on data availability one option would be to simulate representative sections using the SEAWAT variable density code, which can be coupled with MODFLOW 2000. An initial approach would be to undertake modelling of a representative slice in the most suitable aquifers, selected based on evidence of some saline intrusion but not to the point that this is beyond mitigation/control.

C.3.12.6 Model validation and final (small) refinements

Towards the end of the project (year 4) models will be validated against the most recent groundwater head and flow data. This step will allow for final small refinements to be made if required and scenarios to be rerun if needed. Any proposed refinements will need to be considered on a case by case basis and only those which will make any significant difference to the predictive model results will be addressed at this stage. A final cut-off data for receipt of new data to be incorporated into the models will be as of beginning of 4th year. Updates to some material properties or boundary condition parameters would be considered and acceptable at this point, only where this will have a significant benefit in terms of confidence in model outputs. For example, incorporating more recent calibration data or filling in missing calibration targets may lead to changes in derived hydraulic properties. However, any redefinition of model structure could not be accommodated at this late stage due to time constraints on project delivery.

C.3.12.7 Training on the groundwater models

This step involves providing training on the use of the groundwater models to representatives of different stakeholders (MoEW, WE) and also handover in preparation for use of the models in the future, as predictive tools and as databases of hydrogeological knowledge. Models delivered in the frame of this project can be further refined and updated in future years as further monitoring data become available. Predictions and model-derived recommendations on water management can then be updated accordingly.

C.4 PROPOSED PROJECTS AND TIME SCHEDULE

No.	Activities and Projects	Time in years														
		1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**PMU implementation in the MoEW**	*	▬													
2	**Review the licensing procedures of the MoEW for drilling and exploiting private water wells**		▬													
3	**Staff recruitment in the MOEW**		▬													
4	**Preparation of T.O.R for the purchase of vehicles, working tools, softwares, computers, etc... to the benefit of the MoEW.**		▬													
5	**Equipment and vehicles procurement**			▬												
6	**Review of all existing data in the data center in the MoEW and data collection of available and existing geological and hydrogeological studies**		▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
7	**Enter continuously all collected data in the database center in the Ministry of Energy and Water**		▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
8	**Monitor the flows of the majority of the public operating wells with the assistance of the Water Establishments knowing that all the public wells will be equipped with flow monitoring and water level monitoring devices**		▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
9	**Monitor continuously with the assistance of the Water Establishments the quality of the water extracted from the public wells**		▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
10	**Monitor continuously the flows and the water quality of springs which flows are higher than 80 l/sec with the assistance of the Water Establishments**		▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
11	**Folow up with the Department of the river flows monitoring in the Ministry of Energy and Water the flows measurements of rivers**				▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬
12	**Preparation of T.O.R for the preparation of a study to select the sites of the hydrometric stations along the major rivers in Lebanon taking into consideration the hydrologic, geologic and hydrogeologic prevailing conditions**			▬												
13	**Detailed studies for implementing the hydrometric stations in rivers**			▬	▬											
14	**Construction of the hydrometric stations**				▬	▬	▬									
15	**Geological Mapping**															
15.1	Geological survey at 1/20,000 scale of Central area			▬	▬											
15.2	Geological survey at 1/20,000 scale of Eastern area					▬	▬									
16	**Hydrogeological Mapping**															
16.1	Production of hydrogeologic maps at a scale of 1/50,000 and hydrogeologic report on the identified hydrogeologic basins/aquifers of Beirut and Mount Lebanon area			▬	▬											
16.2	Production of hydrogeologic maps at a scale of 1/50,000 and hydrogeologic report on the identified hydrogeologic basins/aquifers of the North Lebanon				▬	▬										
16.3	Production of hydrogeologic maps at a scale of 1/50,000 and hydrogeologic report on the identified hydrogeologic basins/aquifers of the South Lebanon					▬	▬									
16.4	Production of hydrogeologic maps at a scale of 1/50,000 and hydrogeologic report on the identified hydrogeologic basins/aquifers of the Northern and Southern Beqaas areas						▬	▬	▬							
16.5	Production of hydrogeologic maps at a scale of 1/50,000 and hydrogeologic report on the identified hydrogeologic basins/aquifers of the Eastern Lebanon							▬	▬							

C.4 Proposed projects and time schedule

No.	Activities and Projects	Time in years														
		1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15
17	**Aquifer Artificial Recharge**															
17.1	Proceed with the preparation of the detailed design of the AAR pilot project facilities in Berdaouni (A10 site)		■													
17.2	Implement the construction works of the Berdaouni AAR facilities			■	■											
17.3	Follow up the AAR of the Berdaouni aquifer					■	■	■	■	■	■	■	■	■	■	■
17.4	Detailed design of the AAR facilities of Damour			■												
17.5	Construction of the AAR facilities of Damour				■	■										
17.6	Follow up of the AAR of Damour Aquifer						■	■	■	■	■	■	■	■	■	■
17.7	Proceed with the detailed design of the AAR facilities of Mejdlaya - Abou Ali site				■											
17.8	Implement the construction works of Mejdlaya - Abou Ali AAR site					■	■									
17.9	Follow up the AAR of the Mejdlaya - Abou Ali site							■	■	■	■	■	■	■	■	■
17.10	Proceed with the preparation of the feasibility study for the AAR of the Lower Cenomanian Limestones aquifer of Hadath-Hazmieh			■												
17.11	Detailed design of AAR facilities of the Hadath-Hazmieh Lower Cenomanian limestones aquifer				■											
17.12	Implement the construction works of the AAR of Hadath-Hazmieh					■	■									
17.13	Follow up of the AAR constructed site of Hadath-Hazmieh							■	■	■	■	■	■	■	■	■
17.14	Proceed with the preparation of the feasibility study for the AAR of the Daichouniye Jurassic limestones (J4) aquifer			■												
17.15	Detailed design of the AAR facilities of the Jurassic (J4) limestones aquifer (Daichouniye)				■											
17.16	Construction of the AAR Daichouniye site facilities					■	■									
17.17	Follow up of the AAR constructed site of Daichouniye							■	■	■	■	■	■	■	■	■
17.18	Feasibility study of the AAR of Akkar plain alluvial aquifer						■									
17.19	Detailed design study of the AAR of Akkar plain alluvial aquifer							■								
17.20	Construction of the AAR facilities of Akkar plain alluvial aquifer								■	■						
17.21	Follow up of the AAR constructed site of Akkar plain alluvial aquifer										■	■	■	■	■	■
18	**Drilling testing reconnaissance and exploratory wells:**															
18.1	In Hadath-Hazmieh (3 wells)			■												
18.2	In Damour (3 wells)			■												
18.3	In Daichouniye (2 wells)			■												
18.4	In Akkar plain (5 wells			■												
18.5	In Brak (Zahrani) (1 well)			■												
19	**Refresh the water budget studies of the identified aquifers**					■	■	■	■	■	■	■	■	■	■	■
20	**Perform groundwater vulnerability mapping and delineation of protection zones 1 and 2 for springs (Q > 100 l/sec)**						■	■								
21	**Perform groundwater vulnerability mapping and delineation of protection zones 1 and 2 for springs with 10 < Q < 100 l/sec**								■	■						
22	**Modeling of fractured and karst aquifer systems**								■	■	■	■	■	■	■	■
23	**Modeling of aquifer systems: porous, permeable, saline water intrusion**								■	■	■	■	■	■	■	■
	* 1 = year 2020															

C.5 BUDGET ESTIMATES

Budget estimates are summarised as follows (see details in Table C 5 below)

- PMU implementation over 5 years: 8,505,000 USD
- Studies: 33,555,000 USD
- Construction of A.A.R facilities: 28,500,000 USD
- Drilling reconnaissance wells: 6,150,000 USD

65,505,000 USD

Table C 5 Budget estimate for groundwater management and AAR implementation

TASK DESCRIPTION	COST USD
Project Management Unit Implementation	
Implementation of a PMU for a period of 5 years - Experts Engineers	6,700,000
Purchase of cars and computers and software	100,000
Purchase of working tools and IT equipment, for newly recruited staff	100,000
Purchase of current meters and flow monitoring tools for flow measurements and softwares for interpretation	100,000
Purchase of manual dipmeters	25,000
Travel expenses	100,000
Transportation expenses	960,000
Office expenses	420,000
Sub-total	**8,505,000**
Geology and Hydrogeology Mapping and Studies	
Refreshment of the geology at 1/20,000 scale of Central Area	2,200,000
Refreshment of the geology at 1/20,000 scale of Beqaa Area	2,000,000
Refreshment of the geology at 1/20,000 scale of Eastern Area	1,500,000
Hydrogeological mapping and hydrogeological studies of Mount Lebanon	800,000
Hydrogeological mapping and hydrogeological studies of North Lebanon	1,000,000
Hydrogeological mapping and hydrogeological studies of South Lebanon	1,800,000
Hydrogeological mapping and hydrogeological studies of North Bekaa	400,000
Hydrogeological mapping and hydrogeological studies of South Bekaa	400,000
Hydrogeological mapping and hydrogeological studies of East Bekaa	800,000
Sub-total	**9,500,000**

TASK DESCRIPTION	COST USD
Aquifer Artificial Recharge Studies	
Detailed design of the AAR pilot project facilities of Berdaouni site	150,000
Detailed design of Abou Ali AAR facility	500,000
Detailed design of Damour AAR facility	500,000
Feasibility study of the AAR project facilities of Akkar	200,000
Feasibility study of the AAR pilot project facilities of Hadath-Hazmieh	200,000
Feasibility study for the AAR of Daichouniye	200,000
Detailed design of Daichouniye AAR facilities	500,000
Detailed design of Hadath-Hazmieh AAR facilities	500,000
Detailed design of Akkar plain AAR facilities	500,000
Sub-total	**3,250,000**
Aquifer Artificial Recharge Facilities Implementation	
Construction of Berdaouni AAR facility	**3,500,000**
Construction of Abou Ali AAR facility	**5,000,000**
Construction of Damour AAR facility	**5,000,000**
Construction of Hadath - Hazmiyeh AAR facility	**5,000,000**
Construction of Daichouniye AAR facility	**5,000,000**
Construction of Akkar AAR facility	**5,000,000**
Sub-total	**28,500,000**
Water Budget Studies	
Refreshment of water budget studies of major hydrogeological basins	2,000,000
Sub-total	**2,000,000**
Groundwater vulnerability mapping for springs	
Groundwater vulnerability mapping for springs Q > 100	800,000
Groundwater vulnerability mapping for springs 10 < Q < 100	800,000
Sub-total	**1,600,000**
Aquifer Modeling	
Modeling of major and hydrogeological basins karst aquifers	3,000,000
Modeling of major porous, saline aquifer systems	3,000,000
Sub-total	**6,000,000**
Drilling and testing reconnaissance and exploratory wells:	

TASK DESCRIPTION	COST USD
In Hadath-Hazmieh (3 wells)	1,500,000
In Brak (Zahrani) (1 well)	500,000
In Damour (3 wells)	1,050,000
In Akkar plain (5 wells)	2,500,000
In Daichouniye (2 wells)	600,000
Sub-total	**6,150,000**
GRAND TOTAL	**65,505,000**

SECTION D
Guidelines for monitoring water quality

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D.1. NATIONAL LAWS AND STANDARDS

D. 1.1 GENERAL

Water contamination is a major concern that has evolved over time with the increase in population and human activity. Drinking water quality must therefore meet strict public health standards.

Consequently, water quality monitoring became a very important topic in hydrology, and has been developed and implemented by most countries. It is a long-term, standardized measurement and observation of groundwater and surface water in order to detect changes and define water status. The standards and regulations for water quality monitoring are specified under national laws for each country.

D. 1.2 NATIONAL LAWS AND REGULATIONS

Table D 1 gives the most relevant environmental legislation in force in Lebanon.

Libnor 161/1999 (see Table D 2) represents the first standards set for drinking water quality covering over 60 parameters including organoleptic characteristics, chemical and physicochemical, microbiological and specific pollutants related to pollution from industrial sources or agricultural activities.

Table D 1
In force Lebanese legislation relating to pollution and protection of water resources
(Responsible ministry : MoEW)

Document	Date	Subject
Order No. 144	10.06.1925	Protection of Surface and Ground Water Resources
Order No. 320/26	26.05.1926	Protection of Catchment Areas Decision relative to the conservation of public water and its use. It prohibits blocking the free flow of public water or the performance of some works such as drilling for underground or artesian water without obtaining the proper permit from the proper administration.
Decree law 16 L	1932	The decree law based on Decision 320/1926. It mandates the establishment of buffer zones for the protection of all surface and groundwater resources from any type of activity/potential source of pollution. Requirements for buffering are found in Decision 320/26.
Decree No. 639	26.03.1942	Protection of Nabaa Al Assal Spring, Faraya
Decree No. 10276	07.10.1962	Protection Zones for Water Sources and Recharge Areas.
Decree No. 14438	02.05.1970	Restrictions on the Depth of Unlicensed Boreholes
Decision 67	1972	Methodology for bacteriological analysis of water.
Decision No. 2528/C	28.05.1996	Protection of Ground Water at El Kneisse
Law 623	1997	Implementing penalties for vandalism of water, telephone and electricity infrastructure.

Table D 1
In force Lebanese legislation relating to pollution and protection of water resources
(Responsible ministry : MoEW)

Document	Date	Subject
Decree No. 680	15.09.1998	The Preservation and Protection of Boreholes
Decree 1039	1999	Establishes drinking water standards.

Table D 2
In force Lebanese legislation relating to pollution and protection of water resources

PARAMETERS	MAXIMUM ALLOWABLE LIMIT	SAMPLING FREQUENCY
Color	20 units *	ISO 7887:1994
Turbidity	10 units**	ISO 7027: 1990
Taste		
Reduction at 12°C	0	
·Reduction at 25°C	3	
Odor Reduction at 12°C Reduction at 25°C	 0 2	EPA 140.1
Free Chlorine (Cl_2)	0.3 mg/L	Monthly Depending on the number of users
PH value	Between 6.5 and 8.5	
Total dissolved solids	500 mg/L	
Copper (Cu)	1 mg/L	
Iron (Fe)	0.3 mg/L	
Magnesium (Mg)	50 mg/L	
Manganese (Mn)	0.05 mg/L	Monthly Depending on the number of users
Sulfates (SO_4^{--})	250 mg/L	
Zinc (Zn)	5 mg/L	
Calcium expressed as $CaCO_3$	200 mg/L	
Chloride (Cl^-)	200 mg/L	
Total hardness expressed as $CaCO_3$	250 mg/L	
Phenolic compounds (expressed as phenol, excluding natural phenols not reacting with chlorine)	0.001 mg/L	
Mineral oils	Not existing	
Separated chloroform (carbon)	0.2 mg/L	
Alkyl sulfates- gasoline	Not existing	
Ammonia	Not existing	

Table D 2
In force Lebanese legislation relating to pollution and protection of water resources

PARAMETERS	MAXIMUM ALLOWABLE LIMIT	SAMPLING FREQUENCY
Phosphorus pentoxide (P_2O_5)	1 mg/L	
Organic materials	0.5 mg/L	Every season. Depending on the number of users
Nitrite (NO_2)	0.05 mg/L	
Hydrogen sulfide (H_2S)	0.05 mg/L	
Nitrate (NO_3)	45 mg/L	
Sodium (Na)	150 mg/L	
Potassium (K)	12 mg/L	
Aluminum (Al)	0.2 mg/L	
Arsenic (As)	0.05 mg/L	
Cadmium (Cd)	0.005 mg/L	
Cyanide (CN)	0.05 mg/L	
Mercury (Hg)	0.001 mg/L	
Selenium (Se)	0.01 mg/L	
Lead (Pb)	0.01 mg/L	
Chromium(VI) (Cr)	0.05 mg/L	Every season. Depending on the number of users
Barium (Ba)	0.5 mg/L	
Silver (Ag)	0.01 mg/L	
Nickel (Ni)	0.02 mg/L	
Fluoranthene	0.0002 mg/L	
3,4 benzofluoranthene	0.0002 mg/L	
11,12 benzofluoranthene	0.0001 mg/L	
3,4 benzopyrene	0.00001 mg/L	
1,12 benzoperylene	0.0002 mg/L	
Indeno (1,2,3 c.d.) pyrene	0.0002 mg/L	
Fluoride Between 8 and 12 ^oC Between 25 and 30^oC	 1.5 mg/L 0.7 mg/L	Every 6 months. Depending on the number of users
Halogenated organic compounds	0.06 mg/L	
Chloroform	0.1 mg/L	
Aldrin + dieldrin	0.00002 mg/L	
Lindane	0.0002 mg/L	
Methoxy chlore	0.02 mg/L	
Toxaphene	0.003 mg/L	
2,4 dichlorophenoxy acetic acid	0.03 mg/L	
2(2,4,5) thrichlorophenoxy propionic acid	0.009 mg/L	

Table D 2
In force Lebanese legislation relating to pollution and protection of water resources

PARAMETERS	MAXIMUM ALLOWABLE LIMIT	SAMPLING FREQUENCY
Total coliforms	0 in 100 mL	
Fecal streptococcus	0 in 250 mL	
Sporulated sulphite reducing anaerobes	0 in 50 mL	
Fecal coliforms	0 in 250 mL	
Esherichia coli at 37 and 44.5 ^{o}C	0 in 250 mL	**<20 000 users :** 1 sample per 5000 users every two weeks **20 000 to 50 000 users :** One sample per 10000 users every week. **50 000 to 100 000 users** : One sample per 10000 users every 4 days. **> 100 000 users :** One sample per 20000 users every day.
Pseudomonas aeruginosa	0 in 250 mL	
Total microscopic aerobes At 22^{o}C and storing it for 72 hours At 37^{o}C and storing it for 24 hours	 100 in 1 mL 20 in 1 mL	

D. 1.3 PROBLEMS AND GAPS IN THE NATIONAL STANDARDS

- Based on the *Libnor* 161:1999 drinking water standards, the drinking water quality characteristics were defined, the new version 161:2016 has not been published and implemented yet due to the lack of the necessary equipment and human resource in the laboratories.
- No effective monitoring plan is being implemented by the Wes to secure water safety for the users as it was seen in the data collection phase.
- The laboratory of the water establishments are not able to process a large number of samples and no action is being taken.
- Not enough resources are available (grants, human resources, equipment…).
- Unorganized or absence of historical data that allow keeping track of contamination history.

To fill the gaps and update the existing national guidelines and standards, it is recommended to start with taking into consideration International guidelines and standards as a scientific basis for drinking water quality.

D.2. INTERNATIONAL GUIDELINES AND STANDARDS

D. 2.1 THE EU DRINKING WATER DIRECTIVE (2015)

The Drinking Water Directive (Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption) concerns the quality of water intended for human consumption. Its objective is to protect human health from adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean. Annexes II and III concerning monitoring, sampling and parameters to be tested, were amended in Commission Directive (EU) 2015/1787 of 6 October 2015, in light of new scientific research and findings.

It should be noted that a proposal to recast the Directive was written in 2017 but was not officially published. Therefore, the Directive published in 2015 will be taken into consideration for the purpose of this report.

The Drinking Water Directive applies to:

- all distribution systems serving more than 50 people or supplying more than 10 cubic meter per day, but also distribution systems serving less than 50 people/supplying less than 10 cubic meter per day if the water is supplied as part of an economic activity;
- Drinking water from tankers;
- Drinking water in bottles or containers;
- Water used in the food-processing industry, unless the competent national authorities are satisfied that the quality of the water cannot affect the wholesomeness of the foodstuff in its finished form.

The Directive laid down the essential quality standards at EU level. A total of 48 microbiological, chemical and indicator parameters must be monitored and tested regularly. In general, World Health Organization's guidelines for drinking water and the opinion of the Commission's Scientific Advisory Committee are used as the scientific basis for the quality standards in the drinking water.

Annex 1 to the Directive

Annex I of the directive defines the water quality parameters:

- Part A Microbiological parameters
- Part B Chemical parameters
- Part C Indicator parameters

When transposing the Drinking Water Directive into their own national legislation, Member States of the European Union can include additional requirements e.g. regulate additional substances that are relevant within their territory or set higher standards.

Annex 2 to the Directive

The amended Annex II defines the monitoring obligations:

The minimum frequency of sampling and analyses for water intended for human consumption supplied from a distribution network is specified. Member States must take samples at the points of compliance as defined in Article 6(1) to ensure that water intended for human consumption meets the requirements of the Directive. However, in the case of a distribution network, a Member State may take samples within the supply zone or at the treatment works for particular parameters if it can be demonstrated that there would be no adverse change to the measured value of the parameters concerned.

- PART A General objectives and monitoring programmes for water intended for human consumption

  The monitoring programme should be updated and reviewed every 5 years.

- PART B Parameters and frequencies

  Group A parameters

  - Escherichia coli (E. coli), coliform bacteria, colony count 22 °C, colour, turbidity, taste, odour, pH, conductivity; other parameters identified as relevant in the monitoring programme.
  - Ammonium and nitrite, if chlorination is used;
  - Aluminium and iron, if used as water treatment chemicals.

  Group B parameters

  All other parameters not analysed under Group A and set by the member state according to Article 5.

  Sampling frequencies

  Sampling frequency is set in Table D 3 below.

Table D 3
Sampling and analysis minimum frequency for compliance monitoring
(EU Directive, 2015)

Volume of water distributed or produced each day within a supply zone (see Notes 1 and 2)	**Group A parameter number of samples per year** (see Note 3)	**Group B parameter number of samples per year**
< 100 m^3	>0 (see Note 4)	>0 (see Note 4)
100 to 1 000 m^3	4	1
1 000 to 10 000 m^3	4 +3 For each 1 000 m^3/d and part thereof of the total volume	1 +1 For each 4 500 m^3/d and part thereof of the total volume

Table D 3
Sampling and analysis minimum frequency for compliance monitoring
(EU Directive, 2015)

Volume of water distributed or produced each day within a supply zone (see Notes 1 and 2)	**Group A parameter number of samples per year** (see Note 3)	**Group B parameter number of samples per year**
10 000 to 100 000 m^3	4 +3 For each 1 000 m^3/d and part thereof of the total volume	3 +1 For each 10 000 m^3/d and part thereof of the total volume
> 100 000	4 +3 For each 1 000 m^3/d and part thereof of the total volume	12 +1 For each 25 000 m^3/d and part thereof of the total volume

Note 1 A supply zone is a geographically defined area within which water intended for human consumption comes from one or more sources and water quality may be considered as being approximately uniform.

Note 2: The volumes are calculated as averages taken over a calendar year. The number of inhabitants in a supply zone may be used instead of the volume of water to determine the minimum frequency, assuming water consumption of 200 l/(day*capita).

Note 3: The frequency indicated is calculated as follows: e.g. 4 300 m3/d = 16 samples (four for the first 1 000 m3/ d + 12 for additional 3 300 m3/d).

Note 4: Member States that have decided to exempt individual supplies under Article 3(2)(b) of this Directive shall apply these frequencies only for supply zones that distribute between 10 and 100 m3 per day.

- PART C Risk assessment
  Member states can detract from the parameters and frequencies indicated in Part B when a risk assessment is performed according to Part C.

- PART D sampling methods and sampling points
  - EN ISO 19458, sampling purpose B, for microbiological parameters at point of compliance
  - ISO 5667-5 for sampling in the distribution network (except consumer’s tap).
  - EN ISO 19458, sampling purpose A, for microbiological parameters in the distribution network (except consumer’s tap).

  The number of samples shall be distributed equally in space and time.

Annex 3 to the Directive

Annex III, defines the specifications for the analysis of parameters.

Article 8 of the directive refers to 'remedial action and restrictions in use'. Any failure to meet the parametric values set is immediately investigated in order to identify the cause. If, despite the measures taken to meet the obligations, water intended for human consumption does not meet the parametric values set, the Member State concerned shall ensure that the necessary remedial action is taken as soon as possible to restore its quality and shall give priority to their enforcement action, having regard inter alia to the extent to which the relevant parametric value has been exceeded and to the potential danger to human health.

Whether or not any failure to meet the parametric values has occurred, Member States shall ensure that any supply of water intended for human consumption which constitutes a potential danger to human health is prohibited or its use restricted or such other action is taken as is necessary to protect human health. In such cases consumers shall be informed promptly thereof and given the necessary advice. The competent authorities or other relevant bodies shall decide what action should be taken, bearing in mind the risks to human health which would be caused by an interruption of the supply or a restriction in the use of water intended for human consumption. Member States may establish guidelines to assist the competent authorities to fulfil their obligations. Member States shall ensure that, where remedial action is taken, consumers are notified except where the competent authorities consider the non-compliance with the parametric value to be trivial.

D. 2.2 THE WORLD HEALTH ORGANIZATION (WHO) GUIDELINES

D. 2.2.1 Guidelines for drinking-water quality

The WHO guidelines for drinking-water quality (fourth edition incorporating the first addendum - 2017) reflect the importance of public health protection. In fact, it provides recommendations to manage the risks from hazards that may compromise the safety of drinking-water. The report is divided into 12 chapters contributing to developing a water safety plan as shown on Figure D 1

The report includes:

- A holistic approach that systematically assesses the risks of water contamination from the source through to the consumer and proposes management solutions.
- Guidelines to develop a risk management strategy for safe drinking-water.
- Minimum requirements of safe practice to protect the health of consumers and derive numerical "guideline values" for constituents of water or indicators of water quality.
- A scientific point of departure for national authorities to develop drinking-water regulations and standards appropriate for the national situation.
- Description of a water quality that is acceptable for human consumption.
- Prioritization of parameters to respond to the most urgent water problems.
- Implementing a comprehensive water safety plan to consistently ensure drinking-water safety.

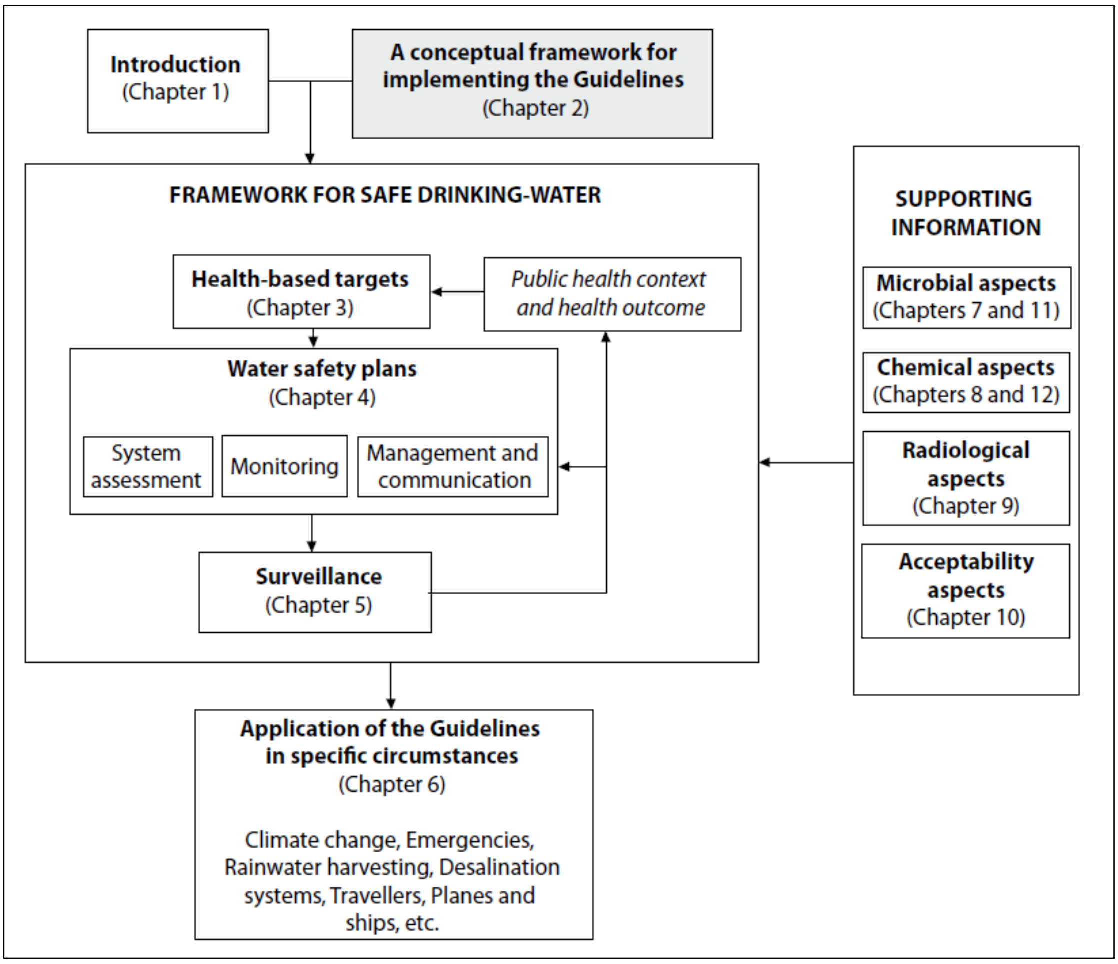

Figure D 1
Summary of WHO guidelines for drinking-water (adapted from WHO,2017)

Usually the EU Directive is updated based on the WHO guidelines latest update. However, they might disagree on some parameters or some concentration limits.

D. 2.2.2 Water Safety Plan Manual

The water safety plan concept (Step-by-step risk management for drinking-water suppliers - -2009) is described in the WHO guidelines of 2017. However, an in-depth explanation is given in the ''Water Safety Plan Manual, Step-by-step risk management for drinking-water suppliers'' of the World Health Organization (WHO), published by the International Water Association (IWA) 2009.

The Outline for developing a Water Safety Plan in 11 steps (module) is shown on Figure D 2 and subsequent Table D 4 and Table D 5. The methodology is quoted from the Water Safety Manual mentioned above.

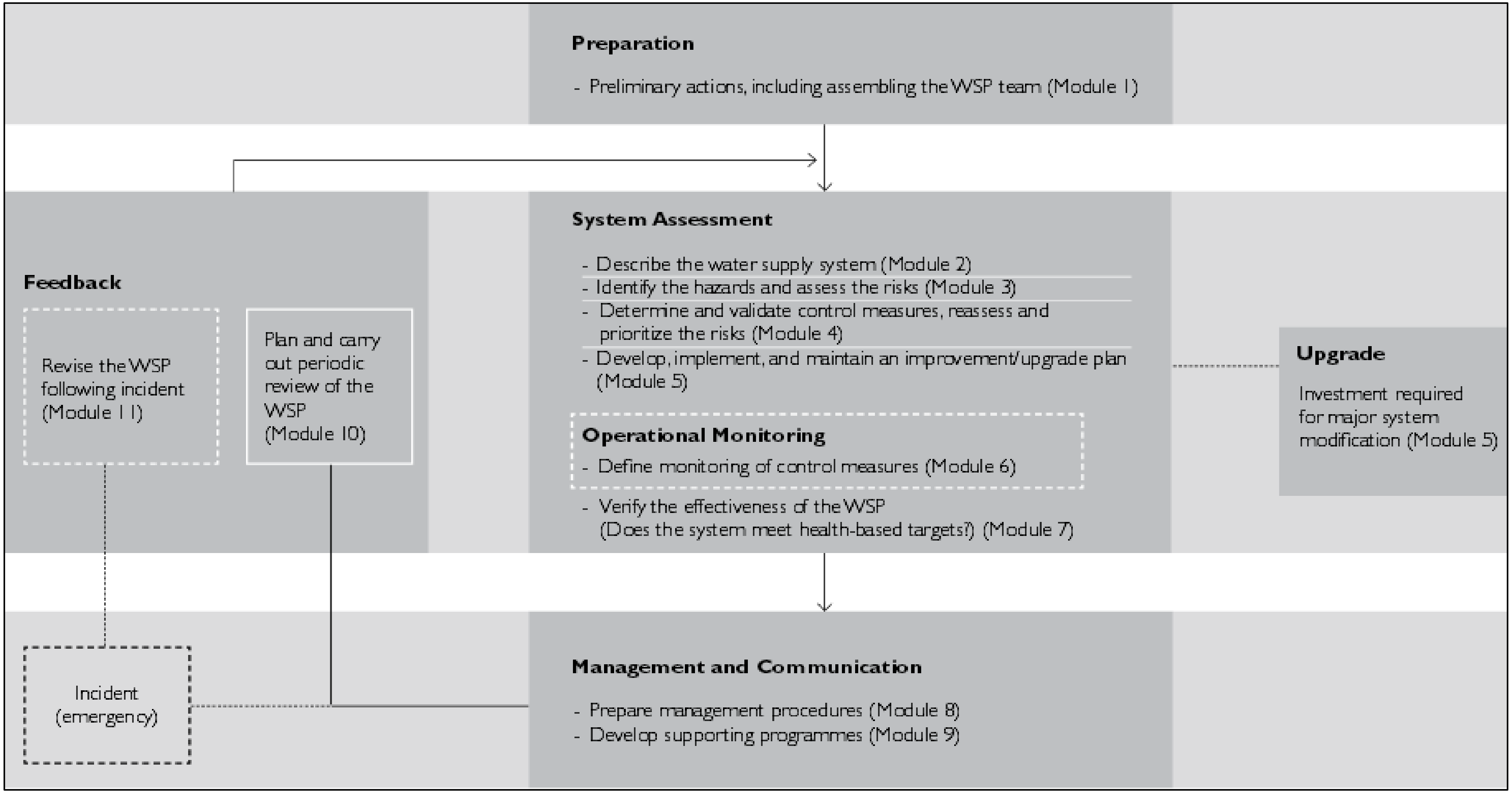

Figure D 2
Develop and implement a Water Safety Plan – an outline (WHO,2009)

Table D 4
Output of hazard and risk assessment using semi-quantitative approach

Process step	Risk	Hazard type	Like-lihood	Severity	Score	Risk rating (before consideration of controls)	Basis
Source (ground water)	Cattle defecation in vicinity of unfenced wellhead causing source of potential pathogen ingress in wet weather	Microbial	3	5	15	High	Potential illness from pathogens from cattle, such as *Cryptosporidium*
Source	Cocktail of pesticides from agricultural uses	Chemical	2	4	8	Medium	Potential introduction of toxic chemicals which could lead to concentrations in finished water above national standards and WHO Guideline values
Source	Potential for informal solid waste disposal	Microbial and chemical	1	1	2	Low	Potential for hazardous waste plus rainfall event causing contamination to water supply is low
Treatment	No back-up power supply	Microbial and chemical	2	5	10	High	Potential loss of treatment and pumps/pressure
Distribution	Leaks on trunk main and distribution system	Microbial	5	3	15	High	Leaks are a potential source of microbial pathogens and contribute to high % of unaccounted for water

Such a matrix provides an overview of the relevant risks and assists their prioritization. This facilitates the development of the Water Safety Plan in its following steps.

“The most effective means of consistently ensuring the safety of a drinking-water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer. In these Guidelines, such approaches are called water safety plans (WSPs)”. WHO, IWA 2009.

Table D 5
Development of a Water Safety Plan in 11 steps

Module	Output of the activity
Module 1: Assemble the WSP team	Establishment of an experienced, multidisciplinary team that understands the components of the system, and is well- placed to assess the risks that may be associated with each component of the system. The team needs to understand the potential health risks and have the expertise to confirm that the system can meet the relevant water quality standards.
Module 2: Describe the water supply system	1. A detailed up-to-date description of the water supply system, including a flow diagram. 2. An understanding of water quality currently being provided by the utility. 3. Identification of the users and uses of water
Module 3: Identify hazards and hazardous events and assess the risks	1. Description of 'what' could go wrong and 'where' in terms of hazards and hazardous events. 2. Assessment of risks expressed in an interpretable and comparable manner, such that more significant risks are clearly distinguished from less significant risks.
Module 4: Determine and validate control measures, reassess and prioritize the risks	1. Identification of the controls. 2. Validation of the effectiveness of the controls. 3. Identification and prioritization of insufficiently controlled risks.
Module 5: Develop, implement and maintain an improvement/upgrade plan	1. Development of a prioritized improvement/upgrade plan for each significant uncontrolled risk. 2. Implementation of the improvement plan according to the planned schedule of short-, medium- or long-term activities. 3. Monitoring the implementation of the improvement/ upgrade plan.
Module 6: Define monitoring of the control measures	1. An assessment of the performance of control measures at appropriate time intervals. 2. Establishment of corrective actions for deviations that may occur.

Table D 5
Development of a Water Safety Plan in 11 steps

Module	Output of the activity
Module 7: Verify the effectiveness of the WSP	1. Confirmation that the WSP itself is sound and appropriate. 2. Evidence that the WSP is being implemented in practice as intended, and working effectively. 3. Confirmation that ***water quality meets defined targets***.
Module 8: Prepare management procedures	Management procedures for normal and incident/emergency conditions which address: • Response actions; • Operational monitoring; • Responsibilities of the utility and other stakeholders; • Communication protocols and strategies, including notification procedures and staff contact details; • Responsibilities for coordinating measures to be taken in an emergency; • A communication plan to alert and inform users of the supply and other stakeholders (e.g. emergency services); • A programme to review and revise documentation as required; • Plans for providing and distributing emergency supplies of water.
Module 9: Develop supporting programmes	Programmes and activities that ensure that the WSP approach is embedded in the water utility's operations.
Module 10: Plan and carry out periodic review of the WSP	A WSP that is up to date and continues to be appropriate to the needs of the water utility and stakeholders.
Module 11: Revise the WSP following an incident	1. Comprehensive and transparent review of why the incident occurred and the adequacy of the utility's response. 2. Incorporation of the lessons learned into WSP documentation and procedures.

D. 2.2.3 International application of WHO parameters and limits

Based on the WHO guidelines report, and on all other WHO publications related to drinking-water standards, the admissible limits for chemical, microbiological, radioactive and acceptability parameters and the sampling frequency recommendations are discussed below. It should be noted that in the WHO drinking-water quality guidelines limits are only set for parameters that present health concerns. In addition, these parameters are not mandatory for all countries (WHO, 2017), and countries might use additional parameters seen as important for the national water conditions.

Chemical parameters

Chemical parameters are divided into five categories: Naturally occurring chemicals, chemicals from industrial sources and human activities, chemicals from agricultural practices, chemicals used in water treatment and pesticides previously used for public health purposes. Naturally occurring chemicals with specified guideline values are shown in Table D 6. These chemicals present a threat for public health when the guideline value is exceeded. The complete list is found in WHO, 2017. More than 80 chemical parameters present health concerns and therefore are given guideline values. The list of inorganic and organic parameters that are used by most countries can be found in A global overview of national regulations and standards for drinking-water quality, WHO, 2018.

Table D 6
Naturally occurring chemicals with guideline values set by WHO
(Adapted from WHO, 2017)

Chemical parameter	Guideline value (mg/l)	Remarks
Inorganic		
Arsenic	0.01 (A) (T)	
Barium	1.3	
Boron	2.4	
Chromium	0.05 (P)	For total chromium
Fluoride	1.5	Volume of water consumed and intake from other sources should be considered when setting national standards.
Selenium	0.04 (P)	
Uranium	0.03 (P)	Only chemical aspects of uranium addressed
Organic		
Microcystin-LR	0.001 (P)	For total microcystin-LR (free plus cell-bound)

A provisional guideline value because calculated guideline value is below the achievable quantification level;
P provisional guideline value because of uncertainties in the health database;
T provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

Microbiological parameters

Microbiological parameters are the most health threatening water quality parameters when found in high concentrations. Table D 7 shows the microbiological parameters that are included in the drinking-water quality standards for most countries (WHO survey in 104 countries - 2018). Where the WHO guideline value is not specified, the admissible limit is based on the median value used by most countries.

Table D 7
Most frequent microbiological parameters

Microbiological Parameters	Admissible limit
E.Coli	0 in 100 ml
Total Coliform bacteria	0 in 100 ml
Total heterotrophic bacteria at 22°C	100 cfu per ml
Total heterotrophic bacteria at 37°C	100 cfu per ml
Enterococci (Fecal streptococci)	0 per 100 ml
Sulphite-reducing Clostridia	0 per 100 ml

Radioactive parameters

The drinking-water guidelines suggest screening levels for gross alpha and gross beta activity (Table D 8) since testing for individual radionuclides is too expensive and time consuming. If the screening shows high values, then an individual radionuclide testing strategy should be considered.

Table D 8
Radioactive screening parameters (WHO, 2017) included in National Standards

Radioactive screening parameters	Admissible limit
Gross α	0.5 Bq/l
Gross β	1 Bq/l

Acceptability parameters

Acceptability parameters are chemical, biological and physical parameters that define whether water is aesthetically acceptable for consumers or not. These are the parameters that can be perceived with human senses. All these parameters do not have a set value in the WHO guideline. The most often specified parameters are listed in Table D 9. The admissible limit is based on the median value used by most countries (WHO, 2018).

Table D 9
Acceptability parameters most frequently included in National Standards

Acceptability parameters	Admissible limit
pH	6.5-8.5
Temperature	25°C
Taste	3 DN
Odour	3 DN
Colour	15 TCU

Table D 9
Acceptability parameters most frequently included in National Standards

Acceptability parameters	Admissible limit
Turbidity	5 NTU
Total dissolved solids (TDS)	1000 mg/l
Chloride	250 mg/l
Iron	0.3 mg/l
Aluminium	0.2 mg/l
Sulphate	250 mg/l
Ammonium	0.2 mg/l

Each country has to critically choose the appropriate parameters according to its national water conditions, keeping the list relevant and short. In fact, parameters should be prioritized depending on the most recurrent contaminations found over the years. In most cases, the highest priority should be given for microbiological contaminants. Relatively, most chemical parameters do not have a direct threat on human health, therefore these chemicals should be given low priorities. Radiological screening parameters (which are not considered in the existing Lebanese standards) are unlikely to have a major impact on public health. However, in the Middle East, radionuclides are found in deeper groundwater, the effect of nuclear energy, and therefore they must be included in the Lebanese standards.

D. 2.2.4 Operational and Compliance monitoring

Operational monitoring

Operational monitoring is part of developing a water safety plan as described in the water safety manual (WHO, 2009). The parameters included are simple, can be measured frequently and return instant results that enable the water supplier to take actions immediately to fix the problem. These parameters include measurable ones such as pH, turbidity and chlorine residuals, and observable ones such as integrity of fences etc…Microbiological parameters require complex tests and therefore might not be included since it takes more time to retrieve the results.

The frequency of sampling depends on the frequency of hazards and hazardous events that may affect the system. Some parameters can be monitored on-line, such as chlorine residual, which can be achieved by using a SCADA system as it is the case in developed countries (WHO, 2009).

Compliance monitoring

Compliance or verification monitoring is included in the next step of the water safety plan: "Verification of the effectiveness of the WSP". This kind of monitoring verifies that water quality parameters are in compliance with the regulations and standards. It is preferable to develop a risk-based monitoring program where the water supplier has the flexibility to deviate from the monitoring requirement based on the system-specific conditions.

Based on Developing drinking-water quality regulations and standards WHO, 2018, sampling frequency should depend on:

- Quality and variability of the source water;
- Type of treatment the water receives;
- Risks of contamination in various parts of the system;
- Complexity of the system (e.g. number of pressure zones, intermittency of operation, pipe material, pipe condition, reservoir condition);
- Water quality history;
- Size of the population supplied with drinking-water; and
- Availability of data produced by monitoring for other purposes (e.g. environmental monitoring)."

It is always important to consider the cost of monitoring. Therefore, by prioritizing parameters, the ones that are seen as stable or unthreatening should not be tested as frequent as microbiological parameters that are susceptible to change frequently. Chemical parameters can then be tested quarterly or biennially and stable parameters can be monitored once a year.

Radiological parameters should be tested at least four times per year for new resources, if found uncontaminated, monitoring frequency can then be decreased.

Monitoring of parameters that are influenced by seasonal variations, such as pesticides, should account for seasonal change.

Sampling locations

Sampling locations should be representative to reflect the quality of water received by consumers, and should account for costs, for the expected presence of a contaminant and for the travel time of a contaminant. A guidance on monitoring locations is given in Table D 10.

Table D 10
Guidance on sampling locations (WHO,2018)

Parameter concentration	Examples[a]	Primary monitoring locations[b]
Is unlikely to change after treatment	• Arsenic • Nitrate (except where chloramines are being used as a residual disinfectant) • Fluoride • Aluminium • Ammonia (except where chloramines are being used as a residual disinfectant) • Barium • Selenium	Exit of treatment plant

Table D 10
Guidance on sampling locations (WHO,2018)

Parameter concentration	Examples[a]	Primary monitoring locations[b]
	• Radionuclides	
Can change after treatment and through the distribution system	• Microbial indicators (e.g. E. Coli) • THMs • Other DBPs • Chlorine residual • Ammonia (where chloramines are being used as a residual disinfectant) • Taste and odours • Turbidity • Manganese • Nitrite and Nitrate (where chloramines are being used as a residual disinfectant)	One of the following locations: • Within the distribution systems • Consumers' taps
Is largely influenced by service connections or plumbing within buildings	• Lead • Copper	Consumers' taps

a Inclusion of a parameter in this table does not imply that the parameter is a high priority in all the water supply systems.
B Not all jurisdictions can monitor at the consumer's tap. If the samples cannot be collected from the consumer's tap, the point of supply to the consumer's property is a satisfactory alternative. For more detailed guidance on monitoring in distribution systems, refer to Water safety in distribution systems. (WHO,2014). For example, in Lebanon the MoEW is responsible for the water quality until the water meter of the property, whereas the MoH is responsible for the water quality at the consumer's tap.

D.3. RECOMMENDATIONS ON THE NATIONAL LEVEL

D. 3.1 GENERAL

This section provides suggested guidelines for monitoring water quality in Lebanon.

Those guidelines are open for discussion. The suggested parameters and sampling frequencies are generally applicable. However, for each water system the environmental situation might differ and therefore adjustments might be required.

As general rule, the following should apply:

- For compliance monitoring, samples should be taken by the Ministry of Health from consumers' tap regularly to verify the compliance of the parameters with the LIBNOR standards.
- All water establishments should abide by the National standards. Currently, heavy metals parameters are almost not being tested by the water establishments, although some are present in the 161:1999 national standards.
- Parameters that are stable should not be tested very frequently, unless a sudden event happens (heavy rain, flooding, leakages…)
- The size of the population served affects the sampling frequency.
- Using ranges and an indexing method to classify water quality. In fact, by setting ranges for each parameter, minimum and maximum admissible limits are known. For example, "Calcium expressed as CaCO3" has a maximum admissible limit of 200 mg/l in the Lebanese standards. However, a concentration below 60 mg/l is not recommended, thus comes the need for a minimum admissible limit. Moreover, by using ranks and indexes water quality can be classified as "very poor", "poor", "good" or "very good", after ranking the result for every tested parameter as: "within the limits", "slightly below/above the limits", "contaminated or highly contaminated".
- Standard Operating Procedures (SOPs) should be written for all water establishments under normal and emergency situations covering water sampling procedure, laboratory practices, maintenance of distribution networks and more…
- Delineation of protection zones and implementation of land use restrictions should be given a high priority in the Water Safety Plan (WSP).
- The WSP should be reviewed whenever a change happens to the water system or in the water establishment for example: WSP member change, new activity in catchment, new treatment infrastructure, improvement plan implemented, etc… The review date should now exceed 5 years from the previous review.

D. 3.2 GAPS AND SOLUTIONS

Some of the water quality monitoring gaps and problems together with proposed solutions, can be summarised as follows:

Table D 11
Water quality gaps and solutions in Lebanon

Current problems	Proposed solutions
The 161:2016 *Libnor* water quality standards have not been published	• Equipping all laboratories with the necessary tools to be able to abide by the new standards (see Section III D.4)
No monitoring plan	• Implementation of Water Safety Plan methodology including operational and compliance monitoring • The plan should be strictly implemented by all water establishments
Lack of resources, unaffordable costs	• Prioritization of parameters that should be tested regularly. Keeping the list relevant and short • Certain parameters should only be tested after an exogenous event.
Water treatment	Chlorination system should be functional for all resources, treatment plants where needed.
Unorganized or unavailable water quality data	Creation of Data Management system (Database) that is centralized in each water establishment, and is updated on a regular basis.

A water safety plan should be developed and implemented, with water quality parameters are divided into operational and monitoring parameters, and monitoring programs are specified for groundwater and surface water.

Based on the International recommendations and examples and based on previous encountered national cases, a tentative water quality monitoring program is suggested for Lebanon showing the minimum requirements.

D. 3.3 SAMPLING LOCATION

For operational monitoring, samples should be taken by the water establishments at the exit of the break tank where water is directly collected from the water source or after treatment. Another sampling point is the distribution network. This includes the main distribution lines and the branches. The locations chosen in the distribution system should be representative of the whole system. For compliance monitoring, samples should be taken from the consumer’s tap by the MoH.

D. 3.4 MONITORING AND SAMPLING FREQUENCY

D. 3.4.1 General operational monitoring

The suggested operational monitoring parameters, for both surface water and groundwater, are as follows :

Parameters	Sampling frequency
pH	On-line or daily
Odour	Weekly
Taste	Weekly
Color	Weekly
Turbidity	On-line or daily
Electrical Conductivity	weekly
Chlorine residual	On-line or daily

D. 3.4.2 Compliance monitoring for groundwater

The suggested water quality monitoring parameters for groundwater, together with their respective sampling frequencies are given in Table D 12

Table D 12
Water quality monitoring for groundwater

Group of parameters		Parameters	Sampling frequency at break tank exit or treatment plant exit	Sampling frequency at the distribution system
Microbiological		E.Coli, Fecal Coliform, Total coliform, Fecal Streptococci, Total heterotrophic bacteria	Weekly	Every 2 weeks
Radioactive		Gross alpha activity, Gross beta activity	Once every 5 years	-
Chemical	Heavy metals	Lead, Arsenic, Selenium, Chromium, Cyanide, Cadmium, Barium, Mercury, Silver, Aluminium, Uranium	Annually or when necessary	Annually or when necessary
	Affecting human health	Fluoride, Nitrate, ortho-phosphate	Weekly, frequency can be lowered if found stable	Monthly, frequency can be lowered if found stable
	Physical	Colour, Turbidity, Taste, Odour	Monthly	Seasonally

Table D 12
Water quality monitoring for groundwater

Group of parameters		Parameters	Sampling frequency at break tank exit or treatment plant exit	Sampling frequency at the distribution system
	Nutrients, Salinity and Hardness	pH, Total Hardness, Calcium, Magnesium, Sodium, Potassium Sulphate, Chloride, Electrical Conductivity	Monthly	Seasonally
	Less toxic metals	Iron, Manganese, Copper, Zinc	Monthly	Seasonally

D. 3.4.3 Compliance monitoring for surface water

The suggested water quality monitoring parameters for surface water, together with their respective sampling frequencies are given in Table D 13

Table D 13
Water quality monitoring for surface water

Group of parameters		Parameters	Sampling frequency at break tank exit or treatment plant exit	Sampling frequency at the distribution system
Microbiological		E.Coli, Fecal Coliform, Total coliform, Fecal Streptococci, Total heterotrophic bacteria	Weekly	Every 2 weeks
Chemical	Heavy metals	Lead, Arsenic, Selenium, Chromium, Cyanide, Cadmium, Barium, Mercury, Silver, nickel, Aluminium, Uranium	Annually or when necessary	Annually or when necessary
	Affecting human health	Fluoride, Nitrate, Ammonium, total sulfur and total Nitrogen, ortho-phosphate	Weekly, frequency can be lowered if found stable	Monthly, frequency can be lowered if found stable
	Organoleptic	Colour, Turbidity, Taste, Odour	Monthly	Seasonally
	Nutrients, Salinity and Hardness	pH, Total Hardness, Calcium, Magnesium, bicarbonate, TDS,	Monthly	Seasonally

Table D 13
Water quality monitoring for surface water

Group of parameters		Parameters	Sampling frequency at break tank exit or treatment plant exit	Sampling frequency at the distribution system
		Sulphate, Chloride, Electrical Conductivity		
	Less toxic metals	Iron, Manganese, Copper, Zinc	Monthly	Seasonally
	Organic pollution (Natural or artificial)	Organochlorinated Pesticides (OCP), Organophosphorus Pesticides (OPP), Volatile Organic Compounds, Phenols	Seasonally, in dry period monthly	Seasonally
	Other Toxicants	Detergents MBAs, Oil and Grease in water, Polynuclear Aromatic hydrocarbons, Polychlorinated Biphenyls, Total suspended solids	Seasonally	Seasonally

D.4. NATIONAL INITIATIVES

D. 4.1 INCENTIVE TOWARDS PUBLISHING THE 161:2016 LIBNOR WATER QUALITY STANDARDS

A review and update of the LIBNOR standards for drinking water, initially issued in 1999, was drafted in 2016, but has not yet been published. This second edition is based on the WHO guidelines (2011) and on the water quality committee expertise. The updates include the following:

- Parameters that should be tested are divided into categories: Physical and aesthetic, naturally occurring chemicals, chemicals from industrial and domestic origin, chemicals from agricultural practices, other pesticides for public health, chemicals used for water treatment, radioactive screening parameters and bacteriological parameters.
- The maximum admissible limits were reviewed and finetuned where necessary
- About 21 new parameters related to industrial and domestic pollution sources are added
- About 26 new parameters related to agricultural practices are added
- Chemicals related to water treatment other than free chlorine are added
- The Radioactive screening parameters that were missing are added in this version
- Some parameters are removed or replaced by more specific parameters. For example, Magnesium is replaced by Mg expressed as $MgCO_3$, Potassium is removed.
- Bacteriological parameters consist now of total coliforms, thermotolerant coliforms, intestinal enterococci and Pseudomonas Aeruginosa.
- The frequency of sampling is indicated for each group of parameters for example: The frequency of sampling is changed from monthly to annually or when necessary for naturally occurring, industrial and domestic chemical compounds except for the Total Organic Carbon (TOC) that should be tested monthly. The frequency of sampling for chemicals from agricultural practices varies between biannually and annually depending on the parameter. However, the tests should be performed when necessary also. The frequency of sampling for bacteriological parameters is changed depending on the type of resource (groundwater/surface water), weather it is protected or not, and on the quantity exploited per day, rather than taking into consideration the population size only. For all proposed sampling frequencies please refer to Annex 1.
- The sampling points are indicated for bacteriological samples.
- Annexes are given for more admissible limits of parameters that are not obligatory but informative.

See LIBNOR NL 161:2016 in *ANNEX III D* for more details.

The MoEW has the intention to publish and implement the new version of the standards, however, the 4 water establishments do not have the human resource capacity, the necessary equipment, nor the financial means to be able to apply them, which is delaying the application of the new standards. In fact, a USAID study, under the Lebanon Water Project, showed in 2018-2019 an overview of the laboratories' capabilities in each water establishment. The key findings for all water establishments were the lack of competency, human resources, equipment and financial resources. The USAID gave general and specific recommendations for each water establishment which include but not limited to:

1. General recommendations:
   - Include quality assurance and quality control measures in water sampling and water analysis procedures.
   - Design a detailed water monitoring plan for each water resource based on expected hazard and intended use of the water resources.
   - Write standard operating procedure for fieldwork and laboratory-based activities.
   - Maintain a documented system in place for overall equipment management
   - Establish a document control index system for internal and external activities
   - Install an automated software to consolidate all available data and information in the water resources systems (wells, springs, networks), subsystems and sampling points.
2. Specific recommendations:
   - Human resources and personnel training
   - Acquisition of necessary equipment, softwares and tools to increase the testing service in order to meet the requirements of LIBNOR 161:2016
   - Monitor the quality of water resources at least annually for organic chemical compounds
   - Subcontract tests with "lower monitoring frequency but requiring high level of expertise" to specialized laboratories while considering the cost.
   - Define a water sampling procedure
   - Define a water monitoring plan

It is also worth mentioning the water quality mapping exercise that was launched by the UNICEF beginning of 2019 and that was later integrated with the Water Safety Plan initiative. The purpose of this study is to collect water quality data on the existing resources and to perform water quality tests for water resources that lack water quality data in order to have a comprehensive knowledge on the current status of groundwater and surface water.

D. 4.2 WATER SAFETY PLAN IMPLEMENTATION

The implementation of the water safety plan described by the World Health Organization (Section D. 2.2) is being carried out by the MoEW with the cooperation of the different stakeholders. This initiative was launched in 2019 and it is an opportunity to work across the board with public, private and civil society. In fact, the involved participants are: Ministry of Energy and Water, Ministry of industry, Ministry of Environment, Ministry of Agriculture, Water establishments, Ministry of interior and municipalities/ Governors/ union of municipalities /municipalities, Landuse planning, Center for Development and Reconstruction, Ministry of Public health, Ministry of public works, Internal Security Forces (ISF), Litani river authority (LRA), LIBNOR (To issue the standard specifications), Academics, Water sector partners, Owners of the contamination sources/entities/persons generating hazards to the water source (gas stations, factories, slaughterhouses, healthcare institutions, wastewater, etc.), media, politicians in power. The major issues that should be taken care of with the collaboration of the different stakeholders are listed below:

- Source and resource protection
- Resource water quality/quantity monitoring
- Treatment and supply monitoring (including correction actions and contingency planning)
- Water quality/quantity at consumer's level
- Recording and updating of all data

It should be noted that workshops, organized by the MoEW, funded by the UNHCR, prepared and given by the IHE Delft University, are being done for the water establishments' staff in order to launch the process of developing a water safety plan (WSP). During the trainings the staff is having a hands-on experience in developing WSPs for pilot areas chosen for each water establishment. During the different steps of the WSP, gaps and constraints that limit the application of the WSP are identified. These constraints should be addressed by the different stakeholders in order to succeed in the development of WSPs for all water systems.

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SECTION E
Wastewater and Sludge management

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E.1 INTRODUCTION

Wastewater is essentially the water supply of the community after it has been used in a variety of applications and which now contains constituents that render it unsuitable for most uses without treatment. When untreated wastewater accumulates and is allowed to go septic, the decomposition of the organic matter it contains will lead to nuisance conditions, including the production of malodorous gases. Wastewater also contains nutrients, which can be stimulate the growth of aquatic plants, and may contain toxic compounds or compounds that potentially may be mutagenic or carcinogenic. For these reasons, the immediate and nuisance-free removal of wastewater from its sources of generation, followed by treatment, reuse, or dispersal into the environment, is necessary to protect public health and the environment. The constituents removed and/or produced in wastewater treatment plants include screenings, grit, scum, and sludge. Of the constituents removed by treatment, sludge is by far the largest in volume, and its processing, reuse, and disposition present perhaps the most complex problem in the field of wastewater treatment.

Huge quantities of treated wastewater and biosolids (sludge) are produced every day all over the world, which exert a strong pressure on the environment. An important question that is raised is “what to do with them?”. An effort is put by the scientific community to eliminate the concept of “waste” and to replace it with the concept of “recycling of resources”, by means of effective management, which does not concern only the users, but all the other groups involved in the problem, such as facility administrators, operations, politicians, scientific community and the general population.

In many countries, quality standards have been developed governing the discharge and/or reuse of wastewater and sludge. To date, Lebanon lacks legislation and/or standards related to:

- Soils and sediments standards;
- Guidelines for the disposal and reuse of sewage sludge; and
- Guidelines for effluent/wastewater reuse.

E.2 WASTEWATER REUSE

E.2.1 RELEVANT NATIONAL STANDARDS AND GUIDELINES

E.2.1.1 Wastewater Treatment and Discharge

The standards for discharge into receiving water bodies are presented in MoE Decision no. 8/1, which updates similar standards set by Decision 52/1.

The following presents relevant standards for wastewater discharge into receiving water bodies (also referred to as ELVs).

Table E 1
Maximum limits (ELVs) for wastewater discharge into receiving water bodies and public sewers

Parameter	Maximum allowable limits for receiving waterbodies		
	Public sewers	Surface water (inland)	Sea
Color	none	none	none
pH	6-9	6-9	6-9
Temperature	35ºC	30 ºC	35ºC
BOD (5 day, 20ºC)	125 mg/l	25 mg/l	25 mg/l
COD (dichromate)	500 mg/l	125 mg/l	125 mg/l
Total Phosphorus	10 mg/l	10 mg/l	10 mg/l
Total Nitrogen*	60 mg/l	30 mg/l	30 mg/l
Suspended solids	600 mg/l	60 mg/l	60 mg/l
AOX	5	5	5
Detergents	-	3 mg/l	3 mg/l
Coliform Bacteria 370 C in 100 ml**	-	2,000	2,000
Salmonellae	Absence	Absence	Absence
Hydrocarbons	20 mg/l	20 mg/l	20 mg/l
Phenol Index	5 mg/l	0.3 mg/l	0.3 mg/l
Oil and grease	50 mg/l	30 mg/l	30 mg/l
Total Organic Carbon (TOC)	750 mg/l	75 mg/l	75 mg/l
Ammonia (NH4+)	-	10 mg/l	10 mg/l
Silver (Ag)	0.1 mg/l	0.1mg/l	0.1 mg/l
Aluminum (Al)	10 mg/l	10 mg/l	10 mg/l
Arsenic (As)	0.1 mg/l	0.1 mg/l	0.1 mg/l

Table E 1
Maximum limits (ELVs) for wastewater discharge into receiving water bodies and public sewers

Parameter	Maximum allowable limits for receiving waterbodies		
	Public sewers	**Surface water (inland)**	**Sea**
Barium (Ba)	2 mg/l	2 mg/l	2 mg/l
Cadmium (Cd)	0.2 mg/l	0.2 mg/l	0.2 mg/l
Cobalt (Co)	1 mg/l	0.5 mg/l	0.5 mg/l
Chromium total (Cr)	2 mg/l	2 mg/l	2 mg/l
Hexavalent Chromium (Cr VI+)	0.2 mg/l	0.2 mg/l	0.2 mg/l
Copper total (Cu)	1 mg/l	0.5 mg/l	1.5 mg/l
Iron total (Fe)	5 mg/l	5 mg/l	5 mg/l
Mercury total (Hg)	0.05 mg/l	0.05 mg/l	0.05 mg/l
Manganese (Mn)	1 mg/l	1 mg/l	1 mg/l
Nickel total (Ni)	2 mg/l	0.5 mg/l	0.5 mg/l
Lead total (Pb)	1 mg/l	0.5 mg/l	0.5 mg/l
Antimony (Sb)	0.3mg/l	0.3mg/l	0.3mg/l
Tin total (Sn)	2 mg/l	2 mg/l	2 mg/l
Zinc total (Zn)	10 mg/l	5 mg/l	5 mg/l
Active (Cl2)	-	1 mg/l	1 mg/l
Cyanides (CN-)	1 mg/l	0.1mg/l	0.1mg/l
Fluorides (F)	15 mg/l	25 mg/l	25 mg/l
Nitrate (NO3-)	-	90 mg/l	90 mg/l
Phosphate (PO43-)	-	5 mg/l	5 mg/l
Sulphate (SO42-)	1,000 mg/l	1,000 mg/l	1,000 mg/l
Sulphide (S2-)	1 mg/l	1 mg/l	1 mg/l

*Sum of Kjeldahl-N (organic N + NH_3),NO_3-N, NO_2-N

**For discharges in close distance to bathing water, a stricter environmental limit value could be necessary

E.2.1.2 Wastewater Treatment and Reuse

In Lebanon, there is no legal basis for reuse of wastewater. There are no regulations, guidelines and standards for the reuse of treated wastewater for different purposes.

Two propositions for Lebanese Guidelines on Sewage Sludge Use in Agriculture and for Lebanese Wastewater Reuse Guidelines have been prepared by FAO in 2010. However, these have not been officially enforced yet (see *Annex III E.1*).

Suggested Activities and Work-Plans in Lebanon: International Water Management Institute (IWMI) – Rewater MENA Project

Safe wastewater reuse is very limited in Lebanon. Instead, farmers use polluted water from rivers and canals or even tap directly into sewage networks. The IWMI-ReWater Mena Project objective is the expansion of safe water reuse in MENA region. The project is taking place in three different countries: Lebanon, Jordan, and Egypt. The project is designed to contribute to achieve target SDG 6.3 and particularly to "substantially increase recycling and safe reuse" of wastewater in the selected countries.

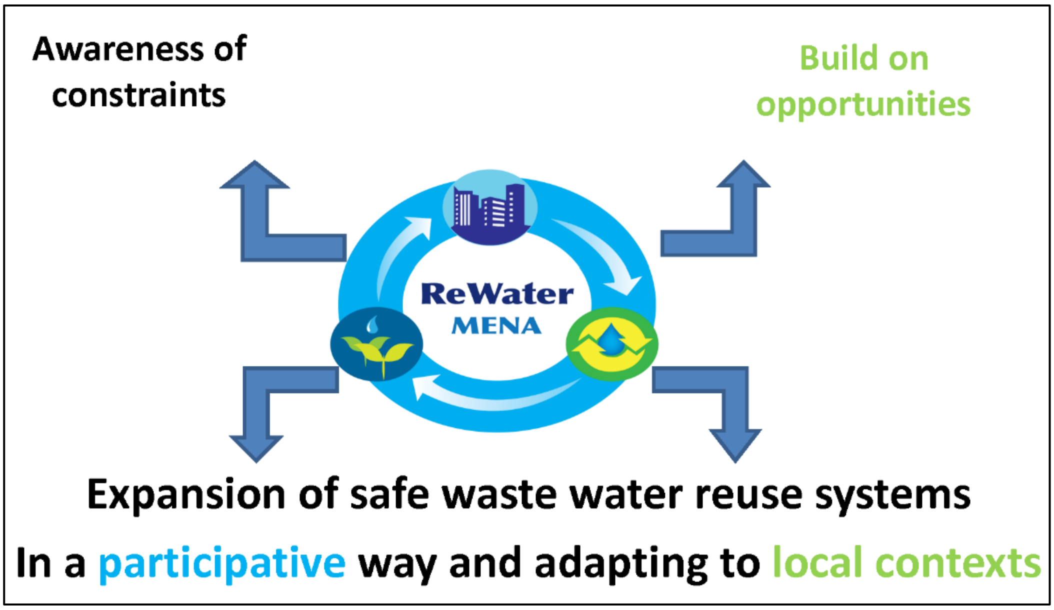

Figure E 1 Retwater MENA in Lebanon[1]

E.2.1.3 Existing WW Reuse Experiences in Lebanon

There is only one small reuse system, on Ablah WWTP (Bekaa), funded by ACCBAT: EU:

- Replaced irrigation from individual wells
- 20 ha of table grapes
- Beneficiaries: 37 farmers
- Better yield and safe use

[1] Source: IWMI Presentation NLA Lebanon Context and work Plans.

Figure E 2 Table grapes irrigated by reused wastewater from Ablah WWTP

E.2.1.4 Project Main Outputs

Output 1: National Baseline Assessment of Reuse Potential

- Help in identifying WWTPs to implement reuse systems (Where? Cost-benefits?)
- Help in better planning future WWTPs (location, design, outlet): where is reuse needed? For who?

Output 2: Update & validation of Reuse quality standards Through the support to LIBNOR committee

- Build on FAO proposed standards (and other reviews done with MoE)
- Compare to ISO norms (used by LIBNOR)
- Compare to other countries in MENA with similar socioeconomic characteristics.
- LARI experimental trials (on Ablah WWTP)
- Revision of parameters and implementing practices in close participation of all stakeholders including RWEs, Operators, Municipalities and Farmers.

Output 3: Development of two local reuse plans

- Select two WWTPs with potential and need for reuse in agriculture
- Preliminary analysis and engagement of local stakeholders
- Participatory selection of reuse models (distribution network, cost-recovery, management) (local workshops)
- Work on conceptual design and feasibility studies (infrastructure, technologies and on-farm practices)
- Implementation plan: governance and cost recovery mechanisms

E.2.2 RELEVANT INTERNATIONAL GUIDELINES AND STANDARDS

E.2.2.1 Standards for the quality of reused treated wastewater

Legally binding standards for water reuse have been developed by several Member States and some third countries and international organizations have also developed specific standards which they recommend. Most of the standards that have been developed at Member State level derive from the WHO and USEPA Guidelines 95,96. These standards usually focused on human health aspects and thus microbiological parameters. In order to ensure that water reuse is safe and compliant with EU legislation both environmental and health aspects have to be sufficiently considered in the development of standards. For Member States where legally binding standards have been adopted, it is obviously necessary to ensure they are complied with (just as it is important to comply with any other relevant national legal obligations, e.g. quality standards for irrigation waters, etc.).

Examples of standards and their use are set out in Table E 2 and Table E 3.

It is important that policy makers examine how standards that might apply in specific national, regional or river basin contexts accommodate different types of use of reused water and ensure that such standards are fit for purpose and do not jeopardize waterbody status. For uses such as reuse in industry, the required quality is determined by the particular industrial use and is, therefore, usually an internal matter for the industries concerned (while also ensuring the safety of the workforce).

Table E 2
Water reuse standards in selected EU Countries

Country	Standards reference	Issuing Institution
Cyprus	Law 106 (I) 2002 Water and Soil pollution control and associated regulations KDP 772/2003, KDP 269/2005	Ministry of Agriculture, Rural Development and Environment Department of Environment
France	JORF n°0201 du 31 août 2010 page 15828 texte n° 34 JORF num. 0153, 4th July 2014 Order of 2014, related to the use of water from treated urban wastewater for irrigation of crops and green areas.	Ministry of Public Health Ministry of Public Health Ministry of Agriculture, Food and Fisheries Ministry of Ecology, Energy and Sustainability
Greece	CMD N0 145116 Measures, limits and procedures for reuse of treated wastewater	Ministry of Environment Energy and Climate Change
Italy	DM 185.2003 Technical measures for reuse of wastewater	Ministry of Environment Ministry of Agriculture, Ministry of Public Health

Table E 2
Water reuse standards in selected EU Countries

Country	Standards reference	Issuing Institution
Portugal	NP 4434 2005 Reuse of reclaimed urban water for irrigation	Portuguese Institute for Quality
Spain	RD 1620/2007 The legal framework for the reuse of treated wastewater	Ministry of Agriculture, Food and Environment, Ministry of Health

Table E 3
Examples of standards developed by third countries and/or international organizations

Organization or country	Comment
World Health Organization (WHO)	Guidelines for the safe use of wastewater, excreta and greywater were first published by the WHO in 1973; a second version was issued in 1989 and a third version in 2006. A revision process of the WHO guidelines started in 2014, with the aim to publish a revised version of the series of technical documents, along with implementation-oriented documents. In addition, the WHO plans to develop specific water reuse guidelines for drinking water production purposes; these guidelines are expected to be published by 2019 and would include limit values for chemicals, while the existing guidelines mainly cover microbiological parameters.
International Standards Organization (ISO)	In 2015, ISO 16075 standards parts 1 to 3 were published on water reused for irrigation101. These documents cover both agricultural and landscape irrigation and provide guidance on planning, operation, water quality and good practices to avoid potential adverse impacts of water reuse on public health, crops, soil and water resources. The last part 4 with guidance on monitoring will be published soon. ISO standards for urban use, performance evaluation and health risks management are under development.
Australia	Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, Australian Health Ministers' Conference (2006). Australian guidelines for water recycling: managing health and environmental risks102.
United States	Guidelines for standards have been produced by the EPA (2012)103 and introduced in California (Title 22).

E.2.2.2 Wastewater Treatment and Reuse for Irrigation

The EU Council Directive 91/271/EEC

The EU Council Directive 91/271/EEC (Directive on Urban Wastewater Treatment) was adopted on 21 May 1991. Its objective is to protect the environment from the adverse effects of urban waste water discharges and discharges from certain industrial sectors. Table E 4 shows the requirements for effluent discharge into water bodies. Table E 5 specifies "*Maximum permitted number of samples which fail to conform*" in function of "*Series of samples taken in any year".*

Table E 4
Requirements for Discharges from Urban Waste Treatment Plants (Directive 91/271/EEC)

Parameters	Concentration	Minimum percentage of reduction (1)	Reference method of measurement
BOD5 (at 20° C) without nitrification (2)	25 mg/L O2	70-90 40 under Article 4(2)	Homogenized, unfiltered, undecanted sample. Determination of dissolved oxygen before and after five-day incubation at 20° C ± 1° C, in complete darkness. Addition of a nitrification inhibitor.
COD	125 mg/L O2	75	Homogenized, unfiltered, undecanted sample Potassium dichromate
TSS	35 mg/L (3) 35 under Article 4 (2) (more than 10000 PE)	90 (3) 90 under Article 4 (2) (more than 10000 PE)	Filtering of a representative sample through a 0.45 µm filter membrane. Drying at 105° C and weighing Centrifuging of a representative sample (for at least five mins with mean acceleration of 2800 to 3200 g), drying at 105° C and weighing

(1) Reduction in relation to the load of the influent
(2) The parameter can be replaced by another parameter: total organic carbon (TOC) or total oxygen demand (TOD) if a relationship can be established between BOD5 and the substitute parameter
(3) This requirement is optional

Table E 5
Maximum permitted number of samples which fail to conform

Series of samples taken in any year	Maximum permitted number of samples which fail to conform
4-7	1
8-16	2
17-28	3
29-40	4
41-53	5
54-67	6
68-81	7
82-95	8
96-110	9
111-125	10
126-140	11
141-155	12
156-171	13
172-187	14
188-203	15
204-219	16
220-235	17
236-251	18
252-268	19
269-284	20
285-300	21
301-317	22
318-334	23
335-350	24
351-365	25

The Directive provides no specifications for treated effluents reuse. Nevertheless, many European countries have adopted respective criteria for the reuse of the treated wastewater. These criteria for Greece and for the neighbouring Cyprus are presented in the following tables.

Table E 6
Effluent Standards for wastewater reuse in Greece

Types of Reuse	Water Quality	Treatment
Restricted use – Agricultural irrigation with restricted access of fodder, industrial crops, seed crops, sod farms, pasture land, non-fruit trees and areas with restricted public access (Sprinkler irrigation is not allowed) – Once through industrial cooling water – Restricted aquifer recharge	BOD5 and TSS in accordance with the EC Directive 91 /271/EEC – E.Coli: ≤ 200/100 ml (intermediate value)	Secondary and disinfection
Unrestricted use – Agricultural irrigation of all crops, such as fruit trees, vegetables, vineyards and crops intended to be eaten raw and irrigation in greenhouses (Sprinkler irrigation is allowed) – Recirculating industrial cooling water, industrial boilers and process water	– BOD5: ≤ 10 mg/L (80% of samples) – TSS ≤ 10 mg/L (80% of samples) – Turbidity: ≤ 2 (intermediate value) – E.Coli: ≤ 5/100 ml (80% of samples) and ≤ 50/100 ml (95% of samples)	Secondary, Tertiary (coagulation + filtration) and disinfection
Unrestricted Urban use – Irrigation of green urban areas with access to the public, such as playfields, parks, resort facilities (Sprinkler irrigation is not allowed) – Use for fire-fighting, roads cleaning and decorative fountains – Aquifer recharge with drilling wells	– BOD5: ≤ 10 mg/L (80% of samples) – TSS ≤ 2 mg/L (80% of samples) – Turbidity: ≤ 2 (intermediate value) – E. coli: ≤ 2/100 ml (80% of samples) and ≤ 20/100 ml (95% of samples)	Secondary, advanced treatment (UF membranes) and disinfection

Table E 7
Effluent Standards for wastewater reuse for irrigation in Cyprus

Crops to be irrigated	**BOD (mg/L)**	**SS (mg/L)**	**E. coli (per 100 mL)**	**Intestinal Nematodes eggs/L**	**Required treatment**
All crops [(a)]	10*	10*	5* 15**	None	Tertiary and disinfection
– Green areas with access to the public – Vegetables to be cooked	A 10* 15**	10* 15**	50* 100**	None	Tertiary and disinfection
– Green areas with limited access to the public – Crops and trees for human consumption	A 20* 30**	30* 45**	200* 1,000**	None	Secondary, disinfection and storage > 7 days or tertiary and disinfection
Fodder crops	A 20* 30**	30** 45**	1,000* 5,000**	None	Secondary, disinfection and storage > 7 days or tertiary and disinfection

Table E 7
Effluent Standards for wastewater reuse for irrigation in Cyprus

Crops to be irrigated	BOD (mg/L)	SS (mg/L)	E. coli (per 100 mL)	Intestinal Nematodes eggs/L	Required treatment
	B-	-	1,000* 5,000**	None	Stabilization ponds (Hydraulic Residence Time-HRT > 60 days)
Industrial crops (e.g. cotton etc.)	A 50* 70**	-	3,000* 10,000**	-	Secondary and disinfection
	B-	-	300* 10,000**	-	Stabilization ponds (HRT > 60 days)

A Treatment with E/M equipped systems (e.g. Activated Sludge, Attached Growth system etc.).
B Treatment in stabilization ponds with high HRT.
* for 80% of the samples.
** Maximum acceptable value.
(a) Excluding foliar vegetables, bulbs and nodules eaten raw.

Table E 8
Standards for metals in wastewater for reuse in Greece and Cyprus

Metal	Maximum allowed concentration (mg/L)	
	Greece	Cyprus
Al	5	5
As	0.1	0.1
B	2	0.75
Be	0.1	0.1
Cd	0.01	0.01
Co	0.05	0.05
Cr	0.1	0.1*
Cu	0.2	0.2
F	1	-
Fe	3	5
Hg	0.002	0.005
Li	2.5	2.5
Mn	0.2	0.2
Mo	0.01	0.01
Ni	0.2	0.2
Pb	0.1	5
Se	0.02	0.02
V	0.1	0.1
Zn	2	2

It should be noted that the above values that are applicable in Cyprus are the same as the ones suggested by FAO for agricultural reuse of the treated wastewater, with the exception of B (Boron) and Hg (mercury) as FAO has not introduced limit values for these parameters.

In addition to the above, Greece has also adopted the following specifications for irrigation of crops with wastewater, in regard to the agronomic characteristics of the crops and the soil:

Table E 9
Recommended agronomic characteristic of wastewater for reuse in agriculture irrigation in Greece

Potential irrigation problem		**Units**	**Degree of restriction on use**		
			None	**Slight to moderate**	**Severe**
Salinity					
Ecw[1]		dS/m	< 0.7	0.7 - 3.0	> 3.0
or					
TDS		mg/l	< 450	450 - 2000	> 2000
Infiltration					
SAR[2] = 0 - 3 and ECw			> 0.7	0.7 - 0.2	< 0.2
	3-6		> 1.2	1.2 - 0.3	< 0.3
	6-10		> 1.9	1.9 - 0.5	< 0.5
	10-20		> 2.9	2.9 - 1.3	< 1.3
	20-40		> 5.0	5.0 - 2.9	< 2.9
Specific ion toxicity					
Sodium (Na)					
	Surface irrigation	SAR	< 3	3 - 9	> 9
	Sprinkler irrigation	mg/L	≤ 70	> 70	
Chloride (Cl)					
	Surface irrigation	mg/L	< 140	140 - 350	> 350
	Sprinkler irrigation	mg/L	≤ 100	> 100	
Miscellaneous effects					
Nitrogen (NO3-N)[3]		mg/l	< 5	5-30	> 30
Bicarbonate (HCO3) only for sprinkler irrigation		mg/l	< 90	90 - 500	> 500
pH		Normal range 6.5 - 8.5			

The above standards adopted in Greece are also the same as the ones specified by FAO for reuse of wastewater in agricultures irrigation (some of the standards are expressed in different units by FAO).

US EPA Standards for Irrigation Reuse

A careful consideration is needed whenever the effluent is reused in agriculture. The treatment requirements must address the local agricultural practices, potential public exposure, and environmental impact.

US EPA guidelines for water reuse make this distinction and the corresponding specifications are described below.

Table E 10
US EPA Effluent Standards for irrigation reuse

Types of Reuse	Treatment	Water Quality
Agricultural irrigation with restricted access of fodder, fiber, seed crops, sod farms, pasture land, and areas with restricted public access	Secondary and chlorination or storage ponds with 25 days of detention time	BOD5 < 30 mg/L, TSS < 30 mg/L, and fecal coliforms < 200/100 mL
Agricultural irrigation of food crops commercially processed, and foods eaten raw and irrigation of orchards and vineyards	Surface Irrigation: Secondary and disinfection	BOD5 < 30 mg/L, TSS < 30 mg/L, and fecal coliforms < 23/100 mL
	Sprinkler Irrigation: Secondary, coagulation, filtration and disinfection	BOD5 < 10 mg/L, NTU < 2 and fecal coliforms < 2.2/100 mL

As it can be seen in the table above, the EPA standards are similar to the standards adopted in Greece for the restricted reuse and the unrestricted reuse for sprinkler irrigation of crops.

WHO Microbial Standards for Reuse in Agriculture

The US EPA standards do not include the required limits for the disease-causing nematode eggs, which are persistent. The WHO standards address these requirements as shown on Table E 11.

Table E 11
WHO Microbial Standards

Category	Re-Use Conditions	Exposed Group	Intestinal Nematodes (arithmetic mean of eggs per 100 mL)	Fecal Coliforms (geometric mean no. per 100 mL)	Wastewater treatment expected to achieve the required microbiological quantity
A	Irrigation of crops likely to be eaten uncooked, sports fields public parks	Workers, consumers, public	<1	<1,000	A series of stabilization ponds designed to achieve the microbiological quality indicated or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees	Workers	<1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal

Table E 11
WHO Microbial Standards

Category	Re-Use Conditions	Exposed Group	Intestinal Nematodes (arithmetic mean of eggs per 100 mL)	Fecal Coliforms (geometric mean no. per 100 mL)	Wastewater treatment expected to achieve the required microbiological quantity
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur.	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation

Furthermore, the third edition of the **WHO Guidelines for the safe use of wastewater, excreta and greywater** has been extensively updated to consider a new scientific evidence and modern approaches to risk management. The Guidelines are presented in four separate volumes: Volume 1: Policy and regulatory aspects; Volume 2: Wastewater use in agriculture; Volume 3: Wastewater and excreta use in aquaculture; and Volume 4: Excreta and greywater use in agriculture.
Volume 4 of the Guidelines describes the present state of knowledge regarding the impact of excreta and greywater use in agriculture on the health of product consumers, workers and their families and local communities. According to WHO, the health-based targets may be achieved through different treatment barriers or health protection measures. The barriers relate to verification monitoring, mainly in large-scale systems, as illustrated in Table E 12 for excreta and greywater.

Table E 12
Guideline values for verification monitoring in large-scale treatment systems of greywater, excreta and faecal sludge for use in agriculture

	Helminth eggs (number per gram total solids or per litre)	E. coli (number per 100 ml)
Treated faeces and faecal sludge	<1/g total solids	<1000/g total solids
Greywater for use in:		
Restricted irrigation	<1/liter	<105 [a] Relaxed to <10^6 when exposure is limited or regrowth is likely
Unrestricted irrigation of crops eaten raw	<1/liter	<10^3 Relaxed to <10^4 for high-growing leaf crops or drip irrigation

It should be noted that the WHO standards are developed with a goal to be implemented also by less advanced countries and localities, where technology and energy are not always readily available.

As already stated, FAO has recently (2010) released a proposition for Lebanese guidelines for wastewater reuse as well as for the use of sewage sludge in agriculture. However, these propositions still need to be reviewed and, most importantly, adopted by the Government of Lebanon (GoL).

Based on the considerations that high risks are associated with intestinal nematodes and bacteria rather than with viruses and taking into account particular conditions in Lebanon, values are proposed as a discussion basis for the establishment of guidelines for the reuse of wastewater. Guideline values are proposed for each parameter and for three different usage categories. Adequate levels of waste water treatment in order to meet the criteria for each use are also presented.

Similarly, the proposition for sewage sludge use guidelines presents treatment methods, proposes a classification of sludge according to its metal content and suggests usages and restriction levels on use for each defined class.

E.2.2.3 Wastewater Treatment and Reuse for Groundwater Recharge

Various sources of water are available for groundwater recharge but, in recent years, the use of nonconventional water resources such as recycled municipal wastewater, has received increasing attention. Using recycled municipal wastewater for artificial recharge of groundwater presents a wide spectrum of technical and health challenges. A major consideration is the possible presence of chemical and microbiological agents in the source water that could be hazardous to human health and to the environment. Concerns about hazardous agents in the water apply particularly to potable reuse. Although non-potable uses such as irrigation can result in human exposure to hazardous agents, there is less potential for exposure and the risks are therefore significantly lower (NRC, 1994).

Four water quality factors are significant in groundwater recharge with recycled water: human pathogens mineral content heavy metals trace organic compounds. Human pathogens and trace organic compounds are of particular concern when groundwater recharge involves aquifers supplying domestic water (Tsuchihashi, Asano & Sakaji, 2002).

Water Framework Directive 2000/60/EC (WFD) objectives for groundwaters relate to chemical status and quantitative status, which are required to meet good status and avoid deterioration in status. The reuse of treated wastewater for recharge of aquifers can contribute to WFD objectives, as long as the water is of sufficient quality.
Member States may reuse treated wastewater in aquifer recharge as a supplementary measure to contribute to WFD objectives for groundwater providing:

- Such recharge is subject to prior authorization.
- The quality of the reused water does not compromise the quality objectives for groundwaters specified by the WFD and GWD.
- Associated controls should be periodically reviewed and where necessary updated, e.g. so as to reflect progress in knowledge about pollutants and their impacts.

Groundwater Directive 2006/118/EC (GWD) establishes further provisions for the protection of groundwater against pollution, including more detailed criteria to assess the chemical status of groundwater bodies and identification of significant and sustained upward trends, along with specific measures to prevent or limit inputs of pollutants to groundwater.

Australia, in its **Water Quality Guidelines for Fresh and Marine Waters (NWQMS, 1992),** has accepted a differential protection policy. In these guidelines, the level of protection offered at sites where recycled water is injected will depend on the potential environmental values of ambient groundwater and, therefore, on its current water quality (Dillon et al., 2001).

Aquifer Recharge for indirect potable reuse

Apart from those in Australia (NWQMS, 1995), regulations concerning aquifer recharge do not rely on the capability of the aquifer to remove pollutants to meet the water quality required within the aquifer. In practice, the recharge water reaching the saturated zone of the aquifer should have previously acquired the quality acceptable for drinking-water. If the recharge is direct, then the injected water should be potable and should, as a minimum requirement, meet the standards enforced in the country or contained in the WHO Guidelines for Drinking-water Quality (WHO, 1996). Moreover, the injected water should be treated to prevent clogging around the injection wells, long-term health risks linked to mineral and organic trace elements, and the degradation of the aquifer. The capacity of the aquifer to remove pollutants provides an additional barrier protecting the abstracted water quality.

Setting requirements for indirect recharge is not an easy task. The quality of infiltrated water may be dramatically improved when percolating through the vadose zone, thanks to retention and oxidation processes.

Recharge for non-potable reuse

The quality of the water extracted from the aquifer should meet the most stringent standards related to the intended water use. In health-related standards applying to wastewater reuse, microorganisms are the main concern. For irrigation, limits can be set for other parameters such as organic matter and heavy metals. Trace organic elements are not likely to present a major harmful impact. As with potable aquifer recharge, relying on the saturated zone of aquifers to improve the recharged water quality is not recommended, even if there is no doubt that filtration effects exist. The saturated zone should only be considered as an additional barrier.

Indirect recharge requires a less treated injectant and is easier to implement. Soil aquifer treatment is an appropriate treatment to meet the required water quality, provided it is properly designed and managed.

E.2.2.4 Industrial Reuse

It is important to note that industrial water reuse is highly determined by the exact quality needs of the individual industrial process and/or product as well as the costs of producing water of the required quality compared to other suitable sources. Industrial water reuse schemes should take into account the overall ecological and economic benefit of different reuse options including those that do not focus on the water itself, but for instance the heat it carries, e.g. in district heating schemes.

Based on EPA – Guidelines for Water Reuse (2012), pulp and paper facilities, textile facilities, and other facilities using reclaimed water for cooling tower purposes, have been the primary industrial users of reclaimed water. Since the publication of the 2004 Guidelines for Water Reuse, the industrial use of reclaimed water has grown in a variety of industries ranging from electronics to food processing, as well as a broader adoption by the power-generation industry These industries have embraced the use of reclaimed water for purposes ranging from process water, boiler feed water, and cooling tower use to flushing toilets and site irrigation.

Cooling Towers

Because water is evaporated, dissolved solids and minerals remain in the recirculated water, and these solids must be removed or treated to prevent accumulation on equipment. Removal of these solids is accomplished by discharging a portion of the cooling water, referred to as blow-down water, which is usually treated by a chemical process and/or a filtration/ softening/clarification process before disposal to a local WWTP.

Boiler Water Makeup

The American Boiler Manufacturers Association (ABMA) maximum recommended concentration limits for water quality parameters for boiler operations is presented in Table E 13

Table E 13
EPA Recommended boiler water limits

Drum Operating Pressure (psig)	0-300	301-450	451-600	601-750	751-900	901-1000	1001-1500	1501-2000	OTSG
Steam									
TDS max (ppm)	0.2-1.0	0.2-1.0	0.2-1.0	0.1-0.5	0.1-0.5	0.1-0.5	0.1	0.1	0.05
Boiler Water									
TDS max (ppm)	700-3500	600-3000	500-2500	200-1000	150-750	125-625	100	50	0.05
Alkalinity max (ppm)	350	300	250	200	150	100	n/a	n/a	n/a
TSS Max (ppm)	15	10	8	3	2	1	1	n/a	n/a
Conductivity max (µmho/cm)	1100-5400	900-4600	800-3800	300-1500	200-1200	200-1000	150	80	0.15-0.25
Silica max (ppm SiO2)	150	90	40	30	20	8	2	1	0.02
Feed Water (Condensate and Makeup, After Deaerator)									

Table E 13
EPA Recommended boiler water limits

Drum Operating Pressure (psig)	0-300	301-450	451-600	601-750	751-900	901-1000	1001-1500	1501-2000	OTSG
Dissolved Oxygen (ppm O2)	0.007	0.007	0.007	0.00	0.007	0.007	0.007	0.007	n/a
Total Iron (ppm Fe)	0.1	0.05	0.03	0.025	0.02	0.02	0.01	0.01	0.01
Total Copper (ppm Cu)	0.05	0.025	0.02	0.02	0.015	0.01	0.01	0.01	0.002
Total Hardness (ppm CaCO3)	0.3	0.3	0.2	0.2	0.1	0.05	ND	ND	ND
pH @ 25º C	8.3-10.0	8.3-10.0	8.3-10.0	8.3-10.0	8.3-10.0	8.8-9.6	8.8-9.6	8.8-9.6	n/a
Nonvolatile TOC (ppm C)	1	1	0.5	0.5	0.5	0.2	0.2	0.2	ND
Oily Matter (ppm)	1	1	0.5	0.5	0.5	0.2	0.2	0.2	ND

Source: Boiler Water Quality Requirements and Associated Steam Quality for Industrial/Commercial and Institutional Boilers (American Boiler Manufacturers Association, 2005)

E.3 SLUDGE REUSE

E.3.1 RELEVANT NATIONAL STANDARDS AND GUIDELINES

In Lebanon, there are no regulations, guidelines and standards for the reuse of treated wastewater and sludge for different purposes. Two propositions for Lebanese Guidelines on Sewage Sludge Use in Agriculture and for Lebanese Wastewater Reuse Guidelines have been prepared by FAO in 2010. However, these have not been officially enforced yet (see *Annex III E.2*)).

E.3.1.1 Master Plan for sludge recovery or disposal – CDR 2003

In a 2003 CDR study[2] for the sludge disposal it was said that among the various sludge disposal and treatment options studied for different stations, the reuse of sludge in the agricultural areas is the preferred alternative. The reuse of sludge, as an organic and fertilizer, is clearly increasing in all industrialized countries and significant efforts are being made in these countries to constantly improve their standards and criteria of use, so that this mode of disposal remains safe and beneficial for society in general, for the environment and for agriculture. The analysed reuse and disposal alternatives are as follows:

- Sludge Reuse Alternative
  - Stabilization and reuse by spreading in agricultural areas (stabilized sludge);
  - Composting and reuse;
  - Co-composting with domestic solid waste and reuse;
  - Drying, granulation and reuse
- Sludge Non-Reuse Alternative
  - Incineration, and
  - Controlled disposal in domestic landfills.

In addition, the 2003 CDR study proposed the following action plan for the study disposal:

- Quantify the agricultural areas suitable for receiving the sewage sludge in each region and identify the origin of the sludge per station;
- Identify the sludge treatment systems required per station. Priority is given for sludge reuse;
- For each treatment plant, determine the quantities of sludge intended for reuse, and identify the agricultural areas that will receive these sludges;
- Determine the quantities of sludge, for each treatment plant, which are intended for drying or incineration;
- Evaluate the areas required for the sludge storage and propose their location taking into account the distances between the stations and the agricultural areas;

[2] Plan directeur de valorisation ou de disposition des boues d'épuration – Mai 2003 (Techswat - KREDO) - CDR

- Determine the costs of sludge disposal and reuse for each station, and estimate the predictable impacts on taxation;
- Compare the No action alternative (non-sludge reuse) to the sludge reuse alternative;
- Develop a legislative and administrative framework, as well as a list of the stakeholders' roles and responsibilities, all adapted to the Lebanese context, for the implementation of the sludge reuse practice;
- Propose the standards and criteria required for the implementation of the reuse practice.

E.3.2 RELEVANT INTERNATIONAL STANDARDS AND GUIDELINES

E.3.2.1 World Bank guidelines options for Sludge Disposal/Reuse

Sludge disposal in a sanitary landfill:

- Dumping together with municipal waste;
- Use of sludge as greening cover of closed sections of landfill;

Sludge reuse in agriculture:

- Use for products, which are not directly consumed (grain, maize, etc.);
- Use for fruit trees;
- Composting of sludge, and subsequent marketing of compost;

Sludge reuse in afforestation:

- For production of wood for construction, furniture, heating, etc.;

Sludge reuse for land application:

- In abandoned mining areas;
- For road embankments, etc.;

Sludge reuse as a replacement of raw materials:

- For production of clay-based bricks or other materials;

Thermal reuse of sludge through incineration.

E.3.2.2 Exemplary Developments

Europe

- No uniform trend across all countries, but some tendencies are apparent:
  - Landfilling will be gradually phased out, and it is mostly just the countries with low sludge production that currently still employ it on a larger scale.

- Reuse in agriculture is decreasing.
- Thermal reuse is increasing.

- Some features from Germany, the largest sludge producer, appear worth noting:
  - Total sludge volume has decreased by -17% from 2007 to 2017 due to focus on sludge minimization at WWTPs.
  - Sludge incineration has increased from 50% to 70% in same period.

India

- The legal signals in India are quite contradictive. The CPHEEO Manual (2013), which is strongly guiding the Indian sanitation sector, defines:
  - "Landfills are not usually recommended for disposal of STP sludge. In case they are adopted, the above points should be considered."
  - "The use of raw sludge as a soil filler directly on land for raising crops as a means of disposal is not desirable since it is fraught with health hazards."
  - Ministry of Environment, Forest and Climate Change, Notification: Solid waste Management Rules (2016) defines quality criteria for compost.
- "Recommendations and Guidelines" published mutually by 7 Indian Institutes of Technology (2010) only recommends thickening + dewatering, as well as generation of biogas in digesters, and composting.
- In practice, this background does not provide for clear guidance, and most sewage sludge is eventually disposed at sites of different quality standards.

Brazil

- Sludge disposal/reuse is not yet fully recognized as a major issue in Brazil;
- Sometimes sludge is also reused in agriculture, however mostly just in rural environments;
- Sludge incineration is not commonly employed;
- Sludge digestion is popular (both via anaerobic wastewater technologies, and in anaerobic sludge digesters), and biogas use for generation of electric energy has become a trend in recent years, receiving a particular push by strongly increased power unit cost since about 2015. (previously most of the biogas was simply flared.)

China

- Within recent years a major shift has taken place from improper dumping to sanitary landfill has become main way of disposal, and recently thermal reuse also gained increasing prominence.

E.3.2.3 Sludge Management and Disposal; The EU, US EPA and WHO Requirements

Across EU, guidelines and requirements for the management and reuse or disposal of sewage sludge are related directly or indirectly with a set of legislation, mainly including the following Directives:

- Directive 2008/98/EC, Waste Framework Directive;
- Directive 1999/31/EC on the Landfill of Waste;
- Directive 86/278/EEC on Sewage Sludge application on land;
- Directive 2009/28/EC on the promotion of the use of energy from Renewable Sources.

Directive 2008/98/EC is the Waste Framework Directive that sets the basic concepts and definitions related to waste management and lays down waste management principles, such as the "polluter pays principle" or the "waste management hierarchy". The latter refers to the hierarchy of waste management which is, from first to last priority, the following:

- Prevention of waste production;
- Preparation for waste reuse;
- Recycling of waste;
- Other recovery, e.g. energy recovery; and
- Disposal.

This legislation has quite a significant effect on sewage sludge management, since it promotes in principal the reuse of the sludge on land application in comparison with energy recovery and disposal in landfills.

Directive 1999/31/EC on the Landfill of Waste implements EU policy for waste management (CEC 1999) which aims to encourage the recovery of value from waste products and to reduce the disposal of biodegradable wastes to landfill. The main obligation under this legislation is to reduce the amount of biodegradable waste sent to landfills by 35% (of 1995 levels) by 2016. This implies that land filling is not considered a sustainable approach to sewage sludge management in the long-term.

Directive 86/278/EEC (Directive on Sewage Sludge) aims to regulate the use of sewage sludge in agriculture in such a way so as to prevent harmful effects to soil, vegetation, animals and man, thereby encouraging the correct use of sewage sludge in agriculture. The Directive lays down limits for concentrations of heavy metals in soil and sludge and for the maximum annual quantities of heavy metals which may be introduced into the soil.

Sludge disposal for land farming is subject to the following conditions:

- Sludge must be treated;
- Concentrations of heavy metals (cadmium, chromium, copper, mercury, nickel, lead and zinc) in soil to which sludge is applied should not exceed the limit values shown on Table E 14

- Concentrations of heavy metals in sludge should not exceed the limit values shown on Table E 15.
- The maximum annual quantities of heavy metals which may be introduced into soil intended for agriculture should be considered and should not exceed the limit values shown on Table E 16.

Table E 14
Limit values for concentration of heavy metals in soil

Elements	Limit values (mg/kg dm) *		
	5<pH<6	6< pH <7	pH ≥7
Cadmium (Cd)	0.5	1	1.5
Chromium (Cr)	30	60	100
Copper (Cu)	20	50	100
Mercury (Hg)	0.1	0.5	1
Nickel (Ni)	15	50	70
Lead (Pb)	70	70	100
Zinc (Zn)	60	150	200

Table E 15
Limit values for concentration of heavy metals in sludge for land application

Elements	Limit Values (mg/kg dm)	Limit Values (mg/kg p)
Cadmium (Cd)	10	250
Chromium (Cr)	1000	25,000
Copper (Cu)	1000	25,000
Mercury (Hg)	10	250
Nickel (Ni)	300	7,500
Lead (Pb)	750	18,500
Zinc (Zn)	2,500	62,500

Table E 16
Limit values for amounts of heavy metals which may be added annually to soil, based on a ten-year average

ELEMENTS	Limit Values (g/ha/year)
Cadmium (Cd)	30
Chromium (Cr)	3,000
Copper (Cu)	3,000
Mercury (Hg)	30
Nickel (Ni)	900
Lead (Pb)	2,250
Zinc (Zn)	7,500

If the above listed conditions cannot be met, the sludge must be disposed either on sanitary landfills or re-diverted to other facilities, e.g. for incineration or energy recovery.

Directive 2009/28/EC is recently adopted legislation on the promotion of the use of energy from Renewable Sources. It sets mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy and for the share of energy from renewable sources in transport. Overall, in 2020 there shall be at least a 20% share of energy from renewable sources in the EU Community's gross final energy consumption. Such targets are likely to create incentives for the use of renewable energy sources, such as the biogas from sewage sludge or its thermal power. Therefore, anaerobic treatment of the sewage sludge and exploitation of the produced biogas and/or thermal treatment of the sewage sludge is promoted through this directive.

US EPA standards require sludge treatment before reuse. To render the sludge safe for reuse in agriculture from a microbiological point of view, two standards are applicable for sludge depending on the types of crops receiving the sludge, exposure conditions, application frequency, etc:

1. Class A treated biosolids are biosolids, in which pathogens are reduced beyond current detectable limits. This type of solids would require Process to Further Reduce Pathogens (PFRP), so that the sludge is used without restrictions. The treatment of sludge in this instance would be very high and would involve methods such as; heat treatment, and active composting.

2. Class B treated biosolids. These are biosolids, in which pathogens are reduced to levels that are unlikely to present any threat to public health and the environment under strictly regulated use conditions. Class B can be applied without restrictions to food, fodder and fiber crops whose edible parts do not touch the biosolids surface (edible parts cannot be harvested before 30 days from the sludge application). It can also be applied to crops with edible parts touching the biosolids but there are restrictions as to the time between the application of the sludge and the harvesting of the edible parts (ranging from 14-38 months). Class B sludge cannot be sold in bags or applied for home use. This type of solids would require Process to Significantly Reduce Pathogens (PSRP), so that the sludge is used with certain restrictions. The treatment of sludge in this instance would comprise of stabilization by digestion, lime stabilization, and/or composting.

Further to the above, EPA standards have been developed for the metals content in the sludge and the loading rates per hectare of sludge application. These standards are presented in the following table:

Table E 17
Metals concentrations and loading rates for land application of biosolids by EPA

Pollutant	Ceiling concentration (mg/kd DS)	Pollutant concentration for exceptional quality (mg/kg DS)	Cumulative pollutant loading rate (kg/ha)	Annual pollutant loading rate (kg/ha)
As	75	41	41	2
Cd	85	39	39	1.9
Cu	4,300	1,500	1,500	75
Pb	840	300	300	15
Hg	57	17	17	0.85
Mo	75	-	-	-
Ni	420	420	420	21
Se	100	100	100	5
Zn	7,500	2,800	2,800	140

The EPA standards appear to be less restrictive in most cases as compared to the corresponding EU standards.

E.3.2.4 WHO Standards

To eliminate health associated risk when reusing treated sludge in agriculture, WHO microbial standards require that intestinal nematode eggs be less than 1 per 100 gms of dry weight of sludge, which can be achieved by storage of treated sewage sludge for a period of one year.

E.3.3 CONCLUSIONS AND RECOMMENDATIONS

The reuse of treated wastewater, or "reclaimed" water, for beneficial purposes such as drinking, irrigation, or industrial uses- is one option that has helped some communities significantly expand their water supplies. Still, the full value of treated wastewater has been recognized in only a few waters stressed Arab countries (Tunisia, Jordan, and the GCC countries). The use of treated wastewater should be regarded as a means of increasing water availability. Therefore, water reuse should be considered an integral component in every country’s national water strategic plan.

E.3.3.1 Recommendations

It is desired to bring attention to actions and research needs which are seen as priorities for overcoming the key constraints to wastewater treatment and reuse. The proposed recommendations have to take the following into consideration:

- Quality and quantity of fresh water sources need to be managed sustainably. In this perspective domestic water sources (aquifers, springs, wells, or surface-water) will be protected against contamination by wastewater, and conditions for water-based recreation (swimming, boating, and fishing) will be enhanced by improvements in water quality and control of marine disposal.

- To mitigate health and environmental risks, common norms and standards for the reuse of treated wastewater and sludge in Lebanon should be elaborated.
- Water conservation by reuse, aquifer recharge, or industrial reuse of treated effluent should be practiced where it is cost-effective and water resources are otherwise inadequate. Irrigation of agricultural lands by wastewater should be promoted provided water quality is monitored and health standards are maintained.
- Water and sludge demand management: Wastewater and sludge reuse should be oriented to demand driven planning by focusing on projects that are committed to reuse.
- Lebanon should develop a platform for disseminating knowledge gained from existing wastewater treatment facilities in the region. Knowledge sharing would lead to improved availability of information on the economic and financial benefits, the volumes of treated and reused wastewater, benefits to the water economy, and cost recovery of water reuse systems.
- A clear-cut sludge treatment technology and thereupon based disposal/reuse strategy should be considered an indispensable, integral part of any WWTP project.
- Investigate and analyse the existing potential for sludge reuse.
- Promote:
  - ✓ Measures to minimize sludge volume, such as anaerobic sludge digesters, and solar sludge drying.
  - ✓ Measures to generate and utilize biogas for power generation.
  - ✓ Regional co-operation in sludge management should be assisted, since economy of scale can help in bringing down sludge disposal/reuse cost.

E.4 MONITORING SYSTEM

E.4.1 GENERAL

The proper implementation of a comprehensive environmental management and monitoring plan will ensure that the proposed wastewater treatment plants meet regulatory and operational performance (technical) criteria. Environmental management/monitoring is essential for ensuring that identified impacts are maintained within the allowable levels, unanticipated impacts are mitigated at an early stage (before they become a problem), and the expected project benefits are realized. A good understanding of environmental priorities and policies, proper management of the plants (at the municipality and the Union levels), knowledge of regulatory requirements and keeping up-to-date operational information are basic to good environmental performance.

E.4.1.1 Monitoring Schemes

In order to successfully implement the Environmental and Monitoring Management Plans, two reference environmental monitoring activities should be considered. The monitoring activities have to be initiated for the proposed wastewater treatment plant to ensure the environmental soundness of the project. The first is compliance monitoring, and the second is impact detection monitoring. Compliance monitoring provides for the control of wastewater treatment operational activities, while impact detection monitoring relates to detecting the impact of the operation on the environment. Together, the objective is to improve the quality and availability of data on the effectiveness of operation, equipment, and design measures and eventually on the protection of the environment.

Compliance monitoring

Compliance monitoring during construction phase comprises on-site inspection of construction activities to ensure the actions described in the environmental management and monitoring plans and induced in the Scope of Work of the contractor are being implemented. This type of environmental monitoring is similar to the normal task of supervising engineer who verifies that the contractor is achieving minimal standards and quality of work. On the other hand, compliance to the regulations set by the authorities limiting air, water, and soil pollution also shall be verified and observed. If required, an environmental specialist could be called on a part-time basis to inspect certain environmental mitigation measures on-site. Compliance monitoring requirements mainly include process control testing, process performance testing, and occupational health monitoring. Compliance monitoring shall be the responsibility of the corresponding project administration.

For effective compliance monitoring, the following shall be assured:

- Trained staff (plant operator, laboratory staff, maintenance team, etc.) and defined responsibilities.
- Adequate analytical facility(ies), equipment, and materials.
- Authorized Standard Operating Protocols (SOPs) for representative sampling, laboratory analysis, and data analysis.
- Maintenance and calibration of monitoring equipment.

- Provision of safe storage and retention of records.

Performance Monitoring for Treated Wastewater Discharged into Surface Waters in Lebanon

As for process performance monitoring of discharged treated wastewater, the list of recommended parameters is exhaustive; however, abidance is highly recommended especially during the first months of plant operation. Once a preliminary database is built, less frequent analysis can be performed, especially for the relatively invariable parameters. The plant operator may adjust the schedule of sampling in accordance to the operational characteristics of the system, and previous monitoring experience; however, utmost responsibility should be taken for uninterrupted compliance. Table E 18 presents the recommended process performance parameters suggested in a draft law by the Lebanese Ministry of Environment (MoE).

Table E 18
Process performance parameters recommended in a draft law set by the Lebanese Ministry of Environment

Sampling Location	Analytical Parameter	Sampling Frequency
Plant influent	Flow	Daily
	pH	Daily
Primary treatment Effluent	pH	Daily
	Total Suspended Solids	Weekly
	Volatile Suspended Solids	Weekly
	Temperature	Daily
Secondary Treatment Effluent	BOD5	Daily
	pH	Daily
	Total Suspended Solids	Once in 2Weeks (1/2 week)
	Volatile Suspended Solids	Once in 2Weeks (1/2 week)
	Temperature	Daily
	Total Nitrogen	Once in 2Weeks (1/2 week)
	Total Phosphorus	Once in 2Weeks (1/2 week)
Tertiary Treatment Effluent / final effluent	BOD5	Daily
	pH	Daily
	Total Suspended Solids	Once in 2Weeks (1/2 week)
	Volatile Suspended Solids	Once in 2Weeks (1/2 week)
	Temperature	Daily
	Total Nitrogen	Once in 2Weeks (1/2 week)

Table E 18
Process performance parameters recommended in a draft law set by the Lebanese Ministry of Environment

Sampling Location	Analytical Parameter	Sampling Frequency
	Total Phosphorus	Once in 2Weeks (1/2 week)
	Residual Chlorine	Daily

Performance Monitoring for Treated Wastewater Agricultural Reuse in Lebanon

Based on the proposition for Lebanese wastewater reuse guidelines (FAO 2010), the standard protocols for sampling and analysis are presented below:

1. Sampling protocol:

   The information referring to the conduction of sampling must be recorded in an appropriate protocol. This protocol presents the following information:

   - When the sampling takes place
   - Where the sampling takes place (inlet and outlet of wastewater treatment unit, sewerage network, etc.)
   - Type of sample collected (grab and/or composite sample)
   - Volume of wastewater collected
   - Reference number (code) of the sample
   - Name and status of the persons carrying out the sampling.

The frequency of sampling at the wastewater treatment units is set, taking into consideration the following issues:

- The requirements of the European legislation (e.g. Directive 91/271/EEC)
- The necessity of achieving treated effluent with such a quality that ensures its safe reuse for irrigation purposes.

The proposed frequency of sampling is given in the table below:

Table E 19
Suggested frequency of sampling

PARAMETER	NUMBER OF SAMPLES
BOD5 Suspended solids Total Phosphorous Total Nitrogen	For wastewater treatment plants with capacity 2000 – 9999 p.e. 12/year (1/month) For wastewater treatment plants with capacity 10000 – 49999 p.e. 12/year (1/month) For wastewater treatment plants with capacity > 50000 p.e. 24/year (2/month)

Inlet flow (m^3/s) Outlet flow (m^3/s)	Daily
Al, As, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, Mn, Mo, Ni, Se, Va, Zn, Hg	1/year (in the cases that the results show high concentration value, a second measurement is suggested within the year)
pH, temperature, color, TDS, nitrates, phosphates, conductivity	1/month
Na, Ca, Mg, K, sulphates, chlorides, B	2/year
E. coli/100 mL Feacal coli/100 mL Helminth eggs/l	24/year (wastewater treatment plants with p.e. > 50.0000) 24/year (wastewater treatment plants with p.e. > 50.0000)

E.4.2 MONITORING PROCESSED SLUDGE CHARACTERISTICS

Based on the proposition for Lebanese guidelines on sewage sludge use in agriculture (FAO 2010), the following parameters should be analysed on every sample of sludge:

- pH (water)
- dry matter
- organic matters

- total N
- NH4-N
- P2O5
- K2O
- MgO
- Heavy metals: cadmium, copper, nickel, lead, zinc, mercury, chromium

- Faecal coliform
- Salmonella
- Ascaris ova

Sludge analysis must be done on a regular basis, to the minimum frequencies shown in Table E 20

Table E 20
Frequency of sludge analysis

Nominal WWTP capacity (PE)	Minimum nbr of analysis per year	Time between 2 consecutives analysis Min	Max
Capacity < 5.000 PE	1	6 months	1 year
5.000 < capacity < 10.000 PE	2	4 months	6 months
10.000 < capacity < 50.000 PE	3	3 months	4 months
50.000 < capacity < 100.000 PE	6	1 month	2 months
Capacity > 100.000 PE	12	15 days	1 month

SECTION F
Strategic Environmental and Social Assessment

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F.1. Introduction

Water is at the centre of economic and social development, it is vital to basic human needs, manage the environment, and sustain economic growth. There are many ways in which water can be collected. The main sources are:

- Surface area: this is water which falls to the ground as rain or hail.
- Rivers or lakes: town or community water supplies are sometimes drawn directly from nearby rivers or lakes.
- Springs: these are found where underground water flows out of the ground naturally without the use of bores, wells, or pumps.
- Excavated dams: these are made by scooping out soil to make a large shallow hole.
- Bores and wells: these are holes drilled into the ground deep enough to find a permanent body of water. A pipe runs down the water and a pump are used to get the water up to ground level. The water is then pumped to the community.

For decades, the Lebanese have grappled with how to improve the way in which natural water resources are managed and sustainability of water resources for human use is assured. Debates abound on the role of the private sector in water and sanitation, number of dams needed, relevance of agriculture and food security, cost effectiveness of infrastructure, public acceptance of water meters, and perhaps most critically, what to do first. History has also proven that these debates can be particularly productive, especially when informed by different opinions and voices. The Qaroun Dam and associated hydroelectric infrastructure, the many water laws dealing with complex issues of inter-basin transfers, private sector participation and corporatization of public water companies, and more recently the development of the National Water Sector Strategy, developed over several years and approved by the Parliament in March 2012, are a few examples of successful Lebanese projects that benefited from intense national debate. On the other hand, there is a growing concern that dam projects cause irreversible environment change, which are often complex, multiple, and essentially negative. Artificial lakes profoundly alter the natural functioning of the entire ecosystem associated with them, ranging from altering flow regimes, changing water temperature and chemistry, modifying algal and macroinvertebrate communities, disrupting resident and migratory fish communities, altering channel geomorphology and sediment transport, and impacting the abundance and diversity of physical habitats.

Then again, the high-water demand in the agriculture sector is exacerbating the water scarcity situation. In the next 35 to 45 years world food production will need to double to meet the demands of increased population. Seventy percent of this increased food production will have to come from irrigated lands. Despite the high-water scarcity, treated sewage and sludge effluents are not utilized to its full potential in the agriculture sector due to incomplete infrastructure, challenges in overcoming perception, and limited regulatory oversight and pricing incentives.

Wastewater is essentially the water supply of the community after it has been used in a variety of applications and which now contains constituents that render it unsuitable for most uses without treatment. Due to the absence of institutional control of public authorities during war period (1975-1990), domestic wastewater in Lebanon was discharged directly into the sea with no treatment prior to disposal. Environmental impacts associated with open sea disposal of untreated wastewater had gained international and local concerns in recent years, particularly with the ever-continuing increase of the population and the enlargement of coastal cities. In the post-war period, several actions have been undertaken by the Government to find out immediate short-run corrective solutions and long-run planning strategies for the whole country. The need for rehabilitating the already existing wastewater collection and disposal systems, and the construction of new treatment facilities are the Government major concerns.

Water and sanitation services incur a high cost to the Lebanese Government. The Ministry of Energy and Water developed a unified framework for the Lebanese water sector that includes a comprehensive water strategy and integrates directions, policies, regulations, and practices in the water sector at the national level. The Lebanese National Water Sector Strategy (NWSS) update aims to work towards addressing all the key challenges, leveraging previous and on-going studies, and reform the water and wastewater sector to ensure sustainable development on Lebanon's water resources while providing affordable high-quality services. The principle measure of sustainable development is that all activities which are carried out to achieve development must take into account the needs of environmental conservation. The sustainability of the ecosystem requires the balance between human settlement development and the natural ecosystem, which is a symbiotic relationship. This can be achieved through careful planning and the establishment of appropriate management systems. In modern times, the need to plan activities has become an essential component of the development process. Consequently, a number of planning mechanisms have been put in place to ensure that minimum damage is caused to the environment. Environmental planning is also integrated with other planning processes such as physical planning, economic planning, and development planning. In fact, the Lebanese administration has been for long time attempting to face environmental issues. Laws that invoke some components of the environment go back to as early as the time of the French mandate when Law No. 144 dated 10 June, 1925 related to public ownership and water rights was issued. Thereafter, Law decree number 21 stipulated in article 3 that Class 1 industrial plants must be located at a certain distance from residential areas. This was followed by Law decree number 1119, which is more rigorous with regards to the issuing of construction permits to industrial facilities. Protection against pollution was then addressed by Decree No. 8735 of October 1974 that prohibited the digging of wells for the disposal of raw sewage, banned infiltration from cesspits, and the use of sewage for the irrigation of vegetables and some fruits. Furthermore, law No. 444 dated June 2002 was developed for protection of the environment. Based on the stipulations of this law, and particularly article 23, the Ministry of Environment (MoE) has prepared a decree 8213/2012 for the Strategic Environmental Assessment (SEA) to define the requirements of projects concerning environmental impacts. Strategic Environmental Assessment (SEA) is considered part of environmental planning. SEAs are undertaken for proposed activities that are likely to have significant adverse impact on the environment and are subject to a decision of a competent national authority.

Consequently, a Strategic Environmental Assessment (SEA) shall be developed for the draft National Water Sector Strategy (NWSS) update and submitted to the Ministry of Environment (MoE) for approval. The SEA shall be used as a decision-making tool for issuing the final NWSS update and shall facilitate the preparation of the Environmental Impact Assessments (EIAs) for specific components by providing an important amount of information to the EIA preparer, especially with respect to baseline conditions, environmental impacts, possible mitigation and monitoring measures.

The planned SEA will build on the 2015 SEA which had identified the following 12 Key Issues from a much longer list of environmental, social, and economic issues (refer to Table 1-1). Many issues were deselected during scoping because it was determined that they did not carry national and/or strategic importance and therefore should be addressed in project-specific EIA studies.

Table F 1 Potential Environmental and Social Impacts

SEA Key Issues	Water		Wastewater
	Production	Distribution	
Climate change adaptation	✓		
Effects on Ecology and Ecosystems	✓		✓
Effects on Marine Environment and Coastal Waters	✓		✓
Effects on Underground Water and Karst	✓	✓	✓
Water-Energy Nexus	✓	✓	
Man-Made Water Bodies and Buffers	✓		
Catastrophic Failure and Emergency Planning	✓		✓
Water-Poverty Nexus		✓	
Treated Sewage Effluent and Sludge Reuse			✓
Construction and Excavation Waste	✓	✓	✓
Operation and Maintenance	✓	✓	✓
Transboundary Waters	✓		

In addition, priority recommendations were integrated in the SEA 2015 as summarized below:

1. <u>Mid-term appraisal of the NWSS.</u>

   There is a strong case for a "mid-term appraisal" of the NWSS through which lessons from experience so far could be learned, targets and methodologies could be re-assessed, and SEA safeguards could be implemented. MEW can now refer to actual experience to see, in part, where NWSS worked, was too ambitious, or was derailed by unforeseen events (budget overruns, Syrian refugee crisis, and 50-year drought occurrence). For example, if the levels of investment predicted by NWSS are shown to be far in excess of anything yet achieved, these must be revised or MEW must explain what new mechanisms are in place to transform their performance.

2. <u>Iterative process for NWSS revisions.</u>

   Based on this mid-term appraisal, the MEW should review the NWSS and its strategic roadmap (2010-2020) and consider scaling-back its dams' program in light of social, economic, and environmental constraints. NWSS revisions must be realistic and implementable in a resource-constrained environment.

3. Implementation Unit for oversight and monitoring.

   There is an urgent need to clearly assign responsibility for oversight and monitoring of the NWSS in one office (Implementation Unit) at the MEW which annually reports to the Council of Ministers. This office will need resources to discharge its mandate; there may be strong donor interest for capacity building in monitoring systems and information management.

4. National Water Dialogue.

   Since the MEW does not have direct power to require ministries and bodies outside its jurisdiction to undertake any action related to the NWSS, it has to rely on dialogue. The proposed National Water Council would be able to address actions that require broad cross-sectoral co-operation including data sharing, catchment protection, climate change adaptation, and Water Demand Management.

5. Regulations, Guidance, and Standards.

   This SEA Report has identified several areas where guidance and/or regulations are urgently needed to complement the NWSS interventions and protect natural resources. The following guidance and regulations are needed:

   - Classification system for dams (small and large, based on World Bank's OP 4.37), which will guide the need for Emergency Action Planning.
   - Guidance notes for the construction and O&M of water projects (production, conveyance, and wastewater).
   - Guidance note on man-made water bodies specifying land use activities, buffer zones, erosion control-measures, and ecological restoration measures.
   - Guidance notes on Treated Sewage Effluent discharge into water courses to avoid pollution of the receiving waters.

The updated SEA will proceed with an analysis of alternatives proposed in the draft updated NWSS and all water and environment related developments since 2015 **(Examples of such developments are found in Volume IV: Proposed Projects)**. The planned SEA will be done following a consultative approach that will include both the private and the public sectors, as well as academia, civil society, international bodies, etc.

The tentative schedule of the planned SEA is as follows:

Table F 2 Planned SEA Tentative Schedule

Task	Time (weeks) *										
	1	2	3	4	5	6	7	8	9	10	11
Draft Scoping Report	x	x	x								
Final Scoping Report				x							
Draft SEA report (including the public consultation)					x	x	x	x	x	x	
Final SEA repot											x

*Excluding the time needed by the MoE to review each submittal

F.2. SEA methodology

Strategic Environmental Assessment (SEA) refers to a family of analytical and participatory approaches that aim to integrate environmental considerations into policies, plans and programs and evaluate the inter linkages with economic and social considerations (OECD 2006). It is increasingly used to facilitate integration of environmental considerations, along with social and economic aspects, into strategic decision making at all stages. SEA was initially promoted as an extension of EIA principles and practice to policies, plans and programs (UNECE, 1992). This approach is widely applied and is evident for example in the requirements of the European SEA directive (2001/42/EC). At the same time, other applications of the SEA process require more flexible approaches that do not conform, procedurally or methodologically, with traditional EIA practice. The key differences between SEA and traditional project-level environmental impact assessments (EIA) are described in the Table 2-1 below.

Table F 3 Comparison between SEA and EIA
(source : OECD 2006)

EIA	SEA
Applied to specific and relatively short-term (life-cycle) projects and their specifications.	Applied to policies, plans and programs with a broad and long-term strategic perspective.
Takes place at early stage of project planning once parameters are set.	Ideally, takes place at an early stage in strategic planning.
Considers limited range of project alternatives.	Considers a broad range of alternative scenarios.
Usually prepared and/or funded by the project proponents.	Conducted independently of any specific project proponent.
Focus on obtaining project permission, and rarely with feedback to policy, plan or program consideration.	Focus on decision on policy, plan and program implications for future lower-level decisions.
Well-defined, linear process with clear beginning and end (e.g. from feasibility to project approval).	Multi-stage, iterative process with feedback loops.
Preparation of an EIA document with prescribed format and contents is usually mandatory. This document provides a baseline reference for monitoring.	May not be formally documented.
Emphasis on mitigating environmental and social impacts of a specific project, but with identification of some project opportunities, off-sets, etc.	Emphasis on meeting balanced environmental, social and economic objectives in policies, plans and programs. Includes identifying macro-level development outcomes.
Limited review of cumulative impact, often confined to phases of a specific project. Does not cover regional-scale developments or multiple projects.	Inherently incorporates consideration of cumulative impacts.

This section provides an introduction to SEA and the benefits it brings to the control of project-level environmental impacts. It continues by outlining the requirements of SEA in Lebanon.

F.2.1 SEA LEGAL STEPS

The legal text defines the scope of the SEA, the different phases, review procedures, screening methodology, validity of the PPP (Policy, Plan, Program), and the content of the scoping and final reports. Table 2-2 presents the various stages of a SEA along with the requirements of each stage.

Table F 4 SEA Process Components
(Adapted from the Strategic Environmental Assessment and Land Use Planning in Lebanon Training Manual, MoE, UNDP, 2005.)

SEA Stage	Description
Screening	• To determine whether the proposed strategic action (plan or program) requires SEA
Scoping	• To delineate the zone of influence of the proposed plan or program (geographical coverage, time span, sector of activity and social groups) • To establish the range of issues and level of detail to be included in the assessment • To decide on the significant impacts to be considered • To determine data collection requirements
Stakeholder involvement	• To inform and ascertain the opinion of all those who are likely to be affected by the proposed plan or program • To determine what tradeoffs are acceptable • To identify implementation needs and mechanisms
Analysis of Alternatives	• To identify, analyze, and compare the impacts of the different shortlisted alternative options • To evaluate the technical and financial feasibility of alternative options • To determine the consistency of the components with pre-set objectives and priorities • To evaluate the compatibility with current legal, institutional, and planning frameworks. • To determine the “most suitable strategic option” and means of implementation
Performing the assessment	• To identify, analyze, and compare the impacts of the most suitable strategic option selected • To propose a relevant Environmental Management Plan (EMP) for reducing or eliminating negative impacts and enhancing environmental opportunities
Submission of SEA report	• To document the methodology and findings of the SEA

Table F 4 SEA Process Components
(Adapted from the Strategic Environmental Assessment and Land Use Planning in Lebanon Training Manual, MoE, UNDP, 2005.)

SEA Stage	Description
Peer review and integration of SEA findings	• To ensure that the assessment has proceeded in a scientific and objective manner • To verify that all significant impacts have been considered • To determine whether the "most suitable strategic option" has been proposed • To determine the feasibility and suitability of the EMP • To review, amend or reformulate the proposed plan or program
Decision making	• To decide whether to adopt, amend or reject the proposed plan or program
Monitoring and quality assurance	• To evaluate performance with respect to set objectives • To monitor implementation and assess the continued suitability of the EMP • To assess the efficiency of the SEA process in "greening" public decisions

F.2.2 SEA SCOPE

The SEA report shall be prepared for all alternatives with particular emphasis on the selected alternative(s).

The SEA report shall include the following:

- Assessment of baseline data on the physical, hydrogeological, environmental, and socio-economic conditions of the project area,
- Identification of environmentally significant areas in the project sites,
- Assessment of the best alternative(s) or option(s) for the project in terms of socio-economic, health, financial, and environmental aspects,
- Identification of potential impacts of the project and assessment of their significance,
- Description of mitigation measures to minimize impacts, and
- Elaboration of an environmental management plan including a monitoring program for the whole project.

The SEA process chronologically follows the four main phases detailed in figure 2-1: Inception, Scoping, Analysis of Alternatives, and SEA report. Another main phase of the SEA process is Stakeholders Consultation, conducted in parallel to these four steps.

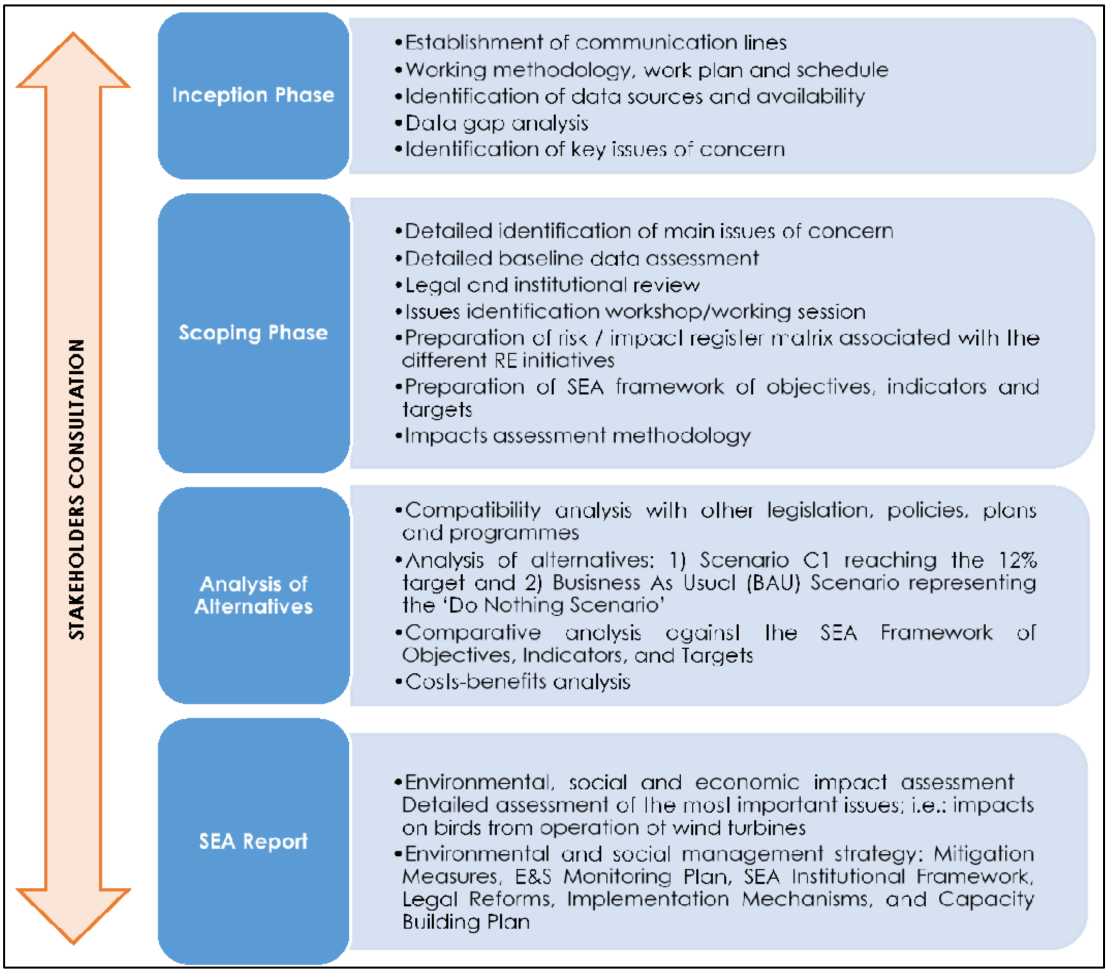

Figure F 1 SEA Methodology

F.3. SEA for the national water sector strategy update

The Ministry of Energy and Water prepared and adopted the Lebanese National Water Sector Strategy (NWWSS) in 2010 which, in turn, was endorsed by the Government of Lebanon in 2012 (Resolution No.2, Date 09/03/2012).

Since then, the Ministry has been implementing plans and projects identified in the strategy and, in parallel, the Council for Development and Reconstruction (CDR) and the Water Establishments have prepared regional water resources allocation plans, and national and regional groundwater resources studies for the catchment, treatment and distribution of water to all areas of Lebanon. In addition, regional plans for the collection and treatment of wastewater were prepared.

Seven years through, it has become time to review what has been realized from the original roadmap and update the Water & Wastewater strategies of 2012 by revisiting the water allocation and supply plans, wastewater collection and treatment plans, water storage / dams master plans, and irrigation plans. The updated strategy will maintain the main strategic principles of the water policies adopted by the Government of Lebanon in 2012, but will reassess the set priorities in the light of today's actual context (see Volume IV: Proposed Projects).

A strategic Environmental Assessment (SEA) report shall be prepared for the draft updated NWSS. The SEA report shall comply with the Decree 8213/2012 requirements and its Annex 3 regarding the information to be included in the SEA report.

F.3.1 ASSESSMENT OF POTENTIAL IMPACTS

F.3.1.1 Water Sector

The operation and existence of dams can have significant effects on floodplains above and below the structures themselves (Federal Emergency Management Agency, 2011). Most dams have minimal impact. However, changes in land use downstream can result in an increase in risk due to the presence of additional structures and people. Historically, dam safety programs have primarily been helping to ensure that dams do not fail. Their focus has been on inspections, operation and maintenance, rehabilitation, repairs, construction and training of owners rather than on impacts on adjacent floodplains. More recently there has been significant attention given to the preparation of Emergency Action Plans, with over 69% of high-hazard-potential dams now having plans.

Hydrologic conditions in the watershed where a dam is located often change, impacting the channel and floodplain downstream of the dam. Changing conditions can result in hazard creep, downstream physical changes that impact life, safety, property, and significant environmental impacts. With climate change there is also a potential for increased frequency of severe rainfall cycles and increased severity of rainfall events that may impact dam safety and floodplain management. Dam owners and public agencies need to take these changing conditions into consideration when following and updating the operating rules for their flood protection dams.

Dams have a significant environmental impact on the functions of rivers and their floodplains. At minimum, dams block a river's flow and can harm clean water, fish and wildlife, and recreational opportunities (American Rivers, 2012). The impacts range from disruption of ordinary riverine processes such as sedimentation, channel changes and evolution, floodplain and coastal delta morphology, and water quantity, temperature and flow, to impacts on river ecosystems and riparian habitat and vegetation. The impacts dams can have on natural sediment transport processes in rivers is substantial. Sediment transport in the river is blocked by the dam so that sediment builds up within the reservoir behind the dam while creating sediment?starved conditions below it that lead to channel bed degradation, channel narrowing and bank erosion. This disruption of sediment processes often disconnects a river from its natural floodplain downstream and submerges riverine floodplains upstream of a dam. These impacts are compounded when there are multiple dams along a river. The decrease in sediment supply downstream means that natural processes like deposition of sediment on floodplains and the creation of deltas and coastal beaches are all negatively impacted by dams. In some cases, this leads to river systems that are no longer naturally self?sustaining (ASFPM Working Group on Dams, 2008). Dams disrupt not only sediment processes but critical debris and nutrient processes as well. Dams prevent these building blocks of riverine habitat from reaching downstream locations, while upstream riverine habitat is submerged by the reservoir itself.

F.3.1.2 Wastewater Sector

Environmental conditions arising from inadequate or non-existing wastewater management pose significant threats to human health, well-being and economic activity.

There are effectively two basic wastewater management systems: on-site (or non-sewered) and off-site (generally sewered with centralized treatment). In sewered systems the removal/transport part of the service chain is performed by the sewer; water washes the waste through a pipe system. This may require the use of pumping stations to ensure that the waste reaches the treatment or disposal point. In on-site systems, waste accumulates on-site in a pit or septic tank, which requires periodic emptying or re-siting; in the case of emptying, waste is taken by road for treatment and/or disposal. Dumping of untreated septic tank/pit contents into rivers, lakes and the sea is, in many low- and middle-in- come countries, a regular practice.

Based on the experiences of industrialized countries, the sewerage systems of a number of developing world cities were designed and built on the separate principle. However, in many cases the separate systems have not been well operated and the control of connections is virtually non-existent, or the system may have been overwhelmed by population growth and the expansion of impermeable surfaces associated with urbanization. So-called separate systems may have many illegal connections of foul sewage made to the surface water system and not to the foul or sanitary sewers as intended. Frequently there are also cross-connections and thus, in many cases, separate systems are effectively operating as expensive combined systems. This has implications when collecting (intercepting) and transporting sewage for treatment as, if only discharges from recognized foul sewers are collected, much of the sewage will continue to be discharged (untreated) through the surface water system diminishing the benefit of collection.

Effective collection systems are a key for good wastewater management where off-site centralized treatment is chosen; they are also the most expensive element of total capital cost of good operational management. However, throughout the world most places have either no collection systems or systems that are dysfunctional. There are a number of reasons for this which can be briefly summarized as:

- The failure to plan and install collection networks (sewerage);
- Old or decaying networks;
- Installation of inappropriate systems;
- Inappropriate sizing of systems (in relation to the wastewater flows or concentrations);
- Inadequate resilience to storm events;
- Ineffective operation and inadequate maintenance; and
- Ineffective regulation and control of connections.

F.3.1.3 Industrial Wastewater

The user groups of industrial wastewaters include olive oil presses, farms, slaughterhouses, in addition to blacksmith and carpentry shops, etc. Large volumes of wastewater are also generated in the oil and gas industry, and projections show that these volumes will only increase.

Among the possible classifications of industrial wastewaters, one distinguishes between diffuse industrial pollutants, such as those from mining and Agri industries, and end-of-pipe point discharges and mostly illegal discharges from tankers. The former is frequently highly polluting and difficult to contain and treat, while the latter can be contained, controlled and treated in circumstances where there is sufficient political will, regulatory power and resources (economic and human capacity) to ensure compliance. Large end-of-pipe discharges are generally easy to identify and can be regulated, controlled and treated. However, some wastewaters arise from concentrations of small enterprises that discharge wastewaters wherever they can and not necessarily to any identifiable sewer. Many are highly polluting containing acids and toxic metals from, for example, small metal finishing (plating) enterprises which have developed in specific localities. Not only do such discharges inflict considerable environmental damage especially to sensitive ecosystems but they also often come into direct (as well as indirect) contact with humans and animals with consequent damage to health.

Several initiatives in the country were set to target the reduction of industrial pollution. the Lebanon Environmental Pollution Abatement Project (LEPAP) had the objective to reduce industrial pollution in targeted industrial enterprises and to strengthen the monitoring and enforcement capabilities of the Ministry of Environment. LEPAP is a joint initiative between the MOE, the Ministry of Finance, Banque Du Liban (BDL), the World Bank and the Italian Cooperation to set up a mechanism for financing the abatement of industrial pollution in targeted industrial enterprises and to provide necessary technical assistance for ensuring the implementation and the sustainability of these interventions.

The key issues which are expected to be addressed by the updated SEA are given in Table F 5 below.

Table F 5 Potential Environmental and Social Impacts

	Water	Dams	Wastewater
Surface & Ground Water Pollution	✓	✓	✓
Water Balance	✓		
GHG emissions	✓		✓
Public Health	✓	✓	✓
Occupational Health and Safety	✓	✓	✓
Impact on archaeological sites or sites of cultural interest	✓	✓	✓
Socioeconomic impacts	✓	✓	✓
Odours			✓
Flora and Fauna		✓	✓
Impact from treated effluent reuse			✓
Impacts from sludge use in agriculture			✓
Air emissions, dust during the construction phase	✓	✓	✓
Noise during the construction phase	✓	✓	✓
Public Health (Risk hazards) – access to construction areas	✓	✓	✓
Residual Risk and Mapping		✓	
Natural & Beneficial Functions of Floodplains		✓	
Climate change	✓	✓	✓

F.3.1.4 Additional Recommendations to the 2015 NWSS SEA

Key conclusions and recommendations for further developing and strengthening the new SEA processes include:

1. Promote the SEA as a set of core assessment activities that can be flexibly integrated into planning and decision-making: the SEA should be instituted as a set of core assessment activities that are integrated into all phases of the planning process from the earliest stage, rather than applied as a separate procedure.

2. SEA should address environmental as well as social and economic concerns of decision-makers and relevant stakeholders: SEA frameworks in the region should provide for an integrated approach for analyzing environmental, social and economic implications of proposed PPPs (Policy, Plan, Program). The scope and focus of SEA should be determined on a case-by-case basis through consultation with decision-makers, environmental authorities and other relevant stakeholders.

3. SEA should use robust assessment approaches that can operate in the face of significant data gaps: SEA practice in the region is constrained by limited access to data and a tradition of impact-focused, quantitative prediction. Simple assessment techniques that can cope with information gaps and use stakeholder inputs may provide a more feasible means of analysis. Pilot projects that test and demonstrate such approaches should be supported, backed by regulatory reforms to guarantee public access to information and promote inter-agency data sharing.

4. SEA should address and evaluate institutional capacities and arrangements for environmental management and integration: SEAs conducted in the region either implicitly or explicitly address institutional systems for managing impacts of development. This aspect of SEA should be strengthened progressively to require analysis of the quality of institutional arrangements and capacities for environmental management and policy integration.
5. Strengthen inter-institutional consultations and gradually improve transparency of SEA processes for the public: SEA processes should require inter-agency consultation and input at the stages of scoping and review of SEA findings, and public access and comment on SEA reports.
6. Produce an effective accountable water sector delivering safe and sustainable services through:
   - Sustainability monitoring, quality surveillance, regular sector reviews;
   - Policy and legislation, planning, coordination, budgeting and finance, regulation, capacity;
   - Service management and operation;
   - Investments in infrastructures water safety planning;
   - Water resources assessments.;
   - Sustainability of water resources for human use.
7. Dam safety and dam hazard risk management should be part of the new SEA
8. Risk MAP procedures should require development of A) a map that assumes the dam operates as planned (current practice), B) a map that assumes the dam is no longer there (highlights potential for removal), and C) a map that assumes the dam fails.
9. Communities should be encouraged to tie land use planning to failure zones to prevent low?hazard potential dams from becoming high?hazard?potential dams.
10. MoEW should lead the effort to provide information about changing hydrologic conditions.
11. As a potential flood risk reduction measure, communities should consider the negative impacts as well as the flood?control benefits when examining a dam
12. The definition of sustainable development includes "avoiding, remedying or mitigating any adverse effects of activities on the environment." Offsets are one form of mitigation for the potential impacts of dam works on natural values. A greater magnitude of offset is generally required for impacts on natural values on sites that are protected or managed for nature conservation, including formal reserves and public lands that are managed for natural values.
13. "Environmental flows" is a system for managing the quantity, timing, and quality of water flows below a dam, with the goal of sustaining freshwater and estuarine ecosystems and the human livelihoods that depend on them. Environmental flows shall be designed to restore any of a river's extreme low flows, low flows, high flow pulses, small floods, and large floods, with the goal of

improving water quality, restoring sediment deposition, addressing the life-cycle needs of fish and wildlife, and restoring the livelihoods of river-based communities.

14. Ensuring adequate planning/zoning of the catchment area of the dams is required.

15. Adopting a strategic approach to all stages of wastewater management:

    In any given setting, developing an overall wastewater management plan, encompassing where possible all wastewater components, should be undertaken based on appropriate boundaries. In any event, an appropriate administrative unit is needed to ensure effective oversight in design and operation. The systems must be flexible to accommodate new populations and sources, and indeed allow communities to have access to an improved level of service.

16. Considering off-site treatment options for rural and remote areas in Lebanon.

17. Optimizing the re-use of wastewater:

    Wastewater, in many cases, is rich in recoverable materials. This may be the nutrient value of domestic wastewater or indeed a particular fraction of an industrial discharge. In many regions the use of wastewater in agriculture is well-understood, albeit in a way that carries significant health risks. Wastewater can be reused to augment scarce supplies and delay future investments in water supply infrastructure. Indeed, reuse should be seen as a critical component of water demand management plans when implemented together with health and environmental risk management.

18. Improving the fragmented institutional responsibility for wastewater:

    One of the main reasons why wastewater has been so much neglected is that it often lacks an institutional home. The drive to commercialize drinking water production and supply has resulted in neglect for wastewater management. Many reformed utilities do not see value in investing in wastewater infrastructure. Until this change, it will be difficult to apportion responsibility for the impacts on health and the environment. Large polluters, particularly industries, can be policed. However unmanaged wastewater flows from unplanned areas and illegal discharge into storm drains etc. must be a municipal responsibility. Improved capacity is therefore needed. Wastewater can be a good business opportunity for utilities and systems developed for billing and revenue collection can be readily adapted for wastewater. At the regional level, mechanisms must be adopted to ensure neighbouring authorities agree on standards for monitoring and enforcement. In local communities there is clearly a role for environmental health professionals to assist in the management of wastewater discharges. With respect to wastewater production, some effort on minimization will be required. Non-point sources of agricultural run-off is a good example. It may be concluded that a combined approach of minimization and effective treatment will be needed.

19. Monitoring and evaluation:

    Projects and programs associated with the use of wastewater should be led and coordinated by inter-agency committees under the aegis of a leading ministry. This entity should also be in charge of monitoring and evaluation programs and should have the legal powers to enforce compliance with local legislation. Monitoring activities for wastewater use projects are of two different types.

Process control monitoring is carried out to provide data to support the operation and optimization of the system, in order to achieve successful project performance. It includes the monitoring of treatment plants, water distribution systems, water application equipment, environmental aspects (such as salinization, drainage waters, water logging), agricultural aspects (such as productivity and yield) and health-related problems (such as the development of disease vectors and health problems associated with the use of wastewater). In addition to providing data for process control, this level of monitoring generates information for project revision and updating as well for further research and development. Responsibility for process control monitoring belongs to the operating agency (for example, a state agency or a municipal sewerage board) which is part of the inter-agency committee.

Compliance monitoring is required to meet regulatory requirements and should not be performed by the same agency in charge of process control monitoring. This responsibility should be extended to an enforcement agency that possesses legal powers to enforce compliance with quality standards, codes of practice and other pertinent legislation. The responsibility for compliance monitoring is usually granted to Ministries of Health because health problems are of prime importance for wastewater.

20. Public awareness and participation:

To achieve general acceptance of reuse schemes, it is of fundamental importance that active public involvement is obtained from the planning phase to the full implementation process. Public involvement starts with early contact with potential users, leading to the formation of an advisory committee and the holding of public workshops on potential reuse schemes. The continuous exchange of information between authorities and the public representatives ensures that the adoption of a specific water reuse program will fulfil real user needs and generally-recognized community goals for health, safety, ecological concerns, program cost, etc. (Crook et al., 1992).

21. The incorporation of wastewater use planning into national water resource and agricultural planning is important, especially where water shortages exist. This is not only to protect sources of high-quality waters but also to minimize wastewater treatment costs, safeguard public health and to obtain the maximum agricultural and aqua cultural benefit from the nutrients that wastewater contains. Wastewater use may well help reduce costs, especially if it is envisaged before new treatment works are built, because the standards of effluents required for various types of use may result in costs lower than those for normal environmental protection. It also provides the possibility of recovering the resources invested in sewerage and represents a very efficient way of postponing investment of new resources in water supply (Laugeri, 1989).

22. Authorities, particularly the Ministries of Health and Agriculture, should investigate current wastewater reuse practices and take gradual steps for upgrading health and agronomic practices. This preliminary survey provides the basis for the clear definition of reuse priorities and the establishment of national strategies for reuse.

23. The implementation of an inter-sectoral institutional framework is the next step that should be taken. This entity should be able to deal with technological, health and environmental, economic

and financial, and socio-cultural issues. It should also assign responsibilities and should create capacity for operation and maintenance of treatment, distribution and irrigation systems, as well as for monitoring, surveillance and the enforcement of effluent standards and codes of practice.

F.4. Conclusion

In conclusion, the SEA study shall examine and identify possible impacts, in a qualitative way and classify them, based on an adopted methodology. Appropriate mitigation measures shall be suggested, even for cases of low impacts. An Environmental Management Plan (EMP) shall be also developed, through which the provisions of the SEA will be implemented. The proposed EMP shall describe the responsibilities of the stakeholders involved, the mitigation measures that need to be implemented, and by whom, as well as the monitoring scheme during the construction and operation phases.

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USAID FROM THE AMERICAN PEOPLE

LEBANON WATER PROJECT

LITANI RIVER AUTHORITY
ASSESSMENT OF RIVER GAUGING STATIONS AND MEASUREMENT LOCATIONS IN LEBANON

SUMMARY

AUGUST 2017

This publication was produced for review by the United States Agency for International Development. It was prepared by DAI Global LLC

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LEBANON WATER PROJECT

LITANI RIVER AUTHORITY
ASSESSMENT OF RIVER GAUGING STATIONS AND MEASURMENT LOCATIONS IN LEBANON

SUMMARY

Program Title:	**LEBANON WATER PROJECT**
Sponsoring USAID Office:	**LEBANON**
Contract Number:	**AID-268-N-I-15-00001**
Contractor:	**DAI Global LLC**
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Contents

ACRONYMS

DAI	DAI Global LLC
DEM	Digital Elevation Model
GIS	Geographical Information System
GS	Gauging Station
LRA	Litani River Authority
LWP	Lebanon Water Project
ML	Measurement Location
PL	Proposed Location
USAID	United States Agency for International Development
RWE	Regional Water Establishment

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INTRODUCTION

PROJECT CONTEXT

The Lebanon Water Project (LWP) is a five-year project funded by the United States Agency for International Development (USAID) to increase reliable and sustainable access to potable water for Lebanese citizens, improve water management practices, and enhance the efficiency and sustainability of public water utilities, while raising awareness on sustainable water use practices. USAID has appointed DAI Global LLC (DAI) to implement the project.

Building on USAID's prior water projects in Lebanon, LWP intends to increase access to clean, reliable, and sustainable water for Lebanese citizens. LWP will improve the effectiveness of the Regional Water Establishments (RWEs) and Litani River Authority (LRA) in water management and service delivery as well as increase their legitimacy via enhanced understanding and engagement of citizens and stakeholders. It is the Water Resources Department of LRA that has the authority to conduct discharge measurements on river levels and spring flows in Lebanon.

To assist LRA in its water management, a contract was signed on May 18, 2016 between DAI and ELARD to assess the status of LRA's existing Gauging Stations (GSs) and Measurement Locations (MLs) and provide recommendations for improvement.

Lebanon has 17 perennial and 23 seasonal streams. Their combined length is approximately 730 km. Twenty-six (26) isolated watersheds are drained seasonally through a diffused drainage system and most flow to the sea. For important water sites, LRA has installed permanent monitoring stations for continuous measurements of the surface water level in the river. For less important water sites, LRA has periodically measured the flow using current meters across a river section, or through a less accurate, method that consists of estimating the average width and height of water in the river section, and visually estimating water flow velocity. This latter practice is typically used during violent flows and deep-water depths. Data collected by LRA Water Resources Department staff is then periodically processed and analyzed.

Seventy-one (71) GSs and ninety (90) predefined MLs established in Lebanon and managed by the LRA Water Resources Department were assessed as part of this assessment.

OVERALL OBJECTIVE

The overall objective was to obtain a clear baseline about the quality of the flow measurements and to estimate the funding required to improve the quality of the data collected. This baseline will increase accuracy of water measurements and provide LRA with data needed for future planning. ELARD provided the following as part of the assessment:

- Assessed the status of installed surface GSs and predefined MLs.
- Evaluated GSs equipment and conditions of operation.
- Assessed the quality of the measurement data.
- Proposed new locations for additional GSs at predefined MLs or at new sites along Lebanese rivers and their main tributaries.
- Estimated the costs of interventions that are needed and that should be done within 3 months and recommended improvements to be implemented within 3 months to 3 years.

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METHODOLOGY

The work methodology to conduct the assessment for LRA included the following activities:

- Desk review of all relevant data for GSs and MLs provided by LRA.
- Field survey of the 71 GS and 90 MLs.
- Creation of GIS geodatabase and watershed delineation.
- Analysis to verify the accuracy of LRA data based on comparing:
  - The river discharges calculated by ELARD to the value of the flow calculated by LRA based on rating curves at different times over several years.
  - The potential maximum flow value obtained by ELARD to the LRA registered flow values.

DESK REVIEW OF RELEVANT DATA

Relevant data pertaining to the GSs and predefined MLs was obtained from LRA. The data was used to conduct an extensive desk review to understand historical data flows and establish reference points for future flow comparisons.

FIELD SURVEY

The 71 GSs sites and 90 predefined MLs were visited to examine their physical and operational conditions. During this field survey, information was collected and updated by the following:

- Taking panoramic, georeferenced photographic documentation of the site.
- GPS recording of site coordinates.
- Inspecting all features at the site and checking status of existing equipment.
- Identifying landmarks, flood plains, and sensitive features on the topographic map.
- Drawing site sketches.
- Measuring water heights at the location of the gauge.
- Conducting surface water flow/velocity measurements.

CREATION OF GIS GEO-DATABASE AND WATERSHED DELINEATION

All field data gathered was uploaded into the GIS geodatabase. The GIS geodatabase was structured to have different feature datasets and feature classes. The database main elements are below.

- GS/ML feature class (name, gauge number, X, Y, Z, latitude, longitude).
- Rivers feature class (name, ID, length).
- Watersheds feature class (name, ID, area, perimeter).
- Caza feature class (name, ID, mouhafazat, area, and perimeter).
- General characterization object class (caza, mouhafazat, river, basin, catchment area, source, gauge type).
- Measurements object class (distance from bridge to stream, maximum measured depth, height of right border, height of left border, flow upstream, flow downstream, etc.).
- Site characteristic object class (flood plain, width of flood plains, overflow risk, type of access road, etc.).
- Supplementary documents object class (site location photos, historical hydrological data, etc.).

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Sixty-seven (67) defined watersheds were delineated with 42 having an area less than 70 km^2 and no permanent streams or GS. As a result, the assessment focus was on the remaining 25 watersheds based on a 2.5 resolution digital elevation model (DEM) using the Arc-Hydro tool of Arc-GIS.

The delineated watersheds are provided in Figure 1.

Figure 1: Watershed Areas as Delineated Using Arc-Hydro Tool

Watershed Location	Watershed Name	Watershed Area in Km²
North Lebanon	Kebir	297.5
	Ostouene	164.0
	Arka	171.6
	Bared	282.0
	Abou Ali	490.7
	Al Asfour	89.7
	Joz	192.9
Mount Lebanon	Ibrahim	309.6
	Kelb	290.9
	Antelias	23.9
	Beirut	225.3
	Ghadir	36.9
	Damour	310.7
Beqaa	Assi	1,342.9
	Yamoune	126.9
	Litani Upper	1,425.0
South Lebanon	Awali	300.9
	Sainik	111.6
	Abou El Assouad	152.2
	Zahrani	155.8
	Litani Lower	664.8
	Hasbani	671.4
	South Litani	514.6

ANALYSIS OF DATA

Based on measured water flow velocities and measured wetted area sections, river and spring discharges were calculated. Two separate methods of comparison with the LRA registered values were used to verify the accuracy of LRA data:

- For a certain section/location, the value of the measured flow obtained was compared to the value of the flow calculated by LRA based on rating curves at different times over the years. Any LRA value differing from the measured value was considered inaccurate.
- For the same section/location, the potential maximum value of the flow obtained was compared to registered flow values as provided by LRA. Any LRA flow value exceeding the potential maximum flow value was considered inaccurate.

The Gauckler–Manning–Strickler Formula (Manning's Equation) was used for the calculation of cross-sectional average velocity flow in rivers and open channels. The Francis Formula was used to calculate the discharge over a sharp-crested Cippoletti weir (trapezoidal shape). Bernoulli's equation was used to calculate the velocity at exit points from a canal.

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FINDINGS, INTERVENTIONS NEEDED, AND RECOMMENDED IMPROVEMENTS

After completing the field assessment, it was determined that findings would be addressed by dividing them into administrative and technical. The administrative and technical findings are discussed below.

ADMINISTRATIVE FINDINGS

Status of LRA Staff/Personnel. There is a staff shortage at the Water Resources Department of LRA. LRA Management should consider providing incentives and capacity building opportunities to motivate personnel engaged in data acquisition, transmission, and record keeping. LRA should also consider adding qualified personnel to its staff in addition to the installation of a tracking system for personnel in charge of obtaining readings.

LRA Measuring and Data Collection Procedures. To measure river flows, LRA follows the procedures below:

- MLs are identified along the river course. Depending on the importance of the location, a permanent monitoring/GS is installed for continuous measurements of surface water levels or staff collect intermittent/periodical surface water level measurements. The data is then transferred to the Water Resources Department of LRA for processing and analyses using one of the following two methods:
  - Data obtained from the permanent GS is converted into flow values using the HYDRAS (by OTT) or HYDATA hydrologic software. Daily flow hydrograph, flow duration curve, and flow statistics such as mean flow, peak flow, highest daily mean, lowest daily mean, and a mean flow and runoff are then calculated. Direct stream flow measurements should be conducted at all stations every 7 or 15 days to calibrate the rating curve used for converting water levels into flows. However, due to LRA's limited resources, calibration is not happening regularly.
  - Flow data obtained from intermittent/periodical flow measurements is used to calculate a rough estimate of the monthly river flow. However, due to limited LRA resources, measurements are not taking place at a regular frequency and are dependent on LRA staff availability.
- The measurements described above, regardless of the procedure followed, are still not accurate because they are often not properly performed. LRA staff estimates flows instead of accurately measuring them.
- The software used (HYDRAS 3 and HYDATA) converts data collected through multiple steps, instead of direct conversion once data is input into the system. A better option would be using a single software that converts data collected into measurements in one single step.

TECHNICAL FINDINGS

Technical findings relate to both GSs and MLs. There are general findings and ones that are more specific. **General technical findings include:**

- The existing GS network does not cover the entire surface water of Lebanon. New GS must be installed in some locations, while in other locations, MLs can be upgraded to permanent GSs.
- Many GS and MLs are located at the seamouth of rivers, and when calculating water flows, they do not take into consideration inflows and outflows from and to other basins. This leads to inaccuracy in

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measuring flows. As an example, the Awali Rivers receives water from the Litani River/Qaraoun Lake through a tunnel.

- There are no measuring stations at the mouth of several rivers. Measuring stations should be installed at these locations to record volumes of entire basins, as the available recorded volumes do not represent the entire basin.
- Most of Lebanon's major springs and public wells are neither gauged nor measured. LRA must measure them because they are a major component of the assessment of Lebanon's water resources.
- Immediate installation of GS at existing dams is a necessity, in addition to providing GSs for proposed dams.
- Measurement general findings:
  - The bed/bottom of catchments of watersheds is highly affected by torrential rains, debris, and sediment accumulation. This affects the stage-discharge curve/relation, which needs to be calibrated more often.
  - During the dry season, the flow measurements may not be accurate because of prevailing shallow water depths, slow velocity, and the impact of irrigation demands.
- Data analysis general findings:
  - Data reporting is a manual process that does not undergo any quality assurance check before data is transmitted to the main office. In additions, there are no data collection verification reports.
  - The software used for data management is acceptable, but the hardware and its peripheral devices need upgraded. A backup storage device must be installed in a remote area with continuous update from the main server for data protection purposes.
  - No operational and maintenance manual is available to ensure continuous and reliable data collection.

It is crucial that LRA and the Water Establishments collaborate closely, especially in all aspects related to water intake measurement.

Specific technical findings include:

- Three (3) GSs and two (2) MLs were not reachable because of security reasons and (22) GSs were not assessed in terms of quality of collected data because the flows were not measurable.
- The following items should be procured and installed:
  - Staff gauge, 44 for GSs and 48 for MLs.
  - Telemetry Equipment, 60 for GSs and 11 for MLs.
  - Sixty-one (61) pressure transducers.
  - Radar equipment for five GSs and two MLs to ensure accurate flow measurement when conventional flow measurement is problematic.
  - Water flow meter loggers, four at GSs and six at MLs.
  - Metallic Pillar, 15 at GSs and metallic boxes, 12 at GSs.
  - Procurement and installation of 18 GSs at defined MLs.
  - Other items: one lock and four identification number plates.
- Civil Works are needed for the rehabilitation of the retaining walls and canalization of riverbeds, 9 for GSs and one for MLs. Construction of concrete chambers is also needed at six GSs.

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- Cleaning of river beds at 33 GSs and 10 MLs. The base of the pillar at six GSs needs cleaning.
- Other various works include the following:
  - Repair of telemetry equipment at five GSs.
  - Fencing for prevention of solid waste at seven GSs.
  - Excavation works at three GSs, obstacles removal at one GS, and embankment removal at one ML.
  - Maintenance of weirs at three GSs.
  - Improved access to four GSs.
  - Relocation of 16 GSs.

Figures 2 and 3 below provide a detailed summary of interventions needed to improve GSs and MLs. The GSs and MLs are grouped by watershed for a more focused approach. A count/number for each type of intervention needed per GS and per ML in each watershed is provided. This information will help LRA in identifying interventions much faster should funds be available in the future.

Cost estimates for improvements are provided in Figures 4 and 5 and correspond to the items listed in Figures 2 and 3.

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Figure 2: Type and Number of Improvements Needed for GSs Grouped by Watershed

INTERVENTION			NORTH LEBANON							MOUNT LEBANON							BEKAA			SOUTH LEBANON							TOTAL NUMBER OF INTERVENTIONS
			Kebir	Ostouene	Arka	Bared	Abou Ali	Al Asfour	Joz	Ibrahim	Kelb	Antelias	Beirut	Ghadir	Damour	Assi	Yamoune	Litani Upper	Awali	Sainik	Abou El Asouad	Zahrani	Litani Lower	Hasbani	South Litani	
1	Re-assessment	When the Flow is Measurable	1			1	1	1	1		3		4		1			5		1		2		1		22
		When the Site is Reachable	2													1										3
2	Procurement and Installation	Staff Gauge	2	3	1	4	4	1	1	3	3	1	3		4			4	2	1		1	3	2	1	44
		Telemetry Equipment	2	3	1	4	4	1	1	3	5	1	4		5	1	1	9	2	1		2	7	1	2	60
		Pressure Transducers	2	3		4	4	1	1	3	4	1	4		5	1	1	9	2	1		3	7	3	2	61
		Radar Equipment								1	1					1		1	1							5
		Installation of Water Flow Meter Loggers								1								1						2		4
		Metallic Pillar	1	2		1	1			2	1	1	1							1		2	2			15
		Metallic Box		1		3				1	1		2					1		1			1		1	12
		Lock																1								1
		Identification Number																				1	1	1	1	4
3	Civil Works	Retaining Wall and Canalization of River Bed		1		1				1	2			1	1			2								9
		Concrete Chamber			1		2				1		1		1											6
4	Cleaning	River Bed	2	1	1	3	1		1		3	1	3	1	1	1	1	4	1	1		1	3	2	1	33
		Base of the Pillar					1			1	1					1		1					1			6
		Relocation of the Station		2	1		1		1				3		2		1	2				1	1	1		16
		Repair Telemetry Equipment									3													2		5
		Fencing for Prevention of Solid Waste		1	1	2					1			1					1							7
		Excavation Works		1			1	1																		3
		Weir Maintenance						1		1								1								3
		Providing Access Means					1						2					1								4

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INTERVENTION			NORTH LEBANON							MOUNT LEBANON						BEKAA			SOUTH LEBANON							TOTAL NUMBER OF INTERVENTIONS
			Kebir	Ostouene	Arka	Bared	Abou Ali	Al Asfour	Joz	Ibrahim	Kelb	Antelias	Beirut	Ghadir	Damour	Assi	Yamoune	Litani Upper	Awali	Sainik	Abou El Asouad	Zahrani	Litani Lower	Hasbani	South Litani	
4	**Cleaning**	Obstacles Damaging the Station				1																				1
		Obstacles and Embankment									1				2								2	1		6
	Details in Volume		V.1	V.2	V.3	V.4	V.5	V.7	V.8	V.9	V.10	V.11	V.12	V.13	V.14	V.20	V.21	V.24	V.16	V.17	V.18	V.19	V.23	V.25	V.26	

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Figure 3: Type and Number of Improvements Needed for MLs Grouped by Watershed

	INTERVENTION		NORTH LEBANON					MOUNT LEBANON		BEKAA				SOUTH LEBANON				TOTAL NUMBER
			Kebir	Ostouene	Arka	Bared	Abou Ali	Ibrahim	Damour	Assi	Yamoune	Litani-Assi	Litani Upper	Awali	Sainik	Litani Lower	Hasbani	
1	**Re-assessment when the site is reachable**		2															2
2	**Procurement and Installation**	Gauging Staff		3	1	2	3	1	3	5	5	1	10	6		5	3	48
		Gauging Station				1	1	1	5	2			2	3	1	1	1	18
		Telemetry Equipment				1	1	1		2			2	2		1	1	11
		Radar Equipment								2								2
		Water Flow Meter Loggers							1			1	2	1			1	6
3	**Civil Works Concerning the Retaining Wall**									1								1
4	**Cleaning of the River Bed**				1	1	1				5			1	1			10
5	**Embankment Removal**													1				1
	Details in Volume		V.1	V.2	V.3	V.4	V.5	V.9	V.14	V.20	V.21	V.22	V.24	V.16	V.17	V.23	V.25	

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COST ESTIMATE

The cost estimate for the needs (immediate action needed and action needed within three months), and proposed improvement works (improvements needed in 3 months to 3 years) is prioritized according to the following four levels:

Needs

- **First priority:** requires taking immediate actions for improvement.
- **Second priority**: requires taking short-term actions for improvement within three months.

Improvement

- **Third priority:** involves taking medium term actions for improvements within 3 months to a year.
- **Fourth priority:** involves taking long-term actions for improvements within 1 to 3 years.

Figures 4 below provides a detailed cost estimate for needs and improvements for GSs and MLs grouped by watershed. Figure 5 provides the cost estimate for Mount Lebanon, Figure 6 for Beqaa, and Figure 7 for South Lebanon.

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Figure 4: **Prioritized Cost Estimation of Interventions Needed in North Lebanon**

Watershed	Station Number	Station Name	GSs Cost Estimation (US$)		MLs Cost Estimation (US$)	Details Provided in Volume Number
			Needs	Improvement	Needs	
KEBIR	101	Arida	1,925.0	0.0		Volume 1
	102	Chadra	5,000.0	50.0		
	104	El-Kabir S.M.	5,925.0	0.0		
	ML	El Safa Wadi Khaled	0.0	0.0	1,100.0	
	ML	Canal Safa Wadi Khaled	0.0	0.0	1,100.0	
OSTOUENE	105	Beit El-Hajj	4,225.0	1,820.0		Volume 2
	106	Halba Bridge	4,050.0	350.0		
	121	Ostouane S.M.	7,300.0	100.0		
	ML	Canal Ostouane 2	0.0	0.0	100.0	
	ML	Canal Ostouane 3	0.0	0.0	100.0	
	ML	Canal Ostouane 4	0.0	0.0	100.0	
ARKA	108	Hakour	2,980.0	4,000.0		Volume 3
	ML	Gebrayel Bridge	0.0	0.0	400.0	
	PL	Ilat (Mavit and Houaich river)	0.0	0.0		

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Watershed	Station Number	Station Name	GSs Cost Estimation (US$) Needs	GSs Cost Estimation (US$) Improvement	MLs Cost Estimation (US$) Needs	Details Provided in Volume Number
BARED	109	Mechmech Qabaiit	4,275.0	1,200.0		Volume 4
	110	Tirane	9,140.0	400.0		
	111	Bared S.M.	3,575.0	2,600.0		
	125	Adwe Bridge	1,375.0	2,725.0		
	ML	Tirane Upstream	0.0	0.0	5,600.0	
	ML	Tirane Downstream	0.0	0.0		
	ML	Tirane After Abou Moussa Dam	0.0	0.0		
	ML	Canal Bebnine	0.0	0.0	400.0	
	ML	Canal Bareed (2)	0.0	0.0		
	PL	Qabaiit (Qemmamine, Kafeltin Abdine Ouadi Jinniyat and El-Bustan spring in addition to the surface runoff of the southern tributary of Nahr El-Bared watershed)	0.0	0.0		
ABOU ALI	112	Kousba	3,700.0	1,250.0		Volume 5
	113	Daraya	0.0	0.0		
	115	Racheine-Zgharta bridge	1,610.0	2,850.0		
	116	Joueit Kfarshghab bridge	2,300.0	2,800.0		
	117	Abou Samra	2,250.0	4,000.0		
	ML	Canal Kousba	0.0	0.0	100.0	
	ML	Canal Abou Samra	0.0	0.0	400.0	
WADI BASRA	ML	Abou Halka Spring	0.0	0.0	5,600.0	Volume 6
AL ASFOUR	118	Bziza Bridge	3,350.0	2,700.0		Volume 7
JOZ	119	Beit Chlala	11,455.0	0.0		Volume 8
	120	EL-Joz S.M.	2,300.0	4,300.0		
TOTAL	**NORTH LEBANON**		**76,735.0**	**31,545.0**	**15,000.0**	

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Figure 5: Prioritized Cost Estimation of Interventions Needed in Mount Lebanon

Watershed	Station Number	Station Name	GSs Cost Estimation (US$)		MLs Cost Estimation (US$)	Details Provided in Volume Number
			Needs	Improvements	Needs	
IBRAHIM	221	Afqa	3,700.0	10,100.0		Volume 9
	222	Majdel-Roueiss	4,050.0	12,460.0		
	223	Ibrahim S.M.	585.0	3,700.0		
	ML	Canal Ibrahim	0.0	0.0	5,600.0	
	PL	Madiq Spring (in Fatre to measure madiq springs before madiq dam)				
KELB	205	Nabaa El-Laban	200.0	200.0		Volume 10
	207	Nabaa El-Aassal	600.0	0.0		
	212	Jeita (proposal to relocate it to the entrance of the grotto)	600.0	0.0		
	213	Kashkoush	500.0	0.0		
	224	Hrajel	5,000.0	460.0		
	226	Daraya	4,800.0	1,680.0		
	228	El-Kalb S.M.	2,025.0	12,700.0		
	229	Dbayye before tunnel	3,600.0	350.0		
	230	Dbayye canal wata	4,350.0	0.0		
	ML	Hrajel-Canal Irrigation	0.0	0.0		
ANTELIAS	219	Fouar Antelias	675.0	3,600.0		Volume 11
BEIRUT	231	Ras El-Metn Jaamani (proposal to relocate)	7,550.0	390.0		Volume 12
	233	Daychounieh	6,450.0	100.0		
	234	Jisr El-Basha 1	3,300.0	3,700.0		
	235	Jisr El-Basha 2	3,125.0	3,875.0		
	ML	Canal Hemmena	0.0	0.0		

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Watershed	Station Number	Station Name	GSs		MLs	Details Provided in Volume Number
			Cost Estimation (US$)		Cost Estimation (US$)	
			Needs	Improvements	Needs	
GHADIR		Kfarshima Bridge	2,185.0	0.0		Volume 13
DAMOUR	236	El-Sett Valley	1,400.0	2,500.0		Volume 14
	237	BouZebli Rechmaya (proposal to relocate)	5,100.0	100.0		
	238	Jisr El-Qadi (proposal to relocate)	2,800.0	2,500.0		
	239	Al-Hammam	3,700.0	100.0		
	240	Damour S.M.	5,900.0	2,500.0		
	ML	Aazzounieh	0.0	0.0	3,000.0	
	ML	Canal Raayen inside plant	0.0	0.0	7,950.0	
	ML	Canal Safa Main	0.0	0.0	3,000.0	
	ML	Canal Beiteddine	0.0	0.0	3,100.0	
	ML	Canal Damour Upper	0.0	0.0	100.0	
	ML	Canal Damour Lower	0.0	0.0	3,100.0	
	PL	Bmehriyeh - Ain Dara (to measure Ain Dara spring on Ain Dara bridge)				
	PL	Nabaa Al Safa after spring				
IKLIM EL KHARROUB			0.0	0.0		Volume 15
TOTAL	**MOUNT LEBANON**		**72,195.0**	**61,015.0**	**25,850.0**	

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Figure 6: Prioritized Cost Estimation of Interventions Needed in the Beqaa

Watershed	Station Number	Station Name	GSs Cost Estimation (US$) Needs	GSs Cost Estimation (US$) Improvement	MLs Cost Estimation (US$) Needs	Details Provided in Volume Number
ASSI	345	Hermel	3,660.0	12,425.0		Volume 20
	ML	Canal Roueiss	0.0	0.0	100.0	
	ML	Canal Moterfe	0.0	0.0	100.0	
	ML	Canal Qaa	0.0	0.0	100.0	
	ML	Ain El-Zarka Spring	0.0	0.0	7,100.0	
	ML	Daffash Spring	0.0	0.0	7,600.0	
	ML	Canal Masmake	0.0	0.0		
YAMOUNE	346	Yammouneh Tunnel entrance	5,400.0	0.0		Volume 21
	ML	Arbaine Spring	0.0	0.0	400.0	
	ML	Mahkan Spring	0.0	0.0	400.0	
	ML	Taffaha Spring	0.0	0.0	400.0	
	ML	Moghr Spring	0.0	0.0	400.0	
	ML	Kazzab Spring	0.0	0.0	400.0	
	ML	Aadous	0.0	0.0		
	ML	Bawalii	0.0	0.0		
LITANI-ASSI	ML	Ras El Ain Baalbeck	0.0	0.0	3,400.0	Volume 22
LITANI UPPER	347	Berdaouni Zahle	1,600.0	3,600.0		Volume 24
	353	Canal Anjar	2,600.0	6,050.0		
	354	Ghzael Damascus Road	2,500.0	13,700.0		
	356	Berdaouni Damascus Road	3,700.0	2,500.0		
		Litani Damascus Road	0.0	0.0		

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Watershed	Station Number	Station Name	GSs Cost Estimation (US$)		MLs Cost Estimation (US$)	Details Provided in Volume Number
			Needs	Improvement	Needs	
LITANI UPPER	359	Chtaura Valley (Massabkeh)	3,600.0	360.0		Volume 24
	360	Ouadi El-Delem Qobb Elias	2,760.0	2,500.0		
	361	Khrayzat Spring	3,700.0	0.0		
	363	Joub Jannine	3,750.0	1,100.0		
	366	El-Zghir Downstream Faour	0.0	0.0		
	367	Yahfouf Ain El-Sikkeh	4,075.0	2,600.0		
	ML	Ghzayel Anjar	0.0	0.0	13,355.0	
	ML	Chamsine after spring	0.0	0.0	15,500.0	
	ML	Faour Bridge	0.0	0.0		
	ML	Terbol Spring	0.0	0.0		
	ML	El Sahour Al El-Nahri	0.0	0.0		
	ML	Yahfoufa - Beginning of Bustan El-Mir	0.0	0.0	100.0	
	ML	Yahfoufa-Irrigation Canal	0.0	0.0		
	ML	Yahfoufa - Canal Nasriyeh	0.0	0.0	100.0	
	ML	Yahfoufa - End of Bustan El-Mir	0.0	0.0	100.0	
	ML	Zanjil Janta	0.0	0.0		
	ML	Housh Bay Spring	0.0	0.0	100.0	
	ML	Ammiq Spring	0.0	0.0	100.0	
	ML	Canal Ain El-Dob Aitanit	0.0	0.0	100.0	
	ML	Canal Nabaa Kneisse (Dayiaa)	0.0	0.0	100.0	
	ML	Canal Nabaa Abou Zeid + Tannour	0.0	0.0	100.0	
	PL	Mansoura	0.0	0.0		

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Watershed	Station Number	Station Name	GSs Cost Estimation (US$)		MLs Cost Estimation (US$)	Details Provided in Volume Number
			Needs	Improvement	Needs	
SUB-TOTAL	**BEKAA**		**37,345.0**	**44,835.0**	**50,055.0**	

Figure 7: Prioritized Cost Estimation of Interventions Needed in South Lebanon

Watershed	Station Number	Station Name	GSs Cost Estimation (US$) Needs	GSs Cost Estimation (US$) Improvement	MLs Cost Estimation (US$) Needs	Details Provided in Volume Number
AWALI	473	Marj Bisri	1,200.0	2,500.0		Volume 16
	475	Awali Saida S.M.	13,800.0	1,000.0		
	ML	Canal Barouk (Right)	0.0	0.0	100.0	
	ML	Canal Barouk (Left)	0.0	0.0	100.0	
	ML	Azzibeh Spring	0.0	0.0	8,900.0	
	ML	Nabaa Jezzine Al Sadd	0.0	0.0	5,900.0	
	ML	Canal Joun-Sad Al Aansyieh	0.0	0.0	100.0	
	ML	Canal Joun-Sad Rsas	0.0	0.0	100.0	
	ML	Canal Joun-Sad Al Mir	0.0	0.0	100.0	
	ML	Ouadi Jezzine	0.0	0.0	3,000.0	
	PL	Ouadi Jezzine (after Ain el Dahab Spring)	0.0	0.0		
SAINIK	476	Ouadi El-Laymoun	4,800.0	825.0		Volume 17
	ML	Sainik S.M.	0.0	0.0	3,300.0	
AOU EL ASOUAD			0.0	0.0		Volume 18
ZAHRANI	478	Ouadi El-Akhdar	1,770.0	4,100.0		Volume 19
	479	Deir El-Zahrani	2,550.0	2,500.0		
	480	Zahrani S.M.	2,200.0	0.0		
LOWER LITANI		Ain El-Zarka	3,600.0	0.0		Volume 23
	368	Qilya (proposal to relocate)	5,100.0	500.0		
	489	Khardale	3,950.0	60.0		
	491	Ghandouryye	3,600.0	0.0		
		Mathane	2,520.0	1,100.0		

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Watershed	Station Number	Station Name	GSs Cost Estimation (US$) Needs	GSs Cost Estimation (US$) Improvement	MLs Cost Estimation (US$) Needs	Details Provided in Volume Number
LOWER LITANI	493	Qasmyeh S.M.	1,925.0	2,600.0		Volume 23
	474	Tayerfilsayh	3,900.0	200.0		
	ML	Canal Jarmaq (Right)	0.0	0.0	100.0	
	ML	Canal Jarmaq (Left)	0.0	0.0	100.0	
	ML	Nabaa Al Ghelle	0.0	0.0	5,600.0	
	ML	Canal Borj Rahhal	0.0	0.0	100.0	
	ML	Canal Tekhshibe	0.0	0.0	100.0	
	PL	Qasmiyeh (after the Qasiyeh bridge to measure Qasmiyeh springs)	0.0	0.0		
HASBANI	496	Fardiss Bridge	1,420.0	2,600.0		Volume 25
	497	Hasbani springs (proposal to relocate)	4,200.0	8,155.0		
	499	Wazzani bridge	600.0	11,660.0		
	ML	Nabaa Al Jaouz	0.0	0.0	3,400.0	
	ML	Nabaa Al Mghara	0.0	0.0	100.0	
	ML	Canal Hasbani	0.0	0.0	5,600.0	
	ML	Nabaa Mery	0.0	0.0		
	ML	Nahr Hasbani before Wazzani	0.0	0.0		
	ML	Nabaa Sreid	0.0	0.0		
SOUTH LITANI	501	Ras El-Ain S.M.	1,400.0	2,600.0		Volume 26
	502	Ras El-Ain Main Canal	1,120.0	2,675.0		
	ML	Borak Ras El Ain-Tehrib	0.0	0.0		
TOTAL	**SOUTH LEBANON**		**59,655.0**	**43,075.0**	**36,700.0**	

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CONCLUSION

Based on the assessment conducted, the main take away is that interventions needed to upgrade the gauging stations are not complicated. They consist of procurement and installation of equipment. The impact of interventions and improvements outweighs the burden of the costs incurred. Once completed, LRA will have a database of accurate information on all water resources in Lebanon, which will facilitate future planning and water sector development.

For guidance purposes only, the total cost for needs is estimated at $245,930. The total cost for improvements is estimated at $180,470.

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ANNEX III C.1

UNDP REPORT 1970 - SUMMARY

UNDP REPORT 1970 - SUMMARY

- 30 basins studied
- 10 billion cubic meter of rainfall over Lebanon, including 3.3 billion over the Beqaa basin.
- 3600 Mcm (million cubic meter) of groundwater is available in Lebanon

0. INTRODUCTION

- Average annual precipitation varies from 800 mm on the coast to 1500 mm in mountainous regions to 200 mm in the Beqaa plain (north).
- Excluding Nahr el Litani, Nahr el Assi and Nahr el Hasbani, the combined average surface area of the 14 most important basins is less than 500 km^2. For the 24 less important (secondary) basins, the combined average surface area is around 75 km^2.
- 14 perennial rivers flowing throughout the year.

1. GENERAL INFORMATION

A. Geologic history

- Mountain ranges in Lebanon characterized by limestones and karsts are regularly subject to rainfall which infiltrates the subsurface in great amounts.
- 65% of the land in Lebanon is highly permeable and well exposed to precipitation.

B. Relief and hydrography

- Lebanon: Zones located at an altitude less than 250m above sea level constitute less than 10% of the surface area of Lebanon.
  Over 50% of the surface area is located between 500 masl and 1500 masl.
- Anti-Lebanon: 15% of the surface area is located at an altitude less than 1200 masl while 70% of the surface area is located between 1200 and 2250 masl.
- Overall, more than 90% of the country's total surface area is located at altitudes exceeding 200 masl including 78% above 500 masl.
- The 17 main rivers in Lebanon are:

Tableau 3. Longueur et surface des 17 principaux fleuves du Liban

Fleuve	Longueur (km)	Surface (km^2)	Fleuve	Longueur (km)	Surfac (km^2)
Nahr el Kébir	60		Nahr ed Damour	31	288
Nahr Oustouèn	22	160	Nahr Bisri	48	302
Nahr el Arka	20	153	Nahr Seymih	20	111
Nahr el Bared	24	277	Nahr Zahrani	25	88
Nahr Abou Ali	42	484	Nahr Abou Assouad	15	132
Nahr ej Jaouze	38	198	Nahr el Litani	170	2 168
Nahr Ibrahim	30	330	Nahr el Assi	46	1 870
Nahr el Kelb	30	260	Nahr el Hasbani	21	526
Nahr Beyrouth	23	231			

- Out of those 17 rivers listed above, 14 drainage basins are located solely on the western side of Lebanon. The Litani river is the only one to cross the central mountain range and eventually flow towards the sea.
- The two main characteristics of the hydrographic network in Lebanon are:

- an extensive partition; and
- steep slopes which highly affect the flow of rivers across the country.

C. Climate

- Throughout the year, winds predominantly travel in a south west to north-east direction. In winter, heavy rainfall is caused by strong storms originating from the Atlantic.
- Although the meteorological network might seem extensive, it is not enough to properly asses the water resources of the country.
- The mean annual rainfall over Beirut River basin is around 887mm on the coast and 1300mm at 20km away from the coast (inland).
- The time lag between the highest precipitation values and the highest river flow values in Lebanon is caused by the melting of the snow cover.
- Measured annual evaporation at Beirut (Airport) station is 1286mm.
- Average annual volume of precipitation across the country is around 9 billion cubic meters (excluding snowfall which its liquid equivalent is estimated to be around 1-2 billion cubic meters).

D. Hydrology

- 30 basins, 21 of which are characterized by a permeable karstic terrain.
- Surface flow constitutes 28% of the total flow of all rivers and springs.
- Rivers flow values and precipitation have a very high correlation coefficient.
- Karst highly influences the infiltration of groundwater in limestones. All tracer tests done throughout the project have yielded a groundwater flow speed exceeding 3 km/d.

- Nahr el Kelb: the flow of the river has been measured since 1949 via Mokhada station. Average monthly flow values between September 1949 and September 1960 are shown in the table below.

Tableau 9. Débits moyens mensuels du Nahr el Kelb (1949-1960)

Mois	*Débit moyen (m^3/s)*	*Mois*	*Débit moyen (m^3/s)*
Janvier	11,4	Juillet	3,7
Février	14,7	Août	2,3
Mars	18,8	Septembre	2,1
Avril	15,3	Octobre	2,12
Mai	9,6	Novembre	2,66
Juin	6	Décembre	6

- The relative flow of Nahr el Kelb is 31.3 l/s/km^2.
- The minimum annual volume discharged from Nahr el Kelb is 121 million cubic meters.
- The discharge across Nahr el Kelb basin is 244 million cubic meters of which 141 mcm are owed to groundwater flow. Therefore, 43 to 57 % of the total discharge are attributed to surface flow and infiltration.
- Maximum groundwater flow is 9.6 cubic meter per second and minimum groundwater flow is 2.1 cubic meter per second.
- Considering an average precipitation of 1500mm across the 249 km^2 area of the basin, the infiltration coefficient would be 37%, that of surface runoff

would be 25% resulting in a flow deficit of 38% (see page 33 of the PDF for more details).

- Nahr el Litani: of the 2168 km^2 surface area of the basin, 1882 km^2 (84%) are situated within the central part and 16% within the Mediterranean slope part. Multiple effluents feed the Litani river along its path:
  - On the left bank, Nahr Ghzayel (which feeds from Chamsine spring + Anjar spring) is the main river that contributes the most whereas Nahr Yahfoufa, which dries in the summer, contributes less.
  - On the right bank, Nahr Berdaouni, Nahr Kab Elias, and springs in Chtaura/Kab Elias and Ammik all discharge into the Litani river.
  - The average monthly flow values between 1938 and 1968 are given in the table below:

Tableau 10. Débits moyens mensuels du Nahr el Litani (1938-1968)

Mois	*Débit moyen (m^3/s)*	*Mois*	*Débit moyen (m^3/s)*
Janvier	15,34	Juillet	3,15
Février	21,50	Août	2,76
Mars	20	Septembre	3,40
Avril	15,80	Octobre	3,72
Mai	9,32	Novembre	5,12
Juin	4,68	Décembre	7,92

  - The average flow of Nahr el Litani is 9.34 cubic meters per second whereas the annual volume discharged is 295 million cubic meters.
  - The relative flow is 7.2 $l/s/km^2$.
  - The rivers/springs that feed into the Litani have been monitored for a long-enough period of time (1963-1968) to be able to calculate the contribution of each as shown below:

	Millions de mètres cubes
Anjar	63,5
Chamsine	14,7
Berdauni	44,51
Chtaura	14,5
Jdita	4,14
Kab Eliâs	21,51
Ammik	22,44
Ras el Aïn	7,04
Faouar	3,64
Aïn el Baïda	8,21
Total	205,16

  - The average annual volume discharged (295 Mcm) is therefore divided into 205 Mcm as groundwater flow and 90 Mcm as surface flow.
  - Considering an average precipitation of 720mm across the 2168 km^2 area of the basin, the infiltration coefficient would be 22%, that of surface runoff

would be 9.8% resulting in a flow deficit of 68.2% (see page 35 of the PDF for more details).

- Rivers and springs can be grouped into 4 major categories as follows:
  - "Drainage springs" flowing from the base of high Cenomanian platforms.
  - "overflow springs" discharging from the base of massive limestones in contact with less permeable young formations.
  - "sub-marine springs"
  - "artesian springs" flowing from outlets out of less permeable rocks.

- After studying five different springs which are Anjar, Safa, Jeita, Berdaouni and Ain Zerka, the authors concluded that in Lebanon, regardless of the flow, the age of the rocks that make the aquifer, the altitude or the region; the major characteristics of springs that are sourced from limestones are relatively similar in exception of artesian springs. The study was based of hydrographs of each of the five springs which resulted in similar curves that follow the same trend.

- Another conclusion the authors have come to, based also on A.Guerre's thesis, is that karstification before the Cretaceous did not play a major role in shaping the karsts of the Jurassic. This conclusion was of high importance because it made the authors doubt whether they should still look into static reserves below the outlets of Keserwan and Barouk.

- Based on Maillet's method, the authors concluded that "overflow springs" are the only springs that could be artificially overexploited during periods of low water levels. "Artesian springs" are naturally well structured whereas "drainage springs" lack any static reserves below their emergence point/outlet.

- In order to seasonally overexploit "overflow springs", fissures must be located at greater depths in order to guarantee the presence of such reserves.

- The exploitation of Ammik spring was deemed feasible whereas that of Anjar spring wasn't. The purpose was to artificially exploit the studied springs through pumping at discharge rates higher than those of the summer. Piezometric levels were lowered upstream of the springs in order to make them dry. Infiltration during winter contributes into refilling the dried-up spring up until the water table is sufficiently recharged for the spring to flow normally again.
  The ultimate target of the experiment was to lower the piezometric surface up to the point where the spring was permanently dry and therefore reduce to the maximum the overflow during winter. This method was eventually considered inapplicable given the geomorphology of the country that prevents "overflow springs" from existing at high altitudes, in exception of those on the western flank of Barouk.
  Therefore, in order to manage mountainous springs/resources regardless of their discharge rate, the authors decided that minimizing the amount of surface runoff (water loss/escape) would be the most suitable option. This can be done through fortifying the catchments, however the amount of water collected wouldn't be that significant.

2. PROJECT OPERATIONS

A. General principles

- Three major types of aquifers are identified:
  - Aquifers made up mainly of karstic limestones located on the coast in which it is necessary to define the relationship between freshwater and seawater as well as set the limits of pumping and the possible extent of exploitation.
  - Aquifers made up mainly of karstic limestones located far from the coast in the center characterized by highly porous fissures and channels which result in "drainage springs" and "overflow springs".
    In the case of "overflow springs", it was necessary, where artificial overexploitation was theoretically feasible, to set the maximum discharge rates possible as well the available static reserves.
  - Aquifers characterized by high interstitial porosity where it would be interesting to delineate zones of highest permeability.

B. Methods adopted (EQUATIONS+FORMULAS)

- Transmissivity/storativity/storage capacity
- Theis-Jacob
- Effective porosity of aquifers
- Maillet's method.

C. Water resources inventory

- Up until February 1969, the overall inventory of the project counted: 1481 wells, 1031 boreholes, and 1121 springs.
- More than 17000 piezometric measurements were done.
- Water sampling was done for all the wells recorded, then on a monthly basis for sample wells and finally after two years of extensive monitoring, every three months across the whole network surveyed. The total number of water samples studied is 7162. The sample were chemically tested but not bacteriologically.

D. Geophysical prospect

- The total number of electrical surveys done is 753 which equates to a distance of 2139 km covering an area of 512 km^2.
  The measurement point density is 3 surveys per square kilometer.

E. Wells/Boreholes

- Initially it was planned that a combined length of 8802m of boreholes would be drilled. Upon completion, 73 boreholes were drilled for a total of 12951m.
- The drilling works were divided into 5 regions:
  - South Beqaa (27 boreholes, 7 piezometers)
    On the eastern flank of Barouk, 7 boreholes have encountered Jurassic limestones up to 150m deep below the subsurface.
    Transmissivities are in the order of 10^{-1} m^2/s.
    In the southern part of the Beqaa plain, faulting occurs still at 240m below ground level.
    The "overflow springs" Chamsine and Anjar represent the major outlets of the Cenomanian limestone aquifer of Anti-Lebanon.

- Akkar Plain (5 boreholes)
  Limestones of Pleistocene age don't exceed a thickness of 60m.
  Miocene is around 250m thick with lagunal facies rich in sulfates.

- Koura (9 boreholes)

- Beirut (12 boreholes)
  The two prominent aquifers that might yield high levels of water are Jurassic limestones and Cenomanian limestones. The Cenomanian limestones which are located in the southern part of Beirut are highly fissured.

- Southern coastal region (13 boreholes)
  Salt water intrusion between Khalde and Saida limits the exploitation in the area to 2-3 l/s.
  South of Saida, the existence of an impermeable chalk layer of Senonian/Eocene age could mean that the Cenomanian limestone aquifer might be isolated from the sea. A proper delineation of freshwater and seawater was not possible with the number of boreholes drilled then, however additional boring was not possible within the frame of the project.

F. Technical assistance of the Government

- In an effort to supply water to several cities within the country, the authors were called upon by the Government to supervise the drilling of multiple boreholes across the country. The final outcome was 82 boreholes totaling a length of 10301 meters scattered across the country as well as the installation of 16 piezometers.

G. Conclusion

- Some areas were studied more than others such as South Beqaa and areas surrounding Beirut.
- The government should follow up and take into consideration all the recommendations and findings stated in the report.

3. SCIENTIFIC AND TECHNICAL KNOWLEDGE OF GROUNDWATER

A. Hydrogeological map

- A hydrogeological map (scale 1:200 000) was published alongside the report.

B. General classification of groundwater

- Two distinct hydrogeological provinces were defined: **the interior province** and the **Mediterranean province** which are separated by mountain peaks (Jabal Barouk and Jabal Niha).
- The interior province is characterized by a closed basin that is only open on its extreme northern and extreme southern ends. All outlets were therefore accurately measured. The province is subject to an arid climate with limited amount of springs and rivers. The most important ones are: Bouqueia, Ouadi Oudine, Jbab el Homr, Ayoun Ourghoche, Yammoune, Kaa el Rim, Kab Elias, Ammik, Korayzat, Machghara and Guelle.

- The Mediterranean province, facing the sea, is located on the western side of the axial limit defined earlier (by mountain tops). Based on its geomorphology, the province can be divided into three major units:
  - Mount Lebanon (Jurassic limestones): including Koura, Akkar plain and Beirut;
  - Barouk (Cenomanian limestones that progressively dip towards the sea)
  - Jabal Amel (Cenomanian limestones, Senonian and Eocene chalks) which also dip towards the sea.

  In all the zones where limestones are in direct contact with the sea, it is very challenging to properly asses the drainage system and define precise water outlets.

C. ***Interior province basins***

- Jurassic basins

  - Eastern Barouk-Niha Jurassic Basin:
    Borehole drilling and geophysical surveying on the eastern flank of Jabal Barouk and Jabal Niha revealed that faulting extends up to 140m below the piezometric level which confirms that karstification occurred well before the accumulation of recent deposits. The presence of submerged karsts could hint at the existence of possible exploitable groundwater reserves in the area.
    The average transmissivity is 6.5 x 10^{-2} m^2/s.
    The water table is located at a depth of 150m.
    Total discharge of all springs located within the basin is 84.5 Mcm per year.

  - Jdita Jurassic Basin:
    Jdita spring owes its emergence to a small anticline of around 8 km^2 located 5km west of Zahle. This anticline is surrounded by less permeable rocks of lower Cretaceous age.
    The basin is mainly fed by infiltration of rain and snowmelt.
    The average annual discharge of the spring is 2.8 Mcm.
    Transmissivity is equal to 5.2 x 10^{-2} m^2/s.
    Storage coefficient is equal to 2.5 x 10^{-2}.
    Two wells were tested in the basin:
    - First well: 12 meters drawdown at a pumping rate of 33 l/s.
      3 meters drawdown at a pumping rate of 20 l/s.
    - Second well: 8 meters drawdown at a pumping rate of 50 l/s.

- Cretaceous (Cenomanian-Turonian) basins
  The most prominent aquifers are made of Cenomanian-Turonian limestones.

  - Mount-Lebanon/Beqaa Cretaceous Basin:
    This basin is bounded from the north by the basalts of Homs, from the west by the axial line of mountain tops, from the south by the Jurassic limestones of Jdita and from the east by the Beqaa plain. The Yammoune fault plays a major role in dividing this basin into three major units:
    - An elevated tabular unit in the west
    - A succession of valleys and depressions in the middle
    - A folded lower unit in the east.

    40% of all water discharged from springs within the "interior province" are sourced from this basin.
    The springs include "discharge/overflow springs" like Yammoune spring, Ayoun Ourghoche, Berdaouni etc., or "artesian springs" like El Assi or Chtaura spring.

Transmissivity measured from 4 pumping tests (done in Berdaouni, Yammoune and Ayoun Ourghoche) ranges between 5.5 x 10^{-3} and 3.1 x 10^{-1} m^2/s with an average of 1.4 x 10^{-1} m^2/s (which is quite high).
The main outlets within this basin are Nahr el Assi, Chtaura and Berdaouni which have a combined average yearly discharge of 420 Mcm (13.4 m^3/s). 70% of this discharge flows in winter with only 130 Mcm flowing between June and September.
The groundwater flow direction was determined through tracer tests which resulted in the following: the part of the basin located east of the Yammoune fault plays a major role in feeding Nahr el Assi.
In conclusion, any pumping attempts at high altitudes within this basin will highly affect the discharge rate of Nahr el Assi but not that of Berdaouni which has its own independent drainage system within the basin.

- Anti-Lebanon Cretaceous Basin:
  This basin is the longest basin in the “internal province” extending over 1115 km^2 covering a large part of Anti-Lebanon and Hermon. It is bounded from the west by Senonian marls and/or quaternary deposits.
  Limestones of Cenomanian age in this basin are dipping towards the north-west with a thickness of 600m.
  The static reserves of Chamsine and Anjar springs extend over an area of 12 km^2 approximately which translates to an aquifer of 170 Mcm capacity.
  The major springs located within this basin are: Ras el Ain, Laboue, Ras Baalbek, Hasbaiya and Wazzani.
  The combined static reserves of both Chamsine and Anjar springs are estimated to be around 4 Mcm.
  The average hydraulic module across the basin is equal to 7 $l/s/km^2$.
  The springs within the basin can be divided into three different categories:
  - North: Ras el Ain and Laboue,
  - Center: Chamsine and Anjar
  - South: Hasbaiya and Wazzani

  In conclusion, although the Anti-Lebanon Cretaceous basin is rich in groundwater, it cannot be overexploited during winter.

- South Beqaa Cretaceous Basin:
  Transmissivity measured from 4 pumping tests ranges between 2.3 x 10^{-3} and 7.4 x 10^{-2} m^2/s.
  Reconnaissance wells located 19 km north of Karaoun Dam in Tell ed Deir were able to denote faulted limestones at 240m below ground level.
  Limestones of Cenomanian age, similarly to those of the Jurassic, were therefore intensely karstified before and during the deposition of quaternary rocks in the Beqaa plain. Static reserves are therefore guaranteed deep in the subsurface.
  The only spring located within this basin seems to be located at the end of the Litani valley upstream of the contact between Cenomanian limestones and Senonian marls. This spring hasn’t been studied before but a discharge of 700 l/s is estimated during the summer of 1952.
  Eocene limestones in Joub Janine/Mejdel Anjar and those of Cenomanian age in Tell Znoub, are directly interlinked. Although they form two separate basins, their exploitation cannot be dissociated and therefore were studied as one.
  In conclusion, this aquifer can be exploited up to a maximum of 30 Mcm per year without any major drawdown effect, regardless of the amount of precipitation over the basin.

- Eocene basins

Limestones of Eocene age in the Beqaa are commonly observed in three different regions: South, East, and West with the southern ones occupying the largest surface area (250 km^2). All together, they cover an area of 317 km^2.

Tableau 39. Extension des affleurements des calcaires éocènes en Békaa

Région	*Surface (km^2)*	*Epaisseur (m)*	*Lithologie*
Békaa-Sud	250	100–800	Calcaires récifaux
Békaa-Est	50	200–300	Calcaires récifaux
Békaa-Ouest	17	200–300	Calcaires récifaux
Total	317		

- Southern Beqaa Eocene Basin:
  Eocene limestones in this region form a syncline that extends from Mejdel Anjar in the north to Marjayoun in the south. Although in some areas these limestones are in direct contact with Jurassic limestones, they do not seem to be connected at the subsurface.
  In Marjayoun, faulting and fractures were observed at 50m below the surface. The limestones within this basin were therefore subject to extreme karstification before and during the deposition of quaternary rocks. No springs seem to be found at the contact between the Eocene limestones and the Neogene deposits in Marjayoun. This is due to the fact that groundwater flows towards Cenomanian limestones such as those of Tell Znoub.
  At the border of El Marj plain, two springs exist which are Hammam and Dardara.
  The two major springs sourced from these Eocene limestones, which are located at the end of the Litani valley, are Ain Zerka and Ain Borghos. Their combined discharge represents three quarter of the total discharge of all springs sourced from this unit.
  Transmissivity measured from 5 pumping tests ranges between 8 x 10^{-3} and 2 x 10^{-2} m^2/s.
  Three groundwater flow directions are delineated within this syncline which subdivides the Southern Beqaa Eocene basin into three more or less independent sub-basins:
  - North of a diving line that extends from Bire to Lela, groundwater flows towards Soultan Yaakoub, joining the groundwater which flows from Mejdel Anjar to finally end up in the Cenomanian limestones of Tel Znoub.
  - In the center region which includes Jabal el Aarbi and Bir ed Dahr, groundwater flows towards the two major outlets Ain Zerka and Ain Borghos
  - South of a dividing line that extends from Hasbaiya to Blate, groundwater flows towards the south to emerge at El Marj plain.

- Eastern Beqaa Eocene Basin:
  Eocene limestones are observed in a discontinuous pattern between Jabal Terbol and the village of Ras Baalbeck. Due to the presence of a transverse fault in Anjar, there seems to be no hydrogeological connection between the limestones of the South and those of the North in Beqaa. This is confirmed by the differences in the altitude of piezometric levels which are 15 to 20 meters

lower in the south than north of the fault.
The Eocene limestones in this basin lie in the east over impermeable Senonian marls whereas in the west, they're in direct contact with overlying conglomerates.
Several transverse faults divide this basin into multiple smaller basins of which the most important is the one located on the extreme southern end between Jabal Terbol and the village of Haour Taala over an area of 27 km^2.
Multiple "overflow springs" are sourced from this basin including Ras el Ain, Faouar and Ain el Baida. Additionally, springs that are sourced from Neogene conglomerates within the Beqaa plain must be considered to originate from the direct outlets of Eocene basins.
Transmissivity ranges between 1.4 x 10^{-2} and 3 x 10^{-1} m^2/s.
Eocene limestones and Neogene deposits are in direct contact.

- Western Beqaa Eocene Basin:
  This basin extends over 17 km^2 between Zahle and Chmistar. It represents the western flank of the Beqaa plain syncline. The basin is surrounded from all directions by Senonian marls and Neogene rocks. Limestones within this basin have a uniform thickness of 400m and represent a good aquifer which has been subject to intense karstification.
  Four "overflow springs" are sourced from this basin: Haouchbey, Zahle, Fourzol and Nabile which have a combined average flow of 120 l/s (of which 80 l/s are from Haouchbay).
  Transmissivity, measured from 2 pumping tests (done for two wells near Fourzol spring), is 10^{-3} m^2/s.
  Piezometric levels are: 1022m in the north near Haouchbey spring, 1300m in the center and 1000m near Zahle.
  Average annual volume that could be pumped from this basin is around 4 Mcm.

- <u>Beqaa Neogene and Quaternary basins</u>
  These basins are bounded from all directions by Jurassic, Cenomanian and Eocene limestones. Two different aquifer levels are observed:
  - the first characterized by Neogene conglomerates well developed in Zahle, Baalbeck, Hermel and El Marj. Due to their carbonated cement, some of these conglomerates can act as a karstic environment for water outlets to emerge like Chtaura spring and Nahr el Assi.
    In most areas however, the conglomerates have an argillaceous cement which renders them less permeable.
  - the second is characterized by non-consolidated quaternary deposits (marls, pebbles and clays) which cover the central part of the Beqaa plain. At their contact with the surrounding limestones, these deposits form an impermeable barrier.

  Transmissivity values vary within the area: in Kfar Dan and Baalbeck they're in the order of 10^{-2} m^2/s whereas in Tell Amara and Rayak, they barely exceed 10^{-4} m^2/s.
  Two groundwater flow directions are observed: the first towards the south-west in the direction of Joub Jannine, and the second towards the north-east in the direction of El Kah plain.
  There is a direct contact between the Neogene/quaternary basin and the Eocene limestones of Terbol whereas in south Anjar, both basins are not connected.
  The groundwater surface never exceeds a depth of 50 mbgl, yet in summer, it rises to the point where the southern part of the plain floods. It varies in the order of 2 to 5 meters throughout year.

The most productive areas for pumping within this basin are east of Kfar Dan and south-west of Baalbeck.

D. Mediterranean province basins

- Jurassic basins
  The three major areas in this province for the development of Jurassic basins are, from north to south, Sir Ed Danie-Ain Yacoub, Keserouane, and Barouk.
  Although Jurassic limestones appear in small patches in the vicinity of Nahr ed Damour, they are not considered of any interest due to their compaction which renders them impermeable.
  Six boreholes drilled in Nahr Beirut valley, in Dekouane, at Nahr el Mot and Nahr ej Jaouze, have proven that if karstification exists below the levels of current springs, it is extremely heterogenous due to individual channels that aren't interconnected.

  - Sir Ed Danie – Ain Yacoub Jurassic Basin:
    This region can be subdivided into two areas: the small plain of Ain Yacoub and the valley of Nahr Abou Moussa. Only the former was studied.
    This basin is bounded from all directions by less permeable lower Cretaceous rocks. It covers an area of 135 km^2 including 20 km^2 for Ain Yacoub.
    At the base of Harf el Haoua, which is intensely karstified and located south-east of Ain Yacoub, outcropping Jurassic dolomites exhibit granular porosity.
    Groundwater in this basin, which flows towards the plain of Ain Yacoub, is interrupted by impermeable layers of lower cretaceous rocks. This favors the emergence of multiple "overflow springs".
    Six boreholes in the area have shown that the Jurassic dolomite layer does not exceed a thickness of 40-50 m.
    The major springs are located at the contact with lower Cretaceous formations near the village of Tikrite.
    Transmissivity measured from 9 pumping tests ranges between 2 x 10^{-3} and 2 x 10^{-2} m^2/s.
    The total discharge of all springs within this basin is estimated to be 3 Mcm per year. The groundwater surface level never exceeds 20 mbgl between Ain Yacoub and Ayoun.
    Total flow rate within the basin is 19 Mcm per year (600 l/s).

  - Keserouane Jurassic Basin:
    This basin extending over 450 km^2 in the core of the Lebanese mountains.
    Jurassic limestones in this basin are bounded from the north-east by Cenomanian limestones, from the west by the big western flexure, and from the south by overlying less permeable lower Cretaceous formations.
    At higher altitudes, Jurassic limestones are tabular with horizontal to sub horizontal layers, however in the west, these layers are dipping towards the sea. These massive Jurassic limestones form an excellent infiltration zone as evidenced by the lack of perennial springs at higher altitudes (in exception of Ain el Delbe). Precipitation infiltrates rapidly the subsurface and only shows up as "overflow springs" at the lowest point of the western flexure.
    Although karstification had started towards the end of the Jurassic, it doesn't seem to exist below the current springs level. In fact, all the reconnaissance wells in the area have come across compacted limestones that do not exhibit any faulting nor karstic channels.
    The major springs within this basin (which originate from underground rivers) are: Nabeh Dalle in Nahr el Jaouze, Jeita in Nahr el Kelb, Antelias in Nahr Antelias and Daychouniye in Nahr Beirut.
    It was impossible to define a specific groundwater flow direction in this basin

due to individualized groundwater channels that aren't necessarily connected. Groundwater reserves in this basin are estimated to be around 290 Mcm.

- West Barouk – Niha Jurassic Basin:
  This basin includes the western flank of Jabal Barouk and Jabal Niha. It extends over 90 km^2 in the regions of Safa, Barouk, Ain Zhalta, Maasser Chouf and Niha.
  The western limit of this basin is clearly defined as the contact between its own Jurassic limestones and the overlying sandstones of the lower Cretaceous formations.
  The eastern limit of this basin is less defined and was delineated using the total discharge of all the springs on each side of the mountain range.
  Similarly to Beqaa, all the springs within this basin are located at the border of the mountains, at the contact with lower Cretaceous sandstones. Most of these springs are classified as "overflow springs".
  The karstic morphology of the basin is quite developed favoring the infiltration of precipitation. At greater depths, karstification extends below base level. This was proven first through Nahr el Safa which emerges from sandstones and second through fractures intersected by the Jezzine tunnel that traverses the Jurassic anticline at an altitude of 750 masl, clearly below all natural outlets/springs.
  Transmissivity is approximately equal to 4.5 x 10^{-1} m^2/s. The total annual discharge of all the springs within this basin (western flank) is equal to 62 Mcm, whereas that of the eastern basin (eastern flank) is 88 Mcm. Springs on either side of the karstic mountain (for example Safa spring vs. Ammik spring) are highly correlated meaning that they share one common water table. Any overexploitation of one group of springs on one side will directly affect the other side and vice versa. Groundwater reserves in this basin are estimated to be around 140 Mcm.

<u>Cretaceous (Cenomanian-Turonian) basins</u>
Cenomanian limestones form the most extensive aquifer level in the Mediterranean province, extending over an area of 2260 km^2. They are highly karstified and represent the highest mountain peaks in Lebanon. They are prominently observed:

- In the north over an area of 700 km^2 including Rachine and Chekka springs;
- In the region between Batroun and Jounie over an area of 360 km^2.
- In Sannine over an area of 150 km^2.
- In Hadath over an area less than 10 km^2.
- In between Damour and Nakoura over an area of 475 km^2.
- In Jezzine and part of the Chouf over an area of130 km^2.

The remaining 440 km^2 are dispersed and do not play any role in the transmission of groundwater.

- North Lebanon Cretaceous Basin:
  This basin is bounded from the north and north-west by the western flexure that separates Akkar and Koura from the Lebanese mountains. Towards the east, the Jurassic complexes of Ain Yacoub, Sir ed Danie and Kadicha mark a clear boundary with higher plateaux. The basin extends over 700 km^2.
  Rachine and Nabeh Kadi springs (overflow springs) are located at the lowest point of contact between Turonian limestones and Senonian marls along the flexure at an altitude of 126m approximately. The layers within this basin are dipping 45 degrees towards the west with the Senonian marls forming an impermeable layer. The 10 boreholes drilled in the area have shown that karstification extends in the subsurface for over 80m below the level of springs.

In Nabeh Kadi, groundwater channels are heavily filled with decalcifying clays and sand. In Chekka, 17 sub-marine springs are located 50m to 1km away from the coast at depths varying between 5 and 47m. Seven of those 17 springs are permanent with the most important one discharging a flow of 50 m^3/s during winter.
Two intermittent springs are located inland within this basin at a distance of 800m away from the coast at an altitude of 24 masl. Their combined discharge is equal to 3 m^3/s for a maximum of three weeks per year.
All the springs in this basin emerge from Senonian marls and quaternary deposits although they're sourced from Cenomanian-Turonian limestones.

- *Rachine and Kadi springs:*
  Transmissivity measured from 5 pumping tests is higher towards Rachine (10^{-3} to 2 x 10^{-2} m^2/s) than in Kadi (3 x 10^{-3} to 6.10 x 10^{-3} m^2/s). An average of 9 x 10^{-3} is adopted. Although both springs are 800m apart, it seems that their networks are not connected regardless of them being located within the same basin. The total annual volume available from both springs combined is 55 Mcm.
- *Chekka spring:*
  Transmissivity ranges between 10^{-4} and 1.3 m^2/s which is explained by the extreme karstification of the limestones which are compacted yet cross-cut by channels. The coexistence of perennial springs and intermittent springs can only be explained by the fact that groundwater channels are independent from one another.
  The variations of piezometric levels, which are directly linked to precipitation rates, are determined by the drop in pressure in the groundwater channels as well as the difference in density between freshwater and sea water (as per the law of Ghyben-Herberg). During summer, when groundwater levels are at their lowest, the deepest springs dry and force an inverse circulation whereby seawater intrudes certain channels. Therefore, chlorine concentrations rise in some parts of the basin and sub-marine springs end up with brackish water.
  During winter, discharge rates increase as well as piezometric levels. Intermittent springs flow again and the inverse circulation ceases to exist. Therefore, all springs including the submarines ones, will have freshwater.
  In conclusion, sub-marine springs are sourced through karstic channels (for more info, see page 140-141).

- Batroun – Jounie Cretaceous Basin:
  This basin extends over 360 km^2 between Ras Chekka and the bay of Jounie. It is bounded from the east and south-east by the western flexure, from the north by the village of Koura. The Cenomanian limestones dip towards the sea within this basin. In the vicinity of Amchit and east of Batroun, the Senonian is distinguished by its fauna and marly facies.
  The lack of sub-marine springs (likes those of Chekka) within this basin shows that along the coast, this basin drains towards the sea directly.
  As a matter of fact, freshwater and seawater are mixed in this region.
  With limestones being highly permeable usually, it is difficult to properly delineate the separation zone between freshwater and seawater. Therefore, it is considered as a horizontal plane located at sea level (altitude 0m).
  All wells located within this basin have pumped brackish water during early stages of pumping. Away from the coast at greater depths, the thickness of the freshwater unit is more significant. This same setting is observed between Khalde and Saida.

Shortly after rainfall, groundwater recharge through infiltration in this basin diminishes and water salinity increases. Seawater intrusion would always invade any groundwater pumped from this basin, therefore, it is necessary to properly delineate the freshwater-seawater separation surface (as done in Khalde) through geophysical investigations.

- High Central Mount Lebanon Cretaceous Basin:
  This tabular region is characterized by limestones whose surface are scattered with karstic features (elongated hollows). The basin extends over an area of 150 km^2. It is bounded from the east by the Yammoune fault, from the west by the massive Jurassic cliffs of Keserouane.
  Groundwater flows partly towards the Mediterranean Sea and partly towards the Beqaa. The limit between both flow directions was approximately delineated as the dividing line of the surface water.
  The base of the western end of this basin is marked by a series of springs which emerge at the contact with Albian marls. The major springs from north to south are: Nabeh Souccar, Mar Sarkis, Kadicha spring, Akoura, Afka, Nabeh el Aassal, Nabaa el Laban and Sannine. Although Kadisha spring emerges from conglomerates that overly Jurassic limestones, its high discharge rate can only be sourced from the basin within the plateau.
  Over the plateau, precipitation and snowmelt infiltrate the subsurface quite rapidly and reach a maximum depth of 500-600 mbgl as they're interrupted by Albian marls.
  Piezometric levels are therefore far away from the surface across the whole plateau but only close to the surface at the borders of it (the plateau).
  Most of the springs located within this basin are covered with snow for most of the year, hence their discharge rates are less known.
  Using Afqa spring flow rates, the estimated annual volume is around 145 Mcm. The highest flow rates are observed during May when snow had finally melted. They increase again in December with heavy rainfall events.

- Hadath – Hazmiye Cretaceous Basin:
  The basin covers an area smaller than 10 km^2. It is bounded from the north by Nahr Beirut, from the south by Nahr el Ghadir, from the east by Albian marls and from the west by quaternary deposits of the coast.
  At greater depths, the limestones are dipping in an east to west direction below the Neogene formations.
  Based on piezometric level variations, both Nahr Beirut and Nahr el Ghadir seem to suggest a very weak groundwater circulation.
  In the areas located west of Hadath-Hazmiye, limestones are 400-500m thick but pinch out (get thinner) towards the east at their contact with Albian rocks.
  Pumping tests have shown that karstification extends for 150mbgl.
  The basin in this area is highly permeable and sourced mainly from precipitation.
  Groundwater flows slowly towards the sea via Neogene deposits and perhaps through limestones that emerge below the sea (sub-marine).
  Piezomteric levels are clearly higher south of Nahr el Ghadir and north of Nahr Beirut. This suggests that, if this basin was ever to be in contact with other basins from the north or the south, they would probably be poorly connected and therefore seawater intrusion from either side would be very limited.
  The Hadath-Hazmie basin discharges towards the sea rather than the less permeable Neogene formations (for more info see page 152).

- Khalde – Naqoura Cretaceous Basin:
  Cenomanian limestones within this basin cover an area of 910 km^2, excluding the Jezzine syncline that forms a separate unit by itself.
  Groundwater flow that is mainly headed towards the sea can be subdivided into two different systems:
  - *between Khalde and Saida, and south of Ras el Ain:* limestones are in direct contact with the sea. Groundwater flow is diffused and seawater invades the coastal zone. This situation is similar to that of Jounie-Batroun.
  - *between Saida and Ras el Ain:* the less permeable formations of the Senonian and Eocene form a barrier that prevents the mixing of freshwater and seawater, isolating the limestones within the basin.

  The faulting network in the area permits in some places the intrusion of seawater into the basin.
  The major springs in the central zone are:
  - Ras el Ain and Rachidiye, both artesian springs that emerge after having travelled through Senonian marls for long distances; and
  - Kasmiye, an overflow spring located at the contact between Senonian marls and Cenomanian limestones.

  Transmissivity measured from 12 pumping tests ranges between 10^{-2} and 2.5 x 10^{-2} m^2/s. This shows how heterogenous groundwater flow is within this basin. The balance between freshwater and seawater was studied in Khalde and Jiye. The overall results obtained could be applied also to Jounie-Batroun basin. Through geophysical investigations on multiple wells located at different distances from the sea, the authors were able to conclude the following:
  - In areas far enough from the sea, at a distance of at least 1.5 km, it is possible to pump any well at a rate less than 3 l/s without risking any increase in the salinity of the water.
  - The interface zone where chlorine concentrations are equal to 1000 mg/l is located at a depth less than 150m below ground level.
  - It is possible to exploit the groundwater reserves but only at very low pumping rates which could either supply villages with lower water needs or irrigate smaller neighboring fields.

  In the coastal area located between Beirut and Saida, the Damour region particularly stands out due to two parallel faults that form a Senonian marl barrier between the Cenomanian limestones and the sea. This has led to the creation of better freshwater reserves in Damour than the north or south of the basin.
  Between Saida and 'Tapline refinery', limestones are highly intruded by seawater at a depth of 300 mbgl. In Ghazie, chlorine concentration in groundwater is 14600 mg/l whereas towards the north, the concentration is 200 mg/l. Groundwater becomes saltier in Aaddousiye with seawater intrusion still being observed at 3km away from the coast (inland) below the Babliye plateau. This trend extends up till Kasmiye where the freshwater-seawater boundary becomes closer to the sea. This boundary retracts inland up until Ras el Ain. Therefore, it is advised to exploit groundwater only in Kasmiye and Ras el Ain. Piezometric levels are affected by seawater level. Groundwater flows towards the west at a gradient of 0.4%, meanwhile inland, the groundwater level is located deep within the subsurface.
  By the sea, due to the difference in density between freshwater and seawater as well as the impermeable layer of Senonian marls, the water table can emerge as artesian such as the case in south Tyr.
- Jezzine Cretaceous Basin:
  This basin extends from Barouk in the north to Nabatiye in the South over an area of 130 km^2. It is bounded from all directions by impermeable Albian

rocks making it an isolated unit separated from all other basins in the Mediterranean province.
All the springs located within this basin are “drainage springs”: Azibe (1010 masl), Jezzine (1020 masl), Nabeh el Tasse (690 masl), Maidani and Jarmaq (400 masl). The synclinal axe between Niha and Jezzine subdivides this basin into two sub-basins: the northern one covering an area of 50 km^2 and the southern one covering an area of 80 km^2.
73 Mcm of water infiltrates the subsurface in the whole basin. Runoff doesn’t exceed 10% of total precipitation. Total annual discharge of all springs combined is 5 Mcm. Piezometric levels in the basin, which are conditioned by the altitude of springs, are located:

- at the surface level near the springs; and
- 200 mbgl in the center of the basin and in regions located at 1200 masl.

- Eocene basins

Eocene formations are located in the south parallel to Saida and cover an area of 540 km^2. They are mostly observed as coastal tabular plateaux that are slightly inclined towards the sea. In the region of Ouadi Doubbe (between Nabatiye and Bint Jbeil), limestones form a syncline whose axis gets lower from the north to the south near the Litani valley. The impermeable substratum of this basin is formed of Senonian marls above which groundwater flows.
The major springs in the basin are located in the Litani valley and the Ouadi Hjeir valley, however they’re intermittent in the latter one. Groundwater flows either towards the sea or towards the Litani valley along the syncline formed by Senonian marls.
Transmissivity measured from pumping tests is relatively low in the order of 10^{-4} m^2/s, in exception of a few limestone lenses where transmissivity can reach 10^{-2} m^2/s.
In the north of Ouadi Doubbe, springs that emerge at the contact with Senonian marls dry-up during summer. The lowering of the groundwater table is comparable to that of the north Litani area.

- Miocene basins

Miocene limestones cover an area of 103 km^2 and are mainly outcropping in the following areas: in Beirut forming the Achrafiye hill (2 km^2), at Nahr el Kelb (11 km^2), in Ras Chekka (10 km^2) and in Koura (75 km^2).

- Beirut Miocene Basin:
  Its proximity to the sea and seawater intrusions in Nahr Beirut limit any exploitation of this basin.

- Nahr el Kelb Miocene Basin:
  This small basin fed from the overflow of Nahr el Kelb during winter is rich in chlorine. Salinity concentrations in the basin drastically rise when the overflow of Nahr el Kelb ceases to exist. The basin is also not exploitable.

- Ras Chekka Miocene Basin:
  This basin is not exploited as it is not profitable. Multiple springs by the sea are sourced from this basin.

- Koura Miocene Basin:
  Through 4 boreholes drilled in the area, two different aquifer layers are identified: conglomerates at the base and karstified reefal limestones.
  - The lower aquifer level is characterized by marly limestones between Amioun and Zgharta, with the top layer of conglomerates being

located at 143 and 161 meters below sea level in Kfar Chakhna and Mejdelaya respectively. These conglomerates are only exposed in the south (Amioun, Kfar Akka) and south-west (Ras Kifa, Khaldiye) of the plateau.

- The upper aquifer level is separated from the lower one by a 170m thick layer of marly limestones. In the center of this plateau, this aquifer level is characterized by lacustrine marls and recent impermeable conglomerates. The thick layer of marly limestones is in direct contact with the sea at the base of Jabal Kelhate whereas in Tripoli, it is isolated by quaternary deposits. The reefal limestones are intensely karstified as evidenced by the cave of Ain Dara (80 mbgl depth). The karstification of reefal limestones is believed to have developed up to the Senonian/Eocene marls as well as up to the marly limestones of Jabal Terbol and Jabal Kelhate. However, below the Koura plateau, the limestones were protected from karstification due to recent impermeable desposits.

Groundwater flows towards the sea with a focus in Tripoli. The hydraulic gradient is around 1%. The depth of the basin varies from a few meters at the coast to 180m approximately in Kfar Chakhna.

The upper aquifer level is fed by the infiltration of precipitation across a surface area of 75 km^2.

The annual discharge of this basin is estimated to be 25 Mcm (4 Mcm from Badaoui spring, 4 Mcm from sub-marine springs, 10 Mcm from Ain Dara cave and 7 Mcm via pumping of Tripoli wells).

Transmissivity in the lower aquifer level, measured from 2 pumping tests, range between 10^{-4} m^2/s (in Medjelaya) and 10^{-2} m^2/s (In Kfar Chakhna). Transmissivity in the upper aquifer level is 10^{-2} m^2/s (at Abou Samra). Reefal limestones pinch-out (get thinner) towards the center of the plateau becoming hydrogeologically mediocre.

- Aptian – Albian basins

  These basins are characterized by a stratigraphic series of alternating argillaceous sands, limestones and marls. The overall stratigraphic thickness is around 300-400 meters covering an area of 450 km^2. The only permeable level in this sequence is a limestone bed 60m thick named “falaise de Blanche”.
  The lower Aptian facies of limestones and sands could also give rise to some springs. Most of the springs in these basins are structurally tabular.
  Total volume discharged by the springs of this basin in summer is 700 l/s.

- Cretaceous sandstone basins

  Lower Cretaceous sandstones cover an area of 250 km^2 at the border of the massive Jurassic mountains of Keserouane and Barouk. They extend the most in Kalaat Fakra, Baskinta, Kfar Salouan, Falougha, Nabeh Safa, Roum (western flank of Jabal Barouk) and east Beirut. Their thickness doesn’t exceed 300m.
  This less permeable unit gives rise to multiple smaller springs that are permanent. Transmissivity is 3 x 10^{-4} m^2/s in Falougha and Sannine whereas in Dekouane, it is 10^{-2} m^2/s.
  The potential amount of groundwater available in this basin probably doesn’t exceed 5 $l/s/km^2$.

- Neogene – Quaternary basins

  Neogene – Quaternary deposits cover a combined area of 375 km^2. Due to the steep slopes of rivers in the Mediterranean province, alluvial deposits are very unlikely to exist. Neogene and Quaternary deposits are thus localized in Akkar plain, around Tripoli, on the Koura plateau and along the coast specifically on the Beirut platform.

If not intruded by seawater, these basins can be exploitable if they are thick and permeable enough. This is only possible in Akkar and Koura. Although these formations are thicker than 250m in Choufeiat, the intrusion of seawater is recorded in the earliest stages of pumping. Over the Koura plateau, the Neogene is represented by conglomerates of argillaceous cement.

- Akkar Neogene/Quaternary Basin:
  No major springs are located in this basin.
  The Cenomanian-Turonian sub-stratum is located close to the surface in the north-east of the Akkar plain. It is intersected at 485 mbgl in Sammakiye where it is covered by a 170m thick layer of Senonian marls. Therefore, across the first 500 mbgl, Neogene/quaternary deposits form the only available basin.
  The basin has an average thickness of 12m in the west and 8m in the east.
  Transmissivity measured from 10 pumping tests is:
  - between 5 x 10^{-3} and 4.5 x 10^{-1} m^2/s for the Pleistocene;
  - between 1.5 x 10^{-2} and 3.1 x 10^{-2} m^2/s for the volcano-sedimentary formations of the Piacenzian.

  The piezometric surface gradient is 0.6% in the east and decreases more towards the west to reach 0.12% by the sea.
  The total discharge of the basin was estimated to be 20 Mcm (only the Lebanese part of the plain.

E. Hydrochemistry

- More than 9000 water samples were collected and tested. The hydrochemistry of each basin was illustrated on the 1:200000 hydrogeological map. All the sample collection points as well as the designated data were submitted to the Government.
- *Non-contaminated basins in a karstic environment:* water is typically rich in bicarbonated calcitic facies. Mineralization and chlorine concentrations are higher in the west than in the Beqaa. The softest waters originate from the Jurassic limestones of Keserouane and Barouk.
- *Non-contaminated basins in a porous environment:* water contained within lower Cretaceous sandstones are generally bicarbonated and have higher concentrations of sulfur due to the oxidation of pyrite (commonly found in these formations). The iron content in these waters is often higher than the limit set for drinking water.
- *Neogene-Quaternary basins:* basins are characterized by high concentrations of dissolved salts due to the low speed of water circulation and the impact of human activity (irrigation, use of chemical fetilizers, etc…).
- *Basins contaminated by the sea:* seawater content in basins with brackish water varies from 0.33% of the total volume like the case of Hadath to 93.6% in regions where limestones are in direct contact with the sea. Seawater invasion is observed all along the coast but only generalized in areas where Cenomanian and Miocene karstic limestones are in direct contact with the sea.
- *Waters of lagunal formations:* these are only observed in deep Miocene formations below the Akkar plain. They are highly mineralized due to the dissolution of gypsum and anhydrite as well as typically rich in sulfates. Hence, they're unsuitable for both drinking and irrigation purposes.

4. GROUNDWATER EXPLOITATION

A. *General conclusion*

The amount of exploitable water (both surface water and groundwater) is 1400 Mcm in Beqaa and 3540 Mcm over the Mediterranean province. Out of 30 basins studied, only 13 were regularly measured.

B. *Groundwater exploitation*

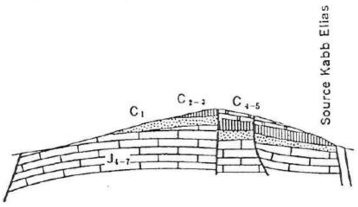
- The total annual discharge of exploitable water being estimated at 4900 Mcm is divided as follows: 1300 Mcm of surface water and 3600 Mcm of groundwater.
- The average volume of groundwater available during summer is 1400 Mcm (1120 Mcm from springs, 100 Mcm from an unmeasured fraction consumed by the population, 80 Mcm from submarine springs and 100 Mcm of diffused flow).
- Around 200 Mcm of water is estimated to flow outside the Lebanese border (into neighboring countries) but from springs located within the country. This amount is obviously not exploitable reducing the total volume of groundwater during summer to 1200 Mcm. Adding the volume of water that accumulates at the surface which is 540 Mcm, the maximum annual volume exploitable during summer is 1740 Mcm.

MODIFICATIONS/MISTAKES IN THE ORIGINAL HYDROGEOLOGICAL MAP

Etude des eaux souterraines au Liban

Carte hydrogéologique au 1:200 000:

1. Les îlots de Ramkîne, Palmier, Sanâni, Moudaoûara, Bella et Taouline, situés au nord-ouest de la ville de Tripoli, doivent être figurés avec le symbole géologique des calcaires récifaux d'époque néogène-miocène;
2. A droite de la coupe hydrogéologique A--A', au lieu de Rachaïy, lire: Rachaïya;
3. Dans la coupe hydrogéologique B--B', la représentation géologique des terrains situés à l'ouest de la source de Kabb Eliâs doit être la suivante:



4. En ce qui concerne la carte des ressources potentielles, donnée en cartouche de la carte hydrogéologique, il convient de noter ce qui suit:
   a) Pour l'unité 21, le débit unitaire disponible est de 15-20 l/sec/km² au lieu de 10-15 l/sec/km²;
   b) Pour l'unité 22, le débit unitaire disponible est de 5-10 l/sec/km² au lieu de 10-15 l/sec/km²;
   c) Pour l'unité 29, le débit unitaire disponible est de 5-10 l/sec/km² au lieu de 0,5-5 l/sec/km²;
   d) Pour la partie inférieure de l'unité 19, le débit unitaire disponible doit être de 10-15 l/sec/km² au lieu de 5-10 l/sec/km²;
   e) L'unité entourée par les unités 1,4 et 11 doit porter le numéro 6.
5. Dans la légende de la carte chimique, donnée en cartouche de la carte hydrogéologique, l'unité de mesure est le milligramme de résidu sec par litre (mg/l R.S.).

ANNEX III C.2

BGR STUDY SUMMARY

BGR STUDY SUMMARY

Study area location and physical settings

The final delineated groundwater catchment stretches in N-S direction from ENE of Tannourine el Faouka to Baskinta (approx. 28 km) and in W-E direction from Jeita to almost the eastern escarpment of the Lebanon mountain range (Upper Cretaceous plateau) (approx. 26 km). The elevation rises from 60 m asl at Jeita to 2628 m asl at Mount Sannine.
The project area covers the eastern part of the surface water catchment of Nahr Ibrahim (198.5 km^2 or 48.9 %) and the northern part of the Nahr el Kalb catchment (207.4 km^2 or 51.1 %).
The project first assumed that Jeita GW was equivalent to its surface water catchment following UNDP 1972 study. However, following detailed tracer testing and hydrogeological investigations it was expanded to its current limits.

Geology and hydrogeology

The geological units of the study area are mainly composed of limestone/dolomites and to a minor extent clastic sediment, displaying alternating transgression/regression paleo-environments. The time scale of the mapped formations ranges from Lower Jurassic (Liassic) to Late Cretaceous (Cenomanian).

The geological survey aimed at achieving the following:

- Detailed geological mapping of the Jeita Spring/Nahr el Kalb catchment supported by remote sensing,
- Structural measurements,
- Delimit karst features, major fault- and fracture zones by various remote sensing methods and to verify them in the field

Based on the results of the geological mapping, the groundwater system was divided into three main units:

- Upper Aquifer: C4 geological unit (highly karstified limestone), assumed thickness up to 1,050 m;
- Aquitard Complex: J5 to C3 geological units, assumed thickness: 500to 800 m;
- Lower Aquifer: J4 geological unit (highly karstified limestone), assumed thickness up to 1,070 m.

Tracer Tests

Tracer tests were conducted between 2010 and 2013 as part of the BGR study on Jeita spring to delineate its contribution zone. Altogether, 14 tracer injections in GW and 10 surface water tracer tests were conducted in the Jurassic and Cenomanian aquifers of Mt. Lebanon, including pollution tracers.

The results of those tests can be summarized in the following points:

- The sub-catchments of all major springs in Jeita GW catchment were delineated,
- The aquitard complex represented by formations J5 to C3 does not allow vertical infiltration to the lower Jurassic aquifer,

- The runoff originating from the Cenomanian aquifer will however infiltrate to the Jurassic aquifer in the Upper Jurassic J4 formation in the form of sinkholes and losing streams.

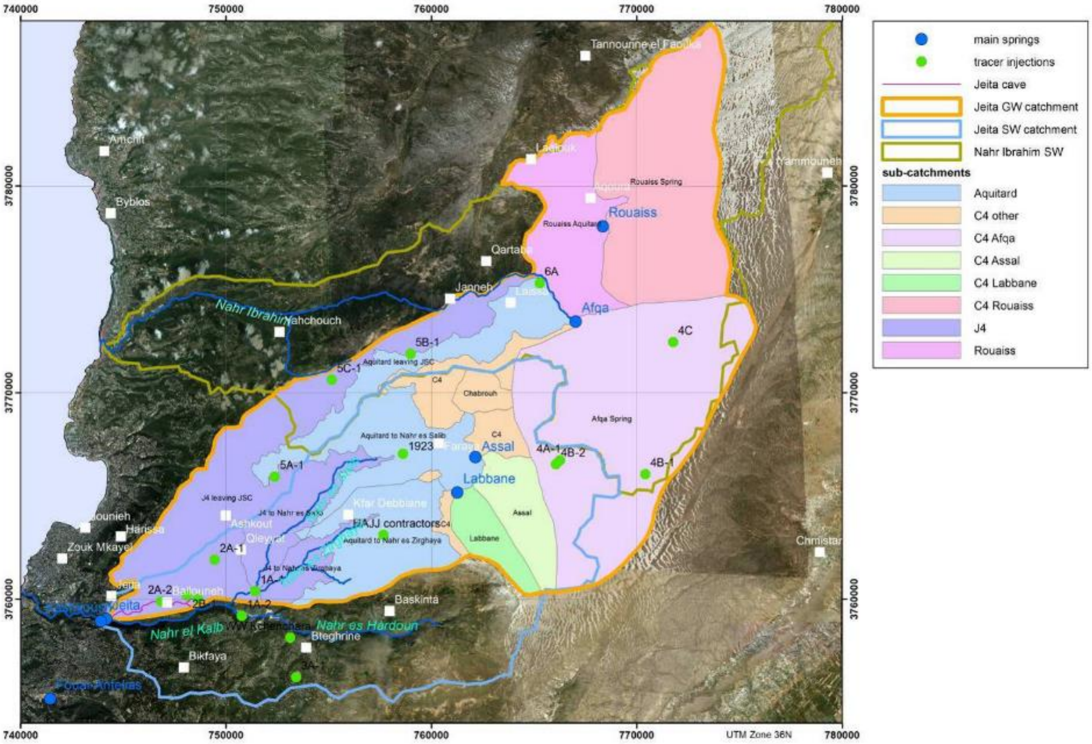


Figure 55: Sub-catchments of Jeita Spring

Groundwater Discharge and Abstraction

The outflows from the main springs were monitored as part of the BGR study in order to quantify the GW discharge from Jeita catchment. Groundwater abstraction by private and public wells were estimated at 0.5 MCM/a. This value corresponds only to the governmental wells abstraction since domestic wells were assumed to be insignificant especially after the establishment of Chabrouh dam. GW abstraction for irrigation is estimated at 5 MCM/a.

Table 10: Groundwater Discharge at Springs

Spring	Discharge [MCM/a]	Source of Information	Discharge in WEAP Model [MCM/a]
Afqa (C4)	123.2	MARGANE & STOECKL, 2013	131.2
Rouaiss (C4)	96.6	SCHULER & MARGANE, 2013	89.3
Assal (C4)	24.0	MARGANE & STOECKL, 2013	21.4
Labbane (C4)	14.4	LRA	14.7
Minor springs (C4+J6)	23.7	Estimated based on various sources	33.2
Total C4	270.2		290.2
Jeita (J4)	166.4	MARGANE & STOECKL, 2013	175.6

Groundwater recharge

Groundwater recharge (GWR) was estimated by well defining the components of the water balance in each sub-catchment, by the following equation:

$$GWR= P-ET- R -I +O$$

where P is precipitation, ET is evapotranspiration, R is runoff, I is inflows and O is outflows. GWR in Afqa sub-catchment was estimated at 80.3% of precipitation, 82% in Assal, 81% in Labbane. In general, recharge in the upper aquifer ranges between 75 to 92%, whereas it reaches 55% in the lower Jurassic aquifer. The low amount of GWR in the Jurassic aquifer was thought to be insufficient to account for the high flow in Jeita spring. Therefore, 41.9% of the flow to the lower Jurassic aquifer is believed to originate from the upper Cenomanian aquifer and 22.7% from the aquitard complex, where both component infiltrate to the J4 through sinkholes and losing streams. This claim was supported by means of hydrochemical analysis (e.g. EC and chloride) where Jeita spring water was observed to be a mixture between the Cenomanian aquifer and the Jurassic aquifer water.

Infiltration to the Jurassic aquifer at Upper Naher Ibrahim

Surface flow measurements were conducted on the Upper Naher Ibrahim valley to confirm that infiltration is indeed occurring in the highly karstified Upper J4 formation. Infiltration ranged between 35% and 52%, according to different measurement campaigns. This result however lacks further tracer tests to confirm that the infiltrated water outflows in Jeita spring and not elsewhere, which is considered as a major setback in this study. On this basis, Janneh dam would act as a recharge facility (MAR) rather than for surface water storage.

Groundwater Balance

Following the quantification of the components of the Groundwater balance, WEAP (Water Evaluation and Planning) model was developed to assess the absolute inflows and outflows of Jeita GW catchment in each of the 13 sub-catchments. The model used monthly time steps and was modeled one water year. The results are summarized in the figure below.

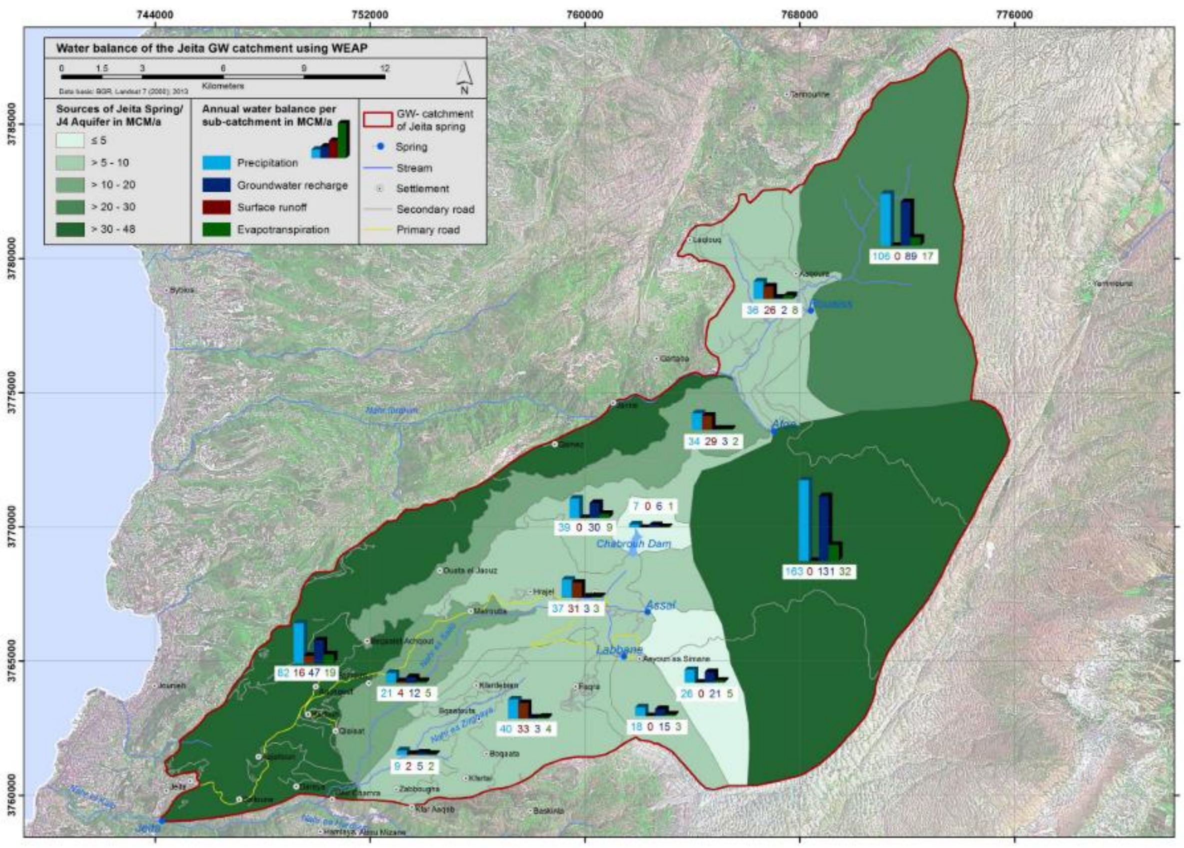


Figure 95: Origin of Flow Contributions to Jeita Spring in MCM/a and simplified Water Balances of all Sub-Catchments

Water isotope analysis

Stable isotope analysis revealed that there is a significant change in the monitored springs of Jeita, Kashkoush, Assal, Labbane, Afqa and Rouaiss. As it might be expected, the springs fed by the higher altitude Cenomanian plateau were correlated with the integral snow samples taken from the higher altitudes, and had a lower percentage of heavy isotopes which precipitates at lower elevation in comparison to the Jurassic aquifer. The Jeita spring isotope analysis shows that a large portion of the water coming from Jeita must be precipitated at elevations > 1400m due to its light isotopic signature.

Groundwater velocity

The water velocity in the discovered underground river of Jeita was measured by dilution tests. Velocity values ranged between 220 and 1900 m/h in the dry and wet seasons respectively.

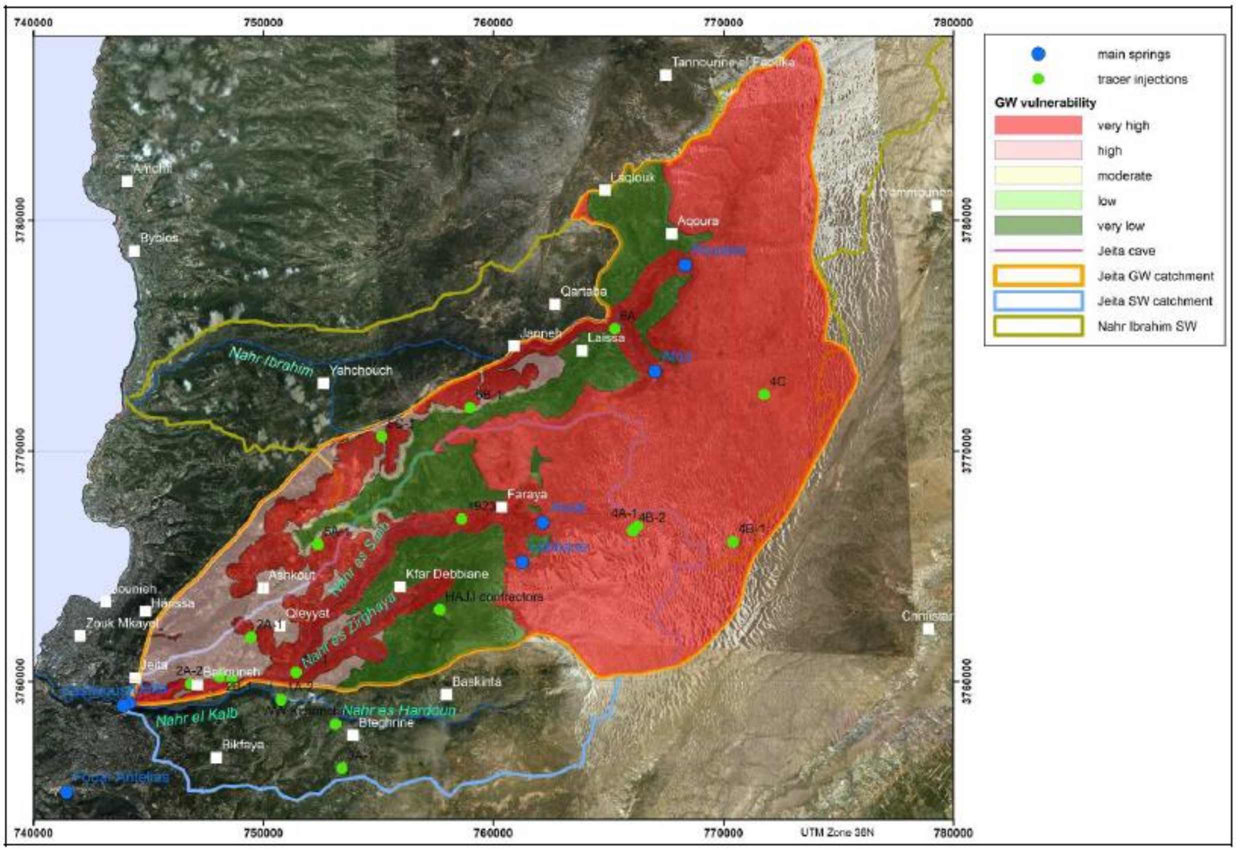
Groundwater Hazards

Following a detailed survey of all possible groundwater hazards in Jeita catchment, the major hazards were identified were: “wastewater disposal in rivers, wells and open cesspits, gas stations (83 stations in the catchment), slaughterhouses, hospitals, quarries, animal farms, and illegal dumping of waste”.

GW vulnerability and protection zones

A groundwater vulnerability map was prepared for the entire groundwater catchment of Jeita spring, based on the COP method (VIAS et al., 2002,2006). This method specifically addresses infiltration processes in karst. To be applicable in all of Lebanon, the method was slightly modified by BGR (MARGANE & SCHULER, 2013). The resulting map is shown in the figure below. Due to the intensive karstification, a large share of the catchment falls into the categories of high and very high vulnerability.

This underlines the urgent need to protect the groundwater resources of Jeita spring.



Based on the above groundwater vulnerability map and the determined flow velocities in the groundwater system, groundwater protection zones were determined for Jeita spring and all other major springs in the Jeitacatchment, i.e. Afqa, Rouaiss, Assal and Labbane spring (MARGANE &SCHULER, 2013). Groundwater protection zones were classified into:

<u>• Zone 1: immediate protection zone</u>
protects groundwater from direct contamination risk > access only for authorized staff

<u>• Zone 2: inner protection zone</u>
protects groundwater more particularly from contamination by pathogenic microbiological constituents such as bacteria, viruses, parasites and worm eggs and from other contamination which may be hazardous.

<u>• Zone 3: outer protection zone</u>
protects groundwater from contamination affecting water over long distances such as contamination by radioactive substances or chemicals which are hardly degradable.

Recommendations

- Install proper monitoring wells for water levels
- An improved spring capture and water conveyance to Dbayeh drinking water plant was recommended to increase water supply to Beirut.
- The project recommends conducting tracer tests at the proposed effluent discharge locations at the beginning of the planning process
- Conduct more hydrogeological studies in Lebanon similar to this project
- A comprehensive groundwater resources assessment is urgently needed
- Creation of a National Water Resources Management Agency
- Creation of a geological survey is highly recommended to prepare updated geological maps and geophysical surveys
- Delineation of protection zones for all springs in Lebanon
- Continuous monitoring of springs discharge and rivers flows
- Establish a water quality monitoring program

ANNEX III C.3

LITANI RIVER BASIN MANAGEMENT SUPPORT PROGRAM
WATER BALANCE – USAID – SUMMARY (2011)

ATTACHMENT C.3

LITANI RIVER BASIN MANAGEMENT SUPPORT PROGRAM
WATER BALANCE – USAID – SUMMARY (2011)

A water balance assessment has been conducted in the upper Litani River Basin which covers about 1500 km2 in the Central and South Bekaa Valley (from Ain Assaouda spring near Baalbeck down to Qaraoun reservoir).
The objectives of this assessment are to:
1. Provide an overview of the current state of knowledge of the water balance for the upper Litani River Basin;

2. Document how the water balance has been established, what available data was used and what reasonable hypotheses were made, and also to guide future water data collection; and

3. Alert water user and decision makers as to the current and future water deficits that jeopardize sustainable water use in the Litani River Basin.

The water balances used to describe the system are:

- Atmospheric balance: Precipitation = Evaporation + Rain Runoff + Groundwater Recharge
- Surface Water Balance: Total/final River Runoff = Rain Runoff + Baseflow – Total Surface Withdrawals (– Surface Storage Recharge if any)
- Groundwater Balance: Groundwater Storage = Groundwater Recharge – Baseflow – Total Groundwater Withdrawals

The data available and needed for the above equations are summarized below.

a) Precipitation data

- Pre-war data: annual/monthly precipitation for different villages in the Bekaa Valley covering several years until the 1970s

- Recent data: daily rainfall since 1998 for a few limited stations (Rayak, Zahle).

The lack of reliable long-term series is a critical issue in Lebanon.
The average annual precipitation rate ranges in the Upper Litani river basin vary between 300 mm inland and between 1300 and 1400 mm over the summit peaks. A further analysis of the different rainfall zones in the basin gave an estimated average of 685 mm/year of precipitation for the entire Upper basin.
The corresponding annual precipitation volume in the ULRB, whose downstream boundaries are the Qaraoun Dam, is estimated to be about 1100 Mm3/year, divided between 1,030 Mm3 in winter (December-May) and 70 Mm3 in summer (June-November).

b) Evaporation data

Little data is available to assess direct evaporation from precipitation in the Litani River Basin. A proxy method is to calculate evapotranspiration using the Penman-Monteith equation as advised by FAO.
In the Bekaa, this equation provides an average evapotranspiration of about 2.5 mm/day (source FAO CROPWAT database) for the six months of the winter rainy season (December-May), which amounts to a total of about 650 Mm3 for the entire ULRB, or about 60% of precipitations.

c) Surface flows data

Available data includes the following:

- Period of 1921-1951: monthly inflows at Mansoura (USBR Hydrology, 1954).
- Period of 1938-1968: monthly inflows at Mansoura (UNDP 1970, Etude des Eaux Souterraines au Liban).
- Period of 1931-1973: LRA daily records at Mansoura station
- Period of 1938-1962: LRA daily records at Qaraoun station.
- Period of 1962-2010: LRA monthly inflows at Qaraoun Dam.
- Period of 1998-2009: LRA records at Joub Jannine Gauging station.

The main issues are that:

- No data exists for the Civil War period from the mid-70s till the mid-90s; and no station exist to compare before and after;
- The Mansoura station is unreliable;
- The Qaraoun station was removed when the dam was built; and
- Other stations exist in the lower basin (Khardale, sea oulet) but are outside of our area and also do not represent natural flows since the early 1960s and the construction of Qaraoun Dam.

Several comments can be made on the Litani river flow:

- Over 80% of river flows occur in winter (December-May);
- Runoff volumes in the Litani River have decreased over the past 50 years, from over 400Mm3/year in the 1940s-50s to 300 Mm3/year today; this is due to:
  - Increasing diversions from springs and river flows for irrigation (mostly in Summer); and
  - Probably also a decrease in base flows caused by the lowering of groundwater tables (due to increased groundwater pumping).

Subsequently summer flows have drastically decreased, from 4-5 m3/s in the 1970s down to 0.5-1 m3/s today; this is a direct consequence of the decrease/disappearance and/or diversion of many spring flows that used to supply the river in summer.

d) Groundwater data

Limited and scarce data is available regarding groundwater flows, in terms of recharge, withdrawals or existing storage and fluctuations

It has been estimated that a total volume of 200-210 Mm3 annually recharge the aquifers within the Litani River Basin (UNDP Etude des Eaux Souterraines, 1970). This total estimate includes infiltration in all aquifers within the River Basin, i.e. Barouk-Niha aquifer, Jdita aquifer, part of South Bekaa aquifer (Qaraoun – Tell ed Deir), East Bekaa Aquifer (Terbol – Ras Baalbeck), West Bekaa aquifer (Zahle – Chmistar) and Quaternary alluvial aquifer in the Bekaa Valley.

Results:

The results (millions of m3 per year) provide interesting findings for policy and decision-making:

Component	Natural State	1940	1970	2010	2030
Precipitation	1100	1100	1100	1100	1100
Evaporation	660	660	660	660	660
Groundwater Recharge	210	210	210	210	210
Total Runoff	440	410	370	300	270
Net Surface Withdrawals	0	30	50	60	60
Net GW Withdrawals	0	0	30	150	200
Groundwater Change	0	0	(-10)	(-70)	(-90)

These findings are evident indicators of unsustainable water allocation practices in the Litani River Basin. More specifically, intensive irrigation practices, uncontrolled groundwater pumping and surface water diversions are the main concerns (along with quality issues, which are not discussed here).

The issue of sustainable water management in the Litani River Basin clearly needs to be addressed, since:

- Current and future water balances for the river basin show that demands exceed availability; and
- Plans are being made to divert Qaraoun Lake volumes to supply Beirut with potable water (Bisri- Awali project), and to irrigate large areas in the South (Canal 800 project).

About 375,000 people live in the Upper Litani River Basin. The Bekaa Water Establishment considers about 150 l/cap/day for domestic needs, which leads to a total needed volume of 20 Mm^3/year. The Bekaa Water Establishment actually pumps larger volumes due to significant leakages (50% and more) in the networks (these leakages are not lost since they recharge the groundwater they were initially pumped from). According to BWE, the volumes annually pumped are around 50Mm^3 and the volumes delivered to customers in the entire Bekaa are around 25 Mm^3/year (source: BWE). Considering that the Litani River Basin covers 2/3 of the Bekaa, area- and population-wise, pumping there is around 35 Mm^3.
Most losses are due to leakage and thus return to groundwater, so the net annual abstraction in the LRB (considering also some private unrecorded pumping, notably by industries) is around 20 Mm^3. Most of the water used by residents, businesses, and industries is not actually consumed (that is disappearing through evaporation), but ends up as wastewater which goes either to septic tanks (where it seeps down to groundwater) or to sewers where it flows back to the river (often without treatment).

Water use practices and behaviors have to be improved in terms of water use efficiencies which can only be addressed through awareness and stewardship/empowerment of water users, and improved performance and coordination among water management agencies, while better water monitoring is also essential to confirm these water balance analyses and guide water management in the Litani River Basin.

ANNEX III C.4

UNDP 2014 STUDY - SUMMARY

SUMMARY OF UNDP 2014 STUDY

Summary of the UNDP2014 study **Assessing the National Groundwater Resources through Data Collection and Field Campaign Assessment of Groundwater Resources across Lebanon** by a Consortium of ELARD (consortium leader), BURGEAP, IGIP and RIBEKA engaged by the United Nations Development Programme (UNDP) through a contract referenced 11/64 and singed on October 4, 2011

The study conducted between 2012-2013 resulted in the production of number of reports or deliverables:

1- Del 01 Inception Report
2- Del 02 Technical Report on Public wells
3- Del 03 Proposed Monitoring Equipment Specifications
4- Del 04 Proposed one year Monitoring Plan
5- Del 05 Initial Installation of a Fully Operational Database at t
6- Del 06A Preliminary Baseline Data Assessment Report
7- Del 06B Private well Survey Report
8- Del 07 Monitoring Plan Implementation
9- Del 08 Technical Report on Dedicated Database
10- Del 09 Data Synthesis and Basin Water Resources Characterization
11- Del 10 Artificial Recharge Preliminary Assessment
12- Del 11 Monitoring Equipment Handover Report
13- Del 12 3D GW modeling Akkar
14- Del 13 Training Completion Report

A summary of the main results of the study is presented here below.

1- TECHNICAL REPORT ON PUBLIC WELLS (DELIVERABLE # 2)

Between November 14, 2011 and February 13, 2012 around 840 public wells from the different Water Establishments were surveyed in the field. The survey resulted in the refinement of the original well database provided by the Water Establishments (WE).
General information was collected on each public well (well depth, pump depth, type of casing, depth to groundwater, operating hour etc.) and completed at the office with the assignment of the expected aquifer tapped and estimates of the discharge rates.
An initial total list of 783 wells was provided by the different WE, but the field inspection was able to identify a total of 841 public wells (218 in BMLWE, 209 in BWE, 277 in the SLWE and 137 in the NLWE). It turned out that many new wells were not on the original lists and others from the list were inaccessible. The total number of abandoned wells is 44 while 68 wells were found to be non-operational.
The gathered data revealed a very low number of properly equipped wells. Flow meters are installed in 287 public wells, and 112 wells have piezometers. Detailed numbers of distribution of flow meters and piezometers in the different areas covered by the various WE are given.
The water quality was tested in 470 public wells for pH, conductivity, salinity and temperature.
According to the survey results the operational public wells are exploiting the various aquifers of Lebanon at a rate of about 248.7 million m3/year which is approximately 18 million m3/year less than the estimated figure in 2010. This actual discharge rate was subdivided into the different estimated major aquifers tapped by the various WEs.

Table 3-1 Summary table of public wells in Lebanon

ESTABLISHMENT	TOTAL NO. OF WELLS SURVEYED IN THE FIELD	TOTAL EXTRAC-TION RATE (m^3/day)	TOTAL EXTRACTION RATE (Million m^3/year)	TOTAL EXTRACTION RATE AS OF MOEW 2010* (Million m^3/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

2- INITIAL INSTALLATION OF A FULLY OPERATIONAL DATABASE AT THE MOEW (DELIVERABLE # 5)

An existing software (GW-Base) developed by RIBEKA (Germany) was selected to serve for groundwater database management with capabilities to store and manage various information (geological, drilling, logging and well construction) needed for the assessment of wells. Groundwater levels can also be interpreted and analyzed, as well as pumping tests and discharge rates data and chemical quality data.

On February 15 and February 16, 2012 the software package was installed by RIBEKA personnel on a dedicated PC located at the offices of the Lebanese Center for Water Management and Conservation at the MoEW and loaded with various datasets on public wells, topographic and hydrogeological maps (from UNDP, 1970) as well.

3- PRELIMINARY BASELINE DATA ASSESSMENT (PRIVATE WELLS SURVEY REPORT- DELIVERABLE # 6B)

The well database obtained from the MoEW contained a total of 20537 private well, included about 2,888 private wells with exploitation permit and about 17,649 private wells with drilling license and no exploitation permit. The survey teams encountered problems of various types in the field, such as inaccurate original data, uncooperative owners, inaccessible locations …

Out of the 2,888 private wells with exploitation permit, about 30% (889 wells) were surveyed. Out of the 17,649 private unlicensed wells without an exploitation permit that were in the MoEW original database, 3,520 could not be located due to wrong or missing coordinates and 958 wells were inaccessible. Only 13,392 wells were surveyed.

The surveyed wells in the four Water Establishments are detailed below:

	Surveyed private with exploitation permit	Surveyed private without exploitation permit
SLWE	88	2088
BWE	110	2026
NLWE	71	2527
BMLWE	624	6743
TOTAL	893	13384

The survey resulted in gathering various data and information on the wells, such as Status and Location, Well operator, Well and Pump details, Well Operation including Discharge Rate and seasonal variations, Monitoring Info (including water level and physicochemical properties), Geological data, Water usage.
Although it was mentioned (Del06B Private well survey report, p2-3) that the same survey form was adopted for public and private wells, however the provided files show major differences in the collected private wells data, such as the missing info on the discharge rate or pump characteristics.

PRELIMINARY SURVEY OF UNLICENSED PRIVATE WELLS

A preliminary survey of the unlicensed private wells was conducted in order to better constrain the potential number of unlicensed wells in the country. A detailed survey of three small pilot areas, two of them in urban settings (within Beirut and Tripoli) and one in a rural zone (in Hermel) was conducted in parallel. Their findings were compared and used to estimate the range of numbers of private unlicensed wells to be around 54,246 to 59,124, i.e. almost three times the number of licensed private wells listed at its time. The study concluded “this number should be considered a very rough approximation and may likely be under estimated” (Del06B Private well survey report, p4-6).
No data on the discharge rate of these wells is listed or mentioned in the study. Only a rough estimate of the pumped volumes in other Mediterranean countries from published data.

4- DATA SYNTHESIS & BASIN WATER RESOURCES CHARACTERIZATION REPORT, II. GROUNDWATER BASINS-BOUNDARIES AND GEOLOGY (PART OF DELIVERABLE # 9)

A re-evaluation of the divisions of the 32 GW basins defined in UNDP1970 study was performed in light of recent studies and research that were conducted during the past 40 years. A new hydrogeological map with the revised divisions of the GW basins was generated.
Refining the GW basins delineations and identification was done by incorporating topographic data and geological boundaries in relation to the structural and stratigraphic features, such as bedding inclination, folds, faults, and lithology. Tracer tests and hydrogeological studies from UNDP1970 and other more recent studies were used to discuss and update the GW flow directions.
Based on the re-evaluation of 32 GW basins from UNDP1970, the study subdivided Lebanon into 50 GW basins “44 productive GW basins were identified: Twenty eight (28) GW basins in the Mediterranean province and sixteen (16) GW basins in the Interior province. Additionally, six (6) relatively unproductive basins were also identified (three (3) in each province)” *(page 4).*
It is worth noting that the re-evaluation was totally based on desktop reviews of available geological and hydrogeological studies.

5- DATA SYNTHESIS & BASIN WATER RESOURCES CHARACTERIZATION REPORT III. KARST (PART OF DELIVERABLE # 9)

The project included mapping and classification of the karstic features on a country scale and resulted in the production of a karstic map of Lebanon. The karstic features (epikarst as well as known caves and sinkholes) were mapped over the aquifer map and followed by classifying the various karstic aquifers into zone types, based on the density of these karstic features and the presence of soil or other surface covers.

6- DATA SYNTHESIS & BASIN WATER RESOURCES CHARACTERIZATION REPORT IV. TRACER TESTS (PART OF DELIVERABLE # 9)

Results from tracer tests conducted in Lebanon are summarized and presented in the study. The reported tests are from the UNDP1970 study as well as from studies executed between 1970 and 2013 by various hydrogeology consultants (locals and international), universities and speleology groups.

7- DATA SYNTHESIS & BASIN WATER RESOURCES CHARACTERIZATION REPORT V. SPRING ASSESSMENT (PART OF DELIVERABLE # 9)

A review of available springs data for Lebanon is made along with a discussion of previous spring classification studies in Lebanon. The report proposes spring types and classes for the country and presents the hydrograph assessment of some of the major springs.

8- DATA SYNTHESIS & BASIN WATER RESOURCES CHARACTERIZATION REPORT, VI. GROUNDWATER TABLE ASSESSMENT (PART OF DELIVERABLE # 9)

Data from a 1-year long (2012-13) groundwater levels monitoring campaign in some of the GW basins of Lebanon, was presented and compared with the levels presented in the UNDP 1970 study for some basins.

DATA COLLECTION AND METHODS OF ANALYSES

The data was collected from all the manually (109) and digitally (20) monitored wells for the monitoring year 2012-2013. Groundwater levels in the manually monitored wells were measured on monthly basis; while in the digitally monitored wells they were recorded every fifteen (15) minutes. The monitored wells were distributed along 26 of the GW basins in Lebanon and their location initially selected to be in close proximity to wells monitored by the UNDP 1970 study.
The monitoring wells were also active production wells. Therefore, in most cases the dynamic water levels were basically excluded in the assessment of the water level variation.
Only in two aquifers (Akkar and Bekaa plains) was there enough data available to generate water table contour maps, the groundwater level and flow directions were estimated in 16 basins, and very little data was available for another group of 11 basins where a rough estimation of the groundwater level variations was done.

In general, the results show a drop of groundwater levels in most of the aquifers that were surveyed and where comparison with the previous reference study of UNDP1970 was possible. The decrease is affecting all aquifers from the Inner and from the Mediterranean provinces and of all formations. These can be summarized as follows grouped by formations:

- Two (Ain Yacoub Sir Ed Dannieh and Keserouane) of the three monitored Jurassic GWB that could be compared to the UNDP1970 study showed a net decrease of ~27m and 1-12m in water level respectively.

- Two (Sarafand-Khaldi and Hadath-Hazmieh) Cretaceous GWB that could be compared to the UNDP1970 study showed a decrease of water level by ~2 and 3-4m respectively.

- One Eocene GWB (Southern Bekaa) that could be compared to the UNDP1970 study showed a decrease of water level by ~4m. Two others (Sour-Sarafand and Eastern Bekaa) showed no significant change in their levels when compared to the 1970 study.

- The Koura Miocene GWB that could be compared to the UNDP1970 study showed a decrease of water level by ~40m.

- Three (Akkar plain, Southern Bekaa and Northern Bekaa) Neogene-Quaternary GWB that could be compared to the UNDP1970 study showed a decrease of water level by ~7, 20-50 and ~33m respectively.

9- DATA SYNTHESIS & BASIN WATER RESOURCES CHARACTERIZATION REPORT, VII. WATER ISOTOPE COMPOSITION OF LEBANON (PART OF DELIVERABLE #9)

This report outlines and reviews the studies on isotope hydrology carried out in Lebanon, focusing on the analysis of isotopes of water molecule only, which includes stable isotopes of hydrogen (deuterium, D) and oxygen (oxygen-18, 18O), and radioactive isotope of hydrogen (tritium, T).
The study concludes to the difficulty to relate the isotopic composition to the different air masses due to the complex topographic and meteorological situation of Lebanon.

10- DATA SYNTHESIS & BASIN WATER RESOURCES CHARACTERIZATION REPORT, VIII. HYDROCHEMICAL ANALYSIS (PART OF DELIVERABLE # 9)
Data collected and acquired:

Physico-chemical analysis of groundwater samples were collected from previous wells or springs assessments done by the various Water Establishments, consultants and research/academic work. A total of 3623 samples were thus collected (2,029 collected from Water Establishments dating back between 2001 and 2012, and 1,594 analysis from private sectors dating between 1968 and 2011).
The parameters reported in the analysis include pH, Conductivity, Total Dissolved Solids , Salinity, Calcium, Magnesium, Sodium, Potassium, Bicarbonate, Sulfate, Chloride, Alkalinity, and Total Hardness.
Moreover, a total of 118 wells, spread over the country were used as observation wells for a 1-year groundwater monitoring program (between years 2012-2013). Automatic monitoring devices were installed in twenty (20) of them for measurements **of Temperature, Conductivity, and Depth to Groundwater** every 15 minutes. The remaining eighty nine (89) wells were designated for monthly manual monitoring. As a result 361 additional samples were manually collected from 60 public wells. The 20 automatically monitored wells covered 13 different basins throughout Lebanon.
The resulting dataset for hydrochemical analysis is unequally distributed in quality and time. Geographically, all the data obtained from WE comes from the Bekaa area in previously monitored wells and only two continuously monitored wells operated in this wide area along with around a dozen of manually monitored water points. The western Mt-Lebanon has widely distributed data points, with concentrations of manually monitored wells in Akkar, Baabda, and the coastal plains of Sarafand-Adloun and Ras el Ain in the south, leaving a few continuously monitored wells sparsly distributed over the rest country. The assessment for many basins relied solely on data obtained from other previous studies. Some other large basins and areas – of importance – had no data of any kind (the Cenomanian aquifers in Nakkoura – Bint Jbeil or Batroun to Akkar areas).

Hydrochemical assessment:
The hydrochemical facies of around 300 samples from 38 GW basins were assessed using both cations and anions from collected samples. It showed that all the sampled GW basins from the interior province belong to the Ca-Mg-HCO3 facies with the same carbonate facies for the groundwater basins as the UNDP 1970 study. This carbonate facies is typical for the carbonate karst aquifers which are the dominant aquifers in Lebanon.
The Piper diagrams constructed for 15 GW basins of the Mediterranean slopes of Lebanon

revealed two hydro-chemical facies: “Ca-Mg-HCO3 facies which is typical of karstic aquifers, and Na-K-CI-S04 facies, indicating a possible influence of seawater intrusion”, “in line with what was identified by the UNDP 1970” (Del09-8 p.15). Mostly basins in direct contact with the Mediterranean Sea (19b, 18, 22, 23d, 21 and 28) are shifting from the Carbonate type hydrochemical facies to Na+K-CI+S04 facies because of invasion of salt water from the sea, as compared with UNDP1970 results.

Monitoring of salt water intrusion:
Chloride concentrations were used to assess seawater intrusion in coastal GW basins.
Around 1455 samples of chloride concentrations from 7 coastal GW basins were used from various datasources (table2-3, p.8 of Del09-8). These samples are not evenly distributed in time and location “and thus can neither give a clear idea on the mechanism of salt water intrusion; nor provide a clear evaluation of the possible irreversible effect of saltwater intrusion and the migration of saltwater zones”(Del09-8 p. 8).
However the interpretation of the collected data along the coast suggest that “salt water intrusion in the GW basins of the Mediterranean province at present is much higher than what it was in the 1970’s during the UNDP investigation. The location and depth of the fresh water salt water interface is much shallower and has shifted further inland” (Del09-8 p.29). All the coastal GW basins where water quality data was available showed a significant impact of the seawater intrusions.

11- DATA SYNTHESIS & BASIN WATER RESOURCES CHARACTERIZATION REPORT, IX. HYDROLOGY REPORT (PART OF DELIVERABLE # 9)

This deliverable includes a re-evaluation of precipitation, evapotranspiration, and runoff for the overall Lebanese territory, and ends with an assessment of the natural recharge by infiltration to the various groundwater aquifer basins in Lebanon as delineated in previous parts of the study. This task reproduces the recharge potential assessment undertaken by the UNDP1970 study using modern methods and tools and incorporating the snow melt equivalent in their water balance. Because of limited precipitation data since the civil war period the task was done based on only two hydrological cycles 2010-11 and 2011-12 considered as a dry and a wet year respectively. The main findings are related to the increased estimates of the runoff rates and of the recharge potential.
Estimated runoff values are consistent when compared with the UNDP 1970 results apart from basins where a high urbanization have occurred since 1970 where a major increase in the runoff is observed. This have pushed the overall runoff rate of the country to around 30%, while it was estimated at about 13% by the UNDP-1970 study.
The groundwater recharge rates obtained in UNDP2014 are significantly higher tan those found in the 1970 study. This increase is observed in all basins in dry and wet cycles. According to the UNDP2014 study the recharge rates amount to 53-56% of total precipitations in a dry or wet year respectively compared to 35% estimated in the 1970 study. Expressed as volumes these numbers amount to 4116 and 6651 MCM compared to only 3246 MCM estimated in the previous study.

12- DATA SYNTHESIS & BASIN WATER RESOURCES CHARACTERIZATION REPORT, X. WATER BUDGET AND SAFE YIELD (PART OF DELIVERABLE # 9)

The preliminary groundwater budget model was compiled as a workbook model in Excel in order to allow for the constant update and easy feeding of the data whenever it becomes available. The model can be used for water management “on condition that all parameters mentioned and used are adequately measured or estimated” which “assumes the establishment of a fairly reliable and accurate monitoring, measuring, and reporting system” (Del09/10.water budget, p.1).
Simple water budgets for the various GW basins were conducted for two hydrological cycles (2010-11 and 2011-12), including the results and data obtained from the various tasks

previously performed.

The study clearly voices its reserves on the exactness of the obtained results, stating "if and when the required data becomes available the model can produce good results for these years analyzed and any other year required" (Del09/10.water budget, p.6).

Moreover it cautions about the use of the results other than "indicators rather than real values"… "because of the lack of the precision and accuracy of some the components of the model" (Del09/10.water budget, p.8).

With these cautionary remarks the results suggest the existence of GW basins with a net positive surplus (essentially the Jurassic aquifers), while others have strong negative surplus considered as deficiencies or signs of overexploitation (such as the coastal aquifers in Akkar plain, Beirut or Hadath-Hazmieh already suffering from seawater intrusion or those with high irrigation needs such as the Bekaa Neogene-Quaternary Basin).

This deliverable ends by another cautionary note regarding the "preliminary budget values obtained in this report are not conclusive and cannot be used as indicator for determining safe yields"(Del09/10.water budget, p.14).

ANNEX III C.5

HYDROGEOLOGICAL CHARACTERIZATION IN 12 PRIORITY CAZAS (UNICEF-UNHCR 2016-2017) - SUMMARY

HYDROGEOLOGICAL CHARACTERIZATION IN 12 PRIORITY CAZAS (UNICEF-UNHCR 2016-2017) - SUMMARY

The aim of the study is to provide an updated understanding of the hydrogeological conditions of the selected Cazas for the ultimate purpose of sustainable water management on the Caza level. In addition, the study aimed at proposing prospective groundwater extraction locations to meet water demand of refugees living in informal settlements.

A well survey was conducted on new public wells drilled after 2012. The well head, riser pipe diameter and water level were measured. They also conducted in-situ measurements of pH, conductivity, TDS, temperature and salinity where possible. Older wells were also visited in order to measure water levels. Water samples for laboratory analysis were collected from public wells tapping the aquifers of the basins that were found with a positive water balance and were accordingly being targeted for water supply. The wells targeted for sampling were the closest accessible to the proposed groundwater extraction zones.

Akkar Caza

Geology

The main deposits and geological formations outcropping within the Akkar Caza consist of: the Quaternary deposits (Q), Pliocene Basalt Complex (BP), Miocene Fm. (mL), Paleocene-Eocene Chekka Complex unit (C6-Pa-e2a), Maameltein Fm. (C5), Sannine Fm. (C4), Hammana Fm. (C3), Mdeirej Fm. (C2b), Abieh Fm. (C2a), Chouf Fm. (C1), Salima Fm. (J7), Bikfaya Fm. (J6), Bhannes (BJ5) and Kesrouane (J4).

There are two main faults in the Akkar Caza: the Yammouneh fault (the main branch of the Dead Sea Transform Fault), and the Akkar thrust fault (secondary). The Yammouneh fault system is present to the East with its main branch trending NE. It is surrounded by a fault zone of 1-2 km width. The Akkar thrust fault bisects the Caza trending NNE-SSW with a displacement of around 300m observed by the presence of Neogene units adjacent to the Sannine- Maamaltein Formation (C4-C5).

Springs

There are around 412 springs, with only 27 of them having a reported minimum average yield. Of these 27 springs, only Ain Aamas Spring emerging from the Kesrouane Limestone (J4) is of Class 3. The remaining 26 springs are of Class 4 to 6. Generally, these springs emerges along the two major fault systems or along one of the faults that bisect them. The remaining springs are considered to be minor springs, generally of class 6 to 8, with a discharge rate of less than 0.1 l/s.

Groundwater basins and wells

There are 35 public wells managed by NLWE:

- 19 public wells in the Sir Ed Danieh – Ain Yacoub Jurassic basin, tapping the J4 aquifer;
- 9 public wells in the Mount Lebanon Bekaa Cretaceous basin, tapping the C4-C5 aquifer;
- 5 public wells in the North Lebanon Cretaceous basin, tapping the C4-C5 aquifer;
- 1 public well in the Pliocene Basalt Complex, tapping the Pliocene basalts;
- 1 public well in the Akkar Neogene-Quaternary basin, tapping the mL aquifer.

Unfortunately, the NLWE does not keep a detailed record on daily extractions. Generally, there is no automated monitoring on the wells to keep a record on exact hours of pumping, volume of water pumped, etc.

There are 806 licensed private wells with a daily extraction rate that doesn't exceed 20 to 30 m^3/day:

- 49 private wells in the Akkar Neogene-Quaternary basin, tapping the upper Pliocene-Quaternary deposits;
- 522 private wells in in the Pliocene Basalt Complex, tapping the Pliocene basalts;
- 78 private wells in the North Lebanon Cretaceous basin, tapping the C4-C5 aquifer;
- 3 private wells in the Qammoua Cretaceous basin, tapping the C4-C5 aquifer;
- 50 private wells in the Mount Lebanon - Bekaa Cretaceous basin, tapping the C4-C5 aquifer;
- 28 private wells in the Sir Ed Danieh - Ain Yacoub Jurassic basin, tapping the J4 aquifer;
- 17 private wells in the General Quaternary basins – Mediterranean basin, tapping either Quaternary deposits or underlying formations that could be J4, C4-C5, or C1-C2a;
- 45 private wells in the Abeih-Mdairej-Chouf Sandstones, tapping either C2b, C1-C2a or J4;
- 14 private wells in the Miocene, tapping the Miocene limestones.

It should be noted that unlicensed wells (estimated to be around 4300 in Akkar Caza) are 3 times or more the number of licensed wells.

Observed water level variation

When comparing the measurements conducted on 6 public wells, all located in Sir Ed Danieh - Ain Yacoub Jurassic basin tapping the J4 aquifer, with the measurements collected in 2013 on the same wells, it was observed that the groundwater level drop ranges from 2.83m to 18.1m. Generally, groundwater levels in the Akkar plain are not expected to drop significantly despite increased pumping. The increase in groundwater exploitation is most likely compensated by increase in sea water intrusion.

Groundwater balance

Sir Ed Danieh-Ain Yacoub Jurassic Basin

The groundwater balance for this aquifer shows a surplus ranging from 21.5 MCM in the typical dry year (2010-2011) to 58 MCM in the typical wet year (2011-2012).

Further exploitation of the northern portion of the aquifer in Ain Yaakoub is therefore not recommended, prior to conducting a comprehensive study, which involves the installation of a monitoring network to better understand the local groundwater flow regime.

The southern portion could eventually be exploited, however this option does not appear to be feasible due to high altitude of the area.

North Lebanon Cretaceous Basin

The groundwater balance of the portion of the aquifer basin located in the Akkar plain shows a surplus ranging from 64.3 MCM in the typical dry year (2010-2011) to 113.7 MCM in the typical wet year (2011-2012). However, based on the UNDP Study of 2014, the entire aquifer basin shows a negative balance of more than 157.1 MCM (dry) and 1.4 MCM (wet).

Further exploitation of the aquifer basin should be concentrated into the northern portion of the basin, preferably along the northern section of Akkar Fault within the outcrop of the Pliocene Basalt complex.

Qammoua Cretaceous Basin

The groundwater balance of this aquifer basin shows a surplus ranging from 9.5 MCM in the typical dry year (2010-2011) to 31.6 MCM in the typical wet year (2011-2012).
The aquifer can be further exploited by installing wells in the northern portion of the basin in the vicinity of the bounding fault trending E-W in areas of lowest altitudes.

Mount Lebanon-Bekaa Cretaceous Basin

The groundwater balance for this aquifer shows a surplus ranging from 64 MCM in the typical dry year (2010-2011) to 106 MCM in the typical wet year (2011-2012).
Further exploitation of the basin is possible, through the installation of wells in any convenient area, preferably in the vicinity of the faults that cross the basin, or along the Yammouneh fault, if needed. Additionally, the C4-C5 can be tapped into, in Wadi Khaled beneath the Pliocene Basalt Complex, or in the Bkaiaa plain (most northern portion of the Caza, beneath Quaternary, and the Basalt).

Akkar Neogene-Quaternary Basin

The groundwater balance for this aquifer shows a slight deficit of -4.7 MCM in the typical dry year (2010-2011) and a small surplus of 1.8 MCM in the typical wet year (2011-2012). These values are very close to the calibrated values of the groundwater model of the Akkar plain conducted as part of the UNDP study of 2014. Based on the model the loss to the sea which amounted to about 9.3 MCM, is mostly compensated by the recharge from the Pliocene-Basalt Complex, in the eastern and southern boundary (6.1 MCM), and by the slight contribution from the rivers (2.2 MCM). Based on the water balance, and the results of the groundwater model, the aquifer is being exploited at its full sustainable capacity. Any further exploitation will favor the increase of sea water intrusion in localized areas. A general increasing trend of salinity was observed while comparing the salinity data from 1970 and 2013. The coastal stretch can be divided into three (3) main regions based on the salinity values observed in coastal wells:

- *Northern stretch:* extending from the northern boundary to Cheikh Zannad. It is characterized by salinities varying from 530 mg/l in 1970 to 1200 mg/l in 2012.
- *Middle stretch:* extending about 3 km south of Cheikh Zannad. In this stretch the salinity measured in a well in 1970 reached about 1840 mg/l. Comparison of data between 1970 and 2013 show that salinity in this stretch has increased but to a lesser extent.
- *Southern stretch:* extending from stretch two (2) till the southern boundary. In this stretch, salinities have increased from an average value of 450 mg/l (FAO 1970) to an average of 520 mg/l.

Proposed groundwater extraction zones

The proposed extraction zones are aimed at tapping the Cretaceous aquifers. Seven (7) candidate extraction zones are proposed.

Groundwater quality

In Akkar Plain, a general increasing trend of salinity was observed while comparing the salinity data from 1970 (FAO 1970) and 2013 (UNDP 2014). TDS values obtained from the 2012-2013 monitoring campaign varied between 360 ppm and 1510 ppm. FAO 1969 values ranged between 275 ppm and 1295 ppm.

Minie-Danniye Caza

Geology

The main deposits and geological formations outcropping within the Minie-Danniye Caza consist of the Quaternary deposits (Q), Miocene conglomerates (mcg), Miocene marls and breccia (m2), Miocene Limestone (mL), Chekka Fm.(C6), Maameltein Fm. (C5), Sannine Fm. (C4), Hammana Fm. (C3), Mdeirej Fm. (C2b), Abieh Fm. (C2a), Chouf Fm. (C1), Chouf Basalts (βC1), Salima Fm. (J7), Bikfaya Fm. (J6), Bhannes & Bhannes Basalts (J5 & β J5), and Kesrouane (J4).

There are two main folds in the Minie-Danniye Caza: The coastal flexure and the Kousba anticline. The Caza is fragmented by many secondary faults trending dominantly ENE-WSW and E-W. Most of the faults are primarily of dextral type with a horizontal displacement reaching sometimes up to 300 m and a vertical displacement reportedly reaching 100 m approximately (Dubertret, 1956).

Springs

There are over 170 springs. Most of the springs are located in the Sannine-Maameltein Cretaceous aquifer and have a relatively large discharge (Magnitude 3).

Groundwater basins and wells

There are 18 public wells managed by NLWE:

- 7 public wells in the Jabal Terbol Miocene basin, tapping the mL aquifer;
- 3 public wells in the Koura Miocene basin, tapping the mL aquifer;
- 8 public wells in the North Lebanon Cretaceous basin, tapping the C4-C5 aquifer.

There is an extraction increase of 8,046 m^3/day from 2012 to 2016 from public wells.

There are 92 licensed private wells:

- 33 private wells in the North Lebanon Cretaceous basin, tapping the C4-C5 aquifer;
- 11 private wells in the Jabal Terbol Miocene basin, tapping the mL aquifer;
- 25 private wells in the Koura Miocene basin, tapping the mL aquifer;
- 18 private wells in the Sir Ed Danieh-Ain Yacoub Jurassic basin, tapping the J4-J7 aquifers;
- 4 private wells in the Bcharre-Danieh Cretaceous basin, tapping the C4-C5 aquifer;
- 1 private well in the Tripoli Quaternary basin, tapping the Quaternary semi-aquifer.

It should be noted that unlicensed wells (estimated to be around 276 in Minie-Danniye Caza) are 3 times or more the number of licensed wells.

Groundwater balance

Mount-Lebanon Bekaa Cretaceous Basin

The groundwater balance of the basin portion located in the Minie-Danniye Caza shows a surplus ranging from 7.6 in a typical dry year (2010-2011) to 14.1 Mm3 in a typical wet year (2011-2012). This basin is situated in elevated areas and far from populated areas; for this reason, it is not considered as an attractive target to be exploited.

Sir Ed Danieh - Ain Yaacoub Jurassic Basin

The groundwater balance of the basin portion located in the Minie-Danniye Caza shows asurplus ranging from 29.1 Mm3 in a typical dry year (2010-2011) to 57.4 Mm3 in a typical wet year (2011-2012). However, this aquifer was found to be in an area where the need of additional sources of water is not required.

North Lebanon Cretaceous Basin

The groundwater balance of the basin portion located in the Minie-Danniye Caza shows a deficit of -49.7 Mm3 in a typical dry year (2010-2011) to -4.8 Mm3 in a typical wet year (2011-2012). Several major springs located within or outside the Caza are draining this basin such as the Chekaa Submarine springs and the Jrade springs located just south of the Caza. The basin is being overexploited as evidenced by the decrease in discharge rate of the Chekka Springs, the high electric conductivity values obtained from the spring (27,333 µS/cm), and the increased seawater intrusion on the coast (El Hajj 2008). Future exploitation of this basin is not recommended.

Jabal Terbol Miocene Basin

The groundwater balance of the basin portion located in the Minie-Danniye Caza shows a deficit of -2.9 Mm3 in a typical dry year (2010-2011) to -2.3 Mm3 in a typical wet year (2011-2012). Future exploitation of this basin is not recommended.

Bcharre-Dannieh Cretaceous Basin

The groundwater balance of the basin portion located in the Minie-Danniye Caza shows a surplus of 77.1 Mm3 in a typical dry year (2010-2011) and a surplus of 121.8 Mm3 in a typical wet year (2011-2012). The water balance of the basin is positive suggesting that the aquifer is not under stress. Future exploitation of the basin may be possible.

Koura Miocene Basin

The groundwater balance of this basin shows a deficit ranging from -1.5 Mm3 in a dry year (2010-2011) to -0.2 Mm3 in a wet year (2011-2012). The basin is extensively exploited inside and outside the Caza. Moreover, there is evidence of saline intrusion in this basin (UNDP 2014). this aquifer is being mined putting the aquifer under danger of salt water intrusion in the low land areas. Therefore, it is not recommended to further exploit the Koura Miocene Basin (23d).

Identification of groundwater pollution sources

Poor sanitary infrastructure, solid waste dumps, industrial areas, poor application of Agrochemicals, and leaking fuel stations.

Water supply

As reported by the NLWE, the demand of the population in the area is about 37,394 m^3/day. Current water supply from public wells used for domestic purposes is 13,424 m^3/day while the total spring discharge is estimated at 311,780 m^3/day after deducting spring discharge used for irrigation. This suggests that the Caza has a relative surplus when the needed water supply is compared to the available water sources.

However, sources of water (mainly springs) are mostly concentrated in the Danniye area, which is the mountainous area of the Caza, while most of the population is concentrated in the coastal portion of the Caza. NLWE reports that the coastal portion of the Caza is currently suffering from water shortage, which is consistent with the fact that the coastal villages are mainly supplied from wells in addition to the demands of the Syrian population, resulting in a deficit of 20,535 m^3/day approximately.

Proposed groundwater extraction zones

The results of the water balance exercise are not supportive of well construction along the coast to relieve the coastal area because coastal aquifers are stressed. The most sustainable solution seems to be conveying water from springs from the upper portions of the Caza to the coastal population.

Groundwater quality

Groundwater was sampled from 2 wells tapping the mL aquifer of the Jabal Terbol Miocene Basin and the C4-C5 aquifer of the North Lebanon Cretaceous Basin. Both wells sampled had bacteriological contamination; this was attributed to potential wastewater contamination or animal waste up gradient or near the wellhead. Alkalinity values in both wells sampled exceed the Lebanese drinking water standards due to the high content of calcium carbonate, which can result from rocks such as limestone or can be leached from dolomite and calcite in the soil.

Koura Caza

Geology

The main deposits and geological formations outcropping within the Koura Caza consist of: The Quaternary deposits (Q), Miocene limestones (mL) and conglomerates (mcg), Paleocene-Eocene Chekka Complex unit (C6-Pa-e2a), Maameltein Fm. (C5), and Sannine Fm. (C4).
There are two secondary folds in the Koura Caza: Qalhat Anticline and Zgharta Syncline. The Qalhat Anticline extends in a NNE-SSE direction and is located in the north western part of the Caza. The Zgharta Syncline which trends in a NNE-SSE direction is located in the middle of the Caza and extends northerly beyond the Caza boundary. The Caza is fragmented by one secondary strike-slip fault, The Batroun fault, trending E-W with a strike slip component of around 3 km and a normal component of around few hundred meters.

Springs

There are over 80 springs. The majority of these springs are sourced from the Miocene limestone aquifer having a small discharge. The two major springs located in the Koura Caza (Abou Halka and Nabaa el Haab) are of drainage/overflow type. They have a lower stratigraphic barrier.

Groundwater basins and wells

There are 21 public wells managed by NLWE:

- 12 public well in the Koura Miocene basin, tapping the Miocene limestones (mL);
- 9 public wells in the North Lebanon Cretaceous basin, tapping the C4-C5 aquifer.

There is an overall decrease in groundwater extraction from public wells between 2011 and 2016.

There are 661 licensed private wells with a daily extraction rate varying between 40 and 320 m^3/day:

- 495 private wells in the Koura Miocene basin, tapping the Miocene limestones (mL);
- 166 private wells in the North Lebanon Cretaceous basin, tapping the C4-C5 aquifer.

It should be noted that unlicensed wells (estimated to be around 2130 in Koura Caza) are 3 times or more the number of licensed wells.

Observed water level variation

When comparing the measurements conducted on 3 wells, two tapping the C4-C5 aquifer of the North Lebanon Cretaceous basin and one tapping the Koura Miocene Basin, with the measurements collected in 2013 on the same wells, it was observed that: the groundwater level in the well tapping the Miocene aquifer had increased most likely due to the fact that it had not been functional for a period of time (possible recovery); whereas in one of the wells tapping the C4-C5 aquifer, the groundwater level had dropped by 11 meters.

Groundwater balance

North Lebanon Cretaceous Basin
The entire basin has a yearly deficit of about 157 MCM (in the dry year 2010-2011), and 1.4 MCM (in the wet year 2011-2012). Several major springs located within or outside the Caza are draining the basin including: the Chekaa Submarine springs and the Jrade springs located just south of the Caza. The basin is being overexploited.

Koura Miocene Basin
The entire aquifer basin is estimated to have a surplus in budget of about 26.2 MCM (in the dry year 2010-2011), and 50.6 MCM (in the wet Year 2011-2012). The basin is extensively exploited inside and outside the Caza. There is evidence of saline intrusion in this basin. Therefore, it is not recommended to further exploit the Koura Miocene Basin.

Proposed groundwater extraction zones

One potential extraction zone is proposed for Koura Caza aimed at tapping the C4-C5 aquifer. It should be concentrated away from the coast, at the western portion of the basin at low relief, preferably below 400 m asl.

Groundwater quality

Groundwater was sampled from 2 wells: one tapping the Miocene Koura basin and one tapping the C4-C5 aquifer of the North Lebanon Cretaceous basin. Both wells sampled had bacteriological contamination with the one tapping the Miocene aquifer being significantly above Lebanese standards. This was attributed to potential wastewater contamination or animal waste up gradient or near the wellhead. Alkalinity values in both wells sampled exceed the Lebanese drinking water standards due to the karstic nature of both North Lebanon Cretaceous basin and Koura Miocene basin.
In the Koura Miocene Basin, chloride concentrations of the groundwater in monitoring wells were found generally below the Lebanese drinking standards with the exception of four (4) wells closest to the sea. The wells are located a few kilometers north of the Caza at the contact of this basin with the Tripoli Neogene-Quaternary Basin. The slightly high chloride values are an early indication of possible salt water intrusion.

Aley Caza

Geology

The main deposits and geological formations outcropping within the Aley Caza consist of the Quaternary deposits (Q), Maameltein Fm. (C5), Sannine Fm. (C4), Hammana Fm. (C3),

Mdeirej Fm. (C2b), Abieh Fm. (C2a), Chouf Fm. (C1), Salima Fm. (J7), Bikfaya Fm. (J6), Bhannes Fm., and Kesrouane Fm. (J4).
There are two main folds in the Aley Caza: The coastal flexure and the Barouk-Niha anticline. The Caza is fragmented by many secondary faults trending dominantly ENE-WSW and E-W. Most of the faults are primarily of dextral type with a horizontal displacement reaching sometimes up to 3km (Dubertret, 1956).

Springs

There are around 300 springs. Most of the springs are located in the Chouf Formation and have small discharge.

Groundwater basins and wells

There are 27 public wells managed by EBML:

- 1 public well in the Beirut Quaternary basin, tapping the Quaternary Semi-Aquifer;
- 13 public wells in the Sarafand-Khaldi Cretaceous basin, tapping the Sannine-Maameltein Aquifer;
- 10 public wells in the Metn-Chouf Sandstone basin, tapping the Chouf Sandstone Semi-Aquifer;
- 3 public wells in the West Barouk-Niha Jurassic basin, tapping the Kesrouane Aquifer.

There is an extraction increase of 1733.45 m3/day from 2012 to 2016 from public wells.
There are 2,447 licensed private wells with a daily extraction rate varying between 24 and 91 m3/day:

- 207 private wells in the Beirut Quaternary basin, tapping the Quaternary Semi-Aquifer;
- 1154 private wells in the Sarafand-Khaldi Cretaceous basin, tapping the Sannine-Maameltein Aquifer;
- 737 private wells in the Metn-Chouf Sandstone basin, tapping the Chouf Sandstone Semi-Aquifer;
- 16 private wells in the West Barouk-Niha Jurassic basin, tapping the Kesrouane Aquifer;
- 8 private wells in the Eastern Barouk-Niha Jurassic basin, tapping the Kesrouane Aquifer;

It should be noted that unlicensed wells are 3 times or more the number of licensed wells.

Observed water level variation

When comparing the measurements conducted on a well, tapping the C4-C5 of the Sarafand-Khaldi Cretaceous basin, with the measurements collected in 2012 on the same well, it was observed that the groundwater level in the well has dropped a bit by a few meters.

Groundwater balance

Beirut Quaternary Basin
The groundwater balance of the basin portion located in the Aley Caza shows a deficit ranging from - 3.9 Mm3 in a typical dry year (2010-2011) to - 3.2 Mm3 in a typical wet year (2011-2012). In general, this basin is extensively exploited and is highly saline due to sea water intrusion inside and outside the Aley Caza.

Western Barouk-Niha Jurassic Basin

The groundwater balance of the part of the aquifer basin located in the Aley Caza shows a surplus in a typical dry year of 4 Mm3 (2010-2011) to a surplus of 12 Mm3 in a typical wet year (2011-2012).

Eastern Barouk-Niha Jurassic Basin

The groundwater balance of the part of the aquifer basin located in the Aley Caza shows a surplus in a typical dry year of 3.6 Mm3 (2010-2011) to a surplus of 11.4 Mm3 in a typical wet year (2011-2012).

Sarafand Khaldi Cretaceous Basin

The groundwater balance of the basin portion located in the Aley Caza shows a surplus ranging from 10.6 Mm3 in a typical dry year (2010-2011) to 24.2 Mm3 in a typical wet year (2011-2012). However, this aquifer was found to be affected by seawater intrusion (UNDP2014). Future exploitation of this basin is therefore not recommended.

Metn-Chouf Cretaceous Sandstone Basin

The groundwater balance of the part of the aquifer basin located in the Aley Caza shows a surplus ranging from 9.8 Mm3 in a dry year (2010-2011) to 15.8 Mm3 in a wet year (2011-2012).

Identification of groundwater pollution sources

Poor sanitary infrastructure, solid waste dumps, industrial areas, poor application of Agrochemicals, and leaking fuel stations.

Water supply

The 2016 water demand of 65,857 m3/day under current network conditions, and taking into account the Syrian population, a deficit of 42,975 m3/day is estimated.

Proposed groundwater extraction zones

The proposed extraction zones are aimed at tapping both the Jurassic aquifer, which is under confined conditions and the Chouf sandstone semi-aquifer. 5 candidate extraction zones are proposed.

Groundwater quality

Groundwater was sampled from 2 wells tapping the karstic C4-C5 aquifer of Sarafand-Khaldi Cretaceous Basin and the Metn-Chouf Sandstone Basin. Alkalinity values in both wells exceed the Lebanese drinking water standards whereas TDS and iron values in the well tapping the sandstone basin exceed the Lebanese drinking water standards. Both wells sampled had bacteriological contamination, in limited amounts; this was attributed to potential wastewater contamination or animal waste up gradient or near the wellhead.

Baabda Caza

Geology

The main deposits and geological formations outcropping within the Aley Caza consist of the Quaternary deposits (Q), Miocene conglomerates (mcg), Maameltein Fm. (C5), Sannine Fm. (C4), Hammana Fm. (C3), Mdeirej Fm. (C2b), Abieh Fm. (C2a), Chouf Fm. (C1), Salima Fm. (J7), Bikfaya Fm. (J6), Bhannes (J5) and Kesrouane (J4).
There are two main folds in the Baabda Caza: The coastal flexure and the Barouk-Niha anticline. The Caza is fragmented by many secondary faults trending dominantly ENE-WSW and E-W. Most of the faults are primarily of dextral type with a horizontal displacement reaching sometimes up to 3km (Dubertret, 1956).

Springs

There are around 300 springs. Most of the springs are located in the Chouf Formation and have small discharge.

Groundwater basins and wells

There are 34 public wells managed by EBML:

- 10 public well in the Hadath-Hazmieh basin, tapping the C4-C5 aquifer;
- 3 public wells in the Sarafand-Khaldi Cretaceous basin, tapping the C4-C5 Aquifer;
- 14 public wells in the Metn-Chouf Sandstone basin, tapping the C1 Semi-Aquifer;
- 3 public wells in the Beirut Quaternary basin, tapping the Quaternary semi-Aquifer;
- 13 public wells in the Kesrouan Jurassic Basin, tapping the J4-J7 aquifers.

There is an extraction increase of 1733 m3/day from 2012 to 2016 from public wells.
There are 2,207 licensed private wells with a daily extraction rate varying between 24 and 91 m3/day:

- 42 private wells in the Kesrouan Jurassic Basin, tapping the J4-J7 aquifers;
- 1158 private wells in the Beirut Quaternary basin, tapping the Quaternary Semi-aquifer;
- 7 private wells in the Sarafand-Khaldi Cretaceous basin, tapping the C4-C5 aquifer;
- 424 private wells in the Metn-Chouf Sandstone basin, tapping the C1 Semi-aquifer;
- 45 private wells in the Hadath-Hazmieh Cretaceous basin, tapping the C4-C5 aquifer.

It should be noted that unlicensed wells are 3 times or more the number of licensed wells.

Observed water level variation

When comparing the measurements conducted on 3 wells, one tapping the C1 and 2 tapping the Hadath-Hazmieh C4-C5, with the measurements collected in 2012 on the same wells, it was observed that the groundwater level in the well has dropped a bit by a few meters.

Groundwater balance

Beirut Quaternary Basin

The groundwater balance of the basin portion located in the Baabda Caza shows a deficit ranging from -49.5 Mm3 in a typical dry year (2010-2011) to -47.9 Mm3 in a typical wet year (2011-2012). In general, this basin is extensively exploited and is highly saline due to sea water intrusion inside and outside the Baabda Caza.

Sarafand Khaldi Cretaceous Basin
The groundwater balance of the basin portion located in the Baabda Caza shows a surplus ranging from 0 Mm3 in a typical dry year (2010-2011) to 0.3 Mm3 in a typical wet year (2011-2012). However, this aquifer was found to be affected by seawater intrusion (UNDP 2014).

Hadath Hazmieh Cretaceous Basin
The groundwater balance of the basin portion located in the Baabda Caza shows a deficit of -2.1 Mm3 in a typical dry year (2010-2011) to a minor surplus of 0.2 Mm3 in a typical wet year (2011-2012). However, this aquifer was found to be affected by seawater intrusion (UNDP 2014).

Western Kneisseh Cretaceous Basin
The groundwater balance of the basin portion located in the Baabda Caza shows a surplus ranging from 4.1 Mm3 in a typical dry year (2010-2011) to 6.4 Mm3 in a typical wet year (2011-2012). However, it is difficult to extract water from this basin for the purpose of public water supply.

Eastern Kneisseh Cretaceous Basin
The groundwater balance of the basin portion located in the Baabda Caza shows a deficit of -0.3 Mm3 in a typical dry year (2010-2011) and a surplus of 0.9 Mm3 in a typical wet year (2011-2012). However, it is difficult to extract water from this basin for the purpose of public water supply.

Metn-Chouf Cretaceous Sandstone Basin
The groundwater balance of the part of the aquifer basin located in the Baabda Caza shows a surplus ranging from 14.6 Mm3 in a dry year (2010-2011) to 24.1 Mm3 in a wet year (2011-2012).

Kesrouane Jurassic Basin
The groundwater balance of the part of the aquifer basin located in the Baabda Caza shows a surplus ranging from 35.4 Mm3 in a dry year (2010-2011) to 65 Mm3 in a wet year (2011-2012).

Identification of groundwater pollution sources

Poor sanitary infrastructure, solid waste dumps, industrial areas, poor application of Agrochemicals, and leaking fuel stations.

Water supply

The 2016 water demand of 189,448 m3/day under current network conditions, and taking into account the Syrian population, a deficit of 121,323 m3/day is estimated.

Proposed groundwater extraction zones

The proposed extraction zones are aimed at tapping the Jurassic aquifer. 5 candidate extraction zones are proposed.

Groundwater quality

Groundwater was sampled from 2 wells tapping the karstic C4-C5 aquifer of the Hadath-Hazmieh Cretaceous Basin and the karstic Kesrouan Basin. Both wells sampled had bacteriological contamination; this was attributed to potential wastewater contamination or animal waste up gradient or near the wellhead. Alkalinity values in both wells sampled exceed the Lebanese drinking water standards whereas Total Hardness, Calcium, Magnesium, Potassium, Sodium, Bicarbonates, Sulfates and Chlorides values in the well tapping Hadath-Hazmieh Basin exceed the Lebanese drinking water standards.

Hermel Caza

Geology

The geological formations that outcrop in the Hermel Caza are from the Quaternary Period through to Jurassic. There are two primary structures in the Hermel Caza: the Bekaa Syncline and the Yammouneh fault.

Springs

There are around 50 springs. Most of the springs are considered overflow springs, structurally controlled by the Yammouneh fault.

Surface Water

The Orontes river flows at an average rate of 11 m^3/s (2001-2013).

Groundwater basins and wells

There are 8 public wells managed by BWE:

- 7 public wells in the Mount Lebanon Bekaa Cretaceous basin, tapping the C4-C5 aquifer;
- 1 public well in the Northern Bekaa Neogene/Quaternary basin, tapping the Quaternary/Neogene aquifers.

The daily extraction rate of these wells range between 100 m3/day and 562 m3/day.
No licensed privatewere identified in the Hermal Caza.
The number of unlicensed wells in the Hermel Caza was estimated to be around 3601 with an extraction rate between 0.05 and 10 l/s.

Observed water level variation

When comparing the measurements conducted on 3 wells, in Mount Lebanon Bekaa Cretaceous basin with the measurements collected in 2013 on the same wells, it was observed that the groundwater level dropped in one well and rose in two wells.

Groundwater balance

Mount Lebanon-Bekaa Cretaceous Basin

The groundwater balance of the part of the aquifer basin located in the Hermel Caza shows a surplus ranging from 226.3 Mm3 in a dry year (2010-2011) to 369.2 Mm3 in a wet year (2011-2012). Further exploitation should be concentrated, on the eastern portion of this basin at the contact with the Northern Neogene/Quaternary Basin.

Sir Ed Danieh-Ain Yacoub Kesrouane Basin

The groundwater budget of this basin shows a surplus ranging from 10.3 Mm3 in a dry year (2010-2011) to 18 Mm3 in a wet year (2011-2012). Currently, there is no significant groundwater extraction from the basin. Future exploitation is not recommended.

Northern Bekaa Neogene/Quaternary Basin

The groundwater budget of this basin shows a deficiency ranging from -7.3 Mm3 in a dry year (2010-2011), to -1.2 Mm3 in a wet year (2011-2012). When considered in its totality this basin is extensively exploited inside and outside the Hermel Caza. Future exploitation is therefore not recommended.

Proposed groundwater extraction zones

One proposed extraction zone is aimed at tapping the C4-C5 aquifer of Mount Lebanona-Bekaa Cretaceous basin.

Groundwater quality

Groundwater was sampled from 2 wells tapping the karstic C4-C5 aquifers Mount Lebanon-Bekaa Cretaceous Basin, which were targeted for potential exploitation. All the results are within the Lebanese Standards, except for Alkalinity and TDS.

Baalbek Caza

Geology

The main deposits and geological formations outcropping within the Baalbek Caza consist of the Quaternary deposits (Q), the Miocene Formation (mL/mcg), Pliocene Basalts (βP), the Upper and lower Eocene Formations (e2b / e2a), the Chekka Formation (C6), the Maameltein Formation (C5) and the Sannine Formation (C4).
There are two main complete fold structures in the Baalbek Caza (the anticline of Mount Lebanon mountain range has its eastern limb only present): the Bekaa Syncline and the Anti-Lebanon anticline. There are two main faults systems that traverse the Baalbek Caza: the Yammouneh and the Serghaya faults.

Springs

There are around 100 springs. Most of the springs are located in the Quaternary and Cretaceous formations.

Groundwater basins and wells

There are 95 public wells managed by BWE:

- 28 public wells in the Mount Lebanon Bekaa Cretaceous basin, tapping the C4-C5 aquifer;
- 4 public wells in the Northern Bekaa Neogene/Quaternary basin, tapping the C4-C5, Quaternary/Neogene aquifers;
- 10 public wells in the Southern Bekaa Neogene/Quaternary basin, tapping the C4-C5 and e2b aquifers;
- 31 public wells in the Northern Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifer;
- 8 public wells in the Central Anti-Lebanon Cretaceous Basin, tapping the C4-C5 aquifers;
- 1 public well in the Figeh Cretaceous Basin, tapping the C4-C5 aquifers;
- 10 public wells in the Eastern Bekaa Eocene basin, tapping the C4-C5 and e2b aquifers;
- 2 public wells in the Western Bekaa Eocene basin, tapping the Quaternary and Neogene aquifers;
- 1 public well in the Serghaya Jurassic basin, tapping the J4-J7 aquifers.

There is an extraction increase of 2200 m3/day from 2012 to 2016 from public wells.
There are 446 licensed private wells with a daily extraction rate varying between 24 and 91 m3/day:

- 26 private wells in the Mount Lebanon Bekaa Cretaceous basin, tapping the C4-C5 aquifer;
- 37 private wells in the Northern Bekaa Neogene/Quaternary basin, tapping the Quaternary/Neogene aquifers;
- 338 private wells in the Southern Bekaa Neogene/Quaternary basin, tapping the Miocene, C4-C5 and quaternary aquifers;
- 4 private wells in the Northern Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifer;
- 16 private wells in the Central Anti-Lebanon Cretaceous Basin, tapping the C4-C5 aquifers;
- 13 private wells in the Eastern Bekaa Eocene basin, tapping the e2b aquifer;
- 27 private wells in the Western Bekaa Eocene basin, tapping the Miocene and Eocene aquifers.

It should be noted that unlicensed wells are 3 times or more the number of licensed wells.

Observed water level variation

When comparing the measurements conducted on 4 wells, 1 in Mount Lebanon Bekaa Cretaceous, 1 in Western Bekaa Eocene, and 2 in Northern Nekaa Neogene-Quaternary, with the measurements collected in 2012 on the same wells, it was observed that the groundwater level in the wells has dropped considerably.

Groundwater balance

Mount Lebanon-Bekaa Cretaceous Basin

The groundwater balance of the basin portion located in the Baalbek Caza shows a surplus ranging from 116.7 Mm3 in a typical dry year (2010-2011) to 319.7 Mm3 in a typical wet year (2011-2012). Future exploitation is possible, and recommended in the eastern portion of the basin, while monitoring any adverse impact on the aquifer.

Western Bekaa Eocene Basin

The groundwater balance of the basin portion located in the Baalbek Caza shows a negligible surplus ranging from 0.4 Mm3 in a typical dry year (2010-2011) to 1.3 Mm3 in a typical wet year (2011-2012). The basin is close to becoming overexploited.

Serghaya Jurassic Basin

The groundwater balance of the basin portion located in the Baalbek Caza shows a surplus ranging from 17.3 Mm3 in a typical dry year (2010-2011) to 25.7 Mm3 in a typical wet year (2011-2012). Future exploitation is not recommended.

Eastern Bekaa Eocene Basin

The groundwater balance of the basin portion located in the Baalbek Caza shows a small surplus ranging from 0.2 Mm3 in a typical dry year to 6.6 Mm3 in a typical wet year. Future exploitation is not recommended.

Southern Bekaa Neogene/Quaternary Basin

The groundwater balance of the basin portion located in the Baalbek Caza shows a deficit ranging from -15.7 Mm3 in a typical dry year (2010-2011) to -8.1 Mm3 in a typical wet year (2011- 2012). When considered in its totality this basin is extensively exploited inside and outside the Baalbek Caza. Future exploitation is therefore not recommended.

Northern Bekaa Neogene/Quaternary Basin

The groundwater balance of the basin portion located in the Baalbek Caza shows a deficit ranging from -62.2 Mm3 in a typical dry year (2010-2011) to -38.8 Mm3 in a typical wet year (2011-2012). When considered in its totality this basin is extensively exploited inside and outside the Baalbek Caza. Future exploitation is therefore not recommended.

Central Anti-Lebanon Cretaceous Basin)

The groundwater balance of the basin portion located in the Baalbek Caza shows a surplus ranging from 7 Mm3 in a typical dry year (2010-2011) to 29 Mm3 in a typical wet year (2011-2012). Future exploitation is possible, and recommended in the western portion of the basin, while monitoring any adverse impact on the aquifer.

Northern Anti-Lebanon Cretaceous Basin

The groundwater balance of the basin portion located in the Baalbek Caza shows a surplus ranging from 264.3 Mm3 in a typical dry year (2010-2011) to 378.4 Mm3 in a typical wet year (2011-2012). Future exploitation is possible, and recommended in the western portion of the basin, while monitoring any adverse impact on the aquifer.

Figeh Cretaceous Basin

The groundwater balance of the small part of the aquifer basin located in the Baalbek Caza shows a surplus ranging from 65.2 Mm3 in a typical dry year (2010-2011) to 68.4 Mm3 in a typical wet year (2011-2012). No Future exploitation of the Figeh Cretaceous Basin is recommended because of accessibility issues.

Identification of groundwater pollution sources

Poor sanitary infrastructure, solid waste dumps, industrial areas, poor application of Agrochemicals, and leaking fuel stations.

Water supply

The 2016 water demand of 94,655 m3/day under current network conditions, and taking into account the Syrian population, a deficit of 14,856 m3/day is estimated.

Proposed groundwater extraction zones

The proposed extraction zones are aimed at tapping the C4-C5 aquifer. 6 candidate extraction zones are proposed with an average well discharge of 5-15 l/s.

Groundwater quality

Groundwater was sampled from wells tapping the karstic C4-C5 aquifers of the Northern Anti-Lebanon Cretaceous Basin and Mount Lebanon-Bekaa Cretaceous Basin, which were targeted for potential exploitation. The physico-chemical results are within the Lebanese Standards, whereas the bacteriological results show some contamination attributed to potential wastewater contamination or animal waste nearby.

West Bekaa Caza

Geology

The main deposits and geological formations outcropping within the West Bekaa Caza consist of the Quaternary deposits (Q), the Miocene Formation (mL/mcg), Pliocene Basalts (βP), the Upper and lower Eocene Formations (e2b and e2a), the Chekka Formation (C6), the

Maameltein Formation (C5), the Sannine Formation (C4), the Hammana Formation (C3), the Mdeirej Formation (C2b), The Abieh Formation (C2a), The Chouf Formation (C1) and the Kesrouane Formation (J4).
There are five folds within the West Bekaa Caza: two are major folds the Barouk-Niha Anticline, and the Bekaa syncline and three minor folds the Quaroun Anticline, Joub Jannine Syncline and Sohmor Syncline. There is one main fault that traverses the West Bekaa Caza: the Yammouneh fault.

Springs

There are over 100 springs of varying discharges. Most of the springs are located in the Jurassic and Eocene formations.

Groundwater basins and wells

There are 38 public wells managed by BWE:
-7 public wells in the Southern Bekaa Eocene basin, tapping the e2b aquifer
-9 public wells in the Eastern Bekaa Eocene basin, tapping the e2b aquifer
-4 public wells in the Central Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifer
-10 public wells in the Qaraoun Cretaceous basin, tapping the C4-C5 aquifer
-7 public wells in the Eastern Barouk-Niha Jurassic Basin, tapping the J4-J7 aquifers
-1 public well in the Southern Barouk-Niha Jurassic Basin, tapping the J4-J7 aquifers
There is an extraction decrease of 937 m3/day from 2012 to 2016 from public wells which might be the result of reporting inaccuracy.
There are 359 licensed private wells with a daily extraction rate varying between 24 and 91 m3/day:

- 20 private wells in the Southern Bekaa Eocene basin, tapping the e2b aquifer;
- 30 private wells in the Eastern Bekaa Eocene basin, tapping the e2b aquifer;
- 33 private wells in the Central Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifer;
- 134 private wells in the Qaraoun Cretaceous basin, tapping the C4-C5 aquifer;
- 24 private wells in the Eastern Barouk-Niha Jurassic Basin, tapping the J4-J7 aquifers;
- 1 private well in the Southern Barouk-Niha Jurassic Basin, tapping the J4-J7 aquifers;
- 62 private wells in the Southern Bekaa Neogene/Quaternary Basin, tapping the Quaternary/Neogene aquifer.

It should be noted that unlicensed wells are 3 times or more the number of licensed wells.

Observed water level variation

When comparing the measurements conducted on 1 well, tapping the Qaraoun C4-C5 aquifer, with the measurements collected in 2012 on the same wells, it was observed that the groundwater level in the well has slightly risen.

Groundwater balance

<u>Southern Bekaa Neogene/Quaternary Basin</u>
The groundwater balance of the basin portion located in the West Bekaa Caza shows a deficit ranging from -7.9 Mm3 in a typical dry year (2010-2011) to -3.8 Mm3 in a typical wet year (2011-2012).
In general, this basin is extensively exploited inside and outside the West Bekaa Caza. Therefore, it is not recommended to further exploit it.

Southern Bekaa Eocene Basin

The groundwater balance of the part of the aquifer basin located in the West Bekaa Caza shows a deficiency in a dry year of -12.4 Mm3 (2010-2011) to a surplus of 13.8 Mm3 in a wet year (2011-2012). Further exploitation is not recommended.

Southern Barouk-Niha Jurassic Basin

The groundwater balance of the part of the aquifer basin located in the West Bekaa Caza shows a surplus in a dry year of 4.5 Mm3 (2010-2011) to a surplus of 8.3 Mm3 in a wet year (2011-2012). Thus, future exploitation is possible.

Qaraoun Cretaceous Basin

The groundwater balance of the basin portion located in the West Bekaa Caza shows a surplus ranging from 20.7Mm3 in a typical dry year (2010-2011) to 45.3 Mm3 in a typical wet year (2011-2012). Future exploitation is possible and is recommended in the northern portion of the basin while monitoring any adverse impact on the basin.

Central Anti-Lebanon Cretaceous Basin

The groundwater balance of the part of the aquifer basin located in the West Bekaa Caza shows a surplus ranging from 6.1 in a dry year (2010-2011) to 8.9 Mm3 in a wet year (2011-2012). Future exploitation is possible, but the location of the basin is not favorable for it.

Eastern Barouk-Niha Jurassic Basin

The groundwater balance of the part of the aquifer basin located in the West Bekaa Caza shows a surplus in a dry year of 8.6 Mm3 (2010-2011) to a surplus of 34.1 Mm3 in a wet year (2011-2012). The location of the basin is not favorable for drilling.

Eastern Bekaa Eocene Basin

The groundwater balance of the part of the aquifer basin located in the West Bekaa Caza shows a small surplus in a dry year of 0.6 Mm3 in a dry year (2010-2011) and a surplus in a wet year of 7.8 Mm3 (2011-2012). In some areas, further exploitation might be possible.

Identification of groundwater pollution sources

Poor sanitary infrastructure, solid waste dumps, industrial areas, poor application of Agrochemicals, and leaking fuel stations.

Water supply

The 2016 water demand of 17,228 m3/day under current network conditions, and taking into account the Syrian population, a surplus of 9,510 m3/day is estimated.

Proposed groundwater extraction zones

The proposed extraction zones are aimed at tapping the e2b and C4-C5 aquifer. 2 candidate extraction zones are proposed with an average well discharge of 5-15 l/s.

Groundwater quality

Groundwater was sampled from wells tapping the karstic J4-J7 aquifer of Eastern Barouk-Niha Jurassic basin and the karstic C4-C5 of Qaraoun Cretaceous basin. The physico-chemical results are within the Lebanese Standards, whereas the bacteriological results show some contamination attributed to potential wastewater contamination or animal waste nearby.

Zahle Caza

Geology

The main deposits and geological formations outcropping within the Zahle Caza consist of the Quaternary deposits (Q), the Miocene Formation (mL/mcg), Pliocene Basalts (βP), the Upper and lower Eocene Formations (e2b and e2a), the Chekka Formation (C6), the Maameltein Formation (C5), the Sannine Formation (C4), and the Kesrouane Formation (J4).
There are twofolds within the Zahle Caza: the Bekaa syncline and the Anti-Lebanon Anticline. There is one main fault that traverses the Zahle Caza: the Yammouneh fault.

Springs

There are over 200 springs of varying discharges. Most of the springs are located in the Quaternary and Cretaceous formations.

Groundwater basins and wells

There are 43 public wells managed by BWE:

- 4 public wells in the Mount Lebanon Bekaa Cretaceous basin, tapping the C4-C5 aquifer;
- 3 public wells in the Jdita Jurassic basin, tapping the J4 aquifer;
- 5 public wells in the Eastern Bekaa Eocene basin, tapping the e2b aquifer;
- 4 public wells in the Western Bekaa Eocene Basin, tapping the e2b aquifer;
- 6 public wells in the Central Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifers;
- 1 public well in the Eastern Barouk-Niha Jurassic Basin, tapping the J4 aquifer;
- 16 public wells in the Southern Bekaa Neogene/Quaternary Basin, tapping the Quaternary/Neogene aquifers;
- 4 public wells in the Metn-Chouf Cretaceous Sandstone basin, tapping the C1 aquifer.

There is an extraction increase of 14426 m3/day from 2012 to 2016 from public wells.
There are 1579 licensed private wells with a daily extraction rate varying between 12 and 180 m3/day:

- 21 private wells in the Mount Lebanon Bekaa Cretaceous basin, tapping the C4-C5 aquifer;
- 2 private wells in the Jdita Jurassic basin, tapping the J4 aquifer;
- 6 private wells in the Eastern Bekaa Eocene basin, tapping the e2b aquifer;
- 1 private well in the Western Bekaa Eocene Basin, tapping the e2b aquifer;
- 12 private wells in the Central Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifers;
- 2 private wells in the Eastern Kneisseh Cretaceous Basin, tapping the C4-C5 aquifers;
- 461 private wells in the Southern Bekaa Neogene/Quaternary Basin, tapping the Quaternary/Neogene aquifers;
- 202 private wells Unproductive basins, tapping the Miocene, C6-e2a, and C2-C3;

It should be noted that unlicensed wells are 3 times or more the number of licensed wells.

Observed water level variation

When comparing the measurements conducted on Jdita well, showed a drop of 43m in the water level from 2012 to 2016. In addition, there is a general drop in water level in the Southern Bekaa Neogene/Quaternary basin when comparing data from UNDP 1970 and 2014.

Groundwater balance

Southern Bekaa Neogene/Quaternary Basin
The groundwater balance of the Basin portion located in the Zahle Caza shows a deficit ranging from -24.9 Mm3 in a typical dry year (2010-2011) to -16.3 Mm3 in a typical wet year (2011-2012). In general, this basin is extensively exploited inside and outside the Zahle Caza. Therefore, it is not recommended to further exploit it.

Western Bekaa Eocene Basin
The groundwater balance of the Basin portion located in the Zahle Caza shows a deficit ranging from -3.1 Mm3 in a typical dry year (2010-2011) to -2.4 Mm3 in a typical wet year (2011-2012). The basin is overexploited.

Eastern Bekaa Eocene Basin
The groundwater balance of the Basin portion located in Zahle Caza shows a deficit of -1 Mm3 in a typical dry year (2010-2011) and a minor surplus of 1.8 Mm3 in a typical wet year (2011-2012). Not recommended for further exploitation.

Mount Lebanon-Bekaa Cretaceous Basin
The groundwater balance of the Basin portion located in the Zahle Caza shows a surplus ranging from 16.9 Mm3 in a typical dry year (2010-2011) to 31 Mm3 in a typical wet year (2011-2012). Further exploitation is not sustainable.

Central Anti-Lebanon Cretaceous Basin
The groundwater balance of the Basin portion located in the Zahle Caza shows a deficit ranging from -19.9 Mm3 in a typical dry year (2010-2011) to -10.2 Mm3 in a typical wet year (2011-2012). It is a potential basin for further exploitation.

Eastern Kneisseh Cretaceous Basin
The groundwater balance of the Basin portion located in the Zahle Caza shows a deficit ranging from -2.6 Mm3 in a typical dry year (2010-2011) to -1.1 Mm3 in a typical wet year (2011-2012). Further exploitation is not recommended.

Matn-Chouf Sandstone Cretaceous Basin
The groundwater balance of the Basin portion located in the Zahle Caza shows a surplus ranging from 1 Mm3 in a typical dry year (2010-2011) to 1.5 Mm3 in a typical wet year (2011-2012). Not considered for further exploitation.

Jdita Jurassic Basin
The Jdita Jurassic Basin is completely located within Zahle Caza. The groundwater balance of this Basin shows a deficit of -1.7 Mm3 in a typical dry year (2010-2011) and a surplus of 1.4 Mm3 in a typical wet year (2011-2012). Not considered for further exploitation.

Eastern Barouk-Niha Jurassic Basin
The overall balance of the Eastern Barouk-Niha Jurassic Basin (1a), as assessed in the UNDP 2014 study, is positive with a surplus of 15.7 Mm3 in a typical dry year (2010-2011) and 55.8 Mm3 in a typical wet year (2011-2012). Suitable for further exploitation while monitoring any adverse impact on the basin..

Identification of groundwater pollution sources

Poor sanitary infrastructure, solid waste dumps, industrial areas, poor application of Agrochemicals, and leaking fuel stations.

Water supply

The 2016 water demand of 96,357 m3/day under current network conditions, and taking into account the Syrian population, a deficit of 18,143 m3/day is estimated.

Proposed groundwater extraction zones

The proposed extraction zones are aimed at tapping the e2b and C4-C5 aquifer. 2 candidate extraction zones are proposed with an average well discharge of 5-15 l/s.

Groundwater quality

Groundwater was sampled from wells tapping the karstic J4 aquifer of Eastern Barouk-Niha Jurassic basin and the karstic C4-C5 of the Central Anti-Lebanon Cretaceous basin. All parameters are within the Lebanese Standards, except for alkalinity.

Rachaya Caza

Geology

The main deposits and geological formations outcropping within the Rachaya Caza consist of: the Quaternary deposits (Q), Miocene Formation (mcg/mL), Upper Eocene Formation (e2b), Lower Eocene Formation (e2a), Chekka Formation (C6), Maameltein Formation (C5), Sannine Formation (C4), Hammana Formation (C3), Mdeirej Formation (C2b), Abieh Formation (C2a), Chouf Formation (C1), Salima Formation (J7), Bikfaya Formation (J6), Bhannes Formation (J5) and Kesrouane Formation (J4).
There are two main folds in the Rachaya Caza: Jib Jannine Syncline and the Mount Hermon Anticline. The Caza is fragmented by three major faults which are: Hasbaya Fault, Rachaya Faults, and Serghaya Fault.

Springs

There are around 143 springs. Discharge data is available for only one, Nabaa el Laboue, with a recorded average minimum discharge of 10.4 l/s. The main water source of this spring is reported to be from the Southern Anti-Lebanon Cretaceous Basin.

Groundwater basins and wells

There are 39 public wells managed by BWE:

- 4 public wells in the Southern Bekaa Eocene basin, tapping the e2b aquifer;
- 2 public wells in the Eastern Bekaa Eocene basin, tapping the e2b aquifer;
- 1 public well in the Central Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifer;
- 7 public wells in the Southern Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifer;
- 25 public wells in the Hermon Jurassic basin, tapping the J4 aquifer.

There is an extraction increase of 3,957 m^3/day from 2012 to 2016 from public wells.

There are 132 licensed private wells with a daily extraction rate varying between 37 and 86 m^3/day:

- 2 private wells in the Southern Bekaa Eocene basin, tapping the e2b aquifer;
- 3 private wells in the Eastern Bekaa Eocene basin, tapping the e2b aquifer;
- 9 private wells in the Central Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifer;
- 30 private wells in the Southern Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifer;
- 33 private wells in the Hermon Jurassic basin, tapping the J4 aquifer.

It should be noted that unlicensed wells (estimated to be around 396 in Rachaya Caza) are 3 times or more the number of licensed wells.

Observed water level variation

When comparing the measurements of the groundwater level conducted in 1 well to those same measurements collected in 2012 on the same well, it was observed that the groundwater level had dropped.

Groundwater balance

Eastern Bekaa Eocene Basin

The groundwater balance of the basin portion located in the Rachaya Caza shows a surplus ranging from 0.2 Mm3 in a typical dry year (2010-2011) to 2.4 Mm3 in a typical wet year (2011- 2012).

It is not recommended to further exploit the Eastern Bekaa Eocene Basin.

Southern Bekaa Eocene Basin

The groundwater balance of the basin portion located in the Rachaya Caza shows a surplus ranging from 17.6 Mm3 in a typical dry year (2010-2011) to 35.1 Mm3 in a typical wet year (2011-2012). Further extraction from this basin should be conditional to conducting long term monitoring to assess any potential adverse impacts to the aquifer / down gradient users, and based on a hydrogeological study at the proposed extraction site.

Hermon Jurassic Basin

The groundwater balance of the basin portion located in the Rachaya Caza shows a surplus of 174.9 Mm3 in a typical dry year (2010-2011) to a surplus of 327.6 Mm3 in a typical wet year (2011-2012). Further extraction in this basin should be conditional to conducting long term monitoring to assess any potential adverse impacts to the aquifer on down gradient users, and based on a hydrogeological study at the proposed extraction site.

Southern Anti-Lebanon Cretaceous Basin

The groundwater balance of the basin portion located in the Rachaya Caza shows a surplus ranging from 21.7 Mm3 in a typical dry year (2010-2011) to 42.3 Mm3 in a typical wet year (2011-2012). If further extraction in this basin is to occur, a groundwater monitoring plan should be implemented to assess any potential adverse impacts to the aquifer on down gradient users, and based on a hydrogeological study at the proposed extraction site.

Central Anti-Lebanon Cretaceous Basin

The groundwater balance of the basin portion located in the Rachaya Caza shows a surplus of 6.8 Mm3 in a typical dry year (2010-2011) and a surplus of 10.1 Mm3 in a typical wet year (2011-2012).

The water budget for this portion of the basin shows positive balance. It is not recommended to support further extraction in the Central Anti-Lebanon Cretaceous Basin.

Identification of groundwater pollution sources

Poor sanitary infrastructure, solid waste dumps, industrial areas, unsustainable application of Agrochemicals, and leaking fuel stations.

Water supply

The water demand in 2016 is 9,889 m^3/day under current network conditions. Accounting for reported 40% losses in the network, a total water supply of 16,481 m^3/day is required. The maximum water supply demand is 10,581.8 m^3/day, and taking into account the Syrian population, the resulting deficit would be about 5,901 m^3/day.

Proposed groundwater extraction zones

The proposed extraction zones are aimed at tapping the Jurassic aquifer. 3 candidate extraction zones are proposed.

Groundwater quality

Groundwater was sampled from 3 wells: 2 wells tapping the karstic C4-C5 aquifer of the Northern Anti-Lebanon Cretaceous Basin and 1 well tapping the Hermon Jurassic Basin. All three wells sampled had bacteriological contamination; this was attributed to potential wastewater contamination or animal waste up gradient or near the wellhead. Alkalinity values in all three wells sampled exceed the Lebanese drinking water standards which can be attributed to the high content of calcium carbonate resulting from rocks such as limestone or can be leached from dolomite and calcite in the soil.

Marjayoun Caza

Geology

The main deposits and geological formations outcropping within the Marjayoun Caza consist of Quaternary deposits (Q), Pliocene Basalts (βP), Miocene Fm(mcg/ml) , Upper and Lower Eocene Fm, Chekka Fm. (C6), Sannine-Maameltein Fm. (C4-C5), Hammana Fm (C3), Mdeirej Fm. (C2b), Chouf Sandstone Fm (C1), Salima Fm. (J7), Bikfaya Fm (J6), Bhannas Basalts (βJ5).
There are five folds within the Marjayoun Caza: the Barouk-Niha and the Mount Hermon Anticlines, which are the two major folds forming two mountain massifs, and the Niha Syncline, Sohmor Syncline and Khiyam Anticline, which are three minor folds. There are three fault systems Marjayoun Caza: the Yammouneh fault, the Hasbaya fault and the Roum fault.

Springs

There are over 60 springs of varying discharges. Most of the springs are located in the Chouf Sandstone Semi-aquifer.

Groundwater basins and wells

There are 21 public wells managed by SLWE:
-6 public wells in the Nabatiye-Bint Jbail Eocene basin, tapping the e2b aquifer

-7 public wells in the Southern Bekaa Eocene basin, tapping the e2b aquifer
-7 public wells in the Naqoura-Sarafand Cretaceous basin, tapping the C4-C5 aquifer
-4 public wells in the Western Bekaa Eocene Basin, tapping the e2b aquifer
-1 public well in the Southern Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifer
There is an extraction increase of 5,639 m3/day from 2012 to 2016 from public wells.
There are 210 licensed private wells with a daily extraction rate varying between 12 and 180 m3/day:
-7 private wells in the Nabatiye-Bint Jbail Eocene basin, tapping the e2b aquifer
-71 private wells in the Southern Bekaa Eocene basin, tapping the e2b aquifer
-26 private wells in the Naqoura-Sarafand Cretaceous basin, tapping the C4-C5 aquifer
-30 private well in the Southern Anti-Lebanon Cretaceous basin, tapping the C4-C5 aquifer
-13 private wells in the Jezzine Sandstone basin, tapping the C1 semi-aquifer
-17 private wells in the Marj Neogene/Quaternary basin, tapping the Quaternary semi-aquifer
-14 private wells Unproductive basins, tapping C2-C3
It should be noted that unlicensed wells are 3 times or more the number of licensed wells.

Groundwater balance

Marj Neogene/Quaternary Basin
The groundwater balance of the basin portion located in the Marjayoun Caza shows a surplus ranging from 0.7 Mm3 in a typical dry year (2010-2011) to 1.8 Mm3 in a typical wet year (2011-2012). It is not considered as a sustainable target for exploitation.

Nabatiye-Bent Jbeil Eocene Basin
The groundwater balance of the basin portion located in the Marjayoun Caza shows a surplus ranging from 18.2 Mm3 in a typical dry year (2010-2011) to 33.2 Mm3 in a typical wet year (2011-2012).

Southern Bekaa Eocene Basin
The groundwater balance of the basin portion located in the Marjayoun Caza shows a deficit of -3.7 Mm3 in a typical dry year (2010-2011) to 1 Mm3 in a typical wet year (2011-2012). Future exploitation of this basin is not recommended.

Jezzine Sandstone Basin
The groundwater balance of the basin portion located in the Marjayoun Caza shows a deficit of 1.1 Mm3 in a typical dry year (2010-2011) to 2.5 Mm3 in a typical wet year (2011-2012).

Southern Anti-Lebanon Cretaceous Basin
The groundwater balance of the basin portion located in the Marjayoun Caza shows a surplus of 1.5 Mm3 in a typical dry year (2010-2011) and a surplus of 8.4 Mm3 in a typical wet year (2011-2012).

Naqoura-Sarafand Cretaceous Basin
The groundwater balance of the basin portion located in the Marjayoun Caza shows a surplus ranging from 9.0 Mm3 in a typical dry year (2010-2011) to 19.8 Mm3 in a typical wet year (2011-2012).

Southern Barouk-Niha Jurassic Basin
The groundwater balance of the basin portion located in the Marjayoun Caza shows a surplus ranging from -2.7 Mm3 in a typical dry year (2010-2011) to 2.5 Mm3 in a typical wet year (2011-2012).

Identification of groundwater pollution sources

Poor sanitary infrastructure, solid waste dumps, poor application of Agrochemicals, and leaking fuel stations.

Water supply

The 2016 water demand of 13,135 m3/day under current network conditions, and taking into account the Syrian population, a surplus of 116 m3/day is estimated.

Proposed groundwater extraction zones

No additional water resources are needed.

Groundwater quality

Groundwater was sampled from wells one tapping the Naqoura-Sarafand Cretaceous Basin, one tapping the Southern Bekaa Eocene Basin and one tapping the Nabatiye-Bint Jbeil Eocene Basin. All parameters are within the Lebanese Standards, except for alkalinity, total coliform and TDS.

Jezzine Caza

Geology

The main deposits and geological formations outcropping within the Jezzine Caza consist of: the Quaternary deposits (Q), Miocene limestones (mL) and conglomerates (mcg), Eocene (e2b), Paleocene-Eocene Chekka Complex unit (C6-Pa-e2a), Maameltein Fm. (C5), Sannine Fm. (C4), Hammana Fm. (C3), Mdeirej Fm. (C2b), Abieh Fm. (C2a), Chouf Fm. (C1), Bhannes (J5) and Kesrouane (J4).
There are two main fault systems that traverse the Jezzine Caza: the Yammouneh fault system and the Roum fault system. Three major folds are also present: the Barouk-Niha anticline, the Aazour anticline and the Jezzine syncline.

Springs

There are over 100 springs. Most of the springs are located in the Chouf Sandstone semi-aquifer and only 2 springs are classified as Class 3. Most of the remaining springs have a small discharge.

Groundwater basins and wells

There are 32 public wells managed by SLWE:

- 2 public well in the Jezzine Sandstone basin, tapping the C1 semi-aquifer;
- 9 public wells in the Sarafand-Khaldi Cretaceous basin, tapping the C4-C5 aquifer;
- 1 public well in the West Barouk-Niha Jurassic basin, tapping the J4-J7 aquifers;
- 9 public wells in the Jarmaq Cretaceous basin, tapping the C4-C5 aquifer;
- 8 public wells in the Jezzine Cretaceous basin, tapping the C4-C5 aquifer;
- 2 public wells in the Albian-Aptian basin, tapping the C1 semi-aquifer;
- 1 public well in the Barouk-Niha Jurassic basin, tapping the J4-J7 aquifers.

There is an extraction increase of 33% between 2011 and 2016 from some public wells.

There are 69 licensed private wells with a daily extraction rate that does not exceed 20 to 40 m^3.

- 23 private wells in the Jezzine Sandstone basin, tapping the C1 semi-aquifer;
- 21 private wells in the Sarafand-Khaldi Cretaceous basin, tapping the C4-C5 aquifer;
- 11 private wells in the Jarmaq Cretaceous basin, tapping the C4-C5 aquifer;
- 5 private wells in the Jezzine Cretaceous basin, tapping the C4-C5 aquifer;
- 8 private wells in the Albian-Aptian basin, tapping the C1 semi-aquifer;
- 1 private well in the Barouk-Niha Jurassic basin, tapping the J4-J7 aquifers.

It should be noted that unlicensed wells (estimated to be around 344 in Jezzine Caza) are 3 times or more the number of licensed wells.

Observed water level variation

When comparing the measurements conducted on 1 well in the Tasse spring area between 2013 and 2016, it was observed that the groundwater level in the well had dropped by only 0.8 meters.

Groundwater balance

West Barouk-Niha Jurassic Basin

The groundwater balance of this basin shows a surplus ranging from 3.9 Mm3, in a dry year (2010-2011), to 7.9 Mm3, in a wet year (2011-2012).The basin can be further exploited in the area between the Azzour anticline and the Barouk-Niha anticline in the north-south trending tributary of the Awali River.

Southern Barouk-Niha Jurassic

The groundwater balance of this basin shows a positive balance of around 11.7 Mm3 in a dry year (2010-2011), and surplus of about 9.9 Mm3 in a wet year (2011-2012). Exploiting this aquifer close to the major disturbed zone of the Yammouneh Fault might be possible.

Sarafand-Khaldi Cretaceous

The groundwater balance of the portion of the aquifer basin located in the Jezzine Caza shows a surplus ranging from 18.1 Mm3 in a dry year (2010-2011) to 33 Mm3 in a wet year (2011-2012). The aquifer basin is extensively exploited outside the Caza. This aquifer is under stress as salt water intrusion.
Future extraction in this basin should be concentrated into the western portion of the basin at the lowest elevation areas of the Caza.

Jarmaq Cretaceous Basin

The groundwater budget of this basin shows a surplus ranging from 23.9 Mm3 in a dry year (2010-2011) to 43.7 Mm3 a wet year (2011-2012). The basin can be exploited by tapping into the static reserves of the Tasse and Ain el Aabara springs, in the dry season (May to October) which will be refilled in the rainy season (November to April), to mitigate losses in the form of overflow from the springs during the wet season.

Jezzine Cretaceous Basin

The groundwater balance of this aquifer basin shows a surplus ranging from 6.9 Mm3 in a dry year (2010-2011) to 11.9 Mm3 in a wet year (2011-2012). In the hydrological cycle of 2004/2005, the estimated discharge of Jezzine Spring and the Nabaa Aazibi is about 11.2 Mm3. The Jezzine Cretaceous Basin should not be further exploited in the Jezzine Caza.

Proposed groundwater extraction zones

The proposed extraction zones are aimed at tapping Cretaceous and Jurassic aquifers. 5 candidate extraction zones are proposed.

Groundwater quality

Groundwater was sampled from 2 wells: one tapping the karstic C4-C5 aquifer of the Jarmaq Cretaceous Basin and one tapping the Southern Barouk - Niha Jurassic Basin. Both wells sampled had bacteriological contamination; this was attributed to potential wastewater contamination or animal waste up gradient or near the wellhead. Alkalinity values in both wells sampled exceed the Lebanese drinking water standards which can be attributed to the high content of calcium carbonate resulting from rocks such as limestone or can be leached from dolomite and calcite in the soil.

ANNEX III C.6

AQUIFERS' ARTIFICIAL RECHARGE

AQUIFERS' ARTIFICIAL RECHARGE

General

Artificial aquifer recharge (AAR) is a process where the groundwater availability is enhanced by using the available surface water to artificially increase the available groundwater resources. This technique can be used for deeper aquifers that have a relatively low recharge rate to increase their water budget as well as to improve water quality in shallow or deep aquifers. The recharge can be made passively by enhancing natural surface infiltration (i.e building check dam along rivers) or artificially by actively injecting water through deep boreholes reaching the target aquifer.

Lebanon is not a dry country. It receives relatively large sums of precipitation and is, unlike most countries in the region, not dependent on inflow from other countries. Advantageous is also that snow constitutes a considerable part of the precipitation, which prolongs the natural runoff into the dry summer.

The country's challenge in water supply is that most water flows rapidly the short distance from the mountains into the sea during the rainy and melting season without being used, while many rivers run dry during the summer when demand for irrigation water is highest. Of Lebanon's 40 streams more than half are seasonal. Thirteen rivers with an average length of <60 km flow from the high Lebanese coastal range directly into the ocean. Utilizing their winter discharge to recharge groundwater reservoirs is a promising method of improving the water supply during the dry summer. Lebanon's water balance, summarized in Table 1, shows that surface flow, i.e. river discharge into the ocean, has a good potential to strengthen the water supply.

The often unregulated and poorly monitored exploitation of groundwater resources by unlicensed wells makes it difficult to pinpoint the hotspots of groundwater stress. However, overall declining water tables and local seawater intrusion speak a clear language. Frequent water shortages and an unreliable public water distribution system lead to relatively high costs for water consumers (Frenken, 2009).

AAR Techniques

To tackle the problem of groundwater over-exploitation AAR currently receives much attention as a high-potential mitigation technique. AAR essentially comprises various techniques by which the groundwater is artificially replenished. Some of the most widely used methods for infiltrating surface water are: the use of percolation basins, inducing infiltration from existing surface water bodies by lowering the natural groundwater level (river bank filtration), facilitate sedimentation to form an artificial aquifer (sand dam), and the direct infiltration through wells.

Previous research

A thorough literature review suggested that the global experience with AAR systems in karstic aquifers is rather scarce. In Lebanon, no successful full-scale pilot project has been implemented until now. However, there seems to have been only one documented trial of artificial aquifer recharge, carried out over four decades ago. Experiments used existing but non-operational wells for gravity infiltration of surface water. Injection rates of 135-174 l/s were achieved in experiments with durations of 10 days to 7 months. Even though the scope of monitoring was rather limited, a noticeable decrease of salinity and a rise of the groundwater table of 1.2 m were observed at 450 m distance of the infiltration well. At a distance of 5.5 km no change in the groundwater table was observed.

However, AAR as a potential mitigation measure in Lebanon has been discussed by various authors theoretically. UNDP (2014) provides a comprehensive assessment of Lebanon's groundwater resources and analyses the potential of MAR> the authors identify 30 potential locations for MAR schemes, 20 of which would use river or spring discharge for infiltration and 10 would use sewage treatment plant effluent. Feasibility studies of AAR facilities at four of the proposed sites were conducted (BTD, 2016a, 2016b, 2016c). The proposed projects are of rather large scale and require considerable investments (US$ 3 - 18 mio.).

In fact, the pre-feasibility study, performed by BTD for UNICEF selected, out of 22 sites proposed by UNDP (2014) for AAR using river or spring discharge for infiltration, only 3 convenient sites. These sites were selected based on six preliminary criteria:

- The aquifer needs to be under stress of over-exploitation and/or seawater intrusion.
- Hydraulic characteristics of the aquifer provide for a large enough recharge capacity.
- Depth to groundwater is rather large to avoid negative effects from ground water bulging.
- Average flow rates of the river providing the infiltration water of >5 m3/s during rainy season.
- A road should exist between the abstraction point at the river and injection point.
- The distance between abstraction point and recharge point should be <500 m.

Table III C 1 shows the 3 sites' characteristics.

Table III C 1 Selection of potential MAR sites in Lebanon

Site name	Geological layer	Groundwater basin	River	Average winter discharge (m^3/s)	Elevation (m asl)	region
A10	C4-C5	3	Berdouni	3.3	1025-1120	Bekaa, Zahle
A14	C4-C5	19b	Damour	17.47	300-350	Mount Lebanon, Chouf
A22	mL	23d	Abou Ali	12,14	41-53	North Lebanon, Tripoli & Zgharta

The findings and recommendations of the selected 3 sites are the following:

Damour site (A14)

The proposed Damour site (A14) is 20 km south of Beirut and upstream from the township of El Mechref and the City of Damour where the Ministry of Energy and Water and the Beirut and Mount Lebanon Water Establishment have drilled numerous wells to supply the southern suburbs of Beirut City with potable water. The extensive pumping from these wells, together with the uncontrolled pumping of the coastal aquifers by private wells over the years has led to a serious seawater intrusion problem in the area.

The main surface water body in the study area is the Damour River and its confluent the El Hammam River. The Damour River originates from the Barouk Spring in the mountains and receives contributions from smaller springs along its course in addition to runoff from gullies and snowmelt along the watershed during the wet season.

The feasibility assessment herein presents options for using the excess river water during the wet season to recharge the over-stressed aquifers down gradient from the springs. The feasibility report covers the proposed method(s) of recharge, the estimated recharge quantities and quality, in addition to a description of the civil and mechanical works required to transmit the recharge water from the source to the storage sites and the anticipated operation and maintenance plan, the monitoring plan and the schedule of required resources. The assessment covered geological and hydrogeological mapping, gauging of the Damour River at 5 sections and conducting a water quality sampling campaign for the surface water. Additionally, geotechnical investigation was conducted by drilling two reconnaissance boreholes with permeability testing being conducted during drilling. The field data was added to the compiled records from previous projects so that technically feasible and sustainable recommendation s could be made.

Geologically, the main aquifer formation in the study area is the Upper Cenomanian (C4c) and Upper Turonian (C5b) Limestone aquifer. The complicated structural setting of the area has contributed to the formation of favorable conditions for artificial aquifer recharge thanks to the physical confinement of the aquifer water and to the formation of a hydrogeological barrier against sea water intrusion. The over-exploitation of the C5b aquifer is depleting its reserves with water salinity levels rising across the aquifer.

Recharge via injection wells was flagged as highly uncertain at the A 14 Site due to very elevated static groundwater levels at the potential recharge site. With local well drilling industry lacking the required expertise to complete open hole wells under pressurized conditions, the risk of ending up with a low efficiency well would result in low recharge volumes and constant overflow of injected water from the wellhead. Therefore, three potential solutions were envisaged for recharging artificially the C4c and C5b aquifers by means of recharge tunnels of varying dimensions and locations. The economical comparative analysis between the 3 solutions, shows the cost to range between 18,119,000 and 18,537,000 USD.

However, considering the high cost of the tunnel option, one possibility could be to attempt to drill a recharge well first and complete it with a Johnson-type (wire wound) screen to maximize the efficiency of the well. Although the cost of such screens is significant, it remains considerably less expensive than the tunnel option.

Mejdlaya – Nahe abou Ali site (A22)

The proposed artificial aquifer recharge site (A22) is at the Majdlaya - Nahr Abou Ali river. The main surface water body in the study area is the Nahr Abu Ali River, which originates high in the mountains and receives inflow from feeding tributaries along its course to the Mediterranean. Field investigations conducted over the course of the project led to the selection of the following water sources for artificial aquifer recharge: Nahr Abou Ali River water, Rachaaine Spring overflow and Nabaa El Qadi Spring overflow. A thorough feasibility assessment was conducted at site. It included a geological and hydrogeological mapping, gauging of Nahr Abu Ali River, the Rachaaine and Nabaa El Qad i springs and a water quality sampling campaign for the surface water. The field data was added to the compiled records from previous projects so that technically feasible and sustainable recommendations could be made.

The feasibility assessment herein presents options for using the excess river water during the wet season to recharge the over-stressed aquifers downgradient from the springs. The feasibility report covers the proposed method(s) of recharge, the estimated recharge quantities and quality, in addition to a description of the civil and mechanical works required to transmit the recharge water from the source to the storage sites and the anticipated operation and maintenance plan, the monitoring plan and the schedule of required resources.

Geologically, the main aquifer formation in the study area is the Lower Vindobonian Limestone (m2a). The complicated structural setting of the area has contributed to the formation of favorable conditions for artificial aquifer recharge thanks to the physical confinement of the aquifer water and to format ion of a hydrogeological barrier against sea water intrusion.

However, the over-exploitation of the m2a aquifer is depleting its reserves both in quality and quantity with water levels dropping and salinity levels rising across the aquifer.

Three potential solutions were considered for recharging the m2a aquifer artificially. The first option for recharge is via injection wells, while the two other options are via recharge tunnels. The economical comparative analysis between the 3 options shows that alternative 1 is the least expensive because it allows a recharge of 6.22 Mm3 of water during 4 months (January, February, March and April), at a cost of 5.15 M USD. The tunnel solutions allow a recharge of 6.22 to 10.5 Mm3 at a cost varying between 24.675 M USD and 25.481 M USD.

From a technical viewpoint, recharge by well i s less risky because it involves a more established recharge method and the recharge locations are spl it among 3 different sites. The tunnel options require the drilling of reconnaissance wells along the axes of each tunnel and undertaking continuous Lugeon and permeability testing i n both the unsaturated and saturated parts of the aquifer. Consequently, unless stakeholder objections end up being unsurmountable. Option I would be the preferred way forward in the case of Site A22.

Berdaouni site (A10)

Based on the findings, the Wadi El Aarayesh (El Berdaouni River) (Site A 10) holds as a potential site for feasible artificial aquifer recharge by natural sources of water (as opposed to recharge by treated effluent) that utilizes excess water of El Berdaouni River during the wet season to recharge the over-stressed aquifers downgradient from El Berdaouni springs catchment works. Three (3) artificial recharge options for this site are discussed under this report, with 2 options for recharge through recharge wells, and a third option for recharge through check dams. The former options utilize the water intake from 2 different sources: El Berdaouni Springs catchment works, and Zahle Hydropower Plant Outfall, with the most feasible and favorable option being Option 2 for design and implementation of artificial recharge.

1. Location and physiographic setting

   The site is located between Qaa er Rim and Wadi el Aarayesh township north of Zahle city in the Bekaa valley, with approximate averages for annual precipitation and temperature of 700mm and 15°C respectively.

   Using limited spring discharge records, the available flow of the El Berdaouni springs catchment works in winter-spring time varies between 1000 - 2000 1/s, and can be used to recharge the site artificially since the water demand during this period is at lowest, and the springs discharge is at maximum. Flow gauging along the El Berdaouni river bed during the period Feb-Apr 2016 at specifically selected stations upstream of the site, revealed natural recharge of the underlying aquifer(s) through infiltration varying between 60 1/s and 435 l/s, taking into consideration inflows from springs, sewage, and industrial effluents, and accounting for private well discharges.

2. Water Quality

   Laboratory analysis for surface water samples collected in the same period defined above, revealed physical (high turbidity levels only after rainfall events) and microbiological (sewage) contamination that can be relatively treated easily (chlorination and sedimentation), without any detection of heavy metals, polychlorinated hydrocarbons or petroleum hydrocarbons. Although industrial contamination was not evident in the analysis, it does not preclude the fact that pollution from industries upstream of the site prevails. In addition, further hydrochemical interpretation of groundwater analysis results revealed that there would be no problems from the mixing of surface water and groundwater

3. Hydrogeology

The artificial recharge at the site of the underlying Upper Cenomanian (C4c) and Upper Turonian (C5b) limestone aquifers that are considered among the best aquifers in Lebanon in terms of hydraulic properties, is estimated at 190 - 210 1/s which is quite feasible volumetrically between the months of January and April. This amounts to approximately 2,000,000 m3 of additional supply over a 4 months period from groundwater wells planned for the City of Zahle by CDR (3 wells in Wadi El Arayesh and 1 well in Dhour Zahle).

4. Risks and benefits of aquifer recharge at site A10

- Risks

  The risks associated with aquifer recharge at Site A 10 are divided into technical and socio-economic risks. The technical risks (5) are associated with: karstic nature of the aquifer impacting storage capacity; proximity to the Yammouneh Fault system with its complex tectonic forces; injection and recovery system with its limiting distances; high dip of aquifer layers limiting recharge and recovery with potential for overflowing; environmental risks imposed by urbanization levels, financial implications, and lack of year-round clean water sources. The socio-economic risks are associated with securing stakeholder buy-in for the supply of recharge water especially that Qaa er Rim municipality is opposing the erection of tapping works on the springs water source on its grounds, in addition to securing stakeholder buy-in for environmental protection involving existing industries, NGO groups, local communities and municipalities, and governmental authorities (Ministry of Energy and Water, Ministry of Environment, Bekaa Water Establishment) to enforce remedial measures.

- Benefits

  Despite the existence of the abovementioned risks, mitigation measures and promising prospects and options are available. The presence of impermeable aquifers that provide physical confinement for the recharged limestone aquifers at Site A 10, and the treatable contamination, among other promising characteristics (homogeneous hydraulic heads, advanced karstification, less likelihood of perched aquifers) favoring a sustainable recharge process, rank Site A 10 among the top shortlisted sites for feasible aquifer recharge from natural sources.

5. Proposed works feasibility

The artificial recharge proposed at Site A 10 is conceptualized as either recharge through Recharge Wells (dual purpose recharge/discharge) or through Check Dams.

- Recharge through Recharge Wells

  This concept utilizes the diversion of the required flow (190 - 210 1/s) during the wet season into a treatment facility within close proximity to the water source location and then conveys the treated water through a piping network to two recharge locations (some 450 m apart) that artificially recharge the Upper Cenomanian (C4c) and Upper Turonian (C5b) limestone aquifers.

- Recharge through Check Dams

  Constructing check dams along the El Berdaouni River reduces the surface river flow velocity and allows the stored water behind the check dams to infiltrate naturally to the underground. Despite being a known methodology, there is no local experience with check dams, which might constitute a certain risk (dam failure due to natural reasons, landslides). in addition to being very expensive, and requiring a more rigorous Environmental Impact Assessment than well drilling permits. Moreover, the water volumes stored are insignificant to recharge the aquifer with the required flow of 190 - 210 l/s, not to mention the problems that will be encountered when expropriating the large required land areas along with the associated high costs. As such, technical, financial and legal evaluation (as outlined below) for the Check Dams option are excluded from this summary and are described in details under the report.

6. Financial Evaluation

Table III C 2 summarizes the 2 options for recharge through recharge wells and highlights their financial aspects:

Table III C 2 Recharge options for Site A10

	Recharge through Recharge Wells	
	Option 1	**Option 2**
Water Source Alternative	El Berdaouni springs catchment works	IZahle Hydropower Plant Outfall
Recharge Rate (l/s)	190 - 210	
Recharge Mode	• 2 recharge sites with 5 recharge wells (1 existing, and 4 new); • Connecting source water to treatment works and delivery network of transmission lines to wellhead accessories.	
Recharge Sites	Total of 2 recharge sites: *Site 1:* • 3 wells (2 new wells - 400m deep, and existing well to be upgraded); • flow of 50 l/s each; *Site 2:* • 2 new wells - 350m deep; • Flow of 20-30 l/s each.	
Water Treatment	Coarse Screening + Sedimentation tank + Rapid Sand Filtration + Disinfection	
fi\rea Expropriation	*Required (refer to report for approximate area - m^2)*	
Cost for Treatment / Drilling Expropriation / Network / Connections (USD, $)	2,772,400	2,813,400
Treatment Costs (USD,$)	940,400	1,060,400
Monitoring Costs (USD, $)	231,000	
Maintenance Costs for Treatment works (USD/Year, $/Year)	136,080	

7. Legal Evaluation

A comparative analysis for the legal evaluation of the 2 recharge through recharge wells alternatives is presented in the following table:

Table III C 3 Legal evaluation options for Site A10

Water Source Alternative	**Assessment**
Option 1: using the water overflowing from El Berdaouni springs catchment works	- Possible opposition from Qaa er Rim Municipality to use the water overflowing from the El Berdaouni Springs Catchment Works, in addition to opposing MEW/CDR plans to treat the overflow and supply City of Zahle with potable water; - Difficulties encountered while constructing the transmission line and the treatment facility - Use of river water after high seasonal rain period reduces turbidity to acceptable levels with a positive impact on treatment cost requiring only disinfection (cost is lowered from \$940,400 to \$40,400), thus reducing also the injection period to 100 days instead of 120 days; - Site constraints limiting the installation of the aquifer recharge transmission lines (new planned water conveyor by MEW/CDR, wastewater lines for nearby municipalities .
Option 2: using the water from the outfall of Zahle Hydropower plant	- Financial cost of this option is almost the same as Option 1; - MEW and EDZ must approve the construction of water conveying facilities in close proximity to the hydropower plant; - Need for good and serious management from the operator to ensure aquifer recharge with less turbid water, thus reducing on treatment costs and land expropriation costs

Considering the above assessment and the limitations on the Check Dams option, the most practical, least problematic, and economically feasible alternative is Option 2 which uses clear water from the Zahle Hydropower Plant Outfall (after high seasonal rainfall period) with treatment by disinfection only, to recharge the aquifers by approximately 2,000,000 m3 over a 100 days/year period.

8. Suggested additional investigations

Additional investigations are required to secure a detailed design and implementation phase for artificial recharge at Site A 10. Such investigations are planned over a period of 8 months (Oct-16 to May-17) and consist primarily of the following:

- Drilling of reconnaissance wells (total 2) and conduct permeability testing of the Upper Cenomanian aquifer and Upper Turonian Aquifers, and equip the wells with water level sensors and data loggers to monitor the water table fluctuations in both aquifers;
- Monitor on bi-monthly basis flows of El Berdaouni springs and Zahle Hydropower Outfall in addition to the water quality and turbidity;
- Install a gauging station with a water level recorder at the inlet channel to the Zahle Hydropower plant;
- Construct a gauging station (weir and water level recorder) on El Berdaouni river at upstream part (outcropping of Upper Cenomanian limestone) and its downstream part where the lower Turonian marls start outcropping, and monitor the flows:

- Construct a gauging station (weir and water level recorder) on El Berdaouni river at downstream part (contact between Upper Turonian limestone and Eocene Senonian marls) and monitor the flows;
- Monitor the water quality of El Berdaouni river at the three gauging stations;
- Monitor water levels and water quality in Dhour Zahle well.

Recommendations

Since large volumes of water flow unused into the ocean during the winter and that storing a fraction of these discharges has great potential for improving the country's water supply. To quantify this potential, and to contribute to the global experience with AAR in karst, a well-designed MAR pilot project in Lebanon would be desirable. Therefore, it is recommended to start with the AAR of site A10 as a pilot project and upon the results obtained, continue on site A22 (Mejdlaya - Abou Ali).

The project at site A10 would benefit the city of Zahle which lies only a few kilometres downstream in the Bekaa Valley. It is a growing city which plans new groundwater abstraction wells with roughly the same capacity that the proposed ASR scheme would provide. Different groups of stakeholders in Zahle and its surroundings would profit from the project. This leads to a good score in the theme 'stakeholder', further outlined in the following.

مواصفة لبنانية

NORME LIBANAISE

LEBANESE STANDARD

NL 161:2016

Deuxième édition
Second Edition
2016

مياه الشرب

EAU POTABLE

DRINKING WATER

مؤسسة المقاييس والمواصفات اللبنانية
--------LIBNOR--------

Numéro de référence
Reference Number
NL 161 (A)
ICS: 13.060.20

مؤسسة المقاييس والمواصفات اللبنانية - ليبنور هي مؤسسة عامة ترتبط بوزارة الصناعة. أنشأت بموجب قانون صادر بتاريخ 23 تموز 1962 تتولى بموجبه "وحدها وضع المقاييس والمواصفات الوطنية ونشرها وتعديلها ومنح حق استعمال شارة المطابقة للمقاييس والمواصفات.

توضع المواصفات والمقاييس وتناقش وتصاغ في لجان فنية اختصاصية تؤلفها المؤسسة لهذا الغرض.

تتناول المقاييس والمواصفات الوطنية – على سبيل المثال لا الحصر – القياسات والمصطلحات والرموز وتحديد النوعية للمنتجات والسلع وطرق الفحص والتحليل والاختبار وأصول العمليات المهنية وقواعد الانشاءات الفنية".

"المقاييس والمواصفات اللبنانية التي تقرها المؤسسة اختيارية مبدئياً، ولكن لاعتبارات تتعلق بالسلامة العامة أو الصحة العامة أو المصلحة الوطنية، يمكن للحكومة أن تعطي لأي من المقاييس والمواصفات اللبنانية صفة الإلزام القانوني بموجب مرسوم يتخذ في مجلس الوزراء".

تشارك ليبنور في أعمال التقييس الدولية من خلال عضويتها وانتسابها إلى المنظمة الدولية للتقييس **(ISO)** واللجنة الأوروبية للتقييس **(CEN)** والمنظمة العربية للتنمية الصناعية والتعدين **(AIDMO)** ولجنة الدستور الغذائي **(CODEX Alimentarius)**.

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فهرست

تمهيـــد

أعدت هذه المواصفة القياسية "مياه الشرب"، رقم 161:2016، وفقًا لإجراءات ليبنور الداخلية، وكانت لجنة "جودة المياه NL TC 147" في مؤسسة المقاييس والمواصفات اللبنانية هي المسؤولة عن إعدادها.

واعتمدت اللجنة الفنية في إعداد هذه المواصفة بشكل أساسي على الدراسة التي أعدتها منظمة الصحة العالمية والتي إستندت فيها على:

- Guidelines for Drinking-Water Quality – Fourth Edition – World Health Organization 2011.
- National Primary Drinking Water Regulations (NPDWRs) – Table of contaminants – US Environmental Protection Agency (EPA)

تلغي هذه المواصفة القياسية المواصفة القياسية اللبنانية التالية: NL 161:1999

وافقت اللجنة الفنية على هذه المواصفة في اجتماعها بتاريخ 2016/8/2.

أقر مجلس إدارة المؤسسة هذه المواصفة في اجتماعه بتاريخ 2016/10/28.

تجدر الإشارة الى أن الملحقات الإعلامية المرفقة بهذه المواصفة غير ملزمة.

ATTACHMENT D

اللجنة الفنية

المنسق:	الجهة:
سحر الحاج سليمان	مؤسسة المقاييس والمواصفات اللبنانية - ليبنور
الأعضاء:	
مايا أسعد	وزارة الصحة العامة
مايا سرور	وزارة الطاقة والمياه
ميرفت كريدية	وزارة الطاقة والمياه
م. لينا عاصي	وزارة الصناعة
م. منى عساف	وزارة الزراعة
د. سابين بركات	وزارة البيئة
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سليمان الجمال	مؤسسة مياه البقاع
أمل الشدياق	مؤسسة مياه لبنان الجنوبي
فائزة السنكري	مؤسسة مياه لبنان الشمالي
نوال الذهب	مؤسسة مياه لبنان الشمالي
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سيلين حجار	مصلحة الأبحاث العلمية الزراعية
م. هوفيك قيومجيان	معهد البحوث الصناعية

مختبر البيئة المركزي – الجامعة الأميركية في بيروت	د. كارول السخن
نقابة المهندسين في بيروت	م. علي برو
منظمة الصحة العالمية	نهال الحمصي
شركة ريم للمياه المعدنية الطبيعية	كارين صباغ
Fluid Design sal & Watermaster sal	م. مشلين الصياح

ATTACHMENT D

مياه الشرب

1. المجال

تختص هذه المواصفة القياسية بمياه الشرب غير المعبأة المعدة للإستهلاك البشري.

2. تعاريف

1.2- مياه الشرب غير المعبأة (مياه الشفة): مياه صالحة للاستهلاك البشري، وتنطبق عليها جميع الخصائص المميزة لها والواردة في هذه المواصفة القياسية.

2.2- المياه السطحية: المياه الجارية في الأنهار والسيول أو مياه البحيرات أو السدود أو البرك أو التجمعات المائية الأخرى.

3.2- المياه الجوفية المحمية: المياه المتواجدة تحت سطح الأرض وغير المعرضة للتلوث والتي تقع ضمن حريم البئر.

4.2- حريم البئر يعني حقوقه من جهاته من كل طرف أربعون ذراعا.

5.2- المياه الجوفية غير المحمية: المياه المتواجدة تحت سطح الأرض والمعرضة للتلوث.

3. المتطلبات والخصائص

يجب أن يتوافر في مياه الشرب ما يلي:

1.3. الخصائص الحسية والفيزيقية

يجب ألا تزيد الخصائص الحسية والفيزيقية لمياه الشرب على الحدود الواردة في الجدول رقم (1) أدناه:

الجدول رقم (1): الحد الاقصى للخصائص الحسية والفيزيقية في مياه الشرب

الخصائص الحسية والفيزيقية	الحد الاقصى المسموح به	وتيرة أخذ العينات لمصادر المياه السطحية، والجوفية المحمية وغير المحمية
الطعم	مقبول لدى المستهلك	يتم تحليل هذه الخصائص عند أخذ أي عينة
الرائحة	مقبول لدى المستهلك	
اللون	أقل من 15 Pt-Co	

الموصلية عند حرارة 20 درجة سْ	200-1500 µS/cm	يتم تحليل هذه الخصائص عند أخذ أي عينة
تركيز شوارد الهدرجين	6.5-8.5	
العكارة	أقلّ من 5 NTU أو أقلّ من 5 FTU	
المواد الصلبة الحلولة	100-750 mg/l	
القساوة الإجمالية محتسبة بكربونات الجير (الناتجة عن الكالسيوم والمغنيزيوم)	500 mg/l	يتم أخذ العينات وتحليلها مرة كل ستة أشهر وعند الضرورة
الكلسيوم محتسباً ككربونات الجير ($CaCO_3$)	300 mg/l	
المغنيزيوم محتسبا ككربونات المغنيزيوم ($MgCO_3$)	200 mg/l	

2.3. الخصائص الكيميائية

يجب أن تتوافق الخصائص الكيميائية لمياه الشرب مع المتطلبات الواردة في الجداول رقم (2) و(3) و(4) و(5) و(6) الواردة أدناه:

الجدول رقم (2): المواد الكيميائيّة المتوفّرة طبيعيًا في الماء

المادة الكيميائية	**الحد الأقصى المسموح به**	**وتيرة أخذ العينات لمصادر المياه السطحية، والجوفية المحمية وغير المحمية**
Sodium (Na) صوديوم	200 mg/l	يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة
Chloride (Cl^-) كلوريد	250 mg/l	
Fluoride (F^-) فلوريد	1.5 mg/l (temp 8-18°C) 0.7 mg/l (temp 25-30°C)	
Barium (Ba) باريوم	0.7 mg/l	
Arsenic الزرنيخ	0.01 mg/l	

ATTACHMENT D

Iron (Fe) الحديد	0.5 mg/l	يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة
Manganese (Mn) المنغنيز	0.1 mg/l	
Boron (B) بورون	2.4 mg/l	
Cadmium (Cd) كادميوم	0.003 mg/l	
الكروم الاجمالي (الكروم سداسي التكافؤ) Total Chromium (Cr) (Hexavalent Chromium Cr VI)	0.05 mg/l	
Molybdenum (Mo) موليبدينوم	0.07 mg/l	
Selenium (Se) سلينيوم	0.04mg/l	
Uranium (U) يورانيوم	0.03mg/l	
خامس أكسيد الفسفور Phosphate (P_2O_5)	0.35 – 0.5 mg/l	

الجدول رقم (3): المواد الكيميائية المتوفّرة في المياه الناتجة من مصادر صناعية والمساكن البشرية

المادة الكيميائية	الحد الأقصى المسموح به	وتيرة أخذ العينات لمصادر المياه السطحية، والجوفية المحمية وغير المحمية
Mercury (Hg)	0.006 mg/l	يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة
Cyanide (CN)	0.05 mg/l	
Hexachlorobutadiene	0.6 µg/l	
Pentachlorophenol	0.009 mg/l	
Nitrilotriacetic acid	0.2 mg/l	
1,4 Dioxane	0.05 mg/l	
Di(2-Ethylhexy) phthalate	0.008mg/l	
Dichloromethane	0.02 mg/l	
1,2 dichloromethane	0.03 mg/l	
1,2 Dichloroethene	0.05 mg/l	
Trichloroethene	0.02 mg/l	
Tetrachloroethene	0.04 mg/l	

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يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة	1 mg/l	1,2 Dichlorobenzene
	0.3 mg/l	1,4 Dichlorobenzene
	0.3mg/l	Ethyl benzene
	0.02 mg/l	Trichlorobenzene
	1 µg/l	Hexachlorobenzene
	0.004 mg/l	Carbon tetrachloride
	0.3 mg/l	Methyl tertiarybutyl ether
	0.7 mg/l	Toluene
	0.5 mg/l	Xylene
	0.02 mg/l	Styrene
	0.01 mg/l	Benzene
مرة شهريا وعند الضرورة	< 2 mg/l for TOC	Total organic carbon (TOC) or equivalent tests

الجدول رقم (4): المواد الكيميائية الناتجة عن النشاطات الزراعية

وتيرة أخذ العينات لمصادر المياه السطحية، والجوفية المحمية وغير المحمية	الحد الأقصى المسموح به	المادة الكيميائية
يتم تحليل هذه الخصائص عند أخذ أي عينة	0.5 mg/l	Ammonia (NH_3)
	45 mg/l	Nitrates (NO_3^-)
	0.05 mg/l	Nitrites (NO_2^-)
يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة	0.01mg/l	Aldicarb
	0.007mg/l	Carbofuran
	0.6 µg/l	Endrin
	0.03 µg/l	Heptachlor and Heptachlorepoxide
	0.002 mg/l	Lindane
	0.02 mg/l	Metoxychlor
	0.2 µg/l	Chlordane

يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة	0.03 µg/l	Aldrin+Dieldrin
	0.03 mg/l	2,4 – Dichlorophenoxyacetic acid
	0.009 mg/l	2,4,5 – Trichlorophenoxyacetic acid
	0.02 mg/l	Alachlor
	0.1 mg/l	Atrazine and its metabolites
	300 µg/l	Bentazone
	0.6 µg/l	Cyanazine
	0.009 mg/l	Isoproturon
	0.002 mg/l	MCPA [4 – (2 – Methyl – 4 – chlorophenoxy) acetic acid]
	0.01 mg/l	Mecoprop
	0.006 mg/l	Molinate
	0.02 mg/l	Pendimethalin
	0.3 mg/l	Permethrin
	0.002 mg/l	Simazine
	0.02 mg/l	Trifluralin
	0.01 mg/l	Metolachlor
	0.006 mg/l	Dimethoate
	0.4 µg/l	1,2Dibromoethane
	0.04 mg/l	1,2 Dichloropropane
	0.001 mg/l	1,2 dibromo-3chloropropane
	0.02 mg/l	1,3 Dichloropropene
	10 ng/l	Nitrosamimes

الجدول رقم (5): بقايا المبيدات لأغراض الصحة العامة

وتيرة أخذ العينات لمصادر المياه السطحية، والجوفية المحمية وغير المحمية	الحد الأقصى المسموح به	المادة الكيميائية
يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة	0.001 mg/l	DDT + Metabolites

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الجدول رقم (6): المواد الكيميائية المستخدمة في معالجة الماء أو في المواد الملامسة لمياه الشرب

المواد الكيميائية المستخدمة في معالجة الماء أو في المواد الملامسة لمياه الشرب		
منتجات التطهير الثانوية	الحد الأقصى المسموح به	وتيرة أخذ العينات لمصادر المياه السطحية، والجوفية المحمية وغير المحمية
الكلور الحرّ (Free chlorine)	للتطهير بشكل فعال، يجب أن لا تقلّ نسبة الكلور المتبقي الحر عن 0.5 مغ/لتر بعد 30 دقيقة على الأقلّ من ملامسة المادة للماء في ظلّ رقم هدروجيني يتراوح بين 6.5 و8.5. ويجب أن لا تقل النسبة المتبقية من الكلور الحر في نظام التوزيع كلّه وفي نقطة التسليم (عند المستهلك) عن 0.2 مغ/لتر، كما يجب أن لا تزيد عن 0.5 مغ/لتر.	يتم تحليل هذه الخصائص عند أخذ أي عينة
Monochloramine	0.5 – 1.5 mg/l	يتم تحليل هذه الخصائص عند أخذ أي عينة
Chlorite	0.7 mg/l	يتم أخذ العينات وتحليلها إذا تمت المعالجة بثاني أوكسيد الكلور ClO2
Chlorates	0.7 mg/l	يتم أخذ العينات وتحليلها إذا تمت المعالجة بثاني أوكسيد الكلور ClO2
Bromates	0.01 mg/l	يتم أخذ العينات وتحليلها مرة كل ستة أشهر وعند الضرورة
Chloroform	0.3 mg/l	
Bromoform	0.1 mg/l	
Bromodichloromethane	0.06 mg/l	
Dibromochloromethane	0.1 mg/l	

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الأسيتونتريلات المهلجنة Halogenated Acetonitriles Dichloroacetonitrile Dibromoacetonitrile	0.02mg/l 0.07mg/l	يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة
Sum of Haloacetic acids	0.06 mg/l	يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة
2,4,6 – Trichlorophenol	0.2 mg/l	يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة

ملوثات من مواد كيميائية مستخدمة في المعالجة	الحد الأقصى المسموح به	وتيرة أخذ العينات لمصادر المياه السطحية، والجوفية المحمية وغير المحمية
Acrylamide	0.5 µg/l	يتم أخذ العينات وتحليلها مرة في السنة و عند الضرورة
Aluminum (Al)	0.2 mg/l	
Epichlorohydrin	0.4µg/l	

ملوثات من الأنابيب والتوصيلات	الحد الأقصى المسموح به	وتيرة أخذ العينات لنظام التوزيع والشبكات
Antimony (Sb)	0.02 mg/l	يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة
Polynuclear aromatic hydrocarbons (the sum) (benzo[a]pyrene)	0.7 µg/l	يتم أخذ العينات وتحليلها مرة كل ستة أشهر وعند الضرورة
Copper (Cu)	1 mg/l	يتم أخذ العينات وتحليلها مرة في السنة و عند الضرورة
Lead (Pb)	0.01 mg/l	
Nickel (Ni)	0.07 mg/l	
Vinyl chloride	µg/l 0.3	

3.3الخصائص الشعاعية

يجب أن يكون الحد المرجعي للخصائص الشعاعية كما هو وارد في الجدول رقم (7) أدناه:

الجدول رقم (7): الحد الأقصى للخصائص الشعاعية في مياه الشرب

الخصائص الشعاعية	الحد الأقصى المسموح به	وتيرة أخذ العينات لمصادر المياه السطحية، والجوفية المحمية وغير المحمية
النشاط الإشعاعي ألفا الإجمالي Gross Alpha Activity	0.5 Bq*/l	يتم أخذ العينات وتحليلها مرة في السنة وعند الضرورة
النشاط الإشعاعي بيتا الإجمالي Gross Beta Activity	1 Bq/l	

* 1 بيكريل (becquerel – Bq) = 1 انحلال في الثانية الواحدة

ملاحظة: إنّ قيمتي 0.1 بيكريل/لتر للنشاط الاشعاعي ألفا الإجمالي و1 بيكريل/لتر للنشاط الاشعاعي بيتا الإجمالي ما زال يوصى بهما كمستويين للكشف في مياه الشرب حيث لا حاجة إلى اتخاذ أي إجراء إذا كانت النتائج أدنى منهما. أمّا إذا تمّ تخطّي مستويات الكشف، يجب عندئذ فحص تركيز النويدات المشعّة الفرديّة ومقارنتها بالمستويات المحدّدة الموصى بها. (تمّ ذكرها في الملحق رقم (5)).

4.3الخصائص الحيوية

يجب ان تكون مياه الشرب خلوا من الفيروسات (تم ذكرها في الملحق رقم 4) وخلوأ من الحشرات او بويضاتها او يرقاتها او حويصلاتها او اجزائها او الحيوانات الاولية (تم ذكرها في الملحق رقم 4) ومن ضمنها الاميبا، وان تكون خلوأ من الطحالب والفطريات.

5.3الخصائص الجرثومية

يجب ألا تزيد الخصائص الجرثومية في مياه الشرب على الحدود الواردة في الجدول رقم (8) أدناه:

الجدول رقم (8): الحد الأقصى للخصائص الجرثومية في مياه الشرب

الخصائص الجرثومية	الحد الأقصى المسموح به	وتيرة أخذ العينات
قولونيات إجمالية Total Coliforms	< 1 CFU in 100 ml	يتم أخذ العينات وفقا للجدول رقم (9)
قولونيات متحملة للحرارة Thermotolerant Coliforms	< 1 CFU in 100 ml	
مكورات معويّة		

ATTACHMENT D

	< 1 CFU in 100 ml	Intestinal Enterococci
	< 1 CFU in 100 ml	بسودوموناس ايروجينوزا Pseudomonas Aeruginosa

4.طرق أخذ العينات للفحص الجرثومي

تؤخذ عينات الفحص الجرثومي من مصادر وشبكات توزيع المياه وفقا للجدول رقم (9):

الجدول رقم (9): وتيرة أخذ عينات مياه الشرب للفحص الجرثومي (بالمتر المكعب يوميا")

مصدر مياه الشرب	وتيرة أخذ العينات للفحص الجرثومي
كمية المصادر الجوفية المحمية	عينة / الشهر
كمية المصادر السطحية بالمتر المكعب: تستثمر أقل من 5 000 م3 / اليوم تستثمر من 5000 حتى 100 000 م3 / اليوم تستثمر أكثر من 100 000 م3 / اليوم	عينة / الشهر عينتين /الشهر بفارق أسبوعين عينة /الأسبوع
كمية المصادر الجوفية غير المحمية بالمتر المكعب:	عينتين / الشهر عينة / الأسبوع
المصادر الرئيسية: تستثمر من 2000 حتى 4000 م3 / اليوم تستثمر أكثر من 5000 م3 / اليوم	
المصادر الفرعية: تستثمر أقل من 2000 م3 / اليوم	عينة / الشهر
كمية الشبكة المائية ، نظام التوزيع (محطات الضخ، الخزانات العامة-الشبكات) :	عيّنة من الخزان /الشهر 3 عينات من الشبكة / الشهر
تستثمر أقل من 5 000 م3 / اليوم	
تستثمر من 5 000 حتى 100 000 م3 /اليوم	عينة من الخزان /الأسبوع 3 عينات من الشبكة / الشهر / 5 000 م3 /اليوم
تستثمر من 100 000 م3 / اليوم حتى 500 000 م3 / اليوم	2 عينة من الخزان /الأسبوع 3 عينة من الشبكة / الشهر /10 000 م3 /اليوم

5.طرق الاختبار

تعتمد طرق الإختبار المعروفة والمناسبة والمثبتة عالميا والصادرة عن المنظمات العالمية التالية:

- APHA: The American Public Health Association
- AOAC International
- EPA: U.S. Environmental Protection Agency
- FDA: U.S. Food and Drug Administration
- ISO: International Organization for Standardization

6.مراجع البحث

- Guidelines for Drinking-Water Quality – Fourth Edition – World Health Organisation 2011.
- National Primary Drinking Water Regulations (NPDWRs) – Table of contaminants - US Environmental Protection Agency (EPA)

ATTACHMENT D

الملحق رقم (1)

(إعلامي)

الملوثات الناتجة عن عوامل حيوية

إنّ الشعيّات والفطريات والزراقم والطحالب تفرز مواد كالجيوسمين،2، ميثيل ايزو بورنيول (Geosmine,2, methyl isoborneol) وغيرها من المواد الكيميائيّة التي تؤثر على طعم مياه الشرب حتى ولو كانت موجودة بكميات ضئيلة جدا (بضعة نانوغرامات في اللتر الواحد من مياه الشرب).

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الملحق رقم (2)

(إعلامي)

جدول الملوثات الكيميائية التي تؤثر على قبولية مياه الشرب

الحد الأقصى المسموح به	المادة الكيميائية
<0.1 µg/l(taste)----<10 µg/l(odour) <0.3 µg/l(taste)----<40 µg/l(odour) <2 µg/l (taste)----<300 µg/l(odour)	Chlorophenols: 2-chlorophenol 2,4-dichlorophenol 2,4,6-trichlorophenol
72-200 µg/l threshold for taste	Ethylbenzene
0.05-0.1mg/l threshold of taste and odour	Hydrogen sulphide
10---20 µg/l threshold for taste and odour 40---120 µg/l threshold for odour	Monochlorobenzene
250 mg/l threshold of taste	Sulfates as sodium
40---120 µg/l threshold of taste 24-170 µg/l threshold of odour	Toluene
10 µg/l(threshold of taste) 5---30 µg/l(taste),30 µg/l(taste and odour) 50 µg/l (taste)	Trichlorobenzenes: 1,2,3-trichlorobenzene 1,2,4-trichlorobenzene 1,3,5-trichlorobenzene
2-10 µg/l(odour), 1 µg/l(taste) 0.3-30 µg/l (odour), 0.6 µg/l (taste)	Dichlorobenzene: 1,2-dichlorobenzene 1,4-dichlorobenzene
300 µg/l (taste), 20-1800 µg/l (odour)	Xylenes
4 mg/l threshold of taste	Zinc (Zn)
4 – 2600 µg/l	Styrene
0.2 mg/l	Anionic detergents as MBAs

ATTACHMENT D

الملحق رقم (3)

(إعلامي)

الإختبارات الجرثومية التي يتمّ إجراؤها عند الضرورة

الحد الأقصى المسموح به	الخصائص
Absence in 1-5 l	السالمونيلا Salmonella
< 1 CFU in 50 ml	البكتيريا اللاهوائية المختزلة للكبريتيت Sulfite reducing anaerobes

الملحق رقم (4)

(إعلامي)

قائمة بالفيروسات والأوالي التي تنتقل بواسطة مياه الشرب

List of Viruses قائمة الفيروسات

Adenoviruses

Astroviruses

Enteroviruses

Hepatitis A virus

Hepatitis E virus

Noroviruses

Rotaviruses

Sapoviruses

List of Protozoa قائمة الأوالي

Acanthamoeba spp.

Cryptosporidium hominis/ parvum

Cyclospora cayetanensis

Entamoeba histolytica

Giardia intestinalis

Naegleria fowleri

ATTACHMENT D

الملحق رقم (5)

(إعلامي)

النويدات المشعّة الفرديّة
Individual Radionuclides

المستويات الموصى بها للنويدات المشعّة الشائعة(أ) الطبيعية والاصطناعية لعامة الناس

الفئة	النويدة المشعّة	معامل الجرعة (Sv/Bq)	المستوى الموصى به(ب) (Bq/l)
نظير مشعّ يتشكّل طبيعيًا ويبدأ سلسلة انحلال اليورانيوم(ج)	Uranium-238	4.5 × 10−8	10
نظائر مشعّة تتشكّل طبيعيًا وتنتمي إلى سلاسل انحلال اليورانيوم	Uranium-234 Thorium-230 Radium-226 Lead-210 Polonium-210	4.9 × 10−8 2.1 × 10−7 2.8 × 10−7 6.9 × 10−7 1.2 × 10−6	1 1 1 0.1 0.1
نظير مشعّ يتشكّل طبيعيًا ويبدأ سلسلة انحلال الثوريوم	Thorium-232	2.3 × 10−7	1
نظائر مشعّة تتشكّل طبيعيًا وتنتمي إلى سلاسل انحلال الثوريوم	Radium-228 Thorium-228	6.9 × 10−7 7.2 × 10−8	0.1 1
نويدات مشعّة اصطناعيّة يمكن إطلاقها في البيئة كجزء من منتجات الانشطار المتوفّرة في انبعاثات المفاعلات النوويّة أو تجارب الأسلحة النوويّة	Caesium-134 (د) Caesium-137 (د) Strontium-90 (د)	1.9 × 10−8 1.3 × 10−8 2.8 × 10−8	10 10 10
نويدة اصطناعية يمكن إطلاقها في البيئة كمنتج انشطار (أنظر أعلاه). ويمكن استخدامها أيضًا في إجراءات الطب النووي وبذلك يمكن إطلاقها في أجسام مائية من خلال مخلفات مياه الصرف الصحّي.	Iodine-131 (د), (ه)	2.2 × 10−8	10

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نظير مشع للهدروجين المنتج اصطناعيًا كمنتج انشطار من مفاعلات الطاقة النووية وتجارب الأسلحة النووية. ويمكن أن يتواجد طبيعيًّا في البيئة بكمّية ضئيلة جدًّا. تواجده في مصدر مياه يفيد عن تلوّث صناعيّ محتمل.	Tritium [ه]	1.8 × 10−11	10 000
نظير مشعّ يتكوّن طبيعيًا ومتوزّع بشكلٍ واسع في الطبيعة ومتوفّر في المركّبات العضويّة وفي جسم الإنسان	Carbon-14	5.8 × 10−10	100
نظير اصطناعي يتشكّل في المفاعلات النوويّة ويتوفّر أيضًا بكمّيات قليلة للغاية في خامات اليورانيوم الطبيعيّة	Plutonium-239 [د]	2.5 × 10−7	1
منتج ثانوي لنظير اصطناعي يتشكّل في المفاعلات النوويّة	Americium-241 [د]	2.0 × 10−7	1

أ- هذه القائمة ليست شاملة، ويجب التحقيق في نويدات مشعّة أخرى في بعض الظروف.

ب- يتمّ تدوير المستويات الموصى بها إلى الرقم الكامل الأقرب.

ج- تتوفّر مستويات موصى بها منفصلة لنظائر اليورانيوم المشعّة المفردة من حيث نشاطها الإشعاعي (أي ما يعبّر عنه ببيكريل/لتر). إنّ القيمة الإسترشادية المؤقتة للمتحوى الإجمالي لليورانيوم في مياه شرب هي 30 ميكروغرام/لتر بحسب سميّتها الكيميائية التي تعتبر راجحة مقارنة بسميّتها الاشعاعية.

د- إنّ هذه النويدات المشعّة قد تتواجد في مياه الشرب في حالات عاديّة أو قد تتواجد بجرعات شحيحة جدًّا بحيث لا يكون لها أيّ تأثير على الصحّة العامّة. لذلك فهي تعتبر ذات أولويّة منخفضة للتحقيق في حال تخطّت المستويات الموصى بها.

ه- على الرغم من أنّه لن يتمّ كشف اليود والترتيوم بواسطة قياسات النشاطات الإجمالية القياسية وبالرغم من عدم ضرورة التحاليل الروتينية لهذه النويدات المشعة، إلا أنّه وفي حال وجود ما يشير إلى إمكانيّة توفّر هاتين المادتين، يجب استخدام تقنيات قياس وأخذ عيّنات خاصّة بالنويدات المشعّة، ولهذا السبب تمّت إضافتهما إلى هذا الجدول.

الملحق رقم (6)

(إعلامي)

قائمة بأحماض الخل

List of Haloacetic Acids

الحد الأقصى المسموح به	أحماض الخل
	Methyl chloroacetate
	Methyl dichloroacetate
	Methyl trichloroacetate
	Methyl bromoacetate
	Methyl bromochloroacetate
	Methyl dibromoacetate
	2,4-Dichloroanisole
	2,4,6-Trichloroanisole
	Chloroacetic acid
0 mg/l	Dichloroacetic acid
0.3 mg/l	Trichloroacetic acid
	Bromoacetic acid
	Bromochloroacetic acid
	Dibromoacetic acid
	2,4-dichlorophenol
	2,4,6-Trichlorophenol

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الملحق رقم (7)

(إعلامي)

قائمة الفتالات

List of Phthalates

التركيبة الجزيئية	الحد الأقصى المسموح به	الفتالات
C20H30O6	0.006 mg/L	Bis (2-n-butoxyethyl) phthalate BBEP
C16H22O6	0.006 mg/L	Bis (2-ethoxyethyl) phthalate BEEP
C24H38O4	0.006 mg/L	Bis (2-ethylexyl) phthalate DEHP
C14H18O6	0.006 mg/L	Bis (2-methoxyethyl) phthalate BMEP
C20H30O4	0.006 mg/L	Bis (4-methyl-2-pentyl) phthalate BMPP
C19H20O4	0.006 mg/L	Butyl Benzyl phthalate BBP
C18H26O4	0.006 mg/L	Diamyl phthalate DAP
C16 H22 O4	0.006 mg/L	Di-n-butyl phthalate DBP
C20H26O4	0.006 mg/L	Dicyclohexyl phthalate DCP
C12H14O4	0.006 mg/L	Diehtyl phthalate DEP
C20H30O4	0.006 mg/L	Dihexyl phthalate DHP
C16H22O4	0.006 mg/L	Diisobutyl phthalate DIBP
C10H10O4	0.006 mg/L	Dimethyl phthalate DMP
C26H42O4	0.006 mg/L	Dinonyl phthalate DNP
C24H38O4	0.006 mg/L	Di-n-octyl phthalate DOP

الملحق رقم (8)

(إعلامي)

قائمة الأمينات النتروزوية

List of Nitrosamines

التركيبة الجزيئية	الحد الأقصى المسموح به	العطريات النتروزية والنترامينات
$(C_2H_5)_2NNO$	10 ng/L	N-Nitrosodiethylamine (NDEA)[3,4]
$C_2H_6N_2O$	10 ng/L	N-Nitrosodimethylamine (NDMA)[3,5]
$C_6H_{14}N_2O$	10 ng/L	N-Nitrosodi-n-propylamine (NDPA)[3,4]
$C_8H_{18}N_2O$	10 ng/L	N-Nitrosodi-n-butylamine (NDBA)[3,4]
$C_3H_8N_2O$	10 ng/L	N-Nitrosomethylethylamine (NMEA)[3,4]
$C_4H_8N_2O_2$	10 ng/L	N-Nitrosomorpholine[4]
$C_5H_{10}N_2O$	10 ng/L	N-Nitrosopiperidine (NPIP)[4]
$C_4H_8N_2O$	10 ng/L	N-Nitrosopyrrolidine (NYPR)[3,4]

الملحق رقم (9)

(إعلامي)

قائمة المستحضرات الدوائية

List of Pharmaceuticals

أسماء وفئات المستحضرات الدوائية ومنتجات الرعاية الشخصيّة :

الفئة	المركّب
Analgesic	Acetaminophen
Steroid	Albuterol
Antibiotic	Ampicillin
Antibiotic	anhyrochlortetracyline (ACTC)
Antibiotic	anyhydrotetracyline (ATC)
Antibiotic	Azithromycin
CNS stimulant	Caffeine
Antibiotic	Carbadox
analghesic/anticonvulsant	Carbamazepine
Antibiotic	cefotaxime
Antibiotic	chlortetracycline
Antihistamine	cimetidine
Antibiotic	ciprofloxacin
Antibiotic	clarithromycin
Antibiotic	clinathromycin
Antibiotic	cloxacillin
sleep-inducing-analgesic	codein
Alkaloid	cotinine
hypertension drug	dehydronifedipine
Antibiotic	demeclocycline
Steroid	digoxigenin
steroid glycoside	digoxin
calcium channel blocker	diltiazem
CNS stimulant	1,7-dimethylxanthine
Antihistamine	diphenhydramine

Antibiotic	doxycycline
Antibiotic	enrofloxacin
Antibiotic	4-epinhydrochlortetracycline
Antibiotic	4-Epinhydrotetracycline (EATC)
Antibiotic	4-Epichlortetracyclin
Antibiotic	4-Epioxytetracycline (EOTC)
Antibiotic	erthromycin
Antibiotic	erythromycin anhydrate
Antibiotic	flumequine
Antidepressant	fluxoetine
Hypolipidemic	gemfibrozil
NSAID	Ibuprofen
Antibiotic	izochlortetracycline
Antibiotic	lincomycin
Antibiotic	lomefloxacin
diabetes drug	metformin
Antifungal	miconazole
Antibiotic	minocycline
Antinflammatory	naproxen
Antibacterial	norfloxacin
acytelated progestin	norgestimate
Antibiotic	ofloxacin
Antibiotic	ormetoprim
Antibiotic	oxacillin
Antibiotic	oxalinic acid
Antibiotic	oxytetracycline
Antibiotic	penicillin V
Antibiotic	penicillin G
Antihistamine	ranitidine
Antibiotic	roxithromycin
Antibiotic	sarafloxacin
Antibacterial	sulfachloropyridazine

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Antibacterial	sulfadiazine
Antibiotic	sulfadimethoxine
Antibacterial	sulfamerazine
Antibacterial	sulfamethazine
Antibacterial	sulfamethiazole
Antibiotic	sulfamethaoxale
Antibacterial	sulfanilamide
Antimicrobial	sulfathiazole
Antibiotic	tetracyclin
Antifungal	thiabendazole
Antibacterial	triclocarban
Antibacterial	triclosan
Antibacterial	trimethoprim
Antibiotic	tylosin
Antibiotic	virginiamycin
Anticoagulant	warfarin
Antibiotic	meclocycline
Antibiotic	4-epitetracyclinre

الملحق رقم (10)

(إعلامي)

ملوثات سلفونات البيرفلوروكتاني

Perfluorooctane sulfonate PFOS

المادة الكيميائية	الحد الأقصى المسموح به
Perfluorooctanesulfonic acid	200 ng/l

ATTACHMENT D

الملحق رقم (11)

(إعلامي)

المصطلحات التقنية

إنكليزي	عربي
Conductivity	الموصلية
PH value	تركيز شوادر الهدروجين
Organoleptic parameters	خصائص حسية
Turbidity	عكارة
Total dissolved solids	المواد الصلبة الحلولة
Total hardness	قساوة إجمالية
Pesticides	مبيدات
Treatment	معالجة
Disinfectants	المواد المطهرة
Disinfection by – products	منتجات التطهير الثانوية
Halogenated acetonitriles	الأسيتونتريلات المهلجنة
Contaminants	ملوثات
Pipes and fittings	الأنابيب والتوصيلات
Pesticide residues	بقايا المبيدات
Gross alpha activity	النشاط الإشعاعي ألفا الإجمالي
Gross beta activity	النشاط الإشعاعي بيتا الإجمالي
Becquerel	بيكريل
Disintegration	إنحلال
Protozoa	حيوانات أولية - الأوالي
Vesicles	حويصلات
Larvae	يرقات
Amaeba	الأميبا
Algae	طحالب
Fungi	فطريات
Total coliforms	قولونيات إجمالية

Thermotolerant coliforms	قولونيات متحملة للحرارة
E. coli	إشريشيا كولاي
Intestinal enterococci	مكورات معوية
Pseudomonas aeruginosa	بسودوموناس أيروجينوزا
Salmonella	سالمونيلا
Sulfate reducing anaerobes	أحياء لاهوائية مختزلة للكبريت
Biologically derived contaminants	ملوثات ناتجة عن عوامل حيوية
Actinomycetes	الشعيات
Cyanobacteria	الزراقم
Geosmine,2,methyl isoborneol	الجيوسمين، 2، ايزو بورنيول
Acceptability	قبولية
Individual Radionuclides	النويدات المشعة الفردية
Radionuclide	النويدة المشعة
Dose coefficient	معامل الجرعة
Guidance level	المستوى الموصى به
Radioactive isotope	نظير مشع
Decay series	سلاسل إنحلال
Fission	الإنشطار
Haloacetic Acids	أحماض الخل
Phthalates	الفتالات
Nitrosamines	الأمينات النتروزوية
Nitroaromatics and Nitramines	العطريات النتروزية والنترامينات
Molecular formula	التركيبة الجزيئية
Pharmaceuticals	المستحضرات الدوائية
Personal-care products	منتجات الرعاية الشخصية
Perfluorooctane sulfonate	سلفونات البيرفلوروكتاني
Informative	إعلامي

Project UTF/LEB/019/LEB

Wastewater reuse and Sludge Valorisation and reuse

*****

Proposition for Lebanese Guidelines on Sewage Sludge Use in agriculture

United Nations - Food and Agricultural Organisation (FAO)
Rome, 2010

Proposition for Lebanese guidelines on sludge reuse in Agriculture

1. SCOPE

The national standard for biosolids products' disposal defines the general quality requirements to be met in order to use the sludge resulted from sewage treatment.

The two constraints for the reuse of sludge are the pathogenic and the heavy metals. But in general the heavy metals content is displayed in priority because in principle the sludge should either be stabilised by appropriate treatment before they are delivered for agricultural use.

2. GENERAL CONDITIONS FOR THE PRODUCTION AND USAGE OF SLUDGE

SLUDGE PRODUCTION REQUIREMENT

- Relevant information from the production site,
  - A diagram that shows the site of production. The different components of sludge production operations shall be clearly displayed on the diagram.
  - An inventory of all production equipment.
- Identification of raw sludge:
  - Rate of sludge production,
  - Description of the treatment process,
  - All necessary information on laboratories in charge of all analysis.
  - Results of produced sludge analysis and its compliance with guidelines
- Other information
  - Environmental Impact Assessment study approved by the Ministry of Environment.
  - Quality control plan for the produced sludge.
  - Emergency plan in case of none compliance with guidelines
  - Identification of disposal sites for non-compliant sludge.

3. SLUDGE TREATMENT

In order for the sludge to be safely used for land application, concentration of heavy metals and pathogens shall not exceed allowable limits. Concerning the treatment methods (see table 1), producers shall comply with the following conditions:

- Treatment shall be monitored on a daily basis
- Parameters shall be measured
- Results of monitoring shall be kept in designated records that shall be made available by authorities.

ATTACHMENT E.1

Table 1: Sludge treatment methods

Process	Description
Advanced treatment	
Thermal drying	80 °C and to contain less than 10% moisture
Aerobic digestion	55 °C for 20 hours, batch treatment
Anaerobic digestion	53 °C for 20 hours, batch treatment
Thermal treatment (hydrolysis)	70 °C for 30 minutes followed by anaerobic digestion 35 °C for 12 days
Lime treatment	pH 12 and 55 °C for 2 h
Lime treatment	pH 12 for 3 months
Conventional treatment	
Aerobic digestion	55 °C for 20 days
Anaerobic digestion	53 °C for 20 days
Lime treatment	pH 12 for 24 h
Anaerobic digestion	35 °C for 15 days
Extended aeration	Batch treatment for period to be determined according to ambient temperature (research need…)
Aerobic stabilisation	
Sludge storage	

Conditions for sludge drying beds

Sludge drying beds shall be filled with fermented sludge in a way that halts the propagation of flies and mosquito and/or odours to the best possible. Drying beds shall be filled once every 4 days at a 15-centimeter depth layer each time. Total depth shall not exceed 45 centimetres. Drying beds shall be isolated to avoid groundwater pollution and other water resources.

4. SLUDGE ANALYSES AND SAMPLING

4.1 Sludge analyses

The analyses are done in a laboratory accepted by the State and the results are consigned in a bulletin.

The following parameters are analyzed on every sample of sludge:
- pH (water);
- dry matter,
- organic matters,
- total N,
- NH4-N
- P2O5
- K2O
- MgO
- Contents on heavy metals: cadmium, copper, nickel, lead, zinc, mercury, chromium.
- Faecal coliform
- Salmonella
- Ascaris ova

The results of the analyses for the heavy metals are expressed in milligrams by kilogram of dry matter.

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4.2 Frequencies of sludge analysis

The analyses of the sludge must be done regularly, to the minimum following the frequencies taken in the table 2.

Table 2: Frequency of sludge analysis

Theoretical WWTP capacity PE	Minimum analysis per year	Time between 2 consecutives analysis (1)	
		minimum	maximum
Capacity < 5.000 PE	1	6 months	1 year
5.000 < Capacity < 10.000 PE	2	4 months	6 months
10.000 < Capacity < 50.000 PE	3	3 months	4 months
50.000 < Capacity < 100.000 Pe	6	1 month	2 months
Capacity > 100.000 PE	12	15 days	1 month

4.3 Methods of sludge sampling

A final representative sample, non lower to 1.000 g is gotten after reduction of a homogenized global sample.

- If the mass of stored sludge is lower to 5 tons, the global sample is constituted from at least 2 withdrawals of about 1.000 g or ml.
- If the mass of sludge stored is superior to 5 tons, the global sample is constituted from elementary withdrawals to the minimum by 5 tons of sludge.
- The number of withdrawals is adapted to get a representative final sample of the sludge to characterize.

5. HANDLING SLUDGE OUTSIDE OF THE SEWAGE TREATMENT PLANTS

5.1 Cases when the use of sludge is not allowed

- Lands where sludge use is restricted by the Ministry of Agriculture,
- Lands where depth of groundwater is estimated at less than 1,5 meter from the surface ground,
- Lands cultivated with raw eatable vegetables or agricultural products in contact with the soil (such as onion and fruits),
- Lands of special chemical or microbial composition as explained in table 4.

5.2 Conditions to be regarded when handling sludge

- Sludge shall not be discarded in water courses or drains,
- Rates of sludge usage shall not exceed those rates stipulated in guidelines,

ATTACHMENT E.1

6. GUIDELINES FOR SLUDGE USE IN AGRICULTURE

6.1 Sludge classification

Sludge is classified according to its metal content into four classes (Table 3):

- Class A, unrestricted use,
- Class B and C restricted use,
- Class D, not suitable for use.

Possible use of each sludge class is explained on Table 4.

It is possible to use the sludge designated for an unrestricted use in unlimited quantities in accordance with the needs of crops and type of soil. Quantity is computed as follows:

$$Bar = \frac{S\max - Sini}{Bused} * \delta$$

Where:
Bar : Biosolids Application Rate (ton/hectare of dry sludge).
Smax : Maximum Allowable Soil Contaminant Concentrations (µg/g), Table 4.
Sini : Initial Soil Contaminant Concentrations (µg/g).
Bused : Biosolids used Concentration (µg/g).
δ : Soil Mass (ton/hectare of dry soil).

TABLE 3: Sludge classes on the basis of the sludge content of heavy metal concentration *(µg/g)*

Metal Element	Class		
	A	B	C
Cadmium	5	20	32
Chromium	250	500	600
Copper	375	1500	1500
Lead	150	300	400
Mercury	4	15	19
Nickel	125	270	300
Zinc	700	2500	2800

Example for Cadmium:

Smax : Maximum Allowable Soil Contaminant Concentrations = 1,0 µg/g
Sini : Initial Soil Contaminant Concentrations = 0,05 µg/g.
Bused : Biosolids used Concentration = 4,6 µg/g

Bar : Biosolids Application Rate
= (1-0,05)/4,6*1000 = 207 ton/ha of dry sludge

Table 4: Sludge use on the basis of its class

Class	***Usage***	***Restriction level***
A	1) Public activities sites 2) Parks and green areas 3) Agriculture (vegetables eatable raw are not allowed)* 4) Forest 5) Reclamation land 6) Landfills 7) Surface soils within the premises of treatment plants	Unrestricted Use
B	3) Agriculture (vegetables eatable raw are not allowed) 4) Forest 5) Reclamation land 6) Landfills 7) Surface soils within the premises of treatment plants	Restricted I
C	4) Forest 5) Reclamation land 6) Landfills 7) Surface soils within the premises of treatment plants	Restricted II
D	6) Landfills 7) Surface soils within the premises of treatment plants	Not suitable for use

* Salad, tomatoes, cucumbers, onions, carrots,…

Table 5: Maximal allowed concentration of heavy metals in agricultural and non-agricultural soils (µg/g of dry weight)

Metal Element	**Agricultural Soils**	**Non-Agricultural soils**
Cadmium	1	5
Chromium	100	250
Copper	100	375
Lead	100	150
Mercury	1	4
Nickel	60	125
Zinc	200	700

Sludge added to agricultural soil is dependant on its Nitrogen content as well as the crop needs. On Table 6, examples of several crops' needs of Nitrogen are shown. Nitrogen limited sludge application rate (Nar) is calculated as follows:

$$Nar = \frac{CropNeed\ (kgN/hectare)}{Nitrogen\ availlable\ in\ sludge\ (kgN/ton)}$$

Nitrogen available is calculated as follows:

$$Nitrogen\ Available\ in\ sludge = \frac{Total\ Ammonium}{5} + NO_3 + NO_2 + Metallic\ Organic\ Nitrogen$$

Metallic Organic Nitrogen = (Total Nitrogen - Ammonium) x Mineralization Rate during the first year (25%).

ATTACHMENT E.1

Mineralization rate of organic Nitrogen during the first year is dependant on the applied wastewater treatment processes. Sludge subject to anaerobic digestion has a mineralization rate of organic Nitrogen of about 15%, aerobic digestion *25%,* non-digestion 10%. The available amount of Ammonium shall be estimated at 1/5 of the total amount of Ammonium available in the sludge. This reduction is attributed to those amounts of Ammonium lost as a result of biological and chemical reactions (dispersion, wash and biological stabilization).

TABLE *6:* Examples of amounts of nitrogen needed by several types of crops (kg/hectare)

Type of Crops	Nitrogen Need
Wheat	80-120
Barley	70-100
Sugar beet	140-180
Beet root	100-150
Potato	80-150
Tobacco	150-200
Maize	150-180
Grass	30-60
Grazing field	100-180
Grazing maize	80-120
Grazing cabbage	70-100
Darnel	120-200
Oats	70-100

6.2 Pathogenic organisms in the dry sludge: Bacteria

Pathogenic organisms in the dry sludge shall not exceed the following limits:

- Faecal coliform <1,000 MPN per g ds (ds = dry solids)
- Salmonella <3 MPN per 4 g ds

6.3 Pathogenic organisms in the dry sludge: Helminth eggs

Ascaris ova concentration < 1 viable egg per 5 g of dry solid

Advantage:
- Need of area to store the sludge during 8 months

Inconvenient:
- Code of good practice has to be applied to avoid contamination by helminths

This standard can be compared to US standards: Helminth ovum <1 viable per 4 grams dry solid. To comply with this standard (Ascaris ova <1 viable per 5 g ds), 8 months of drying time are necessary. To reach the same results, sludge has to be spread on 30-40 cm of thickness. If sludge is stored on a higher thickness, the removal of the parasites slows down. As the parasite eggs are the most time resistant, the standards for faecal coliforms and Salmonella will comply.

Biosolids products that do not fulfil the requirements and conditions with regard to its content of pathogens and heavy metals shall be classified "None Compliant". Non-Complaint biosolids may never be applied to agricultural lands including grazing fields and recreational areas.

7. PLAN OF SLUDGE LAND SPREADING

The use of the sludge cannot drag the overloading of one or several limit values of the heavy metals in the soils foreseen in table 5 considering its contributions in heavy metals and contributions in heavy metals of other matters or products spread.

To this end notably, the end-user establishes or makes establish a plan of sludge land spreading that consider:

- the information on sludge and soil quality and crops history
- the needs in nutritive elements of the crops according to crops history;
- the nitrogen and the phosphor contained in the sludge;
- the sludge land spreading dose;
- the mineral or other complementary manure;
- the contributions of the other land spreading matters or products

8. METHODS OF DISPOSAL OF NON-COMPLIANT SLUDGE

When heavy metal concentrations and pathogens exceed the limits stipulated, sludge shall be placed in a landfill that complies with the required conditions. (Sludge may also be incinerated upon the condition of complying with all environmental regulations especially air pollution.)

9. SAFETY AND CONCERVATION OF THE ENVIRONMENT

To minimize the potential risk to the health of humans, animals and plants it is necessary to coordinate sludge applications in time with planting, grazing or harvesting operations. Committing to the following instructions will ensure the safety and the conservation of the environment:

- Biosolid products can be used after three 8 months of its date of production,
- Biosolids products should be applied to agricultural lands 10 days prior to cultivation,
- Use mechanical burial methods for biosolid products and do not use the manual traditional methods,
- Do not use biosolid products on lands where crops like raw edible vegetables and fruits are cultivated,
- Sludge must not be applied to growing soft fruit or vegetable crops nor used where crops are grown under permanent glass or plastic structures,
- Pasturing on treated lands with biosolid products should not be allowed before two months of its application,
- It is prohibited to spread sludge unless 10 meters of the wells, boring, sources, beaches, crests of the rivers banks, ditches and zones known as flooding areas,

ATTACHMENT E.1

- Biosolids products should not be stored close to the drain, irrigation channels and water resources,
- Skin's wounds and scratches should be covered when handling biosolid products,
- Wear protective cloth when biosolid products are used such as masks, shoes and gloves,
- Wash your hand before you eat, drink or smoke if you came in touch with the biosolid products in any way,
- Minimize the number of times at which biosolid are transported so that agitating its dusts in the air would be minimized,
- Do not eat fallen fruits on the soil.

ATTACHMENT E.1

Project UTF/LEB/019/LEB

Wastewater reuse and Sludge Valorisation and reuse

*****

Proposition for Lebanese Wastewater Reuse Guidelines

United Nations - Food and Agricultural Organisation (FAO)
Rome, 2010

I - Proposition for Lebanese waste water reuse guidelines

It is very important for the government to be able to control the design, construction and operational efficiency of all wastewater treatment plants. There is no point in imposing any kind of effluent requirement or adopting the most advanced technology for wastewater treatment if there is no mechanism to ensure maximum efficiency. It is therefore important to predict whether a proposed technology can be supported by the institutions. Appropriate legislation needs not only to be developed, but also implemented and apply adequate funding.

Viral and microbiological Quality Considerations for Reuse of Wastewater in Agriculture

A risk evaluation endorse the WHO Microbiological Quality Guidelines for wastewater reuse in agriculture (<1000 FC/100ml and <1 egg/1liter for unrestricted irrigation). The high actual risks are associated with intestinal nematodes and bacteria; while viruses have little or no actual risk.

a) <u>Virus</u>

Studies have virtually ignored low level or endemic occurrence of waterborne virus diseases for several reasons (EPA, 1992):

- A significant body of information exists indicating that viruses are reduced or inactivated to low or immeasurable levels via appropriate wastewater treatment, including filtration and disinfection,
- Current virus detection methods are not sufficiently sensitive to accurately detect low concentrations of viruses, even in large volumes of water,
- Enteric virus infections are often not apparent, thus making it difficult to establish the endemicity of such infections,
- There is no consensus among virus experts regarding the health significance of low levels of viruses in reclaimed wastewater;
- The apparently mild nature of most enteric virus infections preclude reporting by the patient or the physician,
- Current epidemiological techniques are not sufficiently sensitive to detect low level transmission of viral diseases through water. The laboratory culturing procedure to determine the presence or absence of viruses in a water sample takes a long time. This adds to the complexity and high cost of laboratory procedures, and the limited number of facilities having the personnel and equipment necessary to perform the analyses,
- Once introduced into a population, person-to-person contact becomes a major mode of transmission of an enteric virus, thereby obscuring the role of water in its transmission, and
- There have been no documented cases of viral disease resulting from the reuse of wastewater at any of the water reuse operations (observation made in the USA).

Studies suggest that (i) using wastewater for crop irrigation may not be as "risky" as using it for the irrigation of golf courses or for recreational impoundments, mainly due

ATTACHMENT E.2

to viral reduction in the environment between application and exposure; and (ii) it may be possible to use secondary effluents, especially when they are chlorinated, and still be below the acceptable level of risk to crop consumers (WHO, XXX).

b) Bacteria

The limit value of 1000 C.F. /100 ml proposed by the WHO is sufficient for the irrigation of all crops for the following reasons:

- a natural death of the pathogenic agents also exists,
- the U.V rays. proceed to a certain inactivation of the pathogenic,
- the effects combined of the desiccation and predators decrease the pathogenic very strongly only in some days,
- even though a effluent used for irrigation contains 1000 C.F. /100 ml, it is weak in relation to the concentrations met in the environment (a survey of the WHO and of the United Nations has shown that 45% of the studied rivers showed concentrations > 1000 C.F. /100 ml). Otherwise we can compare these values to those applied by WHO to the bathing: < 1000 C.F. /100 ml and for the E.E.C.: < 2000 C.F. /100 ml,
- The better-quality studies of sprinkler irrigation of treated wastewater indicate that there may be an increased risk of infection when the quality of the wastewater is 10^6 thermotolerant coliforms per 100 ml, but no increased risk of infection when the water quality is 10^4-10^5 thermotolerant coliforms per 100 ml or less.

c) Parasites

There is some evidence that *Ascaris* infection related to direct contact with wastewater can be reduced when the wastewater is partially treated before use and that the effect depends on the extent of treatment. Studies of diarrhoeal disease related to direct contact with wastewater suggest that:

- there is an increased risk of diarrhoeal disease, particularly in young children and in the dry season, related to exposure to untreated wastewater;
- There is evidence to suggest that direct contact with untreated wastewater through flood or furrow irrigation can lead to increased helminth infection (mainly *Ascaris* infection) and that this effect is more pronounced in children than in adults.
- the major risks are from afar more important for the Helminths.

Considering the development ahead and taking in account the particular conditions in Lebanon: sanitary level, existing or programmed wastewater treatment plan, technological level of treatment systems and cultivated crops, the table 1 is proposed as a discussion basis for the establishment of wastewater reuse guidelines in Lebanon. In this proposition, irrigation of crop eaten raw is not allowed

ATTACHMENT E.2

Table 1: Proposition for wastewater reuse guidelines in Lebanon

Parameter	**Category**		
	I	**II**	**III**
BOD_5 (mg/l)	25	100	100
COD (mg/l)	125	250	250
TSS (mg/l)	60	200	200
pH	6 – 9	6 – 9	6 – 9
Cl_2 residual (mg/l)	0,5 - 2	0,5 - 2	0,5 - 2
N-NO_3 (mg/l)	See table 2		
Faecal Coliforms (in 100ml)	<200	<1000	None required
Helminth ova (in 1 litre)	<1	<1	<1

Category I :

a) Fruit trees and crops that are eaten cooked
b) Parks, public gardens, lawns, golf courses and other areas with direct public exposure
c) In case of stabilisation pounds, the TSS limit value is 100 mg/l.

Water treatment expected to meet the criteria: Secondary treatment + filtration + disinfection

Category II

d) Fruit trees
e) Lawns, wooded areas, and other areas with limited public access, road sides outside urban areas
f) Landscape impoundments: ponds, water bodies and ornamental streams, where public contact with water is not allowed.

Water treatment expected to meet the criteria: Secondary treatment + filtration + disinfection or Secondary treatment + either storage or well-designed series of maturation ponds or infiltration percolation

Category III

g) Irrigation of cereals and oleaginous seeds, fiber, & seed crops
h) Crops for canning industry, industrial crops
i) Fruit trees (except sprinkler-irrigated)
j) Plant nurseries, ornamental nurseries, wooden areas, green areas with no access to the public

Water treatment expected to meet the criteria: Secondary treatment + a few days' storage or Oxidation pond systems.

ATTACHMENT E.2

II - Good irrigation practice

1. Introduction

It is admitted that reuse of treated wastewater is interesting because it provides additional water and nutrients. It has a significant socio-economic impact in arid and semiarid areas. For nutrients, treated wastewater reuse in irrigation offers also diversion pathway towards plant products instead of being discharged into the receiving environment. However, some potential negative impacts must be managed to avoid any environmental damages or sanitary risks. In order to ensure a clean and sanitary use in irrigation, a particular attention must be paid to wastewater composition and to the periodical control. To reach this objective, various practises should be observed. They include the choice of a wastewater treatment system, the minimization of human exposure, the choice of a proper irrigation system and surveillance measures for quality of soils, water and harvested crops.

In addition to mitigating possible health effects associated with the use of wastewater in agriculture, good irrigation practices will need to be followed to ensure a good crop yield and minimize risks to the environment. Irrigation practices with wastewater or with other water sources are similar and depend on the local conditions, including climate, physical and chemical soil properties, drainage conditions and the salt tolerances of the crops to be grown. Good irrigation practices will vary but are based on water quantity, water quality and management practices.

2. Water quantity

The amount of water available for irrigation will ultimately determine what types of crops can be grown and what types of irrigation techniques can be used. Most water applied to crops is lost by evapotranspiration from the plant surface. Therefore, the water required by the crops is usually equal to the amount of water lost by evapotranspiration. The evapotranspiration requirement is largely dependent on crops and climatic factors and thus can be estimated based on local meteorological data (Allen et al, 1998). FAO has developed a computer program (CROPWAT) to help farmers determine crop water requirements based on climatic factors (Pescod, 1992). CROPWAT is available at http://www.fao.org/landandwater/aglw/cropwat.stm. The appropriate quantity of water to use will need to be adjusted for the amount of rainfall, leaching requirements, application losses and other factors.

3. Water quality

Besides the microbiological elements that it is possible to eliminate by the biologic treatment, wastewaters and irrigation conventional water contain also chemical elements that cannot be eliminated by a traditional secondary biologic treatment. The FAO Guidelines for conventional irrigation water quality gives in table 2 some concentration limits to consider.

Often, the limits on concentrations of many chemicals in the irrigation water will be determined by crop requirements and not by health concerns. The nutrients in wastewater (i.e. nitrogen, potassium, phosphorus, zinc, boron and sulphur) should be

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present in the right concentrations, or they can damage the crops and/or the environment. For example, wastewater often contains high concentrations of nitrogen. Although plants require nitrogen for growth, excessive nitrogen can cause overstimulation of growth, delayed maturity or poor-quality produce. Plants require different amounts of nitrogen based on their growth stage. In the first stages of growth, plants may require high quantities of nitrogen (in the earliest stages of growth, plants require lots of nitrogen, but may be too small to usefully assimilate all that is applied), but in the later flowering and fruiting stages, they may require less. In some cases, nitrogen levels will need to be adjusted by blending water supplies (Ayers & Westcot, 1985) if conventional water is available. This is also an important consideration to reduce leaching of nitrate into groundwater supplies, which would pose a potential health risk to consumers of the drinking-water.

Table 2: Water quality for irrigation

Parameter		**Units**	**Degree of restriction on use**		
			None	**Slight to moderate**	**Severe**
Salinity EC_w[a]		dS/m	<0.7	0.7-3.0	>3.0
TDS		mg/l	<450	450-2000	>2000
TSS		mg/l	<50	50-100	>100
SAR[b]	0-3	meq/l	>0.7 EC_W	0.7-0.2 EC_W	<0.2 EC_W
SAR	3-6	meq/l	>1.2 EC_W	1.2-0.3 EC_W	<0.3 EC_W
SAR	6-12	meq/l	>1.9 EC_W	1.9-0.5 EC_W	<0.5 EC_W
SAR	12-20	meq/l	>2.9 EC_W	2.9-1.3 EC_W	<1.3 EC_W
SAR	20-40	meq/l	>5.0 EC_W	5.0-2.9 EC_W	<2.9 EC_W
Sodium (Na^+)	Sprinkler irrigation	meq/l	<3	>3	
Sodium (Na^+)	Surface irrigation	meq/l	<3	3-9	>9
Chloride (Cl^-)	Sprinkler irrigation	meq/l	<3	>3	
Chloride (Cl^-)	Surface irrigation	meq/l	<4	4-10	>10
Chlorine (Cl_2)	Total residual	mg/l	<1	1-5	>5
Bicarbonate (HCO_3^-)		mg/l	<90	90-500	>500
Boron (B)		mg/l	<0.7	0.7-3.0	>3.0
Hydrogen sulfide (H_2S)		mg/l	<0.5	0.5-2.0	>2.0
Iron (Fe)	Drip irrigation	mg/l	<0.1	0.1-1.5	>1.5
Manganese	Drip irrigation	mg/l	<0.1	0.1-1.5	>1.5
(Mn)					
Total nitrogen (TN)		mg/l	<5	5-30	>30
pH		Normal range 6.5-8			
Trace elements (see Table 3)					

TDS, total dissolved solids; TSS, total suspended solids
Sources: Ayers & Westcot (1985); Pescod (1992); Asano & Levine (1998).
[a] EC_W means electrical conductivity in deciSiemens per metre at 25 °C.
[b] SAR means sodium adsorption ratio ($[meq/l]^{1/2}$)

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Sodium chloride, boron and selenium should be monitored carefully. Many plants are sensitive to these substances. Boron is frequently present in wastewater because it is used in household detergents. Many types of trees (e.g. citrus and stone fruits) will have impaired growth even when low boron concentrations are present in the water (Ayers & Westcot, 1985). Concentrations of these elements in the irrigation water may be improved by blending water supplies if other water sources are available.

Water quality is also a factor in selecting the type of irrigation method. For example, sprinkler irrigation with water that contains relatively high concentrations of sodium or chloride ions can cause leaf damage to sensitive crops, especially when climatic conditions favour evaporation (i.e. high temperatures and low humidity) (Ayers & Westcot, 1985). Similar damage to crops occurs when wastewater with high levels of residual chlorine (>5 mg/l) is sprayed directly onto leaves (Asano & Levine, 1998).

Municipal wastewater may contain a range of other toxic substances, including heavy metals, as a result of industrial effluents entering the municipal wastewater stream. Some of these substances may be removed during wastewater treatment processes when available, but others may remain in quantities large enough to cause toxicity to the crops. Heavy metals are usually fixed by the soil matrix and tend to be mobile only in the topmost soil layers. When water containing toxic trace elements is applied to crops, these elements may be concentrated in the soil as the water is lost into the atmosphere (Tanji & Kielen, 2002). Table 3 shows the threshold values for plant toxicity for selected trace elements.

4. Management practices

The management practices set out good agricultural practises for wastewater reuse in arid and semiarid regions. It boils down to answering the following questions: How to irrigate crops? And How to manage nutrients contained in water to avoid groundwater and environment pollution?

Good management practices are important in any irrigation scheme. In addition to those practices previously described for controlling health impacts, it is also necessary for optimal plant growth to properly manage water application rates and timing, land and soil and crops. A summary of these considerations is presented below.

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Table 3: Threshold levels of trace elements for crop production

Element		Recommended maximum concentration[a] (mg/l)	Remarks
Al	Aluminium	5.0	Can cause non-productivity in acid soils (pH <5.5), but more alkaline soils at pH >7.0 will precipitate the ion and eliminate any toxicity.
As	Arsenic	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Be	Beryllium	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cd	Cadmium	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co	Cobalt	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr	Chromium	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu	Copper	0.20	Toxic to a number of plants at 0.1-1.0 mg/l in nutrient solutions.
F	Fluoride	1.0	Inactivated by neutral and alkaline soils.
Fe	Iron	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Li	Lithium	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
Mn	Manganese	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Mo	Molybdenum	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni	Nickel	0.20	Toxic to a number of plants at 0.5-1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pd	Lead	5.0	Can inhibit plant cell growth at very high concentrations.
Se	Selenium	0.02	Toxic to plants at concentrations as low as 0.025 mg/l, and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. Essential element to animals, but in very low concentrations.
V	Vanadium	0.10	Toxic to many plants at relatively low concentrations.
Zn	Zinc	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH >6.0 and in fine textured or organic soils.

Source: Adapted from Ayers & Westcot (1985); Pescod (1992).
[a] The maximum concentration is based on a water application rate that is consistent with good irrigation practices (5000-10 000 m^3/ha per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10 000 m^3/ha per year. The values given are for water used on a continuous basis at one site.

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4.1. Management on wastewater in and out of treatment plant

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1. The sewage treatment and disinfection must be kept and maintained continuously in satisfactory and effective operation so long as treated sewage effluent are intended for irrigation.
2. Skilled operators should be employed to attend the treatment and disinfection plant, following formal approval by the appropriate authority that the persons are competent to perform the required duties, necessary to ensure that conditions of (1) are satisfied.
3. The treatment and disinfection plant must be attended every day according to the program issued by the Authority and records to be kept of all operations performed according to the instructions of the appropriate Authority. A copy must be kept for easy access within the treatment facilities.
4. All outlets, taps and valves in the irrigation system must be secured to prevent their use by unauthorized persons. All such outlets must be colored red and clearly labelled so as to warn the public that the water is unsafe for drinking.
5. No cross connections with any pipeline or works conveying potable water, is allowed. All pipelines conveying sewage effluent must be satisfactorily marked with red tape so as to distinguish them from domestic water supply. In unavoidable cases where sewage/effluent and domestic water supply pipelines must be laid close to each other the sewage or effluent pipes should be buried at least 0.5 m below the domestic water pipes.

4.2. Selection of irrigation methods

The type of irrigation method selected will depend on water supply conditions, climate, soil, crops to be grown, cost of irrigation method and the ability of the farmer to manage the system. However, when using wastewater as the source of irrigation other factors, such as contamination of plants and harvested product, farm workers, and the environment, and salinity and toxicity hazards, will need to be considered. There is considerable scope for reducing the undesirable effects of wastewater use in irrigation through selection of appropriate irrigation methods (Pescod, 1992 and Ayers & Westcot, 1985).

The choice of irrigation method in using wastewater is governed by the following technical factors:

- the choice of crops,
- the wetting of foliage, fruits and aerial parts,
- the distribution of water, salts and contaminants in the soil,
- the ease with which high soil water potential could be maintained,
- the efficiency of application, and
- the potential to contaminate farm workers and the environment.

<u>Border irrigation</u> (and basin or any flood irrigation) system involves complete coverage of the soil surface with treated effluent and is normally not an efficient method of irrigation. This system will also contaminate vegetable crops growing near the ground and root crops and will expose farm workers to the effluent more than any

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other method. Thus, from both the health and water conservation points of view, border irrigation with wastewater is not satisfactory.

Furrow irrigation, on the other hand, does not wet the entire soil surface. This method can reduce crop contamination, since plants are grown on the ridges, but complete health protection cannot be guaranteed. Contamination of farm workers is potentially medium to high, depending on automation. If the effluent is transported through pipes and delivered into individual furrows by means of gated pipes, risk to irrigation workers will be minimum.

Sprinkler, or spray, irrigation methods are generally more efficient in terms of water use since greater uniformity of application can be achieved. However, these overhead irrigation methods may contaminate ground crops, fruit trees and farm workers. In addition, pathogens contained in aerosolized effluent may be transported downwind and create a health risk to nearby residents. Sprinkler systems are more affected by water quality than surface irrigation systems. Primarily as a result of the clogging of orifices in sprinkler heads, potential leaf burns and phytotoxicity when water is saline and contains excessive toxic elements, and sediment accumulation in pipes, valves and distribution systems. Secondary wastewater treatment has generally been found to produce an effluent suitable for distribution through sprinklers, provided that the effluent is not too saline. Further precautionary measures, such as treatment with granular filters or micro-strainers and enlargement of nozzle orifice diameters to not less than 5 mm, are often adopted.

Localized irrigation, particularly when the soil surface is covered with plastic sheeting or other mulch, uses effluent more efficiently, can often produce higher crop yields and certainly provides the greatest degree of health protection for farm workers and consumers. Trickle and drip irrigation systems are expensive, however, and require a high quality of effluent to prevent clogging of the emitters through which water is slowly released into the soil. Solids in the effluent or biological growth at the emitters will create problems but gravel filtration of secondary treated effluent and regular flushing of lines have been found to be effective in preventing such problems. Apart from the high capital costs of trickle irrigation systems, another limiting factor in their use is that they are only suited to the irrigation of row crops. When compared with other systems, the main advantages of trickle irrigation seem to be:

- increased crop growth and yield achieved by optimizing the water, nutrients and air regimes in the root zone,
- high irrigation efficiency - no canopy interception, wind drift or conveyance losses and minimal drainage losses,
- minimal contact between farm workers and effluent,
- low energy requirements - the trickle system requires a water pressure of only 100-300 k Pa (1-3 bar),
- low labour requirements - the trickle system can easily be automated, even to allow combined irrigation and fertilization (sometimes terms fertigation).

Bubbler irrigation, a technique developed for the localized irrigation of tree crops avoids the need for small emitter orifices but careful setting is required for its successful application.

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The decision on irrigation system selection will be mainly a financial one but it is to be hoped that the health risks associated with the different methods will be taken into account. The method of effluent application is one of the health control measures possible, along with crop selection, wastewater treatment and human exposure control. Each measure will interact with the others and thus a decision on irrigation system selection will have an influence on wastewater treatment requirements, human exposure control and crop selection (for example, row crops are dictated by trickle irrigation).

Table 4 gives a summery of the allowed irrigation system for the different crops

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Table 4: Allowed irrigation systems

	Water category	Subsurface irrigation	Drip irrigation	Bubbler irrigation	Mini sprinkler	Sprinkler	Surface irrigation
Crops eaten cooked	I	Yes	Yes	Yes			
Parks, public gardens, lawns, golf courses and other areas *with unlimited public exposure*	I	Yes	Yes	Yes	low angle sprinklers	Sprinkling preferably to be practiced at night and when people are not around	
Fruit trees*	I – II - III	Yes	Yes	Yes	Yes	Yes except water category III with a buffer zone of about 300 meters.	Yes
Lawns, wooded areas, and other areas *with limited public access*, road sides outside urban areas	II	(a)	(a)	Yes	Yes	Allowed with a buffer zone of about 300 meters.	Yes
Landscape impoundments: water bodies and ornamental streams, where public contact with water is not allowed.	II	(a)	(a)	Yes	Yes	Allowed with a buffer zone of about 300 meters.	Yes
Fodder crops **	II	(a)	(a)	Yes	Yes	Allowed with a buffer zone of about 300 meters.	Yes
Irrigation of cereals and oleaginous seeds, fiber, & seed crops	III	(a)	(a)	Yes	Yes	Allowed with a buffer zone of about 300 meters.	Yes
Crops for canning industry, industrial crops	III	(a)	(a)	Yes	Yes	Allowed with a buffer zone of about 300 meters.	Yes
Plant nurseries, ornamental nurseries, wooden areas, green areas with no access to the public	III	(a)	(a)	Yes	Yes	Allowed with a buffer zone of about 300 meters.	Yes

* No fruits to be collected form the ground. In case where crops get wetted irrigation should stop one week before harvesting.
** For fodder crops, irrigation is recommended to stop at least one week before harvesting and no milking animals should be allowed to graze on pastures irrigated with sewage.
(a) Irrigation system allowed if adequate filtration system protect the material of irrigation and drippers against the plugging

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4.3. MINIMIZATION PRACTISES OF NITRATE LEACHING

The specialty of irrigation with treated wastewater is not only about crop yields optimization on a quantitative basis but also on a qualitative perspective. That is why two important interactive elements should be considered to minimize any risk of soil or water-table contamination: (i) the choice of irrigation method which has a significant impact on the irrigation efficiency and (ii) the limitation of nitrate leaching.

When speaking about rational management of irrigation, the concept of water valuation or efficiency is connoted. Table 4 presents some guidelines to improve water efficiency:

Table 4: Guidelines to improve irrigation water efficiency

- Irrespective of the irrigation system, water efficiency and uniformity of watering are never equal to 100%. To improve irrigation efficiency, the following list is presented:
  - estimate the evapotranspiration rate (mostly based on the prevailing climatic conditions - e.g. radiation, temperature, humidity and wind speed)
  - determine the quantity of water to be applied, based on rainfall, drainage, soil infiltration, plant and leaching requirements;
  - Time water applications appropriately - e.g. water can be applied at night to reduce losses to evaporation and reduce sodium and chloride toxicity to plants
  - Assess the water-holding capacity of the soil
  - Assess the need for pre- and post-planting irrigation to avoid water stress and leach salts from soil prior to and after planting
  - Maintain optimal soil moisture levels
  - Install pressure regulators for localized irrigation
  - Design irrigation pipes to deliver the quantities needed by the system
  - Provide a proper irrigation system maintenance

The content of nitrogen and its different forms varies in function of the origin of raw wastewater and the wastewater treatment system. For instance, in effluents from wastewater stabilization ponds, nitrogen is mainly represented by ammonium and

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organic nitrogen. In contrast, in effluents from sand filters, nitrogen is essentially present under its nitrite and nitrate form. However, when treated wastewaters are applied on soils, ammonium undergoes quickly nitrification. In some situations, the risk of groundwater nitrate contamination may be high. That risk is all the more serious as treated wastewater contains too much nitrogen compared to the plant's needs. To minimize that risk, it is important to follow the guidelines presented on table 5.

Table 5: Guidelines to minimize nitrate leaching

❖ It is important to precisely establish the water balance in the soil-plant system by quantifying the inflows (rain, irrigation water) and the outflows (utilisation by the plant and evaporation).
❖ To analyse the content of nutrients and particularly nitrogen in the treated water used for the irrigation. This will make it possible to quantify the quantities of nitrogen brought by the volumes of irrigation applied water analysis).
❖ To take into account the supply of nitrogen by the ground and the residue of mineral nitrogen the amount available in the ground (soil analysis).
❖ The amount of water to be applied plays an active role on the leaching of nitrates. Thus, in sandy grounds, it is advisable to minimize the amounts of water and to increase the frequency. To this effect, it is appropriate to consider the importance of optimizing the nitrogen doses and the height of irrigation water on the basis of nitrogen and water requirements for the crops at various crop stages.
❖ To choose the most nitrogen consuming crops and/or to ensure a maximum cover of the ground by the crops.
❖ To blend water rich in nitrogen and less concentrated water or to alternate the irrigations with these two types of water.
❖ If using organic soil conditioners, to avoid the use of the fresh manure and sewage sludge. It is rather recommended to use stabilized compost and to record the amount nutrients supplied by the compost.
❖ Generally, the nitrogen balance will show that it is useless to bring any additional fertilizers to the crops.

4.4. CROPS MANAGEMENT

Crop management can also be used to improve yields. Irrigation with wastewater may require management practices similar to those for irrigation with saline water. Seed germination is most sensitive to soil salinity. Seeds can be placed in such a way as to minimize the impacts of soil salinity by:

◊ Crop selection according to salt tolerance

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◊ Planting seeds on the shoulder(s) of the ridge during furrow irrigation
◊ Planting seeds on the sloping side of seed beds (seeds should be placed above the water line)
◊ Irrigating alternate rows so that salts move beyond the single seed row
◊ Choosing alternatives to furrow irrigation when the wastewater is highly saline.

5. Standard protocols for the data produced from sampling and analysis

5.1 Sampling protocol

The information referring to the conduction of sampling must be recorded in an appropriate protocol. This protocol presents the following information:

- When the sampling takes place
- Where the sampling takes place (inlet and outlet of the wastewater treatment unit, outlet of primary and secondary treatment stage, sewerage network)
- Type of sample collected (grab and/or composite sample)
- Volume of wastewater collected (the quantity of the wastewater collected must be adequate for the conduction of measurements)
- Reference number (code) of the sample, according to the files kept by the operators of the wastewater treatment unit
- Name and status of the persons carrying out the sampling

Sampling protocol

Date of sampling (day/month/year)		
Sampling point (inlet, outlet, other)		
Type of sample (grab, composite)		
Volume of sample		
Reference number (sample code)		
Persons responsible for sampling		
No	Name	Status
1.		
2.		
3.		
…		

The frequency of sampling at the wastewater treatment units is set, taking into consideration the following issues:

- The requirements of the European legislation (e.g. Directive 91/271/EEC)
- The necessity of achieving treated effluent with such a quality that ensures its safe reuse for irrigation purposes.

In the following table, the suggested frequency of sampling is given.

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Suggested frequency of sampling

Parameter	Number of samples
BOD_5 **Suspended Solids** **Total Phosphorous** **Total Nitrogen**	For wastewater treatment plants with capacity 2000 - 9999 p.e. 12/year (1/month) For wastewater treatment plants with capacity 10000 – 49999 p.e. 12/year (1/month) For wastewater treatment plants with capacity > 50000 p.e. 24/year (1/month)
Inlet flow (m^3/sec) **Outlet flow (m^3/sec)**	Daily
Al, As, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, Mn, Mo, Ni, Se, Va, Zn, Hg	1/year (in the cases that the results show high concentration value, a second measurement is suggested within the year)
pH, temperature, color, TDS, nitrates, phosphates, conductivity	1/month
Na, Ca, Mg, K, sulphates, chlorides, B	2/year
E. Coli/100ml **Feacal Coli/100ml** **Helminth eggs/l**	24/year (wastewater treatment plants with p.e.> 50.0000) 24/year (wastewater treatment plants with p.e.> 50.0000)

3.2 MEASUREMENTS PROTOCOL

The data obtained from the conduction of measurements and analyses must be recorded in an appropriate protocol. This protocol is divided to sub-protocols according to the number of points from where the samples were taken (one sub-protocol per each sampling point). These sub-protocols include the following information:

- The time period for carrying out the measurements and analyses
- Reference number (code) of the sample in which measurements are taken place (in respect with the sampling protocol)
- Flow rate at the sampling point
- Value of each determined parameter
- Name and status of the persons that carry out the measurements

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Protocols for measurements and analyses

A. Wastewater Inlet

Time period of carrying out analyses: from …… to ………		
Reference sample number (sample code)		
Flow rate		***Value***
Inlet (m^3/day)		
Parameter		***Value***
Temperature		
PH		
BOD		
Total Nitrogen (Kjedahl)		
Total Phosphorous		
Suspended Solids (SS)		
Fats, Oils and Greases		
Nitrates		
Phosphates		
Conductivity		
Sulphates		
Chlorides		
E. Coli (per 100ml)		
Faecal Coliforms (per 100ml)		
Nematodes eggs (per litre)		
Persons responsible for carrying out measurements		
No	**Name**	**Status**
1.		
2.		
3.		

B. Wastewater Outlet

Time period of carrying out analyses: from …… to ………	
Reference sample number (sample code)	
Flow rate	***Value***
Outlet (m^3/day)	
Parameter*	***Value***
pH	
BOD	
Total Nitrogen (Kjedahl)	
Ammonia	
Total Phosphorous	
Suspended Solids (SS)	
Temperature	
Conductivity	
Sulphates	
Chlorides	
Al	
As	
Be	
B	

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Time period of carrying out analyses: from …… to ………		
Reference sample number (sample code)		
Flow rate		***Value***
Cd		
Cr		
Co		
Cu		
Fe		
Pb		
Li		
Mn		
Mo		
Ni		
Zn		
Hg		
Se		
E. Coli (per 100ml)		
Faecal Coli (per 100ml)		
Nematodes eggs (per litre)		
Persons responsible for carrying out measurements		
No	**Name**	**Status**
1.		
2.		
3.		

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