CONSULTANCY SERVICES FOR RIVER BASIN MANAGEMENT

REF: 11EKA/D65/ACS/BRT/PRG/18-07-2022

AL ASSI RIVER BASIN

BASELINE REPORT

JANUARY 2023

HawkaMaa - EU
حوكماء - الإتحاد الأوروبي

Funded by the European Union
بتمويل من الاتحاد الأوروبي

ACTED

WeWorld

BUREAU TECHNIQUE
POUR LE DÉVELOPPEMENT

To cite this document:

ACTED, WeWorld-GVC, & BTD. (2023). Consultancy Services for River Basin Management: Al Assi River Basin Baseline Report, Beirut Lebanon.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ARB	Assi River Basin
BWE	Bekaa Water Establishment
IWRM	Integrated Water Resources Management
LULC	LandUse and LandCover
Mm^3	Million cubic meters
MoA	Ministry of Agriculture
MoE	Ministry of Environment
MoEW	Ministry of Energy and Water
NWSS	National Water Sector Strategy
PoM	Programme of Measures
SDG	Sustainable Development Goal
USD	United States Dollar
WEAP	Water Evaluation And Planning
WRMM	Water Resources Management Model
WWTP	Waste Water Treatment Plant

1 Background

1.1 Project Description

The current report is a baseline assessment of the water resources management of Assi River Basin (ARB) located between Baalbek and Hermel districts. It consists of developing a detailed Water Resources Management Model by establishing a node based distributed water balance model using Water Evaluation and Planning WEAP software. The assessment presents the state of the water availability, water demand, water supply, and unmet demand (per sector) in the basin during the last 2 decades, as well as the current state of surface water pollution based on a recently conducted field survey and water sampling.

The work has been conducted in the framework of the project “CONSULTANCY FOR RIVER BASIN MANAGEMENT FOR AL ASSI RIVER BASIN/BEKAA, GHADIR BASIN/ BEIRUT AND MOUNT LEBANON, NAHR AL OSTUAN BASIN/AKKAR”, under EU MADAD funding and as part of the HAWKAMAA-EU Consortium partners.

The purpose of the project is to support effective multi-stakeholder decision making and action through water balance modelling to improve the conservation and management of water resources in the basin and maximize the economic, environmental and social benefits. The overall scope is to improve water management in selected river basins by implementing a bundle of demand management measures which can alleviate the prevailing water stress, increase water availability and network efficiency while decreasing losses.

In parallel to these water quantity issues, the work also focuses on assessing the current pollution levels in the river, in order to mobilize the local community and stakeholders to take action to reduce pollution loads in the basin and mitigate the current problem.

The project promotes an inclusive participatory approach, not only by disseminating the results and outputs to the various target groups, but by also involving them in the consultation process. The participatory approach shall involve ministries, municipalities, agricultural stakeholders, and civil society organizations (CSOs), who play a critical role in shaping the management strategies and solutions for the basin bringing unique perspectives, expertise, and resources to the table and collaborate to achieve shared goals. Stakeholders work collaboratively to establish a shared vision and goals for the river basin, conduct basin assessments, and develop management plans. They identify challenges and opportunities and agree on priority areas for action. Stakeholders are also involved in the implementation of the management plan, providing feedback, resources, and support to ensure the plan's success. Through this collaborative approach, stakeholders can ensure that the management plan is sustainable, effective, and equitable for all.

The following activities have been concluded so far:

Kickoff meeting with the client and Hawkama - EU partners.

Data collection, desk review of previous studies and analysis of hydrometeorological data, geological and land use data, information on the water supply systems, GIS cartographic data and development of a GIS database for the ARB.

Development of a Groundwater model using MODFLOW and a semi distributed (node-based) Water Resources Management Model for ARB in WEAP21 software, at monthly timestep and for the period 2000-2018.

Field investigation (conducted end of August 2022) to assess the current situation of the stream and select sampling points in terms of their representativeness to the major pollution sources.

Sampling campaign and laboratory analysis of water samples from 10 sampling sites along ARB for the summer season conducted on August 31st.
First participatory workshop with the stakeholders on January 18th 2023 at Lazord Hotel, Hermel.
Drafting of the Baseline Report on the assessment of the water resources in ARB, based on the outputs of the WEAP model, including a water quality assessment based on the outputs of the field survey and sampling campaign.

1.2 Link to NWSS

The Ministry of Energy and Water (MoEW) prepared and adopted the Lebanese National Water Sector Strategy (NWSS) in 2010 which was endorsed by the Government of Lebanon in 2012 (Resolution No.2, Date 09/03/2012). Seven years later, in 2019, the MoEW decided to review what has been realized from the original roadmaps and to update the water and wastewater strategies of 2012 by setting a detailed action plan to implement reforms and create a hydrogeological data management system and improve service coverage. The Updated NWSS 2020 merges the National Water and Wastewater strategies of 2012 into one consolidated strategy. It maintains the main strategic principles of the water policies adopted by the Government of Lebanon in 2012, but reassesses the then set priorities in light of today's actual context, and sets the ground for the period extending between 2020 and 2035.

It considers the adopted Water Code (law 192/2020) and its structuring principles, which are in turn in line with the water sector organizing Law 221/2000 and its amendments, as well as studies and projects completed between 2012 and 2021 in the fields of potable water, wastewater and irrigation, and management initiatives implemented during the same period. The newly ratified Water Code includes several IWRM implementation principles and aims 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 to ensure the sustainable management of the Lebanese natural water resources.

As per the water code, the Ministry aims at achieving a financially sustainable sector, that is citizen-centered and service oriented, and which would ultimately allow to reach an integrated approach of the water sector. The updated strategy can be considered as a shift into practical, implementable plans, projects and governance initiatives that set the ground to move towards the UN's Sustainable Development Goal SDG 6 and realize the principles of an Integrated Water Resources Management (IWRM). While doing so, the updated NWSS 2020 targets as well SDG 2 (Zero Hunger), SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action), SDG 14 (Life below Water), SDG 15 (Life on Land) and SDG 17 (Partnerships for Goals); these will be explored throughout the document.

Based on the United Nations' SDG 6, the MoEW aims at providing safe, equitable and affordable water and wastewater services to all, and to properly allocate the water resources to the different economic sectors (agriculture, industry, tourism, services, etc..) based on the priorities of the Government's recovery plan.

These commitments are translated by strengthening the IWRM through targeted proposed projects and improved governance at the basin level, thus the river basin management studies of Al Assi, Ghadir and Al Ostuan.

1.3 Methodology

The assessment of the water resources management situation in ARB was carried out following the below methodology:

Data collection and compilation of a comprehensive GIS database which included the watershed boundary, Landuse, geological and hydrogeological maps, etc.

Desktop review of relevant studies mainly the findings of the NWSS on the water balance of the water distribution systems located within Assi i.e. water demand, water supply sources, deficit and excess, etc. (section 02.5), the geological and hydrogeological description section 2.2.3, the agricultural situation (section 2.6), and the wastewater situation section 2.4.2.

Water quality sampling campaign in coordination with NDU University water laboratory, carried out in August 31st, 2022, which results were included in the WEAP model. The lab report is attached in Appendix A.

Development of ARB groundwater model using MODFLOW to assess the groundwater resources and their contribution to the surface runoff and the global water balance. A three-dimensional (3D) lithological model representing the main formations will be produced using geological cross sections. The MODFLOW Layer Property package (LPF), River package (RIV), and Well package (WEL) were used for the model.

Development of ARB water resources management model using WEAP which assesses the current situation of the water resources management within the basin, the existing surface and groundwater sources, and the supply infrastructure. It will be also used to 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. A baseline and future water balance will be developed, assessed, and translated into policy relevant targets to further support the design corresponding Programme of Measures (PoMs), then propose an action plan in coordination with key stakeholders in the region. The detailed methodology for WEAP is described in section 5.

Drafting the Baseline Report based on the overall project area description and the outputs of the WEAP model, including a water quality assessment and the outputs of the field survey and sampling campaign.

1.4 Previous Studies

As a main river in Lebanon and a transboundary river basin shared between three Eastern Mediterranean countries, Turkey, Syria and Lebanon, ARB has been subject of several river basin management studies since the last century either locally in the context of water resources allocation or internationally in the context of shared waters, water scarcity, climate change, etc. We briefly mention here three studies that were reviewed and found relevant to the context of our current study and helped in understanding the evolution of the water resources management within ARB.

The first study was conducted by the United States Department of the Interior Bureau of Reclamation (USBR) and published in 1957. The report covers a water resources reconnaissance and indicates the water and land resources potentialities of the basin, the data on which this report was based were only indicative of the back then condition existing in the river basin.

The existing springs were partly developed for village water supply and for 12 irrigation developments whose total area carries between 3000 and 7000 hectares depending on the year and season. The study indicated a total surface discharge of about 459 Mm^3 as an average annual flow at the Hermel gauging station. The USBR 1957 study mainly recommended

Detailed hydrological investigation and surveys;

Development of potential irrigation schemes and expansion of the domestic water supply;

Establish a program to educate and train water uses in the proper use of irrigation water and modern agricultural practices;

The second study was carried out in 1994 by the Ministry of Energy and Water and focused more on understanding Al Assi hydrological regime and assessment of its water resources and demand. Despite the limited hydrological and hydrometric information, this study has shed new light on the understanding of the Assi regime by introducing rainfall-runoff correlations and related applications. The study finally recommended to:

Deepen the hydrological studies in order to draw up a water balance of the river basin;

Installation of a network of climatological and hydrometric measurements at different stations, on the main course and springs of Al Assi;

The third was a regional study published in 2015 by UNESCO and entitled “Science diplomacy and transboundary water management The Orontes River case”. The study was realized through the partnership established between UNESCO, Italian Ministry of Foreign Affairs and International Cooperation and the Lebanese Ministry of Energy of Water within the Project “New technologies Information and Communication Technologies (ICT) for an integrated and sustainable management of natural resources in Lebanon”.

It was implemented by a team of Italian and Lebanese experts from the Insubria Center on International Security - ICIS, University of Insubria, Centro Interuniversitario per la Cooperazione allo Sviluppo in campo Agricolo e Ambientale - CICSAA, University of Milan. Global Water Partnership-Mediterranean, GWP-Med, and the Mediterranean Network of Basin Organizations, MENBO.

The Experts from these three institutions strengthened the ICT infrastructure of the Lebanese MEW to increase sustainability of water consumption in the basin and deployed also new technology solutions to stimulate water cooperation among national and international stakeholders. One main activity was the development of a strategy that included a:

Geo-dataset integrating data on local agro-meteorology and water resources;

Digital Elevation Model of the Orontes River Basin;

Model of the groundwater system of the Orontes River Basin via MODFLOW software tool;

Information system based on WEAP software tool for water planning and evaluation with regards to the Orontes River Basin;

The ICT project recommended on the farm level to:

Shift to less water consuming crops (e.g., barley instead of wheat), and/or to drought and heat-tolerant crop cultivars;

Change cropping patterns according to precipitation isohyets;

Change planting dates according to precipitation and temperature variations in order to avoid dry spells;

Adopt sustainable agricultural practices for optimizing water retention in soil;

Improve the efficiency of water irrigation systems by replacing surface irrigation with more efficient methods, and adjust irrigation schedules and water amount according to the increasing water demand;

On the policy Level to:

Review the legislative framework for agriculture and natural resources management to be harmonized with the conventions ratified by the Government on climate change;

Set and implement agriculture specific policies by enlarging stakeholders' participation, with particular attention to farmers' groups;

Support and promote research programs focused on: crop water requirement variability considering climate change, water treatment and recycling, development of models simulating water allocation to different uses, biotechnology for reducing crop water requirement;

Foster the interstate collaboration on research and practice amongst Mediterranean countries with the aim of providing and sharing research findings supporting evidence-based policies;

The fourth study is the BWE Irrigation Master Plan (IMP), (USAID, 2019). It consisted of a comprehensive roadmap developed by BWE to achieve sustainable irrigation practices in its service areas. The study was accomplished within the scope of the Lebanese Water Project (LWP) funded by USAID. The IMP covers all lands and villages stretching to the North of the Beirut-Damascus highway up to the Lebanese-Syrian borders and is bordered by the peaks of Mount Lebanon and Anti-Lebanon. Administratively, the IMP area belongs to the Baalbek-Hermel district and partially covers the Beqaa district. The IMP hosts 36 irrigation schemes and covers a 20-year period from 2020 through 2040 and was developed after a series of activities that included data collection, setup of a GIS database, estimation of water balance and water budget, estimation of the needed infrastructure capital investment, development of a priority action plan and identification of preferred option for the governance of the irrigation sector.

The BWE has been planning to develop and implement an irrigation capital investment program within its service areas to improve water supply from various sources (freshwater, groundwater, and treated wastewater). However, infrastructure planning has been generally made on an ad-hoc basis, often without objective prioritization. Therefore, a holistic planning approach is necessary taking into account not only infrastructure, but all issues related to the Management, Operations and Maintenance of irrigation schemes, including institutional capacity building requirements.

As such the overall objective of the IMP was to provide sufficient guidance to the BWE to be able to take effective control of the existing irrigation systems in its mandated area and provide reliable irrigation water services. This objective is in conformity with the updated NWSS 2020 with the overall goal of supplying water, irrigation and sanitation services on a sustainable basis. The IMP serves as a strategic long-term investment tool that guides BWE to:

- Identify publicly owned irrigation-related assets to cover all publicly owned and developed irrigation schemes and projects in the Beqaa, with the exclusion of schemes and projects that are under the Litani River Authority (LRA) mandate.
- Address the needs of the beneficiaries by providing sustainable irrigation services.
- Allocate available resources rationally in the irrigation sector.
- Define a clear action plan for the period of 2020-2040 to include capital investment needs.
- Keep track of the irrigation service coverage and demand.
- Prepare a strategy for a timely take-over of irrigation schemes by the BWE or by a delegated management organization.

2 General Description

2.1 Location

Al Assi, internationally known as Orontes, rises in the northern section of Bekaa near the ancient Roman city of Baalbek, Lebanon. It flows in a north and northwest direction across northwestern Syria into southeastern Turkey and empties into the Mediterranean Sea, near Samandağ in Turkey. Al Assi river is therefore an international river with its headwaters in Lebanon.

This report covers only the Lebanese part of ARB extending from Baalbek to the Lebanon-Syrian border. This area is a rolling land between Mount Lebanon and Anti-Lebanon Mountain chain. The plain, known as North Bekaa, is a main agricultural area and its altitude ranges between 1000 m and 500 m near the Syrian border. The basin extends from the crest of Mount Lebanon (3088 m) in the west, or northwest, to the crest of Anti-Lebanon Mountains (2600 m) on the east, or southeast. It has a length in a southwest-northeast direction of about 60 kilometers and a width of about 40 kilometers. The basin area in Lebanon as obtained from CNRS is estimated to 1,870 km^2 which makes it the second largest drainage area in Lebanon. In this study, the project area was limited to the surface watershed draining towards the main stream in Hermel and has a total area of 1718 km^2.

ARB is influenced by a Mediterranean climate that has a cold, windy and wet winter and warm and dry summer. Figure 1 below shows ARB location with the basin delineation and stream routing.

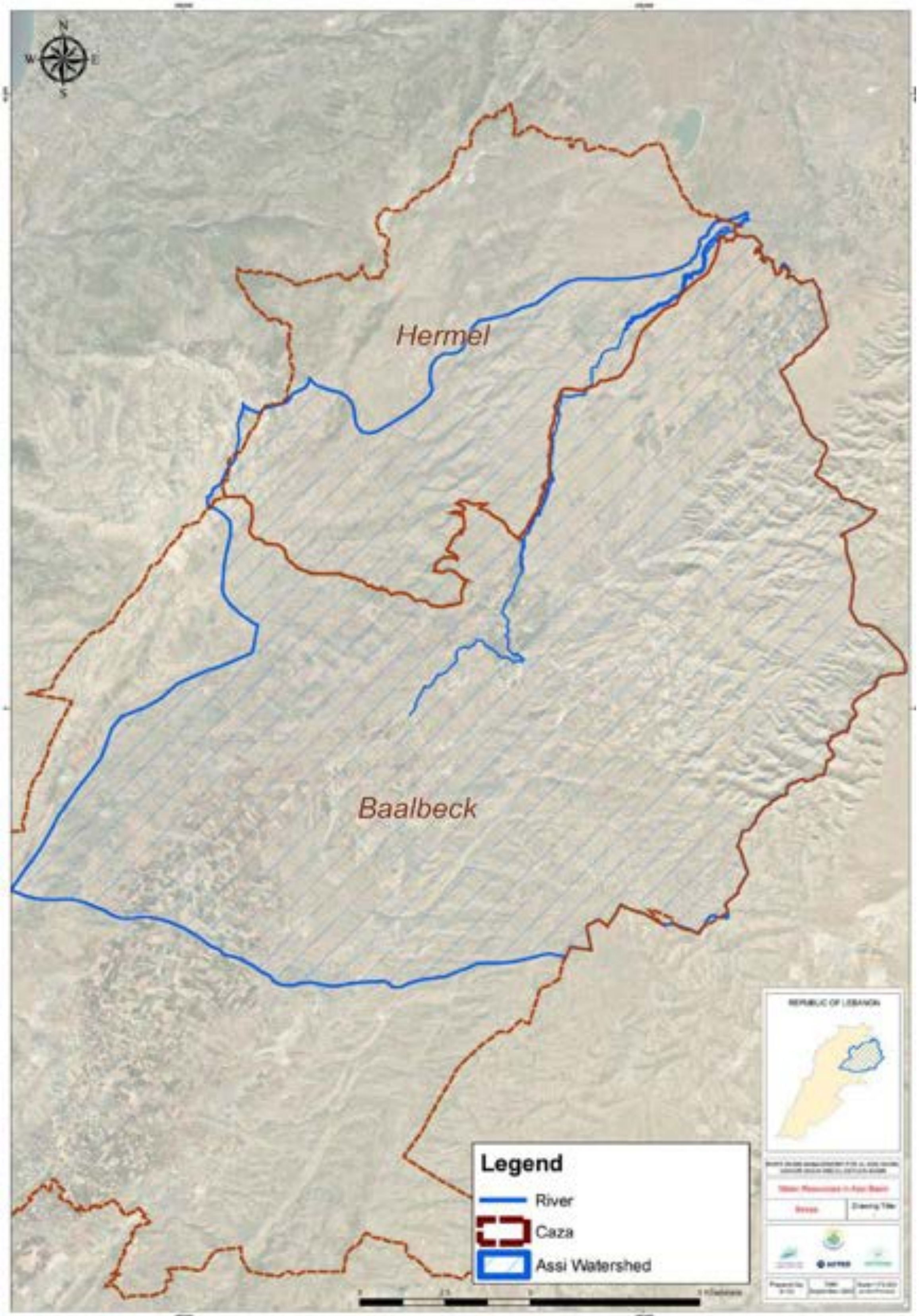

Figure 1 Al Assi river basin location (CNRS)

2.2 Hydro Meteorological Description

2.2.1 General climate description

Lebanon is located on the eastern coast of the Mediterranean, between 33.0° and 35.0° North latitude and is characterized by a Mediterranean climate with precipitation (80%) mainly occurring between October and March while June, July and August are always dry hence affecting water availability in summer.

The Lebanese Meteorological Service (LMS) of the General Directorate of Civil Aviation (DGCA) 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 several stations. 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 Beqaa. (Atlas Climatique du Liban, 1977)

However, ARB climate varies from the coastal area, as Mount Lebanon shield this basin from the warm and humid air flowing in from the Mediterranean Sea. This shielding effect, as well as the altitude of the basin, causes the Lebanese part of Al Assi to have a dry climate instead of the temperate one of the coastal areas.

2.2.1.1 Precipitation

The prevailing winds along the Lebanese coast, are from the west across the Mediterranean Sea. Precipitation, like that on the Mediterranean rim countries, is produced as a result of orographic lifting over Mount Lebanon of the humidity-bearing winds. This orographic lifting is such that the heaviest precipitation occurs on the west side of Lebanon Mountains near the crest then the amount drops rapidly once the crest is passed.

Al Assi river, lying between two mountain ranges, is relatively narrow with dry bearing air descends into it. Therefore, the lifting effect of Anti-Lebanon mountains on its east side does little to produce additional precipitation on either their western slopes or upon their crest. Hence, the eastern side of Nahr Al Assi (Qaa, Arsal, Ras Baalbek) receives less precipitation than does its western side.

Snow and frost occur throughout the river basin, with heavy snowfalls on both Lebanon and Anti-Lebanon Mountains. At high elevations, snow persists until July or August most years and often remains all year near the top of Qornet es Saouda.

Weather stations at Hermel, Deir El Ahmar, Chlifa. and Baalbek are located inside ARB. Yammouneh weather station, although located outside the basin, is somewhat indicative of weather condition along the basin western side and Arsal of Anti-Lebanon mountains in its eastern side.

Daily precipitation values recorded at these stations were collected from the LMS. Data before 1975 were published in the "Monthly Bulletin" of the Climatological Service. Recent data after 2000 were no more published. Several weather stations were installed within Assi basin since 1932 (Hermel station) and more recently in Deir El Ahmar (2000). In result, the average annual precipitation in the basin varies between 200 mm and 900 mm. 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. Thus, the average annual precipitation over this basin is about 360 mm. Table 1 below presents the annual averages of the above-mentioned stations and Table 2 the monthly average precipitation, temperature and humidity at Hermel and Deir El Ahmar after 2000

Table 1 Annual average precipitation in ARB (LMS)

Weather station	Hermel	El-Qaa	Fekha	Arsal	Yammouneh	Flawi	Chlifa	Haouch-Dahab	Baalbek	Deir el Ahmar
Altitude (m)	750	650	1060	1400	1370	1120	1000	1010	1150	943
Annual Average Precipitation (mm)	234	200	210	325	970	680	405	455	410	470
Dates	1932 2018	1966 1972	1933 1970	1964 1970	1939 1969	1964 1972	1944 1959	1961 1972	1939 1972	2000 2017
Number of Years	49	7	22	7	30	9	16	12	32	17

2.2.1.2 Temperature

The average daily temperature in Bekaa valley ranges between 8°C in winter and 29°C in summer (with daily extremes reaching -6.8°C during frost and 46°C during heatwaves); 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 between 0°C in winter (with daily averages reaching -10°C during specific storm events) to 18°C in summer.

2.2.1.3 Humidity

Humidity is relatively high on the Lebanese coast throughout the year. In winter this high humidity results from the action of Atlantic, or Mediterranean, cyclonic disturbances transporting large amounts of humidity to Lebanon.

In summer the short passage of the monsoonal air over the eastern Mediterranean saturates its lower layers sufficiently to maintain high coastal humidity, but not enough to produce precipitation in the mountain areas. This high humidity results in heavy dew occurring many times in summer, with a distinct benefit to vegetation in the coastal area.

Mount Lebanon forms an effective barrier which prevents much of this humid air in summer from entering ARB, hence the lower summer humidity in this basin. The orographic action of this barrier causes much of the winter humidity to precipitate on the western side and just over the crest of these mountains.

Relative humidity records have been maintained for a number of years at Ksara Observatory and Zahle and recent records are available at Hermel and in Deir El Ahmar.

Table 2 Monthly average precipitation, temperature and Humidity at Hermel and Deir El Ahmar after 2000 (LMS)

Station	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
HERMEL	Precipitation (mm)	50	42	20	15	5	1	1	0	3	11	14	50	**212**
	Temperature (°C)	7.8	10.6	13.6	17.9	21.8	25.8	28.2	28.5	25.3	21.3	14.5	9.5	**18.7**
	Min and Max Humidity (%)	59	47	36	32	32	28	27	28	33	38	42	53	**38**
		92	91	83	83	84	84	91	91	88	83	81	88	**87**
DEIR EL AHMAR	Precipitation (mm)	106	107	54	16	10	0	0	1	6	31	42	94	**468**
	Temperature (°C)	6.2	8.0	11.6	15.5	19.3	23.4	26.1	26.0	23.0	18.3	12.4	7.8	**16.5**
	Min and Max Humidity	47	41	30	26	22	17	18	17	20	25	31	40	**28**
		93	89	84	80	78	69	68	71	74	76	83	90	**80**

(%)	

2.2.1.4 WAPOR Data

The WaPOR database (WAter Productivity through Open access of Remotely sensed derived data) is a comprehensive database that provides information on biomass (for food production) and evapotranspiration (for water consumption) for Africa and the Near East in near real-time covering the period from 01-January-2009 to present (FAO, 2020a). The WaPOR offers continuous data at a 10-day average time step for Africa and the Near East at three spatial resolutions. The continental-level data (250m) covers continental Africa and large parts of the Near East (L1). The national-level data (100m) covers 21 countries and four river basins (L2). The third level (30m) covers eight irrigation areas (L3).

Data components soil evaporation – E, plant transpiration – T, rainfall interception – I, reference evapotranspiration – RET, NPP, precipitation – PCP, the normalized difference vegetation index (NDVI) quality layer and land surface temperature (LST) quality layer, are all available for download from the WaPOR portal (FAO 2020a). See Figure 2.

Full-fledged weather stations generally measure all parameters required to calculate RET using the Penman-Monteith equation. Therefore, station RET was compared to WaPOR RET for a number of locations. Since the WaPOR RET data has a spatial resolution of 20 km following MERRA no perfect correlation with station data can be expected. However, the comparison with data from Tal Amara weather station in the Bekaa Valley in Lebanon, surrounded by agricultural fields, yielded good results as the r^2 = 0.89 between the two datasets is considered relatively good. WaPOR RET data follow the seasonality of the station data.

In addition, direct validation to in-situ ground observations with a field survey campaign on the Litani Basin in Bekaa was carried out in July 2017 (by H.Nouri from UT-CTW and M.Blatchford from UTITC). The area represents a mixed cropping system with frequent crop rotation. The visit was done during the potato and wheat harvests; therefore, these crops were the focus of the field survey. In total 19 potato and 15 wheat surveys were used in the validation of the WaPOR NPP (Net Primary Productivity) in the Bekaa Valley. The WaPOR yields for the field plots were estimated by extracting the mean NPP from each delineated plot for each dekad over the season and aggregating the mean values.

WAPOR data was used for the estimation of the irrigation water demand in section 2.6.5. and WEAP hydrological modelling in section 5.

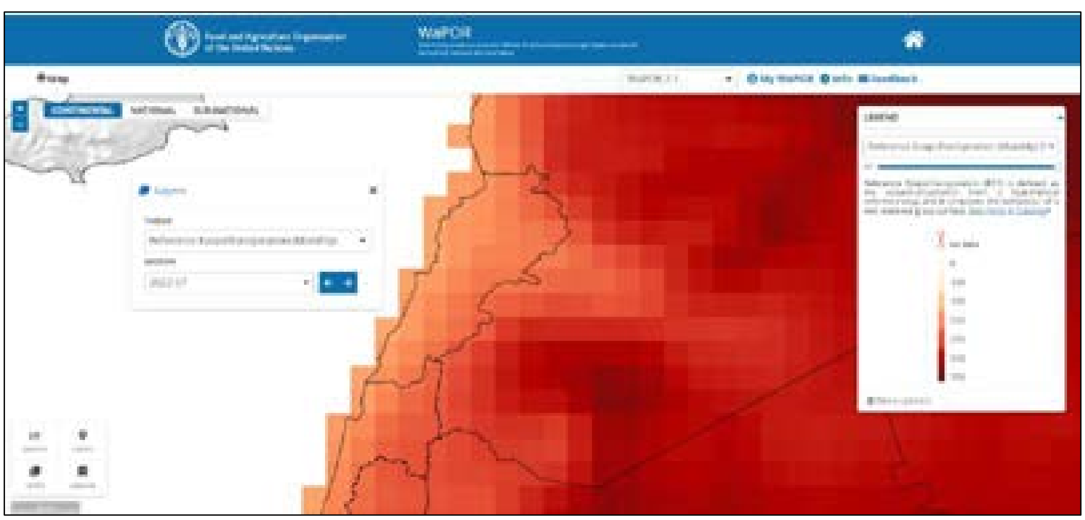

Figure 2 FAO portal for WAPOR

2.2.2 Assi water resources and hydrometric data

2.2.2.1 Assi springs and river flows

The annual precipitation would indicate that a large runoff could be expected during the winter rainy season, but very little runoff occurs. This is due to the geologic formations and manmade changes to the natural drainage channels. The drainage channels have, over many centuries, been mostly terraced and cultivated. The excess water from heavy rains is carried in ditches constructed along the sides of the terraces to other terraces or fields where it is absorbed by the pervious terrain.

Several springs are located within Assi without much contribution to the total river flow except for Laboueh and Fekha when they are not diverted to irrigation and those located in Hermel. The main flow contribution comes from Ain el Zarqa, main contributor to Assi flow, Ras el Mail, Bdita, etc. Little hydrometric data were found for these springs other than LRA and BTD short measurement campaigns therefore average flows were collected from several other reports like UNDP 2014 when available. The average flow of the main springs is presented in Table 3.

Table 3 Average flow of Assi main springs after 2000 (LRA)

Spring	Average Flow (m^3/s)
Laboueh	1.00
Fekha	0.96
Al Raayan – Arsal	1.23
Ain el Zarqa	5.25
Ras El Mal – Hermel	0.23
Bdeita – Hermel	0.08
El Waqf – Hermel	0.09
El Houwe – Hermel	0.04

Despite the wide river basin area, it was found that even after a period of heavy rainfall, only 1 or 2 m^3/s of water was flowing in Nahr Al Assi upstream Ain Zarqa, and most of it originated at Nabaa El Laboueh.

An automatic hydrometric station was installed in 1932 in vicinity of Hermel Bridge (Figure 4). The exact location has varied several times until 1998 when a new gauging point was selected, and a hydrometric station was installed about 400 meters downstream the bridge. This station was first operated by BTD for 2 years and then handed over to LRA in 2000. The station was destroyed during the events of the Syrian war but still monthly measurements were carried on by LRA team. The contributing surface drainage area upstream Hermel station is approximately 1240 km^2. The monthly average runoff is presented in Table 4 below.

Table 4 Assi monthly average runoff flow at Hermel bridge after 2000 (LRA)

Hermel - Bridge	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Annual
Flow (m^3/s)	9.2	8.7	8.4	8.2	8.4	9.2	10.9	12.1	12.2	11.8	10.8	9.9	10.0
Volume (Mm^3)	24	23	22	22	22	23	30	32	33	31	29	26	315

Figure 3 Hydrometric station downstream Hermel Bridge

2.2.2.2 Public and Private Wells

There are currently 80 public wells out of which 65 are exploited for domestic use, 9 under construction or not equipped yet but planned to be operating under 2035 scenario, and 5 out of service. The total yield of the public wells in service is approximately 63,000 m^3/d.

A large portion of the agricultural lands in ARB are irrigated by private wells. An inquiry at the MEW resulted with the collection of data for 3738 private wells within Baalbek Hermel district. It should be noted that a larger number of wells is expected to exist. However, data on those wells is not available (including private unlicensed wells). The total yield of private wells from collected data is approximately 133,500 m^3/d mainly used for the irrigation of 8,600 ha.

Hence, the total current groundwater abstraction estimated to about 196500 m^3/d. Further details and information on abstraction rates and distributions per aquifer are presented in Section 4.6.

Figure 4 below shows the spatial distribution of public wells in blue and in red the private wells grouped into 58 cluster as per villages and yield.

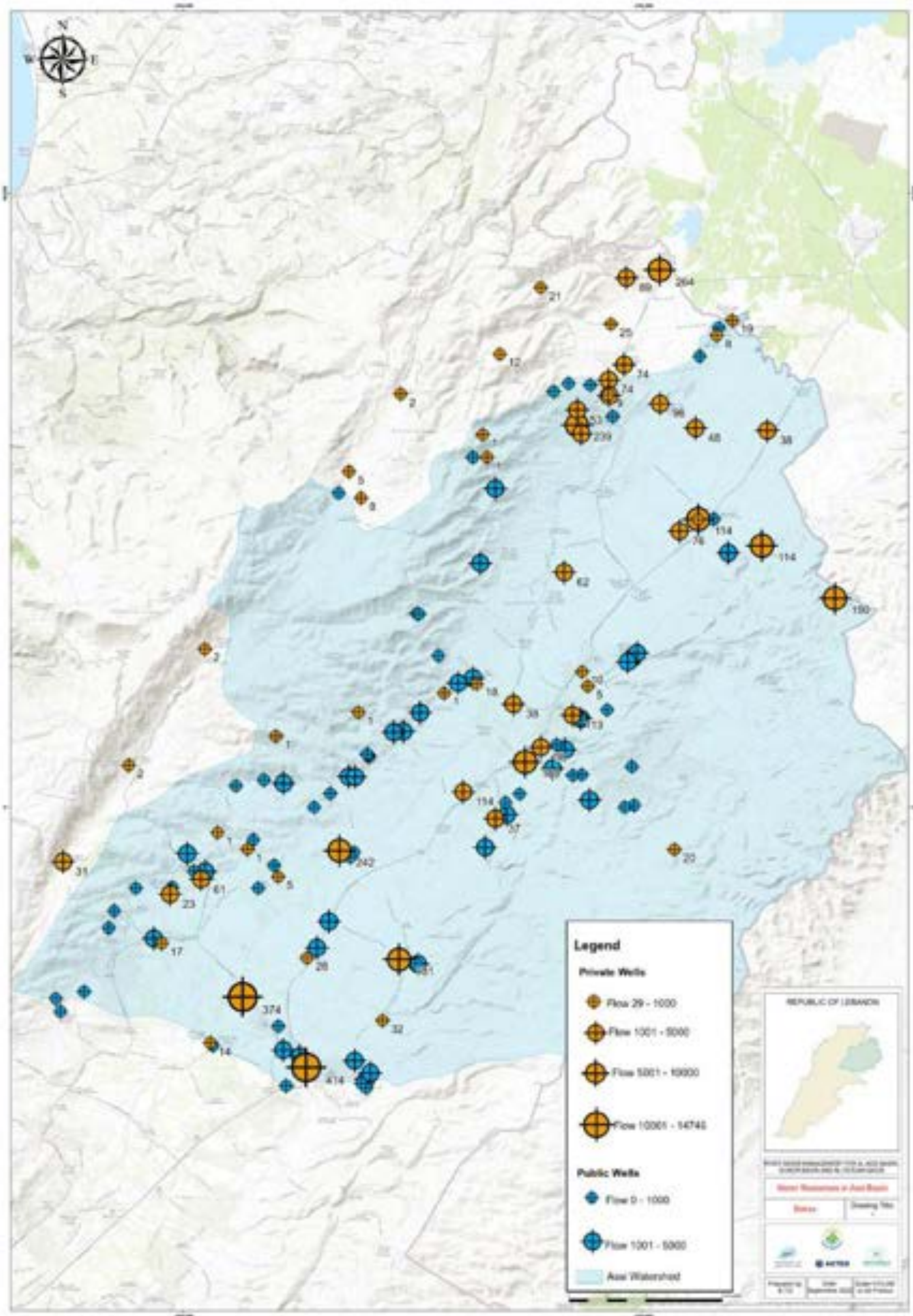

Figure 4 Location map of Public and Private wells in Baalbek – Hermel district (MEW)

2.2.2.3 Recent flow measurement campaign

To check the flow variability of Al Assi river between Ain el Zarka, the main source of the river, and the exit point at Lebanese-Syrian border, a team of 1 hydrogeologist and 2 geologists from BTD carried out a site visit on October 23rd 2022, and attempted to measure the river flow at four different gauging locations, see Figure 5 below. The team managed to reach the gauging locations and dive into the water despite the high velocity and great water depth, however, the flow measurement was unachievable mainly due to equipment constraints (i.e. river bed is deeper than the instrument pole could reach), or safety constraints as to the velocity of the river flow. Detailed description for each location can be found below.

Figure 5 Gauging locations along Al Assi river

The flow measurements were carried out using a hydrometric current meter “moulinet” type C31 (Figure 7). This instrument is used for the accurate determination of the current instantaneous velocity in streams, channels, and rivers. The complete set consists of a meter body which has a cylindrical shape of dimensions 310 x ø 35mm, a propeller of 100mm diameter, a mechanical counter, graduated extension poles, cable, and chronometer. The measurements are made with the device mounted on a pole. Measurements are usually done along a channel section that is divided into several intervals separated by a minimum distance of 15 cm. Multiple measurements should be done at each vertical node where the number of revolutions of the propeller is counted per minute.

Figure 6 The hydrometric current meter "moulinet" type C31

The first gauging location is directly downstream Ain el Zarka spring, where two streams of the river merge into one, see Figure 7 below. The flow measurement of the first stream was possible using the hydrometric current meter method; However, the current on the second stream was too strong and impossible to measure. Therefore, flow measurement was dropped at this location.

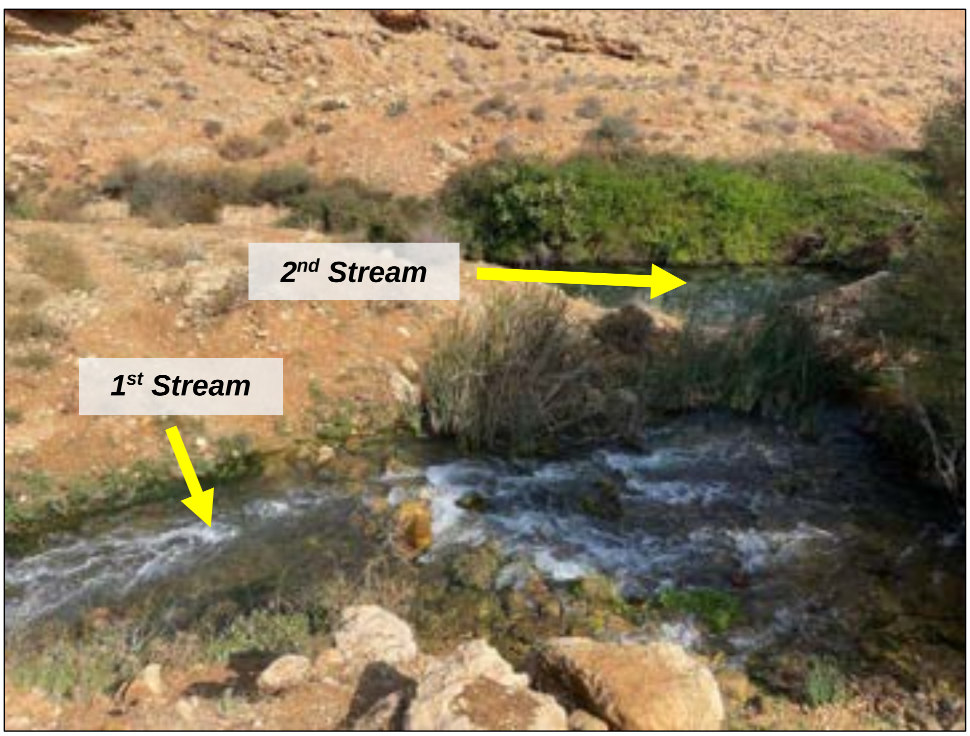

Figure 7 First gauging location and merging point of the two streams

The second gauging location is the hydrometric gauging station operated by LRA at the entrance of Hermel locality, 6 km downstream Ain el Zarka. The flow measurement was impossible due to physical constraints with the equipment at hand, as the water surface was more than 2 m high and the existing bridge was 2 m above the water surface, see Figure 8 below.

Figure 8 Second gauging Location in Hermel

The third gauging location is in Mazraat Beit El Tachm next to Dardara waterfall, 5 km downstream Hermel. The river flow was relatively steady at this point, but the water level at the center of the channel could reach 1.5 meters deep. Although a dinghy was used to navigate the stream, it was impossible to complete flow measurement along the section due to the water depth Figure 9. After multiple trials to complete flow measurement at this gauging location, the current meter cable was damaged preventing any further measurement at the fourth location.

Figure 9 Third gauging Location next to Dardara waterfall

2.2.3 Assi flash floods

Land degradation processes can have significant impacts on the environment, including annual flash floods that can cause catastrophic damage to life and property. Flash floods occur within six hours of heavy localized precipitation in a basin with poor soil development, and are particularly dangerous to human health and well-being due to their rapid development. These floods are common in arid and semi-arid regions and occur frequently in areas with high risk of desertification.

Baalbeck caza is one such hotspot area for desertification, with 90.3% of its territory highly to very highly prone to desertification, according to the National Action Program to Combat Desertification carried out within the Ministry of Agriculture. Heavy flooding following torrential rains in the Anti-Lebanon mountains are common in Northern Bekaa, occurring during May-June or later in autumn (October-November).

Misuse of land, absence of land management, uncontrolled grazing practices, and high land degradation are contributing factors to flash floods in the area. These factors not only contribute to the problem of flash floods but also lead to a high risk of rapid desertification.

The northeast edge of the basin, i.e., Ras Baalbek, Qaa, has witnessed several flash floods on a regular basis causing injuries and mortalities, a huge loss in properties, severe damage to farmers by degradation of vegetation cover. For example, on June 13th, 2018, after repeated floods that hit the northern Bekaa region, especially the town of Al-Qaa, rainfall caused massive floods in the village of Ras Baalbek, leading to the death of a woman after torrents and soil broke into her house. The entire electricity system in the village was disrupted, as the floods damaged electricity poles, destroyed a number of shops, fields, crops, and goods, in addition to submerging the town's landfills. Most of the city was covered by a thick layer of mud and earth washed away by the flood. The walls of the school collapsed, cars were wrecked, trees were uprooted, and roofs collapsed from many old houses.

Floods from the different sub watersheds drain into Assi and directly affect the established farms and vegetation along the river in these areas by delivering huge amounts of sediments with the flood water. According to the records of the Lebanese Higher Relief Council, the direct cost of one flood event in the Aarsal and Fekha towns averages 2.5 million US dollars.

Figure 10 Floods of June 13th 2018 in Ras Baalbek

2.3 Geology and Hydrogeology

2.3.1 Geological conditions

The geological features of Lebanon were mainly described by the French geologist, Louis Dubertret who compiled a general "Geologic Map of Lebanon" on 1:200,000 scale (Dubertret, 1955) and more detailed geologic maps for parts of Lebanon on 1:50,000 scale. The geologic map of the study area is shown on Figure 11. For this project, eight geological sections were constructed to further understand and visualize the geologic structure of the study area (see Appendix C). Those sections were ultimately used to generate a 3D lithological model (Section 4.3) The eastern and western sides of the study area are mainly dominated by the limestones and dolomites of the Cenomanian-Turonian Age (C4-C5 formation); the Quaternary and Neogene deposits occupy the majority of the Bekaa Plain, and are generally overlying the Eocene formation there. The latter is separated from the underlying C4-C5 by the Senonian marls (C6 formation). In other terms, the valley's floor is dominated by lacustrine and alluvial deposits of the Miocene and younger ages, while the basin sides are formed by sharp slopes of the Cretaceous Age. However, under the valley floor, those Cretaceous (and younger deposits) were folded and faulted by compression. On another note, some Eocene formations can be encountered as outcrops along the eastern side of the Bekaa valley. Moreover, limited outcrops of Miocene basalt can be seen in the northern part of the study area, particularly on the right side of Nahr Al Assi.

Structurally, Mount-Lebanon, Anti-Lebanon and the Bekaa Valley form the continuation of a tectonic zone extending from Africa into Turkey while crossing the Dead Sea, Jordan, Lebanon and Syria. The Lebanese mountains have mainly been uplifted due to tectonic movements. Those mountains consist of great masses of Jurassic limestone and dolomite surrounded by folded and faulted deposits of Cretaceous, Tertiary, and Quaternary formations. Under an increasing depositional load, the strata first warped downward before buckling or breaking under great lateral pressure which thrusted the sediments into deeper levels and upward. As a result, Mount-Lebanon and Anti-Lebanon were formed as two massive horsts while the Bekaa became a faulted synclinal basin or graben (USBR, 1957). A low divide, approximately near Baalbek, separates the Bekaa into two drainage basins: a southern basin where surface water flows into the Litani River, and a northern basin where surface water flows into Lake Homs in Syria. In the northern basin, Al Assi River flows through the deposits in a generally northeasterly direction. Two major faults, Yammouneh and Serghaya, are located along the sides of the study area, noting that the most continuous one is the Yammouneh Fault extending along the western side. It is important to note that the study area for the groundwater model is slightly different from the watershed in order to include known boundary conditions, particularly the Yammouneh fault to the west, believed to be acting as a flow barrier.

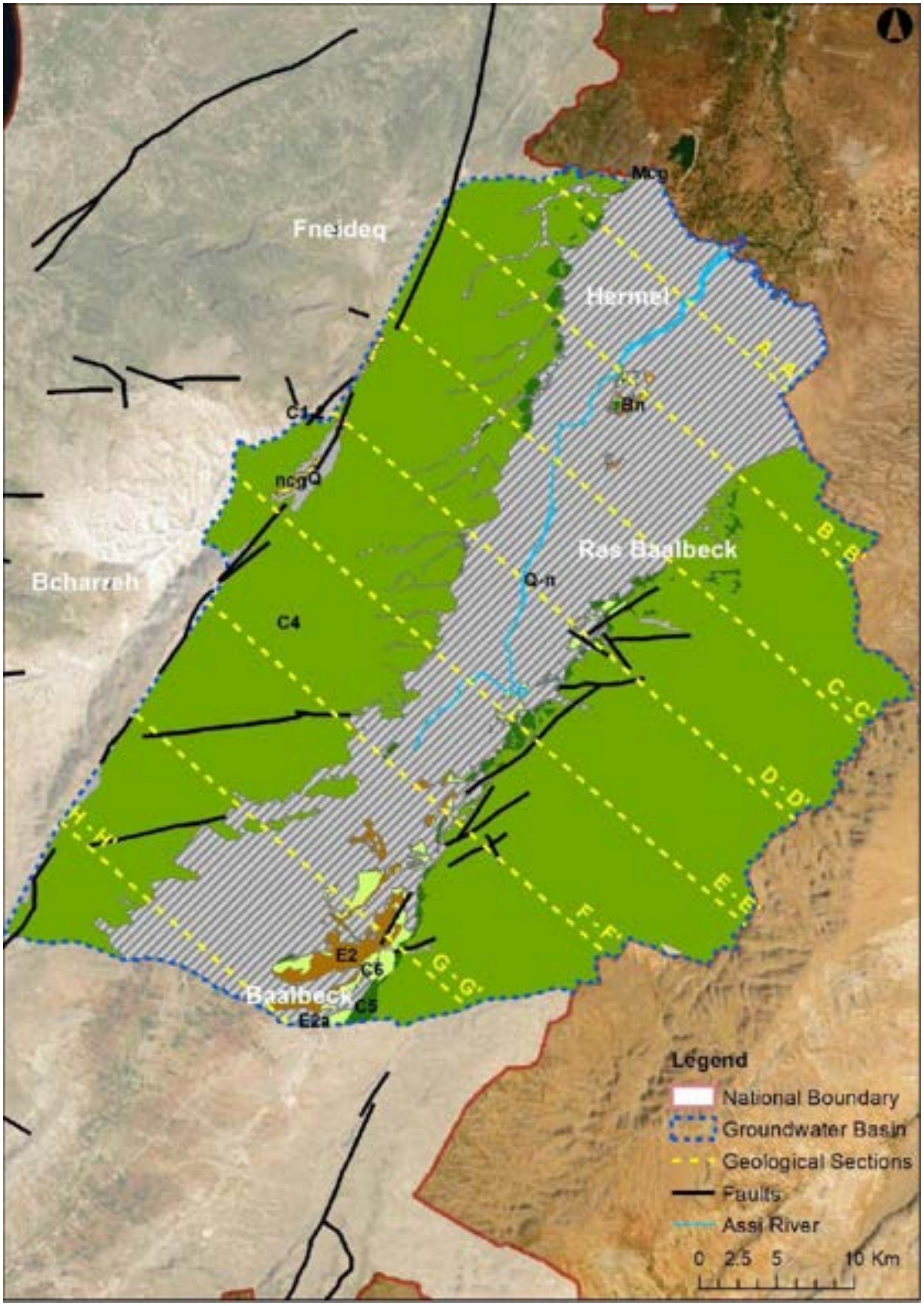

Figure 11 Geological map of Al Assi's Groundwater Basin (modified from Dubertret (1955)): Q-n (Quaternary and neogene deposits), C6 (marly limestones and chakly marls of the Upper Cretaceous), E2 (Marly limestones, sub-reefal white limestones of the Eocene), C4-C5 (limestones and dolomites of the Cenomanian-Turonian), Bn (Stratified basalts of the Neogene)

2.3.2 Hydrogeological conditions

2.3.2.1 Hydrogeological formations and properties

UNDP (1970) published a 1:200,000 hydrogeological map covering Lebanon. The work carried out by UNDP (1970) led to the most comprehensive groundwater study for the country since the presented conclusions were based on drillings, geophysical studies, pumping tests, chemical analyses, groundwater level monitoring, and on information provided by various organizations responsible for meteorology and hydrology. It is important to note that the 1:200,000 geological map of Dubertret (1955) was adopted for all stratigraphic and structural data. Figure 12 shows the outcropping hydrogeological formations of Lebanon as well as the defined groundwater flow directions according to UNDP (1970).

The vertical extent of the hereby description is limited to the Upper Cretaceous. In particular, in the Anti-Lebanon Mountain range, the Jurassic and Upper Cretaceous aquifers are generally separated by thick aquiclude formations. In the northern part of the Anti-Lebanon, the main springs are Ain Zarqa and Laboueh springs which feed Nahr Al Assi (UN-ESCWA and BGR, 2013). Figure 13 shows the existing springs within the study area and gives an indication on the order of magnitude of their discharge.

The limestone formations of the C4-C5 generally have a large thickness within the study area which had permitted the storage of significant amounts of groundwater. The widely present faults in ARB form, in many cases, barriers resulting in further concentration of water and in the emergence of many springs. The groundwater flow direction is mainly controlled by the structural geology and by the hydraulic properties of the subsurface. Moreover, the high solubility of the lithological formations facilitated their enlargement.

Along the sides of ARB, the Cretaceous and Tertiary formations experience a sharp dip under the Bekaa valley. Hence, rainwater and snowmelt that infiltrated into these formations at high altitudes flows downward before being accumulated in synclines or concentrated along fault planes. Part of this water is discharged as springs, while another part (most likely) flows towards Lake Homs. Hence, the flow from the springs is related to the rainfall and snowmelt at high elevations (USBR, 1957). Therefore, the Cenomanian-Turonian limestone presents itself as a remarkable recharge zone for the meteoric waters that reappear at the springs (especially those that run along the major Yammouneh fault). Ain Zarqa (the main spring in the study area) is an artesian spring fed by the Cenomanian limestones of Mount Lebanon. This spring has a clearly different regime from that of all the other springs within the study area since it is characterized by a perennial and almost constant discharge during the year. It is important to note that Ain Zarqa spring and Al Daffach springs (located in the vicinity of Ain Zarqa spring) are the largest contributors to Nahr Al Assi's river discharge with a mean flow of 11 m^3/s according to Wolfart (1967) and 13.6 m^3/s according to UNDP (1970). Hence, Nahr Al Assi is mainly fed by groundwater. UN-ESCWA et al. (1996) stated that groundwater contributes up to 90% of Nahr Al Assi's streamflow. In fact, the river flow is maintained during summer by groundwater discharge (as revealed for instance by the gauging station of Hermel which does not show pronounced seasonal variations). The western slope of the Anti-Lebanon, also characterized by its limestone formations, behaves in a similar way with springs such as Nabaa el Fekha, El Ain and Laboueh emerging at the low points of contact between the Cenomanian limestones and the Senonian marls (C6 formation) on the edge of the plain (UNDP, 1970).

The Eocene limestones appear discontinuously between Jabal Terbol (located at about 35km to the south of the study area) and the village of Ras Baalbek (within the study area). They are lost to the northwest under the Neogene formations of the plain. At a larger scale than the area of interest, it seems that there is no hydrogeological connection between the Eocene limestones of the southern and northern Bekaa due to the existence of transverse faults: this observation was confirmed by UNDP (1970) due to the differences of piezometric levels measured/observed south and north of Anjar's fault (located several kilometers to the south of the study area). The Eocene aquifer feeds a number of contact springs (such as Ain el Baida). However, those springs dry up almost every summer due to increased pumping. In Baalbek, springs originating from the Neogene conglomerates of the plain are believed to be direct outlets of this Eocene limestone aquifer. The analysis of pumping tests carried out in Baalbek region showed transmissivities of 1210 and 5270 m^2/d for the Eocene aquifer and a storage coefficient of 0.015 (UNDP, 1970).

The shallower Pleistocene formation of the Quaternary occupies the central part of the Bekaa Plain. These deposits are encountered near the Syrian border and extend into the southern end of ARB. The poorly sorted and poorly graded material forming this formation generally has low permeability and yield values. Historically, groundwater was abstracted from these materials through shallow large-diameter hand dug wells. Along the sides of the basin, appreciable amounts of water can be extracted at shallow depths from the base of the alluvial deposits (USBR, 1957). According to the produced geological sections, the average thickness of the Quaternary-Neogene deposits within the study area varies between 495m in the northern part and 220m in the southern part (however, this remains an estimation). It is important to note that the thickness of this formation gets thinner at the edges of the valley. The unconsolidated Quaternary formations are mainly made up of marl, gravel and clay. They contain a continuous, low-flow aquifer throughout the Bekaa. The transmissivity of the Neogene and Quaternary aquifers has a high variability from one location to another in the Bekaa: it can reach 8640 m^2/d in Kfar Dan and Baalbek, and rarely exceeds 85 m^2/d in Tell Amara and Rayak (UNDP, 1970). Hence, those formations can have a low permeability in many areas.

2.3.2.2 Groundwater recharge

The relatively thin and sparse layer of soil with its high infiltration rate as well as the highly permeable outcropping formations facilitate groundwater recharge over the Lebanese mountains bordering Nahr Al Assi (especially from Mount-Lebanon). Consequently, groundwater recharge largely depends on the snow cover in Mount Lebanon and the Anti-Lebanon Mountains (UN-ESCWA et al., 1996). Taking place mainly during the winter season, local recharge lasts until spring due to snowmelt (Zwahlen et al., 2014). Surface runoff is only generated after extended precipitation events that saturate the soil and fill the interstices and fractures of the shallow formations (USBR, 1957). UNDP (1970) reported that the average percentage of infiltration obtained for the basins of the Bekaa (including but not limited to the study area) is 38.5%.

However, Droubi (2012) mentioned that groundwater recharge could reach up to 60% of the received precipitation on the mountain ranges characterized by limestone outcrops of the Cenomanian-Turonian aquifer. The Cenomanian-Turonian aquifer is generally underlain by thick aquiclude formations.

Part of the Eocene limestone aquifer benefits from contributions other than those which correspond to the rainfall infiltration: these are essentially lateral groundwater flows from the Quaternary-Neogene aquifer. Since the outcrop area of the Eocene is relatively limited, its recharge largely depends on the hydraulic connection with the overlying Quaternary-Neogene aquifer. UNDP (1970) assumed that 25 MCM of groundwater recharge occurs annually in the Eocene aquifer. The same study also mentioned that it is judicious to limit abstractions to 75% of the average groundwater recharge of the Eocene. It is interesting to note that The Senonian marls formation (C6), underlying the Eocene aquifer, limits the hydraulic connection between the Eocene and the Cenomanian-Turonian formations.

The Quaternary aquifer is mainly fed by the infiltrating rainwater and by contributions from the limestone formations located on its edges noting that it is challenging to quantify those contributions. Groundwater recharge into this aquifer is estimated at around 4.5% of the total rainfall (UNDP, 1970). However, this seems to be a very low rate since the lithological formations of this aquifer are mostly permeable, hence high transmissivities can be expected. Moreover, there is possibility that the Quaternary aquifer is recharged by seepage from the river and/or ephemeral streams. On the other hand, groundwater discharge from the Quaternary to the river (i.e. baseflow) can also take place when and where the river behaves as a gaining (effluent) stream. Hence, this complex behavior (that can vary in time and space) would require a detailed groundwater-surface water interaction assessment.

Further insights on groundwater recharge to the different aquifers are presented in Section 4.8.

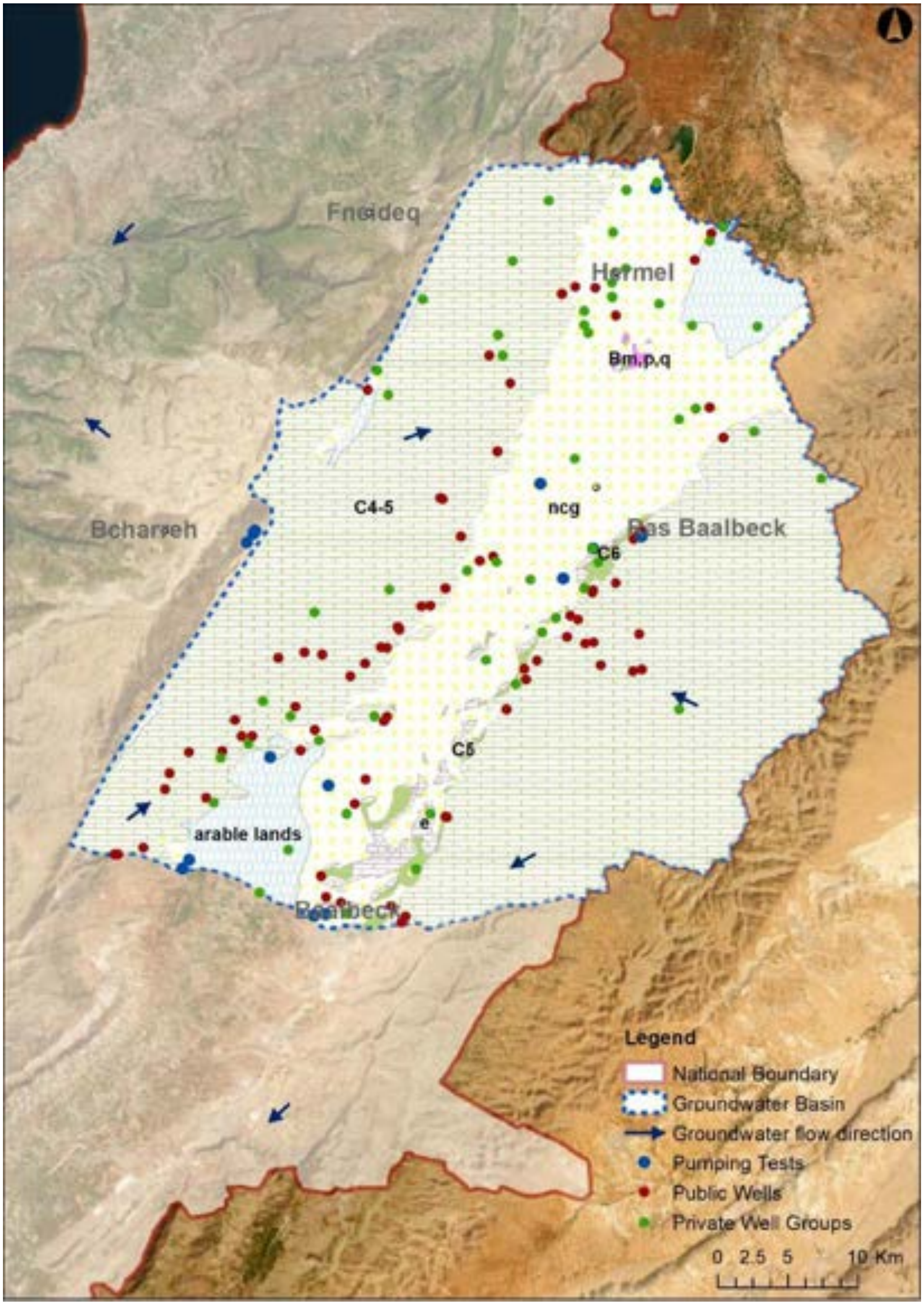

Figure 12 Hydrogeological map of Al Assi's Groundwater Basin (modified from UNDP (1970) showing old pumping test locations, current public wells and grouped private wells. In this map: C4-5 indicates the Cenomanian-Turonian limestone, C5 indicates the Turonian limestone, C6 indicates the Senonian marls, e indicates the Eocene limestone, ncg indicates the Miocene and Pliocene conglomerates, Bm,p,q indicates basalt formations

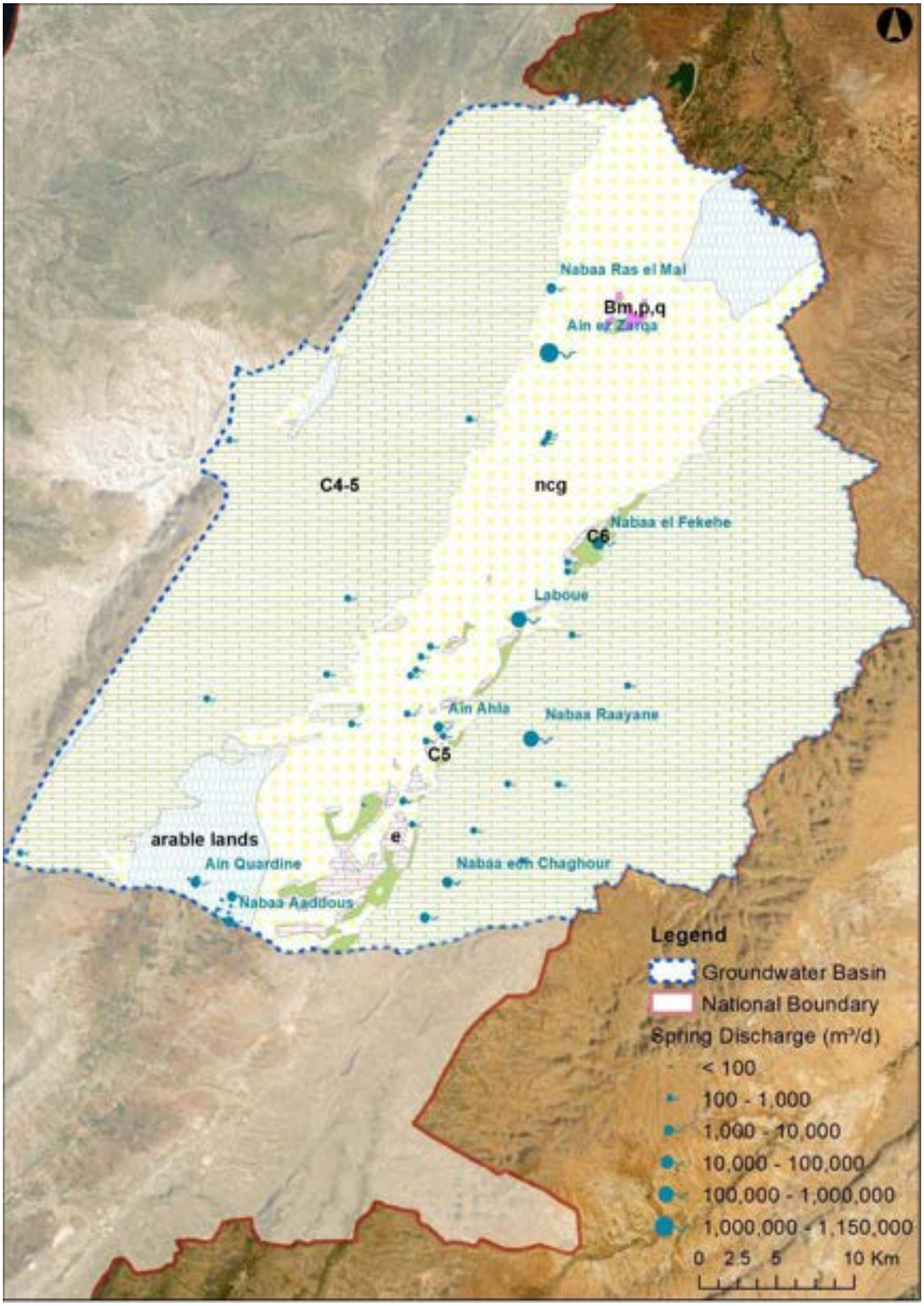

Figure 13 Springs of Al Assi Groundwater Basin (names of the main springs are indicated). Spring discharge values are obtained from USBR (1957), MoEW and UNDP (2014), LRA data, and Consultant's experience.

2.3.2.3 Historical groundwater levels

Figure 14 shows the groundwater level contours reported by UNDP (1970) for the two main considered aquifers for this project (i.e. the Cenomanian-Turonian aquifer and the Quaternary-Neogene aquifer). In the southern part of the basin, the groundwater levels varied between 990 and 1075m AMSL for the Quaternary-Neogene aquifer (with an estimated hydraulic gradient of 0.0046 in the central southern part of the basin and 0.018 in the southeastern part). In the western part of the basin, the groundwater levels varied between 675 and 810m AMSL for the Cenomanian-Turonian aquifer (with an estimated hydraulic gradient of 0.047 in the northern part of the basin and 0.006 in the southern part). Those contours also show that the groundwater direction within the western Cenomanian-Turonian aquifer is towards the east (i.e. towards the Bekaa plain).

The groundwater levels in the Eocene limestones vary between 1025 and 1075m AMSL in the northern part of the basin and between 872 and 1075m AMSL in the southern part. While seasonal fluctuations in piezometric levels are only 3 meters in an average year in the north, they reach 13 meters in the south. The minimum hydraulic gradient is around 0.2% in the Ras el Ain region while the maximum gradient observed between Terbol and Baalbek can reach 0.8% (UNDP, 1970).

Annual variations in the quaternary piezometric levels are between 2 and 5 meters (UNDP, 1970). Groundwater levels showed two main groundwater flow directions in the Neogene and Quaternary aquifers: towards the southwest reaching Joub Jannine, and towards the northeast reaching El Qaa.

Figure 14 Available groundwater level contours of the two main aquifers (modified from UNDP (1970))

2.4 Environment

This section describes the overall environmental situation in ARB, it includes four subsections LandUse and LandCover, Water quality, Air quality and finally the socio-economic environment.

2.4.1 LandUse and LandCover

Landscape refers to the natural scenery constituted of the visible features of a certain area. It comprises the physical elements such as landforms, living elements of fauna and flora, physical conditions like weather and water forms, and human elements such as human activity and the built environment.

A geospatial assessment was conducted in order to determine the LULC composition of Assi Watershed area. The LULC will enable us to identify any potential pollution hotspots and vice versa. It is clear from Table 5 and Figure 15 that ARB is mainly dominated (41%) by natural outcropping formations like bare rocks, bare soil and rocky outcrops, then by medium to large fields of agricultural terraces (17%), and by oaks and Juniper forests (15.3%). The remaining 30% is divided among various types of scrubland, fruit trees and urban areas.

It is concluded from the LULC distribution that the watershed area exhibits typical rural area characteristics with abundant natural outcrops and agricultural farmlands and absence to very low presence of industrial activities.

It is important to note that the juniper forest is scattered on the Anti-Lebanese mountains west of the Assi watershed at elevations varying between 1,329 m and 2,062 m. Juniper is one of the most important forest species in Lebanon. It is a very sturdy tree that can withstand extreme weather conditions. Like most conifers, juniper is an important emitter of oxygen, with around 50 tons per tree per year. In the process, junipers absorb large amounts of other harmful gases such as carbon dioxide (CO_2) and facilitate groundwater recharge thanks to their extensive root systems.

Table 5 Distribution of LULC types inside Assi Watershed (CNRS)

LULC Type	Area (km^2)	Cover Ratio (%)
Bare Rocks	596	34.6%
Field Crops in Medium to Large Terrace	292	16.9%
Clear Oaks/Clear Juniper	263	15.3 %
Fruit Trees	116	6.7%
Bare Soil	91	5.3%
Scrubland	84	4.8%
Scrubland with Some Dispersed Bigger Trees	63	3.7%
Medium Density Urban Fabric	26	1.5%
Abandoned Agriculture Land	23	1.4%
Clear Mixed Wooded Lands	23	1.3%
Rocky Outcrops	23	1.3%
Field Crops in Small Fields/Terrace	20	1.2%
Low Density Urban Fabric	18	1.0%

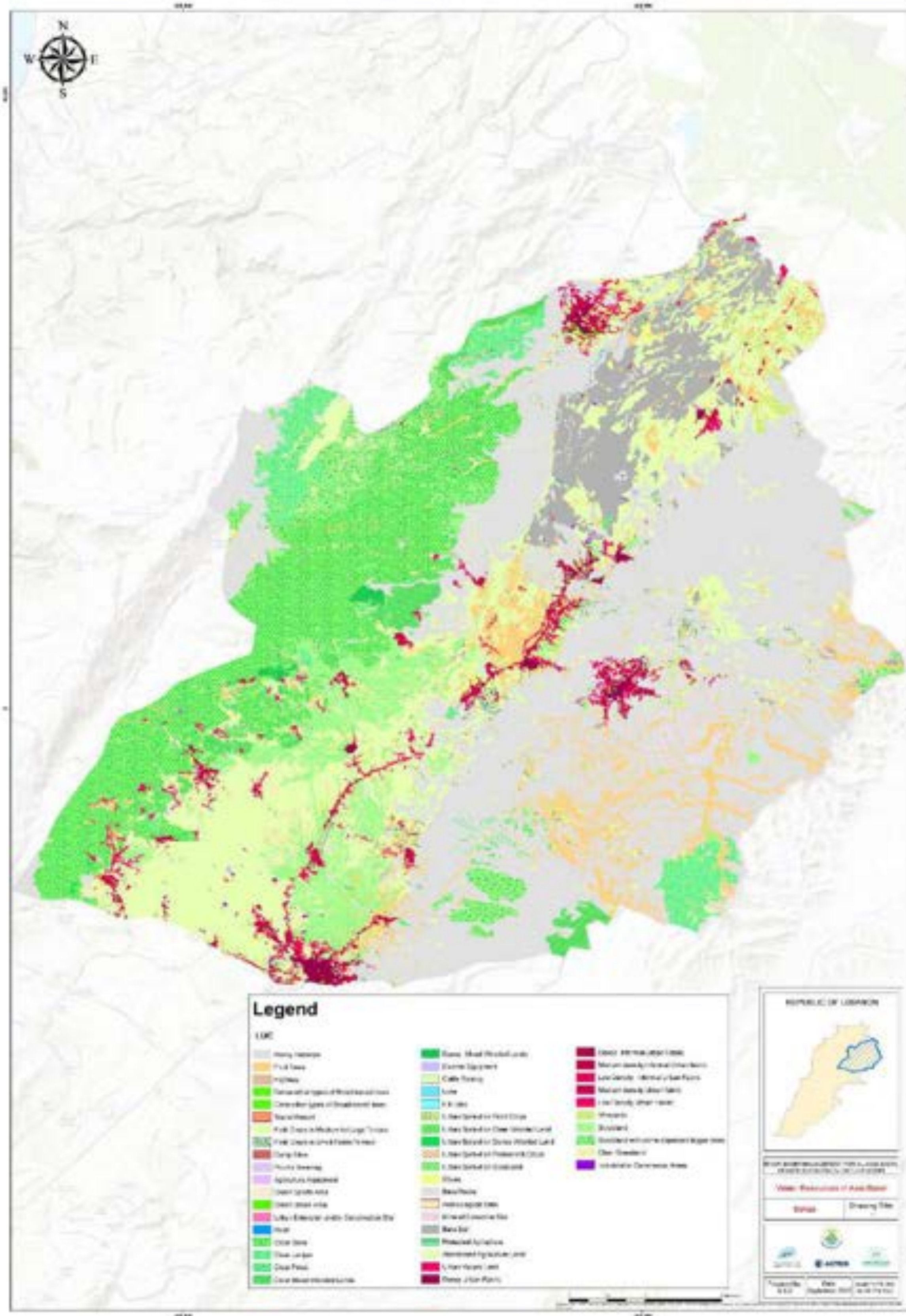

Figure 15 Prevailing LULC features inside Assi Watershed (CNRS)

2.4.2 Wastewater collection and treatment

There are two main Waste Water Treatment Plants (WWTP) within Assi Watershed that are located in Iaat and Deir El Ahmar localities (figure 16). Presently, in year 2022, both plants are not operational due to the lack of diesel fuel attributed to the inflation and economic crisis in Lebanon. In addition, there are several other WWTP proposed and included in the Updated NWSS 2020 as priority 1 such as Hermel and Arsale and priority 2 as Qaa, Ras Baalbek and Chaat.

2.4.2.1 Iaat WWTP

The existing WWTP in Iaat, which started operating in 2007, receives wastewater mainly from the sewered parts of Baalbek, Iaat, Ansar, Ain Bourday, Douris, and Haouch Tall Safiye villages. The wastewater treatment level is secondary without nutrients removal (treatment type: Activated Sludge (AS) – Oxidation Ditch). The capacity of the constructed WWTP is 15,000 m^3/d. After treatment, the effluent is discharged to Massil stream that leads to Assi River, and is occasionally used for irrigation. The dewatered sludge is temporarily stored within the WWTP plot and sometimes collected for free by farmers (at their own responsibility). However, as mentioned before, the plant is currently not operational and the flow is bypassed directly to the stream. It is worth mentioning that there is a plan to increase the hydraulic capacity of the plant to 22,500 m^3/d in order to accommodate the future flow after completing 100% of the sewer network in the serviced villages.

2.4.2.2 Deir El Ahmar WWTP

The existing WWTP in Deir el Ahmar was designed to receive wastewater flows from the sewered part of Deir el Ahmar village (maximum flow: 30-35 m^3/h). The biological treatment process (consisting of a HANS REACTOR – biological filter) was constructed in year 1998. The liquid sewage flows by gravity to the HANS -REACTOR. Air being pumped via an aerator forces sewage that has descended to the bottom of the HANS-REACTOR, upward to the surface filter. Microorganisms' rapid growth at the surface filter develops bacterial biomes consuming organic matter from the sewage. Purified water flows to the final sedimentation compartment where suspended particles sink down to the bottom of the tank. From there, it is recycled back to the septic or sedimentation tank at periodic intervals. When the septic or sedimentation tank becomes filled with sludge to about 50% of its capacity, it requires to be emptied in a standard manner at a frequency of once to twice per year.

In 2017, the WWTP was upgraded by the construction of a fine screening and compacting unit, an equalization tank, a chemical primary settling tank, and a clean water collector.

Deir el Ahmar presently has a wastewater collection network covering about 30% of the housing units. The existing wastewater network was constructed in two phases (years 2004 and 2017 respectively) and consists of concrete pipes (laid on the main roads) and plastic pipes. In general, the concrete pipes need maintenance. Pipes' diameters range between 8" and 14". At the present time, Deir el Ahmar WWTP is not operating, the network discharges, without any treatment, in Al Massil stream or on agricultural lands, causing severe pollution.

2.4.2.3 Sewage Network Coverage (Table 6)

Assi watershed area is very behind when it comes to wastewater network coverage. Only four villages Iaat, Baalbek, Hermel, and Haouch Tall Safiye have a sewer system with 90% coverage, Deir El Ahmar is only covered at 30%, while the remaining villages are considered neglected with complete absence of any sewer system. These villages rely on septic tanks for dumping of generated wastewater. Due to lack of appropriate collection and treatment of wastewater in the area, groundwater and surface water resources remain at high risk of contamination.

Table 6 Sewer network coverage for villages inside the Assi watershed (Updated NWSS 2020)

Villages within Assi Watershed	Sewage Connection Rate (%)
Iaat	95
Baalbek	>90
Haouch Tall Safiye	>90
Deir El Ahmar	30
Hermel	30
Btedaai	<5
Chlifa	<5
Remaining 55 villages	Absence of sewer system (reliant mainly on septic tanks)

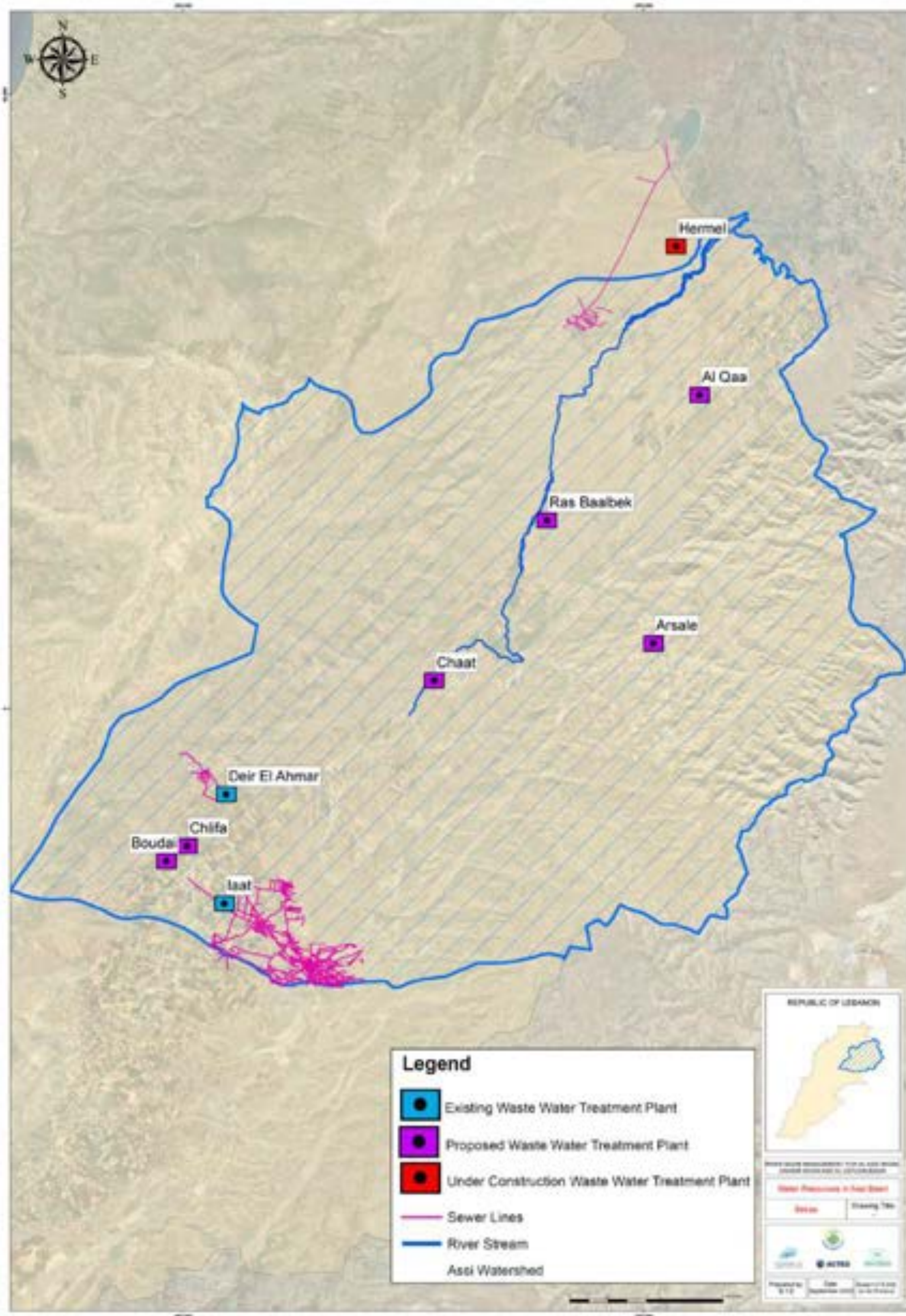

Figure 16 Existing sewer network and WWTP within Assi watershed (Updated NWSS 2020)

2.4.3 Quarries and Dumpsite

A total of 39 dumpsites and 22 quarries exists inside Assi Watershed, divided among the villages as shown in Table 7.

Out of the 39 dumpsites, only 24 are operational, and out of the operational 9 are located in private lands and the remaining 15 are situated in communal land (e.g., Mashaa land belonging to the monasteries). Some dumpsites accept only municipal solid waste (MSW) and other accept both MSW and construction and demolition waste (CDW) (reference is made to Table 8).

Out of the 22 quarries, almost all of them (19) do not have a legal license to operate, however only 9 are operational and the remaining are either stopped or abandoned (Table 9). The remaining 3 legal quarries are all in operation.

Table 7 Distribution of dumpsites within ARB (CNRS)

Village	Dumpsites	Quarries
Aarsal	1	7
Baalback	2	1
Barqa	1	-
Bouday	1	-
Chaat	1	2
Chawaghir	1	-
Chlifa	1	-
Deir el Ahmar	1	1
El Ain	1	-
El Qaa	2	-
Fekha & Jdaide	1	-
Halbata	1	-
Harbta	1	1
Hermel	1	-
Klayle, Harfouche	2	1
Knaisse	1	-
Laboueh	1	1
Maqne	2	1
Moqraq	1	-
Nabha	1	-
Nabi Osman	2	-
Nahle	1	-
Qarha	2	-
Ram, Jebbaniye	3	-
Ras Baalback	1	2
Sbouba	1	1
Tawfiqiye	1	-
Younine	3	-
Zabboud	1	-
Zeghrine	-	3
Wadi Faara	-	1
Total	**39**	**22**

Table 8 Condition of dumpsites withing ARB

Condition of dumpsites	Number of Dumpsites
Non-Operational	**15**
Communal Land	**9**
Multiple (MSW + CDW)	3
Municipal Solid Waste (MSW)	6
Private Land	**6**
Multiple (MSW + CDW)	1
Municipal Solid Waste (MSW)	5
Operational	**24**
Communal Land	**15**
Multiple (MSW + CDW)	2
Municipal Solid Waste (MSW)	13
Private Land	**9**
Multiple (MSW + CDW)	1
Municipal Solid Waste (MSW)	8
Grand Total	**39**

Table 9 Condition of quarries within ARB

Condition of quarries	Number of Quarries
Unlicensed	**19**
Abandoned	7
Operational	9
Stopped	3
Licensed	**3**
Operational	3
Grand Total	**22**

2.4.4 Water Quality

Lebanon depends on water for agriculture (60%) and municipal (29%) and industrial uses (11%). In addition, it has been estimated that 45% of the irrigated land in Lebanon depends on springs and wells as a primary source. As a result, water pollution in Lebanon poses a significant risk to public health and economy.

In general, use of contaminated water has been linked to outbreaks of severe disease. Widespread pollution from untreated sewage has raised concerns about water quality in Lebanon, a country with well-documented infrastructure problems.

In addition, Lebanon's water is increasingly at risk from pollution, mainly due to (1) population growth, including an influx of ~1.5 million refugees (~1 refugee per 4 nationals) since 2011, (2) poor wastewater management and solid waste, and (3) the absence of monitoring and surveillance programs.

In this context, a nationwide study was conducted by AUB in the dry season of 2021 to try and quantify bacterial pollution levels in 14 majors in Lebanon. Samples were collected from the upper, middle and lower reaches of each river and testing parameters included fecal matter, fecal coliform bacteria, and E. Coli. This is important because high densities of faecal indicators have been associated with the occurrence of pathogenic microorganisms such as Salmonella and E. coli, which have a serious impact on human health

With respect to Assi river, given that it is a transboundary large river, samples were taken from 3 locations, namely:

1. Ain el Zerqa
2. Bejaje
3. Laboueh

The acceptable limit of thermo-tolerant coliforms based on the SEQ-EAUX-2003 standard for irrigation water is 100 CFU/100 mL and the permissible limit of fecal coliforms for safe recreational water is 800 CFU/100 mL as per the EPA standards.

With respect to fecal and E coli contamination in Assi, the upstream location in Ain El Zarqa is suitable for irrigation, the midstream location in Bejaj is not suitable for irrigation but suitable for safe recreational water and the downstream location in Laboueh is not suitable for neither irrigation nor recreation.

In the context of this project a recent water quality campaign was carried on the 31st of August 2022 and samples were taken from 10 different locations, see section 3 for more details.

2.4.5 Air Quality

The ambient air pollution can be a significant source of pollutant input to surface water.

In the context of nitrogen dioxide (NO2) air pollutant presented in this project, studies show that precipitation is a significant source of nitrogen in surface waters, and the significance of the associated pollution appears to be a function of increased industrial or agricultural activity. Atmospheric input of nitrogen from the air can come from windblown dust from fertilized soil, from direct fallout of pollutant emissions from fossil fuel combustion, and from precipitation (rainfall).

Atmospheric air quality data was collected from the Sentinel 5P Tropomi Satellite which provides daily freely publicly available near real time data for various gases in the atmosphere. Given the satellite was launched in 2018, the mean tropospheric NO2 column density was calculated using the Google earth engine code java script editor resulting in Figure 17 which shows the mean NO2 values across the border of Lebanon between year 2018 up to October 2022. It is clear from the legend that the NO2 pollution is concentrated above the Beirut area and decreases when moving east to reach its lowest value in the eastern Bekaa plain and at the project area (Assi Watershed) in Baalbek and Hermel districts. This shows that the project area has a relatively good ambient air quality and confirms the absence of polluting stationary sources such as industrial activities. This is expected given that the area is dominated by agricultural activities and natural outcrops and is limited to manual crafts with minimal industrial areas (refer to LULC map).

Finally, an NO2 timeseries was plotted (Figure 17) comparing pollution in Assi watershed and Beirut area. It is clear from the results that the Assi area witnesses a very low constant NO2 concentration whereas in Beirut the pollution fluctuates and is very high. This analysis enables us to conclude that the probability of surface water sources at Assi watershed be polluted from ambient air pollution is very highly unlikely.

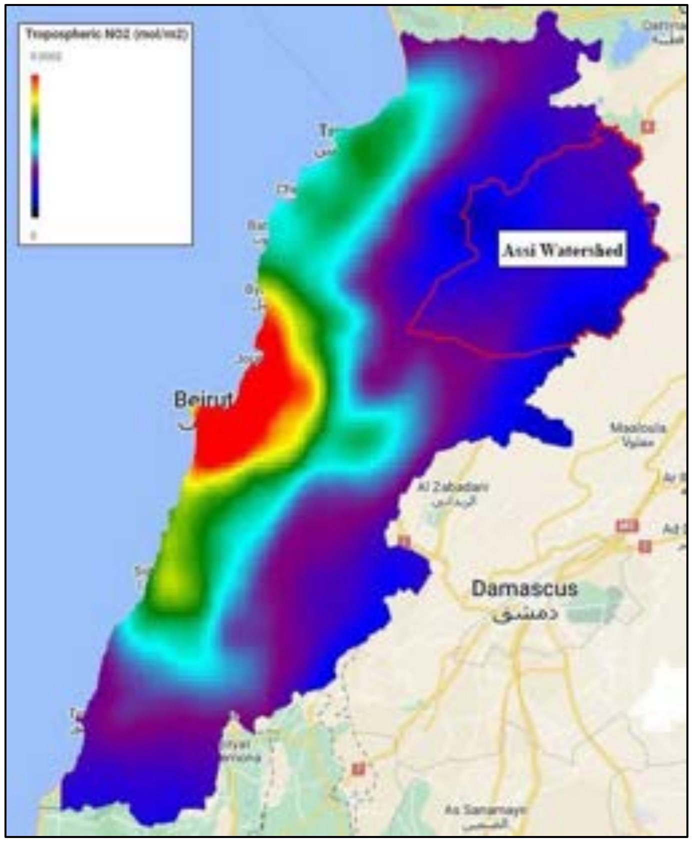

Figure 17 Distribution of air pollutant Nitrogen Dioxide (NO2) in the troposphere above the Lebanese border average from year 2018 up to October 2022 (data retained from Sentinel-5 precursor/TROPOMI Level 2

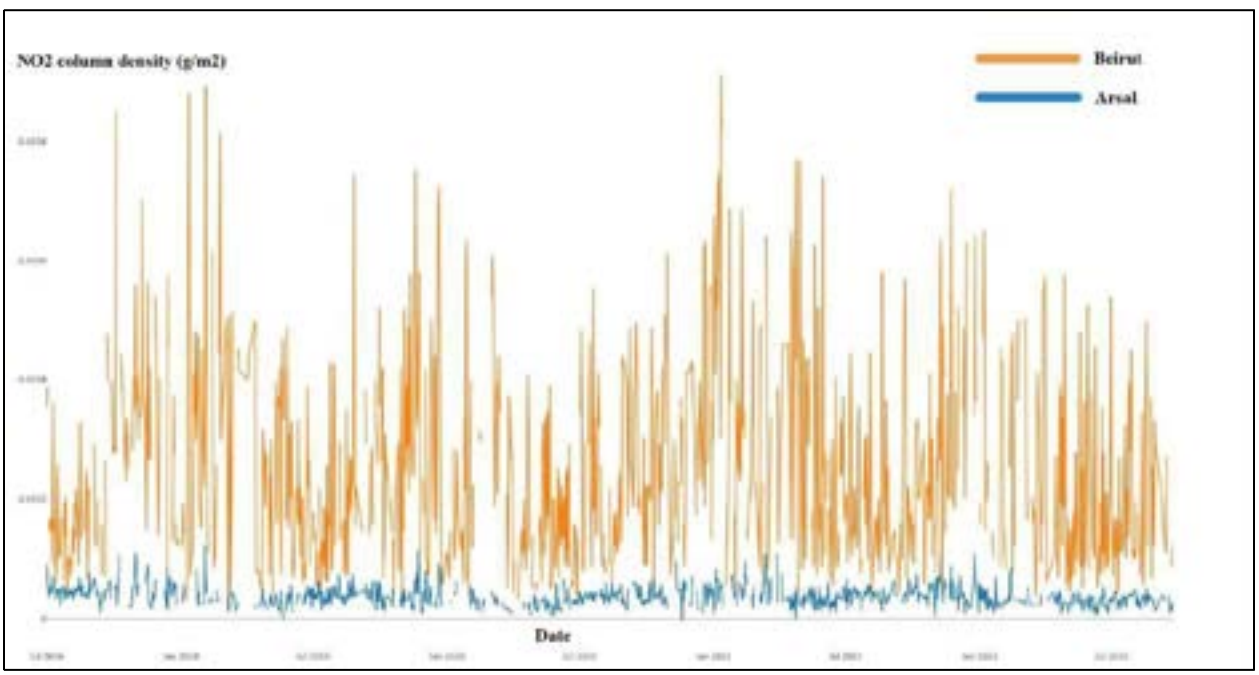

Figure 18 Time series comparing level of NO2 in the troposphere between Beirut and Aarsal located in ARB (data retained from Sentinel-5 precursor/TROPOMI Level 2 Product)

2.4.6 Socioeconomic Environment

2.4.6.1 Demographical Profile

The survey results (CAS 2020) show that in 2018 – 2019, the caza of Baalbek hosted 4.4 % of residents of Lebanon, with around 214,600 residents. 51.9 % of the residents were females and 48.1% males. 45.9 % of the residents in Baalbek were found in the age group 25–64 years. The younger residents of less than 18 years old represented 32.6 % of the total, whereas those aged between 18 and 24 years old represented 13.2 %. The remaining 8.4 % were the older residents (65+ years old).

2.4.6.2 Connectivity to infrastructure and utilities

Although piped water supply was one of the highest nationally and the main source of drinking water in Baalbek as opposed to almost all the districts in Lebanon (54.3 %), 44.8 % of dwellings still relied on non-piped drinking water and 0.9 % of dwellings had no drinking water facility whatsoever. At the national level, piped water supply was considerably lower (22.5 %) whereas non-piped water supply was substantially greater (76.9 %).

Table 10 Yearly expenditures on services for main dwellings (in thousand LBP)

Services	Baalbek		Lebanon	
	Mean	Median	Mean	Median
Public water	264	250	293	300
Electricity	476	420	671	480
Generator	862	720	1100	900
Satellite/Dish	209	180	231	240
Fixed phones (without internet)	386	300	433	360
Total yearly Expenses on services	2567	2315	3308	2940

2.4.6.3 Syrian Refugees

In Baalbek-El Hermel, there are 119,708 Syrian refugees who are officially registered. Among these registered Syrians, 94% are living in extreme poverty. Looking at the employment situation, Bekaa and Baalbek-El Hermel stand out with the highest rates of unemployment, reaching 61% and 52% respectively. Around 26% of households in the region are headed by females. Additionally, almost half of the households, around 48%, have at least one member with a chronic illness. The living conditions are also a cause for concern, as 55% of households reside in temporary shelters, while 68% of households in Baalbek-El Hermel are dwelling in substandard or dangerous conditions. On the positive side, the majority, 86%, of households in the region have access to improved sources of drinking water (VASyR, 2020).

Table 11 Number of Syrians Displaced

Caza	**Total No. of Persons**
Baalbek	113,058
Hermel	6,650

Source: UNHCR, 2020

2.4.6.4 Work and Employment

The Services sector was the largest employment sector for women and men, with respectively 89.9% and 67.3% in Baalbek, compared to 91.7% and 68.8% in Lebanon. In this sector, women surpassed men by 22.6% at the caza level. It was particularly noticeable that 21.8% of working men and 5.1% of working women were employed in industry in Baalbek, compared to 26.6% of working men and 6.7% of working women in the whole of Lebanon. Compared with the national level, employment in agriculture in Baalbek was greater by 6.3% for working men and by 3.3% for working women (CAS 2020)

Based on employment figures updated in year 2021, high unemployment rate continues to prevail, with around 41% of the active population unemployed, superseding the national figure of 29.6% (LFS 2022).

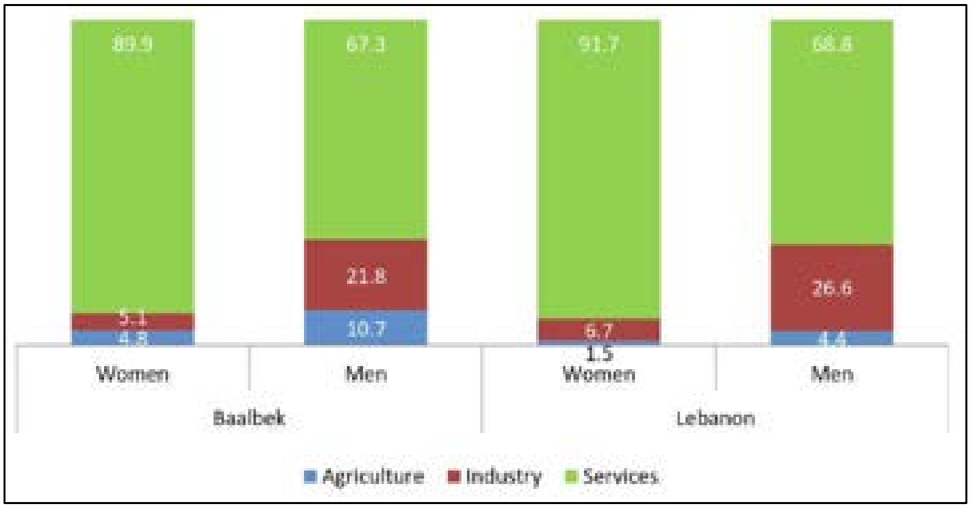

Figure 19 Economic activity sector by gender (%) (LFS 2022)

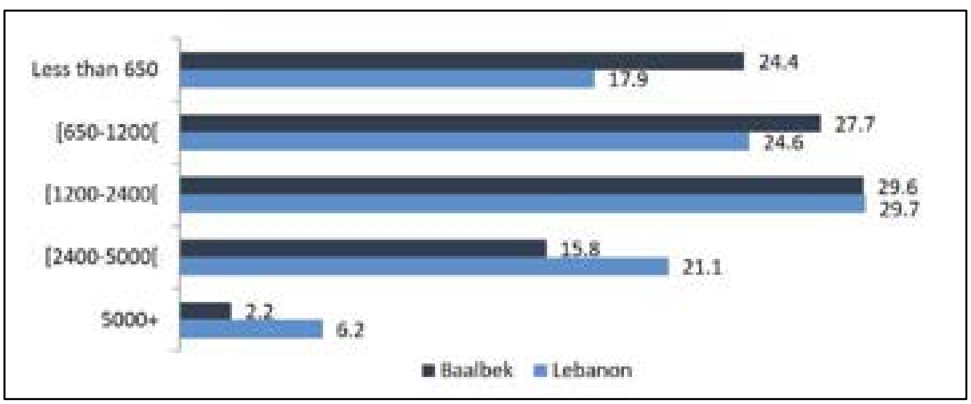

Figure 20 Household income range from all sources Percent in the month preceding the Survey in thousand LBP (%) (1$ = 1,500LBP) (LFS 2022)

2.4.6.5 Fisheries

Freshwater aquaculture has been practiced in Lebanon since the 1930s, with most production being rainbow trout grown in semi-intensive growing systems. These systems were introduced in 1958, and most of them are located along the Assi River (refer to Figure 21 for approximate locations). According to a survey conducted by Al-Akhbar in 2011, rainbow trout production in Lebanon reaches around 1,700 tons annually, with around 150 fish farms in operation, most of which are family-owned. About 70% of aquaculture in Lebanon takes place along the Assi River (Lebbos and Saoud 2006), near the northern border with Syria, in both earthen and concrete raceways. A 2012 survey found a total of 49 farmers along the Assi river owning or renting a total of 199 ponds. It was reported that the Assi River has good water quality for trout aquaculture.

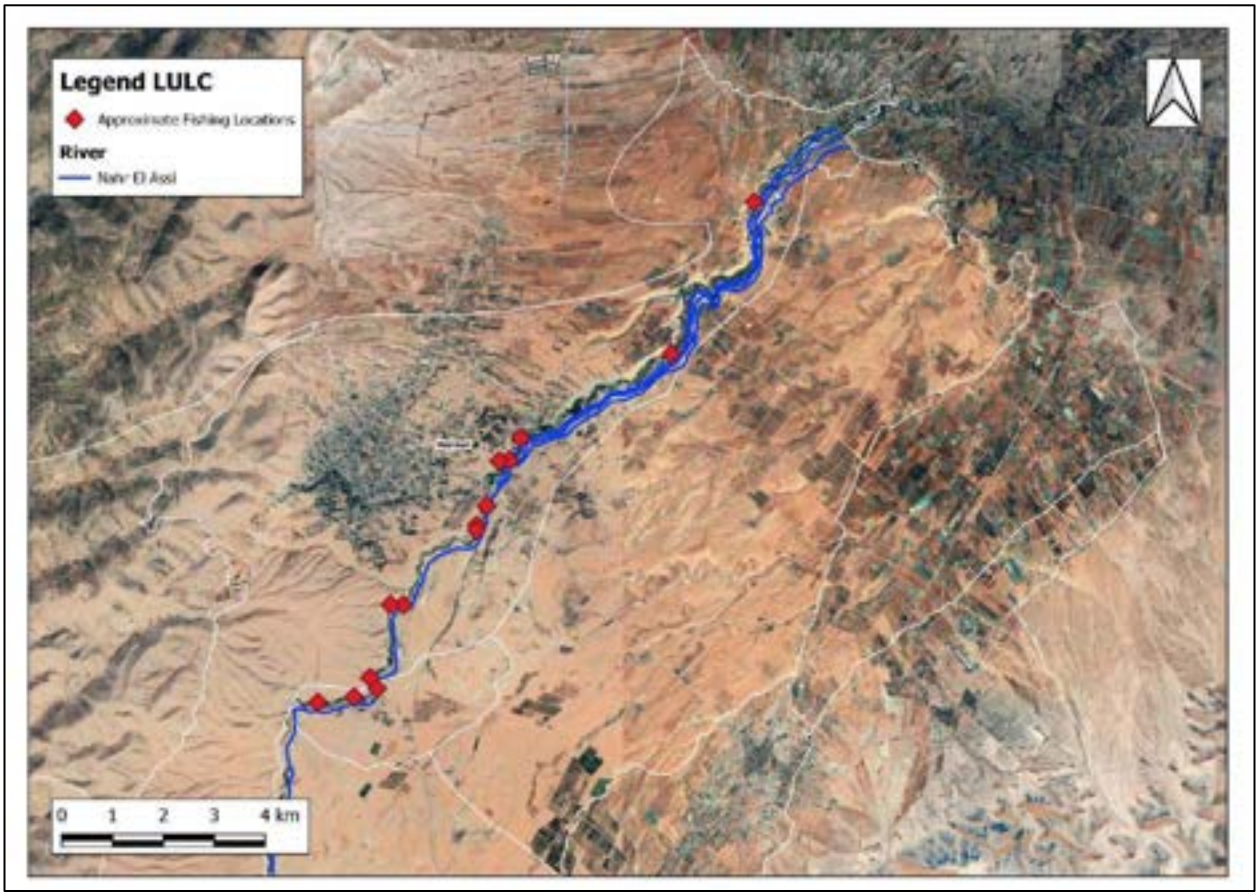

Figure 21 Approximate fishing farms locations along the Assi river shown in red. Locations determined from site visits in year 2022 and coupled with Google earth maps platform and article citations.

In terms of economic activity, aquaculture is the main activity in the Hermel area (Al Hawi, 2012) after crop production, and it contributes to increased income related to restaurants and tourism. Several restaurants, especially in the Bekaa Valley, have special tanks for selling live trout, and then consumers can choose the fish, where it is then prepared. The Ministry of Agriculture is responsible for the development of aquaculture, and the Rural Development and Natural Resources Department is responsible for issuing fishing licenses. The ministry also has an aquaculture facility in Hermel, which is a modern experimental trout production facility and aims to provide several services related to aquaculture.

According to data from the MOA, aquaculture production in Lebanon saw an increase from 600 tons in 2003 to an estimated 1,200 tons in 2014 and approximately 4000 tons in 2022. However, during the same year, the total amount of fish imports amounted to around 20,921 tons, valued at approximately USD 95 million, suggesting potential for growth in the country's aquaculture sector. In terms of trout production, the MOA reports an average annual output of around 1,200 tons, generated by 220 farms. Almost 90% of these farms are located in the Hermel-North Bekaa area, with a combined value of USD 4.0 million and an estimated average yield of 10-12 tonnes per farm (FAO 2021).

Various studies have indicated that with proper development in both technical and marketing aspects, trout production in Lebanon could be boosted to 3,000-4,000 tons. Between 2013 and 2014, the MOA reported an average annual production of trout at roughly 1,200 tons, with a corresponding production value of around USD 4 million. Figure 22, which draws from FAO statistics, illustrates the overall aquaculture production in Lebanon.

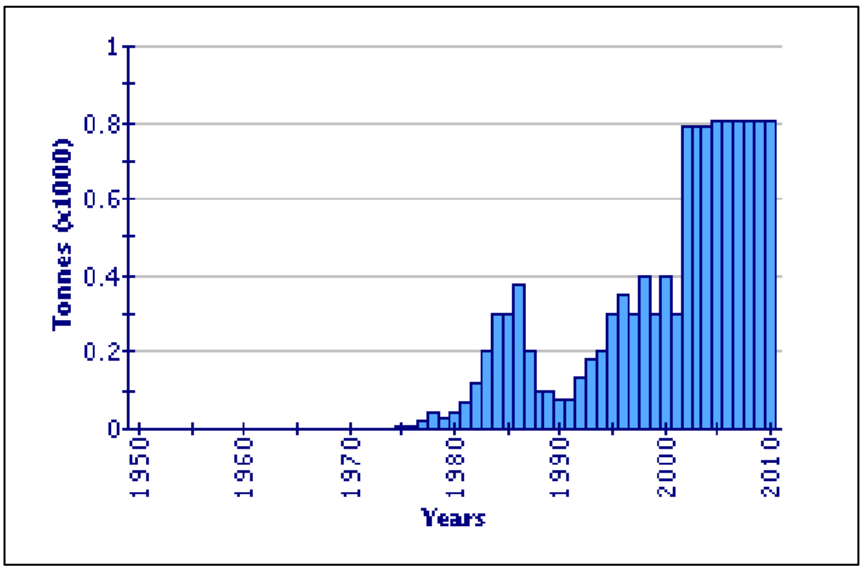

Figure 22 Total aquaculture production from year 1950 to 2010 (FAO, 2010)

In 2014, the Lebanese Customs Office reported that a total of around 20,921 tons of fish, including crustaceans and mollusks, were imported into the country, with a corresponding value of approximately USD 95 million. Turkey ranked as the top exporting country, accounting for 23% of the total imports, followed by Viet Nam (15%), Egypt (10%), the United Kingdom (9%), Norway (8%), and India (7%). Lebanese fish exports amounted to only USD 1,164,000 in 2014, with the majority of exported fish products comprising prepared items. The Syrian Arab Republic stands as the primary market for Lebanese fish exports, with other exports mainly going to Qatar, Saudi Arabia, Iraq, Kuwait, and Liberia.

2.5 Water supply

2.5.1 Water systems, villages, population and water demand

There are 60 different villages that are partially or totally included within ARB. In order to estimate the future population living in the basin, the following formula was adopted from the updated NWSS 2020 and applied to each village population:

$$P_t = P_0 e^{\alpha t}$$

Where:

- P_t = Population at time t
- P0 = Population at time 0 (year 2020)
- α = growth rate (1.5% for rural areas and 0.75% for urban areas)
- t = time period in years

According to the updated NWSS – 2020, the drinking water demand per capita in 2035 was set as follows:

Domestic consumption:	125	l/cap/day		
Non-Domestic = 20 % of the domestic	25	l/cap/day		
			150	l/cap/day
Physical losses = 25 % of the total needs	50	l/cap/day		
Total needs			**200**	**l/cap/day**

As ARB accommodates currently a total of 416,716 resident, the water needs were estimated to 83,343 m^3/d. In 2035, the projected resident population of the basin will reach a total of 489,470 which water needs are estimated to 97,894 m^3/d.

These 60 villages are spread over 25 water distribution systems included within ARB from Baalbek and Hermel regions and are independent from each other.

Table 12 and Figure 23 show the water distribution systems and villages within ARB with the current and projected resident population for 2020 and 2035 and their corresponding water demand.

Table 12 ARB water distribution systems, villages, population and water demand (Updated NWSS 2020)

ID	Water Distribution System	Villages	Urban (U) or Rural (R)	Ratio of the village/WDS population that falls within ARB	Resident Population		Water Demand (m^3/d)	
					2020	2035	2020	2035
1	Laboueh	Part of Al Labouat	U	100%	15,544	17,386	3,109	3,477
		Al-Nabi Osman	R	100%	7,490	9,361	1,498	1,872
		Al-Aine	U	100%	32,285	36,112	6,457	7,222
		Jabouleh et Al-Bijage	R	100%	1,310	1,637	262	327
		Zaboud	R	100%	1,370	1,710	274	342
		Total		100%	57,999	66,206	11,600	13,241
2	El Qaa system	Al-Qa El-Benjakie	R	100%	7,865	9,831	1,573	1,966
		Al-Qa Bayoun	R	100%	3,375	4,217	675	843
		Total		100%	11,240	14,048	2,248	2,810
3	Nabi Sbat	Haouche El-Tal Safyat	R	100%	1,165	1,455	233	291
		Total		3%	1,165	1,455	233	291
4	Ouyoun Orgosh	El-Ram	R	100%	680	848	136	170
		Barka	R	100%	3,470	4,337	694	867
		Bachwat	R	100%	9,345	11,683	1,869	2,337
		Riha	R	100%	2,065	2,580	413	516
		Knaissat	R	100%	3,600	4,499	720	900
		Dair El-Ahmar	R	100%	12,000	15,002	2,400	3,000
		Part of Nabha	U	100%	6,325	7,073	1,265	1,415
		Karha	R	100%	1,710	2,137	342	427
		Total		93%	39,195	48,159	7,839	9,632
5	Yammouneh	Btehdy	R	100%	1,580	1,974	316	395
		Chlifa	R	100%	4,185	5,231	837	1,046
		Part of Bouday	R	100%	16,700	20,877	3,340	4,175
		Total		18%	22,465	28,082	4,493	5,616
6	Younine, Maqne & Nahle	Nahleh	R	100%	13,258	16,574	2,652	3,315
		Part of Younine	R	100%	11,758	14,698	2,352	2,940
		Maqneh	R	100%	7,195	8,995	1,439	1,799
		Total		100%	32,211	40,267	6,442	8,053

ID	Water Distribution System	Villages	Urban (U) or Rural (R)	Ratio of the village/WDS population that falls within ARB	Resident Population		Water Demand (m^3/d)	
					2020	2035	2020	2035
7	Aarsal	Arsale	U	100%	49,420	55,280	9,884	11,056
		Total		100%	49,420	55,280	9,884	11,056
8	Baalbek, Aamechki & Ain Bourday	Baalbek	U	70%	66,616	74,515	13,323	14,903
		Total		70%	66,616	74,515	13,323	14,903
9	Chaat	Part of Younine	R	100%	2,556	3,194	511	639
		Chaat	R	100%	11,354	14,189	2,271	2,838
		Total		100%	13,910	17,383	2,782	3,477
10	Fekha & Jdaide	Al - Fakiat	U	100%	17,685	19,810	3,537	3,962
		Total		100%	17,685	19,810	3,537	3,962
11	Harbata	Part of Harbata	R	100%	4,745	5,930	949	1,186
		Total		100%	4,745	5,930	949	1,186
12	Moqraq-Amhaz-Toufiquiyeh & En Noqra	Mikrak	R	100%	4,175	5,218	835	1,044
		Part of Al Labouat	R	100%	2,627	3,283	525	657
		Part of Harbata	R	100%	2,555	3,193	511	639
		Total		100%	9,357	11,694	1,871	2,339
13	Iaat	Yaat	R	100%	6,500	8,125	1,300	1,625
		Total		100%	6,500	8,125	1,300	1,625
14	Ras Baalbek	Ras Baalbek El-Sahl	R	100%	12,600	15,750	2,520	3,150
		Total		100%	12,600	15,750	2,520	3,150
15	Sbouba	Sbouba	R	100%	5,870	7,337	1,174	1,467
		Total		100%	5,870	7,337	1,174	1,467
16	Yammouneh-Local	Dar El-Ouassia	R	100%	445	561	89	112
		Total		100%	445	561	89	112
17	Halbata-El Kharayeb	Halbata	R	100%	2,175	2,719	435	544
		Al-Kharayeb	R	100%	500	623	100	125
		Total		100%	2,675	3,342	535	668
18	Hermel Upper, Ras El Mal & Ain Zarqa Spring	El Hermel	U	100%	51,000	57,047	10,200	11,409
		Hermel Wata Alkamoue	R	100%	204	253	41	51
		El Mansoura_Tlal Alfar	R	60%	1,576	1,970	315	394
		Sahlet El Chahkouneh	R	20%	31	38	6	8
		Sahel Hermel	R	50%	281	350	56	70
		Total		94%	53,091	59,658	10,618	11,932

ID	Water Distribution System	Villages	Urban (U) or Rural (R)	Ratio of the village/WDS population that falls within ARB	Resident Population		Water Demand (m^3/d)	
					2020	2035	2020	2035
19	Ouadi En Naira-Ouadi Bnit-Zoueitini-Wadi El Karem & Kaeb Wadi El Karem	Wadi En Naira	R	100%	347	431	69	86
		Wadi Bnit	R	100%	500	623	100	125
		Mrah Yassen	R	100%	31	37	6	7
		Wadi El Karem	R	100%	408	508	82	102
		Mrah Zouatini	R	100%	255	317	51	63
		Mazraat El Fakih	R	100%	357	444	71	89
		Kaeb Wadi El Karem	R	100%	51	62	10	12
		Total		100%	1,949	2,422	390	484
20	Ouadi Faara-Mrah El Aaqabet	Al Maaisra	R	100%	31	37	6	7
		Wadi Faara	R	100%	71	87	14	17
		Total		100%	102	124	20	25
21	Chouaghir	Chouaghir	R	100%	2,570	3,211	514	642
		Total		100%	2,570	3,211	514	642
22	Haouch Saeid Ali & Haouch Beit Ismail	Haouch Saied Ali	R	100%	510	636	102	127
		Haouch Beit Smaiil	R	100%	1,428	1,783	286	357
		Beit Hira	R	100%	449	560	90	112
		El Kreine	R	100%	255	317	51	63
		Total		100%	2,642	3,296	528	659
23	Jbeb El Homor	Jbab El Homr	R	100%	104	126	21	25
		Shatah Wadi Alzaraqkt	R	100%	132	165	26	33
		Total		48%	236	291	47	58
24	Ouadi Et Tourkmane Ouadi El Ratel	Wadi El Tourkmane	R	100%	612	763	122	153
		Wadi El Ratel	R	60%	275	344	55	69
		Total		83%	887	1,107	177	221
25	Beit Et Tochem El Charqe Mazraat Chelman	Beit Et Tochom	R	100%	882	1,102	176	220
		El Charkee	R	100%	204	253	41	51
		Mazraat El Chalmane	R	100%	51	62	10	12
		Total		100%	1,137	1,417	227	283

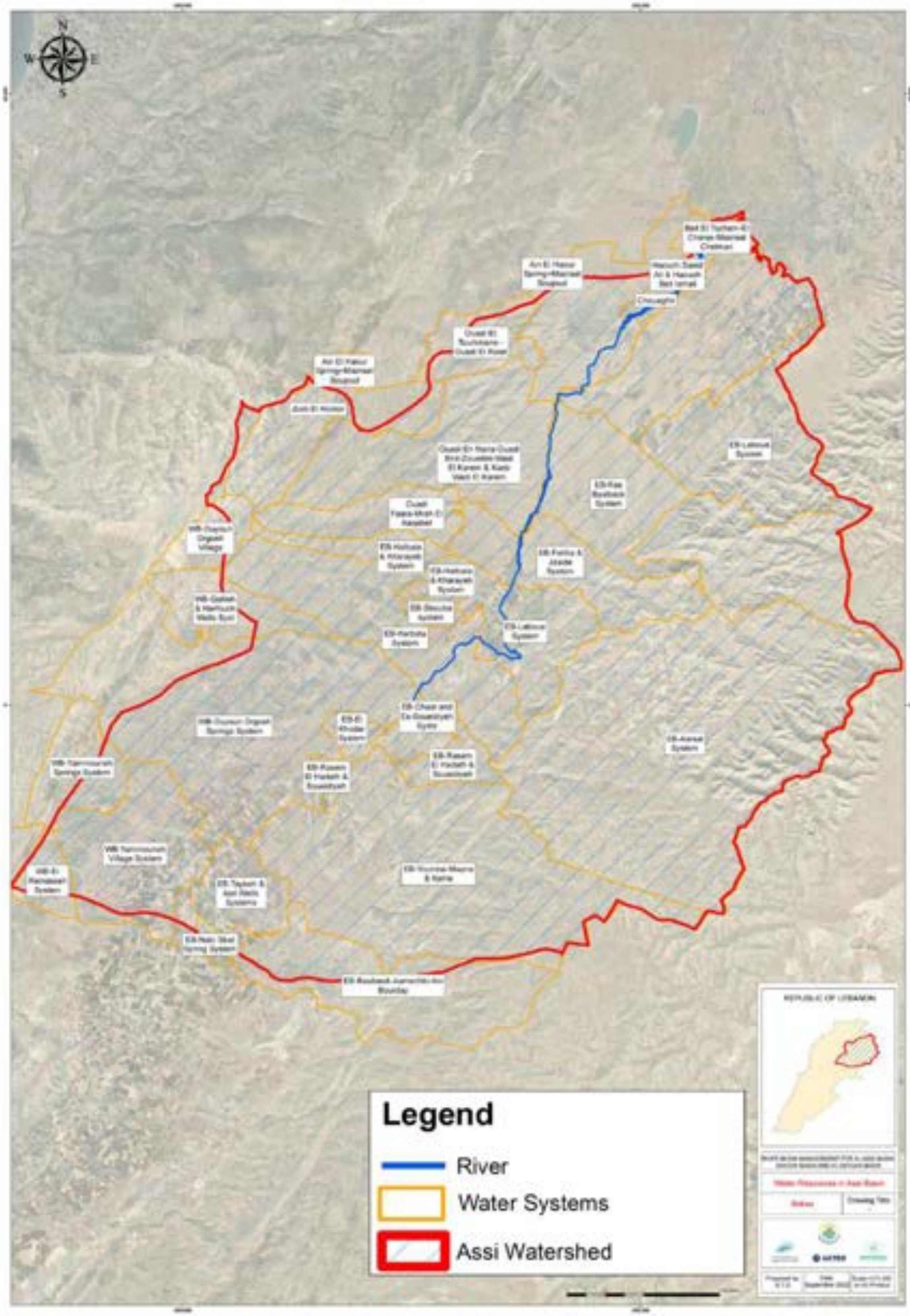

Figure 23 ARB water distribution systems (Updated NWSS 2020)

2.5.2 Water sources

The water distribution systems mentioned above are supplied by public wells and tapped springs located within or at the vicinity of ARB. In this section, we will be presenting the water sources located within ARB limits. These sources are either in service, under construction or out of service.

There are 10 tapped springs falling within ARB out of which 7 are currently exploited for domestic use, 2 under construction, and 1 out of service. 6 of these springs serve the resident population while others serve the population that live outside the basin limits. Table 13 below shows the details for each spring.
Tapped springs are supplying a total flow of 20,849 m^3/d to feed the resident population while a flow of 19,223 m^3/d is diverted for outside the basin. In 2035, an additional diverted flow of 1,814 m^3/d will be extracted from Ain Kawkab and Dardara springs for outside population.

In 2020, out of the 84 wells within ARB, 64 are currently exploited for domestic use of the resident population and 6 for non-residents, 5 under construction, 4 not equipped yet, and 5 out of service. In addition, 5 wells located outside ARB are supplying ARB residents. In total 69 wells are supplying ARB. These wells are supplying a total flow of 76,035 m^3/d to feed the resident population while a flow of 2,738 m^3/d is diverted for outside the basin.

In 2035, out of the 84 wells within ARB, 70 will be exploited for domestic use of the resident population, 9 for non-residents, and 5 out of service. In addition, 3 new wells located outside ARB will be supplying ARB residents increasing the number to 8 wells outside ARB. In total 78 wells will be supplying ARB in 2035. These wells will be supplying a total flow of 83,640 m^3/d with 7,605 m^3/d extracted additionally from the under-construction or not equipped wells, while a flow of 4,812 m^3/d will be diverted to outside the basin limits. The details for each well are given in Table 14 below.

It is worth noting that these flows were estimated under optimal operation conditions to cover the deficit with the current infrastructure i.e. Deir Mar Yousef well will be operating 24 hours continuously instead of suggesting the drilling of new wells while the well of El Zwaytine will be operating 16 hours as no deficit is shown.

Table 13 List of tapped springs located within ARB (Updated NWSS 2020)

Spring Name	Status	Average Discharge (m^3/d)	Total Exploited flow for domestic use (m^3/d)	Water Distribution System	Exploited flow for resident population (m^3/d)	
					2020	2035
Laboueh	In service	77400	1123	Laboueh	1123	1123
Yammouneh Dar Al Ouassaa	In service	86400	21600	Yammouneh	3888	3888
Chaghour	In service	6700	685	Younine, Maqne & Nahle	685	685
Loujouj	In service	5615	5000		5000	5000
Ain Kawkab	Under construction	1296	864	Baalbek, Aamechki & Ain Bourday	0	0
Dardara	Under construction	1296	950		0	0
El Jaouz	In service	1296	864		0	0
El Fekha	In service	82771	432	Fekha & Jdaide	432	432
Ain Ez Zarka	Not used	225000	0	Hermel Upper, Ras El Mal & Ain Zarqa Spring	0	0
Ras el Mal	In service	25000	10368		9721	9721
Total					**20849**	**20849**

Table 14 List of wells supplying or located within ARB (Updated NWSS 2020)

Well Name	Status	Total Yield for domestic use (m^3/d)	Water Distribution System	Extracted yield for resident population (m^3/d) 2020	2035
Ain 1	In service	113	Laboueh	113	113
Ain 2	In service	1080		1080	1080
Ain 3	In service	113		113	113
En Nabi Osmane	In service	540		540	540
En Nabi Osmane New	In service	2016		2016	2016
En Nabi Osmane New BWE	In service	2592		2592	2592
Laboueh	In service	3600		3600	3600
Zabboud	In service	1166		1166	1166
El Qaa New	In service	3024	El Qaa system	3024	3024
El Qaa New BWE	In service	1728		1728	1728
El Qaa New BWE 2	In service	1728		1728	1728
El Qaa Old	In service	518		518	518
Haouch Tell Safiye	In service	120	Nabi Sbat	120	120
Barka	In service	288	Ouyoun Orgosh	288	288
Bechouat	In service	36		36	36
Beit Kozah	In service	126		126	126
Bsailet	In service	1080		1080	1080
Deir Mar Youssef	In service	1440		1440	1440
El Qeddam	In service	1440		1440	1440
Kneisseh	Out of service	0		0	0
Kneisseh 2	Out of service	0		0	0
Nabha	In service	1620		1620	1620
Nabha 1	In service	1350		1350	1350
Nabha 2	In service	691		691	691
PUIT No.1**	Under construction	1467		0	1467
PUIT No.2**	Under construction	1467		0	1467
Qarha	Out of service	0		0	0
Qarha (New BWE)	In service	950		950	950
Ram	Out of service	0		0	0
Beit Abou Slaybe Well*	Not equipped yet	230	Yammouneh	0	0
Btedaii	Under construction	576		0	576
Chlifa	In service	1440		1440	1440
Flewi Well*	Not equipped yet	806		0	0
Mazraat Aljamal, Mazraat Salim, Wadi Em Ali Well*	Not equipped yet	518		0	0
Mazraat Et Tout*	In service	173		0	0
Mazraet Al-Tout Well	Out of service	0		0	0
Yammouneh Dar Al Ouassaa	In service	0		0	0
Maqne 1	In service	1152	Younine, Maqne & Nahle	1152	1152
Maqne 2	In service	1095		1095	1095
Younine well	In service	922		922	922
Younine	In service	1670		1670	1670
Aarsal Ain El Shaeb	In service	495	Aarsal	495	495
Aarsal BH9 (ICRC)	In service	864		864	864
Aarsal High School	In service	525		525	525
Aarsal New Well (IOCC)	In service	864		864	864
Aarsal Wadi El Matlab	In service	525		525	525
Aarsal Wadi Soueid	In service	1167		1167	1167

Well Name	Status	Total Yield for domestic use (m^3/d)	Water Distribution System	Extracted yield for resident population (m^3/d) 2020	2035
Baalbek New Dar Well	In service	1066	Baalbek, Aamechki & Ain Bourday	1066	1066
Baalbek Maslakh	In service	270		270	270
Baalbek No 10*	In service	338		236	236
Baalbek No 12	In service	270		270	270
Baalbek No 9	In service	1257		1257	1257
Baalbek No 14**	In service	1728		1210	1210
Baalbek No 16**	In service	951		666	666
Baalbek No 17**	In service	4752		3326	3326
Baalbek No 18**	In service	4320		3024	3024
Baalbek No 19**	In service	1209		846	846
Loujouj Well, Baalbek	In service	1728		1728	1728
Baalbek Sharawneh	In service	1685		1685	1685
Chaat New	In service	864	Chaat	864	864
Rasm Al Hadath	In service	1276		1276	1276
Chaat Old	In service	864		864	864
Fekha	In service	406	Fekha & Jdaide	406	406
Harbata Baalbek New	In service	1382	Harbata	1382	1382
Harbata Baalbek Old	In service	1382		1382	1382
Moqraq New 1	In service	972	Moqraq-Amhaz-Toufiquiyeh & En Noqra	972	972
Moqraq New 2	In service	2016		2016	2016
Moqraq Old	In service	972		972	972
Iaat 1	In service	1296	Iaat	1296	1296
Iaat 2	In service	864		864	864
Ras Baalbak well	Under construction	1152	Ras Baalbek	0	1152
Ras Baalbek	In service	1440		1440	1440
Ras Baalbek_Municipality	In service	1120		1120	1120
Sbouba	In service	1620	Sbouba	1620	1620
Beit Mcheik Well	Not equipped yet	691	Yammouneh-Local	0	69
El Kharayeb	In service	1124	Halbata-El Kharayeb	1124	1124
Halbata	In service	260		260	260
Hermel Upper 1	In service	980	Hermel Upper, Ras El Mal & Ain Zarqa Spring	980	980
Hermel Upper 2	In service	980		980	980
Mansoura-Hermel*	Under construction	865		0	519
El Zwaytine	In service	1095	Ouadi En Naira-Ouadi Bnit-Zoueitini-Wadi El Karem & Kaeb Wadi El Karem	1095	1095
Ouadi En Naira	Not equipped yet	1155		0	1155
Faara	In service	0	Ouadi Faara-Mrah El Aaqabet	0	0
Ouadi Faara / Mrah-El-Aaqbet	In service	460		460	460
Chouaghir	Under construction	600	Chouaghir	0	600
Haouch Saeid Ali 1	In service	180	Haouch Saeid Ali & Haouch Beit Ismail	180	180
Haouch Saeid Ali 2	Under construction	600		0	600
Jbeb El Homor*	In service	500	Jbeb El Homor	250	250
Ouadi Et Tourkmane*	In service	700	Ouadi Et Tourkmane - Ouadi El Ratel	595	595
Harfouch*	In service	1120	Qalileh & Harfouch	0	0
Klaylet*	In service	900		0	0
Qalile - Harfoush well*	In service	236		0	0

Wells names with (*) are located inside ARB but diverted to supply outside population
Wells names with (**) are located outside ARB but diverted to supply inside population

2.6 Agriculture

2.6.1 Historical background

Cultivation has been carried on in ARB since ancient times. Both irrigated and dry land crops were grown. Dryland cropping however was the dominant type of agriculture accounting by the early 1950's for about 75% of the arable land (USBR, 1958). The principal dryland crops were: wheat, barley, lentils, chickpeas, broad beans, melons, and grapes.

Irrigation in North Bekaa was limited mostly to areas that receive water either from springs, including Laboueh canal, Yammouneh canal, groundwater sources, or from lands in the narrow valley of Nahr Al Assi where direct diversion is possible. Irrigated crops included grains, maize, vegetable, deciduous fruits, legumes, onions, potatoes, turnips, and miscellaneous crops.

Only relatively small areas of the mountainous portion of ARB were used for crop production. These lands are confined largely to Lebanon Mountains, where soil, topographic, and water conditions allow the raising of limited amounts of grains, legumes, grapes, deciduous fruits, and vegetables.

2.6.2 Previous studies and surveys

Many available studies (Jaafar et al. 2016, field survey carried out by Fondazione Giovanni Paolo II and BWE and provided by WW-GVC, MoA Census 2010, MoA Strategy and Updated NWSS 2020) discussing agricultural situation in Al Assi were collected and reviewed have contributed in the description of the irrigation status in ARB.

2.6.3 Modern irrigation development

Nowadays, irrigation depends on groundwater more than before, according to MoA 2012 report based on 2010 Census, there is ~ 57,600 ha of cropped area within Baalbek and Hermel districts, among which only 31,700 Ha are irrigated. Moreover, it is reported that irrigated areas are broken down into 15,200 Ha of permanently irrigated and 16,500 Ha of partially irrigated areas.

Based on the fact that ARB represents only 60% of Baalbek-Hermel districts (1718 / 2847 km^2) and according to field & maps observations and interpretation, the irrigated area within ARB is estimated to range from 18,000 to 20,000 Ha.

2.6.4 Main crops and available cultivated areas

The main crops that can be found within ARB are the following:
Cereals (wheat & barley)
Vegetables (mixed green vegetables) example: cabbage – tomato – cucumber, watermelon)
Root crops and bulbs such as potato – onion – garlic
Legumes beans, lentils, peas.
Feed crops: Alfalfa, lupin, maize
Industrial crops: mainly tobacco.
Perennial crops (apricot trees – cherries – apples – almond – vineyards & olive trees).

The cultivated area can be assessed in two different methods either through direct census as carried out by the Ministry of Agriculture in 2010 and reported in 2012 or through remote sensing from Corine Land Cover. The 'Coordination of information on the environment' (Corine) is an inventory of European land cover split into 44 different land cover classes. Corine also shows the changes between classes over four periods since 1990. Both land cover and land cover change are shown at high resolution on a cartographic map.

The cropped area within Baalbek – Hermel districts as per 2010 Ministry of Agriculture census is 80,624 Ha and can be broken-down as follows:

Table 15 Type of crops in Baalbek – Hermel districts as per MoA Census 2010

Type of Crops	Area (Ha)
Seasonal crops	27,717
Cereals	13,477
Vegetables & legumes	10,034
Protected crops	76
Fallow land	5,420
Perennial crops	23,900
(Fruit trees, Orchards, vineyards & olive trees)	
Total	80,624

The cropped area within ARB according to CORINE Land Cover units (2017) is 45,128 Ha and can be broken-down as follows:

Table 16 Type of crops in ARB as per CLC 2017

Type of Crops	Area (Ha)
Field crops*	31,215
Fruit trees	11,567
Vineyards	1,380
Olive trees	903
Protected agriculture	57
Total	45,128

* Field crops include seasonal crops rotation that allows many crops to use sequentially the same plot or area.

2.6.5 Irrigation considerations

2.6.5.1 Origin of water – irrigation method

In Bekaa, 43% of the area is irrigated by springs and rivers (MoA, 2012). On the other hand, 23% of irrigated land in the Baalbek Hermel area is equipped with sprinkler irrigation, whereas 10% of the irrigated areas are drip irrigated.

Area calculation reveals the existence of ~30,350 ha of irrigation zones[1] within ARB distributed as follows:

[1] Irrigation zones represent areas where irrigation is practiced on a permanent or a partial/ intermittent basis depending on changing crop rotation, intensification and seasons.

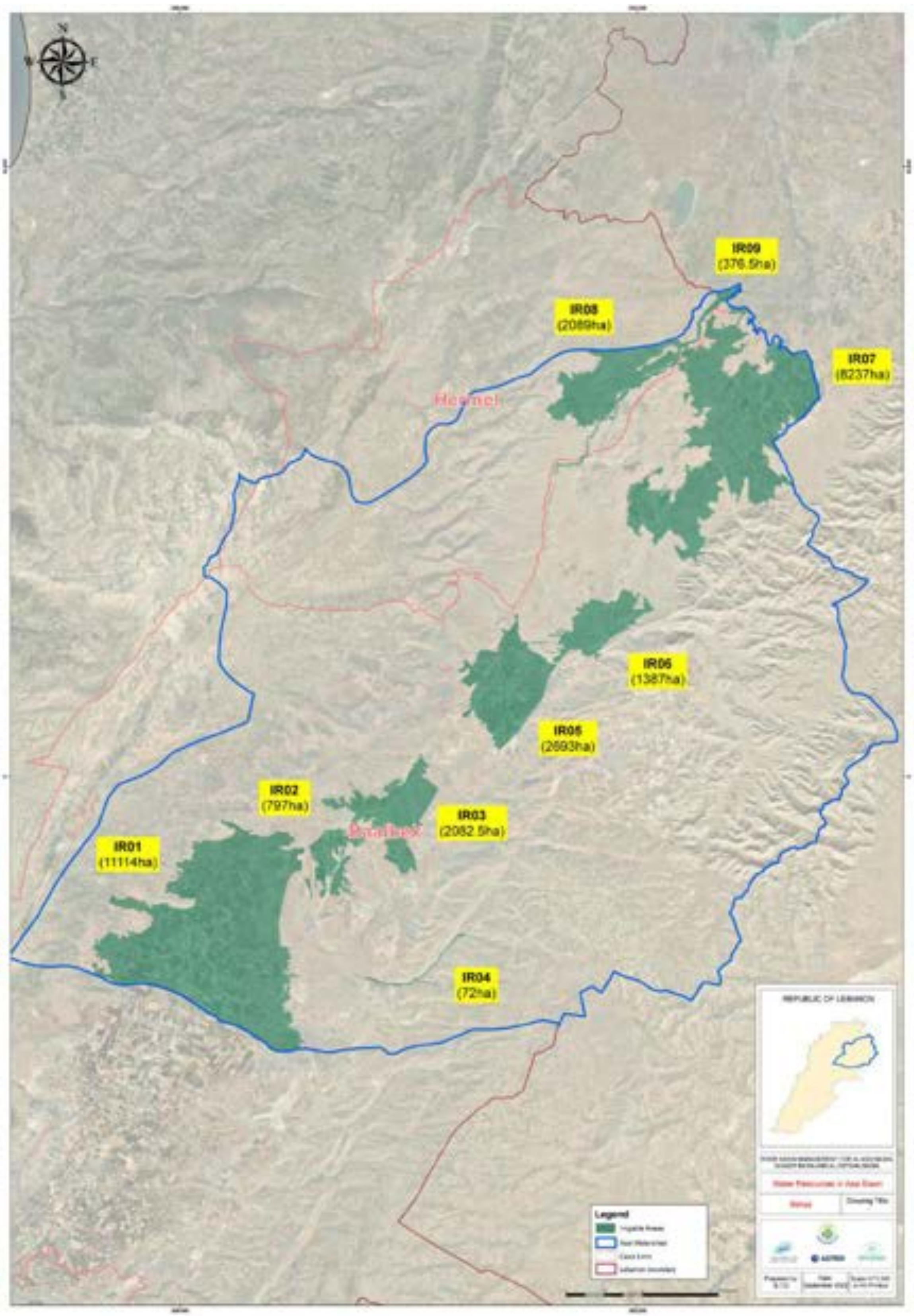

Figure 24 Irrigation zones within ARB

2.6.5.2 Complete vs Partial irrigation

As previously mentioned, within Baalbek – Hermel districts, the irrigation area repartition is as follows (MoA, 2012):

Total cultivated area:	57,625 Ha
Total permanently irrigated area:	31,703 Ha (55%)
Irrigated area:	15,220 Ha (26.4%)
Partially & complementary irrigated area:	16,482 Ha (28.6%)

Permanently irrigated areas correspond mainly to equipped area with irrigated infrastructure (traditional irrigation schemes as well as some areas equipped with water wells).

It was estimated in the Census of 2010 that 60% at least of the total area above, is irrigated from groundwater and tend to use modern irrigation techniques to save water.

In Table 17 below, irrigated area has been identified on satellite map and at a second stage, area calculation has been performed at the level of each irrigation zone to obtain a gross irrigated area for each zone without any distinction wither it is a permanently or partially irrigated area. These identified irrigated zones has been cross checked with the LULC map to finally adopt in line with available irrigation water source the estimated irrigation area for each zone.

Table 17 Irrigation zones within ARB

Irrigation Zones	Concerned Villages	Irrigation Zones Gross area Ha	Irrigation water source	Estimated Irrigated area Ha
IR01	Aaddous baalbek btedaai bouday chlifa deir el ahmar haouch ed dahab haouch tall safiyeh iaat kneisseh (baalbek) maqneh	11,114	Yammouneh Irrigation scheme, local small spring water wells (~1000 wells)	8,300
IR02	Chaat maqneh riha yammouneh	797	Very small local springs and few wells	400
IR03	Chaat harbata nabha ed damdoum yammouneh	2,083	Very small local springs and few wells	1,050
IR04	Nahleh	72	Very small local springs and few wells	40
IR05	Ain (baalbek) bajjajeh Fekha harbata Laboueh moqraq nabi osmane zabboud	2,693	Laboueh spring, local springs and wells	1,900
IR06	Fekha ras baalbek ech charqi ras baalbek es sahel	1,387	Ras Baalbek & Fekha Springs and some 50 wells	400
IR07	Hermel ras baalbek es sahel qaa baalbek qaa baayoun qaa jouar maqiyeh qaa ouadi el khanzir	8,237	Small area from Laboueh spring and pumping from Assi river in addition to more than 3000 wells mainly	5,000
IR08	Hermel	2,089	Ras El Mal, Bdita springs Direct pumping from Assi River, and water wells	450
IR09	Deir mar maroun (baalbek)	377	Direct diversions from the river	150
IR10	Scattered areas	1,500	wells	840
Total		30,349	Total	18,500

2.6.5.3 Reference Evapotranspiration

After the introduction by FAO of the global standard Reference evapotranspiration (RET) (Allen et al., 1998), RET became a well-recognized concept to express the climatologic variability of crop ET. The attractive character of RET is that it is only affected by climatic factors, excluding other factors like for example crop and soil typology (Allen et al., 1998). Over the past decades various approaches have been developed to calculate RET, often based on simpler input data (e.g. Hargreaves and Samani, 1985; de Bruin et al., 2016). However, the Penman-Monteith equation (Allen et al., 1998) is the most applied approach, after it was selected to be the best performing equation in a variety of climates by an FAO expert consultation in 1990. The drawback is that more detailed climatological information is required (radiation, humidity, temperature and wind speed), which is not always everywhere available in weather stations.

Evaporation and transpiration are the primary abstractions of the hydrological cycle. These abstractions are minor during a runoff event and can be neglected. The bulk of evaporation and transpiration takes place during the time between runoff events, which is usually long. Hence, these abstractions are the most important during this time interval. The combined effect of evaporation and transpiration is called evapotranspiration (ET), defined as the water vapor produced from the watershed as a result of the growth of plants in the watershed. There is an important difference between evapotranspiration and free surface evaporation. Transpiration is associated with plant growth and hence evapotranspiration occurs only when the plant is growing, resulting thereby in diurnal and seasonal variations. Transpiration thus superimposes these variations on the normal annual free water-surface evaporation.

The FAO Penman-Monteith (FAO-PM) method has been considered as a universal standard to estimate ET_0. It considers many meteorological parameters related to the evapotranspiration process (net radiation, air temperature, vapor pressure deficit, wind speed).

The FAO-PM method to estimate ET_0 on daily basis can be derived as (Allen et al., 1998):

$$ET_0 = \frac{0.408\,\delta(R_n - G) + 900 y u_2(e_s - e_a)/(T + 273)}{\delta + y(1 + 0.34\,u_2)}$$

Where :
ET_0 : reference evapotranspiration [mm day^{-1}],
R_n : net radiation [MJ m^{-2} day^{-1}],
G : soil heat flux density [MJ m^{-2} day^{-1}],
T : mean daily air temperature at 2 m height [°C]
u_2 : wind speed at 2 m height [m s^{-1}],
e_s : saturation vapor pressure [kPa],
e_a : actual vapor pressure [kPa],
es-ea : saturation vapor pressure deficit [kPa],
Δ : slope of the vapor pressure curve [kPa°C^{-1}],
y : psychrometric constant [kPa°C^{-1}].

The water balance for Assi plain area was calculated using WAPOR RET and effective rain from Hermel and Deir el Ahmar as calculated by FAO Cropwat and shown in Figure 25 and Table 18 below.

Accordingly, irrigation season within ARB usually extends from mid-March till November and is likely to be slightly shorter in deep soil areas such as orchards locations.

Figure 25 Monthly Reference Evapotranspiration ET0 in Assi Plain between 2009 and 2022 (WAPOR)

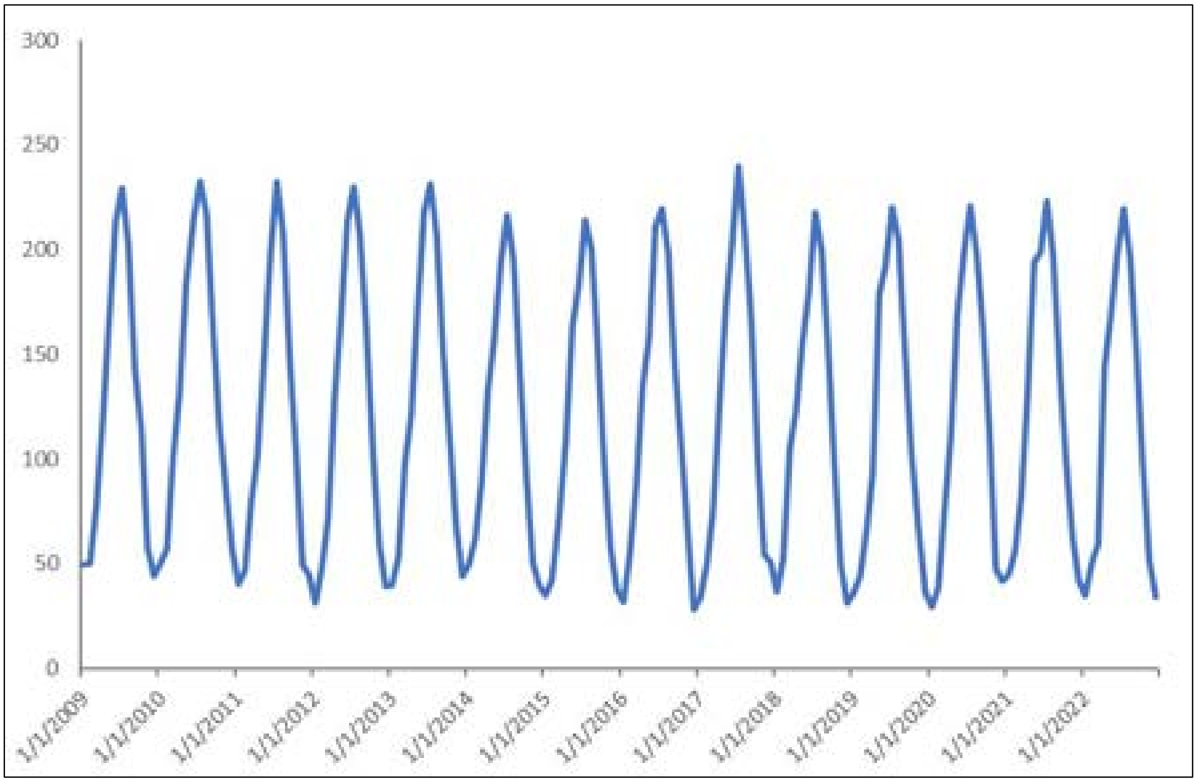

Table 18 Effective rain, ET0 and water balance in ARB

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Eff. Rain	68	66	35	15	7	1	1	1	5	20	27	64	308
ETo	39	50	82	122	168	201	225	202	152	104	59	41	1445
Balance	29	15	-47	-107	-161	-201	-224	-202	-148	-84	-33	23	

2.6.5.4 Calculation of irrigation water needs within the study area

The net water requirements for each dominant crop can be calculated taking into consideration the agro-climatological data, the existing cropping pattern representative of the study area as well as the corresponding crop coefficients Kc for the appropriate growth stage of each cultivated plant in the study area, see Table 19 below.

The Crop Evapotranspiration ETc was estimated by multiplying ET_0 with the Crop Coefficient (Kc) reduced by the Effective rain ($ETc = Kc*ET_0 – Eff.rain$). Kc usually ranges between 0.1 & 1.2 according to the land cover as defined by FAO and plant life cycle (FAO, 1998).

Table 19 Net water requirements per crop

	Month	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual value	
														mm	m³/Ha
	Eto	39	50	82	122	168	201	225	202	152	104	59	41	1445	14453
	Eff.Rain	68	66	35	15	7	1	1	1	5	20	27	64	308	3079
Fruit trees/ vineyard	Kc	0.2	0.2	0.3	0.3	0.4	0.7	0.8	0.95	0.9	0.5	0.3	0.2		
	Etc mm	0.0	0.0	0.0	21.5	59.9	140.3	179.3	191.7	132.4	31.7	0.0	0.0	757	7568
Wheat and barley	Kc	0.5	0.65	0.65	0.7	0.7	0.1				0.2	0.3	0.4		
	Etc mm	0.0	0.0	18.3	70.4	110.3	19.6	-0.5	-0.5	0.0	0.5	0.0	0.0	218	2181
Potato	Kc							0.4	0.6	0.8	0.9	0.6			
	Etc mm	0.0	0.0	0.0	0.0	0.0	0.0	89.4	120.9	117.2	73.3	0.0	0.0	401	4008
Industrial crops	Kc		0.2	0.3	0.5	0.6	0.7	0.7	0.6	0.4	0.2				
	Etc mm	0.0	0.0	0.0	46.0	93.5	140.3	156.8	120.9	56.3	0.5	0.0	0.0	614	6143
mixed Vegetables (Summer)	Kc			0.4	0.6	0.8	1	1.1	0.8	0.3					
	Etc mm	0.0	0.0	0.0	58.2	127.2	200.6	246.7	161.4	41.1	0.0	0.0	0.0	835	8351
mixed Vegetables (Fall)	Kc	0.9	0.3								0.2	0.5	0.8		
	Etc mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0	5

2.6.5.5 Net water requirements per representative Ha

Taking into consideration the crop occupation ratio (%) of each crop variety within ARB we can calculate the net water requirement of a representative Ha as follows. The Net water requirement is equal to weighted sum of Crop Evapotranspiration multiplied by Crop Occupation Ratio. Table 20 below shows that the intensification coefficient is 1.35 in the basin as it takes into consideration the crop rotation. The peak irrigation water requirement is in July and corresponds to 0.55 l/s/Ha.

Table 20 Net water requirement per representative Hectare

	Occupation ratio	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Annual value
Fruit trees/ vineyard	15%	0.00	3.23	8.98	21.04	26.89	28.76	19.86	4.75	113.5
Wheat and barley	30%	5.48	21.12	33.10	5.88	-0.15	-0.15	0.00	0.15	65.4
Potato	15%	0.00	0.00	0.00	0.00	13.41	18.14	17.57	10.99	60.1
Industrial crops	5%	0.00	2.30	4.68	7.01	7.84	6.05	2.82	0.02	30.7
Mixed Vegetables (Summer)	35%	0.00	20.36	44.51	70.20	86.34	56.49	14.39	0.00	292.3
Mixed Vegetables (Fall)	35%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.17
Annual value	135%	30%	85%	85%	85%	70%	70%	70%	100%	
net water requirement	m^3/ha	55	470	913	1041	1343	1093	546	159	5621
	L/s/ha	0.02	0.18	0.34	0.40	0.50	0.41	0.21	0.06	

According to prevailing irrigation practices, bibliography and field observations, we have adopted the following efficiencies taking into consideration, the adopted weighted efficiency coefficient is 0.65.

Table 21 Adopted efficiency coefficient by crop type and irrigation practice

Crop type	Irrigation means and practices	Adopted efficiency coefficient
Fruit trees & vineyards	Majority of the area is furrow irrigated	0.45
Wheat & barley-potato industrial corn	Is usually occasionally and partially irrigated by sprinkler in equipped parcels and traditional irrigation in other parcels	0.60
Mixed vegetables	Trending to drip irrigation	0.70

2.6.5.6 Gross irrigation water requirement of a representative hectare

Based on the previous estimations, the gross irrigation water requirement of one representative Hectare is approximately 8700 m^3/Ha with Irrigation Efficiency of 0.65.

Table 22 Gross irrigation water requirement per 1 representative hectare

		Mar	April	May	Jun	Jul	Aug	Sep	Oct	Annual value
Net water requirement	L/s/ha	0.02	0.18	0.34	0.40	0.50	0.41	0.21	0.06	
Net water requirement with field & conveyance losses	L/s/ha	0.03	0.28	0.53	0.62	0.77	0.63	0.33	0.09	
Irrigation water requirement	Day	2.7	24.2	45.5	53.6	66.9	54.4	28.1	7.9	
	Month	85	726	1409	1608	2074	1687	844	246	8677

2.6.5.7 ARB global irrigation water requirements

The global irrigation water requirement all over ARB can be calculated based on total irrigated area (18,500 ha) obtained from Table 17 and the irrigation water needs of a representative hectare. Hence the irrigation water demand is estimated to:

18,500 x 8,700 m^3/Ha/year = 161 Mm^3/year that can be broken-down per month and per irrigation zone.

Due to the prevailing water scarcity, it is believed that the effective irrigation water consumption does hardly exceed 75% of the global irrigation water requirement especially during peak season.

3 Water Quality Sampling Campaign

3.1 Description

A sampling campaign for water quality check was carried out on the 31st of August 2022 by NDU Laboratory team in coordination with BTD, ACTED and WW-GVC. This section will only present a brief summary of the campaign including main results. The complete report is attached in Appendix A.

The first campaign was made over the dry season to show compliance with established criteria. A second campaign will be carried out in the wet season and compared to the first campaign results to highlight any seasonal variability.

The sampling plan and location were prepared in a way to guarantee representative samples, thus providing an accurate description of the overall quality of the water in ARB.

Furthermore, sampling sites were located in areas that are safe to access, accessible under all conditions of flow, and well mixed to ensure a homogenous sampling collected is easily identifiable for later sampling.

Table 23 Sampling location

ID	Name	Latitude	Longitude
1	Laboueh - Main	34.1974	36.3524
2	Laboueh - Rwess	34.1973	36.3526
3	Fekha	34.2417	36.4068
4	Al Assi – Dardara waterfall	34.4217	36.4573
5	Ras El Mail	34.3904	36.3713
6	Bdita	34.3912	36.3738
7	Al Assi - Hermel Bridge	34.3935	36.4178
8	Zar2a	34.3524	36.3738
9	Deffech	34.3536	36.3824
10	Deffech Upstream	34.3535	36.3824

Figure 26 Water quality sampling sites location

3.2 Results

Results obtained following the physical, biological and chemical testing of data collected, shows that almost all stations are characterized by median of pH between 7.9 and 8.21; so the values are generally within appropriate limits for water supply and aquatic life.

Total Dissolved Solids (TDS) are a measure of all ions in a solution. TDS measurements were less than 500 ppm for all the samples.

The ammonium concentration in the samples showed acceptable values compared to WHO international standards, except for sample 5. The amounts of nitrate, heavy metals, and chloride have not given values that exceed the accepted standards.

Table 24 Summary results of the water quality sampling campaign

TEST/POINT	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10
Turbidity (NTU)	0.19	5.33	0.866	7.570	0.86	0.78	18.05	7.3	8.515	1.000
pH (pH)	8.02	8.203	8.004	8.095	8.214	8.016	8.219	7.8	7.871	7.96
ORP (mV)	251	269	271	266	309	301	289	292	311	326
RDO (mg/L)	7.4	7.502	7.195	8.136	7.499	8.292	7.675	7.449	8.515	8.585
A-Conductivity (µS/cm)	240	248	22	278	175	184	276	124	263	252
S-Conductivity (µS/cm)	292	302	25	336	215	239	333	147	321	308
Salinity (PSU)	0.14	0.146	0.010	0.162	0.102	0.114	0.160	0.070	0.155	0.148
Resistivity (Ω·cm)	4151	3991	4238	3587	5679	5424	3623	8017	3803	3963
Density (g/cm³)	0.99	0.999	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999
TDS (ppt)	39	198	16.6	218	140	155	216	96.1	208	197.7
TS (ppt)	66	310	155	684	184	309	432	108	318	224
Temp(°C)	15.7	15.7	19	16.1	15.4	13.0	16.0	16.6	15.56	15.49
Nitrate (mg/L)	2.55	0.3	4.69	2.96	0.02	20.6	32	2.48	3.13	2.71
Lead (mg/L)	0.034	0.054	0.01	0.05	0.004	0.08	0.04	0.05	0.063	0.01
Cadmium (mg/L)	0.001	0.002	0.003	0.006	0.00002	0.002	0.002	0.002	0.002	0.002
Barium (ųg/L)	3.1	2.1	3.4	6.3	2.2	2.8	0.3	2.9	0.6	2.3
Mercury (ųg/L)	0.085	0.084	0.065	0.173	0.2	0.12	0.03	0.3	0.1	0.18
Sodium (ppm)	10.3	6.3	26.9	10.7	5.8	6.5	4.3	11.5	4.1	8
Potassium	3.3	1.6	10	8.4	4.7	0.9	2.6	4.9	2	2.3
Lithium (ppm)	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.001	0.1
Calcium (ppm)	8	20.2	45.8	11.2	14.9	5.1	26.5	14.9	28.3	30.5
Phosphorus (mg/L	<0.03	<0.03	<0.03	0.04	<0.03	<0.03	0.03	15	0.02	<0.03
Chloride (mg/L)	4.15	195	10.3	10.3	5.3	22.6	22.3	4	10.3	22
Ammonia (mg/L)	0.58	0.9	0.82	0.75	0.021	0.701	0.7	0.8	0.9	0.62
Sulfate	<20	202	12	16	<20	<20	<20	<20	<20	<20
Fluoride	8	10.6	11.3	11.6	13	8	5	4.5	7.3	11
Total Nitrogen	71	72	5.3	82.6	1	21	106	159	85	116
DO	7.15	7.502	7.195	8.136	7.499	8.292	7.675	7.449		8.585
BOD	2.19	6.2	6.5	34	6.3	35.6	47.5	7.3	14	8.2
COD	5.5	8.9	14	149	11.3	64	73.5	20	25	13
Total Coliform	0	10	6	133	0	104	196	10	117	74
Fecal	0	0	0	63.5	0	58	88	2	65	0
Ecoli	0	0	0	99	0	10	58	0	21	0

3.3 Discussion of results

Water samples were collected from Al-Assi River during the dry season and tested for physical qualities, chemical contents, and microbiological counts. Ten sampling points were selected. Water quality parameters, such as conductivity, DO, BOD, COD, pH, TS, DS, and Fecal Coliform were analysed. The concentration of lead, cadmium, mercury, barium, lithium, sodium, potassium, chloride, sulphate, fluoride, ammonia, phosphorus, and nitrate was also analysed at all the points. The examination of the results is shown below:

Measuring **dissolved oxygen (DO)** in drinking water is important to understand water quality. DO is critical for fish and other aquatic organisms to survive. DO values for Al-Assi river, along our reach varied between 7.502 mg/L to 8.585 mg/L. WHO standard for sustaining aquatic life is <4 mg/L, whereas for drinking purposes it is 6 to 8.5 mg/L. Therefore, all the examined points are suitable for drinking and aquatic life. High dissolved oxygen levels are beneficial for drinking water, as it improves the taste; however, high dissolved oxygen levels are linked to the rapid corrosion of water pipes. Furthermore, the results show that DO concentration is reduced when an increase in temperature occurs as oxygen saturation levels are temperature-dependent.

While in the case of **(BOD) concentration, the results** recorded values ranging from 2.19 mg/L at point 1 and 47.5 mg/L at point 7. Most rivers have BOD_5 below 1 mg/L. Moderately polluted rivers may have a BOD_5 value in the range of 2 to 8 mg/L. However, high BOD_5 levels (>8mg/L) can be a result of high levels of organic pollution, caused usually by poorly treated wastewater or from high nitrate levels (EEA, 2001). WHO standard for drinking purposes is 0.2mg/L, which is exceeded to a great extent as shown by the values in Table 24. But for other purposes where the value is quite higher than 0.2 mg/L, Al Assi river water is quite satisfactory. Higher BOD_5 values were detected at sites 4,6, and 7 which may be attributed to recreational activities in the form of restaurants, fisheries, and rafting activities that are located along the river as well as family picnic areas in addition to agricultural runoff. Moreover, this might be due to the discharge of Oil Mill (OM) waste, for example, into the river during the sampling season. OM contains an enormous supply of organic matter which might raise the BOD_5 level (Mekki et al., 2013)

Chemical oxygen demand (COD) is another important parameter of water quality assessment. A standard for drinking purposes is 10 mg/L, which is acceptable for point 1 in terms of our analysed value. Table 17 shows the COD data of ten sampling points. High contaminations exist at points 4, 6, and 7 with COD values of 149, 64, and 74 mg/L respectively. The highest levels of COD recorded may be also attributed to raw sewage discharge and for the same reasons stated in the BOD examination.

Concerning the **pH** which is an indicator of the acidic or alkaline condition of water status, the standard for any purpose is 6.5-8.5, in that respect; the values of our sampled water conform with the standards as for all the samples it varies between 7.800 and 8.214. All sites exhibited values of pH within the limits of the natural values that support aquatic life.

Adding to the above, the value of electric **conductivity** (EC) of Al-Assi river varied between 22 and 278 µs. Conductivity depends on the number of ions present in water. In the dry season, the total volume of water decreases at Al-Assi, as a result, the conductivity was high for most of the points, yet it remained within the limits (<300 µs) for drinking water, and rivers and surface water (< 1500 µs). A main observation from the results is that conductivity is directly influenced by TDS, the higher the TDS the higher the EC (Lawson, 2011). A positive correlation was clear between EC and TDS.

Likewise, **total solids** concentrations in the dry season varied between a minimum of 66 mg/L at point 1 and a maximum of 684 mg/L at point 4. This variation might be due to the fact that a lot of water activities are taking place at point 4 which in turn are increasing the amounts of silt and clay particles in the river water.

Concerning **Dissolved Solids (DS**), the standard for drinking water is 500 mg/L. The maximum value obtained from the samples in the dry season is 216 mg/L at point 7. In this respect, we can conclude that Al-Assi river water is acceptable from the drinking water perspective. High levels of TDS at some points are caused by the presence of potassium, chlorides, and sodium and by toxic ions (lead arsenic, cadmium, and nitrate), and result in an undesirable taste that could be salty, bitter, or metallic (Lawson, 2011).

Similarly, the WHO standard for **ammonia** in surface water for drinking purposes is 1.5 mg/L. The results yielded from the test results showed much lower values ranging from 0.021 to 0.9 mg/L for all the points which means it is quite safe in terms of ammonia pollution.

Comparably, the levels of **nitrate** exhibited a clear fluctuation among the sites ranging from the lowest value of 0.3 mg/ at point 2 to 20.6 mg/L at point 6 yet falling below the limit for surface water (50 mg/l).

Apart from the above, we have traced **metal detection** water. These chemicals are classified as being potentially hazardous and toxic to most forms of life. Results reported that trace metals' concentration for **lead, mercury, and cadmium** were low for all the points except for mercury at point 4, whereas **barium** recorded a mean value higher than the WHO guideline (2004) for nitr of the points.

Moreover, some of the chemical elements like **Sodium, potassium, lithium, and calcium** are essential as micronutrients for the life processes in animals and plants (Kar et al., 2008). Fortunately, acceptable concentrations were found in AL Assi.

Similarly, **phosphorus** concentrations recorded values less than 0.04 mg/L for all the sampled points (except point 8). Comparing these results with WHO limits, they fall within the acceptable level of phosphorus (1mg/L) in rivers. The high level of phosphate at point 8 might be due to anthropogenic sources, mainly, agricultural runoff, animal waste, raw sewage, and household detergents. Excess phosphate in surface runoff might lead to cultural eutrophication. During this phenomenon, PO_4^{3-} in freshwater leads to a favourable condition for algae and weed growth, which ultimately brings a rapid reduction in the ecosystem through oxygen depletion.

The sulphate, as well, recorded a mean value of less than 20mg/L for all the points (except point 2). Compared with WHO guidelines, the results fall within the acceptable range (<200 mg/L).

Similarly, **chloride** concentration documented values varying from 4.00 to 195 mg/L. Compared with WHO guidelines, the level of chloride did not exceed the range (200 mg/L) for drinking water indicating that there are no industrial effluents or urban runoff at the location of the sample.

On the other hand, **calcium** values varied between 5.1 mg/L at point 6 and 46 mg/L at point 3. Calcium is an important micronutrient in the aquatic environment, and it enters the water mainly through the weathering of rocks. The concentration of calcium in rivers may reach 200 mg/L. Results are within the range.

Moreover, **fluoride** concentrations were recorded at all sites, yet no marked variation was observed, an exceeding value greater than 1.5 mg/L was found at all sites. These are clearly unacceptable as far as drinking purposes are concerned. For other activities relating to surface water quality, the values are quite acceptable. The main sources of fluoride contamination are usually industrialization, motorization, fluoride containing pesticides, fluoridation of drinking water supplies, dental products, refrigerants, and fire extinguishers.

Apart from the physical and chemical parameters, the water was tested for microbiological pollutants. The results of the ten sampling points show that for points 1,2,3,5,8, and 10 there is no detection of fecal and E-coli. However, fecal and total coliform counts were too numerous at sites 4,6,7, and 9 indicating the critical condition of excessive microbiological contamination. The presence of fecal coliform bacteria in very high levels indicates potential health risks to swimmers and implies the suitability of the water at these critical points for specific water uses such as swimming is restricted. The source of organic and microbial pollutants present in the water can be accounted for by the presence of trollers used for conveying materials in the area. However, the high number of coliforms at points 4,6,7, and 9 confirms the presence of agricultural runoff, animal waste, raw sewage, and household detergents (Amacha et al., 2012).

According to the WHO standards and the European Economic Community, fecal coliforms in drinking water are not tolerated (0 FC/100ml), and bathing water should not exceed 100 FC/100 ml (Servais et al. 2007). Several health outcomes such as gastrointestinal infections might be associated with fecally polluted l water which may result in a significant burden of disease (WHO 2001). Considering that bacteria densities are greatest during the summer months and the fact that there is no wastewater treatment in the whole catchment area of Al-Assi river, the construction of wastewater treatment systems primarily for large settlements is essential.

To sum up, the results from data analysis show that, the water is certainly unfit for drinking purposes without any form of treatment, but for various other surface water usage purposes, it still could be considered quite acceptable. But as we know, once a trend in pollution sets in, it generally accelerates to cause greater deterioration. So, a few years from now, serious water quality deterioration could take place.

3.4 Conclusion

The physical, bacteriological, and chemical composition of ARB was analyzed in the dry season. Almost all sites exhibited values of pH within the limits of the natural values that support aquatic life. The levels of TDS were fluctuating among the sites with the highest values recorded at site 7 within the acceptable range. Higher BOD_5 values were detected at sites 6 and 7 which may be attributed to recreational activities in the form of restaurants that are located along the river as well as family picnic areas in addition to agricultural runoff. The levels of nitrate exhibited a clear fluctuation among the sites ranging yet falling below the limit for surface water. The levels of sulphate did not exhibit a distinct spatial variation unless for point 2. The estimated indices at sites 1, 3 and 5 were generally good. However, sites 4,7, and 9 exhibited relatively the worst water quality conditions.

Results revealed that the water quality of ARB is generally affected by the activities taking place along its watershed. The best quality was found in the upper sites and the worst at the estuary. The impact of recreational activities in the form of restaurants that are located along the river as well as family picnic areas resulted in poor water quality that is suitable for specific water uses such as swimming is restricted due to the presence of high levels of fecal coliform. Given that recreational use of the river is very important for the development of the area, preventing further deterioration by anticipating and avoiding new impacts is crucial for effective management. If Al Assi river is to be used as a managed water resource, point source discharges, and primarily sewage will require treatment.

Adding to the above, anthropogenic perturbations, the difference in topography among the sampling locations, the actual volume of water in the stream, and flow rate are important factors introducing changes to water quality at several points.

4 MODFLOW Modelling

4.1 Methodology and Theoretical Background

MODFLOW (McDonald and Harbaugh, 1988; Harbaugh et. al. 2000) is a public domain, international industry-standard, groundwater modelling software package being used to evaluate the groundwater conditions for this project. In particular, MODFLOW was applied to construct a three-dimensional finite-difference groundwater flow model of the aquifers under study.

The basic law used in hydrogeology to describe groundwater flow is Darcy's Law, a generalized relationship for flow in porous media. This law states that the rate of fluid flow through a porous medium is proportional to the potential energy gradient within that fluid. The constant of proportionality is the hydraulic conductivity, which is a property of both the porous medium and the fluid moving through the porous medium. However, fissured and fractured limestone aquifers are known by a high proportion of flow along non-Darcian flow lines (Gale, 1983). In fact, conduit flow generally prevails in carbonate terrains. Hence, groundwater modelling in karst environments is challenging and often yields highly uncertain outputs due to the complexity of flowpaths and difficulty to collect site-specific data on the karst channels (such as elevation, slope, fill material, roughness, cross-sectional area, diameter, etc.). Since such information are globally difficult (or sometimes impossible) to obtain, numerical groundwater modelling is generally not performed, or performed with simplifying assumptions. For this study, the groundwater flow equation is derived for a small representative elementary volume (REV), where the properties of the medium are assumed to be effectively constant (Bear, 1972). The mathematical model of groundwater flow consists of two equations:

- Equation of motion (Darcy's equation);
- Equation of continuity.

The combination of the aforementioned equations forms the general groundwater flow partial differential equation:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t}$$

where:

- K_{xx}, K_{yy} and K_{zz} [L/T] are respectively the values of hydraulic conductivity along the x, y and z coordinates axes (assumed to be parallel to the major hydraulic conductivity axes);
- h [L] is the piezometric head;
- W [T^{-1}] is the volumetric flux per unit volume representing sinks/sources;
- S_s [L^{-1}] is the specific storage;
- t [T] is the time.

This equation combined with initial conditions and boundary conditions can describe transient three-dimensional groundwater flow in a heterogeneous and anisotropic medium. For the steady state solution, the head partial derivative with respect to time on the right-hand side of the general groundwater flow equation is set to zero. It should be noted that only steady state simulations are presented in this report.

In the present study, we assume that the hydraulic conductivity, conductance of the General Head Boundary (GHB) and drains, as well as the recharge rates are unknown parameters. A zonal parameterization approach was considered for the hydraulic conductivity and recharge to account for the spatial variability of those parameters. Since karstic aquifers have a high degree of heterogeneity and anisotropy in their (hydro)geological parameters, there are high levels of uncertainty and complication in calibrating such systems for hydraulic heads. Moreover, the available old groundwater data cover a limited spatial extent and it is unclear if the reported figures represent static or dynamic conditions. Hence, the unknown variables were estimated through an inversion that used old spring discharge values as observations. In all cases, the success of any inversion depends on the careful choice and implementation of the optimization algorithm as well as the modeler's judgement. Manual and/or automatic calibrations can be carried out to solve the inverse problem. In this study, PEST (Doherty, 1994; Watermark Numerical Computing, 2005), a model-independent parameter optimizer, was used to accomplish this task.

4.2 Finite Difference Grid Design

The discretization of the model domain is an important step in the development of a groundwater model. As shown by Figure 27, a 62 Km (in the x direction) by 58 Km (in the y direction) structured grid was constructed. It is a cell centered grid formed by 31596 active cells. The cell size is constant with a resolution of 500x500m. In the vertical direction, four layers were simulated to represent the different hydrogeological formations (further details about the layering are presented in Section 4.4).

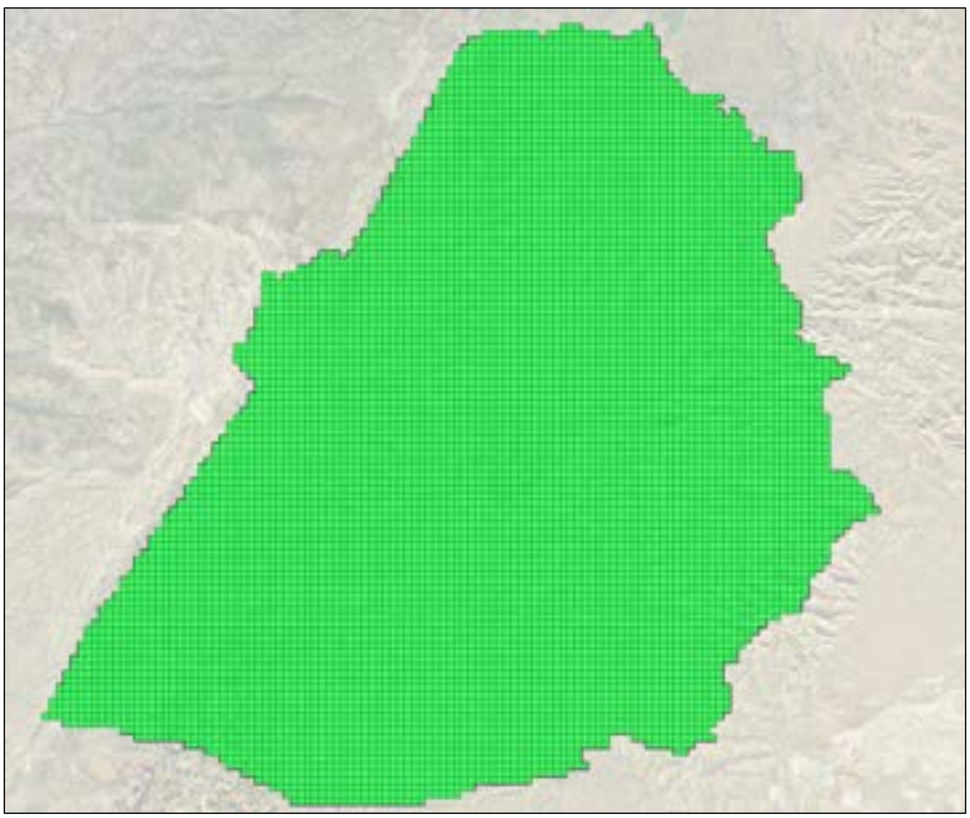

Figure 27 ARB MODFLOW Model extents

4.3 3D Lithological Model

For a better representation of the hydrogeological layering, a three-dimensional (3D) lithological model representing the main formations was produced. The construction of the 3D lithological model was divided into three main steps. The first step consisted of using the geological cross sections (see Appendix C) to generate fictive borehole logs consisting of different lithological layers at different depths, coordinates of the borehole and ground elevations obtained from the DEM. The second step consisted of assigning horizons (unique IDs) to the top of each stratigraphic unit at every borehole. Initially, horizon IDs were assigned automatically. However, manual editing was required for a more realistic representation. After defining the horizons, cross-sections among boreholes were generated to be used to produce the 3D lithological model. The cross sections were automatically created using the previously assigned horizons ID based on the triangulation method (Figure 28). A closed boundary encapsulating the study area is used to define the modeling boundaries while turning the created cross sections into a full three-dimensional solid model. In practice, spatial interpolation is required to convert cross-sections to a full 3D solid. Finally, using the inverse distance weighted interpolation method, a 3D solid model was constructed as shown in Figure 29.

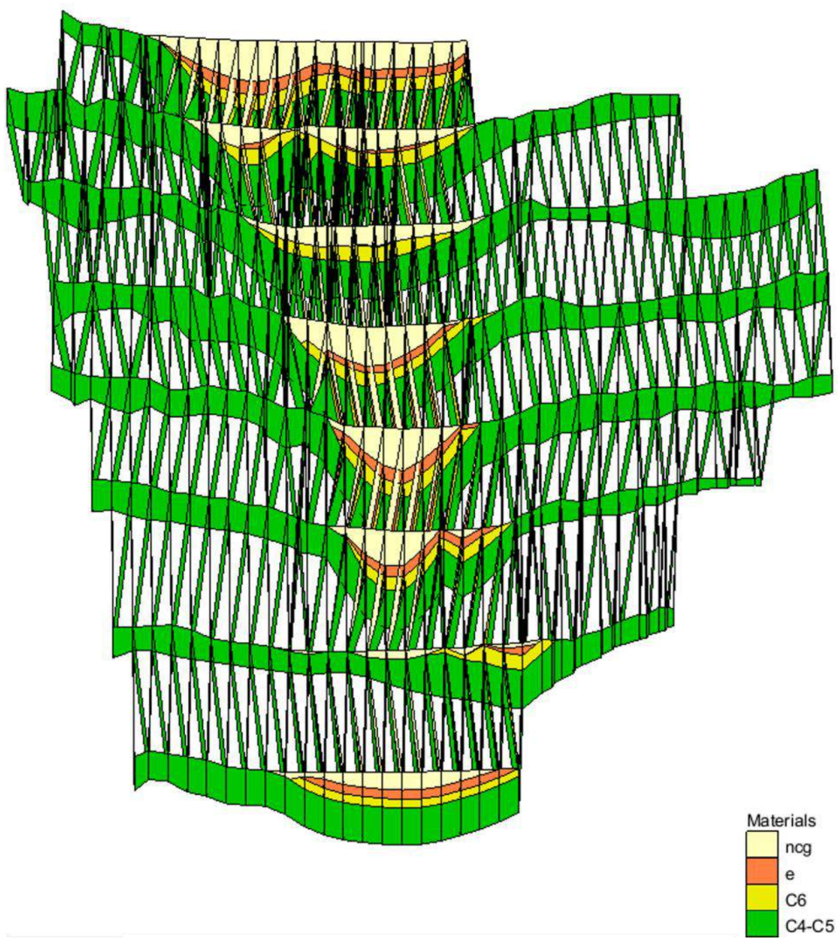

Figure 28 Generated digital cross sections for Al Assi hydrogeological basin (south to north view angle). ncg: quaternary deposits and Neogene conglomerates; e: Eocene limestone; C6: Senonian marls; C4-C5: limestones and dolomites of the Cenomanian-Turonian

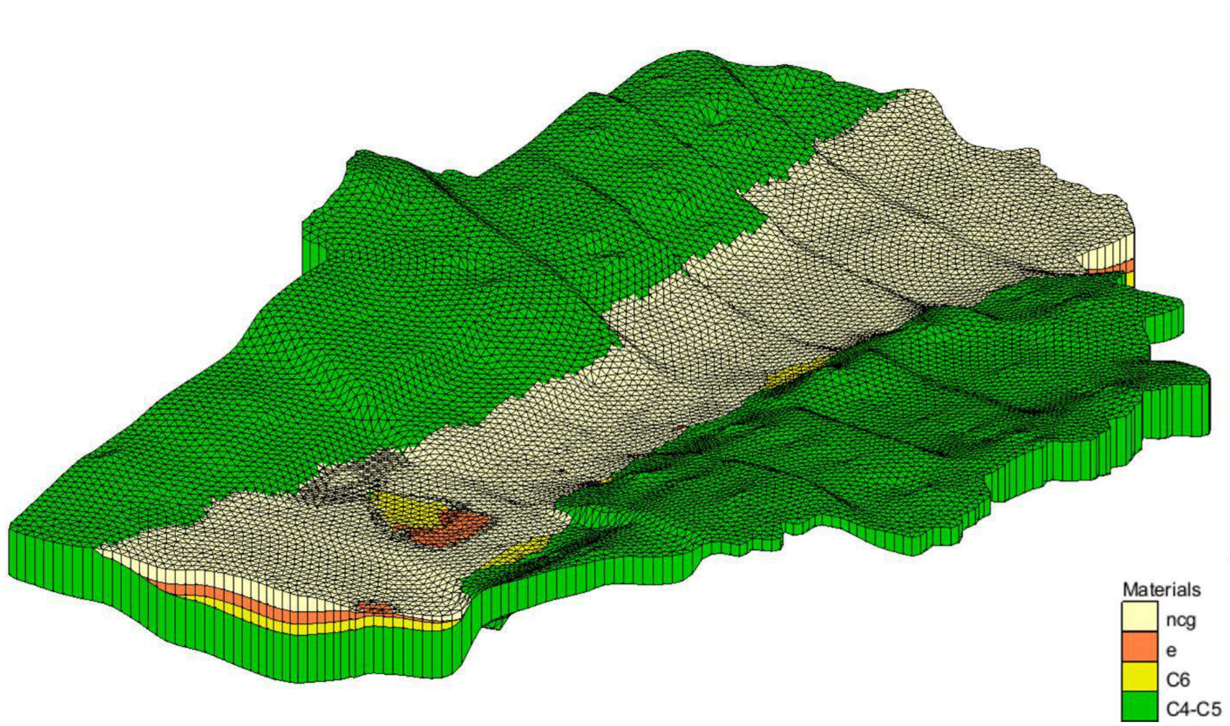

Figure 29 3D lithological model of Al Assi hydrogeological basin (view angle from the south-east). ncg: quaternary deposits and Neogene conglomerates; e: Eocene limestone; C6: Senonian marls; C4-C5: limestones and dolomites of the Cenomanian-Turonian

4.4 Layering

As previously mentioned, the model is composed of four layers (Figure 30) representing the following formations: quaternary deposits and Neogene conglomerates (Layer 1), Eocene limestone (Layer 2), Senonian marls (Layer 3), as well as the limestones and dolomites of the Cenomanian-Turonian formation (Layer 4).

The top level of the model was assigned from ground elevations (obtained from the Digital Elevation Model). The bottom elevations of the four layers were assigned from the 3D lithological model (Figure 29). It is important to highlight that a negligible thickness was given to layers 1, 2 and 3 in the areas where the relevant formations do not exist in reality (i.e. in the eastern and western sides of the study area, where the Cenomanian-Turonian formations are outcropping). Finally, it should be noted that the MODFLOW Layer Property package (LPF) was used in this model rather than the Block-Centered Flow (BCF) package.

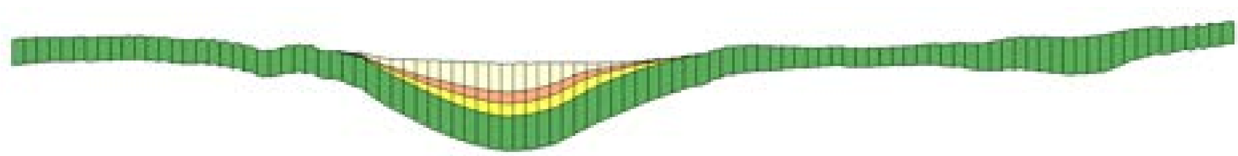

Figure 30 Cross-sectional view of row 72 of the modelled area

4.5 Boundary Conditions

The boundary conditions in MODFLOW are controlled through the IBOUND array (a value of 0 indicating no flow conditions, 1 indicating variable head cell and -1 indicating a constant head cell). Among the 4 boundaries of the model:

- The eastern, western and southern boundaries are considered no flow boundaries (mainly reflecting the subsurface water divide shown in Figure 12). Hence, for these cells IBOUND = 0 was assumed. In other terms, these boundaries are of the second type (Neumann conditions) where the flux across the boundary is known (specified flow boundaries with a flow value of zero under the natural conditions). In fact, the southern boundary matches the river basin divide (separating waters flowing to the Litani River Basin from those flowing to the Assi River; however, it should be noted that hydrological and hydrogeological divides do not necessarily coincide). The Yammouneh fault to the west and the highs to the east were also considered as no-flow boundaries;
- The northern boundary is considered as a GHB. Hence, IBOUND = 1 was assumed for the relevant cells. This boundary follows the third type (Cauchy conditions) where the flux across the boundary is a function of the head at the boundary. The conductance values of the GHB were calibrated for the baseline scenario. The GHB package is used to simulate groundwater flow from an external source into or out of a cell.

4.6 Sources and Sinks

The **Recharge package** (RCH) was used to simulate areally distributed recharge into the groundwater system. The recharge applied to the model is defined by the following equation:

$$QR_{i.j} = I_{i.j}.DELR_j.DELC_i$$

where:

- $QR_{i.j}$ [L^3/T] represents the recharge flow rate to the cell (i,j);
- $I_{i.j}$ [L/T] represents the recharge flux to the area $DELR_j.DELC_i$.

A different recharge parameter was assigned for each outcropping formation. In addition, the main outcropping formations (i.e. C4-C5 and Quaternary-Neogene) were subdivided to different recharge zones (using Plassard's rainfall isohyet map (Plassard, 1971)) to reflect local climate variabilities in terms of precipitation. The resulting subdivision is shown in Figure 31.

The estimated recharge values should be read as "net recharge" knowing that evapotranspiration is not directly modelled since it will only affect the shallow part of the different aquifers. In fact, modeling evapotranspiration requires the definition of maximum evaporation rate, evaporation extinction depth, and evaporation surface elevation. In all cases, the groundwater level within the study area is much deeper than the extinction depth (i.e. the depth below which evapotranspiration from the water table ceases). As an indicative example, the extinction depth for a top sandy bare soil is 0.5m (Shah et al., 2007).

The **Drain package** was used to represent the springs. The drain feature in MODFLOW was originally developed to simulate agricultural tiles that aim to abstract groundwater at a rate that is proportional to the head difference between the aquifer and a fixed drain elevation (as long as the head in the aquifer exceeds that specified elevation) (McDonald and Harbaugh, 1988). For this simulation, the drain elevations were assumed to be equal to the elevations of the associated discharge points (i.e. springs). In addition, the drain conductance should be specified. In this case, drain conductance was one of the adjusted parameters to achieve an acceptable model calibration. In fact, drain conductance is a lumped parameter incorporating information on the drain characteristics, its surrounding formation, and the head loss between the drain and the aquifer (McDonald and Harbaugh, 1988). Prior applications of MODFLOW in karst environments have made use of the drain package to represent springs: Yobbi (1989) in Florida (USA), Panagopoulos (2012) in Greece, Duran and Gill (2021) in Ireland, etc. The simulated nine main springs (Figure 13) are those having a reported discharge of more than 1000 m^3/d. Although there are (at least) 40 other identified springs, the selected main springs account for 98.8% of the reported total springs' discharge within the study area.

El Assi River was simulated as a head-dependent flux boundary using the **River package** (RIV). Hence, MODFLOW can be also applied to investigate surface water-groundwater interactions.

The **Well package** (WEL) was used to simulate the outflow through pumping wells. The different considered wells were simulated by specifying the location of each individual well or groups of wells, and their daily abstraction rates (by assigning a negative value of Q to indicate well discharge). Private wells were grouped by village and simulated as one equivalent well per village. However, in many cases, private wells in the same village are believed to be tapping different formations. As such, this was taken into account by assigning an abstraction layer for each well. Locations of the 80 public wells and 54 grouped private wells (representing in reality 3738 individual private wells) were previously shown in Figure 12. It should be noted that 66 out of the 80 public wells are considered to be operational in the current scenario (since the remaining 14 public wells are out of service, under construction and/or not equipped). The considered abstraction rates from each aquifer for the current scenario are summarized in Table 25. However, it is important to note that the number of private of wells can be much higher than the reported figures.

Table 25 Abstractions per well category and aquifer

Aquifer	From Public Wells (m^3/d)	From Private Wells (m^3/d)	Total Abstractions (m^3/d)
Quaternary-Neogene	6000	43000	49000
Eocene	-	24000	24000
Cenomanian-Turonian	57000	66500	123500

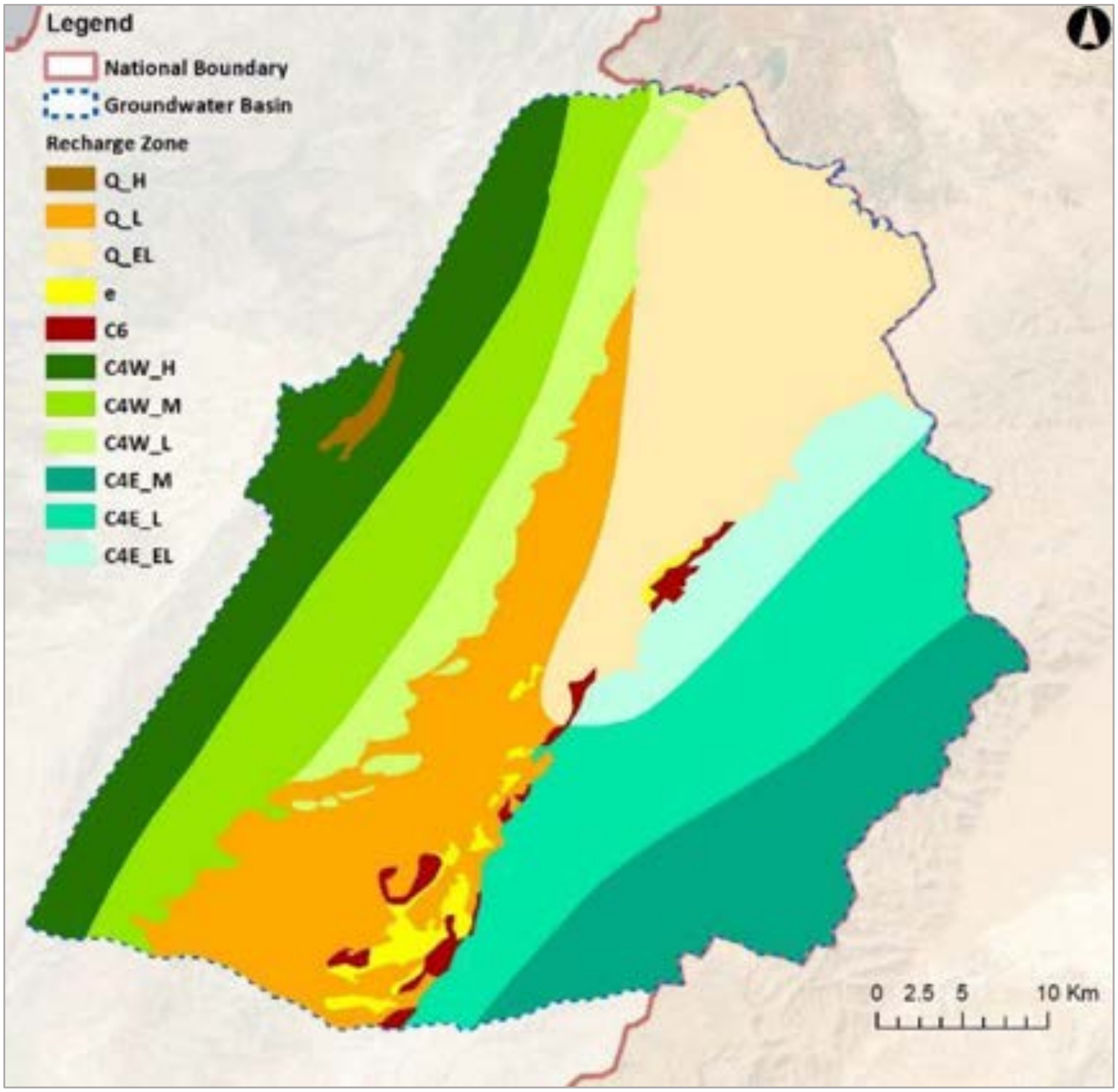

Figure 31 Recharge zones (as defined in MODFLOW): Q indicating the Quaternary-Neogene aquifer, e indicating the Eocene aquifer, C6 the Senonian aquiclude, and C4 the Cenomanian-Turonian aquifer (referred to as C4 instead of C4-C5 in this map to avoid lengthy naming). The different rainfall conditions are reflected by: H: high rainfall, M: moderate rainfall, L: low rainfall and EL: extremely low rainfall

4.7 Hydraulic Properties

At this stage, the study didn't consider transient simulations. Therefore, the specific storage and specific yield values won't be of interest for the groundwater modelling part. The main hydraulic parameter to be discussed will be the hydraulic conductivity. It should be noted that a high spatial variability of hydraulic conductivity values is expected, especially in carbonate rock aquifers. As such, Layer 4 was subdivided into different zones to account for this spatial variability as shown by Figure 32. During model calibration, HK value for each zone was estimated. For the remaining layers, homogeneous conditions were considered (which also minimizes the numerical instability of the model). Estimated values of hydraulic conductivity are presented in Section 4.8.

Figure 32 Hydraulic conductivity zones of layer 4

4.8 Model Calibration (Baseline Scenario)

As previously mentioned, inverse modeling (i.e. model calibration) was performed to estimate the unknown parameters, in particular the hydraulic conductivity, the conductances of the drains and General Head Boundary, as well as the recharge rates. Log-transformation was applied for the hydraulic conductivity to allow this parameter to be log transformed throughout the estimation process.

Typically, calibration should be performed under natural conditions. However, old data on groundwater were not continuously available for an extended period of time. Relying on spot measurements from different months and years normally leads to temporal inconsistency in terms of calibration targets, especially that interannual climate variations are expected in the study area. The used spring discharge values, mainly representing the phase before the year 1970, were obtained from multiple sources (USBR, 1957; MoEW and UNDP, 2014; LRA data). Hence, those values were cautiously used. Although the aforementioned uncertainty remains valid, this temporal selection tries to consider a scenario where anthropogenic influence is minimal. The selection of the phase before the year 1970 for the baseline scenario (and calibration) was made due to the expected relatively low anthropogenic impacts during that period.

The calibration process gave a perfect fit for the considered main springs as shown by Figure 33. Although the curve shows a perfect fit the relative residual flow varied between 0.1% (Laboueh spring) and 1.8% (Nabaa ech Chaghour spring). Overall, the Absolute Residual flow is 724 m^3/d and the Root Mean Squared Residual (RMSR) is 1492 m^3/d.

The most important estimated model parameters are the recharge rates and the hydraulic conductivities. The estimated horizontal hydraulic conductivity (HK) and vertical hydraulic conductivity (VK) are the following: HK=1.87 m/d and VK=0.12 m/d for the Quaternary-Neogene aquifer, HK=13.01 m/d and VK=0.56 m/d for the Eocene aquifer, HK=0.1 m/d and VK=0.04 m/d for the Senonian aquiclude. The Cenomanian-Turonian aquifer had a VK of 7.7 m/d and was subdivided to 5 horizontal hydraulic conductivity zones: the eastern part of this aquifer had a horizontal hydraulic conductivity of 10 m/d while the south-western and north-western parts had values of 33 and 97 m/d, respectively. In the central subsurface, the estimated HK was 15 m/d (while the small outcropping patches of this aquifer in the southern part of the valley showed an HK value of 41 m/d).

Groundwater recharge, expressed as percentage of the precipitation, varied between 33 and 42% where the Quaternary-Neogene aquifer is outcropping, 65 to 77% for the eastern Cenomanian-Turonian aquifer, and 77 to 85% for the western Cenomanian-Turonian aquifer. This is in-line with the reported presence of karstic features (as the western side of the study area is characterized by the presence of more karstic features, mainly sinkholes). In fact, Zwahlen et al. (2014) mentioned that El Assi basin contains significant karstic water resources. On the other hand, the relatively high recharge rate for the Quaternary-Neogene aquifer might be indicating irrigation return flows (most likely occurring in the agricultural areas of the Bekaa valley). Other outcropping formations were represented as one zone. Hence, the recharge parameters of the Eocene aquifer and Senonian aquiclude were estimated to be 23% and 5% of the precipitation, respectively. The recharge rates were particularly useful as they are, among other groundwater-related parameters, required as input to the WEAP component of this project. Besides the parameterization of WEAP's groundwater nodes, MODFLOW will be employed to model the effects of potential future scenarios, such as the installation or operation of more wells by 2035, On the other hand, WEAP will use the outcomes of MODFLOW to assess how changes in climate patterns will affect spring flows and recharge rates.

Generally, the estimated parameter values seem to be realistic. In fact, an assisted calibration approach was adopted by setting the minimum and maximum values for the different parameters (by relying on the literature and previous studies) in order to avoid unrealistic calibration results.

Following the baseline scenario development, projected simulations will be carried out to assess the potential impacts of different water management scenarios.

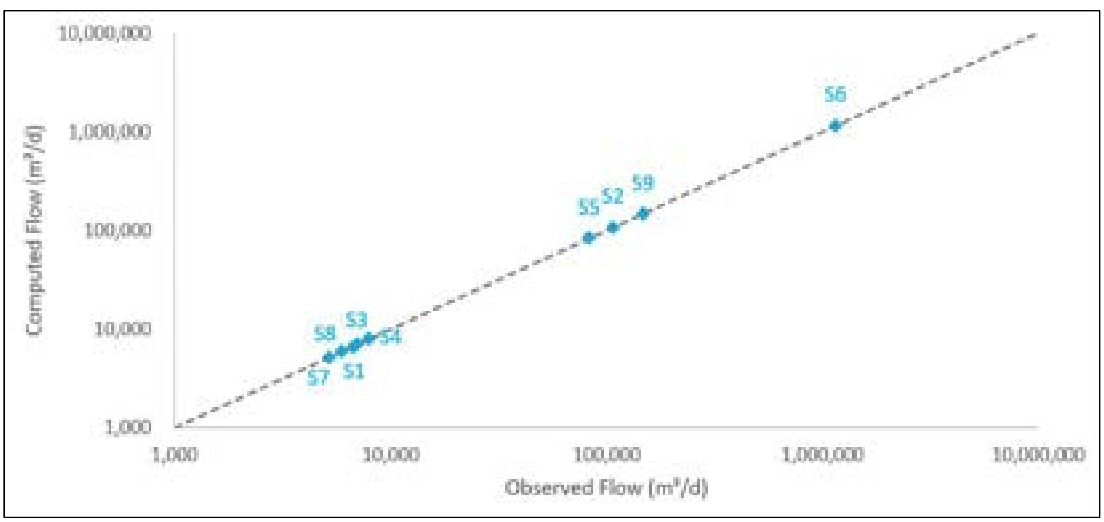

Figure 33 Computed and observed flows of the main springs. S1: Nabaa Ras el Mal, S2: Nabaa Raayane, S3: Nabaa ech Chaghour, S4: Ain Ahla, S5: Nabaa el Fekha, S6: Ain ez Zarqa, S7: Ain Quardine, S8: Nabaa Aaddous, S9: Laboueh

5 WEAP Modelling

Water Evaluation and Planning (WEAP) is a software tool for integrated water resources planning that provides a comprehensive, flexible and user-friendly framework for planning and policy analysis. The primary support for development was provided by The Stockholm Environment Institute, while a number of agencies, including the US Army Corps, UN, World Bank, USAID, US EPA, IWMI, Water Research Foundation and the Global Infrastructure Fund of Japan have provided project support.

It has been applied in water assessments in dozens of countries, including: the United States, Mexico, Brazil, Germany, Ghana, Burkina Faso, Kenya, South Africa, Mozambique, Egypt, Israel, Oman, Central Asia, India, Sri Lanka, Nepal, China, South Korea, and Thailand.

WEAP operates in many capacities:

Water balance database	Scenario generation tool	Policy analysis tool
WEAP provides a system for maintaining water demand and supply information.	WEAP simulates water demand, supply, runoff, streamflows, storage, pollution generation, treatment and discharge and instream water quality.	WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.

The goal of the model for ARB is to establish the baseline scenario for current water resources management (WRM) in the area, contemplating both water sources and demands. This model will shed a light into current and projected unmet demands and serve as a baseline on which to build upon different scenarios for WRM.

With this in mind, it is therefore necessary to input all the different water demands, mainly domestic consumption and irrigation requirements, and all the different water sources that are comprised mainly of groundwater abstractions and springs diversion.

5.1 Data input and modeling

5.1.1 Time horizon

The time horizon for the project has been set to 2020 – 2035. The model has been subdivided into 12-time steps per year, using a calendar month partition and including leap days as well.

As a consequence, the year 2020 will be used as the Current Accounts Year in which all parameters and variables are defined. These will be projected throughout 15 years to establish the baseline scenario. In general, unless specified otherwise, parameters will remain constant; and variables will only be modified if they are related to the progression of time, like for instance when considering population growth.

The following sections will provide a brief description of these variables and parameters related to water supply and demand.

5.1.2 Water Distribution Systems

In order to articulate on an efficient manner between the current assignment and the National Water Sector Strategy from 2020, it was decided that water supply and demand will be organized according to water systems.

As it was mentioned before, the study of ARB involves 25 water systems that are totally or partially within the basin limits. Each water system consists of one or more villages from Baalbeck and Hermel regions, as seen in Figure 34.

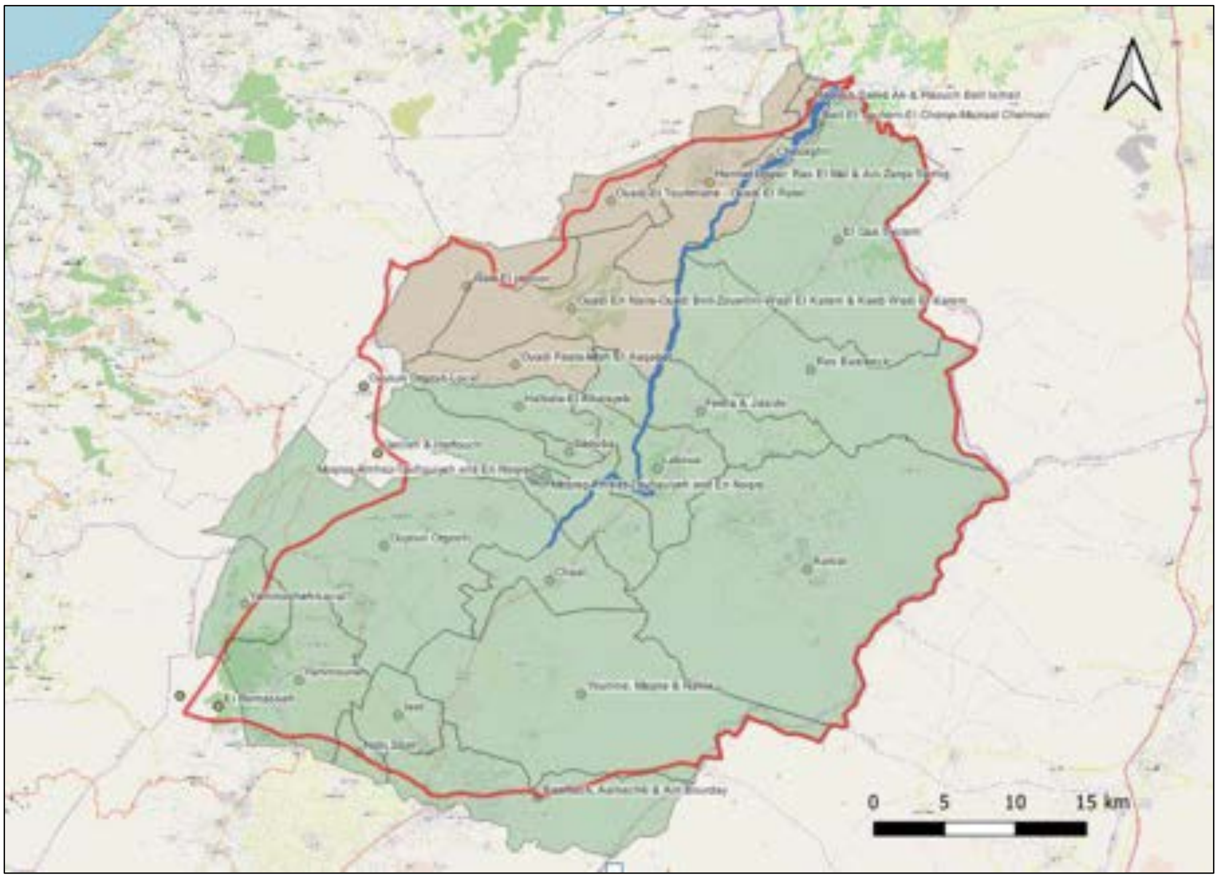

Figure 34 Hermel (brown) and Baalbek (green) districts within ARB (red)

5.1.3 Water Demand

Domestic water demand has been included in the model, following the water systems criteria. Additionally, irrigation water demand has been incorporated through irrigation nodes. These water demand nodes, will be later joint to their respective sources through transmission links.

5.1.3.1 Domestic water demand

Within the barycenter of each water system area, a single node was input containing the sum of the domestic water demand for the diverse villages that are part of this system. Figure 35 shows the 25 water systems which were labelled in a standardized way to aid to a later visualization of results. This labelling can be found in Table 26. In terms of the water demand, formulas and populations were followed as described in section 2.5.

Figure 35 WEAP labeled water distribution systems within ARB

Table 26 WEAP ID for water distribution systems

ID	Water System Name	ID	Water System Name
WS01 LABO	Laboueh	WS14 RABA	Ras Baalbek
WS02 EQAA	El Qaa system	WS15 SBOU	Sbouba
WS03 NASB	Nabi Sbat	WS16 YAML	Yammouneh-Local
WS04 OUOR	Ouyoun Orgosh	WS17 HAKH	Halbata-El Kharayeb
WS05 YAMM	Yammouneh	WS18 HERM	Hermel Upper, Ras El Mal & Ain Zarqa Spring
WS06 YOMN	Younine, Maqne & Nahle	WS19 OUAD	Ouadi En Naira-Ouadi Bnit-Zoueitini-Wadi El Karem & Kaeb Wadi El Karem
WS07 AARS	Aarsal		
WS08 BAAL	Baalbek, Aamechki & Ain Bourday	WS20 FAMR	Ouadi Faara-Mrah El Aaqabet
WS09 CHAA	Chaat	WS21 CHOU	Chouaghir
WS10 FEJD	Fekha & Jdaide	WS22 HAOU	Haouch Saeid Ali & Haouch Beit Ismail
WS11 HARB	Harbata	WS23 JBEB	Jbeb El Homor
WS12 MATN	Moqraq-Amhaz-Toufiquiyeh & En Noqra	WS24 TORA	Ouadi Et Tourkmane - Ouadi El Ratel
WS13 IAAT	Iaat	WS25 BETO	Beit Et Tochem-El Charqe-Mazraat Chelman

Considering that this model will be later used to include different scenario explorations, the urban demand by water system was disaggregated as much as possible by the use of Key Assumptions. This will later provide more flexibility to change these variables and analyze their impact. Some considerations to be noticed:

- Urban and rural population were introduced for each node in a disaggregated manner.
- Domestic and Non-Domestic consumption were included as Key Assumptions.
- Physical losses were included as a Key Assumption implemented within the transmission links between supply and demand. Theoretically, the losses are not part of the demand but is an issue of the network that connects supply with demand. These networks are symbolized as transmission links.
- Urban and Rural Growth Rate were included as Key Assumptions separately to be used for computation of future populations following inbuilt formulae that matches the Updated NWSS 2020 exponential proposition.

5.1.3.2 Irrigation water demand

An irrigation node for each irrigation zone has been introduced to take into consideration the irrigation demand as seen in Section 2.6.5. For each one of these nodes, the irrigated area was introduced to obtain the water demand for the sector and related to an average water demand per hectare that amounts to 8700 m^3/ha/year. This value was introduced as a Key Assumption to be used for all of the nodes, along with a typical monthly distribution of this annual demand.

5.1.4 Water Supply

Within this model, three different types of water sources can be identified: Springs, Groundwater Abstractions and River Water Intakes. The latter one is not a current source but could be studied within the scenario development as an option.

5.1.4.1 Springs

As described in section 2.5, 10 springs have been included within the model. A standardized label was input as well following the identification in Table 27:

Table 27 WEAP ID for Springs

Code	Spring Name	Code	Spring Name
SP01 LABO	Laboueh	SP06 DARD	Dardara
SP02 YAMM	Yammouneh Dar Al Ouassaa	SP07 ELJA	El Jaouz
SP03 CHAG	Chaghour	SP08 ELFE	El Fekha
SP04 LOUJ	Loujouj	SP09 AEZA	Ain Ez Zarka
SP05 AKAW	Ain Kawkab	SP10 REMA	Ras el Mal

Spring elements have been introduced as a node of “Other Supply” as it does not fall into the category of “Groundwater node, Reservoir or Catchment”. Within WEAP, this type of nodes is limited within their functionality for which a modelling intervention had to be implemented.

This intervention consisted of adding to each spring a river element which will complete the required functionality. As an example, this arrangement can be seen in Figure 36 the spring Yammouneh Dar AL Ouassaa (SP02 YAMM) which is a source for the Yammouneh water system (WS05 YAMM). Each one of these springs has a similar arrangement. For each one of these, the corresponding discharge has been entered in m^3/s.

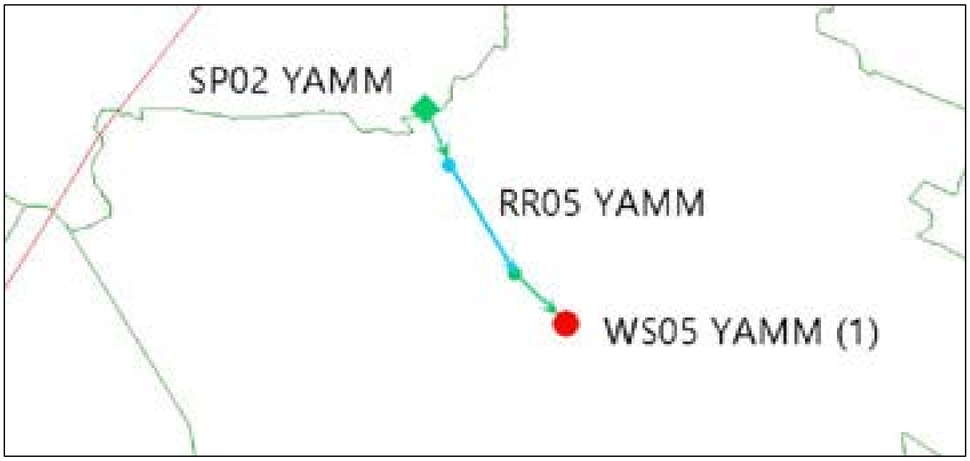

Figure 36 Arrangement for spring sources in WEAP

5.1.4.2 Groundwater Abstraction

Two main aquifer systems are being tapped by the wells in the area. These aquifers are the Neogene-Quaternary (ncg) and the Sannine Maameltein (C4-C5). Their characteristics are summarized in Table 28. It is important to mention that storage capacity and initial storage values are a gross estimation and could differ significantly. Only two aquifer formations were represented since the public wells present in the area are tapping only these formations. These two formations have been subdivided into a total of seven aquifer zones to account for different recharge rates in accordance with MODFLOW calibration results for the groundwater model of the region described in section 4.

Table 28 Characteristics of the aquifer systems

Symbol	Formation Name	Public Wells in service	Outcrop Area (km^2)	GW Recharge (% of Rainfall)	Storage Capacity (Bm^3)	Initial Storage (%)
Q_L	Neogene-Quaternary	5	302.2	42	24.5	81
Q_EL	Neogene-Quaternary	4	353	33	28.6	81
C4W_M	Sannine-Maameltein	16	269.2	82	46.8	53
C4W_L	Sannine-Maameltein	20	127.2	85	22.1	53
C4W_H	Sannine-Maameltein	3	237.7	77	41.3	53
C4E_L	Sannine-Maameltein	16	301.4	77	52.4	53
C4E_EL	Sannine-Maameltein	16	101.1	75	17.6	53

Within the watershed, these systems are tapped by a total of 80 public wells to supply domestic water (71 of them tap the Sannine-Maameltein formation) (Table 5) and a large number of private wells to supply irrigation. The location of the public wells can be seen in the following Figure and the list of names in Table 29.

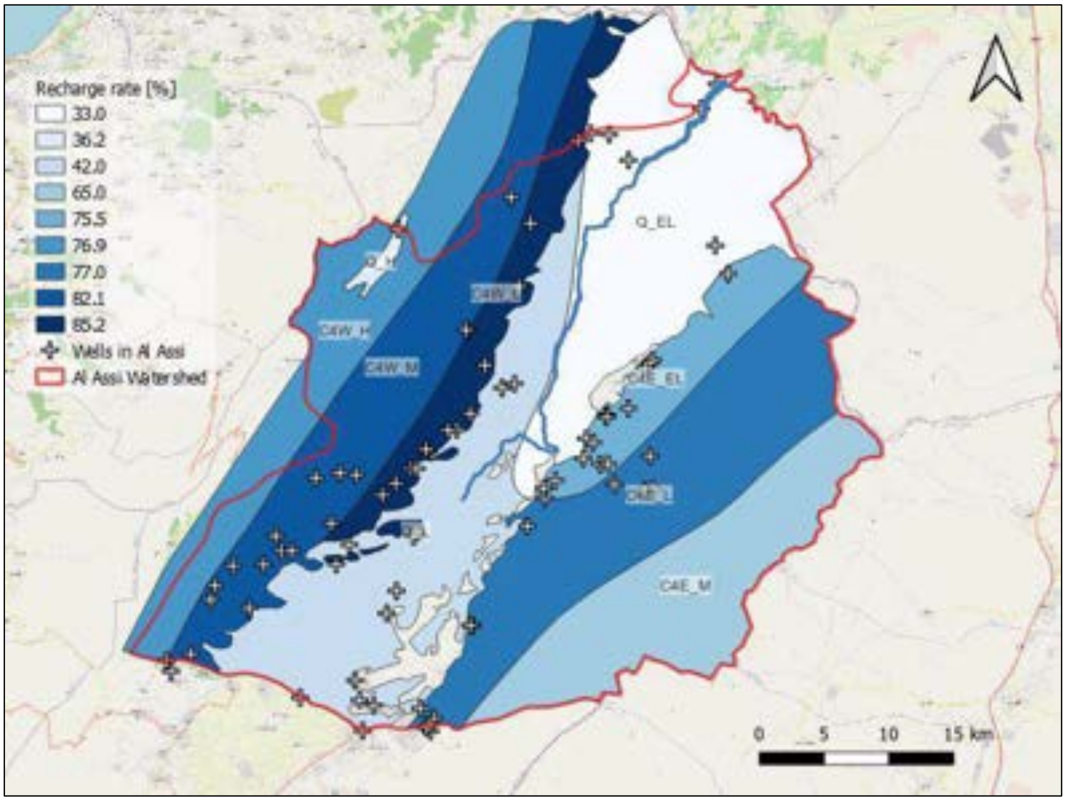

Figure 37 Recharge zones and position of wells

In order to take into account all of these parameters, it was decided to include a groundwater node per aquifer per water distribution system. These groundwater nodes will have pondered values of recharge and storage according to the size of the water system and the recharge zones in which it is located. This type of representation is based on the assumption that the bigger the water system is, the larger the demand and therefore the regional groundwater abstraction. This assumption had to be made due to the challenges imposed by a karstic formation when it comes to establishing groundwater capture zones.

Groundwater abstraction nodes were included in WEAP, using transmission links to represent the flow going to the respective water systems. As it was mentioned in section0, part of the abstracted water is used for supplying the villages that fall within the area delimited by ARB (inner villages), while another part of the abstraction supplies the villages falling outside the area of ARB (outer villages) that correspond to the same water system.

To represent these villages that belong to the same water system but fall outside the watershed area, external demand nodes were added. From the wells, two separate transmission links represent the water transfer from the abstraction to the inner and outer villages, respectively.

This representation can be seen as an example in Figure 38, where the red line symbolizes the northern limit of the Al Assi watershed. WS23 JBEB represents the demand of the inner villages, while EX23 JBEB the outer ones for Jbeb El Homor water system. It can be seen that groundwater node GW C4W_H, which relates to all the wells that are tapping that recharge zone of that precise aquifer, has two transmission links supplying the inner and outer villages respectively, considering the aggregated diverted flow rates presented in section0. ***These transmission links aggregate all the wells that are supplying Jbeb El Homor and tapping the mentioned aquifer.***

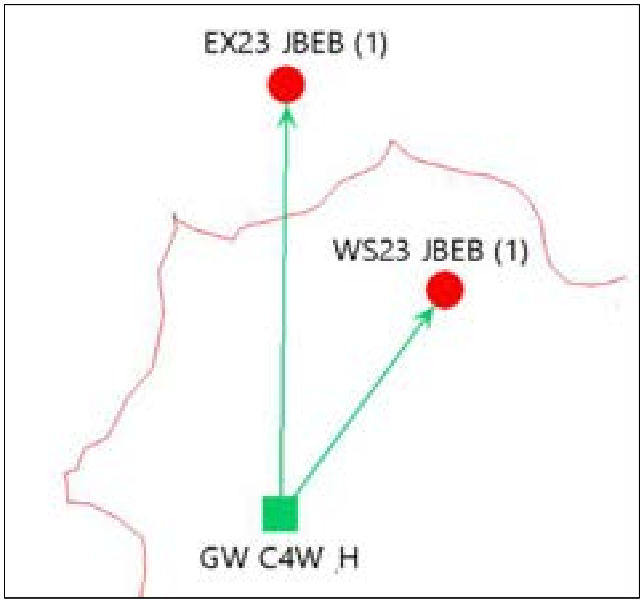

Figure 38 Groundwater configuration in WEAP

Table 29 List of public wells and recharge zones

Well Name	Zone	Well Name	Zone	Well Name	Zone
Zabboud	Q_L	Nabha	C4W_L	Aarsal New Well (IOCC)	C4E_L
Haouch Tell Safiye	Q_L	Nabha	C4W_L	Aarsal Wadi Soueid	C4E_L
Baalbek Sharawneh	Q_L	Qarha	C4W_L	Baalbek New Dar Well	C4E_L
Iaat 1	Q_L	Qarha (New BWE)	C4W_L	Baalbek Maslakh	C4E_L
El Kharayeb	Q_L	Chaat New	C4W_L	Baalbek No 10	C4E_L
El Qaa Old	Q_EL	Chaat Old	C4W_L	Baalbek No 12	C4E_L
Chouaghir	Q_EL	Harbata Baalbek New	C4W_L	Baalbek No 9	C4E_L
Haouch Saeid Ali 1	Q_EL	Harbata Baalbek Old	C4W_L	Loujouj Well, Baalbek	C4E_L
Haouch Saeid Ali 2	Q_EL	Sbouba	C4W_L	Rasm Al Hadath	C4E_L
Barka	C4W_M	Halbata	C4W_L	Iaat 2	C4E_L
Bechouat	C4W_M	Hermel Upper 1	C4W_L	Ain 1	C4E_EL
Beit Kozah	C4W_M	Hermel Upper 2	C4W_L	Ain 2	C4E_EL
Bsailet	C4W_M	Mansoura-Hermel	C4W_L	Ain 3	C4E_EL
Deir Mar Youssef	C4W_M	El Zwaytine	C4W_L	En Nabi Osmane	C4E_EL
El Qeddam	C4W_M	Ouadi En Naira	C4W_L	En Nabi Osmane New	C4E_EL
Ram	C4W_M	Harfouch	C4W_L	Laboueh	C4E_EL
Beit Abou Slaybe Well	C4W_M	Klaylet	C4W_L	El Qaa New	C4E_EL
Btedaii	C4W_M	Qalile - Harfoush well	C4W_L	Aarsal Ain El Shaeb	C4E_EL
Chlifa	C4W_M	Mazraat Et Tout	C4W_H	Aarsal Wadi El Matlab	C4E_EL
Flewi Well	C4W_M	Mazraet Al-Tout Well	C4W_H	Fekha	C4E_EL
Mazraat Aljamal, Mazraat Salim, Wadi Em Ali Well	C4W_M	Jbeb El Homor	C4W_H	Moqraq New 1	C4E_EL
Yammouneh Dar Al Ouassaa	C4W_M	Maqne 1	C4E_L	Moqraq New 2	C4E_EL
Faara	C4W_M	Maqne 2	C4E_L	N/A	C4E_EL
Ouadi Faara / Mrah-El-Aaqbet	C4W_M	Younine well	C4E_L	Ras Baalbak well	C4E_EL
Ouadi Et Tourkmane	C4W_M	Younine	C4E_L	Ras Baalbek	C4E_EL
Kneisseh	C4W_L	Aarsal BH9 (ICRC)	C4E_L	Ras Baalbek_Municipality	C4E_EL
Kneisseh 2	C4W_L	Aarsal High School	C4E_L		

The corresponding maximum flow rates diverted abstracted to supply the inner and outer villages of each water system were added into the transmission links as maximum flow volumes, including as well a 33% loss rate, to account for leakages in the distribution. Following the Updated NWSS 2020, the daily demand amounts to 150 l/cap/day while losses are estimated in 50 l/cap/day making them a 33% of the demand, although current situation suggests a 50% loss.

Additionally, in order to be able to estimate the recharge, an average precipitation value was computed for each month from the available rainfall records. These records are described in the next section.

5.1.4.3 River Water Intakes

As mentioned, currently there are no river water intakes to be considered as a supply for the upper-mentioned water systems. Nevertheless, a hydrological modelling was performed to characterize the availability and variability of the resource.

5.1.4.3.1 Basic hydro-meteorological data and approach

The attainable precision and reach of a hydrological model rely on the available data that serves as its foundation. In this case, the determining factors were the availability of data from both hydrometry and pluviometry stations, as shown in Figure 39 :

- Pluviometry from Deir el Ahmar station, covering from Jan-2000 to Dec-2017 with monthly rainfall data as well as other parameters related to temperature and humidity with some small gaps in measurements.
- Pluviometry from Hermel station, covering from Jun-2006 to May-2017 with monthly rainfall data as well as other parameters related to temperature, humidity, wind speed and direction. Small gaps in measurements are found as well.
- Hydrometric measurements in Hermel hydrometric station, covering from Sep-2000 to Aug-2013 and from Sep-16 to Aug-18 with monthly average discharge.

Taking this into consideration, an upslope area was calculated upstream the hydrometric station to define the draining sub-catchment from which rainfall generates the discharge. Figure 40 shows the representation within WEAP of such catchment and the location of the hydrometric station along Assi river.

As a general approach, it was decided to model the catchment using a Rainfall-Runoff simplified coefficient method which would allow a gross calibration and sufficient precision. As an advantage, the simplicity of the method avoids the need of estimating the unknown parameters that are required for more complex methods like the soil-moisture one for example. The time period was set to be in a calendar year basis, starting from **Jan-2007 until Dec-2012** to use as much continuous hydrometric measurements as possible in the calibration and a separate WEAP model area was created just to focus on calibration of parameters.

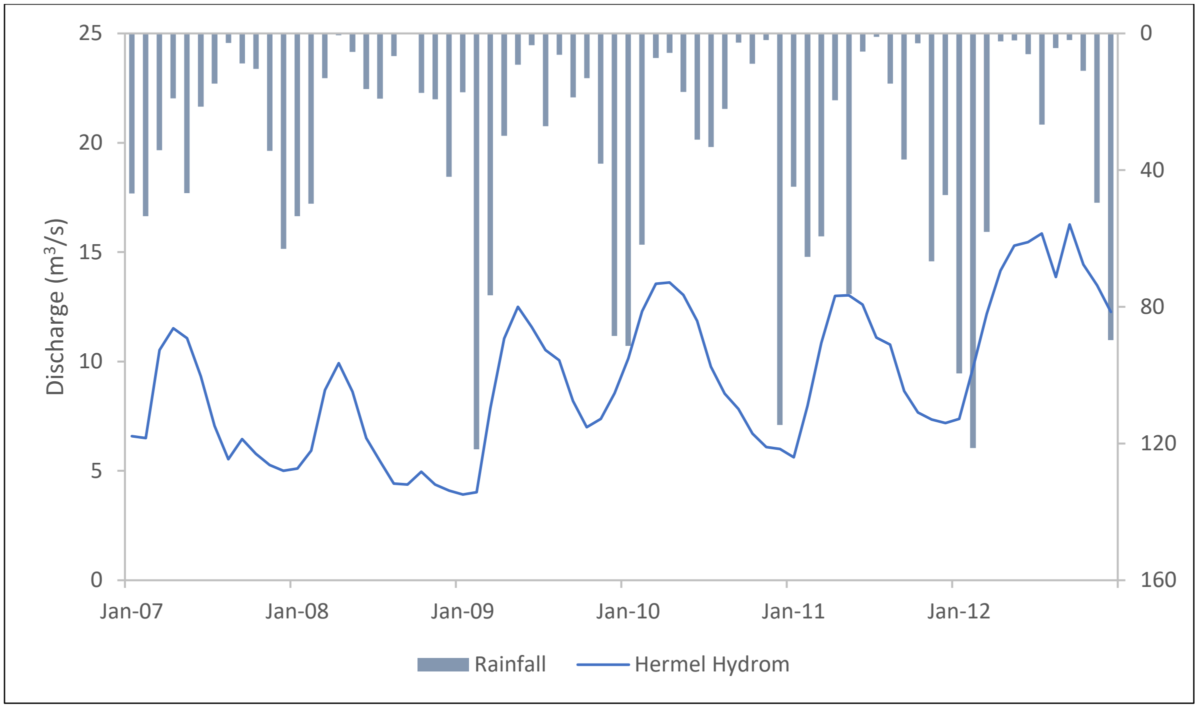

Figure 39 Al Assi rainfall vs discharge

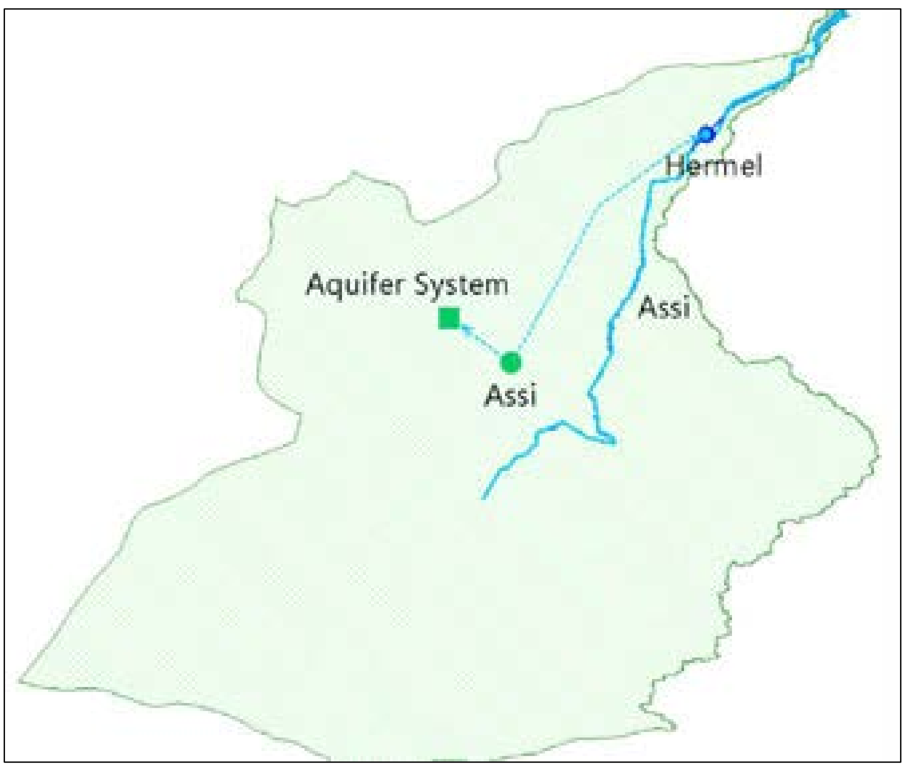

Figure 40 WEAP representation of Assi sub-catchment for hydrological modeling

Other required parameters for the simplified coefficient method include Reference Evapotranspiration, Runoff-Groundwater split, and Land Use data. The latter one, relates to Area, Crop coefficient (Kc) and Effective Precipitation.

Reference Evapotranspiration (RET)

Reference Evapotranspiration was obtained from WaPOR (FAO) datasets on a monthly basis from 2009. The information is available on a continental scale with a resolution close to 20 km per pixel. In the case of Al Assi sub-basin, a spatial average of RET shapefiles was computed. Figure 41 shows the averaged values used as an input in WEAP calculations.

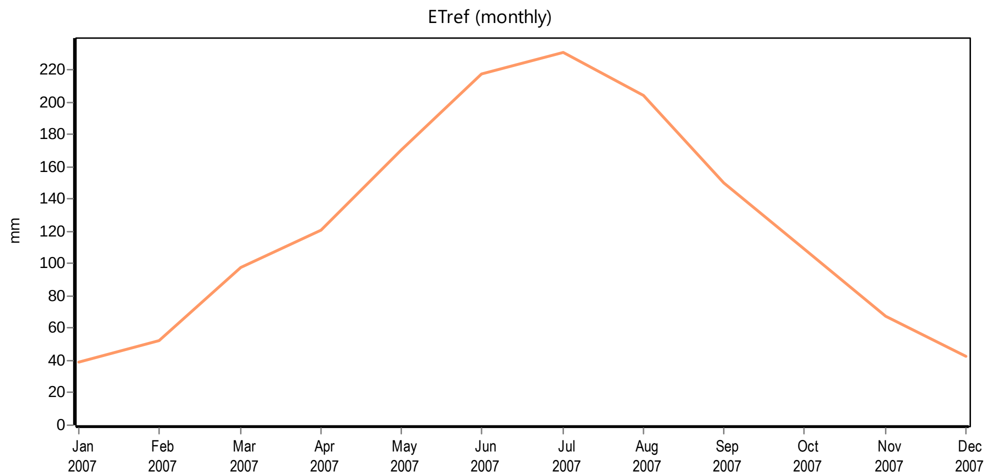

Figure 41 Monthly average values of RET used in WEAP

Land Use area and Crop Coefficient

The Land Use Classification was obtained from CNRS and corresponds to the year 2017 as a shapefile covering the area with different levels of aggregation. The area of interest comprising the sub-basin upstream the Al Assi hydrometric station, was reclassified to account only for the land uses with significant areas, as seen in the following table:

Table 30 LandUse class by area for Assi subbasin

LandUse Type	Area (km^2)	Percentage	Kc
Wooded Lands	412	34%	0.8
Unproductive Areas	382	32%	0.3
Agricultural Areas	328	27%	Variable
Other	84	7%	0.4
Total	**1206**	**100%**	

Crop coefficients (KCs) were assigned from international experience with a deeper analysis for the agricultural areas, which account to a 27% of the subbasin area. A monthly KC value was assigned to the main types of crops to be found within this 27% of agricultural area. These values change throughout the year due to the cycle of crops. With this in mind, a weighted average was computed considering the area covered by these.

Effective Precipitation

Within WEAP's rainfall-runoff simplified coefficient method, Effective Precipitation [%] is defined as the percentage of precipitation available for evapotranspiration, where the remainder goes either directly to groundwater or to runoff (see Figure 40). This is a key term as the calibration of the model relies on the component diverted to runoff.

To have a magnitude of the effective precipitation it is important to take into account the actual evapotranspiration occurring in the area. To do this in a consistent way, WAPOR datasets for The actual EvapoTranspiration and Interception (ETIa) were obtained for the same period.

In this case, these datasets have a 100 m/pixel resolution for Lebanon on a monthly basis. Each one of the raster files representing one month of estimated ETIa was processed in GIS to obtained a weighted average of the ETIa for the area of interest from Jan-09 to Dec-13. As an example, Figure 42 shows the distribution of ETIa within the sub-basin for October.

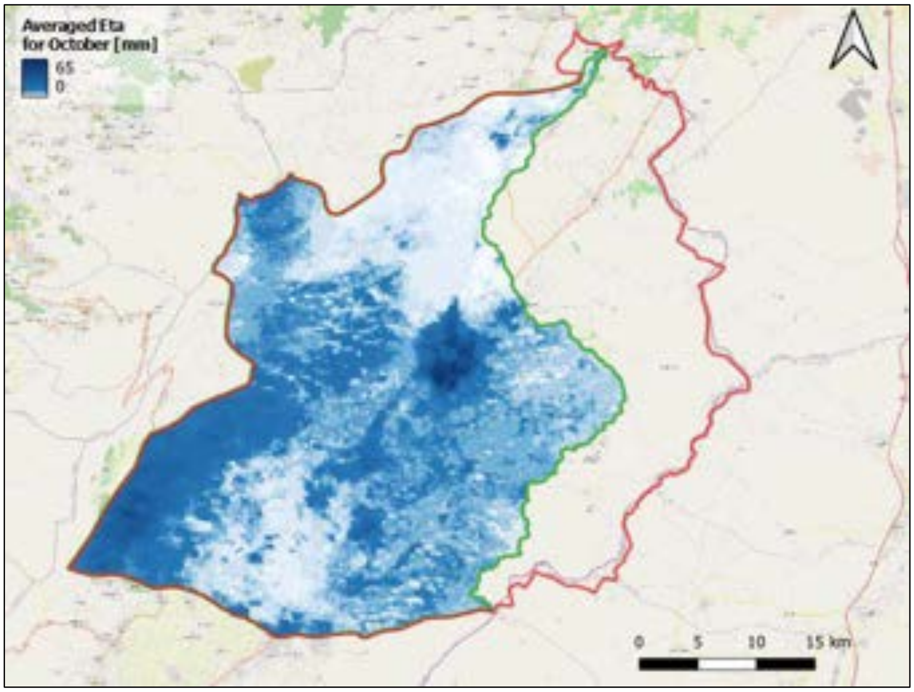

Figure 42 Example of ETIa processed from WAPOR

It is important to recall at this point that WEAP model's time period was set to be from Jan-2007 until Dec-2012, matching the pluviometric and hydrometric data correlation period. WAPOR datasets instead, start in 2009 on a calendar year basis.

Using average monthly values, a rough initial effective precipitation was estimated by comparing the averagely expected ETIa with the recorded rainfall for that month. Since the sources of data are different, rainfall coming from the pluviometric stations and ETIa coming from remote sensing computations, a mismatch in certain months is to be expected when comparing month to month. In this case, since only averaged values were used, this mismatch is greater but allows an extrapolation when projecting values for future scenarios.

An iterative calibration was performed taking into account the gross values of ETIa included in WAPOR datasets and the resulting values calculated in WEAP when the upper mentioned parameters are used (which take into account indirectly the WAPOR values). Resulting ETIa from WEAP calculations was calibrated to be in a similar range to the values derived from WAPOR by adjusting slightly averaged monthly effective precipitation values.

Runoff-Groundwater Split

Taking into account that the remainder of the effective precipitation will be either infiltrating or generating the runoff that turns into river flow, the last parameter to set and calibrate is the Runoff-Groundwater Split. A first iteration was set to be that a 5% of this remainder goes into surface runoff and a 95% to infiltration. However, after many calibration runs, the final split was set for each month as described in the following Table 31.

Table 31 Runoff-Groundwater Split [%]

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Runoff	5.0	6.1	1.5	0.8	0.7	1.7	9.1	19.5	18.4	0.0	0.0	0.0
Groundwater	95.0	93.9	98.5	99.2	99.3	98.3	90.9	80.5	81.6	100	100	100

It is important to notice that given the simplicity of the model, these values are over-fitted for this precise method and subbasin, influenced as well by the way in which data was provided as an input, its consistency and scarcity. An extrapolation to other areas is not possible and the physical sense of the groundwater/runoff split is not to be evaluated directly from this calibration results as it is a loose representation of the hydrological cycle for a limited period of time. Results of the model will be shown in following section.

5.2 Results exploration

This section will explore the main results obtained for the baseline modelling of Assi watershed.

5.2.1 Results for Hydrological model

Following the iterative calibration process described in section 5.1.4.3 River Water Intakes, results for runoff generation were compared against streamflow measurements from Hermel hydrometric station (see Figure 40).

Since the objective of the model is to assess water resources, the main results of interest are the monthly discharged averaged throughout the years. Figure 43 and Table 32 show the comparison of the resulting hydrograph from WEAP simulation, as opposed to the actual measurements in Hermel hydrometric station.

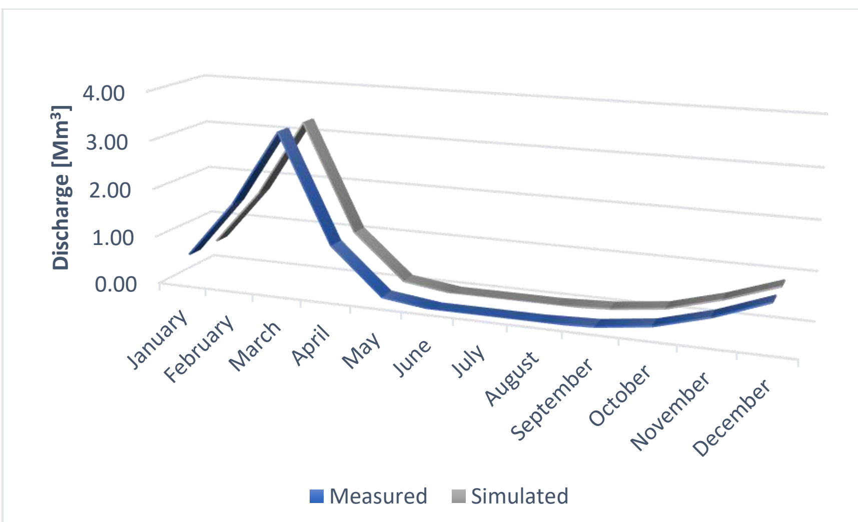

Figure 43 Hydrograph comparison of discharge volume in million cubic meters

Table 32 Hydrograph comparison of discharge volume in million cubic meters

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Measured	0.58	1.76	3.3	1.08	0.13	0	0	0	0.04	0.18	0.48	0.89
Simulated	0.58	1.74	3.29	1.07	0.14	0	0	0	0.05	0.18	0.48	0.86

Figure 44 shows the monthly calculations for the given time period. It is possible to see that the obtained values are within the order of magnitude, however there is a certain dispersion when looking at some specific months. For the purposes of this model, these types of results are acceptable.

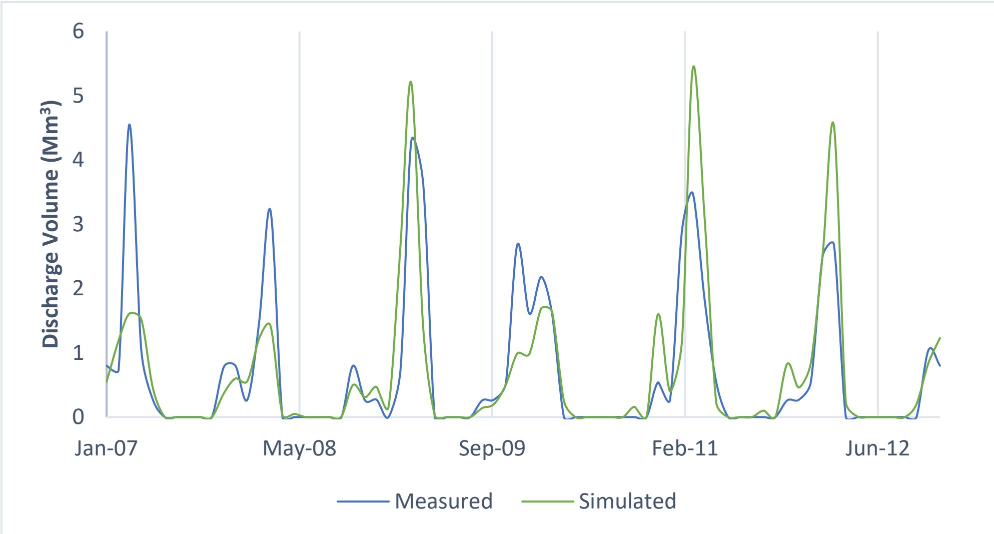

Figure 44 Monthly Hydrograph comparison in million cubic meters

Table 33 Statistical computation of hydrological model error

Param	Time Period	NSE	KGE	NRMSE	PBIAS	RSR	LNS	RMSE [MCM]	MAE [MCM]	r	r^2
Value	2007-12	0.57	0.78	106%	-0.22%	0.65	0.55	0.74	0.38	0.79	0.62

5.2.2 Results of the node-based water management model

Regarding the node-based model, many different outputs can be explored from WEAP. The most relevant in this study is the interaction between supply and water demand. Appendix D will complete this summary with a tabulated presentation of modelling results that allow a deeper analysis of certain components if needed. Figure 45 presents the WEAP model scheme, including all nodes, links and rivers.

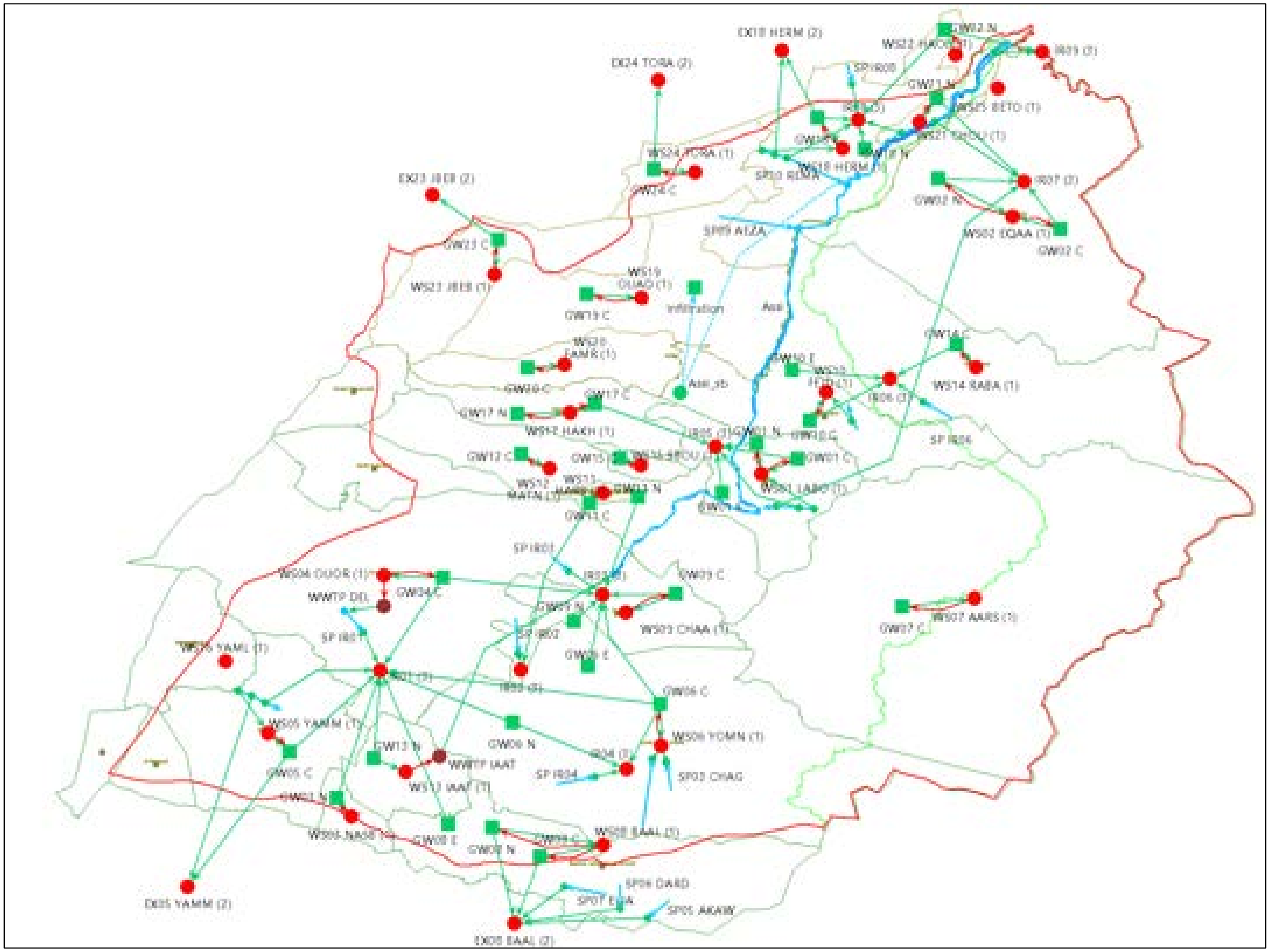

Figure 45 WEAP node-based representation for ARB. The red dots represent water demands, the blue lines the rivers, the green squares the groundwater systems and the green losanges the springs.

5.2.2.1 Demand coverage for baseline scenario

One of the main outputs is the demand coverage considering the current and projected sources and demands. Figure 46 and Figure 47 show the percentage of the covered domestic water demand for 2020 for the 25 Water Distribution Systems of ARB under 50% and 75% network efficiency.

Only 10 distribution systems are fully covered under 50% network efficiency while the number increases to 18 under 75% network efficiency.

The systems of Yammouneh-local, Chouaghir and Beit el Tochem didn't include any supply infrastructure as per the NWSS either due to lack of data or operating privately. However, their total demand represents less than 1% of ARB total demand.

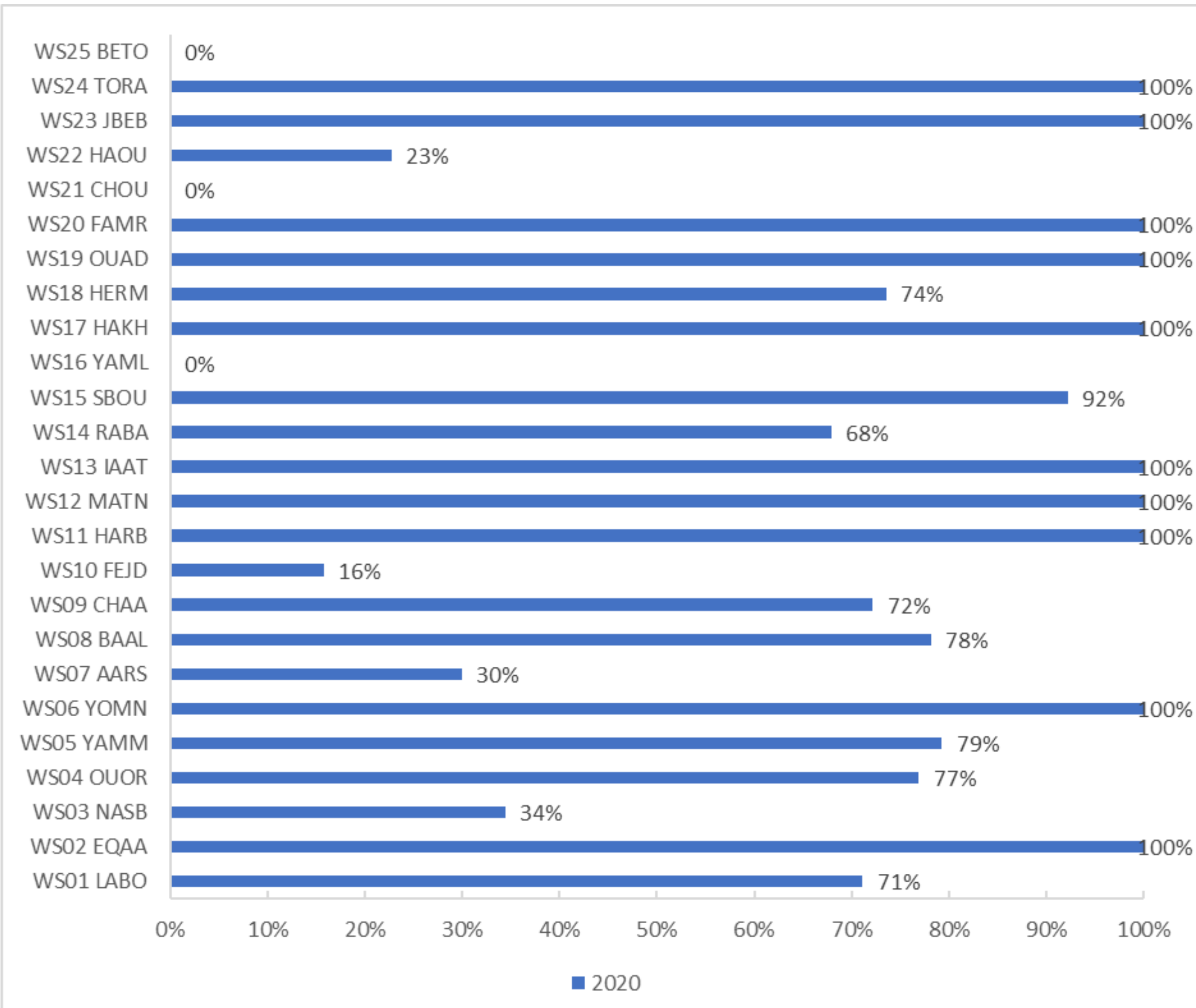

Figure 46 Annual domestic water demand coverage of 2020 in [%] for ARB water distribution systems with 50% network efficiency

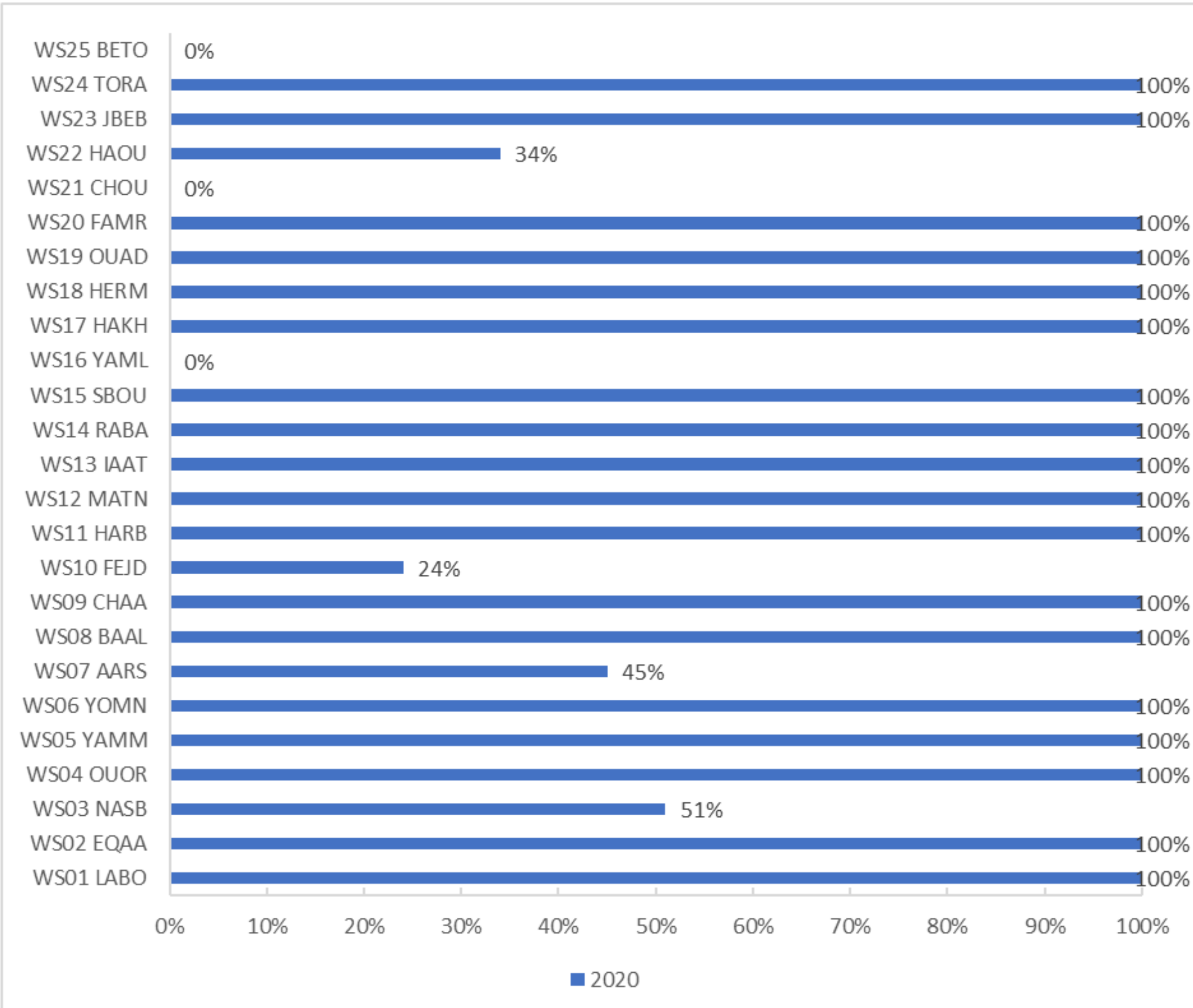

Figure 47 Annual domestic water demand coverage of 2020 in [%] for ARB water distribution systems with 75% network efficiency

In a similar way, it is possible to quantify the domestic unmet demand which arise for all ARB systems to a total of 6.78 Mm^3 for 2020 under 50% network efficiency and to 2.6 Mm^3 under 75% network efficiency, See Appendix D Figure 49.

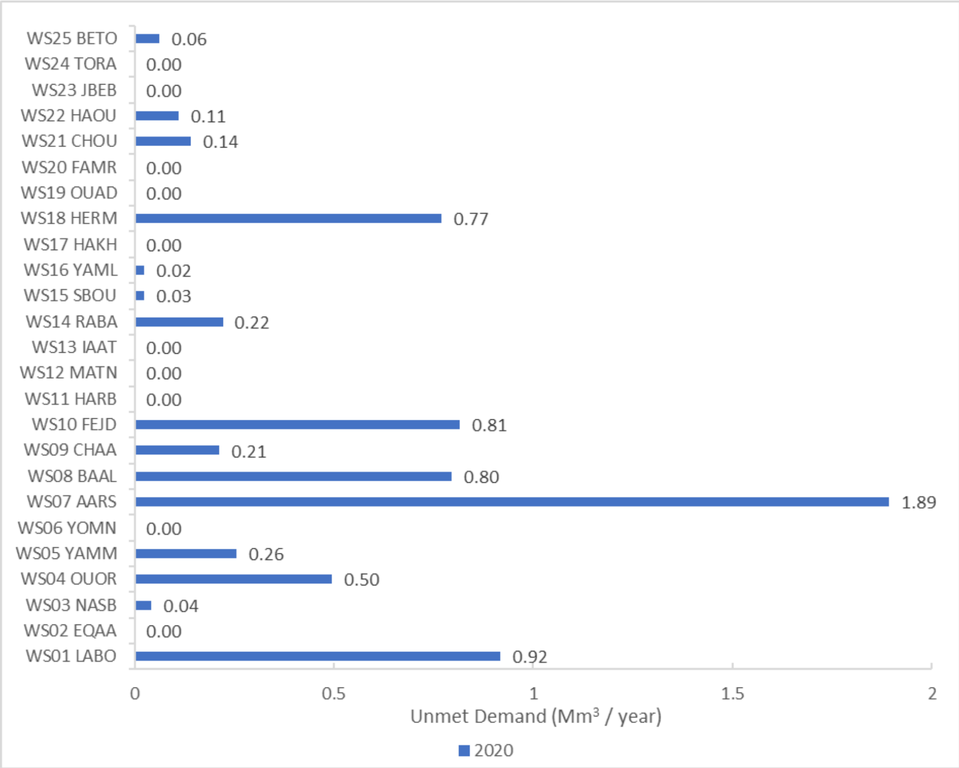

Figure 48 Annual domestic water unmet demand of 2020 in Mm³ for ARB water distribution systems under 50% network efficiency

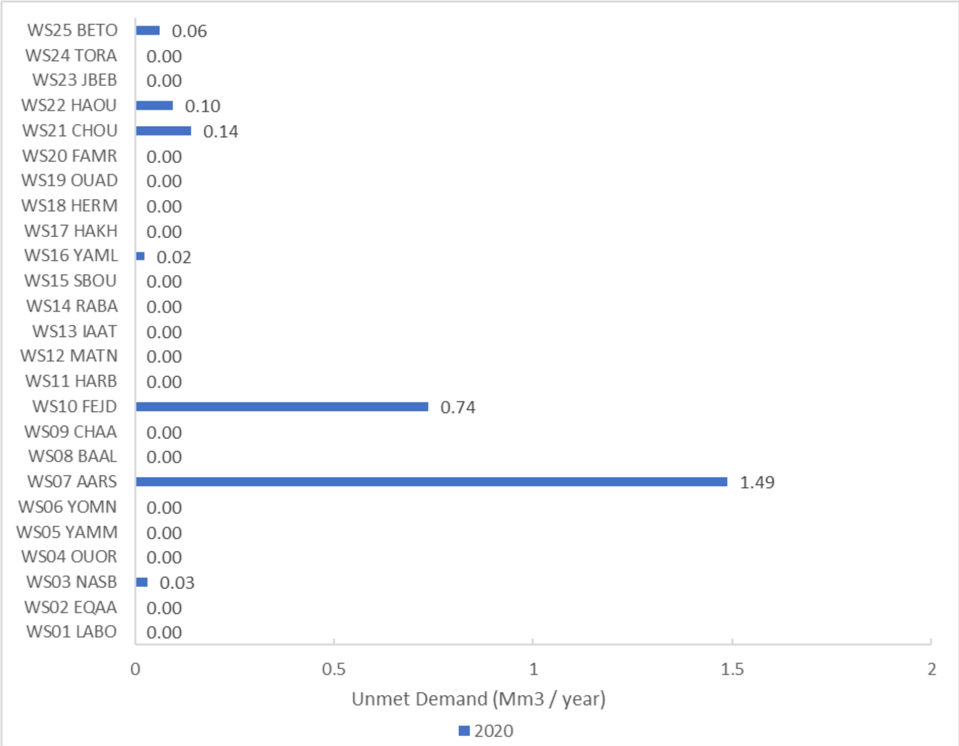

Figure 49 Annual domestic water unmet demand of 2020 in Mm³ for ARB water distribution systems under 75% network efficiency

When it comes to the irrigation water demand, as it was mentioned in the Section Agricultural Considerations, both private wells and springs supply the 9 defined irrigation zones (IR01 to IR09). Within the spring supply, some of them are also diverted for water systems, for which a certain resources competition is present.

The following Table 34 and Figure 50 present the water demands in million cubic meters, taking into account the different areas, crops, agricultural calendar and irrigation needs and the estimated losses.

Table 34 Irrigation zones monthly water demand in Mm³

Irrigation zones	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
IR01	0	0	0.2	2.9	7.0	9.0	12.3	10.3	5.2	2.3	0	0	49.2
IR02	0	0	0.0	0.1	0.3	0.4	0.6	0.5	0.2	0.1	0	0	2.4
IR03	0	0	0.0	0.4	0.9	1.1	1.6	1.3	0.7	0.3	0	0	6.2
IR04	0	0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0	0	0.2
IR05	0	0	0.0	0.7	1.6	2.1	2.8	2.4	1.2	0.5	0	0	11.3
IR06	0	0	0.0	0.1	0.3	0.4	0.6	0.5	0.2	0.1	0	0	2.4
IR07	0	0	0.1	1.8	4.2	5.4	7.4	6.2	3.1	1.4	0	0	29.6
IR08	0	0	0.0	0.2	0.4	0.5	0.7	0.6	0.3	0.1	0	0	2.7
IR09	0	0	0.0	0.1	0.1	0.2	0.2	0.2	0.1	0.0	0	0	0.9
Total	0	0	0.4	6.3	15.0	19.2	26.3	21.9	11.0	4.8	0	0	104.8

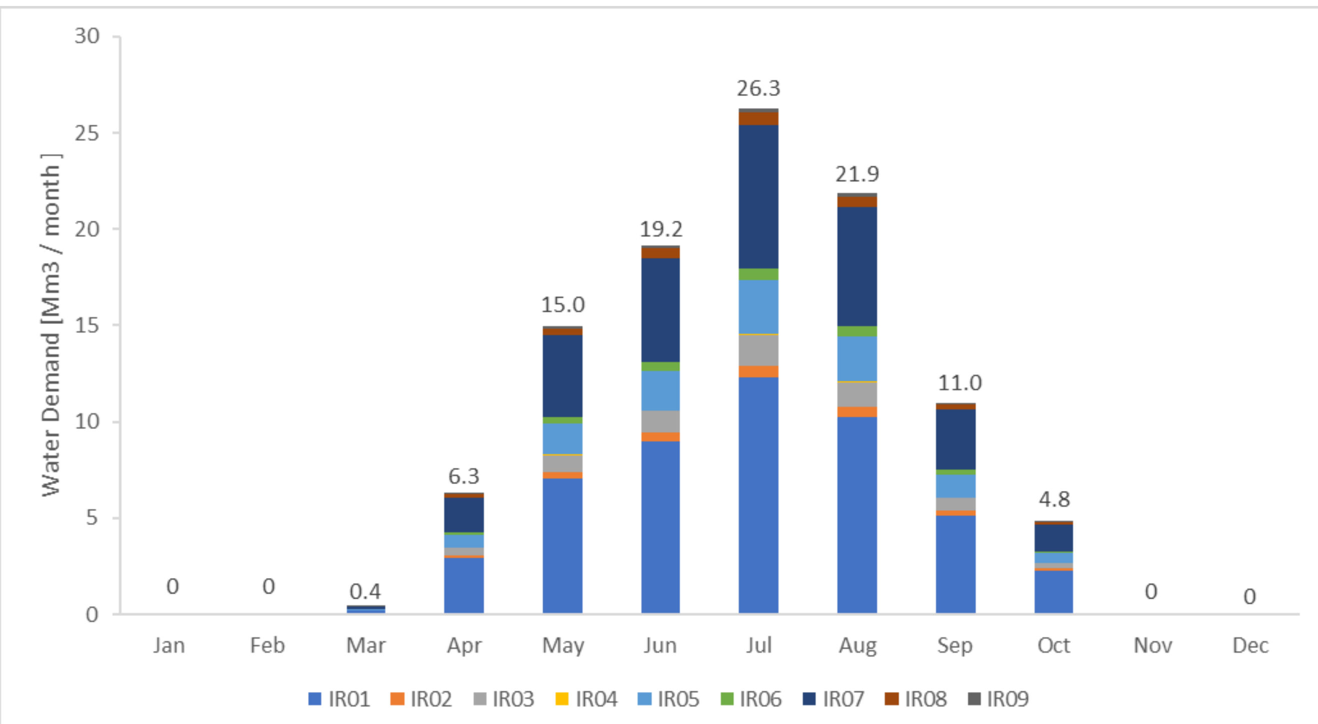

Figure 50 Monthly irrigation water demand

Taking into account that the water demand is variable throughout the year, the resulting coverage shows a correlated variation, showing in general a reduction to up to 75% of coverage during the month where irrigation is most needed, namely July, as seen in Table 35.

Table 35 Monthly coverage of irrigation water demand in %

Irrigation zones	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IR01	100	100	100	100	100	100	75	90	100	100	100	100
IR02	100	100	100	100	100	100	75	90	100	100	100	100
IR03	100	100	100	100	100	100	75	90	100	100	100	100
IR04	100	100	100	100	100	100	75	90	100	100	100	100
IR05	100	100	100	100	100	85	64	77	100	100	100	100
IR06	100	100	100	100	100	100	75	90	100	100	100	100
IR07	100	100	100	100	100	100	75	90	100	100	100	100
IR08	100	100	100	100	100	100	75	90	100	100	100	100
IR09	100	100	100	100	100	100	75	90	100	100	100	100

Due to the irrigation schedule, it was observed that the month of August is also a demanding month in terms of water resources. In the case of the irrigation zone IR05, we can observe that the estimated coverage is more affected, since the supply coming from Laboueh spring enters in competition with the domestic water demand required by Laboueh distribution system WS01 from the same spring. In general, the model prioritises domestic water supply over irrigation which results in a lower coverage.

In terms of irrigation, it is important to note that many zones have access to springs or river abstractions that have not been measured. Consequently, the maximum supply of these sources is estimated based on the assumption that they can achieve a 75% coverage in July for each irrigation zone. However, in the case of IR05, the supply only relies on private wells and Laboueh spring, for which the maximum flow is known. The abstraction rates of the private wells are based on estimations and measurements from 2005, which introduces uncertainty regarding the accuracy of the values included in the models.

Considering that the month of July is the most severe in terms of irrigation water demand, Table 36 shows the split between groundwater and surface water allocation for that month.

Table 36 Surface and Groundwater allocation for July

Irrigation zone	Source	Flow (m^3/d)	Flow (x1000 m^3/month)	Ratio (%)
IR01	Private wells	34187	1060	7%
	Yammouneh	64806	2009	14%
	Local springs	360000	11160	78%
IR02	Private wells	29	1	0%
	Local springs	22097	685	100%
IR03	Private wells	17626	546	30%
	Local springs	40387	1252	70%
IR04	Private wells	922	29	42%
	Local springs	1290	40	58%
IR05	Private wells	13681	424	15%
	Laboueh	76265	2364	85%
IR06	Private wells	2448	76	11%
	Ras Baalback & Fekha	19677	610	89%
IR07	Private wells	31537	978	11%
	Assi River	244839	7590	89%
	Laboueh	32	1	0%
IR08	Private wells	16877	523	68%
	Ras El Mal	2645	82	11%
	Assi River	2645	82	11%
	Bdita springs	2645	82	11%
IR09	Private wells	547	17	7%
	Assi River	7710	239	93%
	TOTAL	962893	29850	

To take into account the uncertainty regarding the number and yield of private well, an alternative scenario has been studied where the number and yield of private wells was doubled, and the spring supply was recalculated to reach once again the minimum 75% coverage for July where possible.

Results presented in Table 37 show a significant reduction over the estimation of the local springs in IR01, IR03 and the abstractions from Assi to supply IR07. IR08 shows that the flow from private wells is covering its needs without any contribution from surface water. Moreover, the coverage for IR05, which was 64% for the original scenario, reaches 74% when well supply is doubled.

Table 37 Surface and Groundwater allocation for July with doubled private wells

Irrigation zone	Source	Flow (m^3/d)	Flow (x1000 m^3/month)	Ratio (%)
IR01	Private wells	68374	2120	15%
	Yammouneh	64806	2009	14%
	Local springs	325000	10075	71%
IR02	Private wells	58	2	0%
	Local springs	22065	684	100%
IR03	Private wells	35252	1093	61%
	Local springs	22774	706	39%
IR04	Private wells	1844	57	84%
	Local springs	355	11	16%
IR05	Private wells	27362	848	26%
	Laboueh	76265	2364	74%
IR06	Private wells	4896	152	22%
	Ras Baalback & Fekha	17226	534	78%
IR07	Private wells	63074	1955	23%
	Assi River	213323	6613	77%
	Laboueh	-	-	0%
IR08	Private wells	33754	1046	100%
	Ras El Mal	-	-	0%
	Assi River	-	-	0%
	Bdita springs	-	-	0%
IR09	Private wells	1094	34	13%
	Assi River	7161	222	87%
	TOTAL	962893	30525	

6 Al Assi River Basin Management Assessment

During the first phase of this study, the water and environmental resources of ARB were quantitively and qualitatively assessed for the baseline period between the years 2000 and 2020.

Previous relevant studies were reviewed, mainly the geological and hydrogeological description, the agricultural situation, the findings of the NWSS on the water balance of the water distribution systems located within Assi i.e. water demand, water supply sources, deficit and excess, etc., and the wastewater situation. The concept design for the training of Assi river related to the flooding of the downstream urban area of Assi was also reviewed. Hydrometeorological data were also collected and analysed. And cartographic data were compiled in a comprehensive GIS database which included the basin boundary, Landuse, geological and hydrogeological maps.

The state of the water resources in ARB has been assessed for the baseline period based on the outputs of a detailed WRMM developed in WEAP21 software. The baseline assessment investigated water availability, water demand, and unmet demand (per sector) in the basin.

Based on the model results for the baseline year 2020, the water demand of 10 water systems is fully covered under 50% network efficiency. Between these water systems El Qaa, Younine, Harbata, Moqraq, Iaat, etc. The water systems which require the most attention are Arsal, Fekha & Jdaide, Haouch Saeid Ali & Haouch Beit Ismail systems as they are less than 35% covered.

The systems of Yammouneh-local, Chouaghir and Beit el Tochem did not include any supply infrastructure as per the NWSS either due to lack of data or operating privately. However, their total demand represents less than 1% of ARB total demand.

The total annual unmet demand is approximately 16,580 m^3/day or 6.8 Mm^3/year, which represents 30% of the total required water supply for ARB. This basically means that, on average, 16 Mm^3/year or 70% of the water needs are covered by the available water resources in Assi.

In the second phase of the project, the WEAP model will be used to simulate future distribution 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 taken into consideration suggestions from the participatory approach and proposed projects from the Updated NWSS 2020.

A baseline and future water balance will be developed, assessed, and translated into policy relevant targets to further support the design corresponding PoM, then propose an action plan in coordination with key stakeholders in the region.

7 References

Al-Hawi Ibrahim, head of the Fish Breeding Center in Anjar, Lebanon, The second periodic meeting of officials and experts of research and technology transfer in the field of fisheries under the title: Research and transfer of fish farming technology, Fish farming and technology transfer in Lebanon (2012).

Atlas Climatique du Liban. (1977). Ministère des Travaux Publics et des Transports, Service Météorologique du Liban avec l'aide de l'Observatoire de Ksara, Beyrouth, Liban.

Bear J (1972) Dynamics of Fluids in Porous Media, American Elsevier

Boyd, C. E. (2019). *Water quality: an introduction*. Springer Nature.

Dagher, L. A., Hassan, J., Kharroubi, S., Jaafar, H., & Kassem, I. I. (2021). Nationwide assessment of water quality in rivers across Lebanon by quantifying fecal indicators densities and profiling antibiotic resistance of Escherichia coli. Antibiotics, 10(7), 883.

David W. Armentrout, USEPA 1977. The Effects of Air Pollution on Water Quality

Doherty J (1994) PEST: Corinda, Australia, Watermark Computing, 122 p

Droubi A (2012) Internal communication. Meeting of the Project IHEID Orontes River basin, Lebanon-Syria. Nov. Bekaa

Dubertret L (1955) Carte géologique du Liban au 1:200,000 avec notice explicative. République Libanaise. Ministère des Travaux Publics, Beyrouth, 74 p

Duran L, Gill L (2021) Modeling spring flow of an Irish karst catchment using MODFLOW-USG with CLN. Journal of Hydrology, 597, 125971

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, Rome, 300(9), D05109.

FAO. 2020. WaPOR V2 quality assessment – Technical Report on the Data Quality of the WaPOR FAO Database version 2. Rome.

FAO and IHE Delft. 2019. WaPOR quality assessment. Technical report on the data quality of the WaPOR FAO database version 1.0. Rome. 134 pp.

Farajallah, N., Daou, Y., & Saoud, I. P. (2014). Environmental Impact of Trout Aquaculture on the Lebanon Portion of the Assi River. World Aquaculture, 19.

Gale SJ (1983) The hydraulics of conduit flow in carbonate aquifers. Journal of Hydrology, v. 70, pp. 309-327

Griffiths, C., Klemick, H., Massey, M., Moore, C., Newbold, S., Simpson, D., & Wheeler, W. (2012). US Environmental Protection Agency valuation of surface water quality improvements. *Review of Environmental Economics and Policy*.

Harbaugh A.W, Banta E.R, Hill M.C, McDonald M.G (2000) MODFLOW-2000, the U.S. Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p

Hespanhol, I., & Prost, A. M. E. (1994). WHO guidelines and national standards for reuse and water quality. *Water Research*, *28*(1), 119-124.

Jaafar, H and King-Okumu, C, Haj-Hassan, M, Abdallah, C, El-Korek, N and Ahmad, F. 2016. Water resources within the Upper Orontes and Litani Basins: a balance, demand and supply analysis amid the Syrian refugees crisis. IIED Working Paper. IIED, London.

"Labour Force and Household Living Conditions Survey 2018-2019 in Baalbek", Central Administration of Statistics, 2020

Lebanon Follow-up Labour Force Survey – January 2022 – Fact Sheet

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020). Environmental and health impacts of air pollution: a review. Frontiers in public health, 14.

McDonald M.G, Harbaugh A.W (1988) A modular three-dimensional finite-difference ground-water flow model, Techniques of Water-Resources Investigations 06-A1, USGS, 576p

MoEW, UNDP (2014) Assessment of Groundwater Resources of Lebanon. Ministry of Energy and Water, Lebanese Republic

Panagopoulos G (2012) Application of MODFLOW for simulating groundwater flow in the Trifilia karst aquifer, Greece. Environmental Earth Sciences, 67(7), 1877-1889

Plassard J (1971) Carte pluviométrique du Liban au 1/200 000. Lebanon: Ministry of Public Works and Transport

Shah N, Nachabe M, Ross M (2007) Extinction Depth and Evapotranspiration from Ground Water under Selected Land Covers. Vol. 45, No. 3—GROUND WATER—May–June 2007 (pages 329–338)

UNDP (United Nations Development Programme) (1970) Liban Etude Des Eaux Souterraines. New York

United States. Environmental Protection Agency. Office of Water Regulations, & Standards. (2013). *Water quality standards handbook*. US Environmental Protection Agency, Office of Water Regulations and Standards.

USBR (United States Bureau of Reclamation) (1957) Water resources investigations, Nahr El Assi Basin, reconnaissance report, Washington DC

UN-ESCWA, UNEP and IDB (United Nations Economic and Social Commission for Western Asia; United Nations Environment Programme et al.) (1996) Water Resources Assessment in the ESCWA Region Using Remote Sensing and GIS Techniques. New York

UN-ESCWA, BGR (United Nations Economic and Social Commission for Western Asia; Bundesanstalt für Geowissenschaften und Rohstoffe) (2013) Inventory of Shared Water Resources in Western Asia. Beirut

USAID (2013) Litani river basin management support program - Groundwater Modeling Within the Upper Litani Basin

Watermark Numerical Computing (2005) Model-Independent Parameter Estimation User Manual: 5th Edition

Yobbi DK (1989) Simulation of steady-state ground water and spring flow in the Upper Floridan aquifer of coastal Citrus and Hernando Counties, Florida (Vol. 88, No. 4036). Department of the Interior, US Geological Survey

Zwahlen F, Bakalowicz M, Gonzalez R, Asaad AH, Saade-Sbeih M, Jaubert R (2016) Groundwater flow in the Orontes River basin and the Syria–Lebanon water sharing agreement (Vol. 23, p. 53). CRC Press

8 Appendix

A.Water quality sampling campaign report

AL ASSI RIVER
WATER QUALITY MONITORING

JANUARY 2023

NDU Team Members
Dr. Jacques Harb/Quality Assurance-Reporting
Dr. Claudette Hajj/Monitoring and Testing
Mr. Elie Lahoud/Sampling

Table of Contents

List of Tables

List of Figures

1 Overview of the followed Monitoring Process in Al Assi River

Notre Dame University of Louaize (NDU) team abided by the EPA (2013) guidelines during the monitoring and testing of the water quality in Al Assi River. The monitoring steps followed by NDU are presented in Figure 1 below.

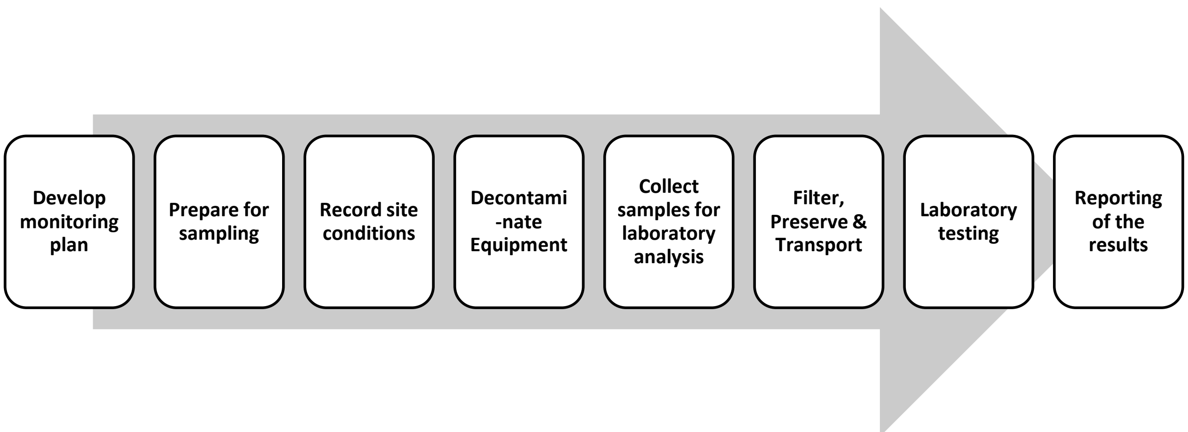

Figure 1 Stages of monitoring Process followed by NDU Team

1.1 Developing the Monitoring Plan

To guarantee that monitoring of Al Assi river basin is relevant, accurate, targeted, and cost-effective, a monitoring plan was developed by Notre Dame University after coordination with BTD. The last documents contained all the details of the actions, responsibilities, and timeframes that enables a delivery that meets the project objectives. Figure 2 shows the elements of the monitoring plan.

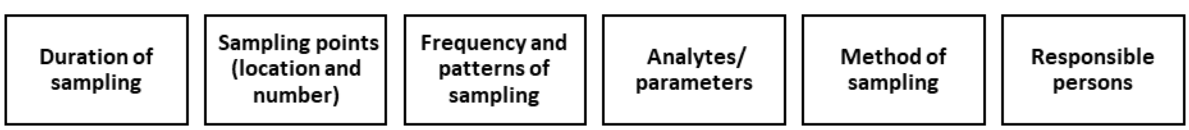

Figure 2 Elements of the Monitoring Plan

To accurately reflect the quality of the water in Al Assi, sampling was planned in a way that reflects water quality during both the dry and the wet seasons. The locations of the samples were chosen by BTD and GVC. The first sampling from Al Assi river took place on 31st of August 2022.

1.1.1 Duration of sampling

For this project, sampling was made over the Dry season from the Al Assi river to show compliance with established criteria. Campaign monitoring is important in our case due to the variability of the conditions in both seasons. Therefore, two visits are to be performed per year to the river. This report describes the general procedure followed in the campaigns to Al Assi.

Sampling in Al Assi can deliver information regarding the variability in the water due to random and systematic influences.

1.1.2 Sampling Locations

The sampling plan to monitor water composition in Al Assi river was prepared in a way to guarantee that samples are collected at sites and times that provide a representative sample, thus providing an accurate description of the overall quality of the water in the river.

Furthermore, sampling sites were located in areas that are safe to access, accessible under all conditions of flow, and well mixed to ensure a homogenous sampling collected is easily identifiable for later sampling.

Permanent sampling locations were chosen by BTD and GVC to ensure that representative samples can be compared over time.

Table 1, Figure 1 and Figure 2 show the coordinates and Name of the points chosen for sampling in Al Assi River.

Table 1 Coordinates and location of the chosen points for sampling

Number	Name	Latitude	Longitude
1	Labwe	34.19738896	36.35235192
2	Rwess	34.19725842	36.35263003
3	Fekeha	34.24174423	36.4067546
4	Al Assi	34.42169489	36.45730323
5	Ras El Mail	34.39036962	36.37131148
6	Bdita	34.39121696	36.37379257
7	Mizen	34.39347664	36.41776117
8	Zar2a	34.35236	36.37377
9	Deffech	34.35358121	36.38239757
10	Deffech Upstream	34.35352	36.38239

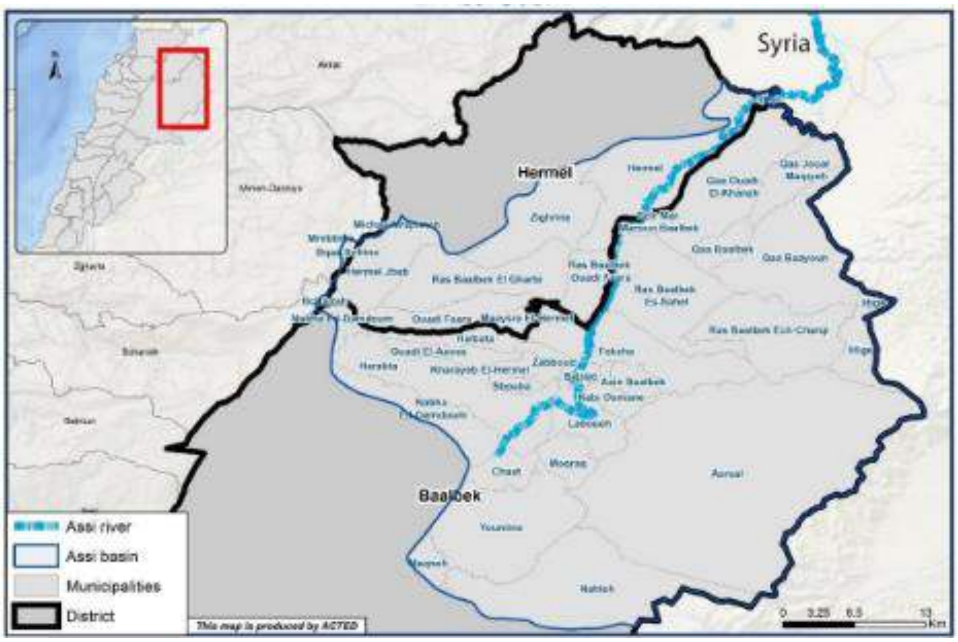

Figure 3 Broad representation of the Assi river between Syria and Lebanon

Figure 4 Representation of the different sampling locations illustrated by red points

1.1.3 Water sampling and Procedures

The number of samples needed to determine the composition of water defines the accuracy/precision of the project (Griffiths, 2012). During the AL Assi first visit on August 31 (2022), ten sampling points were chosen by BTD and agreed upon by the ACTED team. The grab sampling technique was used in AL Assi. This method is recommended when the parameters to be tested are not expected to greatly vary over time.

Grab samples were chosen for this trip as they are considered samples that provide a 'snapshot' of the water quality characteristics at the time of sampling (dry season). Therefore, grab sampling was used as it shows the concentrations at the Ten points location (differently) and time of sampling. Nonetheless a high number equal to ten samples was used to show the nature of change over time. The sampling of all the ten points in al Assi was performed in one day over five hours. This method helps in showing the worst-case scenario situations, eg in the presence of surface scums of algae or oil and greases, or even very high pollution.

A sample of water was taken directly from the rivers in all the points using both plastic and glass containers.

Sub-surface samples were taken from approximately 25 to 35 cm depth, with cares taken to ensure that no floating films or organic material were collected unless they were of specific interest. NDU team tried to collect the sample at a reasonable distance from the edge. In most points, NDU team collected the samples directly into the sample container. For the case it was not practical such as at point 7, an intermediate container was used.

1.1.4 Sampling frequency and patterns of sampling

NDU team agreed with the stakeholders that two sampling campaigns will occur in Al Assi River. The first during August (2022) and the second during January (2023). The purpose of sampling during both wet and dry seasons aims at determining the variability of water quality. This sampling frequency (twice a year in two different seasons) ensures that the characteristics of the waters are adequately described resulting in a good understanding of the system and potentially accurate reporting of compliance or noncompliance with the standards (Hespanhol, & Prost, 1994).

1.1.5 Analytes

The choice of analytes with ACTED team depended on the contaminants present in Al Assi River and the criteria against which the monitoring is to be evaluated. Preserving a sound environmental condition of water as well as load discharge within limit is the main concern

Table 2 below includes the final list of analytes to be examined on Al Assi river:

Table 2 Final list of analytes

Turbidity (NTU)	Phosphorous (mg/L)
pH (pH)	Chloride (mg/L)
ORP (mV)	Ammonia (mg/L)
RDO (mg/L)	Sulphate
Conductivity (µS/cm)	Fluoride
TDS (ppt)	Lithium
TS (ppt)	Calcium
Temp (°C)	Potassium
Nitrate (mg/L)	Sodium
Lead (mg/L)	DO
Cadmium (mg/L)	BOD
Barium (ųg/L)	COD
Mercury (ųg/L)	Total Coliform
Ecoli	Fecal Coliform

2 Planning the Sampling Event

Careful planning and preparation of the sampling event amongst NDU, BTD, and ACTED is important and help to save time and resolve the number of problems that might occur during sampling. Overall, the sampling event was very smooth, and no unexpected hurdle occurred. This was the result of careful preparation of the trip that constitutes of the following:

2.1 Logistics

The basic steps followed by NDU for planning the sampling event are as follows:

1. NDU team reviewed the monitoring plan before the trip, including monitoring locations, number of samples required, sampling methods, and Occupational Health, Safety and Welfare (OHS&W) issues.
2. NDU team informed the personnel at NDU laboratories of the intended schedule.
3. NDU team prepared a list of the needed logistics such as the containers of suitable material and volume that contain preservatives. Table 3 shows a sample of the table that describes the followed procedure to do the testing.
4. BTD team scheduled the monitoring event. NDU team planned for the day including planning how and when NDU will transport the samples back to the laboratory. NDU team prepared a template to be taken on-site that aimed to show how samples are to be preserved and delivered to the laboratory as quickly as possible and within recommended holding times. This is especially relevant for samples with holding times of 24 hours or less (see Table 3).
5. NDU team checked all equipment required for the sampling event. It ensures that the equipment is operational and calibrated and checked one day before the sampling event. Moreover, Dr. Claudette Hajj and her team from NDU have decontaminated the equipment and the sample containers to be used or even reused between samples.

Table 3 Containers, Preservation Methods and Holding times

Analyte	Container Type	Volume (ml)	Filling Technique	Preservation	Holding time
Conductivity	Glass or Plastic	100	Fill container completely to exclude air	Not required	24 Hrs.
BOD	Glass	1000	Do not pre-rinse container with sample	Refrigerate and store in the dark	24 Hrs.
PH	Glass or Plastic	100	N.A.	Refrigerate	6 Hrs.
Solids	Glass or Plastic	500	Fill a container to exclude air	Refrigerate	24 Hrs.
Turbidity	Glass or Plastic	100	Fill container completely to exclude air	Not required	24 Hrs.
Metals	Glass or Plastic	100	N.A.	Acidify with nitric acid to pH 1 to 2	1 month
Fecal,E coliforms	Sterilized Glass or plastic,	200	Do not completely fill a container	Refrigerate	preferably < 6 hrs.

Figure 5 Autoclaving the Containers

2.2 Preparation of the Equipment before and during the Sampling

Major items of equipment that were prepared by the NDU team before the sampling process are:

1. Prepare and print the Records of observations and actions sheet. Table 4 was prepared to guarantee that a complete record of each sampling site and event is kept.

Table 4 Records of observations and actions sheet Sample

Sampling summary

Sampler	Claudette	Project number	Acted- Trip 1
Date	August 31, 2022	Time (begin and end)	11:39 am

Site information

Site ID	Point 4	GPS	Table 1
Location	Al Assi	Photo numbers	

Field observations

Weather	Temperature	31 C	
	Wind and direction Cloud cover/rain	Not present-Sunny	
Water	Tide/depth	1m	
	Flow Choppy/mixed/calm	Flow	
Observations examples	Surface film?	Yes	
	Algae/phytoplankton? Debris? Odour?	No Yes Yes	
Other/additional			

During every sampling event, observations of field conditions that could assist in the interpretation of monitoring data were recorded by NDU team. This provides useful information about the water being sampled, which can help diagnose the source and potential impact of pollutants found by chemical analysis.

Examples of such field conditions recorded by the NDU team are as follows:

- Presence of Wind and Rain: YES/**NO**
- Shading from clouds and vegetation YES/**NO**
- Any abnormalities that indicate pollution or affect water quality, such as the absence of flow, presence of surface scum, **watercolor or odors**, excessive algal or plant growth, dead fish, or invertebrates should also be noted. The above were recorded at each point.

2. Prepare and print all Chain of Custody forms that includes all the details about each sample (sampler name, time, date, type of tests, preservation method used, container type and size, type of analysis needed) and labels and packed them for the trip.
3. Use Navigational aids (NAVA 400 GPS) to accurately locate the sampling site for future reference.
4. Decide before the trip on the field testing meters.

Decide on the analytes that quickly degrade after they are sampled and therefore must be tested in the field. Some field measurements were undertaken in situ. The following analytes were measured in the field as concentrations of these analytes can be significantly changed during transport and storage:

• Dissolved oxygen (DO)

• Temperature

• PH

• Conductivity

• Redox (reduction/oxidation potential)

• Turbidity

• Chlorine

• Salinity

The above analytes were measured using multi-parameter meters. Field meters were calibrated one day before use. In particular, dissolved oxygen, pH, and turbidity that drift from day to day were calibrated using a standard solution twice during the sampling day.

Figure 6 Field measurement of the parameters using the In-Situ Aqua troll 500 multimeter

5. To preserve the integrity of the sample, the team ensured appropriate sample containers for each of the various parameters. The sample containers and preservation methods are presented in Table 2.
6. Prior to heading to the site, the team decontaminated the sampling equipment. All sampling equipment presents a risk of cross-contamination and therefore are thoroughly cleaned between samples with ethanol and distilled water. Moreover, multiple-use equipment are decontaminated prior to each sampling and between the collection of samples.
7. Most types of the sample require chilling as a means of preservation. NDU team prepared the needed esky . Samples are stored on ice in a car refrigerator, and the temperature maintained between 1°C and 4°C by adding two packs of ice every 2 hrs.

2.3 Collection of samples for analysis

Samples were collected using grab sampling from all the points in triplicates as shown in figures 7 to 12. Before the samples collection, the team made sure that the equipment is inert, and does not cause contamination or interference with the sample.

As organics have a tendency to adsorb to plastic, stainless steel equipment such as buckets and sampling rods were used. Glass sample containers were used in most cases, additional samples were taken in plastic containers. The team followed EPA Appendix 2 for information on the type of sampling container (eg glass, plastic), typical required volume, filling technique and preservation requirements for common analytes.

2.4 Sample Identification, Transport, and Storage

All samples were labeled by NDU team so they can be readily identified at all times. Sample containers were marked using permanent markers in such a way that they can be identified and distinguished from other samples in the laboratory. Care was taken when packing samples, as samples are often subject to vibration during transport. Sample labels have specified a clear and unique identifying code that can be cross-referenced to the monitoring location and time of sampling and includes: the date of sampling, time of sampling, location, name of sampling site, and name of a sampler.

Figure 7 Sampling directly into the container

Figure 8 Filling and Labeling of the Samples on Site

During sample transport and storage, the NDU team followed key precautions to ensure effective transport and storage:

- Samples appropriately packed to avoid breakage and cross-contamination.
- Ensure the time between sampling and analyzing not to exceed holding time.
- Sample containers sealed, carefully packed with appropriate packing material, chilled or frozen (as required), and transported in an appropriate cooler or fridge.

2.5 Lab testing

Table 5 shows the test methods used at NDU labs to perform the needed testing. The procedure followed in these sections were accurately followed.

Table 5 Test methods

Parameter	Test Method
BOD 5	EMDC1 1173: Part 3 ± Five-day BOD Method
COD	EMDC1 1173: Part 4 ± Dichromate Digestion Method
PH	EMDC1 1173: Part 2 ± Electrometric Method
Temperature	EMDC1 1173: Part 1 ± Electrometric Method
Total Suspended Solids	EMDC1 1173: Part 1 ± Gravimetric Method
TS	EMDC1 1173: Part 3 ± Gravimetric Method
Turbidity	APHA Standard Methods:2130 B. Nephelometric Method
Chlorides (Cl -)	APHA Standard Methods: 4110 B. Ion Chromatography with Chemical Suppression of Eluant Conductivity
Cadmium	EMDC1 1173: Part 7 ± Flame Atomic Spectrometry Absorption Spectrometry
Barium (Ba)	EMDC1 1173: Part 7 ± Direct Nitrous Oxide-Acetylene Flame Atomic Absorption
Fluorides (F-)	APHA Standard Methods: 4110 B. Ion Chromatography with Chemical Suppression
Lead	EMDC1 1173: Part 7 ± Flame Atomic Absorption Spectrometry
Mercury (Hg)	EMDC1 1173: Part 10 ± Cold-Vapor Atomic
Nitrates (NO3 -)	APHA Standard Methods: 4110 B. Ion Chromatography with Chemical Suppression
Phosphorus	EMDC1 1173: Part 6 ± Colorimetric
Lithium	EMDC1- Flame photometry
Calcium	EMDC1 Flame photometry
Sodium	EMDC1 Flame photometry
Potassium	D992 Flame photometry
Nitrate	D1254 11C2: Flame Atomic Absorption Spectrometry
Ammonia	D1426: Flame Atomic Absorption Spectrometry
Total Coliform Organism	ISO 6222:1999, Microbiological method

3 Lab Results

Results obtained following the physical, biological and chemical testing of data collected (see Table 6Table 5 to Table 15), shows that almost all stations are characterized by median of pH between 7.9 and 8.21; so the values are generally within appropriate limits for water supply and aquatic life. Total Dissolved Solids are a measure of all ions in a solution (TDS). TDS measurements were less than 500 ppm for all the samples.

The ammonium concentration in the samples carried out during the months of September showed acceptable values compared to WHO international standards. The amounts of nitrate, heavy metals, and chloride have not given values that exceed the accepted standards.

Below are the results of the field measurement:

Table 6 Results of Point 1

Point Number		**Point Name**		**Nb of readings**
1		**Labwe Spring**		**3**
Report Properties		Start Time = 2022-08-31 08:46:48 Duration = 00:00:20		
Sample Number	1a - Labwe	1b-Labwe	1c-Labwe	**Average**
Turbidity (NTU)	0.2	0.2	0.18	**0.1933**
pH (pH)	8.11	7.98	7.96	**8.02**
ORP (mV)	252.734	251.522	249.716	**251.324**
RDO (mg/L)	7.307	7.476	7.519	**7.434**
Actual Conductivity (µS/cm)	239.005	241.992	240.553	**240.516**
Specific Conductivity (µS/cm)	288.997	295.260	294.709	**292.989**
Salinity (PSU)	0.139	0.142	0.141	**0.140**
Resistivity (Ω·cm)	4165.56	4132.39	4157.10	**4151.68**
Density (g/cm³)	0.999	0.999	0.999	**0.999**
TDS (mg/L)	38	39	39	**39**
TS (mg/L)	60	70	68	**66**
Temp (°C)	16.1	15.7	15.4	**15.7**
Nitrate (mg/L)	2.5	2.4	2.7	**2.55**
Lead (mg/L)	0.04	0.04	0.03	**0.034**
Cadmium (mg/L)	0.001	0.001	0.001	0.001
Barium (ųg/L)	3.4	3.2	3	**3.2**
Mercury (ųg/L)	0.1	0.08	0.08	**0.085**
Phosphorous (mg/L)	<0.3	<0.3	<0.3	**<0.3**
Chloride (mg/L)	4	4.2	4	**4.15**
Sodium (ppm)	10.3	10.5	10.1	**10.3**
Potassium (ppm)	3.1	3.5	3.3	**3.3**
Lithium (ppm)	0.1	0.1	0.1	**0.1**
Calcium (ppm)	8	8	8	**8**
Ammonia (mg/L)	0.56	0.6	0.58	0.58
Sulphate	<20	<20	<20	<20
Fluoride	10	8	9	8
Total Nitrogen	72	70	70	71
DO	7.15	7.17	7.14	7.15
BOD	2.18	2.2	2.15	2.19
COD	5	5.5	7	5.5
Total Coliform	0	0	0	0
Fecal	0	0	0	0
Ecoli	0	0	0	0

Figure 9 Sampling at point 1

Table 7 Results of Point 2

Point Number		**Point Name**		**Nb of readings**
2		**Rwess Spring**		**3**
Sample Number	2a-Rwess	2b-Rwess	2c-Rwess	Average
Date Time	8/31/2022 9:01	8/31/2022 9:01	8/31/2022 9:01	
Turbidity (NTU)	5	5	6	5.33
pH (pH)	8.303	8.217	8.088	8.203
ORP (mV)	261.829	273.251	272.822	269.301
RDO (mg/L)	7.492	7.545	7.470	7.502
Actual Conductivity (µS/cm)	243.428	250.561	250.418	248.135
Specific Conductivity (µS/cm)	295.310	305.372	306.959	302.547
Salinity (PSU)	0.143	0.147	0.147	0.146
Resistivity (Ω·cm)	3991.22	3991.05	3991.68	3991.32
Density (g/cm³)	0.999	0.999	0.999	0.999
TDS (ppt)	197	198	199	198
TS (ppt)	300.00	302.00	330.00	**310**
Temp (°C)	16.1	15.6	15.4	15.7
Nitrate (mg/L)	0.3	0.3	0.3	0.3
Lead (mg/L)	0.04	0.06	0.06	0.054
Cadmium (mg/L)	0.002	0.002	0.002	0.002
Barium (ųg/L)	2.1	2.2	2	2.1
Mercury (ųg/L)	0.08	0.09	0.08	0.084
Sodium (ppm)	6.4	6.3	6.5	6.3
Potassium (ppm)	1.4	1.8	1.6	1.6
Lithium (ppm)	0.1	0.1	0.1	0.1
Calcium (ppm)	20	20.4	20.2	20.2
Phosphorous (mg/L)	<0.3	<0.3	<0.3	<0.3
Chloride (mg/L)	200	185	200	195
Ammonia (mg/L)	0.9	0.88	0.93	0.9
Sulphate	200	195	210	202
Fluoride	10	11	11	10.6
Total Nitrogen	72	70	74	72
DO	7.492	7.545	7.470	7.502
BOD	6.18	6.2	6.15	6.19
COD	9	8.6	8.8	8.9
Total Coliform	10	10	10	10
Fecal	0	0	0	0
Ecoli	0	0	0	0

Table 8 Results of Point 3

Point Number	Point Name			Nb of readings
3	**Fekeha**			**3**
Sample nb	3a-Fekeha	3b-Fekeha	3c-Fekeha	**Average**
Date Time	8/31/2022 9:31	8/31/2022 9:31	8/31/2022 9:31	
Turbidity (NTU)	0.8	0.9	0.9	**0.8667**
pH (pH)	8.016	7.996	8.001	**8.004**
ORP (mV)	271.468	271.520	270.727	**271.238**
RDO (mg/L)	7.204	7.191	7.190	**7.195**
Actual Conductivity (µS/cm)	21.506	23.263	22.553	**22.441**
Specific Conductivity (µS/cm)	24.077	26.067	25.296	**25.147**
Salinity (PSU)	0.0099	0.0109	0.0105	**0.0104**
Resistivity (Ω·cm)	42026.03	41831.94	43283.86	**42380.61**
Density (g/cm^3)	0.998	0.998	0.998	**0.998**
TDS (ppt)	17	17	16	**16.6**
TS (ppt)	160	151	155	**155.52**
Temperature	19	19	19	**19**
Nitrate (mg/L)	4.71	4.7	4.66	**4.69**
Lead (mg/L)	0.01	0.01	0.01	**0.01**
Cadmium (mg/L)	0.003	0.003	0.003	**0.003**
Barium (ɥg/L)	3	3	4	**3.4**
Mercury (ɥg/L)	0.07	0.06	0.07	**0.065**
Sodium (ppm)	26.9	26.8	27	**26.9**
Potassium (ppm)	12	11	7	**10**
Lithium (ppm)	0.2	0.2	0.2	**0.2**
Calcium (ppm)	45.8	44.8	46.8	**45.8**
Phosphorous (mg/L	<0.3	<0.3	<0.3	**<0.3**
Chloride (mg/L)	10	10	11	**10.3**
Ammonia (mg/L)	0.85	0.82	0.80	**0.82**
Sulphate	12	12	12	**12**
Fluoride	11	11	12	**11.3**
Total Nitrogen	5	6	5	**5.3**
DO	7.204	7.191	7.190	**7.195**
BOD	5	6	5	**6.5**
COD	12	17	16	**14**
Total Coliform	5	6	7	**6**
Fecal	0	0	0	0
Ecoli	0	0	0	0

Figure 10 Sampling at point 3

Table 9 Results of Point 4

Point Number		Point Name		Nb of readings
4		**AL Assi**		**3**
Sample Nb	4a-Assi	4b-Assi	4c-Assi	**Average**
Date Time	8/31/2022 10:33	8/31/2022 10:33	8/31/2022 10:33	
Turbidity (NTU)	8.177	7.704	6.829	**7.570**
pH (pH)	8.111	8.075	8.100	**8.095**
ORP (mV)	265.494	266.859	265.765	**266.039**
RDO (mg/L)	8.025	8.157	8.225	**8.136**
Actual	278.483	277.879	278.299	**278.220**
Specific	335.930	336.550	336.858	**336.446**
Salinity (PSU)	0.162	0.162	0.162	**0.162**
Resistivity	3577.666	3593.198	3592.879	**3587.914**
Density (g/cm³)	0.999	0.999	0.999	**0.999**
TDS (ppt)	218	218	218	**218**
TS (ppt)	680	690	682	**684**
Temperature (°C)	16.3	16.0	15.9	**16.1**
Nitrate (mg/L)	2.98	2.9	3	**2.96**
Lead (mg/L)	0.05	0.05	0.05	**0.05**
Cadmium (mg/L)	0.003	0.003	0.003	**0.003**
Barium (ug/L)	5.7	6	6.3	**6.3**
Mercury (ug/L)	0.18	0.08	0.16	**0.173**
Sodium (ppm)	10.5	10.9	10.7	**10.7**
Potassium	8.4	8.4	8.4	**8.4**
Lithium (ppm)	0.2	0.2	0.2	**0.2**
Calcium (ppm)	11	11	11.5	**11.2**
Phosphorous	0.2	0.17	0.18	**0.216**
Chloride (mg/L)	10	11	10	**10.3**
Ammonia (mg/L)	0.8	0.78	0.77	**0.75**
Sulphate	15	16	17	**16**
Fluoride	12	11	12	**11.6**
Total Nitrogen	80	86	82	**82.6**
DO	8.025	8.157	8.225	**8.136**
BOD	36	36	31	**34**
COD	52	50	47	**149**
Total Coliform	140	130	130	**133**
Fecal	60	65	62	**63.5**
Ecoli	99	100	98	**99**

Figure 11 Sampling point 4

Table 10 Results of Point 5

Point Number		Point Name		Nb of readings
5		Ras El Mail		3
Sample Nb	5a Ras el Mail	5b-Ras el Mail	5c-Ras el Mail	Average
Date Time	8/31/2022 11:19	8/31/2022 11:19	8/31/2022 11:19	
Turbidity (NTU)	0.7	1	0.88	0.86
pH (pH)	8.278	8.192	8.172	8.214
ORP (mV)	311.758	309.034	307.229	309.340
RDO (mg/L)	7.269	7.486	7.741	7.499
Actual Conductivity (µS/cm)	176.801	175.632	175.177	175.870
Specific Conductivity (µS/cm)	212.743	215.975	217.697	215.472
Salinity (PSU)	0.101	0.103	0.103	0.102
Resistivity (Ω·cm)	5657.1	5700.5	5679.7	5679.1
Density (g/cm³)	0.999	0.999	0.999	0.999
TDS (ppt)	138	140	142	140
TS (ppt)	183	186	182	184
Temp (°C)	16.2	15.2	14.8	15.4
Nitrate (mg/L)	0.02	0.02	0.02	**0.02**
Lead (mg/L)	0.004	0.004	0.004	**0.004**
Cadmium (mg/L)	0.00002	0.00002	0.00002	**0.00002**
Barium (ɥg/L)	2.19	2.4	2	**2.2**
Mercury (ɥg/L)	0.2	0.2	0.2	**0.2**
Sodium (ppm)	5.8	5.6	5.8	**5.8**
Potassium (ppm)	4.3	5	4.8	**4.7**
Lithium (ppm)	0.1	0.1	0.1	**0.1**
Calcium (ppm)	15	14.8	15	**14.9**
Phosphorous (mg/L)	<0.3	<0.3	<0.3	<0.3
Chloride (mg/L)	5	5	6	**5.3**
Ammonia (mg/L)	0.021	0.02	0.021	0.021
Sulphate	<20	<20	<20	**<20**
Fluoride	13	13	13	**13**
Total Nitrogen	1	1	1	1
DO	7.269	7.486	7.741	7.499

BOD	6	6	7	**6.3**
COD	12	10	12	**11.3**
Total Coliform	0	0	0	**0**
Fecal	0	0	0	**0**
Ecoli	0	0	0	**0**

Table 11 Results of Point 6

Point Number		Point Name		Nb of readings
6		Bdita		3
Sample nb	**6a- Bdita**	**6b- Bdita**	**6c- Bdita**	**Average**
Date Time	8/31/2022 11:33	8/31/2022 11:33	8/31/2022 11:33	
Turbidity (NTU)	0.7	0.9	0.75	**0.78**
pH (pH)	8.019	8.025	8.002	**8.016**
ORP (mV)	301.729	301.038	301.436	**301.401**
RDO (mg/L)	8.108	8.372	8.397	**8.292**
Actual Conductivity (µS/cm)	184.522	184.128	184.408	**184.353**
Specific Conductivity (µS/cm)	237.578	239.037	241.087	**239.234**
Salinity (PSU)	0.113	0.114	0.115	**0.114**
Resistivity (Ω·cm)	5419.418	5430.504	5422.778	**5424.233**
Density (g/cm³)	0.999	0.999	1.000	**0.999**
TDS (ppt)	154	155	156	**155**
TS (ppt)	312	310	305	**309**
Temp (°C)	13.3	13.0	12.7	**13.0**
Nitrate (mg/L)	20.5	20	22	**20.6**
Lead (mg/L)	0.08	0.08	0.08	**0.08**
Cadmium (mg/L)	0.002	0.002	0.002	**0.002**
Barium (ųg/L)	2.5	3.2	3	**2.8**
Mercury (ųg/L)	0.13	0.11	0.11	**0.12**
Sodium (ppm)	6	7	6.5	**6.5**
Potassium (ppm)	0.7	0.8	1	**0.9**
Lithium (ppm)	0.1	0.1	0.1	**0.1**
Calcium (ppm)	4.8	5.2	5.2	**5.1**
Phosphorous (mg/L)	<0.3	<0.3	<0.3	**<0.3**
Chloride (mg/L)	23	22	23	**22.6**
Ammonia (mg/L)	0.7	0.68	0.73	**0.705**
Sulphate	<20	<20	<20	<20
Fluoride	8	8	8	**8**
Total Nitrogen	21	21	21	**21**
DO	8.108	8.372	8.397	**8.292**
BOD	35	35	37	**35.6**
COD	67	62	62	**64**
Total Coliform	100	105	106	**104**
Fecal	55	59	60	**58**
E coli	10	10	10	**10**

Table 12 Results of Point 7

Point Number		Point Name		Nb of readings
7		Mizen		3
Sample nb	7a- Mizen	7b- Mizen	7c- Mizen	Average
Date Time	8/31/2022 11:53	8/31/2022 11:53	8/31/2022 11:53	
Turbidity (NTU)	18.656	16.615	18.893	**18.055**
pH (pH)	8.229	8.218	8.210	**8.219**
ORP (mV)	289.815	289.028	288.358	**289.067**
RDO (mg/L)	7.659	7.665	7.703	**7.675**
Actual Conductivity (µS/cm)	277.805	276.690	274.777	**276.424**
Specific Conductivity (µS/cm)	334.197	334.360	332.763	**333.773**
Salinity (PSU)	0.161	0.160	0.160	**0.160**
Resistivity (Ω·cm)	3585.784	3647.542	3636.301	**3623.209**
Density (g/cm³)	0.999	0.999	0.999	**0.999**
TDS (ppt)	218	215	216	**216**
TS (ppt)	415	450	433	**432**
Temp (°C)	16.2	16.0	15.9	**16.0**
Nitrate (mg/L)	32	30	33	**32**
Lead (mg/L)	0.04	0.04	0.04	**0.04**
Cadmium (mg/L)	0.002	0.002	0.002	**0.002**
Barium (ųg/L)	0.3	0.3	0.3	**0.3**
Mercury (ųg/L)	0.3	0.3	0.3	**0.3**
Sodium (ppm)	4	4	5	**4.3**
Potassium (ppm)	2.4	2.8	2.6	**2.6**
Lithium (ppm)	0.1	0.1	0.1	**0.1**
Calcium (ppm)	26	27	26.5	**26.5**
Phosphorous (mg/L	3	4	3.5	**3.5**
Chloride (mg/L)	23	22	22	**22.3**
Ammonia (mg/L)	0.7	0.7		**0.7**
Sulphate	<20	<20		**<20**
Fluoride	5	5	5	**5**
Total Nitrogen	107	105	106	**106**
DO	7.659	7.665	7.703	**7.675**
BOD	49	48	46	**47.5**
COD	70	75	75	**73.5**
Total Coliform	200	199	189	**196**
Fecal	90	88	86	**88**
Ecoli	61	58	56	**58**

Table 13 Results of Point 8

Point Number		**Point Name**		**Nb of readings**
8		**Zar2a**		**3**
Sample nb	7a- Zar2a	7b- Zar2a	7c- Zar2a	**Average**
Date Time	8/31/2022 12:22	8/31/2022 12:22	8/31/2022 12:22	
Turbidity (NTU)	7	7	8	**7.3**
pH (pH)	7.873	7.798	7.773	**7.815**
ORP (mV)	289.435	292.947	295.798	**292.727**
RDO (mg/L)	7.282	7.423	7.641	**7.449**
Actual Conductivity (µS/cm)	124.852	125.010	124.107	**124.66**
Specific Conductivity (µS/cm)	147.069	148.357	148.253	**147.893**
Salinity (PSU)	0.070	0.070	0.070	**0.070**
Resistivity (Ω·cm)	8003.981	7998.676	8049.235	**8017.297**
Density (g/cm³)	0.999	0.999	0.999	**0.999**
TDS (ppt)	95.5	96.4	96.3	**96.1**
TS (ppt)	100.00	117.14	107.99	**108.38**
Temp (°C)	16.5	16.8	16.5	**16.6**
Nitrate (mg/L)	2.47	2.5	2.46	**2.48**
Lead (mg/L)	0.05	0.05	0.05	**0.05**
Cadmium (mg/L)	0.002	0.002	0.002	**0.002**
Barium (ųg/L)	3.1	3	2.7	**2.9**
Mercury (ųg/L)	0.3	0.3	0.3	**0.3**
Phosphorous (mg/L)	15	14	16	**15**
Sodium (ppm)	11.5	11	12	**11.5**
Potassium (ppm)	4.9	4.9	4.3	**4.9**
Lithium (ppm)	0.1	0.1	0.1	**0.1**
Calcium (ppm)	15	14.8	14.8	**14.9**
Chloride (mg/L)	4	4	4	**4**
Ammonia (mg/L)	0.8	0.8	0.8	0.8
Sulphate	<20	<20	<20	<20
Fluoride	5	4	5	**4.5**
Total Nitrogen	160	155	162	**159**
DO	7.282	7.423	7.641	**7.449**
BOD	7	8	7	**7.3**
COD	11	11	13	**20**
Total Coliform	11	11	9	**10**
Fecal	2	2	0	**2**
Ecoli	0	0	0	**0**

Figure 12 Sampling at point 8

Table 14 Results of Point 9

Point Number	Point Name			Nb of readings
9	Deffech			3
Report Properties	Start Time = 2022-08-31 – Duration = 00:00:30-12:42:00		9c-Deffech	Average
Sample Nb	9a-Deffech	9b-Deffech	9c-Deffech	
Date Time	8/31/2022 12:41	8/31/2022 12:41	8/31/2022 12:41	Average
Turbidity (NTU)	8.207	8.613	8.727	**8.515**
pH (pH)	7.882	7.864	7.867	**7.871**
ORP (mV)	310.947	310.954	311.382	**311.094**
RDO (mg/L)	8.207	8.613	8.727	**8.515**
Actual Conductivity (µS/cm)	256.626	266.206	266.248	**263.027**
Specific Conductivity (µS/cm)	309.881	327.082	328.172	**321.712**
Salinity (PSU)	0.149	0.157	0.158	**0.155**
Resistivity (Ω·cm)	3897.267	3756.504	3755.891	**3803.221**
Density (g/cm³)	0.999	0.999	0.999	**0.999**
TDS (ppt)	201	212	213	**208.6667**
TS (ppt)	315	318	320	**318**
Temp(°C)	16.12	15.30	15.26	**15.56**
Nitrate (mg/L)	3.07	3.1	3.2	**3.13**
Lead (mg/L)	0.06	0.07	0.055	**0.063**
Cadmium (mg/L)	0.002	0.002	0.002	**0.002**
Barium (ųg/L)	0.4	0.6	0.7	**0.6**
Mercury (ųg/L)	0.1	0.1	0.1	**0.1**
Sodium (ppm)	4	4.3	4	**4.1**
Potassium (ppm)	2	2	2	**2**
Lithium (ppm)	0.001	0.001	0.001	**0.001**
Calcium (ppm)	28	27.7	28.3	**28.3**
Phosphorous (mg/L	0.2	0.2	0.2	**0.2**
Chloride (mg/L)	10	11	11	**10.3**
Ammonia (mg/L)	0.9	0.9	0.9	**0.9**
Sulphate	<20	<20	<20	**<20**
Fluoride	7	8	7	**7.3**
Total Nitrogen	85	85	85	**85**
DO	8.207	8.613	8.727	**8.515**
BOD	13	15	13	**14**
COD	27	25	22	**25**
Total Coliform	110	120	120	**117**
Fecal	61	63	68	**65**
Ecoli	20	21	22	**21**

Table 15 Results of Point 10

Point Number	Point Name			Nb of readings
10	Deffech Upstream			3
Sample Nb	10a- Deffech UP	10b- Deffech UP	10c- Deffech UP	Average
Date Time	8/31/2022 12:43	8/31/2022 12:43	8/31/2022 12:43	
Turbidity (NTU)	1.000	1.000	1.000	**1.000**
pH (pH)	7.969	7.962	7.950	**7.960**
ORP (mV)	393.745	291.593	293.770	**326.369**
RDO (mg/L)	8.494	8.583	8.679	**8.585**
Actual Conductivity (µS/cm)	254.816	246.103	256.447	**252.455**
Specific Conductivity (µS/cm)	310.035	301.327	314.649	**308.670**
Salinity (PSU)	0.149	0.145	0.151	**0.148**
Resistivity (Ω·cm)	3927.614	4063.347	3899.986	**3963.649**
Density (g/cm^3)	0.999	0.999	0.999	**0.999**
TDS (ppt)	194.0	195.0	204.0	**197.7**
TS (ppt)	220.00	222.71	230.10	**224.00**
Temp(°C)	15.676	15.487	15.324	**15.496**
Nitrate (mg/L)	2.69	2.7	2.72	**2.71**
Lead (mg/L)	0.01	0.01	0.01	**0.01**
Cadmium (mg/L)	0.002	0.002	0.002	**0.002**
Barium (ųg/L)	2.3	2.3	2.3	**2.3**
Mercury (ųg/L)	0.2	0.18	0.16	**0.18**
Sodium (ppm)	7	8	9	**8**
Potassium (ppm)	2.3	2.3	2.3	**2.3**
Lithium (ppm)	0.1	0.1	0.1	**0.1**
Calcium (ppm)	30	31	30.4	**30.5**
Phosphorous (mg/L	<0.3	<0.3	<0.3	**<0.3**
Chloride (mg/L)	22	21	22	**22**
Ammonia (mg/L)	0.6	0.65	0.6	**0.62**
Sulphate	<20	<20	<20	**<20**
Fluoride	11	12	10	**11**
Total Nitrogen	114	119	116	**116**
DO	8.494	8.583	8.679	**8.585**
BOD	8	7.8	8.5	**8.2**
COD	13	13	13	**13**
Total Coliform	75	76	71	**74**
Fecal	0	0	0	**0**
Ecoli	0	0	0	**0**

Table 16 Who Standards Limit Table (Boyd,2019)

Chemical Product	WHO Limit	Chemical Product	WHO Limit
Ph	6.5-8.45	CL- (mg/L)	250
Temp °C	15-21	F^{-} (mg/L)	1.5
EC (ɥS/cm)	1500	$PO_4{}^{3-}$ (mg/L)	1
TDS (mg/L)	500	Ca^{2+} (mg/L)	200
BOD (mg/L)	25	Mercury (mg/L)	0.002
COD (mg/L)	25	Barium (mg/L)	1.3
Na^{2+} (mg/L)	150	Cadmium (mg/L)	0.005
$K+^{+}$(mg/L)	12	Lead (mg/L)	0.015
NH_4^{+} (mg/L)	1.5	Total Nitrogen	50
SO_4^{2-} (mg/L)	250	NO_3^{-} (mg/L)	50

Table 17 Summary of the results

Test/Point	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10
Turbidity (NTU)	0.19	5.33	0.866	7.570	0.86	0.78	18.05	7.3	8.515	1.000
pH (pH)	8.02	8.203	8.004	8.095	8.214	8.016	8.219	7.8	7.871	7.96
ORP (mV)	251	269	271	266	309	301	289	292	311	326
RDO (mg/L)	7.4	7.502	7.195	8.136	7.499	8.292	7.675	7.449	8.515	8.585
A-Conductivity (µS/cm)	240	248	22	278	175	184	276	124	263	252
S-Conductivity (µS/cm)	292	302	25	336	215	239	333	147	321	308
Salinity (PSU)	0.14	0.146	0.0104	0.162	0.102	0.114	0.160	0.070	0.155	0.148
Resistivity (Ω·cm)	4151	3991	4238	3587	5679	5424	3623	8017	3803	3963
Density (g/cm^3)	0.99	0.999	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999
TDS (ppt)	39	198	16.6	218	140	155	216	96.1	208	197.7
TS (ppt)	66	310	155	684	184	309	432	108	318	224
Temp(°C)	15.7	15.7	19	16.1	15.4	13.0	16.0	16.6	15.56	15.496
Nitrate (mg/L)	2.55	0.3	4.69	2.96	0.02	20.6	32	2.48	3.13	2.71
Lead (mg/L)	0.034	0.054	0.01	0.05	0.004	0.08	0.04	0.05	0.063	0.01
Cadmium (mg/L)	0.001	0.002	0.003	0.006	0.00002	0.002	0.002	0.002	0.002	0.002
Barium (ųg/L)	3.1	2.1	3.4	6.3	2.2	2.8	0.3	2.9	0.6	2.3
Mercury (ųg/L)	0.085	0.084	0.065	0.173	0.2	0.12	0.03	0.3	0.1	0.18
Sodium (ppm)	10.3	6.3	26.9	10.7	5.8	6.5	4.3	11.5	4.1	8
Potassium	3.3	1.6	10	8.4	4.7	0.9	2.6	4.9	2	2.3
Lithium (ppm)	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.001	0.1
Calcium (ppm)	8	20.2	45.8	11.2	14.9	5.1	26.5	14.9	28.3	30.5
Phosphorus (mg/L	<0.03	<0.03	<0.03	0.04	<0.03	<0.03	0.03	15	0.02	<0.03
Chloride (mg/L)	4.15	195	10.3	10.3	5.3	22.6	22.3	4	10.3	22
Ammonia (mg/L)	0.58	0.9	0.82	0.75	0.021	0.701	0.7	0.8	0.9	0.62
Sulphate	<20	202	12	16	<20	<20	<20	<20	<20	<20
Fluoride	8	10.6	11.3	11.6	13	8	5	4.5	7.3	11
Total Nitrogen	71	72	5.3	82.6	1	21	106	159	85	116
DO	7.15	7.502	7.195	8.136	7.499	8.292	7.675	7.449		8.585
BOD	2.19	6.19	6.5	34	6.3	35.6	47.5	7.3	14	8.2
COD	5.5	8.9	14	149	11.3	64	73.5	20	25	13
Total Coliform	0	10	6	133	0	104	196	10	117	74
Fecal	0	0	0	63.5	0	58	88	2	65	0
Ecoli	0	0	0	99	0	10	58	0	21	0

4 Discussion and Interpretations

Water samples were collected from Al-Assi River during the dry season and tested for physical qualities, chemical contents, and microbiological counts. Ten sampling points were selected. Water quality parameters, such as conductivity, DO, BOD, COD, pH, TS, DS, and Fecal Coliform were analysed. The concentration of lead, cadmium, mercury, barium, lithium, sodium, potassium, chloride, sulphate, fluoride, ammonia, phosphorus, and nitrate was also analysed at all the points. The examination of the results is shown below:

Measuring **dissolved oxygen (DO)** in drinking water is important to understand water quality. DO is critical for fish and other aquatic organisms to survive. DO values for Al-Assi river, along our reach varied between 7.502 mg/L to 8.585 mg/L. WHO standard for sustaining aquatic life is <4 mg/L, whereas for drinking purposes it is 6 to 8.5 mg/L. Therefore, all the examined points are suitable for drinking and aquatic life. High dissolved oxygen levels are beneficial for drinking water, as it improves the taste, however, high dissolved oxygen levels are linked to the rapid corrosion of water pipes. Furthermore, the results show that DO concentration is reduced when an increase in temperature occurs as oxygen saturation levels are temperature-dependent.

While in the case of **(BOD) concentration, the results** recorded values ranging from 2.19 mg/L at point 1 and 47.5 mg/L at point 7. Most rivers have BOD_5 below 1 mg/L. Moderately polluted rivers may have a BOD_5 value in the range of 2 to 8 mg/L. However, high BOD_5 levels (>8mg/L) can be a result of high levels of organic pollution, caused usually by poorly treated wastewater or from high nitrate levels (EEA, 2001). WHO standard for drinking purposes is 0.2mg/L, which is exceeded to a great extent as shown by the values in Table 17. But for other purposes where the value is quite higher than 0.2 mg/L, Al Assi river water is quite satisfactory. Higher BOD_5 values were detected at sites 4,6, and 7 which may be attributed to recreational activities in the form of restaurants, fisheries, and rafting activities that are located along the river as well as family picnic areas in addition to agricultural runoff. Moreover, this might be due to the discharge of Oil Mill (OM) waste, for example, into the river during the sampling season. OM contains an enormous supply of organic matter which might raise the BOD_5 level (Mekki et al., 2013)

Chemical oxygen demand (COD) is another important parameter of water quality assessment. A standard for drinking purposes is 10 mg/L, which is acceptable for point 1 in terms of our analysed value. Table 17 shows the COD data of ten sampling points. High contaminations exist at points 4, 6, and 7 with COD values of 149, 64, and 74 mg/L respectively. The highest levels of COD recorded may be also attributed to raw sewage discharge and for the same reasons stated in the BOD examination.

Concerning the **pH** which is an indicator of the acidic or alkaline condition of water status, the standard for any purpose is 6.5-8.5, in that respect; the values of our sampled water conform with the standards as for all the samples it varies between 7.800 and 8.214. All sites exhibited values of pH within the limits of the natural values that support aquatic life.

Adding to the above, the value of electric **conductivity** (EC) of Al-Assi river varied between 22 and 278 µs. Conductivity depends on the number of ions present in water. In the dry season, the total volume of water decreases at Al-Assi, as a result, the conductivity was high for most of the points, yet it remained within the limits (<300 µs) for drinking water, and rivers and surface water (< 1500 µs). A main observation from the results is that conductivity is directly influenced by TDS, the higher the TDS the higher the EC (Lawson, 2011). A positive correlation was clear between EC and TDS.

Likewise, **total solids** concentrations in the dry season varied between a minimum of 66 mg/L at point 1 and a maximum of 684 mg/L at point 4. This variation might be due to the fact that a lot of water activities are taking place at point 4 which in turn are increasing the amounts of silt and clay particles in the river water.

Concerning **Dissolved Solids (DS**), the standard for drinking water is 500 mg/L. The maximum value obtained from the samples in the dry season is 216 mg/L at point 7. In this respect, we can conclude that Al-Assi river water is acceptable from the drinking water perspective. High levels of TDS at some points are caused by the presence of potassium, chlorides, and sodium and by toxic ions (lead arsenic, cadmium, and nitrate), and result in an undesirable taste that could be salty, bitter, or metallic (Lawson, 2011).

Similarly, the WHO standard for **ammonia** in surface water for drinking purposes is 1.5 mg/L. The results yielded from the test results showed much lower values ranging from 0.021 to 0.9 mg/L for all the points which means it is quite safe in terms of ammonia pollution.

Comparably, the levels of **nitrate** exhibited a clear fluctuation among the sites ranging from the lowest value of 0.3 mg/ at point 2 to 20.6 mg/L at point 6 yet falling below the limit for surface water (50 mg/l).

Apart from the above, we have traced **metal detection** water. These chemicals are classified as being potentially hazardous and toxic to most forms of life. Results reported that trace metals' concentration for **lead, mercury, and cadmium** were low for all the points except for mercury at point 4, whereas **barium** recorded a mean value higher than the WHO guideline (2004) for nitr of the points.

Moreover, some of the chemical elements like **Sodium, potassium, lithium, and calcium** are essential as micronutrients for the life processes in animals and plants (Kar et al., 2008). Fortunately, acceptable concentrations were found in AL Assi.

Similarly, **phosphorus** concentrations recorded values less than 0.04 mg/L for all the sampled points (except point 8). Comparing these results with WHO limits, they fall within the acceptable level of phosphorus (1mg/L) in rivers. The high level of phosphate at point 8 might be due to anthropogenic sources, mainly, agricultural runoff, animal waste, raw sewage, and household detergents. Excess phosphate in surface runoff might lead to cultural eutrophication. During this phenomenon, PO_4^{3-} in freshwater leads to a favourable condition for algae and weed growth, which ultimately brings a rapid reduction in the ecosystem through oxygen depletion.

The sulphate, as well, recorded a mean value of less than 20mg/L for all the points (except point 2). Compared with WHO guidelines, the results fall within the acceptable range (<200 mg/L).

Similarly, **chloride** concentration documented values varying from 4.00 to 195 mg/L. Compared with WHO guidelines, the level of chloride did not exceed the range (200 mg/L) for drinking water indicating that there are no industrial effluents or urban runoff at the location of the sample.

On the other hand, **calcium** values varied between 5.1 mg/L at point 6 and 46 mg/L at point 3. Calcium is an important micronutrient in the aquatic environment, and it enters the water mainly through the weathering of rocks. The concentration of calcium in rivers may reach 200 mg/L. Results are within the range.

Moreover, **fluoride** concentrations were recorded at all sites, yet no marked variation was observed, an exceeding value greater than 1.5 mg/L was found at all sites. These are clearly unacceptable as far as drinking purposes are concerned. For other activities relating to surface water quality, the values are quite acceptable.

Apart from the physical and chemical parameters, the water was tested for microbiological pollutants. The results of the ten sampling points show that for points 1,2,3,5,8, and 10 there is no detection of fecal and E-coli. However, fecal and total coliform counts were too numerous at sites 4,6,7, and 9 indicating the critical condition of excessive microbiological contamination. The presence of fecal coliform bacteria in very high levels indicates potential health risks to swimmers and implies the suitability of the water at these critical points for specific water uses such as swimming is restricted. The source of organic and microbial pollutants present in the water can be accounted for by the presence of trollers used for conveying materials in the area. However, the high number of coliforms at points 4,6,7, and 9 confirms the presence of agricultural runoff, animal waste, raw sewage, and household detergents (Amacha et al., 2012).

According to the WHO standards and the European Economic Community, fecal coliforms in drinking water are not tolerated (0 FC/100ml), and bathing water should not exceed 100 FC/100 ml (Servais et al. 2007). Several health outcomes such as gastrointestinal infections might be associated with fecally polluted l water which may result in a significant burden of disease (WHO 2001). Considering that bacteria densities are greatest during the summer months and the fact that there is no wastewater treatment in the whole catchment area of Al-Assi river, the construction of wastewater treatment systems primarily for large settlements is essential.

To sum up, the results from data analysis show that, the water is certainly unfit for drinking purposes without any form of treatment, but for various other surface water usage purposes, it still could be considered quite acceptable. But as we know, once a trend in pollution sets in, it generally accelerates to cause greater deterioration. So, a few years from now, serious water quality deterioration could take place.

5 Conclusion

The water quality of the Al-Assi River was analysed. The physical, bacteriological, and chemical composition of the river was studied in the dry season. Almost all sites exhibited values of pH within the limits of the natural values that support aquatic life. The levels of TDS were fluctuating among the sites with the highest values recorded at site 7 (within the acceptable range) indicating that there is no seawater intrusion. Higher BOD_5 values were detected at sites 6 and 7 which may be attributed to recreational activities in the form of restaurants that are located along the river as well as family picnic areas in addition to agricultural runoff. The levels of nitrate exhibited a clear fluctuation among the sites ranging yet falling below the limit for surface water. The levels of sulphate did not exhibit a distinct spatial variation unless for point 2. The estimated indices at sites 1 and 3 were generally good. However, sites 4,7, and 9 exhibited relatively the worst water quality conditions.

WHO specifies guidelines and imperative values for drinking and aquatic life were used. This assessment was adopted as the Lebanese Ministry of Environment (MOE) Standards for surface waters, do not include all of the parameters reported here.

Results revealed that the water quality of the AL Assi River is generally affected by the activities taking place along its watershed. The best quality was found in the upper sites and the worst at the estuary. The impact of recreational activities in the form of restaurants that are located along the river as well as family picnic areas resulted in poor water quality that is suitable for specific water uses such as swimming is restricted due to the presence of high levels of fecal coliform. Given that recreational use of the river is very important for the development of the area, preventing further deterioration by anticipating and avoiding new impacts is crucial for effective management. If Al-Assi river is to be used as a managed water resource, point source discharges, and primarily sewage will require treatment.

Adding to the above, anthropogenic perturbations, the difference in topography among the sampling locations, the actual volume of water in the stream, and flow rate are important factors introducing changes to water quality at several points.

Table 4: Various drinking water quality standards

Parameter	Drinking water quality as per		
	EQS standard	WHO standard	EC standard
pH	6.0-8.5	6.5-8.5	6.5-8.5
TDS (mg/L)	1,000	1,000	1,000
Iron (mg/L)	0.3-1.0	0.3	0.20
Sodium (mg/L)	200	200	175
Chloride (mg/L)	150-600	250	250
Sulphate (mg/L)	400	400	25
Fluoride (mg/L)	1.0	1.5	1.5
Arsenic (mg/L)	0.05	0.05	0.05
Ammonium (mg/L)	0.5	1.5	0.5
Nitrate (mg/L)	10	10	10
Phosphate(mg/L)	6.0	--	5.0
Potassium (mg/L)	12.0	--	10
Endrin (μg/L)	0	0.2	0.2
Heptachlor (μg/L	0	0.1	0.1
DDT (μg/L)	0	1.0	0.1

6 Quality Assurance and Performance

Quality assurance (QA) plan contains the policies, procedures and actions established to provide and maintain a degree of confidence in data integrity and accuracy. For the monitoring trip to AL Assi River to successfully meet its objectives, NDU took rigorous and thorough steps to ensure that its testing campaign is reliable. The team followed EPA standards for monitoring and sampling procedures. The QA system shown in Table 18 was followed.

Moreover, Water sampling quality control ensures that the monitoring data taken sufficiently represents the in-situ conditions of the Al Assi River. Any significant change of contamination to the sample due to containers, handling and transportation is identified through the incorporation of QC. Therefore, all labs tests at NDU were taken in triplicates and a comparison of the results was examined. In all cases no outliers was found, and the average was taken for all the parameters

Table 18 Quality control in monitoring

Monitoring Step	QC protocols	Purpose	Refer to Compulsory
Develop monitoring plan	Various, including control sites, multiple sample locations, duplicate samples, sampling times	Ensure the sample collected is representative of the body from which it was taken	Section 1 in this report
Sample collection	Appropriate containers, filling, and preservation techniques	Minimize changes to sample (physical and chemical)	Section 2
	Sample blanks—field, transport, equipment, and container	Quantify contamination of samples during the sampling process	Section 3
	Decontamination of sampling equipment	Minimize contamination	Section 3
Field testing	Equipment calibration	Minimize and quantify bias and error in-field equipment	Section 3
Transport and storage	Appropriate preservation techniques	Minimize physical and chemical changes to sample	Section 4
Analysis	NDU lab accredited by ABET for required analysis	Ensure the laboratory undertakes appropriate QC including spikes, calibration of equipment, and make sure the results are reported in triplicates	Section 5 and 6
Reporting	Peer review validation	Validate that sampling is undertaken as per the monitoring plan and by sampling guidelines	Section 5 to 7

References

Boyd, C. E. (2019). *Water quality: an introduction*. Springer Nature.

Griffiths, C., Klemick, H., Massey, M., Moore, C., Newbold, S., Simpson, D., & Wheeler, W. (2012). US Environmental Protection Agency valuation of surface water quality improvements. *Review of Environmental Economics and Policy*.

Hespanhol, I., & Prost, A. M. E. (1994). WHO guidelines and national standards for reuse and water quality. *Water Research*, *28*(1), 119-124.

United States. Environmental Protection Agency. Office of Water Regulations, & Standards. (2013). *Water quality standards handbook*. US Environmental Protection Agency, Office of Water Regulations and Standards.

B.First participatory workshop report

المشاكل المائية المتعلقة بحوض العاصي

1. مخالفات بناء على مجرى النهر
2. مخالفات المسالخ
3. المكبات العشوائية
4. قلة التحريج في المناطق (الغطاء النباتي)
5. التعديات على مجرى النهر
6. عرقلة الحلول المطروحة بسبب المشاكل الاجتماعية و المناطقية و اختيار المتعهدين
7. تحديث الدراسات القديمة (التي تمت مسبقا)
8. تلوث الينابيع و مصادر العاصي
9. السيول
10. تربية السمك و مخاوف من ارتفاع حرارة المياه جراء السدود على تربية الاسماك
11. السياحة
12. الزراعة
13. فشل الادارة الحكيمة و ضعف سلطة الدولة
14. مياه الصرف الصحي (محطات الصرف الصحي)
15. الحوكمة و قلة الموارد البشرية
16. دراسة الاثر البيئي لكل مشروع
17. الابار العشوائية
18. التصحر و قطع الاشجار
19. عدم وجود شبكات مياه شفة و تهالكها
20. عدم تطبيق القوانين

الحلول المقترحة المتعلقة بحوض العاصي:

انشاء لجنة مختصة لحوض العاصي :

- وزارة الطاقة
- وزارة الزراعة
- وزارة البيئة
- وزارة الصحة
- وزارة الداخلية
- مؤسسة المياه
- وزارة السياحة
- الجيش اللبناني والقوى الأمنية المختصة

مهامها :

- التقييد بالقوانين و قمع المخالفات
- وضع مخطط توجيهي لادارة الموارد الطبيعية
- اجتماع اللجنة دوريا

استغلال مياه الصرف بالزراعة
ضبط الابار العشوائية
دعم اعلاف المسامك لتكون بديل عن الاعلاف الملوثة
ورش عمل للمزارعين وذلك لارشادهم بطريقة استعمال الاسمدة والمبيدات وتنظيم الري
انشاء برك تجميع مياه الامطار و رفع نسبة تسريب مياه الامطار
التشجير, تجليل و الزراعات البديلة
ترشيد استهلاك المياه
ترميم اقنية المياه
صيانة محطات التكرير
تفعيل الاستراتيجيات الموجودة
انشاء وحدات تكرير للمنشات السياحية على ضفاف النهر
فرز النفايات من المصدر وانتاج الطاقة / تشجيع إنتاج السماد الزراعي عبر تقنيات التخمير الهوائي واللاهوائي
العمل على اشراك وزارة التربية والتعليم في عملية التوعية

C.Geological sections

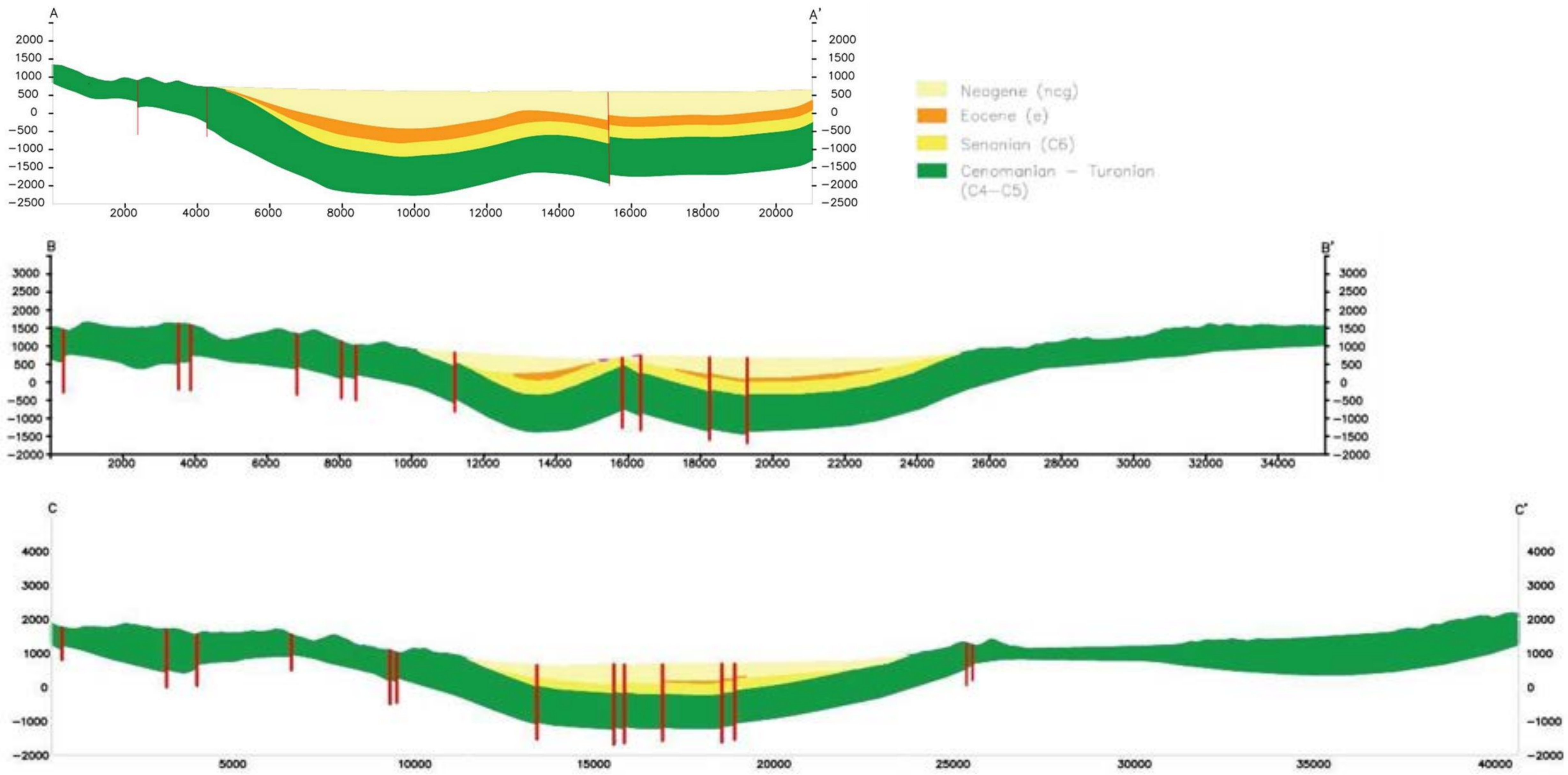

Figure A 1 Geological section AA', BB', CC'

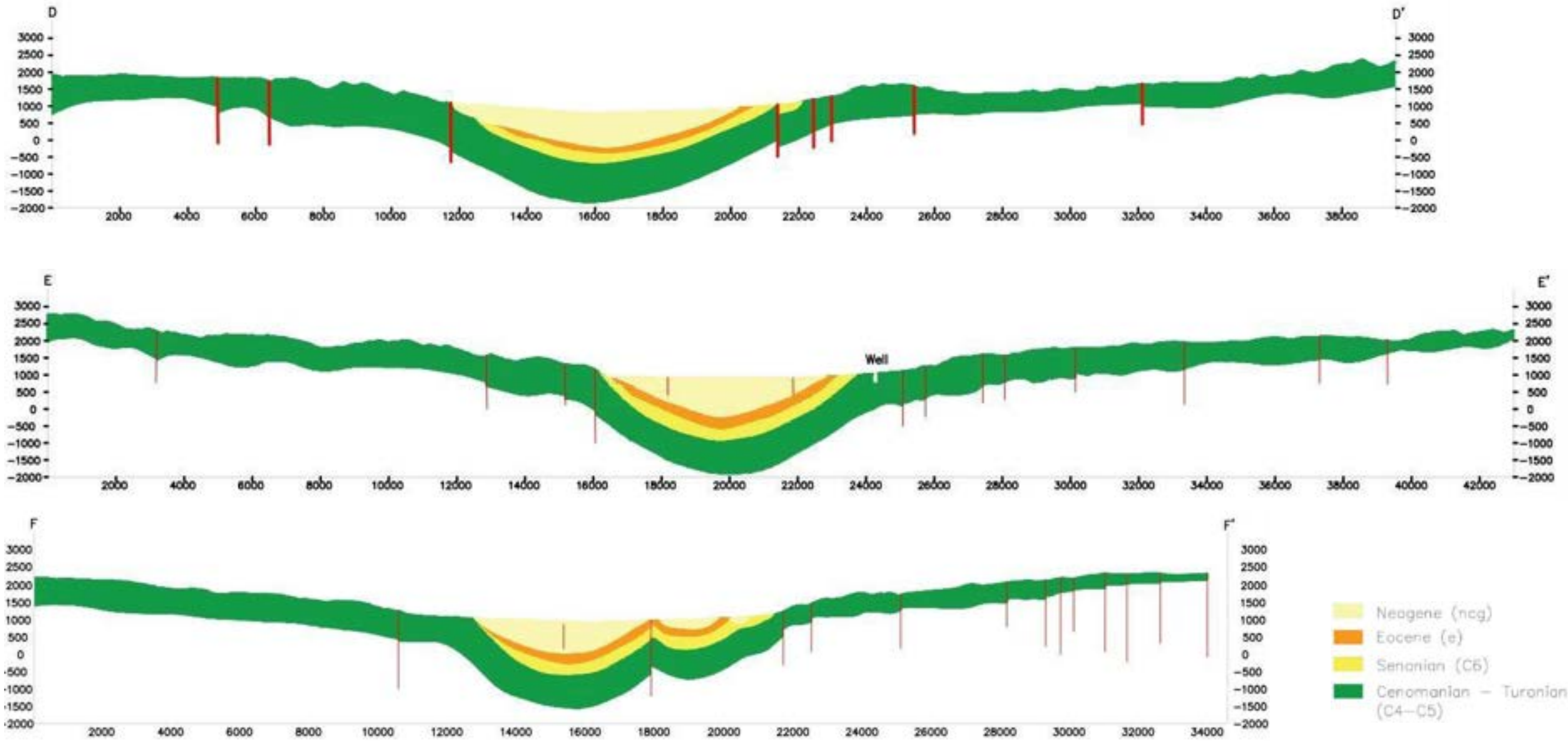

Figure A 2 Geological section DD', EE', FF'

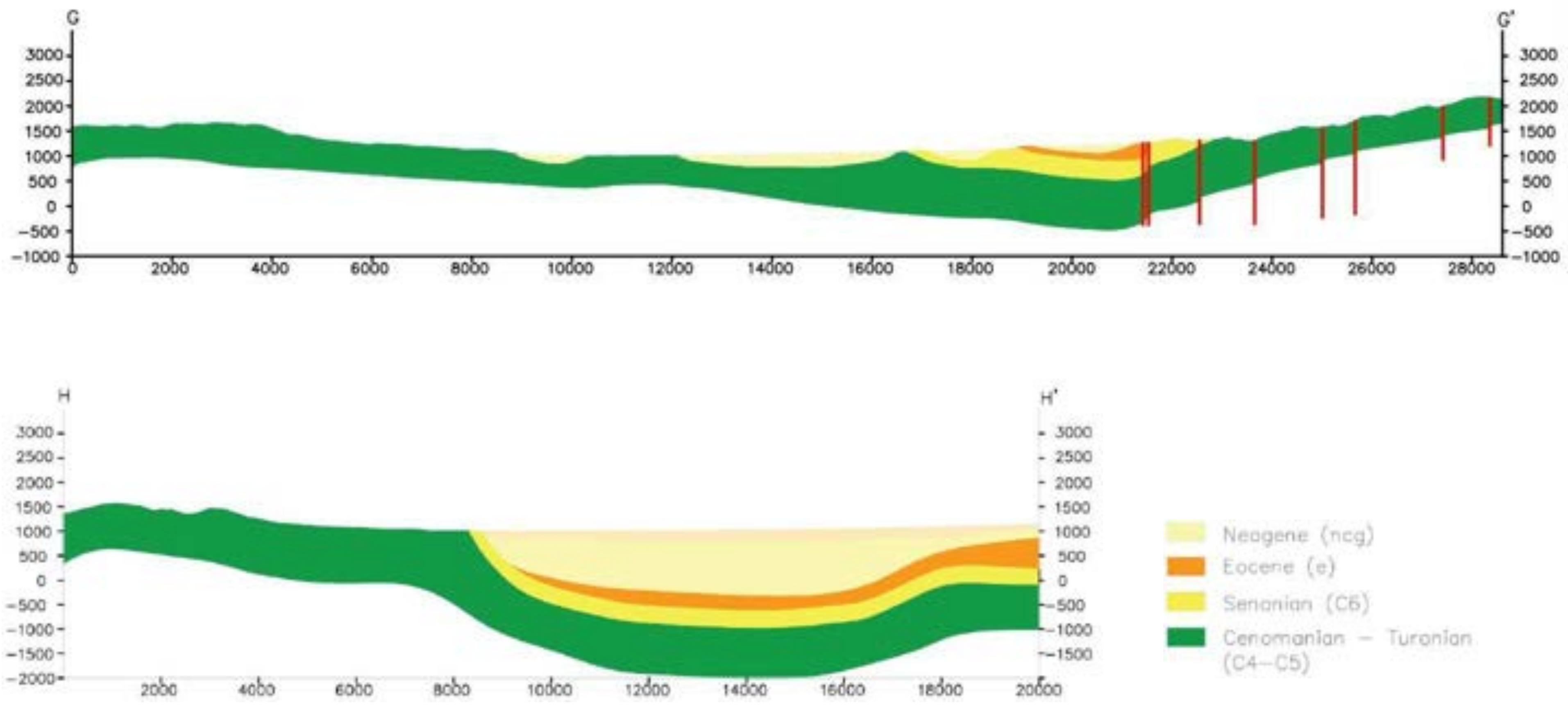

Figure A 3 Geological section GG' and HH'

D.Detailed WEAP Results

Water Demand (not including loss, reuse and DSM) (Cubic Meter)
Scenario: Reference, Selected Branches (39/40)

Branch	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20
EX05 YAMM	554,435.0	518,665.0	554,435.0	536,550.0	554,435.0	536,550.0	554,435.0	554,435.0	536,550.0	554,435.0	536,550.0
EX08 BAAL	29,924.3	27,993.7	29,924.3	28,959.0	29,924.3	28,959.0	29,924.3	29,924.3	28,959.0	29,924.3	28,959.0
EX18 HERM	20,057.0	18,763.0	20,057.0	19,410.0	20,057.0	19,410.0	20,057.0	20,057.0	19,410.0	20,057.0	19,410.0
EX23 JBEB	7,750.0	7,250.0	7,750.0	7,500.0	7,750.0	7,500.0	7,750.0	7,750.0	7,500.0	7,750.0	7,500.0
EX24 TORA	3,255.0	3,045.0	3,255.0	3,150.0	3,255.0	3,150.0	3,255.0	3,255.0	3,150.0	3,255.0	3,150.0
IR01	-	-	196,461.0	2,946,911.0	7,025,585.0	8,987,242.0	12,325,501.0	10,265,515.0	5,157,340.0	2,259,102.0	-
IR02	-	-	9,475.5	142,133.0	338,852.0	433,465.0	594,474.0	495,118.0	248,745.0	108,959.0	-
IR03	-	-	24,847.2	372,708.0	888,554.0	1,136,653.0	1,558,856.0	1,298,321.0	652,269.0	285,718.0	-
IR04	-	-	941.9	14,127.9	33,681.6	43,086.0	59,090.1	49,214.2	24,725.0	10,830.4	-
IR05	-	-	44,966.1	674,491.0	1,608,021.0	2,057,007.0	2,821,070.0	2,349,579.0	1,180,416.0	517,065.0	-
IR06	-	-	9,475.5	142,133.0	338,852.0	433,465.0	594,474.0	495,118.0	248,745.0	108,959.0	-
IR07	-	-	118,359.0	1,775,381.0	4,232,599.0	5,414,409.0	7,425,560.0	6,184,511.0	3,107,065.0	1,361,007.0	-
IR08	-	-	10,643.4	159,650.0	380,615.0	486,889.0	667,741.0	556,140.0	279,402.0	122,388.0	-
IR09	-	-	3,541.5	53,121.9	126,645.0	162,007.0	222,183.0	185,049.0	92,967.8	40,723.3	-
WS01 LABO	268,958.0	251,606.0	268,958.0	260,282.0	268,958.0	260,282.0	268,958.0	268,958.0	260,282.0	268,958.0	260,282.0
WS02 EQAA	52,123.2	48,760.4	52,123.2	50,441.8	52,123.2	50,441.8	52,123.2	52,123.2	50,441.8	52,123.2	50,441.8
WS03 NASB	5,402.5	5,053.9	5,402.5	5,228.2	5,402.5	5,228.2	5,402.5	5,402.5	5,228.2	5,402.5	5,228.2
WS04 OUOR	181,759.0	170,032.0	181,759.0	175,896.0	181,759.0	175,896.0	181,759.0	181,759.0	175,896.0	181,759.0	175,896.0
WS05 YAMM	104,177.0	97,455.7	104,177.0	100,816.0	104,177.0	100,816.0	104,177.0	104,177.0	100,816.0	104,177.0	100,816.0
WS06 YOMN	149,372.0	139,735.0	149,372.0	144,553.0	149,372.0	144,553.0	149,372.0	149,372.0	144,553.0	149,372.0	144,553.0
WS07 AARS	229,175.0	214,390.0	229,175.0	221,782.0	229,175.0	221,782.0	229,175.0	229,175.0	221,782.0	229,175.0	221,782.0
WS08 BAAL	308,918.0	288,988.0	308,918.0	298,953.0	308,918.0	298,953.0	308,918.0	308,918.0	298,953.0	308,918.0	298,953.0
WS09 CHAA	64,504.8	60,343.2	64,504.8	62,424.0	64,504.8	62,424.0	64,504.8	64,504.8	62,424.0	64,504.8	62,424.0
WS10 FEJD	82,010.6	76,719.6	82,010.6	79,365.1	82,010.6	79,365.1	82,010.6	82,010.6	79,365.1	82,010.6	79,365.1
WS11 HARB	22,004.0	20,584.4	22,004.0	21,294.2	22,004.0	21,294.2	22,004.0	22,004.0	21,294.2	22,004.0	21,294.2
WS12 MATN	43,391.2	40,591.7	43,391.2	41,991.5	43,391.2	41,991.5	43,391.2	43,391.2	41,991.5	43,391.2	41,991.5
WS13 IAAT	30,142.4	28,197.7	30,142.4	29,170.1	30,142.4	29,170.1	30,142.4	30,142.4	29,170.1	30,142.4	29,170.1
WS14 RABA	58,429.9	54,660.2	58,429.9	56,545.1	58,429.9	56,545.1	58,429.9	58,429.9	56,545.1	58,429.9	56,545.1
WS15 SBOU	27,220.9	25,464.7	27,220.9	26,342.8	27,220.9	26,342.8	27,220.9	27,220.9	26,342.8	27,220.9	26,342.8
WS16 YAML	2,086.8	1,952.2	2,086.8	2,019.5	2,086.8	2,019.5	2,086.8	2,086.8	2,019.5	2,086.8	2,019.5
WS17 HAKH	12,404.8	11,604.5	12,404.8	12,004.6	12,404.8	12,004.6	12,404.8	12,404.8	12,004.6	12,404.8	12,004.6
WS18 HERM	246,199.0	230,315.0	246,199.0	238,257.0	246,199.0	238,257.0	246,199.0	246,199.0	238,257.0	246,199.0	238,257.0
WS19 OUAD	9,038.1	8,455.0	9,038.1	8,746.5	9,038.1	8,746.5	9,038.1	9,038.1	8,746.5	9,038.1	8,746.5
WS20 FAMR	473.0	442.5	473.0	457.7	473.0	457.7	473.0	473.0	457.7	473.0	457.7
WS21 CHOU	11,917.8	11,149.0	11,917.8	11,533.4	11,917.8	11,533.4	11,917.8	11,917.8	11,533.4	11,917.8	11,533.4
WS22 HAOU	12,251.7	11,461.3	12,251.7	11,856.5	12,251.7	11,856.5	12,251.7	12,251.7	11,856.5	12,251.7	11,856.5
WS23 JBEB	1,089.8	1,019.5	1,089.8	1,054.6	1,089.8	1,054.6	1,089.8	1,089.8	1,054.6	1,089.8	1,054.6
WS24 TORA	4,113.3	3,847.9	4,113.3	3,980.6	4,113.3	3,980.6	4,113.3	4,113.3	3,980.6	4,113.3	3,980.6
WS25 BETO	5,272.6	4,932.4	5,272.6	5,102.5	5,272.6	5,102.5	5,272.6	5,272.6	5,102.5	5,272.6	5,102.5
Sum	2,547,856.0	2,383,479.0	2,966,567.0	8,746,324.0	17,521,261.0	21,619,890.0	28,816,804.0	24,426,421.0	13,457,341.0	7,362,608.0	2,465,667.0

Water Demanc
Scenario: Refe

Branch	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21
EX05 YAMM	554,435.0	554,435.0	500,780.0	554,435.0	536,550.0	554,435.0	536,550.0	554,435.0	554,435.0	536,550.0	554,435.0
EX08 BAAL	29,924.3	29,924.3	27,028.4	29,924.3	28,959.0	29,924.3	28,959.0	29,924.3	29,924.3	28,959.0	29,924.3
EX18 HERM	20,057.0	20,057.0	18,116.0	20,057.0	19,410.0	20,057.0	19,410.0	20,057.0	20,057.0	19,410.0	20,057.0
EX23 JBEB	7,750.0	7,750.0	7,000.0	7,750.0	7,500.0	7,750.0	7,500.0	7,750.0	7,750.0	7,500.0	7,750.0
EX24 TORA	3,255.0	3,255.0	2,940.0	3,255.0	3,150.0	3,255.0	3,150.0	3,255.0	3,255.0	3,150.0	3,255.0
IR01	-	-	-	196,461.0	2,946,911.0	7,025,584.0	8,987,242.0	12,325,501.0	10,265,515.0	5,157,340.0	2,259,102.0
IR02	-	-	-	9,475.5	142,133.0	338,852.0	433,465.0	594,474.0	495,118.0	248,745.0	108,959.0
IR03	-	-	-	24,847.2	372,708.0	888,554.0	1,136,652.0	1,558,856.0	1,298,321.0	652,269.0	285,718.0
IR04	-	-	-	941.9	14,127.9	33,681.6	43,086.0	59,090.1	49,214.2	24,725.0	10,830.4
IR05	-	-	-	44,966.1	674,491.0	1,608,021.0	2,057,007.0	2,821,070.0	2,349,579.0	1,180,416.0	517,065.0
IR06	-	-	-	9,475.5	142,133.0	338,852.0	433,465.0	594,474.0	495,118.0	248,745.0	108,959.0
IR07	-	-	-	118,359.0	1,775,381.0	4,232,599.0	5,414,409.0	7,425,560.0	6,184,511.0	3,107,065.0	1,361,007.0
IR08	-	-	-	10,643.4	159,650.0	380,615.0	486,889.0	667,741.0	556,140.0	279,402.0	122,388.0
IR09	-	-	-	3,541.5	53,121.9	126,645.0	162,007.0	222,183.0	185,049.0	92,967.8	40,723.3
WS01 LABO	268,958.0	272,073.0	245,743.0	272,073.0	263,296.0	272,073.0	263,296.0	272,073.0	272,073.0	263,296.0	272,073.0
WS02 EQAA	52,123.2	53,050.0	47,916.1	53,050.0	51,338.7	53,050.0	51,338.7	53,050.0	53,050.0	51,338.7	53,050.0
WS03 NASB	5,402.5	5,498.5	4,966.4	5,498.5	5,321.1	5,498.5	5,321.1	5,498.5	5,498.5	5,321.1	5,498.5
WS04 OUOR	181,759.0	184,770.0	166,889.0	184,770.0	178,810.0	184,770.0	178,810.0	184,770.0	184,770.0	178,810.0	184,770.0
WS05 YAMM	104,177.0	106,029.0	95,768.3	106,029.0	102,609.0	106,029.0	102,609.0	106,029.0	106,029.0	102,609.0	106,029.0
WS06 YOMN	149,372.0	152,028.0	137,316.0	152,028.0	147,124.0	152,028.0	147,124.0	152,028.0	152,028.0	147,124.0	152,028.0
WS07 AARS	229,175.0	231,527.0	209,121.0	231,527.0	224,058.0	231,527.0	224,058.0	231,527.0	231,527.0	224,058.0	231,527.0
WS08 BAAL	308,918.0	312,088.0	281,886.0	312,088.0	302,020.0	312,088.0	302,020.0	312,088.0	312,088.0	302,020.0	312,088.0
WS09 CHAA	64,504.8	65,651.7	59,298.3	65,651.7	63,533.9	65,651.7	63,533.9	65,651.7	65,651.7	63,533.9	65,651.7
WS10 FEJD	82,010.6	82,852.0	74,834.1	82,852.0	80,179.4	82,852.0	80,179.4	82,852.0	82,852.0	80,179.4	82,852.0
WS11 HARB	22,004.0	22,395.2	20,227.9	22,395.2	21,672.8	22,395.2	21,672.8	22,395.2	22,395.2	21,672.8	22,395.2
WS12 MATN	43,391.2	44,162.7	39,888.9	44,162.7	42,738.1	44,162.7	42,738.1	44,162.7	44,162.7	42,738.1	44,162.7
WS13 IAAT	30,142.4	30,678.4	27,709.5	30,678.4	29,688.8	30,678.4	29,688.8	30,678.4	30,678.4	29,688.8	30,678.4
WS14 RABA	58,429.9	59,468.9	53,713.8	59,468.9	57,550.5	59,468.9	57,550.5	59,468.9	59,468.9	57,550.5	59,468.9
WS15 SBOU	27,220.9	27,704.9	25,023.8	27,704.9	26,811.2	27,704.9	26,811.2	27,704.9	27,704.9	26,811.2	27,704.9
WS16 YAML	2,086.8	2,123.9	1,918.4	2,123.9	2,055.4	2,123.9	2,055.4	2,123.9	2,123.9	2,055.4	2,123.9
WS17 HAKH	12,404.8	12,625.3	11,403.5	12,625.3	12,218.1	12,625.3	12,218.1	12,625.3	12,625.3	12,218.1	12,625.3
WS18 HERM	246,199.0	248,798.0	224,720.0	248,798.0	240,772.0	248,798.0	240,772.0	248,798.0	248,798.0	240,772.0	248,798.0
WS19 OUAD	9,038.1	9,198.8	8,308.6	9,198.8	8,902.1	9,198.8	8,902.1	9,198.8	9,198.8	8,902.1	9,198.8
WS20 FAMR	473.0	481.4	434.8	481.4	465.9	481.4	465.9	481.4	481.4	465.9	481.4
WS21 CHOU	11,917.8	12,129.8	10,955.9	12,129.8	11,738.5	12,129.8	11,738.5	12,129.8	12,129.8	11,738.5	12,129.8
WS22 HAOU	12,251.7	12,469.6	11,262.8	12,469.6	12,067.3	12,469.6	12,067.3	12,469.6	12,469.6	12,067.3	12,469.6
WS23 JBEB	1,089.8	1,109.1	1,001.8	1,109.1	1,073.4	1,109.1	1,073.4	1,109.1	1,109.1	1,073.4	1,109.1
WS24 TORA	4,113.3	4,186.4	3,781.3	4,186.4	4,051.4	4,186.4	4,051.4	4,186.4	4,186.4	4,051.4	4,186.4
WS25 BETO	5,272.6	5,366.4	4,847.0	5,366.4	5,193.3	5,366.4	5,193.3	5,366.4	5,366.4	5,193.3	5,366.4
Sum	2,547,856.0	2,573,886.0	2,324,800.0	2,992,596.0	8,771,514.0	17,547,291.0	21,645,080.0	28,842,833.0	24,452,451.0	13,482,531.0	7,388,637.0

Water Demanc
Scenario: Refe

Branch	Nov-21	Dec-21	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25
EX05 YAMM	536,550.0	554,435.0	554,435.0	500,780.0	554,435.0	536,550.0	554,435.0	536,550.0	554,435.0	554,435.0	536,550.0
EX08 BAAL	28,959.0	29,924.3	29,924.3	27,028.4	29,924.3	28,959.0	29,924.3	28,959.0	29,924.3	29,924.3	28,959.0
EX18 HERM	19,410.0	20,057.0	20,057.0	18,116.0	20,057.0	19,410.0	20,057.0	19,410.0	20,057.0	20,057.0	19,410.0
EX23 JBEB	7,500.0	7,750.0	7,750.0	7,000.0	7,750.0	7,500.0	7,750.0	7,500.0	7,750.0	7,750.0	7,500.0
EX24 TORA	3,150.0	3,255.0	3,255.0	2,940.0	3,255.0	3,150.0	3,255.0	3,150.0	3,255.0	3,255.0	3,150.0
IR01	-	-	-	-	196,461.0	2,946,911.0	7,025,584.0	8,987,242.0	12,325,501.0	10,265,515.0	5,157,340.0
IR02	-	-	-	-	9,475.5	142,133.0	338,852.0	433,465.0	594,474.0	495,118.0	248,745.0
IR03	-	-	-	-	24,847.2	372,708.0	888,554.0	1,136,652.0	1,558,856.0	1,298,321.0	652,269.0
IR04	-	-	-	-	941.9	14,127.9	33,681.6	43,086.0	59,090.1	49,214.2	24,725.0
IR05	-	-	-	-	44,966.1	674,491.0	1,608,021.0	2,057,007.0	2,821,070.0	2,349,579.0	1,180,416.0
IR06	-	-	-	-	9,475.5	142,133.0	338,852.0	433,465.0	594,474.0	495,118.0	248,745.0
IR07	-	-	-	-	118,359.0	1,775,381.0	4,232,599.0	5,414,409.0	7,425,560.0	6,184,511.0	3,107,065.0
IR08	-	-	-	-	10,643.4	159,650.0	380,615.0	486,889.0	667,741.0	556,140.0	279,402.0
IR09	-	-	-	-	3,541.5	53,121.9	126,645.0	162,007.0	222,183.0	185,049.0	92,967.8
WS01 LABO	263,296.0	272,073.0	281,816.0	254,544.0	281,816.0	272,726.0	281,816.0	272,726.0	281,816.0	281,816.0	272,726.0
WS02 EQAA	51,338.7	53,050.0	56,305.3	50,856.4	56,305.3	54,489.0	56,305.3	54,489.0	56,305.3	56,305.3	54,489.0
WS03 NASB	5,321.1	5,498.5	5,835.9	5,271.2	5,835.9	5,647.7	5,835.9	5,647.7	5,835.9	5,835.9	5,647.7
WS04 OUOR	178,810.0	184,770.0	195,189.0	176,300.0	195,189.0	188,892.0	195,189.0	188,892.0	195,189.0	195,189.0	188,892.0
WS05 YAMM	102,609.0	106,029.0	112,536.0	101,645.0	112,536.0	108,905.0	112,536.0	108,905.0	112,536.0	112,536.0	108,905.0
WS06 YOMN	147,124.0	152,028.0	161,357.0	145,742.0	161,357.0	156,152.0	161,357.0	156,152.0	161,357.0	161,357.0	156,152.0
WS07 AARS	224,058.0	231,527.0	238,551.0	215,465.0	238,551.0	230,856.0	238,551.0	230,856.0	238,551.0	238,551.0	230,856.0
WS08 BAAL	302,020.0	312,088.0	321,556.0	290,438.0	321,556.0	311,183.0	321,556.0	311,183.0	321,556.0	321,556.0	311,183.0
WS09 CHAA	63,533.9	65,651.7	69,680.3	62,937.1	69,680.3	67,432.6	69,680.3	67,432.6	69,680.3	69,680.3	67,432.6
WS10 FEJD	80,179.4	82,852.0	85,365.7	77,104.5	85,365.7	82,611.9	85,365.7	82,611.9	85,365.7	85,365.7	82,611.9
WS11 HARB	21,672.8	22,395.2	23,769.5	21,469.2	23,769.5	23,002.7	23,769.5	23,002.7	23,769.5	23,769.5	23,002.7
WS12 MATN	42,738.1	44,162.7	46,872.7	42,336.6	46,872.7	45,360.7	46,872.7	45,360.7	46,872.7	46,872.7	45,360.7
WS13 IAAT	29,688.8	30,678.4	32,560.9	29,409.9	32,560.9	31,510.6	32,560.9	31,510.6	32,560.9	32,560.9	31,510.6
WS14 RABA	57,550.5	59,468.9	63,118.1	57,009.9	63,118.1	61,082.0	63,118.1	61,082.0	63,118.1	63,118.1	61,082.0
WS15 SBOU	26,811.2	27,704.9	29,405.0	26,559.4	29,405.0	28,456.5	29,405.0	28,456.5	29,405.0	29,405.0	28,456.5
WS16 YAML	2,055.4	2,123.9	2,254.2	2,036.1	2,254.2	2,181.5	2,254.2	2,181.5	2,254.2	2,254.2	2,181.5
WS17 HAKH	12,218.1	12,625.3	13,400.1	12,103.3	13,400.1	12,967.8	13,400.1	12,967.8	13,400.1	13,400.1	12,967.8
WS18 HERM	240,772.0	248,798.0	256,652.0	231,815.0	256,652.0	248,373.0	256,652.0	248,373.0	256,652.0	256,652.0	248,373.0
WS19 OUAD	8,902.1	9,198.8	9,763.3	8,818.4	9,763.3	9,448.3	9,763.3	9,448.3	9,763.3	9,763.3	9,448.3
WS20 FAMR	465.9	481.4	511.0	461.5	511.0	494.5	511.0	494.5	511.0	511.0	494.5
WS21 CHOU	11,738.5	12,129.8	12,874.1	11,628.2	12,874.1	12,458.8	12,874.1	12,458.8	12,874.1	12,874.1	12,458.8
WS22 HAOU	12,067.3	12,469.6	13,234.8	11,954.0	13,234.8	12,807.8	13,234.8	12,807.8	13,234.8	13,234.8	12,807.8
WS23 JBEB	1,073.4	1,109.1	1,177.2	1,063.3	1,177.2	1,139.2	1,177.2	1,139.2	1,177.2	1,177.2	1,139.2
WS24 TORA	4,051.4	4,186.4	4,443.3	4,013.3	4,443.3	4,300.0	4,443.3	4,300.0	4,443.3	4,443.3	4,300.0
WS25 BETO	5,193.3	5,366.4	5,695.7	5,144.5	5,695.7	5,511.9	5,695.7	5,511.9	5,695.7	5,695.7	5,511.9
Sum	2,490,857.0	2,573,886.0	2,659,345.0	2,401,989.0	3,078,055.0	8,854,217.0	17,632,750.0	21,727,782.0	28,928,292.0	24,537,910.0	13,565,233.0

Water Demanc
Scenario: Refe

Branch	Oct-25	Nov-25	Dec-25	Jan-30	Feb-30	Mar-30	Apr-30	May-30	Jun-30	Jul-30	Aug-30
EX05 YAMM	554,435.0	536,550.0	554,435.0	554,435.0	500,780.0	554,435.0	536,550.0	554,435.0	536,550.0	554,435.0	554,435.0
EX08 BAAL	29,924.3	28,959.0	29,924.3	29,924.3	27,028.4	29,924.3	28,959.0	29,924.3	28,959.0	29,924.3	29,924.3
EX18 HERM	20,057.0	19,410.0	20,057.0	20,057.0	18,116.0	20,057.0	19,410.0	20,057.0	19,410.0	20,057.0	20,057.0
EX23 JBEB	7,750.0	7,500.0	7,750.0	7,750.0	7,000.0	7,750.0	7,500.0	7,750.0	7,500.0	7,750.0	7,750.0
EX24 TORA	3,255.0	3,150.0	3,255.0	3,255.0	2,940.0	3,255.0	3,150.0	3,255.0	3,150.0	3,255.0	3,255.0
IR01	2,259,102.0	-	-	-	-	196,461.0	2,946,911.0	7,025,584.0	8,987,242.0	12,325,501.0	10,265,515.0
IR02	108,959.0	-	-	-	-	9,475.5	142,133.0	338,852.0	433,465.0	594,474.0	495,118.0
IR03	285,718.0	-	-	-	-	24,847.2	372,708.0	888,554.0	1,136,652.0	1,558,856.0	1,298,321.0
IR04	10,830.4	-	-	-	-	941.9	14,127.9	33,681.6	43,086.0	59,090.1	49,214.2
IR05	517,065.0	-	-	-	-	44,966.1	674,491.0	1,608,021.0	2,057,007.0	2,821,070.0	2,349,579.0
IR06	108,959.0	-	-	-	-	9,475.5	142,133.0	338,852.0	433,465.0	594,474.0	495,118.0
IR07	1,361,007.0	-	-	-	-	118,359.0	1,775,381.0	4,232,599.0	5,414,409.0	7,425,560.0	6,184,511.0
IR08	122,388.0	-	-	-	-	10,643.4	159,650.0	380,615.0	486,889.0	667,741.0	556,140.0
IR09	40,723.3	-	-	-	-	3,541.5	53,121.9	126,645.0	162,007.0	222,183.0	185,049.0
WS01 LABO	281,816.0	272,726.0	281,816.0	294,542.0	266,038.0	294,542.0	285,041.0	294,542.0	285,041.0	294,542.0	294,542.0
WS02 EQAA	56,305.3	54,489.0	56,305.3	60,656.8	54,786.8	60,656.8	58,700.2	60,656.8	58,700.2	60,656.8	60,656.8
WS03 NASB	5,835.9	5,647.7	5,835.9	6,286.9	5,678.5	6,286.9	6,084.1	6,286.9	6,084.1	6,286.9	6,286.9
WS04 OUOR	195,189.0	188,892.0	195,189.0	209,076.0	188,843.0	209,076.0	202,332.0	209,076.0	202,332.0	209,076.0	209,076.0
WS05 YAMM	112,536.0	108,905.0	112,536.0	121,233.0	109,501.0	121,233.0	117,322.0	121,233.0	117,322.0	121,233.0	121,233.0
WS06 YOMN	161,357.0	156,152.0	161,357.0	173,827.0	157,005.0	173,827.0	168,220.0	173,827.0	168,220.0	173,827.0	173,827.0
WS07 AARS	238,551.0	230,856.0	238,551.0	247,632.0	223,667.0	247,632.0	239,644.0	247,632.0	239,644.0	247,632.0	247,632.0
WS08 BAAL	321,556.0	311,183.0	321,556.0	333,797.0	301,494.0	333,797.0	323,029.0	333,797.0	323,029.0	333,797.0	333,797.0
WS09 CHAA	69,680.3	67,432.6	69,680.3	75,065.5	67,801.1	75,065.5	72,644.1	75,065.5	72,644.1	75,065.5	75,065.5
WS10 FEJD	85,365.7	82,611.9	85,365.7	88,615.3	80,039.6	88,615.3	85,756.7	88,615.3	85,756.7	88,615.3	88,615.3
WS11 HARB	23,769.5	23,002.7	23,769.5	25,606.5	23,128.4	25,606.5	24,780.4	25,606.5	24,780.4	25,606.5	25,606.5
WS12 MATN	46,872.7	45,360.7	46,872.7	50,495.2	45,608.6	50,495.2	48,866.3	50,495.2	48,866.3	50,495.2	50,495.2
WS13 IAAT	32,560.9	31,510.6	32,560.9	35,077.3	31,682.8	35,077.3	33,945.8	35,077.3	33,945.8	35,077.3	35,077.3
WS14 RABA	63,118.1	61,082.0	63,118.1	67,996.1	61,415.8	67,996.1	65,802.7	67,996.1	65,802.7	67,996.1	67,996.1
WS15 SBOU	29,405.0	28,456.5	29,405.0	31,677.5	28,612.0	31,677.5	30,655.7	31,677.5	30,655.7	31,677.5	31,677.5
WS16 YAML	2,254.2	2,181.5	2,254.2	2,428.4	2,193.4	2,428.4	2,350.1	2,428.4	2,350.1	2,428.4	2,428.4
WS17 HAKH	13,400.1	12,967.8	13,400.1	14,435.7	13,038.7	14,435.7	13,970.0	14,435.7	13,970.0	14,435.7	14,435.7
WS18 HERM	256,652.0	248,373.0	256,652.0	266,833.0	241,010.0	266,833.0	258,225.0	266,833.0	258,225.0	266,833.0	266,833.0
WS19 OUAD	9,763.3	9,448.3	9,763.3	10,517.8	9,500.0	10,517.8	10,178.5	10,517.8	10,178.5	10,517.8	10,517.8
WS20 FAMR	511.0	494.5	511.0	550.4	497.2	550.4	532.7	550.4	532.7	550.4	550.4
WS21 CHOU	12,874.1	12,458.8	12,874.1	13,869.0	12,526.9	13,869.0	13,421.7	13,869.0	13,421.7	13,869.0	13,869.0
WS22 HAOU	13,234.8	12,807.8	13,234.8	14,257.6	12,877.8	14,257.6	13,797.7	14,257.6	13,797.7	14,257.6	14,257.6
WS23 JBEB	1,177.2	1,139.2	1,177.2	1,268.2	1,145.5	1,268.2	1,227.3	1,268.2	1,227.3	1,268.2	1,268.2
WS24 TORA	4,443.3	4,300.0	4,443.3	4,786.7	4,323.5	4,786.7	4,632.3	4,786.7	4,632.3	4,786.7	4,786.7
WS25 BETO	5,695.7	5,511.9	5,695.7	6,135.8	5,542.1	6,135.8	5,937.9	6,135.8	5,937.9	6,135.8	6,135.8
Sum	7,474,096.0	2,573,560.0	2,659,345.0	2,772,088.0	2,503,821.0	3,190,798.0	8,963,323.0	17,745,493.0	21,836,888.0	29,041,035.0	24,650,653.0

Water Demanc
Scenario: Refe

Branch	Sep-30	Oct-30	Nov-30	Dec-30	Jan-35	Feb-35	Mar-35	Apr-35	May-35	Jun-35	Jul-35
EX05 YAMM	536,550.0	554,435.0	536,550.0	554,435.0	602,646.0	544,326.0	602,646.0	583,206.0	602,646.0	583,206.0	602,646.0
EX08 BAAL	28,959.0	29,924.3	28,959.0	29,924.3	86,158.3	77,820.4	86,158.3	83,379.0	86,158.3	83,379.0	86,158.3
EX18 HERM	19,410.0	20,057.0	19,410.0	20,057.0	30,783.0	27,804.0	30,783.0	29,790.0	30,783.0	29,790.0	30,783.0
EX23 JBEB	7,500.0	7,750.0	7,500.0	7,750.0	7,750.0	7,000.0	7,750.0	7,500.0	7,750.0	7,500.0	7,750.0
EX24 TORA	3,150.0	3,255.0	3,150.0	3,255.0	3,255.0	2,940.0	3,255.0	3,150.0	3,255.0	3,150.0	3,255.0
IR01	5,157,340.0	2,259,102.0	-	-	-	-	196,461.0	2,946,911.0	7,025,584.0	8,987,242.0	12,325,501.0
IR02	248,745.0	108,959.0	-	-	-	-	9,475.5	142,133.0	338,852.0	433,465.0	594,474.0
IR03	652,269.0	285,718.0	-	-	-	-	24,847.2	372,708.0	888,554.0	1,136,652.0	1,558,856.0
IR04	24,725.0	10,830.4	-	-	-	-	941.9	14,127.9	33,681.6	43,086.0	59,090.1
IR05	1,180,416.0	517,065.0	-	-	-	-	44,966.1	674,491.0	1,608,021.0	2,057,007.0	2,821,070.0
IR06	248,745.0	108,959.0	-	-	-	-	9,475.5	142,133.0	338,852.0	433,465.0	594,474.0
IR07	3,107,065.0	1,361,007.0	-	-	-	-	118,359.0	1,775,381.0	4,232,599.0	5,414,409.0	7,425,560.0
IR08	279,402.0	122,388.0	-	-	-	-	10,643.4	159,650.0	380,615.0	486,889.0	667,741.0
IR09	92,967.8	40,723.3	-	-	-	-	3,541.5	53,121.9	126,645.0	162,007.0	222,183.0
WS01 LABO	285,041.0	294,542.0	285,041.0	294,542.0	307,907.0	278,109.0	307,907.0	297,974.0	307,907.0	297,974.0	307,907.0
WS02 EQAA	58,700.2	60,656.8	58,700.2	60,656.8	65,344.6	59,021.0	65,344.6	63,236.7	65,344.6	63,236.7	65,344.6
WS03 NASB	6,084.1	6,286.9	6,084.1	6,286.9	6,772.8	6,117.4	6,772.8	6,554.3	6,772.8	6,554.3	6,772.8
WS04 OUOR	202,332.0	209,076.0	202,332.0	209,076.0	223,992.0	202,315.0	223,992.0	216,766.0	223,992.0	216,766.0	223,992.0
WS05 YAMM	117,322.0	121,233.0	117,322.0	121,233.0	130,602.0	117,963.0	130,602.0	126,389.0	130,602.0	126,389.0	130,602.0
WS06 YOMN	168,220.0	173,827.0	168,220.0	173,827.0	187,261.0	169,139.0	187,261.0	181,221.0	187,261.0	181,221.0	187,261.0
WS07 AARS	239,644.0	247,632.0	239,644.0	247,632.0	257,058.0	232,182.0	257,058.0	248,766.0	257,058.0	248,766.0	257,058.0
WS08 BAAL	323,029.0	333,797.0	323,029.0	333,797.0	346,503.0	312,971.0	346,503.0	335,326.0	346,503.0	335,326.0	346,503.0
WS09 CHAA	72,644.1	75,065.5	72,644.1	75,065.5	80,866.9	73,041.1	80,866.9	78,258.3	80,866.9	78,258.3	80,866.9
WS10 FEJD	85,756.7	88,615.3	85,756.7	88,615.3	91,988.6	83,086.4	91,988.6	89,021.2	91,988.6	89,021.2	91,988.6
WS11 HARB	24,780.4	25,606.5	24,780.4	25,606.5	27,585.4	24,915.9	27,585.4	26,695.6	27,585.4	26,695.6	27,585.4
WS12 MATN	48,866.3	50,495.2	48,866.3	50,495.2	54,397.7	49,133.4	54,397.7	52,642.9	54,397.7	52,642.9	54,397.7
WS13 IAAT	33,945.8	35,077.3	33,945.8	35,077.3	37,788.3	34,131.3	37,788.3	36,569.3	37,788.3	36,569.3	37,788.3
WS14 RABA	65,802.7	67,996.1	65,802.7	67,996.1	73,251.1	66,162.3	73,251.1	70,888.2	73,251.1	70,888.2	73,251.1
WS15 SBOU	30,655.7	31,677.5	30,655.7	31,677.5	34,125.7	30,823.2	34,125.7	33,024.9	34,125.7	33,024.9	34,125.7
WS16 YAML	2,350.1	2,428.4	2,350.1	2,428.4	2,616.1	2,362.9	2,616.1	2,531.7	2,616.1	2,531.7	2,616.1
WS17 HAKH	13,970.0	14,435.7	13,970.0	14,435.7	15,551.3	14,046.4	15,551.3	15,049.7	15,551.3	15,049.7	15,551.3
WS18 HERM	258,225.0	266,833.0	258,225.0	266,833.0	277,433.0	250,584.0	277,433.0	268,483.0	277,433.0	268,483.0	277,433.0
WS19 OUAD	10,178.5	10,517.8	10,178.5	10,517.8	11,330.7	10,234.1	11,330.7	10,965.2	11,330.7	10,965.2	11,330.7
WS20 FAMR	532.7	550.4	532.7	550.4	593.0	535.6	593.0	573.9	593.0	573.9	593.0
WS21 CHOU	13,421.7	13,869.0	13,421.7	13,869.0	14,940.9	13,495.0	14,940.9	14,458.9	14,940.9	14,458.9	14,940.9
WS22 HAOU	13,797.7	14,257.6	13,797.7	14,257.6	15,359.5	13,873.1	15,359.5	14,864.0	15,359.5	14,864.0	15,359.5
WS23 JBEB	1,227.3	1,268.2	1,227.3	1,268.2	1,366.2	1,234.0	1,366.2	1,322.1	1,366.2	1,322.1	1,366.2
WS24 TORA	4,632.3	4,786.7	4,632.3	4,786.7	5,156.6	4,657.6	5,156.6	4,990.3	5,156.6	4,990.3	5,156.6
WS25 BETO	5,937.9	6,135.8	5,937.9	6,135.8	6,610.0	5,970.4	6,610.0	6,396.8	6,610.0	6,396.8	6,610.0
Sum	13,674,339.0	7,586,839.0	2,682,666.0	2,772,088.0	3,006,994.0	2,715,995.0	3,425,704.0	9,190,651.0	17,980,399.0	22,064,217.0	29,275,941.0

Water Demand
Scenario: Refe

Branch	Aug-35	Sep-35	Oct-35	Nov-35	Dec-35	**Sum**
EX05 YAMM	602,646.0	583,206.0	602,646.0	583,206.0	602,646.0	33,225,658.0
EX08 BAAL	86,158.3	83,379.0	86,158.3	83,379.0	86,158.3	2,424,748.0
EX18 HERM	30,783.0	29,790.0	30,783.0	29,790.0	30,783.0	1,307,712.0
EX23 JBEB	7,750.0	7,500.0	7,750.0	7,500.0	7,750.0	456,500.0
EX24 TORA	3,255.0	3,150.0	3,255.0	3,150.0	3,255.0	191,730.0
IR01	10,265,515.0	5,157,340.0	2,259,102.0	-	-	245,818,275.0
IR02	495,118.0	248,745.0	108,959.0	-	-	11,856,107.0
IR03	1,298,321.0	652,269.0	285,718.0	-	-	31,089,623.0
IR04	49,214.2	24,725.0	10,830.4	-	-	1,178,485.0
IR05	2,349,579.0	1,180,416.0	517,065.0	-	-	56,263,070.0
IR06	495,118.0	248,745.0	108,959.0	-	-	11,856,107.0
IR07	6,184,511.0	3,107,065.0	1,361,007.0	-	-	148,094,457.0
IR08	556,140.0	279,402.0	122,388.0	-	-	13,317,339.0
IR09	185,049.0	92,967.8	40,723.3	-	-	4,431,196.0
WS01 LABO	307,907.0	297,974.0	307,907.0	297,974.0	307,907.0	16,790,393.0
WS02 EQAA	65,344.6	63,236.7	65,344.6	63,236.7	65,344.6	3,386,526.0
WS03 NASB	6,772.8	6,554.3	6,772.8	6,554.3	6,772.8	351,006.0
WS04 OUOR	223,992.0	216,766.0	223,992.0	216,766.0	223,992.0	11,718,666.0
WS05 YAMM	130,602.0	126,389.0	130,602.0	126,389.0	130,602.0	6,768,533.0
WS06 YOMN	187,261.0	181,221.0	187,261.0	181,221.0	187,261.0	9,704,929.0
WS07 AARS	257,058.0	248,766.0	257,058.0	248,766.0	257,058.0	14,182,844.0
WS08 BAAL	346,503.0	335,326.0	346,503.0	335,326.0	346,503.0	19,117,854.0
WS09 CHAA	80,866.9	78,258.3	80,866.9	78,258.3	80,866.9	4,190,977.0
WS10 FEJD	91,988.6	89,021.2	91,988.6	89,021.2	91,988.6	5,075,346.0
WS11 HARB	27,585.4	26,695.6	27,585.4	26,695.6	27,585.4	1,429,632.0
WS12 MATN	54,397.7	52,642.9	54,397.7	52,642.9	54,397.7	2,819,193.0
WS13 IAAT	37,788.3	36,569.3	37,788.3	36,569.3	37,788.3	1,958,400.0
WS14 RABA	73,251.1	70,888.2	73,251.1	70,888.2	73,251.1	3,796,284.0
WS15 SBOU	34,125.7	33,024.9	34,125.7	33,024.9	34,125.7	1,768,586.0
WS16 YAML	2,616.1	2,531.7	2,616.1	2,531.7	2,616.1	135,582.0
WS17 HAKH	15,551.3	15,049.7	15,551.3	15,049.7	15,551.3	805,957.0
WS18 HERM	277,433.0	268,483.0	277,433.0	268,483.0	277,433.0	15,266,284.0
WS19 OUAD	11,330.7	10,965.2	11,330.7	10,965.2	11,330.7	587,219.0
WS20 FAMR	593.0	573.9	593.0	573.9	593.0	30,731.8
WS21 CHOU	14,940.9	14,458.9	14,940.9	14,458.9	14,940.9	774,321.0
WS22 HAOU	15,359.5	14,864.0	15,359.5	14,864.0	15,359.5	796,014.0
WS23 JBEB	1,366.2	1,322.1	1,366.2	1,322.1	1,366.2	70,803.7
WS24 TORA	5,156.6	4,990.3	5,156.6	4,990.3	5,156.6	267,246.0
WS25 BETO	6,610.0	6,396.8	6,610.0	6,396.8	6,610.0	342,569.0
Sum	24,885,559.0	13,901,668.0	7,821,745.0	2,909,994.0	3,006,994.0	683,646,903.0

Unmet Demand (Cubic Meter)
Scenario: Reference, Selected Demand Sites (34/40)

Demand Site	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21
IR01	0	0	0	0	0	37442	3077301	1017315	0	0	0	0	0	0	0	0	0
IR02	0	0	0	0	0	2045.34	148664	49308	0	0	0	0	0	0	0	0	0
IR03	0	0	0	0	0	5302.14	389798	129263	0	0	0	0	0	0	0	0	0
IR04	0	0	0	0	0	202.064	14776.8	4900.98	0	0	0	0	0	0	0	0	0
IR05	0	0	0	0	0	303203	1008870	537379	0	0	0	0	0	0	0	0	0
IR06	0	0	0	0	0	2002.62	148629	49273	0	0	0	0	0	0	0	0	0
IR07	0	0	0	0	0	24671.3	1856101	615052	0	0	0	0	0	0	0	0	0
IR08	0	0	0	0	0	2288.38	167002	55415.9	0	0	0	0	0	0	0	0	0
IR09	0	0	0	0	0	748.237	55548.9	18415.9	0	0	0	0	0	0	0	0	0
WS01 LABO	77668.5	72656.3	77668.5	75162.4	77668.5	75162.4	77668.5	77668.5	75162.4	77668.5	75162.4	77668.5	80778.4	72961.1	80778.4	78172.6	80778.4
WS02 EQAA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS03 NASB	3542.93	3314.35	3542.93	3428.64	3542.93	3428.64	3542.93	3542.93	3428.64	3542.93	3428.64	3542.93	3638.91	3286.76	3638.91	3521.53	3638.91
WS04 OUOR	41968.1	39260.5	41968.1	40614.3	41968.1	40614.3	41968.1	41968.1	40614.3	41968.1	40614.3	41968.1	44954.5	40604.1	44954.5	43504.4	44954.5
WS05 YAMM	21601.8	20207.7	21601.8	20904.3	21601.8	20904.3	21601.8	21601.8	20904.3	21601.8	20904.3	21601.8	23453.7	21183.9	23453.7	22696.9	23453.7
WS06 YOMN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS07 AARS	160377	150030	160377	155203	160377	155203	160377	160377	155203	160377	155203	160377	162717	146970	162717	157468	162717
WS08 BAAL	67405.9	63057.1	67405.9	65231.5	67405.9	65231.5	67405.9	67405.9	65231.5	67405.9	65231.5	67405.9	70577.6	63745.6	70577.6	68300.3	70577.6
WS09 CHAA	17951.7	16793.5	17951.7	17372.6	17951.7	17372.6	17951.7	17951.7	17372.6	17951.7	17372.6	17951.7	19098.1	17249.9	19098.1	18482	19098.1
WS10 FEJD	69023.6	64570.6	69023.6	66797.1	69023.6	66797.1	69023.6	69023.6	66797.1	69023.6	66797.1	69023.6	69865	63104.1	69865	67611.4	69865
WS11 HARB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS12 MATN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS13 IAAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS14 RABA	18756	17545.9	18756	18151	18756	18151	18756	18756	18151	18756	18151	18756	19797.2	17881.3	19797.2	19158.6	19797.2
WS15 SBOU	2115.07	1978.61	2115.07	2046.84	2115.07	2046.84	2115.07	2115.07	2046.84	2115.07	2046.84	2115.07	2598.72	2347.23	2598.72	2514.89	2598.72
WS16 YAML	2086.78	1952.15	2086.78	2019.47	2086.78	2019.47	2086.78	2086.78	2019.47	2086.78	2019.47	2086.78	2123.89	1918.35	2123.89	2055.38	2123.89
WS17 HAKH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS18 HERM	65168.6	60964.3	65168.6	63066.6	65168.6	63066.6	65168.6	65168.6	63066.6	65168.6	63066.6	65168.6	67767.6	61213.8	67767.6	65581.9	67767.6
WS19 OUAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS20 FAMR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS21 CHOU	11917.8	11149	11917.8	11533.4	11917.8	11533.4	11917.8	11917.8	11533.4	11917.8	11533.4	11917.8	12129.8	10955.9	12129.8	11738.5	12129.8
WS22 HAOU	9462.01	8851.56	9462.01	9156.79	9462.01	9156.79	9462.01	9462.01	9156.79	9462.01	9156.79	9462.01	9680.13	8743.35	9680.13	9367.87	9680.13
WS23 JBEB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS24 TORA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS25 BETO	5272.6	4932.44	5272.6	5102.52	5272.6	5102.52	5272.6	5272.6	5102.52	5272.6	5102.52	5272.6	5366.36	4847.03	5366.36	5193.25	5366.36
Sum	574318	537264	574318	555791	574318	933696	7441007	3050640	555791	574318	555791	574318	594547	537013	594547	575367	594547

Unmet Deman
Scenario: Refe

Demand Site	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25	Oct-25
IR01	37442	3077401	1017415	0	0	0	0	0	0	0	0	0	37442	3077301	1017315	0	0
IR02	2045.34	148664	49308	0	0	0	0	0	0	0	0	0	2045.34	148664	49308	0	0
IR03	5302.14	389798	129263	0	0	0	0	0	0	0	0	0	5302.14	389798	129263	0	0
IR04	202.064	14776.8	4900.98	0	0	0	0	0	0	0	0	0	202.064	14776.8	4900.98	0	0
IR05	303203	1008870	537379	0	0	0	0	0	0	0	0	0	303203	1008870	537379	0	0
IR06	2002.62	148629	49273	0	0	0	0	0	0	0	0	0	2002.62	148629	49273	0	0
IR07	24681.3	1856101	615052	0	0	0	0	0	0	0	0	0	24671.3	1856101	615052	0	0
IR08	2288.38	167002	55415.9	0	0	0	0	0	0	0	0	0	2288.38	167002	55391.5	0	0
IR09	748.237	55548.9	18415.9	0	0	0	0	0	0	0	0	0	748.237	55548.9	18415.9	0	0
WS01 LABO	78172.6	80778.4	80778.4	78172.6	80778.4	78172.6	80778.4	90526.4	81763.8	90526.4	87605.5	90526.4	87605.5	90526.4	90526.4	87605.5	90526.4
WS02 EQAA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS03 NASB	3521.53	3638.91	3638.91	3521.53	3638.91	3521.53	3638.91	3977.18	3592.29	3977.18	3848.88	3977.18	3848.88	3977.18	3977.18	3848.88	3977.18
WS04 OUOR	43504.4	44954.5	44954.5	43504.4	44954.5	43504.4	44954.5	55375.1	50016.2	55375.1	53588.8	55375.1	53588.8	55375.1	55375.1	53588.8	55375.1
WS05 YAMM	22696.9	23453.7	23453.7	22696.9	23453.7	22696.9	23453.7	29960.5	27061	29960.5	28993.3	29960.5	28993.3	29960.5	29960.5	28993.3	29960.5
WS06 YOMN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS07 AARS	157468	162717	162717	157468	162717	157468	162717	169777	153347	169777	164300	169777	164300	169777	169777	164300	169777
WS08 BAAL	68300.3	70577.6	70577.6	68300.3	70577.6	68300.3	70577.6	80046.1	72297.8	80046.1	77463.3	80046.1	77463.3	80046.1	80046.1	77463.3	80046.1
WS09 CHAA	18482	19098.1	19098.1	18482	19098.1	18482	19098.1	23126.9	20888.8	23126.9	22380.9	23126.9	22380.9	23126.9	23126.9	22380.9	23126.9
WS10 FEJD	67611.4	69865	69865	67611.4	69865	67611.4	69865	72378.7	65374.5	72378.7	70043.9	72378.7	70043.9	72378.7	72378.7	70043.9	72378.7
WS11 HARB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS12 MATN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS13 IAAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS14 RABA	19158.6	19797.2	19797.2	19158.6	19797.2	19158.6	19797.2	23442.1	21173.5	23442.1	22685.9	23442.1	22685.9	23442.1	23442.1	22685.9	23442.1
WS15 SBOU	2514.89	2598.72	2598.72	2514.89	2598.72	2514.89	2598.72	4299.01	3882.98	4299.01	4160.33	4299.01	4160.33	4299.01	4299.01	4160.33	4299.01
WS16 YAML	2055.38	2123.89	2123.89	2055.38	2123.89	2055.38	2123.89	2254.22	2036.07	2254.22	2181.5	2254.22	2181.5	2254.22	2254.22	2181.5	2254.22
WS17 HAKH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS18 HERM	65581.9	67767.6	67767.6	65581.9	67767.6	65581.9	67767.6	75622.1	68314.8	75622.1	73183	75622.1	73183	75622.1	75622.1	73183	75622.1
WS19 OUAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS20 FAMR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS21 CHOU	11738.5	12129.8	12129.8	11738.5	12129.8	11738.5	12129.8	12874.1	11628.2	12874.1	12458.8	12874.1	12458.8	12874.1	12874.1	12458.8	12874.1
WS22 HAOU	9367.87	9680.13	9680.13	9367.87	9680.13	9367.87	9680.13	10447.5	9436.47	10447.5	10110.5	10447.5	10110.5	10447.5	10447.5	10110.5	10447.5
WS23 JBEB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS24 TORA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS25 BETO	5193.25	5366.36	5366.36	5193.25	5366.36	5193.25	5366.36	5695.65	5144.46	5695.65	5511.92	5695.65	5511.92	5695.65	5695.65	5511.92	5695.65
Sum	953282	7461336	3070969	575367	594547	575367	594547	659802	595957	659802	638517	659802	1016421	7526491	3136100	638517	659802

Unmet Deman
Scenario: Refer

Demand Site	Nov-25	Dec-25	Jan-30	Feb-30	Mar-30	Apr-30	May-30	Jun-30	Jul-30	Aug-30	Sep-30	Oct-30	Nov-30	Dec-30	Jan-35	Feb-35	Mar-35
IR01	0	0	0	0	0	0	0	37442	3077301	1017315	0	0	0	0	0	0	0
IR02	0	0	0	0	0	0	0	2045.34	148664	49308	0	0	0	0	0	0	0
IR03	0	0	0	0	0	0	0	5302.14	389798	129263	0	0	0	0	0	0	0
IR04	0	0	0	0	0	0	0	202.064	14776.8	4900.98	0	0	0	0	0	0	0
IR05	0	0	0	0	0	0	0	303203	1008870	537379	0	0	0	0	0	0	0
IR06	0	0	0	0	0	0	0	2002.62	148629	49273	0	0	0	0	0	0	0
IR07	0	0	0	0	0	0	0	24671.3	1856101	615052	0	0	0	0	0	0	0
IR08	0	0	0	0	0	0	0	2288.38	167002	55391.5	0	0	0	0	0	0	0
IR09	0	0	0	0	0	0	0	748.237	55548.9	18415.9	0	0	0	0	0	0	0
WS01 LABO	87605.5	90526.4	103252	93258.1	103252	99920.8	103252	99920.8	103252	103252	99920.8	103252	99920.8	103252	116617	105329	116617
WS02 EQAA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS03 NASB	3848.88	3977.18	4427.26	3998.82	4427.26	4284.45	4427.26	4284.45	4427.26	4427.26	4284.45	4427.26	4284.45	4427.26	4913.68	4438.16	4913.68
WS04 OUOR	53588.8	55375.1	69288	62582.7	69288	67052.9	69288	67052.9	69288	69288	67052.9	69288	67052.9	69288	84198.5	76050.3	84198.5
WS05 YAMM	28993.3	29960.5	38657.7	34916.5	38657.7	37410	38657.7	37410	38657.7	38657.7	37410	38657.7	37410	38657.7	39100.1	35316.1	39100.1
WS06 YOMN	0	0	10767.1	9725.16	10767.1	10419.8	10767.1	10419.8	10767.1	10767.1	10419.8	10767.1	10419.8	10767.1	24201.2	21859.1	24201.2
WS07 AARS	164300	169777	178864	161555	178864	173095	178864	173095	178864	178864	173095	178864	173095	178864	188269	170050	188269
WS08 BAAL	77463.3	80046.1	92286.7	83353.8	92286.7	89309.1	92286.7	89309.1	92286.7	92286.7	89309.1	92286.7	89309.1	92286.7	104990	94830.1	104990
WS09 CHAA	22380.9	23126.9	28517.4	25757.6	28517.4	27597.5	28517.4	27597.5	28517.4	28517.4	27597.5	28517.4	27597.5	28517.4	34319.9	30998.6	34319.9
WS10 FEJD	70043.9	72378.7	75628.3	68309.6	75628.3	73188.7	75628.3	73188.7	75628.3	75628.3	73188.7	75628.3	73188.7	75628.3	79001.6	71356.4	79001.6
WS11 HARB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS12 MATN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS13 IAAT	0	0	1603.03	1447.9	1603.03	1551.32	1603.03	1551.32	1603.03	1603.03	1551.32	1603.03	1551.32	1603.03	4311.64	3894.39	4311.64
WS14 RABA	22685.9	23442.1	28320.4	25579.7	28320.4	27406.8	28320.4	27406.8	28320.4	28320.4	27406.8	28320.4	27406.8	28320.4	15734.3	14211.7	15734.3
WS15 SBOU	4160.33	4299.01	6576.26	5939.85	6576.26	6364.12	6576.26	6364.12	6576.26	6576.26	6364.12	6576.26	6364.12	6576.26	9019.42	8146.58	9019.42
WS16 YAML	2181.5	2254.22	2428.43	2193.42	2428.43	2350.1	2428.43	2350.1	2428.43	2428.43	2350.1	2428.43	2350.1	2428.43	2616.11	2362.94	2616.11
WS17 HAKH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS18 HERM	73183	75622.1	85802.8	77508.9	85802.8	83035.3	85802.8	83035.3	85802.8	85802.8	83035.3	85802.8	83035.3	85802.8	88352.8	79804.5	88352.8
WS19 OUAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS20 FAMR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS21 CHOU	12458.8	12874.1	13869	12526.9	13869	13421.7	13869	13421.7	13869	13869	13421.7	13869	13421.7	13869	5644.67	5098.41	5644.67
WS22 HAOU	10110.5	10447.5	11468.8	10358.9	11468.8	11098.8	11468.8	11098.8	11468.8	11468.8	11098.8	11468.8	11098.8	11468.8	3271.57	2954.97	3271.57
WS23 JBEB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS24 TORA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS25 BETO	5511.92	5695.65	6135.84	5542.05	6135.84	5937.91	6135.84	5937.91	6135.84	6135.84	5937.91	6135.84	5937.91	6135.84	6610.04	5970.36	6610.04
Sum	638517	659802	757894	684555	757894	733444	757894	1111349	7624583	3234191	733444	757894	733444	757894	811172	732672	811172

Unmet Demand
Scenario: Refer

Demand Site	Apr-35	May-35	Jun-35	Jul-35	Aug-35	Sep-35	Oct-35	Nov-35	Dec-35	**Sum**
IR01	0	0	37442	3077301	1017315	0	0	0	0	20660490
IR02	0	0	2045.34	148664	49308	0	0	0	0	1000084
IR03	0	0	5302.14	389798	129263	0	0	0	0	2621815
IR04	0	0	202.064	14776.8	4900.98	0	0	0	0	99399.3
IR05	0	0	303203	1008870	537379	0	0	0	0	9247256
IR06	0	0	2002.62	148629	49273	0	0	0	0	999521
IR07	0	0	24671.3	1856101	615052	0	0	0	0	12479128
IR08	0	0	2288.38	167002	55391.5	0	0	0	0	1123458
IR09	0	0	748.237	55548.9	18415.9	0	0	0	0	373565
WS01 LABO	112854	116617	112854	116617	116617	112854	116617	112854	116617	5522726
WS02 EQAA	0	0	0	0	0	0	0	0	0	0
WS03 NASB	4755.17	4913.68	4755.17	4913.68	4913.68	4755.17	4913.68	4755.17	4913.68	241485
WS04 OUOR	81482.5	84198.5	81482.5	84198.5	84198.5	81482.5	84198.5	81482.5	84198.5	3483974
WS05 YAMM	37838.1	39100.1	37838.1	39100.1	39100.1	37838.1	39100.1	37838.1	39100.1	1799472
WS06 YOMN	23420.5	24201.2	23420.5	24201.2	24201.2	23420.5	24201.2	23420.5	24201.2	411724
WS07 AARS	182196	188269	182196	188269	188269	182196	188269	182196	188269	10131028
WS08 BAAL	101604	104990	101604	104990	104990	101604	104990	101604	104990	4892064
WS09 CHAA	33212.8	34319.9	33212.8	34319.9	34319.9	33212.8	34319.9	33212.8	34319.9	1448969
WS10 FEJD	76453.2	79001.6	76453.2	79001.6	79001.6	76453.2	79001.6	76453.2	79001.6	4310372
WS11 HARB	0	0	0	0	0	0	0	0	0	0
WS12 MATN	0	0	0	0	0	0	0	0	0	0
WS13 IAAT	4172.56	4311.64	4172.56	4311.64	4311.64	4172.56	4311.64	4172.56	4311.64	69640.5
WS14 RABA	15226.8	15734.3	15226.8	15734.3	15734.3	15226.8	15734.3	15226.8	15734.3	1249258
WS15 SBOU	8728.48	9019.42	8728.48	9019.42	9019.42	8728.48	9019.42	8728.48	9019.42	289813
WS16 YAML	2531.72	2616.11	2531.72	2616.11	2616.11	2531.72	2616.11	2531.72	2616.11	135582
WS17 HAKH	0	0	0	0	0	0	0	0	0	0
WS18 HERM	85503.4	88352.8	85503.4	88352.8	88352.8	85503.4	88352.8	85503.4	88352.8	4508285
WS19 OUAD	0	0	0	0	0	0	0	0	0	0
WS20 FAMR	0	0	0	0	0	0	0	0	0	0
WS21 CHOU	5462.59	5644.67	5462.59	5644.67	5644.67	5462.59	5644.67	5462.59	5644.67	664866
WS22 HAOU	3166.03	3271.57	3166.03	3271.57	3271.57	3166.03	3271.57	3166.03	3271.57	522256
WS23 JBEB	0	0	0	0	0	0	0	0	0	0
WS24 TORA	0	0	0	0	0	0	0	0	0	0
WS25 BETO	6396.81	6610.04	6396.81	6610.04	6610.04	6396.81	6610.04	6396.81	6610.04	342569
Sum	785005	811172	1162910	7677861	3287470	785005	811172	785005	811172	88628800

Transmission Link Flow (Cubic Meter)
Scenario: Reference, All Transmission Links, Annual Total

Transmission Link	2020	2021	2025	2030	2035	**Sum**
Transmission Link from GW01 C to IR05	1235923	1235923	1235923	1235923	1235923	6179616
Transmission Link from GW01 C to WS01 LABO	2730474	2723108	2723015	2723015	2723015	13622627
Transmission Link from GW01 E to IR05	1014552	1014552	1014552	1014552	1014552	5072760
Transmission Link from GW01 N to IR05	247782	247782	247782	247782	247782	1238910
Transmission Link from GW01 N to WS01 LABO	1375428	1371670	1371670	1371670	1371670	6862108
Transmission Link from GW02 C to IR07	3460771	3460771	3460771	3460771	3460771	17303855
Transmission Link from GW02 C to WS02 EQAA	1230780	1249242	1325900	1428370	1538761	6773052
Transmission Link from GW02 N to IR07	2841492	2841492	2841492	2841492	2841492	14207460
Transmission Link from GW02 N to WS02 EQAA	0	0	0	0	0	0
Transmission Link from GW03 N to IR01	86242	86242	86242	86242	86242	431210
Transmission Link from GW03 N to WS03 NASB	43908.7	43790.5	43770.3	43792.4	43779.7	219042
Transmission Link from GW04 C to IR01	542490	542490	542490	542490	542490	2712450
Transmission Link from GW04 C to IR03	7105	7105	7105	7105	7105	35525
Transmission Link from GW04 C to WS04 OUOR	3300864	3292429	3292389	3291795	3291907	16469383
Transmission Link from GW05 C to EX05 YAMM	63318	63145	63145	63145	630793	883546
Transmission Link from GW05 C to IR01	332984	332984	332984	332984	332984	1664920
Transmission Link from GW05 C to WS05 YAMM	526834	525402	525394	525394	735610	2838634
Transmission Link from GW06 C to IR01	66340	66340	66340	66340	66340	331700
Transmission Link from GW06 C to IR03	516653	516653	516653	516653	516653	2583264
Transmission Link from GW06 C to IR04	172036	172036	172036	172036	172036	860182
Transmission Link from GW06 C to WS06 YOMN	1447288	1505877	1725559	1765666	1765666	8210057
Transmission Link from GW06 E to IR03	754136	754136	754136	754136	754136	3770680
Transmission Link from GW06 N to IR01	106144	106144	106144	106144	106144	530720
Transmission Link from GW06 N to IR04	8848	8848	8848	8848	8848	44240
Transmission Link from GW07 C to WS07 AARS	1624529	1620357	1619522	1619360	1619865	8103632
Transmission Link from GW08 C to EX08 BAAL	0	0	0	0	0	0
Transmission Link from GW08 C to WS08 BAAL	5086276	5072338	5072338	5072338	5072394	25375682
Transmission Link from GW08 E to IR01	3155644	3155644	3155644	3155644	3155644	15778220
Transmission Link from GW08 N to EX08 BAAL	37075.8	36974.5	36974.5	36974.5	36974.5	184974
Transmission Link from GW08 N to WS08 BAAL	616527	614842	614842	614842	614842	3075897
Transmission Link from GW09 C to IR03	945757	945757	945757	945757	945757	4728786
Transmission Link from GW09 C to WS09 CHAA	1099254	1096263	1096258	1096133	1096106	5484015
Transmission Link from GW09 N to IR03	878898	878898	878898	878898	878898	4394490
Transmission Link from GW10 C to IR06	78245.8	78245.8	78245.8	78245.8	78245.8	391229
Transmission Link from GW10 C to WS10 FEJD	148548	148142	148142	148142	148142	741116
Transmission Link from GW10 E to IR06	20330	20330	20330	20330	20330	101650
Transmission Link from GW11 C to IR02	2447.98	2447.98	2447.98	2447.98	2447.98	12239.9
Transmission Link from GW11 C to WS11 HARB	519578	527371	559733	602991	649592	2859265
Transmission Link from GW11 N to IR03	600231	600231	600231	600231	600231	3001155
Transmission Link from GW12 C to WS12 MATN	1024591	1039960	1103776	1189080	1280977	5638385
Transmission Link from GW13 N to IR01	3022956	3022341	3022956	3022956	3022956	15114165
Transmission Link from GW13 N to WS13 IAAT	711750	722426	766757	788266	788321	3777520
Transmission Link from GW14 C to IR06	439796	439796	439796	439796	439796	2198978
Transmission Link from GW14 C to WS14 RABA	936816	934204	934306	934299	1354427	5094052
Transmission Link from GW15 C to WS15 SBOU	592822	591211	591206	591095	591213	2957546
Transmission Link from GW17 C to IR05	5307	5307	5307	5307	5307	26535
Transmission Link from GW17 C to WS17 HAKH	0	0	0	0	0	0
Transmission Link from GW17 N to WS17 HAKH	292913	297306	315550	339937	366209	1611914
Transmission Link from GW18 C to EX18 HERM	0	0	0	0	126290	126290
Transmission Link from GW18 C to IR08	1937405	1937405	1937405	1937405	1937405	9687027
Transmission Link from GW18 C to WS18 HERM	716756	714788	714775	714778	904355	3765452
Transmission Link from GW18 N to IR08	990288	990288	990288	990288	990288	4951439
Transmission Link from GW19 C to WS19 OUAD	213415	216617	229909	247677	266819	1174438
Transmission Link from GW20 C to WS20 FAMR	11169	11336.5	12032.2	12962.1	13963.8	61463.6
Transmission Link from GW21 N to IR07	627840	627809	627840	627840	627840	3139168
Transmission Link from GW21 N to WS21 CHOU	0	0	0	0	218911	218911
Transmission Link from GW22 N to IR08	27920.7	27920.7	27958.1	27958.1	27958.1	139716
Transmission Link from GW22 N to IR09	122479	122479	122479	122479	122479	612395

Transmission Link Flow (Cubic Meter)
Scenario: Reference, All Transmission Links, Annual Total

Transmission Link	2020	2021	2025	2030	2035	**Sum**
Transmission Link from GW22 N to WS22 HAOU	65873.4	65686.9	65635	65671.4	284651	547517
Transmission Link from GW23 C to EX23 JBEB	91500	91250	91250	91250	91250	456500
Transmission Link from GW23 C to WS23 JBEB	25732.5	26118.5	27721.2	29863.6	32171.6	141607
Transmission Link from GW24 C to EX24 TORA	38430	38325	38325	38325	38325	191730
Transmission Link from GW24 C to WS24 TORA	97126.5	98583.4	104633	112719	121431	534493
Transmission Link from RW IR01 to IR01	14169447	14169447	14169447	14169447	14169447	70847236
Transmission Link from RW IR01S to IR01	47797133	47797441	47797133	47797133	47797133	238985975
Transmission Link from RW IR02 to IR02	3337867	3337867	3337867	3337867	3337867	16689334
Transmission Link from RW IR03 to IR03	5056546	5056546	5056546	5056546	5056546	25282729
Transmission Link from RW IR04 to IR04	151142	151142	151142	151142	151142	755711
Transmission Link from RW IR05 to IR05	11962840	11962840	11962840	11962840	11962840	59814199
Transmission Link from RW IR06 to IR06	2802116	2802116	2802116	2802116	2802116	14010582
Transmission Link from RW IR07A to IR07	30821389	30821404	30821389	30821389	30821389	154106958
Transmission Link from RW IR07L to IR07	3976306	3976306	3976306	3976306	3976306	19881532
Transmission Link from RW IR08 to IR08	244624	244624	244624	244624	244624	1223120
Transmission Link from RW IR08A to IR08	244624	244624	244624	244624	244624	1223120
Transmission Link from RW IR08S to IR08	307079	307079	307079	307079	307079	1535393
Transmission Link from RW IR09 to IR09	1126023	1126023	1126023	1126023	1126023	5630113
Transmission Link from RW01 LABO to WS01 LABO	411018	409895	409895	409895	409895	2050598
Transmission Link from RW05 YAMM to WS05 YAMM	1423008	1419120	1419120	1419120	1419120	7099488
Transmission Link from RW06 YOMN3 to WS06 YOMN	249816	249134	249134	249134	249134	1246352
Transmission Link from RW06 YOMN4 to WS06 YOMN	1830000	1825000	1825000	1825000	1825000	9130000
Transmission Link from RW10 FEJD to WS10 FEJD	158112	157680	157680	157680	157680	788832
Transmission Link from RW18 HERM to WS18 HERM	3557886	3548165	3548165	3548165	3548165	17750546
Transmission Link from RWE05 YAMM to EX05 YAMM	6482592	6464880	6464880	6464880	6464880	32342112
Transmission Link from RWE08 BAAL5 to EX08 BAAL	0	0	0	0	315360	315360
Transmission Link from RWE08 BAAL6 to EX08 BAAL	0	0	0	0	346750	346750
Transmission Link from RWE08 BAAL7 to EX08 BAAL	316224	315360	315360	315360	315360	1577664
Transmission Link from RWE18 HERM to EX18 HERM	236802	236155	236155	236155	236155	1181422
Transmission Link from WWTP DEL to SP IR01	0	0	0	0	0	0
Transmission Link from WWTP IAAT to Assi	0	0	0	0	0	0
Sum	185581216	185610009	186086133	186431158	189352147	933060663

Unmet Demand (Cubic Meter)
Scenario: Minor losses, Selected Demand Sites (34/40)

Demand Site	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21
IR01	0	0	0	0	0	37442	3077301	1017315	0	0	0	0	0	0	0	0	0
IR02	0	0	0	0	0	2045.34	148664	49308	0	0	0	0	0	0	0	0	0
IR03	0	0	0	0	0	5302.14	389798	129263	0	0	0	0	0	0	0	0	0
IR04	0	0	0	0	0	202.064	14776.8	4900.98	0	0	0	0	0	0	0	0	0
IR05	0	0	0	0	0	303203	1008870	537379	0	0	0	0	0	0	0	0	0
IR06	0	0	0	0	0	2002.62	148629	49273	0	0	0	0	0	0	0	0	0
IR07	0	0	0	0	0	24671.3	1856101	615052	0	0	0	0	0	0	0	0	0
IR08	0	0	0	0	0	2288.38	167002	55415.9	0	0	0	0	0	0	0	0	0
IR09	0	0	0	0	0	748.237	55548.9	18415.9	0	0	0	0	0	0	0	0	0
WS01 LABO	77668.5	72656.3	77668.5	75162.4	77668.5	75162.4	77668.5	77668.5	75162.4	77668.5	75162.4	77668.5	0	0	0	0	0
WS02 EQAA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS03 NASB	3542.93	3314.35	3542.93	3428.64	3542.93	3428.64	3542.93	3542.93	3428.64	3542.93	3428.64	3542.93	2709.67	2447.44	2709.67	2622.26	2709.67
WS04 OUOR	41968.1	39260.5	41968.1	40614.3	41968.1	40614.3	41968.1	41968.1	40614.3	41968.1	40614.3	41968.1	0	0	0	0	0
WS05 YAMM	21601.8	20207.7	21601.8	20904.3	21601.8	20904.3	21601.8	21601.8	20904.3	21601.8	20904.3	21601.8	0	0	0	0	0
WS06 YOMN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS07 AARS	160377	150030	160377	155203	160377	155203	160377	160377	155203	160377	155203	160377	128312	115895	128312	124173	128312
WS08 BAAL	67405.9	63057.1	67405.9	65231.5	67405.9	65231.5	67405.9	67405.9	65231.5	67405.9	65231.5	67405.9	0	0	0	0	0
WS09 CHAA	17951.7	16793.5	17951.7	17372.6	17951.7	17372.6	17951.7	17951.7	17372.6	17951.7	17372.6	17951.7	0	0	0	0	0
WS10 FEJD	69023.6	64570.6	69023.6	66797.1	69023.6	66797.1	69023.6	69023.6	66797.1	69023.6	66797.1	69023.6	63371	57238.1	63371	61326.4	63371
WS11 HARB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS12 MATN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS13 IAAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS14 RABA	18756	17545.9	18756	18151	18756	18151	18756	18756	18151	18756	18151	18756	0	0	0	0	0
WS15 SBOU	2115.07	1978.61	2115.07	2046.84	2115.07	2046.84	2115.07	2115.07	2046.84	2115.07	2046.84	2115.07	0	0	0	0	0
WS16 YAML	2086.78	1952.15	2086.78	2019.47	2086.78	2019.47	2086.78	2086.78	2019.47	2086.78	2019.47	2086.78	2123.89	1918.35	2123.89	2055.38	2123.89
WS17 HAKH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS18 HERM	65168.6	60964.3	65168.6	63066.6	65168.6	63066.6	65168.6	65168.6	63066.6	65168.6	63066.6	65168.6	0	0	0	0	0
WS19 OUAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS20 FAMR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS21 CHOU	11917.8	11149	11917.8	11533.4	11917.8	11533.4	11917.8	11917.8	11533.4	11917.8	11533.4	11917.8	12129.8	10955.9	12129.8	11738.5	12129.8
WS22 HAOU	9462.01	8851.56	9462.01	9156.79	9462.01	9156.79	9462.01	9462.01	9156.79	9462.01	9156.79	9462.01	8286.04	7484.16	8286.04	8018.74	8286.04
WS23 JBEB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS24 TORA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS25 BETO	5272.6	4932.44	5272.6	5102.52	5272.6	5102.52	5272.6	5272.6	5102.52	5272.6	5102.52	5272.6	5366.36	4847.03	5366.36	5193.25	5366.36
Sum	574318	537264	574318	555791	574318	933696	7441007	3050640	555791	574318	555791	574318	222299	200786	222299	215127	222299

Unmet Deman
Scenario: Mino

Demand Site	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25	Oct-25
IR01	22442	3062001	1002015	0	0	0	0	0	0	0	0	0	27942	3067601	1007615	0	0
IR02	2045.34	148664	49308	0	0	0	0	0	0	0	0	0	2045.34	148664	49308	0	0
IR03	5302.14	389798	129263	0	0	0	0	0	0	0	0	0	5302.14	389798	129263	0	0
IR04	202.064	14776.8	4900.98	0	0	0	0	0	0	0	0	0	202.064	14776.8	4900.98	0	0
IR05	290655	995838	524426	0	0	0	0	0	0	0	0	0	298883	1004301	532979	0	0
IR06	2002.62	148629	49273	0	0	0	0	0	0	0	0	0	2002.62	148629	49273	0	0
IR07	24761.3	1856251	615122	0	0	0	0	0	0	0	0	0	24701.3	1856231	615012	0	0
IR08	2288.38	167002	55391.5	0	0	0	0	0	0	0	0	0	2288.38	167002	55391.5	0	0
IR09	748.237	55548.9	18415.9	0	0	0	0	0	0	0	0	0	748.237	55548.9	18415.9	0	0
WS01 LABO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS02 EQAA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS03 NASB	2622.26	2709.67	2709.67	2622.26	2709.67	2622.26	2709.67	3046.35	2751.54	3046.35	2948.08	3046.35	2948.08	3046.35	3046.35	2948.08	3046.35
WS04 OUOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS05 YAMM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS06 YOMN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS07 AARS	124173	128312	128312	124173	128312	124173	128312	135378	122277	135378	131011	135378	131011	135378	135378	131011	135378
WS08 BAAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS09 CHAA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS10 FEJD	61326.4	63371	63371	61326.4	63371	61326.4	63371	65884.7	59508.5	65884.7	63758.9	65884.7	63758.9	65884.7	65884.7	63758.9	65884.7
WS11 HARB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS12 MATN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS13 IAAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS14 RABA	0	0	0	0	0	0	0	3610.35	3260.96	3610.35	3493.89	3610.35	3493.89	3610.35	3610.35	3493.89	3610.35
WS15 SBOU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS16 YAML	2055.38	2123.89	2123.89	2055.38	2123.89	2055.38	2123.89	2254.22	2036.07	2254.22	2181.5	2254.22	2181.5	2254.22	2254.22	2181.5	2254.22
WS17 HAKH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS18 HERM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS19 OUAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS20 FAMR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS21 CHOU	11738.5	12129.8	12129.8	11738.5	12129.8	11738.5	12129.8	12874.1	11628.2	12874.1	12458.8	12874.1	12458.8	12874.1	12874.1	12458.8	12874.1
WS22 HAOU	8018.74	8286.04	8286.04	8018.74	8286.04	8018.74	8286.04	9052.57	8176.52	9052.57	8760.56	9052.57	8760.56	9052.57	9052.57	8760.56	9052.57
WS23 JBEB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS24 TORA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS25 BETO	5193.25	5366.36	5366.36	5193.25	5366.36	5193.25	5366.36	5695.65	5144.46	5695.65	5511.92	5695.65	5511.92	5695.65	5695.65	5511.92	5695.65
Sum	565574	7060806	2670414	215127	222299	215127	222299	237796	214783	237796	230124	237796	594239	7090346	2699953	230124	237796

Unmet Demand
Scenario: Mino

Demand Site	Nov-25	Dec-25	Jan-30	Feb-30	Mar-30	Apr-30	May-30	Jun-30	Jul-30	Aug-30	Sep-30	Oct-30	Nov-30	Dec-30	Jan-35	Feb-35	Mar-35
IR01	0	0	0	0	0	0	0	35242	3075101	1015115	0	0	0	0	0	0	0
IR02	0	0	0	0	0	0	0	2045.34	148664	49308	0	0	0	0	0	0	0
IR03	0	0	0	0	0	0	0	5302.14	389798	129263	0	0	0	0	0	0	0
IR04	0	0	0	0	0	0	0	202.064	14776.8	4900.98	0	0	0	0	0	0	0
IR05	0	0	0	0	0	0	0	303203	1008870	537379	0	0	0	0	0	0	0
IR06	0	0	0	0	0	0	0	2002.62	148629	49273	0	0	0	0	0	0	0
IR07	0	0	0	0	0	0	0	24681.3	1856111	615062	0	0	0	0	0	0	0
IR08	0	0	0	0	0	0	0	2288.38	167002	55391.5	0	0	0	0	0	0	0
IR09	0	0	0	0	0	0	0	748.237	55548.9	18415.9	0	0	0	0	0	0	0
WS01 LABO	0	0	7599.19	6863.78	7599.19	7354.05	7599.19	7354.05	7599.19	7599.19	7354.05	7599.19	7354.05	7599.19	20968.4	18939.2	20968.4
WS02 EQAA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS03 NASB	2948.08	3046.35	3498.05	3159.53	3498.05	3385.21	3498.05	3385.21	3498.05	3498.05	3385.21	3498.05	3385.21	3498.05	3984.45	3598.86	3984.45
WS04 OUOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14268.3	12887.5	14268.3
WS05 YAMM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS06 YOMN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS07 AARS	131011	135378	144419	130443	144419	139760	144419	139760	144419	144419	139760	144419	139760	144419	153849	138961	153849
WS08 BAAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS09 CHAA	0	0	5232.07	4725.74	5232.07	5063.29	5232.07	5063.29	5232.07	5232.07	5063.29	5232.07	5063.29	5232.07	11038.3	9970.1	11038.3
WS10 FEJD	63758.9	65884.7	69134.3	62443.6	69134.3	66903.7	69134.3	66903.7	69134.3	69134.3	66903.7	69134.3	66903.7	69134.3	72507.6	65490.4	72507.6
WS11 HARB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS12 MATN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS13 IAAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS14 RABA	3493.89	3610.35	8492.71	7670.84	8492.71	8218.75	8492.71	8218.75	8492.71	8492.71	8218.75	8492.71	8218.75	8492.71	0	0	0
WS15 SBOU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS16 YAML	2181.5	2254.22	2428.43	2193.42	2428.43	2350.1	2428.43	2350.1	2428.43	2428.43	2350.1	2428.43	2350.1	2428.43	2616.11	2362.94	2616.11
WS17 HAKH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS18 HERM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS19 OUAD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS20 FAMR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS21 CHOU	12458.8	12874.1	13869	12526.9	13869	13421.7	13869	13421.7	13869	13869	13421.7	13869	13421.7	13869	995.064	898.767	995.064
WS22 HAOU	8760.56	9052.57	10075.8	9100.76	10075.8	9750.81	10075.8	9750.81	10075.8	10075.8	9750.81	10075.8	9750.81	10075.8	0	0	0
WS23 JBEB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS24 TORA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WS25 BETO	5511.92	5695.65	6135.84	5542.05	6135.84	5937.91	6135.84	5937.91	6135.84	6135.84	5937.91	6135.84	5937.91	6135.84	6610.04	5970.36	6610.04
Sum	230124	237796	270884	244669	270884	262146	270884	637861	7135383	2744992	262146	270884	262146	270884	286838	259079	286838

Unmet Demand
Scenario: Mino

Demand Site	Apr-35	May-35	Jun-35	Jul-35	Aug-35	Sep-35	Oct-35	Nov-35	Dec-35	**Sum**
IR01	0	0	31842	3071701	1011715	0	0	0	0	20562390
IR02	0	0	2045.34	148664	49308	0	0	0	0	1000084
IR03	0	0	5302.14	389798	129263	0	0	0	0	2621815
IR04	0	0	202.064	14776.8	4900.98	0	0	0	0	99399.3
IR05	0	0	303203	1008870	537379	0	0	0	0	9195435
IR06	0	0	2002.62	148629	49273	0	0	0	0	999521
IR07	0	0	24681.3	1856101	615052	0	0	0	0	12479588
IR08	0	0	2288.38	167002	55415.9	0	0	0	0	1123458
IR09	0	0	748.237	55548.9	18415.9	0	0	0	0	373565
WS01 LABO	20292	20968.4	20292	20968.4	20968.4	20292	20968.4	20292	20968.4	1253346
WS02 EQAA	0	0	0	0	0	0	0	0	0	0
WS03 NASB	3855.92	3984.45	3855.92	3984.45	3984.45	3855.92	3984.45	3855.92	3984.45	197702
WS04 OUOR	13808	14268.3	13808	14268.3	14268.3	13808	14268.3	13808	14268.3	663492
WS05 YAMM	0	0	0	0	0	0	0	0	0	255038
WS06 YOMN	0	0	0	0	0	0	0	0	0	0
WS07 AARS	148886	153849	148886	153849	153849	148886	153849	148886	153849	8510080
WS08 BAAL	0	0	0	0	0	0	0	0	0	795825
WS09 CHAA	10682.3	11038.3	10682.3	11038.3	11038.3	10682.3	11038.3	10682.3	11038.3	403516
WS10 FEJD	70168.2	72507.6	70168.2	72507.6	72507.6	70168.2	72507.6	70168.2	72507.6	4004516
WS11 HARB	0	0	0	0	0	0	0	0	0	0
WS12 MATN	0	0	0	0	0	0	0	0	0	0
WS13 IAAT	0	0	0	0	0	0	0	0	0	0
WS14 RABA	0	0	0	0	0	0	0	0	0	363946
WS15 SBOU	0	0	0	0	0	0	0	0	0	24971.4
WS16 YAML	2531.72	2616.11	2531.72	2616.11	2616.11	2531.72	2616.11	2531.72	2616.11	135582
WS17 HAKH	0	0	0	0	0	0	0	0	0	0
WS18 HERM	0	0	0	0	0	0	0	0	0	769411
WS19 OUAD	0	0	0	0	0	0	0	0	0	0
WS20 FAMR	0	0	0	0	0	0	0	0	0	0
WS21 CHOU	962.965	995.064	962.965	995.064	995.064	962.965	995.064	962.965	995.064	610120
WS22 HAOU	0	0	0	0	0	0	0	0	0	434496
WS23 JBEB	0	0	0	0	0	0	0	0	0	0
WS24 TORA	0	0	0	0	0	0	0	0	0	0
WS25 BETO	6396.81	6610.04	6396.81	6610.04	6610.04	6396.81	6610.04	6396.81	6610.04	342569
Sum	277584	286838	649899	7147927	2757560	277584	286838	277584	286838	67219866

Transmission Link Flow (Cubic Meter)
Scenario: Minor losses, All Transmission Links, Annual Total

Transmission Link	2020	2021	2025	2030	2035	**Sum**
Transmission Link from GW01 C to IR05	1235923	1235982	1235982	1235923	1235923	6179734
Transmission Link from GW01 C to WS01 LABO	2730474	2605615	2681820	2723131	2723058	13464098
Transmission Link from GW01 E to IR05	1014552	1014552	1014552	1014552	1014552	5072760
Transmission Link from GW01 N to IR05	247782	247782	247782	247782	247782	1238910
Transmission Link from GW01 N to WS01 LABO	1375428	1371670	1371670	1371670	1371670	6862108
Transmission Link from GW02 C to IR07	3460771	3460771	3460771	3460771	3460771	17303855
Transmission Link from GW02 C to WS02 EQAA	1230780	832828	883933	952247	1025840	4925628
Transmission Link from GW02 N to IR07	2841492	2841492	2841492	2841492	2841492	14207460
Transmission Link from GW02 N to WS02 EQAA	0	0	0	0	0	0
Transmission Link from GW03 N to IR01	86242	86242	86242	86242	86242	431210
Transmission Link from GW03 N to WS03 NASB	43908.7	43781.8	43793.2	43782.5	43774.4	219041
Transmission Link from GW04 C to IR01	542490	542490	542490	542490	542490	2712450
Transmission Link from GW04 C to IR03	7105	7105	7105	7105	7105	35525
Transmission Link from GW04 C to WS04 OUOR	3300864	2900691	3064255	3282276	3292434	15840520
Transmission Link from GW05 C to EX05 YAMM	63318	63145	63145	63145	630793	883546
Transmission Link from GW05 C to IR01	332984	332984	332984	332984	332984	1664920
Transmission Link from GW05 C to WS05 YAMM	526834	405591	447887	504577	688589	2573478
Transmission Link from GW06 C to IR01	66340	66340	66340	66340	66340	331700
Transmission Link from GW06 C to IR03	516653	516653	516653	516653	516653	2583264
Transmission Link from GW06 C to IR04	172036	172036	172036	172036	172036	860182
Transmission Link from GW06 C to WS06 YOMN	1447288	312540	458995	654765	865666	3739254
Transmission Link from GW06 E to IR03	754136	754136	754136	754136	754136	3770680
Transmission Link from GW06 N to IR01	106144	106144	106144	106144	106144	530720
Transmission Link from GW06 N to IR04	8848	8848	8848	8848	8848	44240
Transmission Link from GW07 C to WS07 AARS	1624529	1620357	1619709	1620331	1620268	8105195
Transmission Link from GW08 C to EX08 BAAL	0	0	0	0	0	0
Transmission Link from GW08 C to WS08 BAAL	5086276	4284598	4433243	4625407	4824886	23254409
Transmission Link from GW08 E to IR01	3155644	3155644	3155644	3155644	3155644	15778220
Transmission Link from GW08 N to EX08 BAAL	37075.8	36974.5	36974.5	36974.5	36974.5	184974
Transmission Link from GW08 N to WS08 BAAL	616527	614842	614842	614842	614842	3075897
Transmission Link from GW09 C to IR03	945757	945757	945757	945757	945757	4728786
Transmission Link from GW09 C to WS09 CHAA	1099254	1030661	1093906	1096310	1096233	5416365
Transmission Link from GW09 N to IR03	878898	878898	878898	878898	878898	4394490
Transmission Link from GW10 C to IR06	78245.8	78245.8	78245.8	78245.8	78245.8	391229
Transmission Link from GW10 C to WS10 FEJD	148548	148153	148153	148153	148153	741161
Transmission Link from GW10 E to IR06	20330	20330	20330	20330	20330	101650
Transmission Link from GW11 C to IR02	2447.98	2447.98	2447.98	2447.98	2447.98	12239.9
Transmission Link from GW11 C to WS11 HARB	519578	351581	373155	401994	433062	2079369
Transmission Link from GW11 N to IR03	600231	600231	600231	600231	600231	3001155
Transmission Link from GW12 C to WS12 MATN	1024591	693307	735851	792720	853985	4100454
Transmission Link from GW13 N to IR01	3022956	3026174	3026174	3026174	3026174	15127652
Transmission Link from GW13 N to WS13 IAAT	711750	481618	511171	550677	593235	2848451
Transmission Link from GW14 C to IR06	439796	439796	439796	439796	439796	2198978
Transmission Link from GW14 C to WS14 RABA	936816	933597	934207	934139	1149963	4888723
Transmission Link from GW15 C to WS15 SBOU	592822	434938	461627	497303	535737	2522427
Transmission Link from GW17 C to IR05	5307	5307	5307	5307	5307	26535
Transmission Link from GW17 C to WS17 HAKH	0	0	0	0	0	0
Transmission Link from GW17 N to WS17 HAKH	292913	198204	210367	226625	244139	1172247
Transmission Link from GW18 C to EX18 HERM	0	0	0	0	126290	126290
Transmission Link from GW18 C to IR08	1937405	1937405	1937405	1937405	1937405	9687027
Transmission Link from GW18 C to WS18 HERM	716756	357690	480997	640823	807232	3003499
Transmission Link from GW18 N to IR08	990288	990288	990288	990288	990288	4951439
Transmission Link from GW19 C to WS19 OUAD	213415	144411	153273	165118	177879	854097
Transmission Link from GW20 C to WS20 FAMR	11169	7557.69	8021.46	8641.39	9309.23	44698.8
Transmission Link from GW21 N to IR07	627840	628623	628623	627778	627824	3140689
Transmission Link from GW21 N to WS21 CHOU	0	0	0	0	218935	218935
Transmission Link from GW22 N to IR08	27920.7	27958.1	27958.1	27958.1	27920.7	139716
Transmission Link from GW22 N to IR09	122479	122479	122479	122479	122479	612395

Transmission Link Flow (Cubic Meter)
Scenario: Minor losses, All Transmission Links, Annual Total

Transmission Link	2020	2021	2025	2030	2035	**Sum**
Transmission Link from GW22 N to WS22 HAOU	65873.4	65677.1	65655.8	65649	241127	503983
Transmission Link from GW23 C to EX23 JBEB	91500	91250	91250	91250	91250	456500
Transmission Link from GW23 C to WS23 JBEB	25732.5	17412.3	18480.8	19909.1	21447.7	102982
Transmission Link from GW24 C to EX24 TORA	38430	38325	38325	38325	38325	191730
Transmission Link from GW24 C to WS24 TORA	97126.5	65722.3	69755.2	75146.2	80953.8	388704
Transmission Link from RW IR01 to IR01	14169447	14329614	14269768	14189922	14226844	71185595
Transmission Link from RW IR01S to IR01	47797133	47703902	47738057	47783595	47762364	238785052
Transmission Link from RW IR02 to IR02	3337867	3337867	3337867	3337867	3337867	16689334
Transmission Link from RW IR03 to IR03	5056546	5056546	5056546	5056546	5056546	25282729
Transmission Link from RW IR04 to IR04	151142	151142	151142	151142	151142	755711
Transmission Link from RW IR05 to IR05	11962840	12022062	11983225	11962840	11962840	59893806
Transmission Link from RW IR06 to IR06	2802116	2802116	2802116	2802116	2802116	14010582
Transmission Link from RW IR07A to IR07	30821389	30763419	30801635	30821404	30821389	154029235
Transmission Link from RW IR07L to IR07	3976306	4033015	3995092	3976306	3976306	19957026
Transmission Link from RW IR08 to IR08	244624	244624	244624	244624	244624	1223120
Transmission Link from RW IR08A to IR08	244624	244624	244624	244624	244624	1223120
Transmission Link from RW IR08S to IR08	307079	307079	307079	307079	307079	1535393
Transmission Link from RW IR09 to IR09	1126023	1126023	1126023	1126023	1126023	5630113
Transmission Link from RW01 LABO to WS01 LABO	411018	293964	370724	409895	409895	1895496
Transmission Link from RW05 YAMM to WS05 YAMM	1423008	1258953	1318800	1398646	1361723	6761129
Transmission Link from RW06 YOMN3 to WS06 YOMN	249816	249134	249134	249134	249134	1246352
Transmission Link from RW06 YOMN4 to WS06 YOMN	1830000	1825000	1825000	1825000	1825000	9130000
Transmission Link from RW10 FEJD to WS10 FEJD	158112	157680	157680	157680	157680	788832
Transmission Link from RW18 HERM to WS18 HERM	3557886	3548165	3548165	3548165	3548165	17750546
Transmission Link from RWE05 YAMM to EX05 YAMM	6482592	6464880	6464880	6464880	6464880	32342112
Transmission Link from RWE08 BAAL5 to EX08 BAAL	0	0	0	0	315360	315360
Transmission Link from RWE08 BAAL6 to EX08 BAAL	0	0	0	0	346750	346750
Transmission Link from RWE08 BAAL7 to EX08 BAAL	316224	315360	315360	315360	315360	1577664
Transmission Link from RWE18 HERM to EX18 HERM	236802	236155	236155	236155	236155	1181422
Transmission Link from WWTP DEL to SP IR01	0	0	0	0	0	0
Transmission Link from WWTP IAAT to Assi	0	0	0	0	0	0
Sum	185581216	180877204	181911299	183107172	186108164	917585056

E. MAPS

-280,000
-250,000
N
W
E
S
40,000
0
Hermel
Baalbeck
REPUBLIC OF LEBANON
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Assi Basin
Bekaa
Drawing Title:
-
HawkaMaa - EU
ACTED
BUREAU TECHNIQUE POUR LE DEVELOPPEMENT
Prepared by: B.T.D
Date: September 2022
Scale=1/75,000 on A0 Printout
Legend
River
Caza
Assi Watershed
5
2.5
0
5 Kilometers
Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

-280,000
-250,000
0
-40,000
N
E
S
W
Ras el Mal
Ain Ez Zarka
El Fekha
Laboue
Yammouneh Dar
Al Ouassaa
Chaghour
Loujouj
Dardara
El Jaouz
Ain Kawkab
Legend
River
Assi Springs
Geology
Rock Fall
Landslide
B, Basalts
Q, Quaternary deposits (Quaternary)
BQ, Recent basaltic deposits (Quaternary)
Q-n, Quaternary and neogene deposits (Quaternary)
BP; BP 1-2; BP 3, Basalts, dolerites, cinerites (Pliocene)
Pl, Marls, marly and sandy limestones (Pliocene)
ncg, Lacutrine Marls, torrential conglomerates (Neogene)
N2, Conglomerates (Neogene)
N1, Lacustrine marls (Neogene)
Bn, Stratified basalts (Neogene)
M2, Conglomerates, reefal limestones and sandy marls (Miocene)
ML1, Conglomerates (Lower-Middle Miocene)
ML, Lacustrine marls (Lower-Middle Miocene)
M2b, Limestones, marly limestones (Miocene)
M2a, Breccia and conglomerates (Miocene)
Mcg, Conglomerates, red clays (Upper Miocene)
BM, Miocene basalts (Miocene)
M, Lacustrine marls, conglomerates and red clays (Miocene)
E2b, Marly limestones, sub-reefal white limestones (Eocene)
E2a, Marly limestones, sub-reefal white limestones (Eocene)
E1; E2; E2-3; e, Marly limestones, sub-reefal white limestones (Eocene)
C6, Marly limestones and chakly marls rich in Globigerinas (Upper Cretaceous)
C5, Limestones rich in rudists, crystalline limestones, and oolitic limestones (Turonian)
C4-C5, Finely bedded limestones, marly limestones and dolomites (Cenomanian-Turonian)
BC4, Basalts interstratified (Cenomanian)
Bj, Basalts, tuffs and others (Upper Jurassic)
C4d, Alternating limestones and marly limestones finely bedded (Upper Cenomanian)
C4c, Alternating limestones and marly limestones finely bedded (Upper Cenomanian)
C4, Alternating limestones and marly limestones finely bedded (Cenomanian)
C'4, Dark grey dolomitic limestone (Cenomanian)
C3-C4, Alternating limestones, green dolomitic marls, and oolitic limestones (Albian-Cenomanian)
C3b, Limestones, dolomitic limestones (Albian)
C3a, Dolomites, limestones (Albian)
C3, Green marls and alternating limestone units (Albian)
C2b, Marls, marly limestones and dolomites (Aptian)
C2a, Argillaceous sandstones (Barremian)
BC2, Basalts, tuffs, cinerites and associated rocks (Lower Cretaceous)
C2, Limestone and sandstone (Barremian-Aptian)
C1-2a, Quartz sandstone, ferruginous sandstone, clayey sandstone, limestones rich in ferruginous ooliths (Lower Cretaceous)
C1-2, Sandstones, argillaceous limestones and marls (Lower Cretaceous)
BC1, Basalts and other deposits stratified within sandstones rich in lignites (Valanginian-Hauterivian)
C1, Pink quartz sandstone, sandstone rich in lignites (Valanginian-Hauterivian)
BC, Basalts, volcanic tuffs (Cretaceous)
C
J7, Ochrish limestones [detritic or oolitic] (Upper Jurassic)
BJ6, Basalts, tuffs and others (Upper Jurassic)
J6, Grey limestones, ochrish limestones, overlying volcanic terrains (Upper Jurassic)
J5, Yellow marls (Upper Jurassic)
J4; J4-J6, Massive grey limestones (Middle-Upper Jurassic)
J3, Hermon limestones (bluish), yellow marls (Lower Jurassic)
J2, Hermon limestones (bluish), yellow marls (Lower Jurassic)
J1; J1-3a, Hermon limestones (bluish), yellow marls (Lower Jurassic)
5 2.5 0 5 Kilometers
REPUBLIC OF LEBANON
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Assi Basin
Bekaa
Drawing Title: -
HawkaMaa - EU
ACTED
BUREAU TECHNIQUE POUR LE DEVELOPPEMENT
Prepared by: B.T.D
Date: September 2022
Scale=1/75,000 on A0 Printout


-280,000
-250,000
40,000
0
N
S
E
W
Legend
LUC
Rocky Outcrops
Fruit Trees
Highway
Dense-other types of Broadleaved trees
Clear-other types of Broadleaved trees
Tourist Resort
Field Crops in Medium to Large Terrace
Field Crops in Small Fields/Terrace
Dump Sites
Poultry Breeding
Agriculture Equipment
Green Sports Area
Green Urban Area
Urban Extension and/or Construction Site
River
Clear Oaks
Clear Juniper
Clear Pines
Clear Mixed Wooded Lands
Dense Mixed Wooded Lands
Diverse Equipment
Cattle Raising
Lake
Hill Lake
Urban Sprawl on Field Crops
Urban Sprawl on Clear Wooded Land
Urban Sprawl on Dense Wooded Land
Urban Sprawl on Permanent Crops
Urban Sprawl on Scrubland
Olives
Bare Rocks
Archeological Sites
Mineral Extraction Site
Bare Soil
Protected Agriculture
Abandoned Agriculture Land
Urban Vacant Land
Dense Urban Fabric
Dense Informal Urban Fabric
Medium density Informal Urban fabric
Low Density Informal Urban Fabric
Medium density Urban fabric
Low Density Urban Fabric
Vineyards
Scrubland
Scrubland with some dispersed bigger trees
Clear Grassland
Industrial or Commercial Areas
REPUBLIC OF LEBANON
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Assi Basin
Bekaa
Drawing Title: -
HawkaMaa - EU
ACTED
BUREAU TECHNIQUE POUR LE DEVELOPPEMENT
Prepared by: B.T.D
Date: September 2022
Scale=1/75,000 on A0 Printout
5 2.5 0 5 Kilometers
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

-280,000
-250,000
40,000
0
N
W
E
S
1
2
3
4
5
6
7
8
9
10
Legend
River
Assi Watershed
5
2.5
0
5 Kilometers
REPUBLIC OF LEBANON
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Assi Basin
Bekaa
Drawing Title:
-
HawkaMaa - EU
ACTED
BUREAU TECHNIQUE
Prepared by: B.T.D
Date: September 2022
Scale=1/75,000 on A0 Printout
Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

N
S
E
W
-280,000
-250,000
40,000
0
21
89
264
25
19
8
12
74
74
9
2
53
239
96
48
38
1
1
5
8
114
76
114
62
190
2
10
5
18
1
38
113
1
1
58
189
2
114
37
1
1
242
20
31
61
5
23
17
26
181
374
32
14
414
Legend
Private Wells
Flow 29 - 1000
Flow 1001 - 5000
Flow 5001 - 10000
Flow 10001 - 14746
Public Wells
Flow 0 - 1000
Flow 1001 - 5000
Assi Watershed
5 2.5 0 5 Kilometers
REPUBLIC OF LEBANON
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Assi Basin
Bekaa
Drawing Title: -
HawkaMaa - EU
ACTED
BUREAU TECHNIQUE POUR LE DÉVELOPPEMENT
Prepared by: B.T.D
Date: September 2022
Scale=1/75,000 on A0 Printout

N
S
E
W
-280,000
-250,000
40,000
0
Beit Et Tochem-El Charqe-Mazraat Chelman
Ain El Haour Spring+Mazraat Soujoud
Haouch Saeid Ali & Haouch Beit Ismail
Chouaghir
Ouadi Et Tourkmane - Ouadi El Ratel
Ain El Haour Spring+Mazraat Soujoud
Jbeb El Homor
Ouadi En Naira-Ouadi Bnit-Zoueitini-Wadi El Karem & Kaeb Wadi El Karem
EB-Laboue System
EB-Ras Baalbeck System
Ouadi Faara-Mrah El Aaqabet
WB-Ouyoun Orgosh Village
EB-Halbata & Kharayeb System
EB-Fekha & Jdaide System
EB-Halbata & Kharayeb System
WB-Qalileh & Harfouch Wells Syst
EB-Sbouba system
EB-Laboue System
EB-Harbata System
EB-Chaat and Es-Soueidiyeh Syste
WB-Ouyoun Orgosh Springs System
EB-El Khoder System
EB-Aarsal System
EB-Rasem El Hadath & Soueidiyeh
WB-Yammouneh Springs System
EB-Rasem El Hadath & Soueidiyeh
WB-Yammouneh Village System
EB-Younine-Maqne & Nahle
WB-Er Remasseh System
EB-Taybeh & Iaat Wells Systems
EB-Nabi Sbat Spring System
EB-Baalbeck-Aamechki-Ain Bourday
REPUBLIC OF LEBANON
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Assi Basin
Bekaa
Drawing Title: -
ACTED
Legend
River
Water Systems
Assi Watershed
Prepared by: B.T.D
Date: September 2022
Scale=1/75,000 on A0 Printout
5 Kilometers


-280,000
-250,000
N
W
E
S
40,000
0
Hermel
Al Qaa
Ras Baalbek
Arsale
Chaat
Deir El Ahmar
Chlifa
Boudai
Iaat
Legend
Existing Waste Water Treatment Plant
Proposed Waste Water Treatment Plant
Under Construction Waste Water Treatment Plant
Sewer Lines
River Stream
Assi Watershed
5 2.5 0 5 Kilometers
REPUBLIC OF LEBANON
RIVER BASIN MANAGEMENT FOR AL ASSI BASIN, GHADIR BASIN AND AL OSTUAN BASIN
Water Resources in Assi Basin
Bekaa
Drawing Title: -
ACTED
BUREAU TECHNIQUE
Prepared by: B.T.D
Date: September 2022
Scale=1/75,000 on A0 Printout
Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community