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Research Report

Analysis of Water Reuse Potential for Irrigation in Lebanon

Karim Eid-Sabbagh, Salim Roukoz, Marie-Hélène Nassif, Naga Velpuri and Javier Mateo-Sagasta

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Project

This research study was undertaken as part of the ReWater MENA project in Lebanon, specifically output 3: National plans for expansion of wastewater treatment and reuse in three countries - Lebanon, Jordan and Egypt.

Collaborators

International Water Management Institute (IWMI)

The Lebanese Agricultural Research Institute (LARI) is the main partner of the ReWater MENA project in Lebanon. It hosted the project office, and facilitated field visits, access to data and venues for meetings when conducting this study.

Donors

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Acronyms and Abbreviations

AFD	Agence Française de Developpement
AP	Actual potential
AUB	American University of Beirut
BMLWE/BMTL	Beirut and Mount Lebanon Water Establishment
BTD	Bureau Technique pour le Développement
BWE	Bekaa Water Establishment
CDR	Council for Development and Reconstruction
CMD	Command area
DEM	Digital Elevation Model
ETc	Crop evapotranspiration
ETo	Reference evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GIS	Geographic Information System
GTM	Grounded Theory Methodology
IFI	Issam Fares Institute for Public Policy and International Affairs
IMF	International Monetary Fund
IP	Ideal potential
IPCC	Intergovernmental Panel on Climate Change
KII	Key informant interview
LIBNOR	Lebanese Standards Institution
LL	Lebanese Lira
LRA	Litani River Authority
LULC	Land use and land cover
LWP	Lebanon Water Project
MENA	Middle East and North Africa
MEW	Ministry of Energy and Water
MoA	Ministry of Agriculture
MoE	Ministry of Environment
NGO	Nongovernmental Organization
NLA	National Learning Alliance
NLWE	North Lebanon Water Establishment
NWSS	National Water Sector Strategy
NWSSU	National Water Sector Strategy Update
O&M	Operation and maintenance
RCP	Representative Concentration Pathway
RWE	Regional Water Establishment
SLWE	South Lebanon Water Establishment
UFW	Unaccounted for water
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
WHO	World Health Organization
WWTP	Wastewater treatment plant

Summary

The aim of this report is to contribute to knowledge on expansion of water reuse in Lebanon. Our study assesses the potential for water reuse at the national level, develops a technical assessment of the quantities of treated water available for safe reuse in irrigation, and identifies the wastewater treatment plants (WWTPs) that have the highest potential for that purpose. We also examine the governance barriers hindering this potential from materializing in practice.

Based on the available estimates of population in Lebanon (ranging from 4.8 to 6.5 million inhabitants), the volume of municipal wastewater generated in the country is considered to vary between 275 million cubic meters (Mm^3) and 328 Mm^3 per year. For the purposes of this study, a database of the existing and planned WWTPs was created based on the updated National Water Sector Strategy (2020), and further developed through interviews. At the time of writing, of the 104 existing plants, 41 were 'operational' and 20 'partially operational' (subject to limitations to adequate operation), another 35 were categorized as 'built not operational', and eight were 'under construction', including those in various stages of construction or awaiting commission.

As per the database, the total volume of wastewater receiving some form of treatment amounts to 81 Mm^3 per year. This is about 25-30% of the annually generated wastewater. The three largest WWTPs (Sayniq/Saida, Ghadir and Tripoli) currently provide primary-level treatment to a total of 145,000 m^3/day, which adds up to 52.9 Mm^3 per year. At the national scale, only 28 Mm^3, or 34%, of the treated wastewater can be considered fit for reuse currently, which amounts to about 8-10% of the total municipal wastewater generated.

In our study to quantify the potential for water reuse in Lebanon, we modeled the reuse potential area and assigned a reuse potential score to each WWTP—be it an existing plant or a planned one. For the purposes of our study, the reuse potential area is linked to a given WWTP and refers to the agricultural area potentially irrigable by that WWTP during an irrigation season; and the reuse potential score models the risks related to a WWTP's operation and the reuse opportunities it provides while also considering the existence of industrial influents, effluent water quality, type of crops, agricultural area and the availability of irrigation infrastructure in the vicinity. The modeling exercise was done using a geographic information system platform with recent data. We worked on two scenarios: the scenario of actual potential (AP), in which we considered the actual volume of wastewater treated; and the scenario of ideal potential (IP), in which we considered the full capacity of a WWTP. On the basis of our methodology, the aggregate reuse potential areas for the AP and IP scenarios were found to be approximately 2,202 ha and 4,993 ha, respectively. Currently, less than 10 ha are part of an implemented reuse system (supplied by the Ablah WWTP, which, however, has been kept on hold due to a local conflict). Our study also found that in an actual potential scenario, 48 WWTPs would have a reasonably high reuse potential score, while in an ideal potential scenario, as many as 82 would be in the same bracket. Segregation by management type indicated that rehabilitation of smaller and/or municipality-run WWTPs would be a worthwhile undertaking with regard to realizing wastewater treatment and reuse potential.

However, structural shortcomings in the wastewater sector combined with challenges of governance and the lack of a regulatory framework for reuse management impede the materialization of this potential. Our review of literature and fieldwork also revealed poor administrative capacities in the planning, implementation and management of existing WWTPs and future reuse systems. The mandates of state authorities are fragmented and often conflicting. In the current economic, financial and political crisis in Lebanon, these barriers have become more entrenched and tend to dramatically attenuate the technical potential calculated. Capacities to govern the use of treated wastewater have become greatly reduced in all administrative bodies, as has their ability to plan and implement projects. The collapse of revenues due to the dramatic impoverishment of the country's population and the collapse of the Lebanese lira reveal the failure of market environmentalist approaches to resource management that are focused on full cost recovery from users. Taken together with the problems mentioned above, this is another attenuating factor hindering the realization of reuse potential in Lebanon.

Analysis of Water Reuse Potential for Irrigation in Lebanon

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Introduction and Background

This section puts wastewater production and volumes in the context of Lebanon's water resources and the stated goal of the country to establish water reuse across its territories. We provide an overview of the state and knowledge of water resources and their use, and the demand and supply situation in the domestic water and agriculture sector. This will be complemented by a brief discussion of the expected effects of climate change. As water shortage is experienced throughout Lebanon during the summer irrigation season, additional supplies by way of treated wastewater would be beneficial to the agriculture sector, and potentially release more water for use in the domestic sector.

Water Resources, Budgets and Balances

Lebanon, compared to its neighboring countries, is endowed with relatively plentiful water resources. Its mountainous geography and the nature of its geology set it apart from the more arid countries in the Middle East. The relatively ample precipitation—comprising rainfall and snow—infiltrates the karstic rock formations and is stored as groundwater, which feeds 17 perennial rivers, 23 seasonal streams and some 2,000 springs. While most of the precipitation occurs during the November-April period, melt from the accumulated snowpack feeds aquifers well into June. As a result of this precipitation regime, water availability is lowest in the summertime when demand is highest, particularly for irrigation but also for domestic water supply.

The National Water Sector Strategy (NWSS) of 2012 (and its 2020 update) presents, at the national scale, a water balance that was established in the early 1990s for an average year (Figure 1). According to this water budget, annual precipitation in Lebanon amounts to 8.6 billion cubic meters (Bm^3), of which a little more than half is lost to evapotranspiration. About 1.4 Bm^3 flow into neighboring territories or seep into the sea as groundwater. Only 2.7 Bm^3 remain within Lebanon's territory: 0.5 Bm^3 as groundwater and 2.2 Bm^3 as surface flows, implying that exploitable resources are well below this total. However, the results of a United Nations Development Programme (UNDP)-financed assessment of groundwater resources (MEW and UNDP 2014) as well as the findings of Bakalowicz (2009)—suggesting that the total exploitable resources may be as high as 2.6 Bm^3 per year[1]—differ from the NWSS estimates. A comparison of results from different assessments shows considerable variance for individual components of the water balance too (Table 1). Specifically, evapotranspiration varies by a factor of 2.

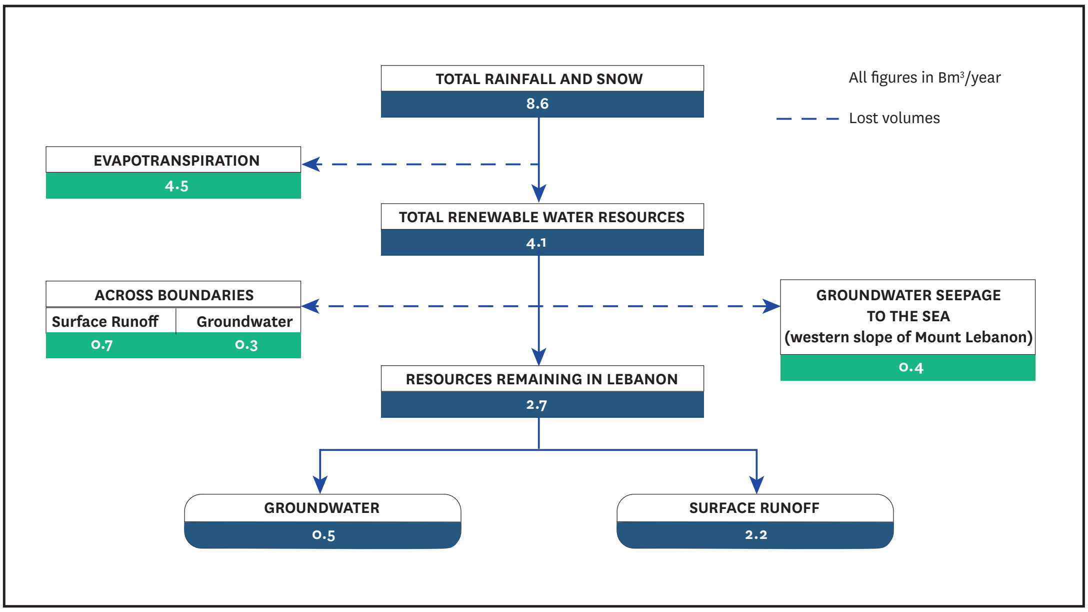

Figure 1. The national water budget of Lebanon as per the NWSS Update of 2020.
Source: MEW 2020.

[1] Note that exploitability is a function of cost (infrastructure, and more importantly, energy) and technology, and thus always a subjective value.

Table 1. Water balances presented in the latest assessment of groundwater resources by Lebanon's Ministry of Energy and Water.

Description	UNDP 1970	UNDP 2013	
		Dry season	Wet season
		2010-11	2012-13
Precipitation (Mm³)	9,700[a]	7,830	11,933
Evapotranspiration (Mm³)	ND[b]	2,110	2,022
Deficiency in runoff (Mm³)	5,400	ND	ND
Surface runoff (Mm³)	1,300	2,150	3,806
Estimated total inflow to groundwater (Mm³)	3,000	3,570	6,105

Source: MEW and UNDP 2014.

Notes: [a] Over an estimated surface area of Lebanon of 10,200 km².

[b] ND: Not defined.

Assessment of the Lebanese water budget is further complicated by diverging analyses and findings on the effect of climate change on total precipitation. The National Water Sector Strategy Update (NWSSU) of 2020 (MEW 2020, Vol. II A 3) draws on rainfall trends (identified by the Issam Fares Institute for Public Policy and International Affairs [IFI] [IFI 2014] of the American University of Beirut [AUB]) suggesting that there is no declining trend of precipitation.[2] On the other hand, a study by Shaban (2009), based on an analysis of precipitation and snow cover area, indicates a declining trend in rainfall and snow. A study by ECODIT (2015) suggests an increase in drought occurrence (Figure 2). According to a compilation of precipitation data (1876-2014) in Beirut by AUB, "the occurrence of consecutive dry years (amounting to a drought) is increasing, as evidenced by at least five such incidents in the last 30 years, compared to only three such incidents in the 100-year period from 1876 to 1975." The higher precipitation variability and increase in drought occurrence coincide with studies that suggest a greater variability in the seasonal north-south movement of the jet streams, the westerlies in the case of Lebanon, and the associated cloud cover and rain (Tyrlis et al. 2014). The NWSSU (MEW 2020) mentioned above goes on to show an increasing trend in temperatures, which coincides—if not in numbers, at least in trend—with the results of temperature modeling for the region. Lelieveld et al. (2016) predict an increase in mean and maximum temperatures as well as an extension of warm spells[3] (for the climate change scenarios designated RCP[4] 4.5 and RCP 6.0). Other studies also indicate an increase in summer temperatures across the region (Waha et al. 2017) with Lebanon seemingly less affected than Syria, Iraq or the Persian Gulf countries.

In addition to increasing evapotranspiration, several studies forecast that rising temperatures will have a negative effect on river and spring flow regimes. A modeling of runoff scenarios for the Ibrahim River (Nahr Ibrahim) conducted by Hreiche et al. (2007) predicts that peak river flow will be reached earlier, and volumes will decrease "15 days to a month earlier," thus prolonging the summer drought period. Doummar et al. (2018) show that increasing temperatures will affect the spring discharge regimes of mountains. Reduced snowpack and rainfall variation would likely cause the recession period[5] to begin up to a month earlier by 2034-2040 (in the RCP 6.0 scenario) with smaller overall flow volumes. As a result of higher intensity rainfall events (leading to greater runoff), as well as a decrease in snowpack cover, storage in the aquifers is also likely to be negatively affected. Finally, in 2010, the NWSS estimated renewable water resources per capita at around 840 m³ for 2015 compared to around 926 m³ for 2009, the former being below the scarcity threshold. It is notable, however, that these numbers remain highly imprecise.

Supply and Demand Balance at National Scale

The water balance produced by the NWSS (MEW 2012) for a dry year (Figure 3) shows a water shortage between 2011 and 2015. After this period, hydraulic projects planned by the NWSS were expected to produce additional volumes of water to meet the increasing demand.[6] Most of these projects, however, have not materialized, and only a fraction of the planned additional volume has been added across all the regional water establishments (RWEs) since 2011. The water shortage continues. The NWSSU (2020) estimates that about 100 of the 375 domestic

[2] Given the uncertainties regarding climate change modeling and the positive feedback mechanism on the rate of temperature rise, it seems dangerously optimistic to plan with a scenario in which average rainfall will not be altered. At the very least, a worst-case option should be considered for contingency.

[3] Periods during which the maximum temperature ranges in the top 90 percentile for spells longer than 5 days.

[4] The Representative Concentration Pathway (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by the Intergovernmental Panel on Climate Change (IPCC). It is represented as watts/m². The RCPs represent different modeling scenarios of increasing numbers indicating higher temperature rises and later reversal of carbon concentration in the atmosphere.

[5] When the spring flow volume starts decreasing.

[6] The large-scale dams have not been implemented as planned. The Janneh Dam (with an estimated volume of 90 Mm³/year) is still under construction while the Bisri Dam (120 Mm³/year) has been put on hold due to popular and expert contestation. The South Lebanon Irrigation Project (known as Canal 800), which was planned to provide irrigation water to some 15,000 ha in south Lebanon, remains to be completed. Similarly, the institutional and organizational improvement goals as well as the financial and commercial goals (such as the introduction of a new tariff structure) stated in the 2012 plan were not achieved. Finally, the influx of nearly 1.5 million refugees as a result of the civil war in Syria has further increased the pressure on water resources.

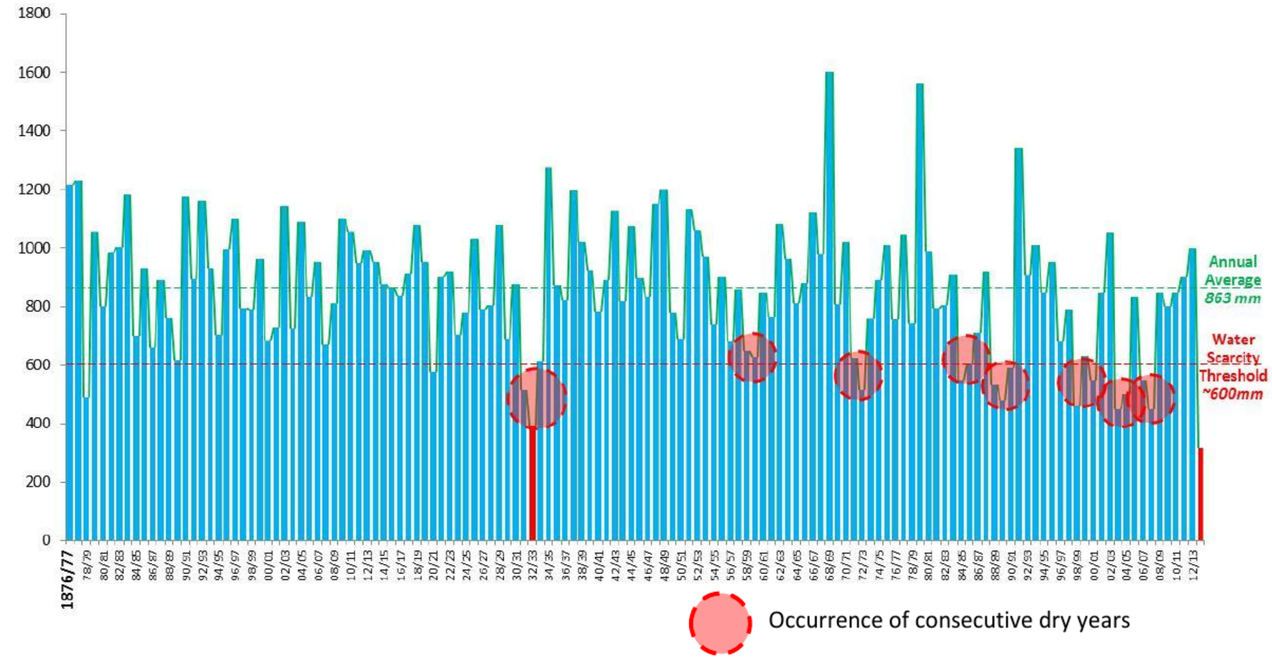

Figure 2. Precipitation in Beirut (AUB, 1876-2014) and occurrence of consecutive dry years.
Source: ECODIT 2015.

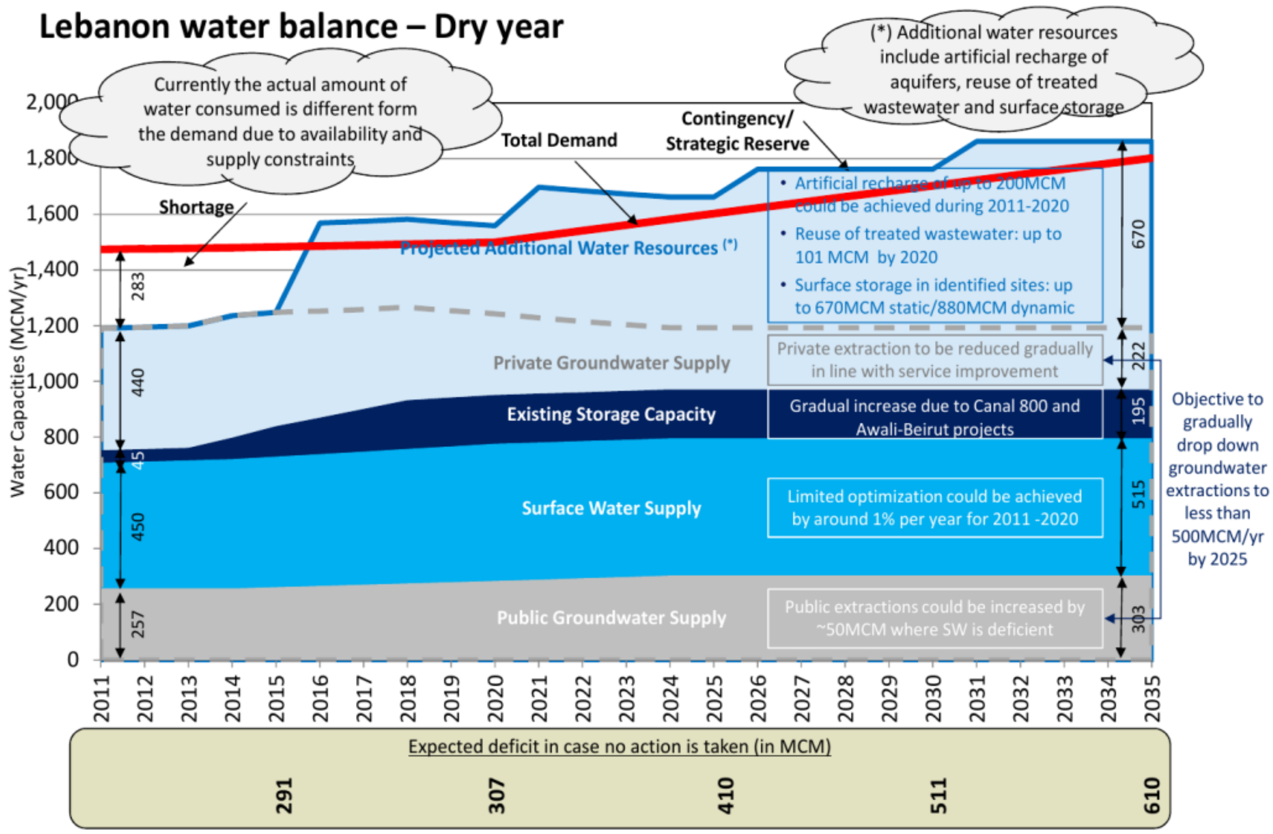

Figure 3. Lebanon's water balance as presented in the National Water Sector Strategy.
Source: MEW 2012.
Note: MCM - Million cubic meters.

water supply schemes covering the Lebanese territory are currently in deficit, and that an additional 65 would likely fall into deficit by 2035, assuming current levels of water productivity and a gross water need of 200 L/cap/day (MEW 2020).[7] The areas most affected by water shortages are the densely populated coastal areas such as Greater Beirut, Tripoli and Saida (as well as the South more generally) in addition to areas in the northeastern Bekaa.

Further, different water uses are affecting groundwater resources. As revealed in the latest National Groundwater Assessment (MEW and UNDP 2014), coastal aquifers as well as those in the Bekaa are under stress.[8] Largely illegal or poorly monitored (when legally regulated) abstractions are at the root of groundwater depletion. The NWSSU (2020) states that "the total volume extracted from wells is impossible to assess with an acceptable margin due to the poor data available from the RWEs, and the absence of data on private wells" (MEW 2020). The update estimates that the 943 public wells (managed by national administrations) considered to be in service (out of a total of 1,449) produce about 270 Mm^3/year of groundwater. A study conducted by the International Water Management Institute (IWMI) (Molle et al. 2017) estimates that there are some 100,000 private wells in the country, up from the NWSS (2012) estimate of around 44,000 (MEW 2012) and the 2014 National Groundwater Assessment estimate of 80,000 (MEW and UNDP 2014). Of these, only 21,800 are licensed by the MEW. These private wells are estimated to produce a total of 430 Mm^3/year, so the sum of public and private groundwater abstractions amounts to 700 Mm^3/year. This total exceeds, by 200 Mm^3/year, the 500 Mm^3/year renewable groundwater estimated in the 2020 NWSSU. The large number of wells and the lack of data[9] about them suggest that estimates of groundwater abstraction by the NWSS as well as its 2020 update (MEW 2012, 2020) are likely to be underestimates.

Irrigation Water Demand and Use

Irrigation is closely linked to agriculture, and all interventions concerning irrigation directly affect farmer livelihoods. Irrigated land is highly unevenly distributed in Lebanon, both geographically and by size of holdings (see Annex 1 for an overview of the socioeconomic structure of Lebanon's agriculture sector). According to the 2020 NWSSU, some 104,000 ha, out of about 240,000 ha of agricultural land, are irrigated.

An agricultural census conducted in the *cazas* (sub-districts) of the Bekaa and the coastal plains in the year 2000 found that close to or more than half of the agricultural area was irrigated, and that about two-thirds of the irrigated area used groundwater. In the *cazas* of Nabatieh and Marjayoun, only 20-40% of the agricultural land was irrigated, but more than half of the irrigated area drew groundwater. In the mountainous regions (see Annex 1 for more details), the proportion of irrigated land was less, but the majority of irrigated lands depended on surface water.

The NWSSU estimates the gross demand for irrigation water at 879 Mm^3/year. The bulk of this demand is in the Bekaa (595 Mm^3/year), with North Lebanon needing 215 Mm^3/year, Mount Lebanon 37 Mm^3/year and South Lebanon 31 Mm^3/year. The update goes on to identify a 25% "serious gap between irrigation water demand and irrigation water current use" (MEW 2020, p.IV B 5). Only 660 Mm^3/year, equally divided between groundwater and surface water, are currently being used in agriculture, according to this estimate. According to the agricultural census of Lebanon (MoA and FAO 2012), gravity is the predominant mode of irrigation, practiced on nearly 50% of the irrigated area. Sprinkler and drip irrigation make up the rest, and occupied nearly the same share about a decade ago.[10] In 2020, drip irrigation came to be more widely used but no recent data could be found in that regard. According to the NWSSU, most of the existing collective irrigation schemes experience water shortages (MEW 2020) as is evident from the frequent reports of conflict over water use and rights, competition between domestic and irrigation use in many villages, intensive drilling of wells within schemes, and the commonly observed degradation of irrigation infrastructure in the older collective schemes.

Total Estimated Municipal Wastewater Production

At the national scale, the total available volume of municipal wastewater is estimated at 80% of domestic water consumption, in addition to commercial and industrial wastewater. As per the NWSSU 2020, the total quantity of water abstracted for municipal use and irrigation is highly uncertain. The update states that due to missing data and the lack of consistent measurements over time, it is not possible to assess the volumes used for drinking or irrigation purposes. Additionally, population estimates greatly vary in Lebanon. While the latest study published by the Central Administration of Statistics (CAS and ILO 2020) estimates the population at 4.8 million, the World Bank Open Data database puts it at 6.9 million (World Bank 2020); in 2016, the World Health Organization (WHO) estimated it at 6 million, and

[7] For 2020, this would mean that a deficit of 282,000 m^3/day affects 4 million people, or about two-fifths of a total population modeled at 9.1 million (in this exercise in the NWSS 2020 update, population data are said to have been taken from existing designs and studies. The basis of these studies is not clear; the deficit can be assumed to be the inability to meet peak demand for individual systems). In the 2035 scenario, 8.1 million, or two-thirds of the total population, are projected to be short of 662,500 m^3/day.
[8] This national-scale view also serves to replace analysis of balances at the watershed scale. Clearly, all watersheds leading to the coast, as well as the two watersheds draining the Bekaa area, suffer deficits. Further, groundwater catchments and watersheds do not necessarily overlap in a geology dominated by karstic formations. See the Jeita groundwater catchment analysis produced by the Federal Institute for Geosciences and Natural Resources (BGR) (Steinel and Margane 2011).
[9] For instance, a total of "25,000 licenses for drilling private wells were issued in 2017-2018 by the Ministry of Interior without the knowledge of the Ministry of Energy and Water, and no data on the locations of these wells could be obtained" (MEW 2020, Vol. III, p. III C 8).
[10] The NWSS (MEW 2012) claims that 6.2% of the area is served by drip irrigation, 23.4% by sprinkler and 70.4% by gravity (open canals).

the Lebanese consultancy firm Information International reckoned with 5.5 million (Ramadan 2019). For its water need estimate covering all supply schemes, the NWSSU (MEW 2020) considers a population of roughly 9 million inhabitants in 2020 and around 12 million in 2035.[11]

Current water use greatly varies by area.[12] In the NWSSU, water demand is calculated on the basis of the figure 200 L/cap/day.[13] As mentioned above, this number is also used to project the deficit of individual water supply schemes in 2035. The 200 L/cap/day figure includes three components:

- Domestic consumption[14] — 125 L/cap/day
- Non-domestic (20% of domestic consumption) — 25 L/cap/day
- Physical losses (20% of total need) — 50 L/cap/day

Based on this figure of 200 L/cap/day, the NWSSU estimates per capita wastewater flow (80% of the total need, excluding physical losses) at 120 L/cap/day. It further states that due to the strategic aim of generalizing water metering in order to remove illegal connections and reduce unaccounted for water (UFW), water consumption in 2035 is likely to be "significantly less" than it is today. The NWSSU then revises downward the 2012 assumption from 160 L/cap/day for the urban zone to 140 L/cap/day, suggesting that water use in 2035 may be limited to 125 L/cap/day. The 2012 NWSS assumes a water demand in the range of 160-200 L/cap/day for different scenarios but suggests that water use might be less due to supply constraints.

Based on the suggestion in the NWSSU that actual water use could be "significantly" higher than the estimates for 2035, we use in our study a figure of 150 L/cap/day for 2020 for our calculation of wastewater flow.[15] For the sake of simplicity, infiltration into canals and losses from the network are assumed to be roughly equal as components of wastewater flows, balancing each other out. In the absence of confirmed population data, we reckoned the current population to be between 5 and 6 million inhabitants, and estimated the annual volume of wastewater to be ranging between 273.75 Mm^3 and 328.5 Mm^3 per year:

5,000,000 inhabitants * 150 L/cap/day * 365 days = 750,000 m^3/day * 365 days = 273.75 Mm^3/year

6,000,000 inhabitants * 150 L/cap/day * 365 days = 900,000 m^3/day * 365 days = 328.5 Mm^3/year

In 2012, assuming a population of around 4.4 million, the NWSS had estimated annual wastewater generation at 310 Mm^3—slightly higher than the above estimate—with 250 Mm^3 coming from domestic sources and 60 Mm^3 from industrial sources.

Objectives and Structure of the Report

This study assesses the potential for water reuse in irrigation in Lebanon. Specifically, it assesses how much municipal wastewater is currently produced, collected and treated, how much is discharged into the sea and the rivers, and how much is directly used. The core of the report provides a measure of the reuse potential of wastewater treatment plants across the country. The goal is to provide a quantitative measure of this potential as well as a qualitative assessment. Our analysis of the water reuse potential is done at a national scale covering all existing and proposed WWTPs, which we documented extensively in two databases. The choice of using the term 'water reuse' instead of 'wastewater reuse' is explained in Box 1 below.

Box 1. A Note on Terminology.

This report uses the term 'water reuse' rather than 'wastewater reuse'. 'Water reuse' describes treated water that is used in cities and is then reused in agriculture. So, the term is technically correct and is likely to receive more public acceptance. To avoid any ambiguity, the term does not include agricultural drainage water. Moreover, 'wastewater reuse' is a misleading term because treated or recycled water is not wastewater anymore. Wastewater is not reused, it is only used; so there is a distinction between direct irrigation with wastewater as opposed to water reuse.

[11] These latter numbers are very high and result from an addition of the population numbers from all the domestic water supply schemes. As a large number of people go to their villages of origin in the summer, there is an increase in water demand in the rural systems during the summer. Concurrent water use must be well below the sum of the capacities of all urban systems.
[12] Some studies report that domestic consumption reaches 300-400 L/cap/day in some rural areas (GVC 2016) while others report considerably lower average consumption (225 m^3/year/household or about 150 L/cap/day.). See also Ghanem et al. (2017).
[13] MEW 2020 (p. IV B 3 and p. IV C 127 onward).
[14] The water demand calculations in the NWSSU are based "on realistic water consumption for different uses, with assessment of 5.8 persons per household". See the NWSSU (MEW 2020, p. IV C 3).
[15] This assumes a domestic consumption level of 150 L/cap/day in 2020, lower than the estimates presented in NWSS 2012, an additional 20% for non-domestic use, and 20% losses in use (as per NWSSU 2020).

We assess the reuse potential by modeling the agricultural area that can be irrigated with treated volumes, and qualify the results with an assessment of the suitability of crops, the risk due to harmful waste inflows and the effluent quality as well as the proximity of existing irrigation networks. The study also ranks WWTPs on the basis of wastewater use potential. Our analysis is supplemented with a review of the governance barriers for safe water reuse. We present eight in-depth case studies based on field trips and a series of key informant surveys. The aim of this study is to contribute to a critical and productive engagement with wastewater as a potential resource. We also identify sites at the national scale where existing or future WWTPs show a high potential for successful implementation of water reuse projects.

The report is subdivided into four sections. The first section establishes that water shortages are prevalent in the summer months. The second presents the modeling methodology adopted to define and estimate reuse potential. The third presents a discussion of the WWTP database and the modeling results. The fourth section looks at the governance barriers and considers the enabling environment for safe water reuse. Finally, we present in an annex eight detailed case studies of reuse potential at different sites.

Methodology

This section presents the methodology employed in this study to determine water reuse potential and assess the governance barriers to realizing that potential and the enabling environment needed to achieve it.

Our assessment of reuse potential—how much wastewater is collected, treated and discharged into water bodies—is based on two WWTP databases. These databases were constructed with the aid of available reports, the database produced for the National Water Sector Strategy Update (NWSSU) presented by the Ministry of Energy and Water in 2020, and key informant interviews (KIIs). The data used were checked and validated as much as possible but cannot be considered fully representative, as explained in Box 2.

We modeled the quantitative and qualitative measures of reuse potential using a geographic information system (GIS), the programming language R, and a spreadsheet application (such as Microsoft Excel). Reuse potential was modeled in terms of the potentially irrigable area based on crop water requirement and treated water volume. This was termed the **potential area.** This potential was qualified with the help of a weighted sum score combining an assessment of (1) the suitability of existing crops in the proximity of WWTPs related to their effluent quality; (2) the type of influent as an indicator of supply quality and quantity risks due to harmful waste inflows; and (3) the proximity of irrigation schemes. This score was termed the **potential score**. Taken together, the potential area and the potential score of individual WWTPs allow a nuanced reading of the potential for implementation of treated wastewater use projects.

Our analysis of governance barriers and the enabling environment for water reuse is based on KIIs, an extensive literature review and fieldwork. We use eight case studies to illustrate our analysis of reuse potential and the associated implementation and management difficulties. This presentation of our methodology starts below with a description of the qualitative components of our methodology which served to identify governance issues and their linkages with the technical aspects of water reuse potential. This is followed by an elaboration of the methods used to assess this technical potential.

Methodology for Identifying Governance Obstacles and Challenges

This study—specifically, our analysis of governance barriers—uses a Grounded Theory Methodology (GTM) approach to produce "mid-range theories grounded in data" (Bryant and Charmaz 2007). This theoretical approach is usefully described as inductive qualitative research and as a family of methods that give primacy to observation rather than preconception. Accordingly, categories of analysis are derived from data obtained from research, and are therefore grounded. They are also iteratively refined. The categories of analysis are progressively refined with the accumulation of data. New insights from data collection are used to adapt the methodology and questionnaires and so on. The inclusion of case studies in the initial terms of reference further lent itself to the GTM approach, which allows researchers to produce useful, applicable analysis specifically with a view to practice-oriented research. GTM is also particularly suited to participatory research as applied in the framework of the ReWater MENA project's Lebanon component (Dick 2007).

This participative research was launched with the first National Learning Alliance (NLA) meeting organized by IWMI in October 2019. The purpose of this meeting was the presentation of the goals and draft outline of this study as well as an initial exploration of the necessary conditions for water reuse in Lebanon. The participants included 38 Lebanese stakeholders and project cooperators (IWMI 2019). They were brought together in four groups to brainstorm over different opportunities and challenges of water reuse in the context of Lebanon. The results of this participatory work formed the starting point of the Lebanon-specific qualitative aspects of this research including the identification of context-specific topics and issues.

Building on this workshop, interviewees were identified using a simple snowball sampling technique that drew both on the initial participant stakeholders at the first NLA meeting as well as stakeholders from a variety of administrative and professional entities. Interviews were semi-structured, using pre-designed questionnaires to guide the discussion but leaving open possibilities for the exploration of topics emerging from interviewee responses. Iteratively, analysis and questionnaires for subsequent interviews were adapted to include issues and topics emerging from previous rounds of analysis. As a matter of principle, interviewees were offered anonymity to allow for open discussion. With interviewees often clearly stating that aspects of the interviews were sensitive, we opted to identify interviewees only by date and location. A second NLA meeting was organized in June 2021 to present and discuss the results of the present study with the same objective of gathering stakeholder inputs, validating the main findings pertaining to governance barriers and further documenting them.

Some 150 documents and reports[16] pertaining to water and wastewater management in general and in Lebanon specifically were reviewed and assessed. Existing and available GIS data were collected and assessed including the geodatabase of WWTPs produced in the framework of the NWSSU. Thirty-seven semi-structured interviews with key informants were conducted either directly or remotely—as COVID-related restrictions forced a shift from direct fieldwork to remote research. These included water sector consultants, academics and officials from the Ministry of Energy and Water (MEW) and RWEs as well as the Council for Development and Reconstruction (CDR) and other ministries. Field visits to 11 locations took place over 9 fieldwork days for observation of treatment processes as well as key informant surveys with facility operators, municipalities and nearby farmers (Table 2). Some sample questionnaires for KIIs and field visits are shown in Annex 10.

Box 2. A Note on Data Limitations.

Fine-grained data on the state of water resources, supply, demand and use are limited in Lebanon. This is true of data related to wastewater too. As has been shown in the section *Introduction and Background*, data regarding wastewater production are lacking or inconsistent. We observed discrepancies with regard to the reported volumes of wastewater collected and treated in specific WWTPs. The NWSSU identifies a “severe lack of reliable data” as one of the important challenges facing adequate management.[17] According to this document, the lack of time series data prevents the assessment of surface water yields on a monthly basis or the volumes used for drinking and irrigation purposes. The NWSSU makes the same assessment for groundwater too (MEW 2020).

The problem of data accuracy and availability is not restricted to the water sector. Population data in Lebanon exist only in the form of approximations as the last official census dates back to 1932.

Table 2. Summary of interviews and fieldwork done for assessment of water reuse potential.

Interviews	Number of interviews	Site visits	Water establishment
MEW	2 x Ministry of Energy and Water	Aintourine, Jbaa, Ehden WWTPs (North Lebanon area)	North Lebanon Water Establishment (NLWE)
RWEs	3 x BWE, 3 x NLWE, 3 x SLWE, 3 x BMLWE, 1 x Litani River Authority (LRA)	Joub Janine WWTP	Bekaa Water Establishment (BWE)
CDR	2 x CDR	Yammouneh WWTP	
Academic	1 x AUB	Zahleh WWTP	
Private sector	3 x Beirut	Aitanit WWTP	
Technicians	1 x Bater, 2 x Baadarane, 1 x Jbaa, 2 x Hammana, 2 x Ablah, 1 x Yammouneh	Ablah WWTP (Central Bekaa area)	
		Baadarane and Bater WWTPs (Chouf-Mount Lebanon area)	Beirut and Mount Lebanon Water Establishment (BMLWE)
Municipal officials	3 x Hammana, 1 x Addaysseh, 2 x Ehden, 1 x Yammouneh	Hammana WWTP (Metn-Mount Lebanon area)	
Nongovernmental organizations (NGOs)/ donors	1 x Agence Française de Developpement (AFD), 1 x United States Agency for International Development (USAID)/ Lebanon Water Project (LWP)	Chabriha (Sour[18]) WWTP	South Lebanon Water Establishment (SLWE)

[16] See Annex 11 for a list of selected useful documents.
[17] Thirty years after the end of the civil war, data collection and management efforts have not produced much. The infrastructure is still severely lacking, and data are used as a bargaining chip between and within institutions.
[18] Latin name: Tyr.

Key Terms and Steps for Modeling of Water Reuse Potential

The potential for water reuse in irrigation depends on the quality of the treated water as well as the total volume available. Reuse potential is expressed as a composite of two individual criteria representing the quantitative and qualitative aspects of potential: (1) the **reuse potential area,** measured in hectares; and (2) the **reuse potential score**, which is calculated on a scale of 0 to 1 as a function of influent quality, taken as a proxy for reliability, effluent quality, crop type as well as proximity to an irrigation network.

For our study, reuse potential was modeled using GIS software (ArcGIS and QGIS) and a spreadsheet program (such as Microsoft Excel or LibreOffice Calc). Modeling for safe reuse was based on quality guidelines proposed for the Lebanese context by the Food and Agriculture Organization of the United Nations (FAO) in 2010. As a result, it tends to produce a conservative estimate of the potential. Figure 4 gives a schematic representation of the modeling process. It has the following steps:

1. The creation of databases for the existing and planned WWTPs (as per NWSSU) detailing their key characteristics, including precise geolocation.

2. Delineation of the area (termed **command area**) in the proximity of WWTPs using the programming language R.

3. Estimation of the gross and net irrigation requirement within the command area, using data from FAO's Water Productivity open-access portal (WaPOR) and available land use and land cover (LULC) data in a GIS format.

4. Modeling of the **reuse potential area** based on the gross irrigation requirement within the command area and the volume of treated water from WWTPs.

5. Modeling of the **reuse potential score** based on crop types within the command area, effluent quality, proximity of irrigation schemes and influent type (categorized as domestic or mixed), to serve as a proxy for risk to reliability of supply quantity and quality.

6. Modeling of two investment scenarios differentiating the extent of the command area. This was done for comparison and validation.

    a. **Base scenario**, setting the maximum distance of conveyance at 3 km including pumping to an elevation up to 20 m.

    b. **High-cost scenario**, assuming a 5 km maximum distance and pumping up to 50 m elevation.

7. Two interpretations of potential were modeled, differing on the input from the database:

    a. **Actual potential (AP)**, assessing the reuse potential of a WWTP in its current state of operation and considering the actual volume of treated wastewater currently produced. This gives a measure of the potential realizable at present.

    b. **Ideal potential (IP)**, assessing the reuse potential of a WWTP operating at 90% of capacity, assuming that it is rehabilitated and operating as designed. This gives a measure of the potential for an increase in irrigated area in the future.

Building the Wastewater Treatment Plant Database

The first step in the modeling process was the production of two detailed databases: One listing the existing WWTPs as per their characteristics, and the second listing the WWTPs proposed to be built by the national authorities (or other relevant stakeholders). The database of existing WWTPs included the name of each, its geographic coordinates, operational status, design capacity, actual average volume treated, treatment technology, designed level of treatment (tertiary to primary), actual level of treatment, management authority and type of influent (mixed or domestic). Given the inconsistent quality of the data available, we included a note in the database about WWTPs whose data were unclear or conflicting (see Annex 2). For the proposed plants, the database was taken entirely from the NWSSU, which drew the data—location, name and design capacity—from existing studies and plans (see Annex 3).

For the database on existing WWTPs, data were first compiled from the numerous reports on wastewater management in Lebanon, and from a preliminary version of the database produced for the NWSSU with only partial location data. We obtained the fully georeferenced database later in the research process. Additionally, communications with officials of the water establishments as well as operators, contractors and consultants served to validate some of the information (such as current operational status and management) and to identify some existing plants (17) that had not been listed in the NWSSU. Precise geolocation was drawn from reports and from the GIS database of the NWSSU, both for existing and proposed WWTPs. The location data were subsequently confirmed and corrected visually using Google Earth and GeoEye satellite imagery (resolution 0.5 m) dating from 2014.

Data for the GIS Model

To calculate the command area of WWTPs, a **digital elevation model (DEM)** with 30 m resolution was used to extract the elevation of each WWTP based on the exact geolocation as well as the flow patterns (flow direction).

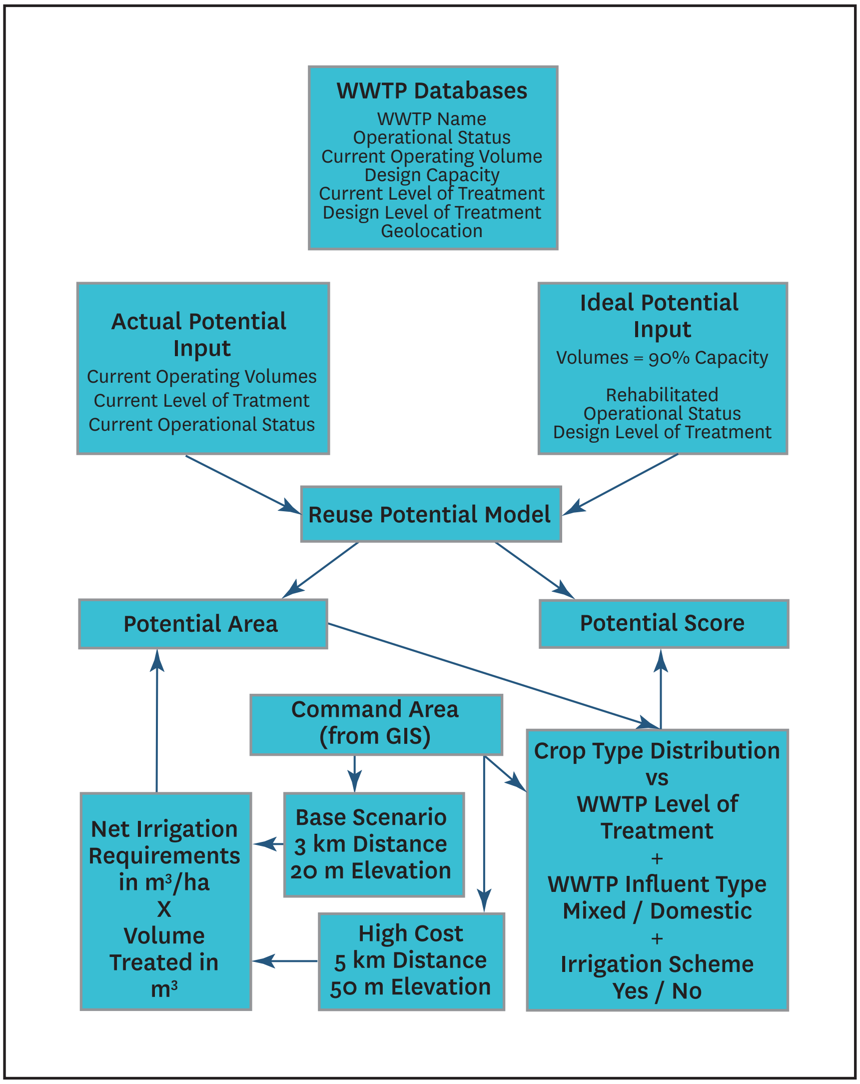

Figure 4. A schematic representation of the modeling process.

LULC data based on 2012 high-resolution satellite imagery from GeoEye allowed us to differentiate crop classes as follows: fruit trees, citrus fruit trees, banana, olives and vineyards. This also subdivided field crops into field crops in medium to large fields, field crops in small fields/terraces, abandoned agricultural land and protected agriculture. This breakdown of agricultural land use conditioned the model, as will be discussed below. The LULC data used for this study are the most up-to-date data currently existing.

A **GIS database for existing irrigation schemes** as well as planned and existing canals was obtained from the MEW and used to assess whether the WWTPs were close to irrigation schemes. This database contains information on public irrigation schemes. However, irrigation schemes are modeled over large areas and this introduces some uncertainty as to the proximity of networks and canals. These data were not used for the modeling of command areas.

GIS data for groundwater could not be obtained from the relevant department in the ministry and was hence not included in the modeling either. As all surface watersheds overlap with stressed groundwater aquifers, as discussed above (see section *Introduction and Background*), it was assumed that concrete demand for additional water resources exists at all locations. Nevertheless, it is important to highlight that some areas, specifically in South Lebanon and northeastern Bekaa, have considerably scarcer accessible water resources.

Calculating Net Irrigation Requirement

Based on LULC data, the net irrigation requirement was calculated as follows:[19]

- The computation and estimation of the net irrigation requirement was based on the spring/summer season, extending from March to

[19] While the precision of such a number is always contestable, the importance here is to create a coherent and comparable set of results to be able to differentiate and grade the potentials of individual WWTPs.

September (220 days), of a typical climatic year (in terms of the rainfall regime).

- The typical year considered was 2018. Monthly maps of reference evapotranspiration (ETo) and rain (R) corresponding to that period were obtained from WaPOR, the open-access FAO portal providing remotely-sensed derived data.
- Then the data were aggregated using GIS software to obtain the seasonal maps of ETo and R for a typical irrigation season.
- Crop evapotranspiration (ETc) was computed using GIS by multiplying the layer of ETo by average crop coefficients corresponding to the considered categories of crops.
- Corrections were made to account for differences in the seasonal length of different crops.
- Finally, the net irrigation requirement was mapped by subtracting the layer of ETc from the layer of R (assuming that on average the effective rain is 70% of total R).

Determining the Command Area

The command area of each WWTP was modeled using the programming language R (see Annex 4 for the logical steps and code). The model allows for pumping uphill from the WWTP and assumes that distribution happens by gravity from the highest possible point. The command area includes all the points included in a lateral buffer that follows the flow path from the WWTP location or at a chosen elevation from the WWTP and excludes all the points above that elevation.

Two command area scenarios were modeled: The **base scenario** command area was modeled with a buffer radius of 3 km and a stream buffer of 750 m, assuming that pumping is possible to a maximum of 20 m; and the **high-cost scenario** command area was modeled with a 5 km buffer and a stream buffer of 1 km, assuming pumping to a maximum of 50 m. The buffer radius (3 km or 5 km) represents the maximum length of conveyor pipe or canal. The stream buffer (750 m or 1 km) is parallel to the natural flow path. It serves to model the gravity water flow and the maximum pumping distance from a stream.

The low- and high-cost scenarios accord to different expected levels of investment. In terms of the reuse potential area, the base scenario represents the lower cost alternative with a shorter conveyor requiring fewer manholes and less pumping. The higher cost scenario reflects a potentially higher investment cost. The 3 km command area was chosen as the base scenario since in the present context of economic disintegration in Lebanon, it is unlikely that water establishments or municipalities will have the funds for investment or the operation and maintenance (O&M) costs over the short or medium term. The ongoing devaluation of the Lebanese lira further suggests that over the medium-term farmers will not be able to offset the high energy cost (linked to the US dollar) with income from production on the local market.[20]

The command areas linked to existing WWTPs are shown in Figure 5. In further steps, agricultural areas in the proximity of each plant were computed based on these command areas and LULC data, resulting in the following outputs:

- total agricultural area;
- total area of fruit trees (excluding olive trees);
- total area of field crops (Figure 6); and
- average net irrigation requirement in the command area of each WWTP (Figure 7).

The command areas of proposed WWTPs, their agricultural areas and net irrigation requirements are outlined in Annex 5 (Figures A5.1, A5.2 and A5.3).

Reuse Potential Area

The reuse potential area is calculated for an irrigation season by dividing the volume produced by a WWTP by the average gross irrigation requirement of the agricultural land cover within the command area. For our study, this was done for both base and high-cost scenarios. Irrigation efficiency was estimated at 55%.

Reuse Potential Score

As not all potentially irrigable areas will have the same suitability for treated wastewater use, we developed a score to qualify and rank the identified potential areas. The reuse potential score is calculated from the weighted sum of three parameters.

The first and most important parameter, level of treatment/crop, assesses the suitability of crops in relation to the level of treatment taken as proxy for effluent quality in accordance with reuse guidelines currently used as reference in Lebanon (FAO 2010). The second parameter, influent type, assesses the risk to the continuity of treatment associated with the highly variable quality of WWTP influent, which includes industrial effluents, i.e., mixed-type influent.[21] Domestic influent is considered much more stable, thereby posing less risk to the operational continuity of the WWTP. The third parameter, irrigation scheme, ranks the presence or absence of an irrigation scheme which, in case of presence, represents a lower investment need and greater ease of implementation. In the following equation, each parameter (score) was given a coefficient representing its relative importance in the model.

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[20] In the context of hyperinflation, and given the already tremendous food import dependency, policies advocating export-oriented agricultural production will increase food insecurity in the country.

[21] The difficulties that industrial inflows create were brought up on a number of occasions by our interviewees. See the next section *Type of Influent Parameter*. The literature also points to these problems.

Potential score = 0.6 * Score "Lvl Treatment/Crop" + 0.15 * Score "Irrigation" + 0.25 * Score "Influent Type"

The weighting of the different parameters was based on a simple point allocation method drawing on inputs from KIIs, the literature, and the subjective assessment of the research team (Odu 2019; Hadipour et al. 2016). More complex weighting approaches were deemed unnecessary as this multi-criteria model is very simple. The score serves to compare WWTPs, and as long as the ranking criteria remain within the conditions defined below, no substantial differentiation in the relative ranking of WWTPs appears. The section *A Guide to Interpretation* below explains how to read the scores.

The level of treatment parameter has a weight greater than the sum of the weights of the other two. The relatively higher weight assigned to the influent type parameter compared to the irrigation scheme parameter reflects the centrality of the treatment process, its effective management and the relative risk associated with critical interruption due to disruptive wastewater loads in the case of mixed rather than domestic wastewater (hence the relatively higher importance of rigorous monitoring). Thus, in the sociotechnical assemblage that defines safe water reuse, the treatment process is modeled as systematically more central and more vulnerable.

Conversely, the relatively lower weight given to the irrigation scheme parameter (Score "irrigation") reflects the possibility of creating new irrigation schemes adapted to the requirements. Irrigation schemes, specifically open-channel gravity schemes, make up a larger (if not the entire) part of the schemes recorded in the MEW database. Technically and financially, these would be easier to repair and maintain, and appear to be less vulnerable to failure. Finally, as the database covers only publicly managed/registered schemes, the lower weight also reflects the remaining uncertainty associated with this parameter (see section *Total Estimated Municipal Wastewater Production*).

The resulting potential score ranges from 1 = highest potential to 0 = no potential.

Level of Treatment/Crop Parameter

There are no official and legally binding water reuse standards in Lebanon. So, the water quality parameters for our modeling exercise were defined on the basis of the treated wastewater typology included in the "Proposition for Lebanese Wastewater Reuse Guidelines" produced by FAO in 2010 (Table 3).

In these proposed standards, crop categories are defined as follows:

Category I

- Fruit trees and crops eaten cooked (the FAO guidelines have no provision for crops irrigated with treated wastewater that are eaten raw)

Water treatment recommendation: Secondary treatment + filtration + disinfection

Category II

- Fruit trees

Water treatment recommendation: Secondary treatment + filtration + disinfection, or secondary treatment + either storage or well-designed series of maturation ponds or filtration percolation

Category III

- Cereals and oleaginous seeds, fiber and seed crops
- Crops for the canning industry, industrial crops
- Fruit trees (except sprinkler-irrigated plantations)
- Plant nurseries, ornamental nurseries, etc.

Water treatment recommendation: Secondary treatment + a few days' storage or oxidation.[22]

Table 3. Quality parameters for treated wastewater based on FAO guidelines for Lebanon.

Parameter	Category		
	I	II	III
BOD_5 (mg/L)	25	100	100
COD (mg/L)	125	250	250
TSS (mg/L)	60	200	200
pH	6-9	6-9	6-9
Cl_2 residual	0	0	0
N-NO_3 (mg/L)	Depending on use and application technique (see FAO 2010)		
Fecal coliforms (in 100 ml)	<200	<1,000	None required
Helminth ova (in 1 L)	<1	<1	<1

Source: FAO 2010.

Notes: BOD – Biochemical oxygen demand; COD – Chemical oxygen demand; TSS – Total suspended solids; NO_3 – Nitrate; Cl_2 – Chlorine.

[22] For reasons of brevity, this list mentions only agricultural crop-related points. Public parks and recreational areas have been omitted.

Most of the quality test data obtained within the framework of our study reported influent and effluent measures only for a single date. Only one very limited time series of effluent quality tests could be obtained for a newly operational plant (Tebnine WWTP). So, it was not possible to establish reliable evidence of an effluent quality trend. The tests that were made available (see Annex 6 for samples) indicated that most of the operational plants with tertiary treatment facilities meet the water quality criteria for Category I crops. However, some of these tests were found to exceed total and fecal coliform requirements by small margins. The WWTPs classified as operating with secondary treatment facilities meet—or are capable of meeting—Category II, or at least Category III, standards proposed in the FAO guidelines. The level of treatment classification "secondary" was assigned to WWTPs where treatment information could not be verified with enough certainty. It was also assumed that with relatively minimal investment, the treatment process of these plants can be improved to meet or approach the above requirements.[23] The FAO standards are strict compared to several other national and international standards; they allow irrigation with treated water only for crops eaten cooked, while other standards do allow it for crops that are eaten raw, for example, those in which the edible part is under the surface, or depending on the combination of vegetable and irrigation technique.[24] For the purpose of modeling, it was assumed that agricultural areas designated as "open field crops" in the LULC data contain a sufficient extent of crops that are irrigable with treated water meeting Category I standards. Accordingly, the potential of WWTPs classified as operating with tertiary treatment was modeled considering all agricultural areas within their command area. This modeling choice, on account of the available data, represents a softening of the FAO guidelines, appropriate to the regulatory context that is still in the process of being defined. Tertiary treatment plants were assigned a higher reuse potential score (1) if more than half of the reuse potential area can be used to irrigate "fruit trees" within the command area and a slightly lower score (0.90) if less than half of the potential area serves "fruit trees" to account for the reduced risk associated with fruit trees.

For modeling the reuse potential of WWTPs operating with secondary treatment, only agricultural areas growing fruit trees (such as oranges and bananas) as well as vineyards and abandoned agricultural lands were considered. Plants with secondary treatment were assigned the same score as the lower-tier tertiary treatment plants (0.90) when the ratio of "fruit trees" to "potential area" was larger or equal to 70%; a score of 0.5 was assigned when the ratio of "fruit trees" to "potential area" was smaller than 70% and larger than or equal to 30%; and a score of 0.25 was assigned when the ratio of "fruit trees" to "potential area" was less than 30%. Plants operating with only primary treatment processes were modeled as having no reuse potential. The scores modeling is detailed below:

Logical expression "level of treatment/crop" score - Score "Lvl Tr/A":

IF "tertiary" AND IF ratio of area of "fruit trees"/potential area > = 50%,	Score = 1
IF "tertiary" AND IF ratio of area of "fruit trees"/potential area < 50%,	Score = 0.90
IF "secondary" AND IF ratio of area of "fruit trees"/potential area > = 70%,	Score = 0.90
IF "secondary" AND IF ratio of area of "fruit trees"/potential area < 70% AND > = 30%,	Score = 0.5
IF "secondary" AND IF ratio of area of "fruit trees"/potential area < 30% AND > 0,	Score = 0.25
IF "secondary" AND IF ratio of area of "fruit trees"/potential area = 0	Score = 0
IF "primary"	Score = 0

Type of Influent Parameter

The modeling of influent quality implies taking into consideration the management of WWTPs, not only in the regulatory context but also in terms of the administrative ability to enforce regulation. Given the structural problems of the wastewater sector (see section *Governance Barriers to Water Reuse*), it was deemed appropriate in the Lebanese context—where discharge of industrial wastewater harmful to the treatment process remains a recurrent problem—to include a parameter representing the risk to WWTP operation. The influent quality affects water reuse in two ways: (1) Municipal wastewater can contain a variety of toxic substances, heavy metals among them. Specifically, where industrial wastewater enters the municipal wastewater collection network, the risk of negative effects on plant health and human health is elevated and needs to be monitored; and (2) certain types of industrial wastewater can affect plant operation over a longer time period, especially when operational capacity is weak. A toxic shock can render the wastewater useless for irrigation for days or even weeks, reducing the reliability of reuse schemes and imposing additional costs and risks upon farmers. The following description by an engineer responsible for wastewater treatment in the SLWE illustrates the problem:

[23] Interview, SLWE, March 25, 2020. An engineer responsible for wastewater treatment conducted an assessment of rehabilitation requirements of WWTPs in his area of responsibility. According to him, most of the smaller WWTPs require relatively minor investment (ranging from a few thousand US Dollars to USD 20,000) to improve treatment operations.

[24] This observation relies on the results of discussions conducted in the framework of the IWMI and Lebanese Standards Institution (LIBNOR) consultative process around the design of national standards. See also Alcalde-Sanz and Gawlik (2017).

"In Nabatiyeh (Charqiye WWTP), for example, the COD (chemical oxygen demand) went up to around 5,000. I don't know what entered the system. Sometimes the pH drops. We get filamentous bacteria in large quantities. It kills the other bacteria and stops the settling process as they don't flock, they remain suspended. We get black water that comes out. So we stop the station, chlorinate to kill the bacteria and then we start over. We bring a new seed of bacteria and rebuild the bacteria. Sometimes there is blood coming, or other substances with low pH. In the industrial zones, you don't know what goes in the plant. Sometimes, we get the waste (rennet) coming from the cow and animal farms that make labneh (strained yoghurt)."[25]

For our modeling purposes, and based on interviews with experts as well as available reports, wastewater influent was categorized as mixed for the large urban agglomerations and industrial zones. Where information about the type of influent was available for smaller rural plants, this was incorporated in the database. For the majority of rural plants, the influent was considered the domestic type. Domestic influent was given a higher score compared to mixed influent as follows:

Logical expression "Influent Type" score:	
IF "domestic",	Score = 1
IF "mixed",	Score = 0

It is worth mentioning here that an increased inflow of heavy metals seems to occur regularly at the beginning of the rainy season. The first rains wash away dust, car exhaust, car tire particulates, oil and other potentially toxic substances that would have accumulated on the roads and paved surfaces over the dry summer months. In many cases across the country, storm and wastewater networks are combined, and the quality of the infrastructure is often subject to infiltration, all of which will carry considerable amounts of toxic wastewater into treatment plants.[26]

Irrigation Parameter

It was assumed that the presence of irrigation schemes in the relative proximity of WWTPs would make reuse projects less costly since treated water could be injected into existing infrastructure, thereby increasing reuse potential. Therefore, WWTPs having irrigation schemes within their command area were rated higher than those without (see Figure 8).

Logical expression for irrigation scheme score:	
IF "irrigation scheme",	Score = 1
IF "no irrigation scheme",	Score = 0

Ideal Potential and Actual Potential

It is useful to distinguish between potential at current capacity and operational status and potential at possible operating capacity and improved status. For the existing WWTPs, we modeled two reuse potentials in order to differentiate between the immediately available scenario and a future scenario in which good development policy has led to a more efficient use of resources and treatment capacity, leading to larger wastewater volumes. Each of these two scenarios were modeled for a lower cost scenario (3 km buffer for command area delineation) and a higher cost scenario (5 km buffer for command area delineation).

Ideal Potential (IP) is based on the design capacity of plants and the designed level of treatment. It represents an idealized future scenario, wherein existing plants are rehabilitated and operating at 90% capacity.

The **Actual Potential (AP)** scenario models the present state of WWTPs. It considers the actual volume treated, the current operational status of a plant and the actual level of treatment. For WWTPs whose actual volume treated was unknown, it was assumed to be equal to 31%, which represents the average ratio of design capacity and actual volume treated for all operational WWTPs whose actual volumes were known.

In the AP scenario, the following factors were applied to the "level of treatment/crop" parameter for plants characterized as:

- "Operational" = 1, wherein the potential score remains the same when a WWTP operates well.
- "Under construction" = 0.7, when WWTPs in various stages of construction have funding secured and can thus be expected to start operating in the short- to medium-term future.
- "Partially operational" = 0.5, reflecting the associated risk with a variety of factors such as inefficient treatment processes, flow interruptions, probable investment needs for WWTPs, etc.
- "Built not operational" = 0.

[25] Interview, SLWE, January 30, 2020.
[26] Interview, CDR, June 20, 2020.

A Guide to Interpretation

With all the parameters now elaborated, Table 4 explains a few reference scores to help with the interpretation of results presented in the next section. The actual potential scores modify these according to the operational status of WWTPs.

Table 4. Interpretation of reuse potential scores.

Potential score	Description
1	The WWTP in question is reported as operating tertiary treatment, has an irrigation scheme in relative proximity, and the influent is domestic, thus less risky to WWTP operation.
0.94–0.7	This includes WWTPs with a high ratio of fruit tree area to reuse potential area with one or more secondary parameter scoring.
0.69–0.54	Includes WWTPs with tertiary treatment without secondary parameter scoring or scoring on irrigation, as well as WWTPs with operating secondary treatment with a mid-range ratio of fruit tree area to potential area and at least domestic-type influent, thus less risky to the treatment process.
0.53–0.0	Includes WWTPs operating secondary treatment with mid to low ratio of fruit tree area to potential area.

Technical Potential for Water Reuse

In this section, we present the results of our modeling of the technical potential for using treated wastewater in Lebanon. Building on the databases of existing and proposed WWTPs (as per NWSSU), we modeled the reuse technical potential of 104 existing plants—including those in the process of being built—and 164 proposed plants (Figure 9).

Existing and Proposed WWTP Databases

Of the 104 existing plants, 61 were considered either "operational" (41) or "partially operational" (20)—the latter term denoting WWTPs operating their treatment process only partially or being subject to limitations on full operation. There were 35 WWTPs categorized as "built, not operational"; these represented projects that might have been operational at some point but had fallen into varying states of disrepair and were thus receiving no volumes, or were receiving wastewater but rendering no treatment. Finally, 8 WWTPs were considered as "under construction"; these included projects at various stages of construction and those awaiting commission.

The majority of WWTPs are under the administrative responsibility of municipalities (62). For an additional 8 plants, we were not able to confirm with certainty that they were managed by municipalities (Table 5).[27] Of these 70 municipally run plants, 34 were either "operational" or "partially operational" while 33 were not operational. Regional water establishments (RWEs) manage 17 WWTPs. The North Lebanon Water Establishment (NLWE), however, does not manage any of the WWTPs in its territory (Figure 10). In contrast, the Beirut and Mount Lebanon Water Establishment (BMLWE) manages 10 operational plants. The Council for Development and Reconstruction (CDR) currently manages 17 WWTPs, of which six are under construction. Among them, most of the operational plants are in the NLWE area.

[27] Nevertheless, they were included in the municipality category.

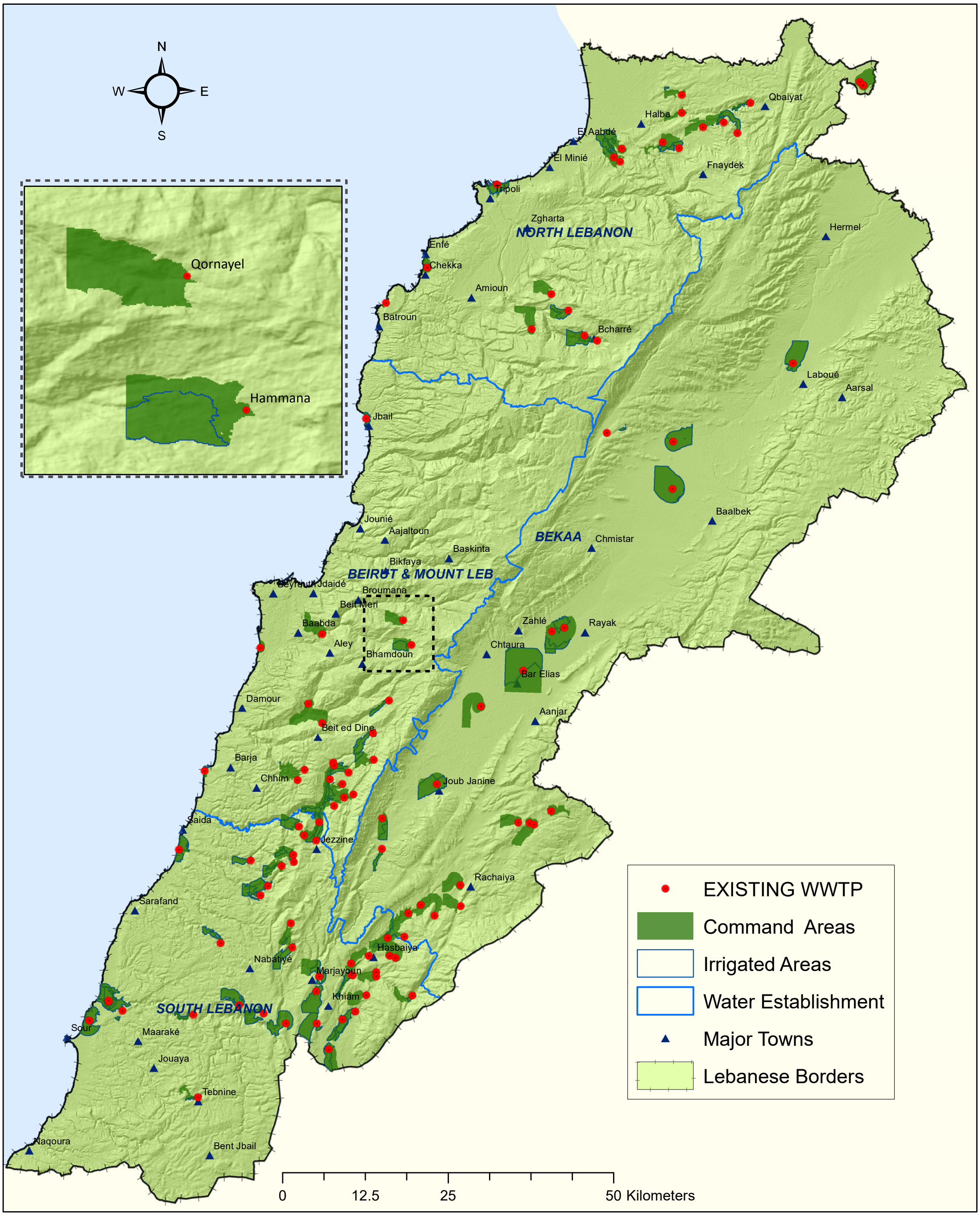

Figure 5. The command areas of existing WWTPs.

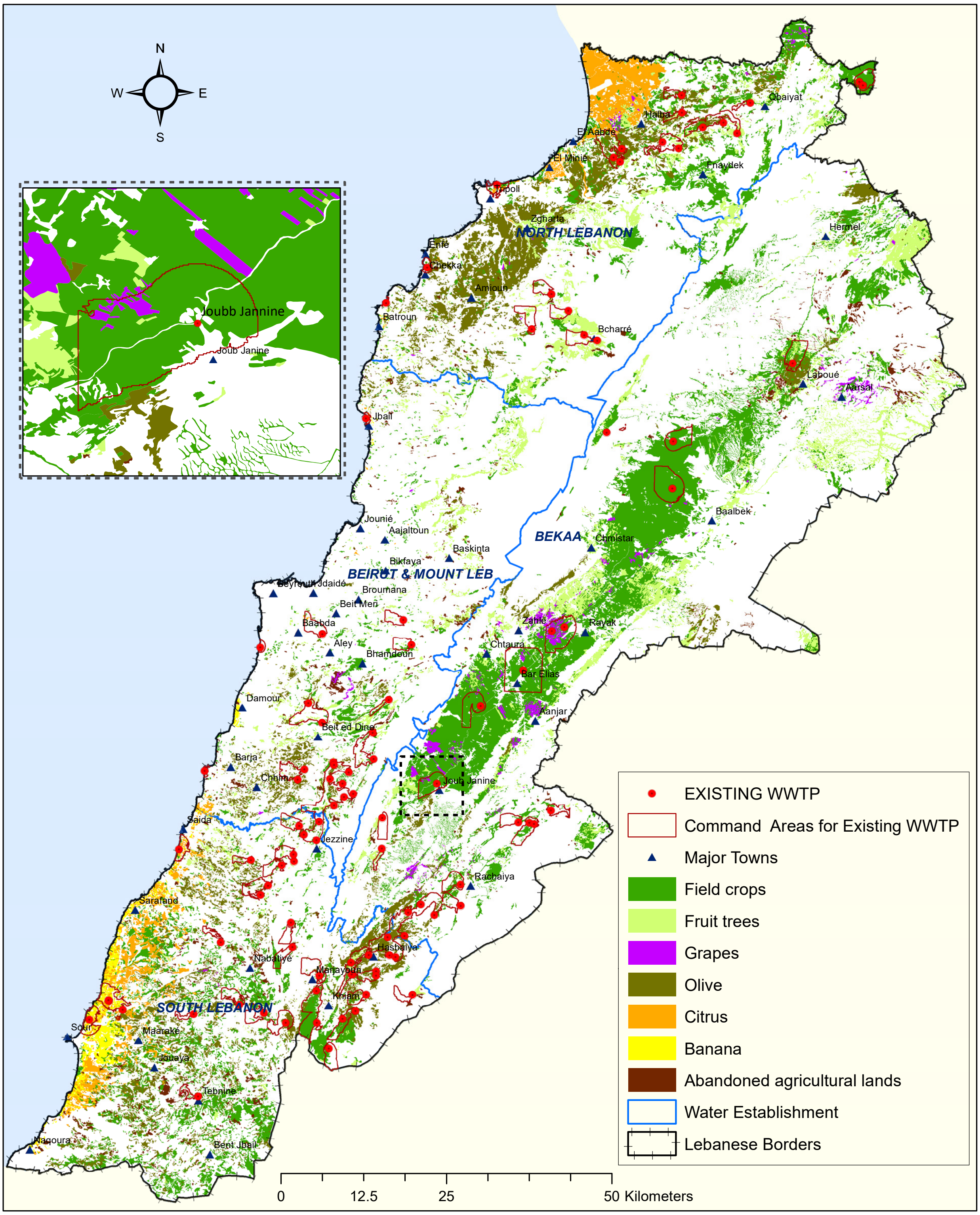

Figure 6. Agricultural areas and crops in the command area of existing WWTPs.

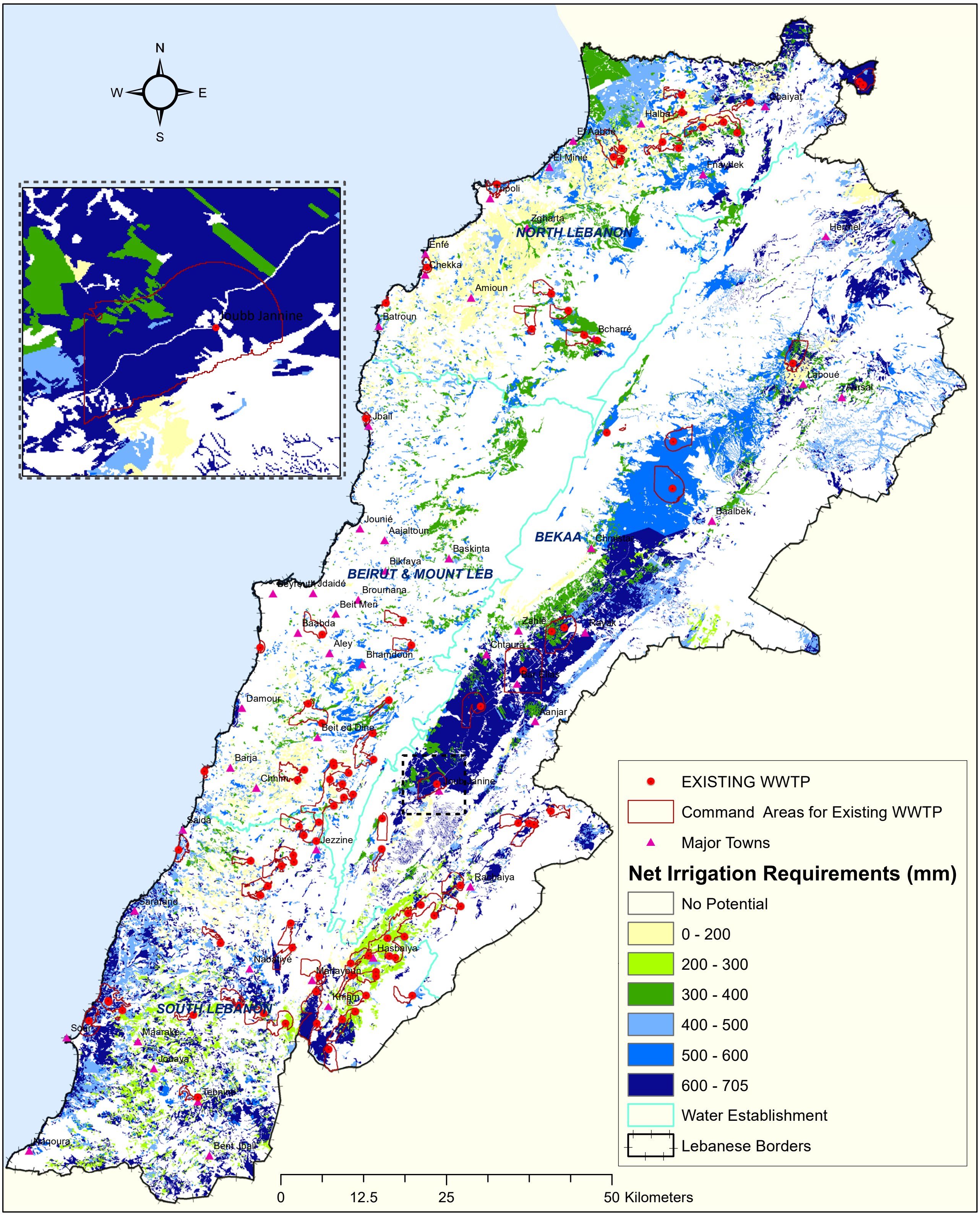

Figure 7. Net irrigation requirement in the command areas of WWTPs.

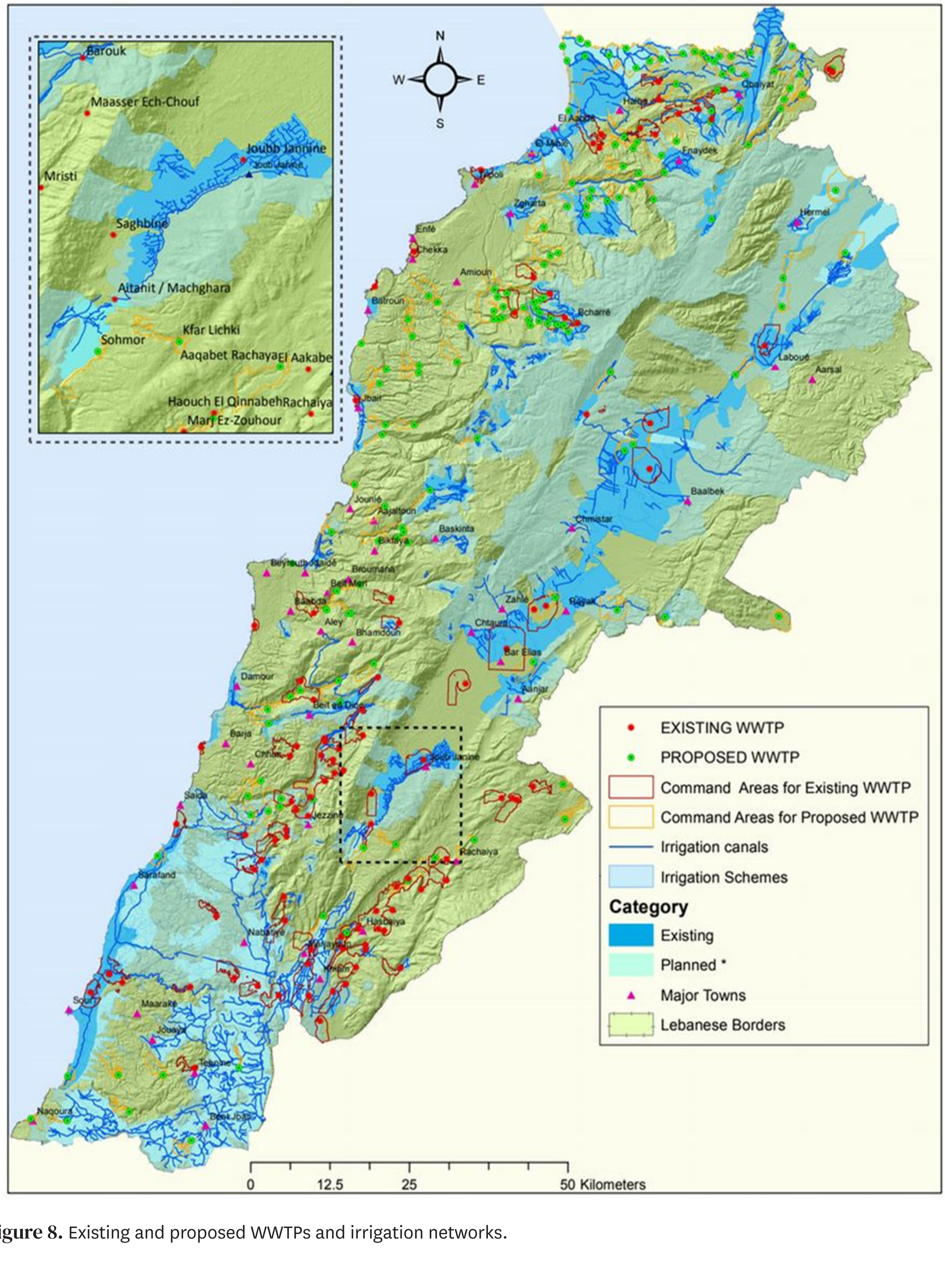

Figure 8. Existing and proposed WWTPs and irrigation networks.

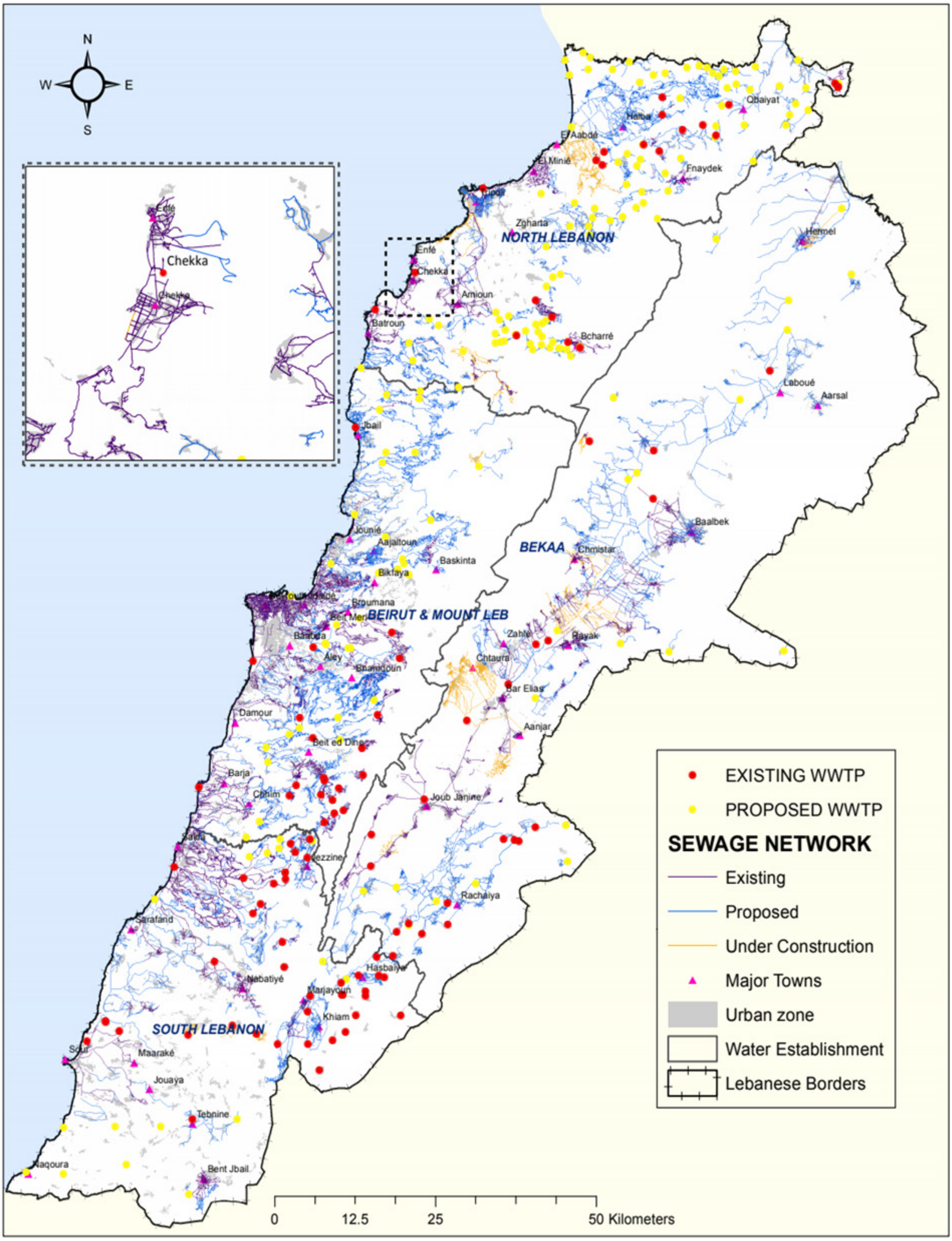

Figure 9. Existing and proposed WWTPs and sewage network.

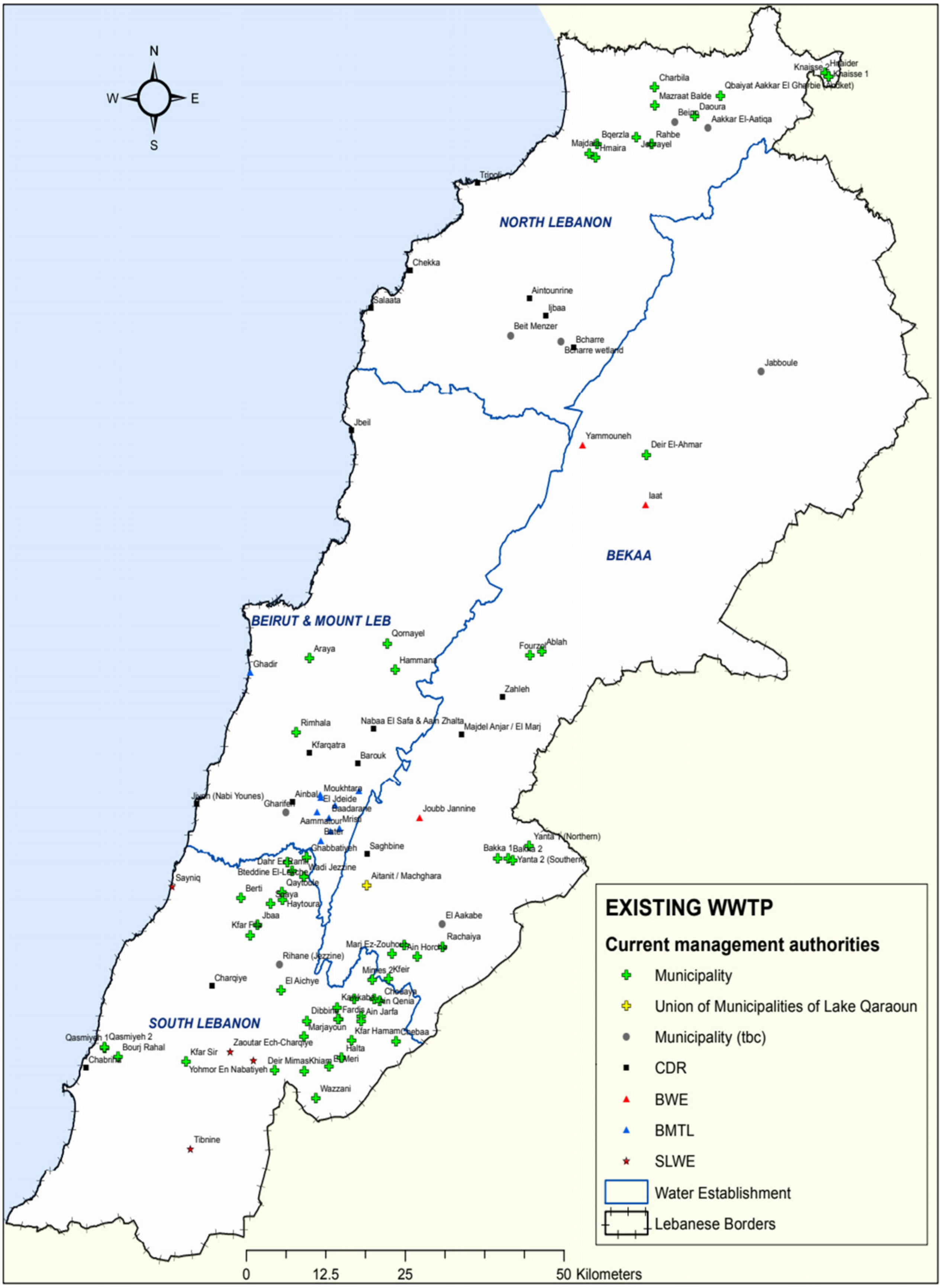

Figure 10. Wastewater treatment plants by managing authority.

Table 5. Distribution of WWTPs by managing authority and operational status.

	Operational status									
Managing public authority	Built, not operational		Operational		Partially operational		Under construction		Total	
BMLWE			10%	10					10%	10
BWE	1%	1	1%	1	1%	1			3%	3
CDR	1%	1	6%	6	4%	4	6%	6	16%	17
Municipalities	32%	33	19%	20	13%	14	2%	2	66%	69
SLWE			3%	3	1%	1			4%	4
Union of Municipalities of Lake Qaraoun	0%		1%	1	0%		0%		1%	1
Total	34%	35	40%	41	19%	20	8%	8	100%	104

The largest volume of wastewater is treated by CDR-managed plants (Table 6). Of the total volume of 222,366 m^3/day that are actually treated, 40% goes through WWTPs managed by contractors hired by CDR, 28% by WWTPs under the management of BMLWE, and 25% by WWTPs managed by the SLWE. Finally, 5% of the volume is treated by BWE plants and only about 2% of the actually treated wastewater passes through municipal WWTPs (Figure 11).

Table 6. Actual volume of wastewater treated by managing authority.

	Actual volume treated (m^3/day)				
Managing authority	Built, not operational	Operational	Partially operational	Under construction	Total
BMLWE		61,735			61,735
BWE	50	6,000	5,000		11,050
CDR	0	33,740	37,200	17,000	87,940
Municipalities	100	4,430	541	0	5,071
SLWE		370	55,000		55,370
Union of Municipalities of Lake Qaraoun		1,200			1,200
Total	150	107,475	97,741	17,000	222,366

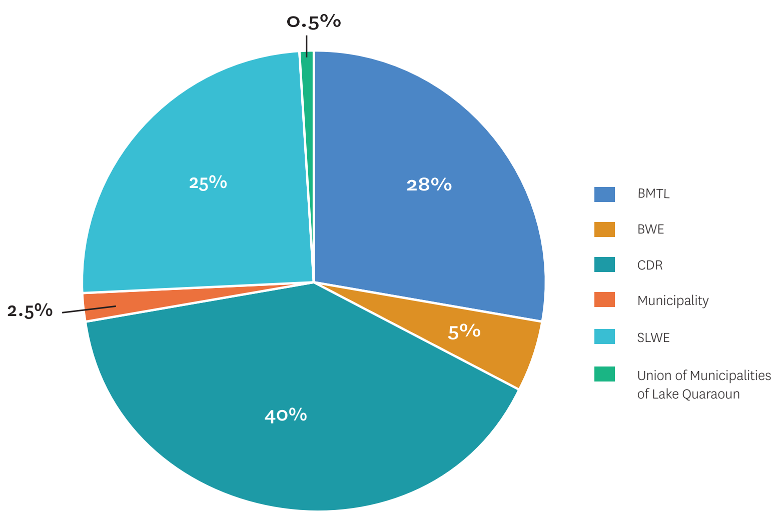

Figure 11. Actual volume of wastewater treated by a managing authority.

Table 7 gives a breakdown of the volume of treated water in relation to the total volume of municipal wastewater generated. The total volume of wastewater actually receiving some form of treatment amounts to 81.2 Mm^3 per year. This is 25-30% of the wastewater generated yearly. The three largest WWTPs in Lebanon (Sayniq/Saida 55,000 m^3/day, Ghadir 60,000 m^3/day and Tripoli 30,000 m^3/day) currently only treat, at a primary level, a total of 145,000 m^3/day or 52.9 Mm^3 per year, and account for 86% of the treated water discharged into the sea. Currently, only 34% of the treated wastewater can be considered for use in irrigation, which is about 8-10% of the (estimated) total wastewater generated. Calculated for the irrigation season, this amounts to about 16.6 Mm^3/year of actually treated wastewater which are currently available for reuse in irrigation.

In the absence of any accounting of indirect reuse—due to the lack of water use and water production data—it remains impossible to estimate the volumes that can be added to the existing water use.

Table 7. Total wastewater (Mm^3) generated, treated and discharged.

	Annual	Seasonal	% of total
Total municipal wastewater generated	273.7–328.5	164.2–198.2	100
Total treated water produced	81.2	48.9	25–30%
Total treated water discharged into the sea	60.2	36.3	18–22%
Total treated water discharged into inland water bodies	20.9	12.6	6.3–7.6%
Total put to direct reuse (2020)	0	0	0
Total indirect reuse	Indirect reuse, widespread as water from rivers is persistently used for irrigation, cannot be quantified because of a lack of water use and water production data.		

Table 8 presents the treatment capacity of the existing and operational plants, as well as the present production of treated wastewater according to the authorities that currently manage them. The third column of the table shows the volume of treated wastewater produced per season at 90% of design capacity for a scenario in which WWTPs are assumed to have been rehabilitated and operating at 90% capacity (a scenario in which wastewater network coverage has increased, existing networks have been rehabilitated and under-construction networks have been completed). The fourth column of the table shows the current generation of treated volume per season as reported and presented in the database. The fifth column shows volumes for a seasonal scenario where all existing non-operational plants have been rehabilitated and restored to operate at current utilization levels. Under the assumption that currently non-operational plants can be rehabilitated and operated at an average utilization level of 31% of designed volume, at least an additional 5 Mm^3 of treated wastewater could potentially be mobilized for use. If WWTPs operated at 90% of current design capacity, as much as 48.6 Mm^3 could potentially be mobilized.

These numbers further suggest that considerable quantities would be available for groundwater recharge outside of the irrigation season. This is an option that should certainly be explored wherever the effluent quality is appropriate and the quantities are interesting. However, reuse for groundwater recharge falls outside of the scope of this report.

The 164 WWTPs being planned for expansion of treatment capacity, proposed in the NWSSU, would add another 182 Mm^3 (at 90% of designed capacity utilization) per year or about 110 Mm^3 per season, if implemented in totality.

Following this summary analysis of water volumes for reuse, the next section takes up the question of technical reuse potential for a more nuanced understanding of the technical potential to use wastewater for irrigation in Lebanon.

Table 8. Yearly and seasonal volumes (Mm^3) by reuse possibility and managing authority.

		Seasonal			Annual		
Managing authority	Qualitative assessment of reuse possibility[a]	Total volume at 90% of average capacity	Total average volume treated (all plants)	Total actual volume treated (only operational)	Total volume at 90% of average capacity	Total actual average volume treated (all plants)	Total actual volume treated (only operational)
BMLWE	Reuse not possible	27.3	11.9	11.9	50.4	21.9	21.9
	Reuse possible	1.1	0.3	0.3	2.0	0.7	0.6
BWE	Reuse possible	6.9	2.2	1.7	12.7	4.0	4.0
CDR	Reuse not possible	30.4	7.1	3.5	56.0	13.0	11.0
	Reuse possible	32.1	15.6	12.5	59.2	28.7	21.1
Municipalities	Reuse possible	6.6	2.5	1.4	12.2	4.8	1.9
SLWE	Reuse not possible	12.9	10.9	5.4	23.7	20.1	20.1
	Reuse possible	0.9	0.3	0.3	1.7	0.5	0.1
Union of Municipalities of Lake Qaraoun	Reuse possible	1.0	0.2	0.2	1.8	0.4	0.4
Subtotal	Reuse not possible	70.6	29.8	20.9	130.1	55.0	52.9
	Reuse possible	**48.6**	**21.3**	**16.5**	**89.6**	**39.2**	**28.2**
Grand total		119.2	51.1	37.4	219.7	94.2	81.2

Note: [a] Reuse possibility over the next decade.

Reuse Potential: Modeling Results

Annexes 7 and 8 show in tabular form the results of our modeling exercise for existing and proposed WWTPs, respectively. Graphic representations of the results for four scenarios[28] for existing WWTPs and one scenario for proposed WWTPs are shown in Figures 12 to 16. For the proposed plants, we modeled only for the ideal potential (IP) in a low-cost scenario (with a 3 km buffer for command area delineation), and omitted the influent factor as it was assumed that, notwithstanding the current political and economic crisis in Lebanon, the new networks will be separate from the storm water networks and not connected to industrial establishments and therefore secure from the risk of industrial influent. Table 9 shows the distribution of scores of existing WWTPs over six scoring levels in each of the four scenarios. Table 10 shows the total reuse potential areas (both ideal and actual) in the low-cost and high-cost scenarios.

It can be seen that about 80% of the WWTPs have a high score in terms of the ideal potential (IP) in a low-cost (base) scenario. This increases to 90% in the high-cost scenario.

The high number of WWTPs (39%) with a zero actual potential (AP) score reflects the high number of non-operational plants. However, 36 WWTPs have a high reuse potential score (between 0.7 and 1) in terms of actual potential (AP) in the base scenario. Of those, five are under the responsibility of CDR, 13 are under some form of municipal management and the remaining are in the hands of the RWEs (Table 11).

In Table 10, the total irrigation potential per season, expressed in ha, represents the total area irrigable by wastewater from plants operating at 90% of design capacity—regardless of the existence of agricultural areas within their command areas—in accordance with the gross

[28] Ideal reuse potential [IP] and actual reuse potential [AP] in low-cost (base) as well as high-cost scenarios.

irrigation requirement associated with the command area. It includes the high volumes produced by WWTPs serving the large urban agglomerations on the coast, which do not have equivalent agricultural areas associated with them. The next column showing the total potential area in the command area is a better indicator of the ideal potential (IP) as it shows the irrigable agricultural area within the command area, which is in relative proximity of the plant. The fact that this, the irrigation potential in the command area in a base (low-cost) scenario increases by almost 900 ha for the high-cost scenario reflects the additional potential that can be mobilized when the larger plants operate closer to capacity.

Table 9. Summary of scores for actual and ideal reuse potential of existing WWTPs as per base and high-cost scenarios.

	Base scenario		High-cost scenario	
Score	Ideal potential (IP)	Actual potential (AP)	Ideal potential (IP)	Actual potential (AP)
1	11	9	23	16
0.94–0.7	64	27	69	25
0.69–0.54	17	14	8	17
0.53–0.37	6	12	1	6
0.3–0.15	1	1	1	1
0	5	41	2	39

Table 10. Total ideal and actual potential areas (ha) as per low-cost (base) and high-cost scenarios.

Base scenario			High-cost scenario		
Total irrigation potential per season (IP[a])	Total potential area in command area (IP)	Total irrigation potential per season (AP[b])	Total irrigation potential per season (IP)	Total potential area in command area (IP)	Total irrigation potential per season (AP)
9,902.1	4,993.4	2,202.6	10,405.4	5,857.4	2,340.1

Notes: [a] IP: Ideal potential.
[b] AP: Actual potential.

Table 11. Distribution of WWTPs by their actual potential score and managing authority.

	Reuse potential score									
Managing authority	0	0.23	0.38	0.4	0.45	0.52	0.53	0.55	0.57	0.61
BMLWE[a]	1									
BWE[b]	1	1			1					
CDR[c]	2		1	2	1		1		1	1
Municipalities	36			2		4		2		
SLWE[d]	1									
Union of Municipalities of Lake Qaraoun										
Total	41	1	1	4	2	4	1	2	1	1

	Reuse potential score									
Managing authority	0.67	0.69	0.7	0.78	0.79	0.82	0.85	0.94	1	Total
BMLWE								4	5	10
BWE										3
CDR	1	2		1	1	1	1		1	17
Municipalities	7		2	1	3		1	9	2	69
SLWE								2	1	4
Union of Municipalities of Lake Qaraoun								1		1
Total	8	2	2	2	4	1	2	16	9	104

Notes: [a] BMLWE = Beirut and Mount Lebanon Water Establishment. [b] BWE = Bekaa Water Establishment.
[c] CDR = Council for Development and Reconstruction. [d] SLWE = South Lebanon Water Establishment.

As shown in Table 12, the WWTP at Sour (Chabriha, #24 in Annex 8), for example, has an irrigation potential of 691 ha, of which 542.5 ha would fall in the command area in an ideal potential (IP), low-cost scenario, suggesting that this plant could irrigate more agricultural area than the command area. However, the actual potential of this WWTP is 326 ha in the low-cost scenario with no significant increase in the higher cost scenario where the actual potential is 329 ha. The variation is due to the change in average net irrigation requirement of the enlarged command area. The difference in the Chabriha WWTP's reuse potential score between the ideal potential scenario (0.75) and the actual potential scenario (0.57) derives from the fact that the plant had not yet started operations (at the time of writing) and was still bypassing wastewater collected from a highly urbanized area to the sea outfall.

The Zahleh and Iaat WWTPs in the Bekaa are two other plants where the ideal potential area increases from the base to higher cost scenarios but remains largely unchanged when modeled against actual treated volumes. For the large majority of plants, the potential area does not vary in a meaningful way but only as a result of the above-mentioned variation in average net irrigation requirement. In all cases, analysis of the different scenarios for existing plants and the single scenario for proposed plants indicates that many small WWTPs are interesting sites for reuse and should not be neglected in a search for high-impact single projects.

Table 12. Reuse potential of the Chabriha wastewater treatment plant.

				Base scenario		
#	WWTP	Irrigation potential per season (ha) (IP[a])	Reuse potential in command area (IP)	Reuse potential score (IP)	Reuse potential area (ha) (AP[b])	Reuse potential score (AP)
24	Chabriha	691	543	0.75	326	0.57
				High-cost scenario		
#	WWTP	Irrigation potential per season (ha) (IP)	Reuse potential in command area (IP)	Reuse potential score (IP)	Reuse potential area (ha) (AP)	Reuse potential score (AP)
24	Chabriha	697	697	0.75	329	0.57

Notes: [a] IP = Ideal potential.
[b] AP = Actual potential.

Table 13 shows the distribution of the reuse potential areas of WWTPs (in both the ideal and actual scenarios) by managing authority alongside the actually treated volumes and design capacities. It shows that a lot of potential area is associated with the CDR, though it also shows that large volumes of wastewater do not translate into potential. The results also show that the reuse potential area in the command area of municipal plants could be raised by 400% through rehabilitation and proper operation of plants. There is also much potential to unlock in the SLWE where the IP area and AP area differ by a factor of 8.5. The possible increases of reuse potential area are considerably smaller for the other administrative bodies but still range around a factor of 3.

Table 13. Ideal and actual potential area and actual treated volume by managing authority.

Managing authority	Ideal potential area (ha) (IP[a])	Potential area in command area (3 km) (IP)	Current design capacity (m^3/day)	Actual potential area (ha) (AP[b])	Actual volume treated (m^3/day)
BMLWE[c]	172.9	172.9	142,275	59	61,735
BWE[d]	690	690	34,800	234.4	11,050
CDR[e]	6,527	2,883.1	313,310	1,639.3	87,940
Municipalities	911.4	865.7	22,197	202.7	5,072
SLWE[f]	1,464.9	297.7	69,575	34.5	55,370
Union of Municipalities of Lake Qaraoun	136	84	5,000	32.6	1,200
Total	9,902.2	4,993.4	587,157	2,202.5	222,367

Notes: [a] IP = Ideal potential scenario; [b] AP = Actual potential scenario; [c] BMLWE = Beirut and Mount Lebanon Water Establishment; [d] BWE = Bekaa Water Establishment; [e] CDR = Council for Development and Reconstruction; [f] SLWE = South Lebanon Water Establishment.

Tables 14 and 15 compare the reuse potential scores and reuse potential areas for the actual (AP) and ideal potential (IP) scenarios, respectively. Just above half of the actual potential area has a reuse potential score higher than 0.6. This proportion increases in the ideal potential case where about two-thirds of the potential area has a score higher than 0.6. This again highlights the gains that would accrue from rehabilitation and improved management of WWTPs.

Our analysis of the reuse potential of proposed WWTPs (summarized in Table 16) shows that only around 40% of the potential area (in an IP low-cost scenario) is associated with WWTPs scoring higher than 0.6. It also shows that a number of large plants are located in areas with little to no agricultural area available, as can be seen from the difference between the total reuse potential area and the potential within the command area. The difference accumulates from WWTPs with low reuse potential scores with almost 10,000 ha of the potential area associated with plants with a score lower than 0.6. The difference between the potential area falling within the command area and the total potential area is much lower for WWTPs with scores higher than 0.6.

Table 14. Actual reuse potential (AP) area and seasonal volumes as per actual reuse potential score.

Potential score (AP)	Actual potential area (ha)	Actual volume treated per season (m^3)	Total volume (m^3) per season at design capacity (90% average)	Number of WWTPs
0	2.8	20,325,044	70,915,482	41
0.225	95.5	495,000	4,752,000	1
0.378	289.5	1,933,470	8,910,000	1
0.4	127.9	530,608	1,359,072	4
0.45	138.9	1,752,696	5,623,200	2
0.52	6.4	21,062	143,550	4
0.528	65.4	429,660	1,980,000	1
0.55	6.5	40,511	142,560	2
0.57	326.3	2,356,200	7,128,000	1
0.61	41.4	214,830	990,000	1
0.67	115.8	477,378	1,355,706	8
0.69	668.8	5,940,000	9,088,200	2
0.7	38.1	247,253	507,870	2
0.778	28.6	181,231	835,164	2
0.79	13.5	106,920	152,460	4
0.82	12	77,339	356,400	1
0.85	11.2	650,470	776,160	2
0.94	161.9	1,257,874	3,396,690	16
1	52.1	369,270	744,480	9
Total	2,202.6	37,406,816	119,156,994	104

Table 15. Ideal potential (IP) area and seasonal volume of treated wastewater as per ideal potential score.

Potential score (IP)	Ideal potential area (ha) (IP)	Reuse potential in command area (3 km) (IP)	Total volume (m^3) per season at design capacity (90% avg)	No. of WWTPs
0	14.8	14.8	27,473,886	5
0.3	1,360.1	218.6	12,870,000	1
0.4	225.3	189.3	1,200,672	5
0.54	933.9	933.9	8,910,000	1
0.55	465.8	348.9	3,152,160	10
0.69	5,016.5	1,674	44,871,750	8
0.7	98.7	87.7	796,950	5
0.75	691	542.5	10,771,200	2
0.79	173.3	171.9	1,284,426	14
0.85	56	56	917,730	4
0.94	723.4	612.4	5,789,520	38
1	143.4	143.4	1,118,700	11
Total	9,902.2	4,993.4	119,156,994	104

Table 16. Summary analysis of the reuse potential of proposed WWTPs.

Score	Reuse potential area (ha) (IP[a])	Reuse potential in command area (3 km) (IP)	Total volume (m^3) per season at design capacity (90% avg)	No. of WWTPs
0.00	2,564.4	152.4	19,963,944	12
0.18	1,787.8	512.2	12,246,300	11
0.35	167.3	167.1	944,460	3
0.48	5,985.6	2,156.2	50,076,972	22
0.63	1,409.1	715.4	27,663,570	37
0.65	331	306.3	2,234,430	7
0.70	18.5	18.5	64,435,338	3
0.93	1,824.2	1,690.6	14,610,420	59
1.00	85.6	85.5	933,372	10
Total result	14,173.5	5,804.2	193,108,806	164

Note: [a] IP = Ideal potential scenario.

WWTPs and Agricultural Lands with Higher Reuse Potential

Tables 17 to 20 rank wastewater treatment plants by different measures of potential. We use these model results to produce a list of 16 WWTPs with the highest actual potential by reading the reuse potential areas and reuse potential scores together.

Table 17 lists the 16 highest ranked WWTPs by actual potential area, that is, reuse potential area calculated on the basis of the current volume of treated water produced. As the table shows, some WWTPs, such as Majdel Anjar, on account of being under construction, and Iaat, on account of the level of treatment and operational status, have very low actual potential scores. Other plants such as Charqiye, Jbeil and Bcharre have only small reuse potential areas within the command area, meaning that water would have to be transported farther to irrigate the potential area. Annex 7 shows the results for the high-cost scenario.

Table 17 serves to identify projects with large impact while placing less emphasis on the ease of implementation. The Chabriha (Sour) plant, for example, has a high reuse potential area but low reuse potential score on account of not having been in operation at the time of the research. It also faces obstacles to reuse implementation that are of a bureaucratic nature (see below), which are not accounted for in the technical modeling.

Table 18 ranks WWTPs by their actual reuse potential score but excludes WWTPs whose potential area within the command area is smaller than 20 ha. This measure combines the promise of easier implementation with the promise of a future increase from additional wastewater volumes; it helps in identifying potentially easier-to-implement projects with relatively high local impact.

For comparison, Table 19 shows a selection based only on reuse potential scores. The reuse potential areas in these cases are considerably smaller. Such a selection might be useful to NGOs or local associations interested in supporting or funding small feasible projects on a limited budget.

Drawing from the above discussion, we propose the selection of 16 WWTPs listed in Table 20 as those most promising for a substantial mobilization of the reuse potential.

The above summary of our results shows the usefulness of such a modeling exercise. The maps shown in Figures 12 to 16, in combination with the tables of results given in Annexes 7 and 8, provide a good tool for further exploration, prioritization and selection. The case studies presented in Annex 9 present further details, combining maps and a combination of qualitative and quantitative information about WWTPs and their surroundings. The case studies include Zahleh, Chabriha, Aintourine, Ijbaa, Ablah and Hammana from the list in Table 20, as well as Yammouneh and Iaat as illustrations of some of the obstacles potentially faced at the local level.

Finally, without an understanding of the policy context—which at the current historical juncture is still rapidly deteriorating—technical potential by itself gives a misleading picture of the reuse potential in Lebanon. The next chapter will situate technical potential in context to give a better understanding of the possibility for water reuse to materialize more or less systematically across the Lebanese territory.

Table 17. Ranking of WWTPs by actual reuse potential in command area.

#	WWTP	Irrigation potential per season (ha) (IP[a])	Potential in command area (IP)	Potential score (IP)	Irrigation potential per season (ha) (AP[b])	Potential score (AP)
100	Zahleh	738.1	738.1	0.69	527.2	0.69
24	Chabriha	691	542.5	0.75	326.3	0.57
72	Majdel Anjar/El Marj	933.9	933.9	0.54	289.5	0.38
26	Charqiye	308.7	8.2	0.69	141.6	0.69
59	Joub Janine	231.5	231.5	0.69	138.9	0.45
52	Iaat	458.5	458.5	0.69	95.5	0.23
9	Aintourine	91.9	91.9	0.79	91.9	0.4
53	Ijbaa	86.8	86.8	0.94	86.8	0.67
57	Jbeil	211	14.2	0.69	65.4	0.53
16	Bcharre	133.5	16.6	0.55	41.4	0.61
10	Aitanit/Machghara	136	84	0.94	32.6	0.94
8	Ainbal	121.2	86	0.4	30.3	0.4
3	Ablah	44.1	44.1	0.94	28.6	0.94
92	Tebnine	77.1	51.3	0.94	23.9	0.94
79	Nabaa El Safa & Aain Zhalta	71.1	71.1	0.94	22	0.78
40	Fourzol	21.3	21.3	0.94	21.3	0.94

Notes: [a] IP = Ideal potential scenario.
[b] AP = Actual potential scenario.

Table 18. Ranking of WWTPs by actual potential score (those with reuse potential within a command area [CMD] >20 ha).

#	WWTP	Irrigation potential per season (ha) (IP[a])	Potential in command area (IP)	Potential score (IP)	Irrigation potential per season (ha) AP[b])	Potential score (AP)
15	Bater	25.4	25.4	1	15.6	1
10	Aitanit/Machghara	136	84	0.94	32.6	0.94
92	Tebnine	77.1	51.3	0.94	23.9	0.94
3	Ablah	44.1	44.1	0.94	28.6	0.94
37	El Jdeide	43.4	43.4	0.94	3.9	0.94
2	Aammatour	31.7	31.7	0.94	9.7	0.94
40	Fourzol	21.3	21.3	0.94	21.3	0.94
82	Qbaiyat Aakkar El Gharbie	39.4	39.4	0.7	12.2	0.94
49	Hebbariyeh	36	36	0.85	11.2	0.85
14	Barouk	38.6	38.6	1	12	0.82
79	Nabaa El Safa & Aain Zhalta	71.1	71.1	0.94	22	0.78
45	Hammana	31.1	31.1	0.7	19.5	0.7
43	Gharifeh	60	60	0.55	18.6	0.7
100	Zahleh	738.1	738.1	0.69	527.2	0.69

Notes: [a] IP = Ideal potential scenario.
[b] AP = Actual potential scenario.

Table 19. WWTP ranking by actual potential score.

#	WWTP	Irrigation potential (ha) per season (IP[a])	Potential (ha) in command area (IP)	Potential score (IP)	Irrigation potential (ha) per season (AP[b])	Potential score (AP)
15	Bater	25.4	25.4	1	15.6	1
88	Saghbine	14	14	1	2.5	1
11	Baadarane	12.9	12.9	1	7.1	1
70	Maasser Ech-Chouf	11.6	11.6	1	2.6	1
101	Zaoutar Ech-Charqiye	10.9	10.9	1	3.9	1
78	Mristi	7.7	7.7	1	3.1	1
56	Jbaa Ech-Chouf	7.4	7.4	1	5.8	1
33	Deir Mimas	6.8	6.8	1	6.8	1
21	Bourj Rahal	6	6	1	4.8	1
10	Aitanit/Machghara	136	84	0.94	32.6	0.94
92	Tebnine	77.1	51.3	0.94	23.9	0.94

Notes: [a] IP = Ideal potential scenario.
[b] AP = Actual potential scenario.

Table 20. Summary selection of WWTPs with high technical reuse potential.

#	WWTP	Irrigation potential (ha) per season (IP[a])	Potential (ha) in command area (IP)	Potential score (IP)	Irrigation potential (ha) per season (AP[b])	Potential score (AP)
100	Zahleh	738.1	738.1	0.69	527.2	0.69
24	Chabriha	691	542.5	0.75	326.3	0.57
59	Joub Janine	231.5	231.5	0.69	138.9	0.45
9	Aintourine	91.9	91.9	0.79	91.9	0.4
53	Ijbaa	86.8	86.8	0.94	86.8	0.67
10	Aitanit/Machghara	136	84	0.94	32.6	0.94
3	Ablah	44.1	44.1	0.94	28.6	0.94
92	Tebnine	77.1	51.3	0.94	23.9	0.94
79	Nabaa El Safa & Aain Zhalta	71.1	71.1	0.94	22	0.78
40	Fourzol	21.3	21.3	0.94	21.3	0.94
15	Bater	25.4	25.4	1	15.6	1
2	Aammatour	31.7	31.7	0.94	9.7	0.94
82	Qbaiyat Aakkar El Gharbie	39.4	39.4	0.7	12.2	0.94
49	Hebbariyeh	36	36	0.85	11.2	0.85
14	Barouk	38.6	38.6	1	12	0.82
45	Hammana	31.1	31.1	0.7	19.5	0.7

Notes: [a] IP = Ideal potential scenario.
[b] AP = Actual potential scenario.

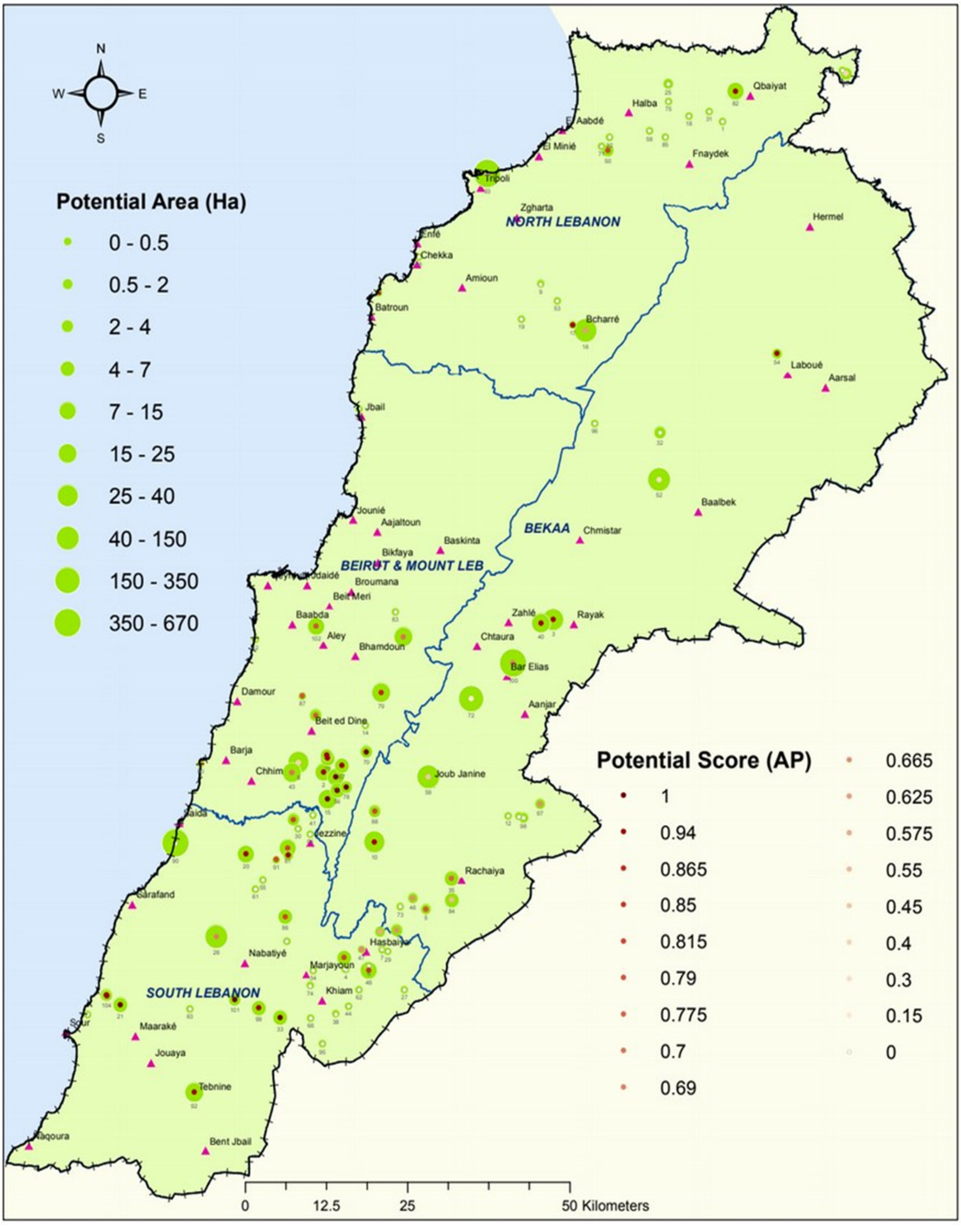

Figure 12. Modeling result: Actual potential (AP) of existing WWTPs in a base, or low-cost, scenario.

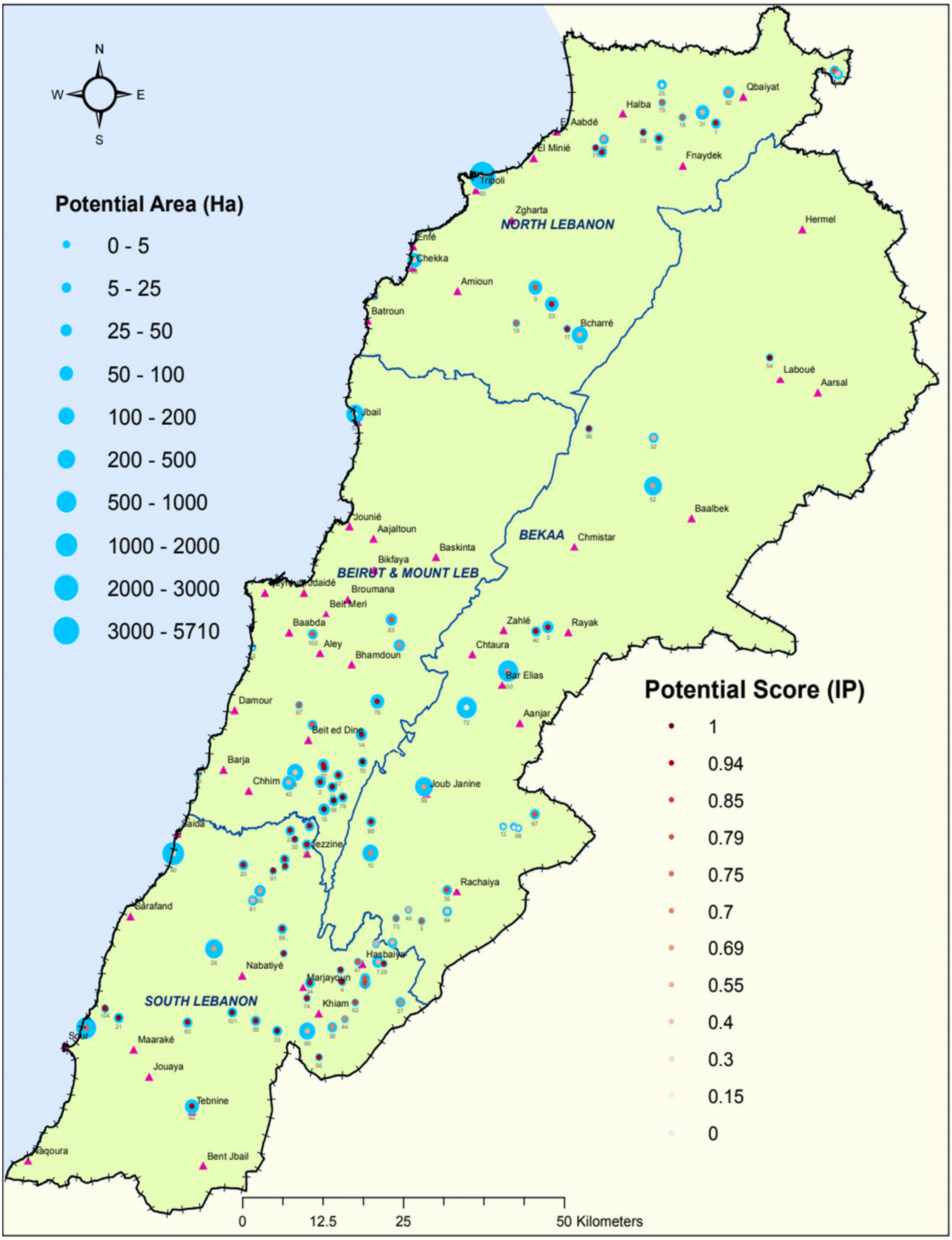

Figure 13. Modeling result: Ideal potential (IP) of existing WWTPs in a base, or low-cost, scenario.

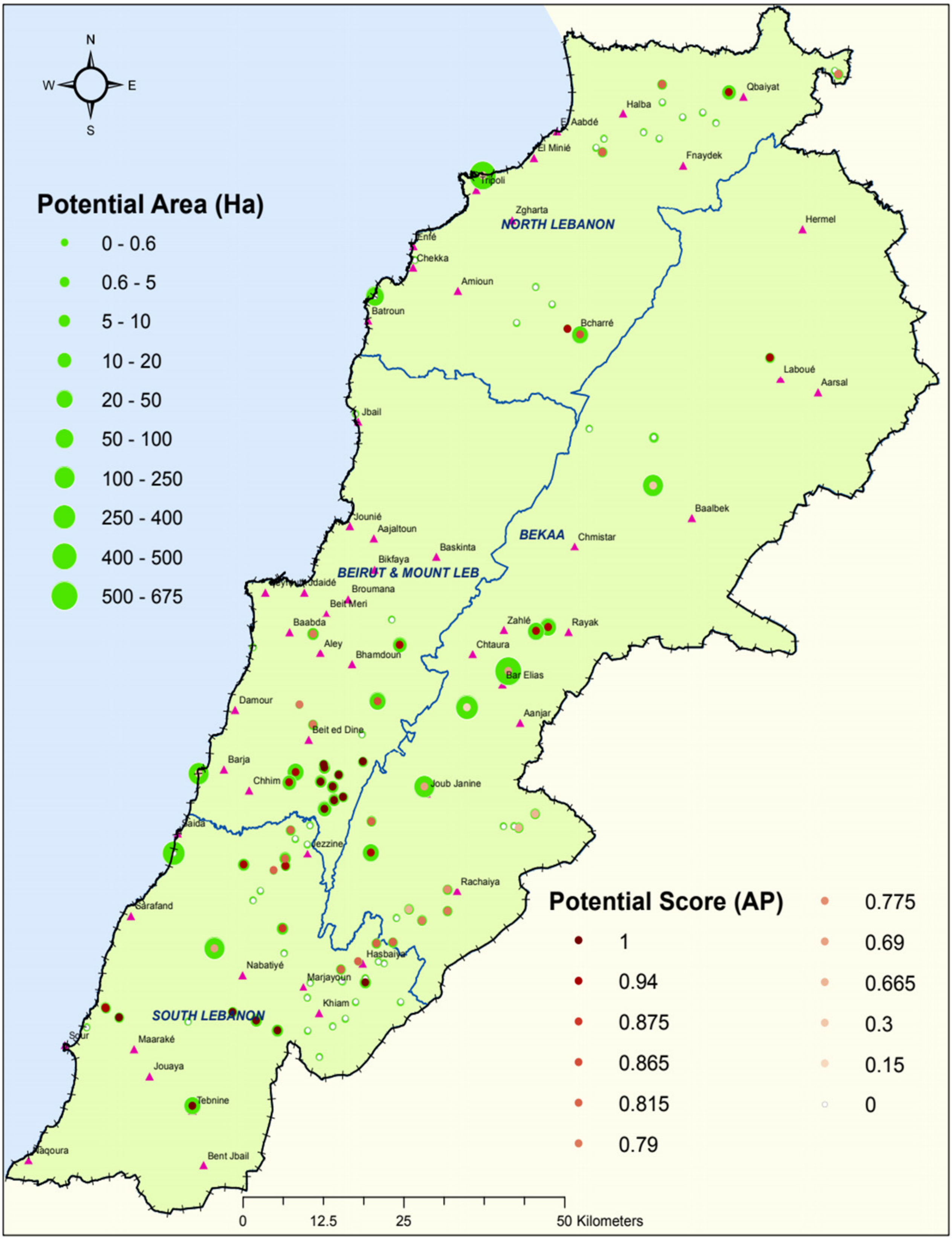

Figure 14. Modeling result: Actual potential (AP) of existing WWTPs in a high-cost scenario.

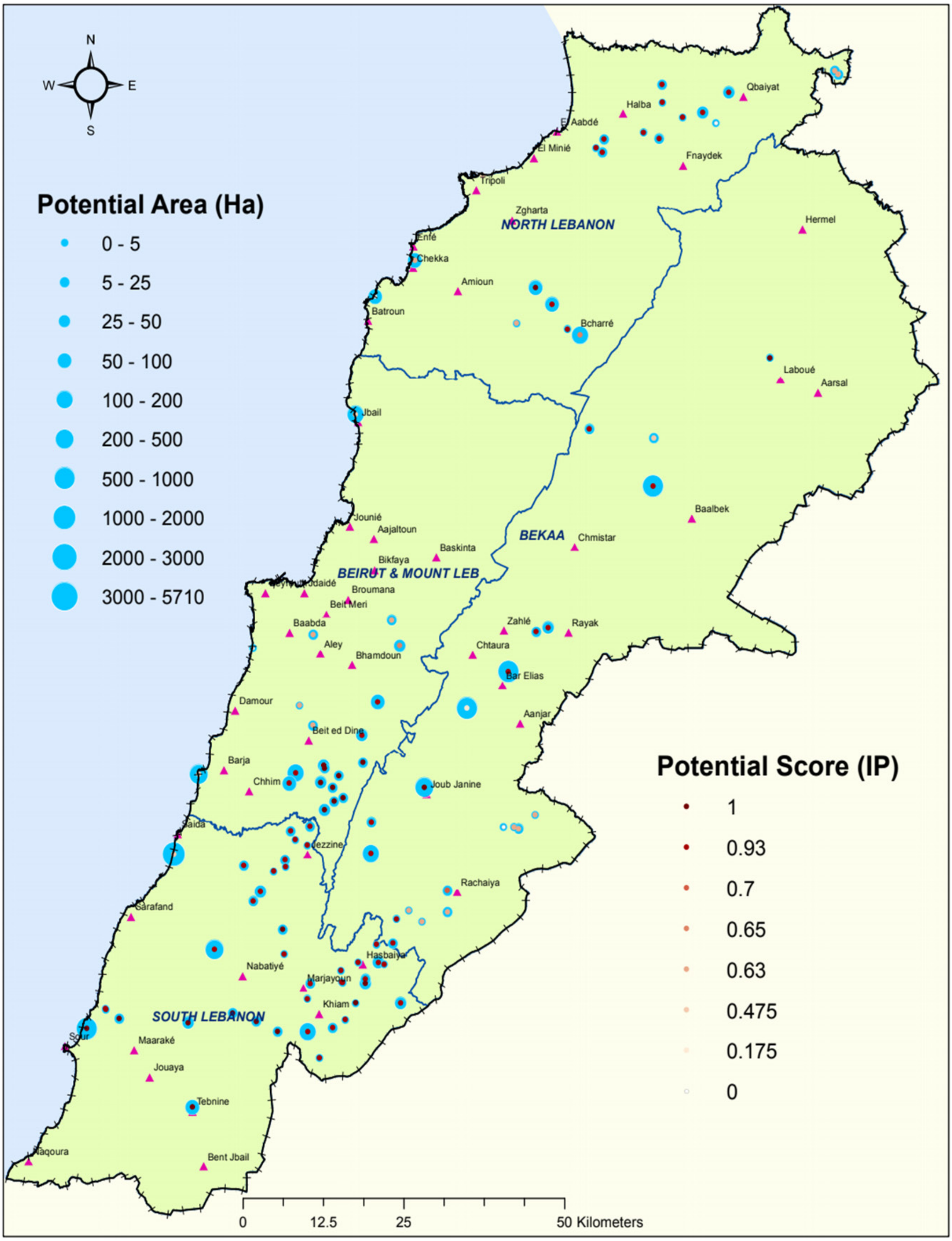

Figure 15. Modeling result: Ideal potential (IP) of existing WWTPs in a high-cost scenario.

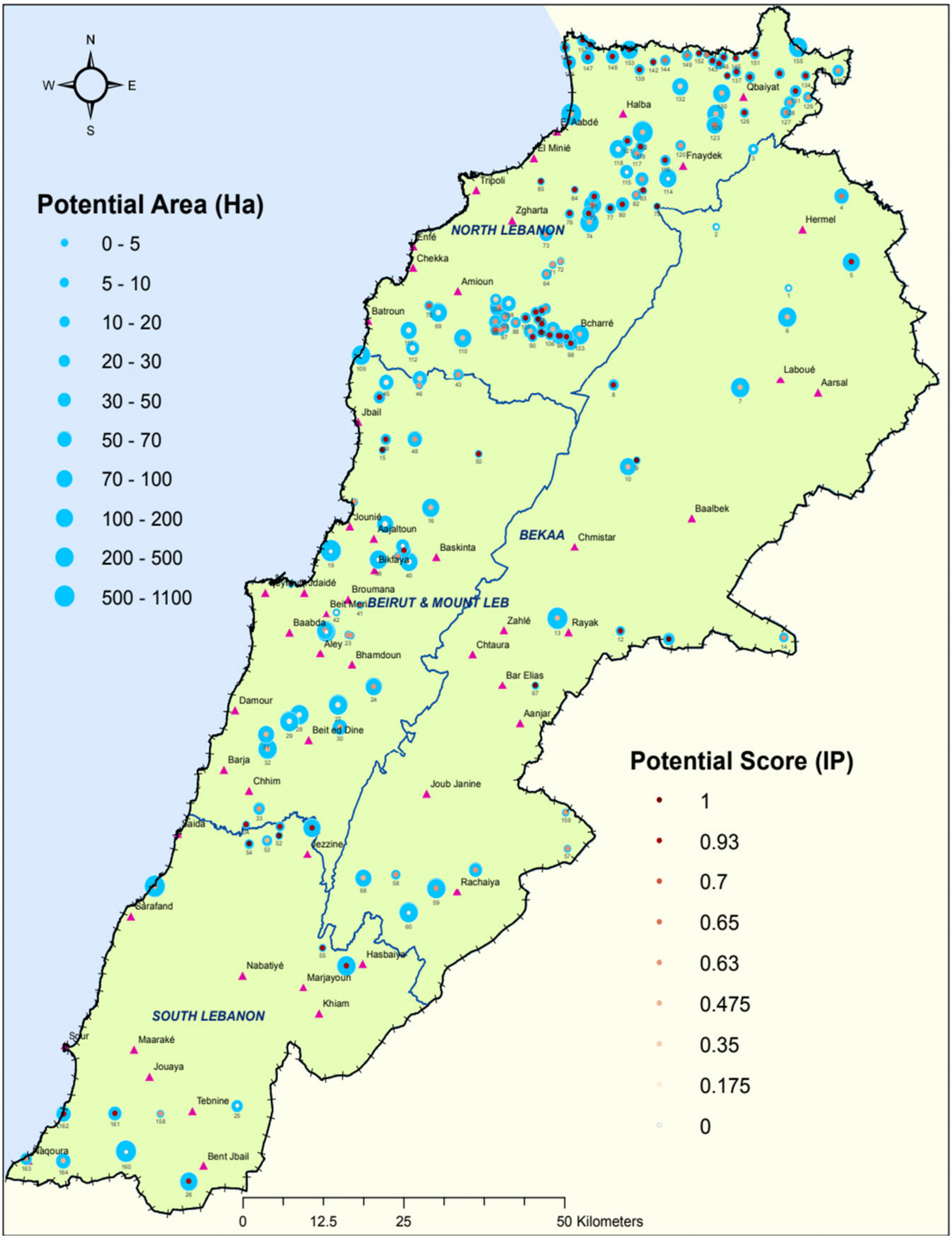

Figure 16. Modeling result: Ideal potential (IP) of proposed WWTPs in a base, or low-cost, scenario.

Governance Barriers to Water Reuse

Further to the technical aspects discussed in the preceding sections of this report, this section focuses on the governance barriers to water reuse in Lebanon with a highlight thrown on the institutional framework of wastewater management. The impact of the ongoing financial crisis on the administration of the water sector is also considered (but should not be understood as the main cause of the dysfunctionalities of the sector). This section is structured to move from the highest level of governance to the local level.

For the subject of this study, the state of the water and wastewater sector administration is considered the primary determinant of safe water reuse. Sustainability and reliability of the WWTPs' effluent quantity and quality are the determining factors for safe reuse projects. They are a function of the administrative and legal contexts alongside technical capabilities, which is why reuse potential can only make sense when read in the socioeconomic context. In the current context in Lebanon, even if formal regulatory frameworks for quality standards and water reuse governance were enacted, it seems doubtful that the present administration would in the near future be able to provide adequate wastewater treatment, monitoring and enforcement. The structural impediments seem to be daunting.

As a matter of fact, the water sector in Lebanon has long been dysfunctional. Despite massive international funding and assistance and adoption of legal and institutional reforms, successive governmental and international reports and strategies still identify the same sectoral weaknesses and requirements (see, for example, Lyonnaise des Eaux-Dumez 1994; MEW 2012, 2020; World Bank 2010). The recent National Water Sector Strategy Update is testimony of how persistent the ailments of the sector are. Below is an abbreviated list of the chronic issues of the sector as presented in the NWSSU:[29]

- A severe lack of funding affects all aspects of resource management.
- Sector efficiency is low, as can be seen, for example, from the very high levels of UFW, which hover around 50% on average.
- The MEW and the RWEs lack engineering and management staff, technicians to supervise, plan, operate and maintain services. Additionally, mismatches between staff qualifications and their assigned responsibilities and tasks are common.
- Sector organization is still hampered by incoherent distribution of institutional responsibilities and an incomplete legal framework relating to water reuse standards.[30] Institutional overlap and competition cause a lack of coordination and communication, leading to a dilution of responsibilities in the different segments of services management.
- The RWEs do not have the organizational capacity to manage wastewater and irrigation though mandated by Law 221/2000. Their current organizational charts do not even include these services.
- The RWEs are still not in a position to act with full autonomy. The MEW is still involved in the supervision of the RWEs—which affects even routine daily operations—rather than monitoring, as intended by reforms and the law.
- Lack of technical, management and monitoring capacities across the water sector administration is at the root of data deficiencies, incomplete or incoherent consumer data, lack of physical data on groundwater, flow, water production, etc.

This short summary already introduces the main obstacles affecting the public management of water, wastewater and irrigation and, consequently, any policy of safe water reuse in irrigation. A quick look at the track record illustrates how this translates in the wastewater sector. The 2012 National Water Sector Strategy set out new goals for the wastewater sector. The same goals were reiterated in the National Wastewater Strategy (2012) that was produced in parallel,[31] and are worth quoting here in detail for their overly optimistic vision considering the structural dysfunctionalities of the sector:

- Increase the present wastewater collection (60%) and treatment (8%) to 80% collection and treatment by 2015, and 95% collection and treatment by 2020.
- Pre-treatment of all industrial wastewater by 2020.
- Increase of treated effluent from zero in 2010 to 20% of treated wastewater by 2015, and 50% by 2020.
- Secondary treatment and reuse of all inland wastewater by 2020, and secondary treatment by 2020 of coastal wastewater where reuse is economically justified.
- Full recovery of all O&M costs by 2020 following the 'polluter pays' principle and full recovery for BOT (Build-Operate-Transfer) projects.

By 2020, none of these goals were achieved. As shown in the analysis of the WWTP databases in the section

[29] For an extensive list, see the NWSSU 2020 Vol. I, pages 1-23 (MEW 2020). See also MEW 2012 and UNESCWA 2007.
[30] A revision of the water law passed in 2018 awaits ratification in parliament and subsequent elaboration of implementation decrees. The NWSSU optimistically expected this to take place in the summer of 2020 but given the current political crisis this process is likely to be delayed for an unknown period of time.
[31] The fact that a separate wastewater strategy was produced was interpreted by the director of a bilateral development agency as being related only to the politics of appearance and competition between different factions in the ministry and judged as unnecessary. See Eid-Sabbagh 2015 (p. 120).

Technical Potential for Water Reuse above, only 8–10% of wastewater receives some form of secondary treatment in Lebanon. Only one organized reuse project has been established in Ablah. It produced some 1,000–1,500 m^3/day, but is currently hampered by litigation issues (see case study of Ablah in Annex 9A).

The persistence of these issues points to their **structural character**, and casts doubt on a short-term, sustainable and broad-based materialization of the technical potential for water reuse identified in the first part of this report, all the more so when considering the financial and economic crisis currently ravaging the country. Any strategy or policy for planned water reuse in irrigation will have to take account of the developing crisis.[32]

Economic and Financial Crisis

The postwar economic order in Lebanon has seen a dramatic collapse, beginning in 2019. The policy of exchange rate stabilization that was put in place in the early 1990s was predicated upon balancing ballooning debt in the Lebanese lira (LL) with ever larger USD reserves to maintain the currency at LL 1,507 to the USD. The needed currency reserves were engineered with a high interest rate policy for USD deposits and T-Bills to encourage Lebanese banks to deposit their USDs with the central bank.[33] By mid-2019, the market exchange rate had already started to depart from the LL 1,507 peg. The crisis expressed itself in a flareup of popular protests in October 2019. This was followed by a rapid deterioration of the LL exchange rate in 2020. In early March of 2020, a new government defaulted on USD denominated claims.[34] At the time of writing this report, it was estimated that about 70% of the Lebanese population had sunk into poverty as compared to about 25-30% before the crisis. On the open market, the Lebanese lira has fallen to LL 23,000 to the USD and is expected to fall further in the coming months.[35] As of July 2021, no economic rescue plan had been articulated and the fear of continued hyperinflation caused by the total exhaustion of currency reserves loomed large.

In 2019, the total state debt was estimated at about USD 86 billion with the debt-to-gross domestic product (GDP) ratio at around 156%. Before the ammonium nitrate explosion at the Beirut harbor on August 4, 2020, the IMF estimated that the Lebanese GDP would shrink by about 12% after having suffered a 6.5% contraction in the latter half of 2019. The harbor explosion is estimated to have caused losses between USD 5 billion and USD 15 billion, further amplifying the economic crisis. Government revenues decreased by around 28% (Hadchiti 2020) by June 2020, and so did expenditure because of a reduced fuel bill for electricity generation[36] as well as the government's refusal to service the foreign debt due in March 2020.

As will be illustrated below, the financial crisis has had a tremendous impact on the water and wastewater administrations, and further weakened their capacity for planning, funding and managing their services. For instance, as a consequence of the end of government subsidies on fuel, employees of different Lebanese ministries and water authorities were only coming to their offices one day per week, being unable to cover their transportation expenses with their devalued salaries (Elnashra.com 2021).

Governance and Gridlock

The structural problems of the water sector are rooted in the Lebanese political landscape at large. The reconfiguration of political power in the postwar era (starting 1990) led to a structural need for political consensus between the three positions at the head of the state, and favored perpetual gridlock in legislative processes (Leenders 2012; Picard 2002). The law-making process in general was severely hampered by this and, accordingly, state budget laws and sector reforms including in the water and wastewater domains.

In this context, the Water Law (Code de l'Eau) took until 2018 to be passed after a first draft had been presented in 2005 and reviewed and rewritten on a number of occasions since then. Even today the law requires amendments, according to the advisor to the minister of water and energy, and awaits the articulation of implementation decrees.[37] This severely hampers the needed institutional building effort (see below for the case of RWEs) but also the implementation of international donors' funds, which are often conditioned by these reforms. Moreover, foreign loans for project funding are often delayed as a result of the gridlock since they need to be approved by law. This delays infrastructure building in the wastewater sector where most plants are financed by foreign loans or grants.[38] Institutional improvement and project implementation are thus dependent on the

[32] The NWSSU only briefly mentions the economic crisis and its effects on RWE fee collection rates but does not address its implication for planning any further.
[33] A financial arrangement likened to a Ponzi scheme (Chaker 2020a, 2020b). See also Halabi and Boswall (2019).
[34] Lazard, the consulting company tasked with providing technical assistance to manage debt restructuring, estimated that total losses in the financial system amounted to around USD 50 billion, which included the losses of Lebanese banks, their deposits at the central bank (Banque du Liban), losses of the central bank, and state obligations. This assessment was opposed by the governor of the Banque du Liban and a parliamentary finance committee, which claimed that no losses had occurred. The International Monetary Fund (IMF), solicited by the Lebanese government to provide technical assistance on debt restructuring, sided with the government's and Lazard's position in this disagreement with the governor of the central bank and the parliamentary committee. As a result of this impasse, the IMF paused consultations over emergency support loans.
[35] The official rate is maintained at LL 1,515 by the central bank in an effort to avoid bankruptcies in the banking system, while banks pay out their customers' USD claims at a rate of LL 3,900 to the USD. A new rate of LL 12,000 to the USD is applied to some withdrawals.
[36] Beirut had only three hours of state electricity a day for a long period in May-June, 2020.
[37] Interview with an official at the MEW.
[38] Grants are provided mostly in the case of smaller plants.

presence of an operational government, but the latter is often paralyzed.

The economic collapse and the state's structural inability to address it over the past year and a half suggest that recovery will take years. It is also very unlikely that foreign funding will return to pre-crisis levels anytime soon as funders and foreign government officials have insisted on reforms being carried out as a precondition for action on their part.

Uncertain Future of Water Sector Development

Donors' dissatisfaction with project outcomes and the delay of funder-demanded market environmentalist[39] reforms have led donors to take a more active role in project planning, capacity development aimed at further commercialization of establishments,[40] and a more prominent role in project supervision. In recent years, funders and Lebanese institutions have adapted to the Lebanese reality, and projects are now designed to include networks associated with WWTPs to avoid a repetition of earlier experiences that saw plants built without the necessary collection networks in place.

Similarly, donors now budget for project supervision, and include other soft aspects as capacity building and "social engineering", or awareness building, to prepare populations for coming projects. This results in considerably higher project costs and loan agreements, and allows for more influence of international development actors on policies and project management. The current crisis and the inability of the Lebanese state to implement the reforms demanded by donors do not bode well for a timely implementation of existing plans. Our interviewees suggested that in the foreseeable future, only those projects with funding agreements already in place and ratified by parliament will see implementation. For example, the first phase of the Bourj Hammoud WWTP is secured with some USD 20 million and will provide pretreatment. The second phase will have to wait until funding can be secured.

A WWTP in the northern Bekaa serving the town of Aarsal is also expected to profit from a grant. As a representative of Agence Française de Developpement (AFD) explained:

> *"This is a grant. We are trying to have around 38 million euros grant funding from the AFD and a grant funding from the EU (European Union). But we are going to have a good component of social engineering to raise awareness not only in Aarsal but also in the villages of the valley. The CDR is finalizing a study on a wastewater treatment plant in Fekha for 10+1 villages in Bekaa. We are talking about collecting sewage from Nabi Othman, Ras Baalbeck, Fekha, el Ain, Jdeideh, etc. We were supposed to take this on and start building it together with the Aarsal component but this is a loan and we know the country cannot take on more loans, so this is delayed. We are not even doing a feasibility study. We are just waiting for the CDR to finish and then we are going to discuss with the authorities what to do."*[41]

Donors are also trying to adapt to the implementation difficulties that the financial crisis has produced. Whether or not these arrangements proposed by AFD are actually feasible and the impact on Lebanese institutions in terms of loss of agency remains to be seen:

> *"As with the financial crisis, in terms of access to liquidity and finances in the banks, we expect that impact would be solved by AFD guaranteeing that payments be paid directly to the contractors and consultants from France. We're changing all our legal agreements to allow this. We know that many small and large companies are not able to pay their employees, so if the solution is to have fresh money come directly from outside Lebanon then let it be."*[42]

With this in mind, it can reasonably be expected that water reuse projects will require foreign donor funding on a project basis, supervised and implemented with the donors closely involved. The projects in Ablah and Fourzol are two such examples, and a project in Roum involving reed-bed filters and encouraging reuse is another.[43] These dynamics focusing on smaller municipal-scale plants can be expected to continue and intensify, since implementation is likely less complex.

Administrative Barriers in the Water and Wastewater Sectors

The discussion above already pointed to the most prominent features of water sector management. But before turning to the specific problems that affect wastewater management and safe water reuse, a brief

[39] "Market environmentalism: A mode of resource regulation which aims to deploy markets as the solution to environmental problems. Market environmentalism offers hope of a virtuous fusion of economic growth, efficiency, and environmental conservation: through establishing private property rights, employing markets as allocation mechanisms, and incorporating environmental externalities through pricing, proponents of market environmentalism assert that environmental goods will be more efficiently allocated if treated as economic goods—thereby simultaneously addressing concerns over environmental degradation and inefficient use of resources" (quoted from Bakker 2007).
[40] Commercialization: The incorporation of market institutions and models in resource management organizations. See Bakker (2014).
[41] Interview, AFD, April 16, 2020.
[42] Interview, AFD, April 16, 2020.
[43] Interview, Lebanon Water Project (LWP), April 4, 2020.

introduction to the administrative structure of the water sector is required. Numerous reports give fairly detailed descriptions of the water sector governance framework. We will refer interested readers to these studies and reports for more detailed information and analysis. Our intent here is solely to orient the reader and provide a quick overview of the water sector and its stakeholders (Pluschke 2016; Machayekhi et al. 2014; EIB 2009).

The sector suffers from considerable overlap and lack of clarity in the distribution of responsibilities. Similar responsibilities have been assigned to different ministries and administrative bodies. These dynamics are structural: As we discussed above, they are considerably rooted in the distribution of power and the competition around administrative competencies and resources that derives from it. Figure 17 shows a summary of different responsibilities in the wastewater sector.

Studies have reported coordination to be lacking also (mainly) at the higher levels and found relationships to be horizontal and competitive rather than hierarchical—for example, between the MEW, the CDR and the LRA (Nassif 2019). The process of project and loan approval was described as follows by a CDR official, highlighting the difficulties in coordination and cooperation:

> *"The problem here in Lebanon with regard to wastewater treatment is that there are multiple bosses in charge. Coordination is a very broad term; now we can't execute any projects unless there is formal approval from the ministry, the council of ministers and parliament. You can't get a loan approved otherwise. Here you have three different departments/ managements that are aware of the project and all its details. Then there is a problem with coordination on the executional level."* [44]

Ministry of Energy and Water

The Water Sector Reform Law 221/2000 and its amendments (Law 241/2000 and Law 337/2001) redefined the institutional framework of the water sector in Lebanon. In an attempt to decentralize, 22 water offices were integrated into four regional water establishments (RWEs) which were supposed to be under the tutelage

Role	CDR	MoEW	MoF	MoE	MoA (irrigation)	MoPH (drinking water)	Municipalities	WE	WB	Donors	NGOs	Research	Media	Water Users
Funding	X		X					Cost recovery?	X	X				
Policy & Strategy	X Master Plan	X National		X	X	X		X Regional	X	X		X		
Planning	X	X			X			X	X	X		X		
Contracting/ Constructing	X	X			X		X	X	X	X	X			
Development & Implementation	X	X					X	X		X	X			
Operation & Maintenance	X						X	X		X				
Tariff/ Tax Collection			X				X	X Propose tariffs						X
Legislation, rules and regulation		X		X	X	X					X Lobby	X		
Services & interactions with water users		X		X	X		X			X	X		X	X
Monitoring & Evaluation		X		X	X	X		X		X	X	X		

Figure 17. An illustration of the administrative overlap in the wastewater sector of Lebanon.

Source: Pluschke 2016.

Notes: MoEW = Ministry of Energy and Water; MoF = Ministry of Finance; MoE = Ministry of Environment; MoA = Ministry of Agriculture; MoPH = Ministry of Public Health; WE = Water Establishments; WB = World Bank.

[44] Interview, CDR, June 20, 2020.

of the MEW but enjoy greater liberty of action than the water offices absorbed. In parallel, the law redefined the MEW's tasks. The MEW is responsible for the study, planning and management of water resources in their totality, including quantitative and qualitative protection and the elaboration of all necessary legal texts. However, the restructuring of the ministry and its departments with necessary capacity building remained elusive. Until today, application decrees finalizing the implementation of Law 221 have not been passed.

The MEW's role in the wastewater sector (and the water sector more generally) has been overshadowed by the Council for Development and Reconstruction, which has been the driving force planning and implementing wastewater management at the national scale over the last decades.[45]

> *"Since 2012, actually, the Ministry (has been) taking over in leading planning while it was the CDR before. Normally, the CDR has to implement (the) plans of the Ministry but (it) took the initiative of planning in the water sector. This is changing now."* [46]

Council for Development and Reconstruction

The Council for Development and Reconstruction (CDR), created in 1977, was turned into a super ministry after the end of the civil war (1990) and was given tremendous independence in spending and planning with regard to most public infrastructure (drinking water and irrigation networks, WWTPs and sewage networks, roads and others). The CDR is directly accountable to the Office of the Prime Minister. Its budget is largely discretionary and not subject to government budget oversight (Eid-Sabbagh 2015; Riachi 2013). Until very recently, it was the sole institution endowed with the power to negotiate and implement projects funded through foreign loans. Most WWTPs have been financed and implemented through CDR as funding has almost exclusively been of foreign origin. The council manages WWTPs by outsourcing them to a contracting entity as local administrations do not have the expertise to operate them. Since contracts are between CDR and the contractors, such as Veolia, the latter have an obligation to communicate and coordinate with the CDR but not the RWEs. In some cases, communication with the RWEs takes place but is wholly a function of courtesy; the contractors remain answerable to CDR. Like all other ministries today, it does not seem to have the staff to provide a level of follow-up that matches the scale of its projects across sectors.

Regional Water Establishments

The four regional water establishments were created by Law 221/2000. The existing 21 public water offices and 209 local water committees (community managed) were regrouped into the North Lebanon Water Establishment (NLWE), the Beirut and Mount Lebanon Water Establishment (BMLWE), the South Lebanon Water Establishment (SLWE) and the Bekaa Water Establishment (BWE). The RWEs were tasked with conducting studies, and implementing, exploiting, maintaining and renewing water projects to distribute domestic and irrigation water supply. They are also responsible for collection, treatment and disposal of wastewater. The establishments are further tasked with water quality control in the domestic, irrigation and wastewater systems. All of their activities have to follow the water and wastewater master plans. The RWEs do not have the mandate to set tariffs independently but may recommend the tariff structure and rates to the MEW. They are subject to periodic audits (MEW) and their "administrative activities are subject to the government's administrative regulator (central inspectorate)" (ECODIT 2015, p.67).

Financial autonomy was a guiding principle in the creation of the RWEs. The ultimate goal was that these administrations cover their O&M expenses from their own revenues, which are mostly dependent on fees levied on residential units. The contradiction inherent in their mandate, stipulating that financial sustainability should stem from user fees while taking into account the social conditions in the country, is one of the reasons that have prevented the RWEs from being financially autonomous. This has become obvious with the financial and economic crises.

Litani River Authority

The Litani River Authority (LRA) kept its competencies in implementing and managing irrigation projects at the level of the Litani Project. Consequently, irrigation remained under the responsibility of the LRA in South Bekaa[47] and South Lebanon while the BWE and SLWE are strictly responsible for domestic water and wastewater management.[48]

The LRA has irrigation responsibilities in Bekaa, south of the Damascus road, and in the South. Accordingly,

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[45] It was the CDR that commissioned the 1982 and 1994 wastewater master plans.
[46] Interview, MEW, April 9, 2020.
[47] The border of the LRA territory is south of the Damascus road, the limit of the long-planned Litani Project where 23,000 ha were expected to be implemented in South and Central Bekaa (see Nassif 2019 for a detailed analysis of the planning process and its local geopolitics).
[48] See Nassif 2019. Established in 1954, the LRA is one of the oldest water administrations in Lebanon. Its tasks were (1) to plan and operate all water-related infrastructure schemes associated with the Litani River; (2) measure all flows from rivers and springs in the country; and (3) operation and implementation of hydroelectric plants. As described above, the Law 221/2000 preserved LRA's mandate of implementation and management of the Litani Project. It also kept the LRA's responsibility of water monitoring. Throughout the postwar period, other responsibilities were assigned to the LRA, such as groundwater and water quality monitoring at the level of the Litani River Basin. See the same work for a detailed historical analysis of the legal and de facto role of the LRA.

it should be involved in questions of water reuse for irrigation in these areas. Yet, experience suggests that the current Director General is not open to the idea, having reneged on agreements for cooperation on the design of reuse systems, taking advantage of the existing irrigation infrastructure under the responsibility of the LRA. A similar attitude was reported in relation to groundwater recharge projects.[49] This opposition to cooperation is in all likelihood rooted in competition over water planning and management with the SLWE and BWE but also rooted in broader partisan competition (Nassif 2019, p.428-442). In any case, these dynamics will need to be understood by any party attempting to engage the LRA in a reuse project on its territory—specifically, for projects with a large potential area such as in Joub Janine and Chabriha (Sour).

Municipalities

Municipalities remain important actors in the wastewater sector. According to Law 118 of 1877, municipal councils have the authority to implement water supply and wastewater projects. Specifically, Law 347/2001, amending the reform Law 221/2000, states that the latter (Law 221) does not in any way diminish the responsibilities and competencies of the municipalities as enshrined in the municipal law and the law on municipal taxes. Legally, the municipalities levy a local residential tax related to the rental value of properties as well as the maintenance of sidewalks and sewer networks. They retain their responsibility (as enshrined in Law 118) to manage wastewater networks within municipal boundaries, and as some have argued, their mandate to protect public health can be interpreted to include wastewater treatment (Machayekhi et al. 2014).

Furthermore, municipalities are involved in project implementation since they are in charge of issuing construction permits within their respective localities, which gives them effective veto power over any infrastructure project.[50] Additionally, municipalities are directly involved in the management of local domestic and irrigation networks, through historical water rights legalized by the Lebanese state. Municipalities still play a key role in implementing, operating and maintaining water, wastewater, and irrigation systems. Although Law 221 gives the priority of water and irrigation management to the RWEs, hundreds of municipalities still largely operate their local systems, or at least contribute to O&M activities to compensate for the insufficient service provided by the RWEs.[51]

Challenges to Cooperation at the Local Level

At the regional and local levels of the administration of water and wastewater, cooperation, coordination and consultation remain underdeveloped, if not absent. The NWSSU recognizes that the lack of cooperation and consultation by the CDR and the RWEs with municipalities has negatively affected the infrastructure production process at the local level. The municipalities' proximity to citizens and their legal ability to deny construction permits within municipal boundaries gives them considerable weight and negotiating power and has often led to delays in project implementation. While their involvement in the infrastructure production process is reported to be evolving, wastewater management still suffers from their historical exclusion from planning and implementation.

Both at the CDR and the MEW there seems to be reluctance to engage with the municipalities substantively. Yet, it is understood that all projects need municipality approval. The MEW sees the role of the municipalities as subordinate. The view is that municipalities should be alert to the quality of project implementation, avoid political interference and report infringements, but it seems inconceivable that they should have a participatory role in planning and design. Much rather, municipalities seem to be seen and treated as opposition and as a source of problems. The view is that environmental and social impact assessments are the space where municipalities and other stakeholders can input their perspectives. And the initiative for coordination is expected from the side of the municipalities:

> *"They should take initiatives if they have something to say. They can reach out to the Ministry and other responsible parties. You have to have the will to coordinate. It is not for the Ministry to contact municipalities. Often, municipalities create problems out of ego. Also, they are not technically capable of giving their opinion on the design."* [52]

At the project design stage, the main reason for the blocking of projects is found in the acquisition of real estate. In some cases, private actors refuse or resist land expropriation; often enough, clientelistic relations are mobilized to support such opposition, be it in price negotiations or an outright refusal to allow expropriation. In other cases, municipalities, invoking the NIMBY ('not

[49] Interview, AUB, June 24, 2020.
[50] So has been the case in numerous municipalities such as Bourj Hammoud, Jeita, etc.
[51] See Nassif (2019) concerning the existing role of municipalities in the Bekaa.
[52] Interview, MEW, April 9, 2020.

in my backyard') principle, refuse the implantation of WWTPs for fear of environmental and social nuisances. Private opposition is often resolved through negotiations or by searching for an alternative site. Project bottlenecks at the level of municipalities have proven to be more difficult to resolve, and have held up projects for years.[53]

In addition to the potential benefits to project implementation, municipalities are in many cases well placed to address questions of irrigation management or mediate on questions of water rights. In Bater, for example, the municipality has a crucial role in organizing the annual election of the irrigation network manager. This is rooted in an understanding of the importance of that position for social peace. In Ablah, the municipality manages both the treatment plant and the reuse scheme (though that has been temporarily interrupted due to litigation). This is done by a competent engineer from the region who was involved in the design of the WWTP and who was later recruited by the municipality. As a matter of fact, the engagement of local experts and engineers recruited by municipalities (or part of the municipal council) was observed in many towns such as Hammana, Zahleh and Zgharta/Ehden. There is much to be said for a close and substantive participatory engagement with municipalities even where they lack technical and financial capacity. In many cases, they do have an ability to mobilize and negotiate between competing social groups. It is an ability that can make them valuable partners.

The critique of a failed municipal WWTP project of the early 2000s, funded by the United States Agency for International Development (USAID) and implemented by international NGOs, is often mobilized as an argument against small, municipality-run WWTPs. This appears to be misplaced, as reported in a Ministry of Environment (MoE) report of 2004 (MoE 2004, p. IV-V). While it is true that the majority of constructed WWTPs failed to be sustainably operated,[54] the responsibility is mistakenly linked to the proposed decentralized management model. The poor project structure proposed by donors and implementing NGOs as well as poor supervision and follow-up are identified alongside the financial and technical weakness of the public sector. For example, the grants allowed only for investment without including funds for operation, thus condemning the plants from the outset to suffer from municipal budget difficulties, and quickly rendering them unusable because of lack of cleaning and maintenance. Additionally, given the failure to include provisions for operations in project design, neither contractor nor NGO had any incentive to produce robust designs including quality execution, training, etc. Further, deficient plants and the ecological nuisances produced a popular demand for closure. Eight of these plants were built in communities without municipal status, thus without staff and budget. The MoE list of failures closes by observing that "the use of treated wastewater for irrigation is at present impossible, again due to the poor quality of the effluent. The failure of this project is found not in municipalities but rather in incoherent project planning by donor and NGOs." The report makes clear that it is crucially important that process selection, plant design and management plans be developed in an integrated manner at the beginning of the project cycle. "These initial choices must respect the real possibilities of the beneficiary municipalities and include long-term realistic commitments by these municipalities regarding operation" and that all involved contracts regarding training and funding must be assured before construction (MoE 2004, p. IV – V).

In fact, a follow-up project, also funded by USAID, shows that small, municipality-run plants can also be successful (Social Impact 2013). This project was run in cooperation with the Ministry of Interior and Municipalities. USAID, as a US government agency and following US government policy, chose not to work with the MEW because the minister at the time was associated with Hezbollah. Accordingly, it addressed municipalities directly rather than, as intended by the new reform law, the regional water establishments. While this approach was counter to the water reform efforts, it did produce operating plants in Ablah, Aitanit and Fourzol. Having integrated lessons learned from the earlier project, the three plants in the Bekaa were planned, designed and executed with O&M in mind.

A total of 35 small plants (at or below 2,000 m^3/day design capacity), not all managed by municipalities, have been reported operating in Lebanon. Of these, 9 are operated by BMLWE, 2 by SLWE, 3 by CDR, and the remaining 21 by municipalities. These represent 85% of plants categorized as "operational" in the database. In the light of these numbers, it would be hard to argue that a strategy of smaller decentralized plants is inoperable. Much to the contrary, given the failure of so many large-scale projects, the argument could easily be reversed.

The arguments about plant size are also intertwined with arguments about treatment technology and associated O&M costs. They juxtapose more complex and energy-intensive technologies with more space-consuming, low-energy and low-maintenance technologies. Seen in the context of wastewater sector development in Lebanon, the argument about economies of scale mobilized in support of large and

[53] In Chekka, after years of negotiations, the WWTP was eventually positioned on the border of two municipalities. In Keserwan, on multiple occasions, municipalities refused to have WWTPs built within their area. The Bourj Hammoud plant has been held up for more than a decade because of resistance from the municipality. None of this is to imply that municipal concerns are not legitimate; quite the contrary. Bourj Hammoud, for example, already receives a large quantity of the solid waste from Greater Beirut, and suffers from air pollution from two highways, to name only a couple of issues the municipality is struggling with. It explains the fear of another potentially problematic project.

[54] Of the 42 WWTPs constructed, only 26 were operating. Of these only 6 were actually providing treatment; the remainder were either unfinished or abandoned at the time of writing this report.

centralized treatment systems fail to convince at the strategic level. Measuring investment (including expropriation cost and interest on debt) versus level of treatment and actual volume treated since construction started on these large projects is not unlikely to skew the argument in favor of smaller plants.

As indicated by our analysis, smaller plants on average show higher reuse potential scores while the larger plants show lower scores. It is conceivable that a more decentralized approach to wastewater planning could increase the total volumes potentially reusable for irrigation, specifically with regard to the coastal WWTPs which serve large areas and drain into the Mediterranean.

The wastewater treatment project currently underway for Wadi Qanoubin, funded by AFD, is likely to provide interesting insights into a decentralized approach to treatment. The project consists of 23 treatment plants serving small communities (usually at the municipal level). The majority of the WWTPs will use reed-bed technologies. Importantly, the planning approach has been reported to have involved, from the onset, a large number of stakeholders at all levels: the CDR, the NLWE and the municipalities.[55] It seems essential that a critical and rigorous study of the technical, institutional, economic and social outcomes of this project be produced and published to inform a development of substantive cooperation mechanisms and processes. More so, because in their current form, water establishments seem a long way from being able to contribute substantially to direct safe water reuse for irrigation.

Operational Barriers at the Level of Regional Water Establishments

Legally charged with wastewater treatment, the RWEs are a key link in wastewater management and, accordingly, any future reuse. The weak development of the sector and the low efficiency of wastewater treatment is in part a reflection of the weaknesses of RWEs. Reuse potential is a function of RWE capabilities to manage wastewater and potential reuse schemes where they have been assigned irrigation competencies.[56]

The RWEs lack dedicated wastewater and irrigation services. With the exception of SLWE, which has a small wastewater unit, they have neither wastewater nor irrigation services included in their organizational chart. The procedures to establish such services are complex, and would require the approval of the Council of Ministers. The NWSSU observes that the organizational charts are outdated and require updating as well as a simplification of procedures for the RWEs to be able to adapt their internal organization to changing needs. It provides a number of recommendations to that end, but for the time being the absence of these services remains an important obstacle to the implementation of reuse planning more generally and reuse management more specifically.

Limited Financial Capacities of Water Establishments

The more fundamental reason for the weakness of RWEs lies in their limited financial capacities. The water and wastewater sectors have been underfunded since the 1990s. Left largely to their own devices, water establishments have been struggling to increase their revenues since then. It was hoped, following the dominant market logic, that O&M could be financed via revenues from fees. The director of BMLWE expressed this clearly on the occasion of a public discussion on the effects of the crisis on the water sector:

> *"The establishments, especially in water, live only on fee collection ... all our operations depend on the collection of fees."* [57]

The collection rate had been low even before the crisis, as shown by the latest figures (Figure 18).[58] The wastewater fees have been talked about for a while but are still not implemented nor collected systematically or coherently. The tariff structure discussed in the NWSSU has been rendered obsolete by the economic and financial meltdown.

Collection rates have dropped significantly during the current crisis. The director of BMLWE talked about a reduction of 25% in 2019. In the Bekaa, the collection rate had dropped to 35% of its annual average by February 2020, according to its director. The number for SLWE was 50%, while the director of NLWE also saw important reductions in collection, and expected the impact to be even worse in the second half of the year. It is unlikely that collection rates will recover quickly with poverty rates increasing as rapidly as they are.

The lack of funds has directly affected wastewater operations. The largest cost factor in WWTP operations is electricity and diesel for the generators, where necessary. Before the crisis, the RWEs had already been highly indebted to electricity suppliers.[59] The costs of WWTP operation are the main reason why the RWEs are reluctant to accept responsibility for them. Examples of difficulties abound: The two plants serving Ehden, Aintourine and

[55] Interview, AFD, April 16, 2020.
[56] In the south and the southern Bekaa, it is the LRA that is charged with irrigation management.
[57] Interview, AUB researcher, April 2020.
[58] Interview, AUB researcher, April 2020.
[59] BMLWE stands out as it also is the RWE serving the highest population, estimated at about 2 million.

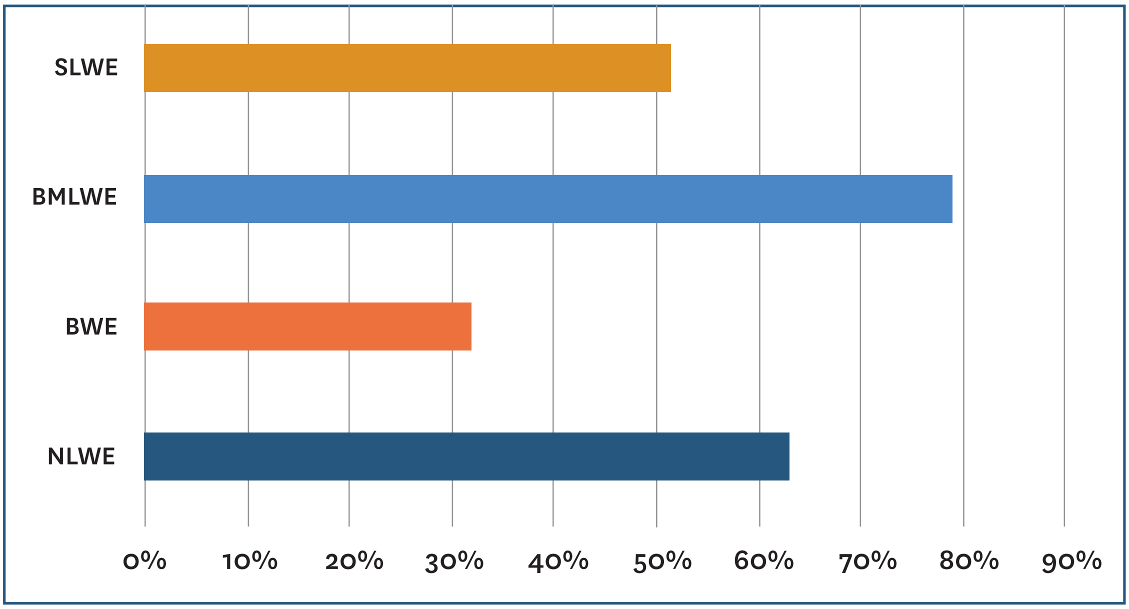

Figure 18. The collection rates of RWEs as per NWSSU 2020.

surrounding villages were reported to have a contract for USD 1.2 million financed by CDR. The Tripoli plant follows the same pattern. The plant in Yammouneh was reported to be non-operational for a number of reasons, among them, operational costs. The Zahleh plant has a sludge problem because the cost of dewatering is too high. The same is true for the plant in Joub Janine. Plants in Sour and Tebnine were also threatened with closure because of sludge disposal problems and associated cost (Khalil 2021).

This explanation given by an AFD representative illustrated the depth of the crisis:

> *"My first priority right now is how to save the existing water pumping stations and wastewater treatment plants. Because if water establishments fail…if they are not able to collect money because people are not paying—Bekaa is 0% collection—this can last 3 months…. For the Bekaa and the south mainly. ICRC (International Committee of the Red Cross) is providing fuel, generators. Same for UNICEF (United Nations Children's Fund) …. If you can't run the station, then it's unsustainable. How will they actually pay their salaries?… It took 5 years of constant work to raise the collection of tariffs nationwide to 50 or 60%. Since the October revolution, in the Bekaa for example, the collection rate was 20% in December, 50% in January, 10% in March, 0% now! So how are we going to get this back with all the current financial and economic crises is unknown."* [60]

In addition to collapsing revenues, budgetary regulations have further affected the RWEs' capacity to act. According to the financial regulations in place, the RWEs have the authority to independently engage in expenses above LL 50 million requiring only the approval of the director general of the RWE, and LL 200 million by the board of the RWE without consulting the regulatory authority at MEW. This is true where the budgets have received approval from MEW; where that is not the case, their ability to spend is more curtailed. Expenditure up to LL 10 million can be handled internally by the RWE through the director and/or the board, while material expenses above LL 10 million require a formal request to and approval by MEW, and the observance of proper tendering procedures (including 3 offers, qualifications, etc.).[61]

Due to the present crisis and the coinciding price inflation related to imported materials, the sums anchored in legal decrees effectively reduce the RWEs' ability to act. As of April 2021, MEW approval would have to be sought for expenses lower than USD 1,000 in practice. Even in regularized budgetary conditions, the LL 200 million limit on independent spending is now equivalent to less than USD 20,000. One outcome of the crisis then is the RWEs' increased dependence on MEW; a second is their reduced ability to react in a timely manner to breakages in the infrastructure, be they of a mechanical or civil engineering nature.[62]

[60] Interview, AFD, April 16, 2020.
[61] Interview, BWE, March 10, 2020.
[62] Projects that were ongoing or planned have suffered from the crisis too. Ongoing projects were halted as the cost of imported material was rapidly exceeding the contract values notated in LL. In the SLWE, rehabilitation plans for small municipal WWTPs were shelved. The longer the crisis continues the more the RWEs and the existing infrastructure will degrade further, affecting their ability to provide services. It needs to be mentioned here that what is true for the RWEs is also true for municipalities. In summer 2021, Ablah WWTP stopped operating for several weeks. It continues to be only partially operational because of power cuts.

Limited Human Capacities of Water Establishments

As a result of the falling revenues, the RWEs had to cut work hours and reduce staff. Contractual workers and day laborers were the first to suffer the consequences.[63] The staff reduction was a dramatic development for RWEs, which were already understaffed across all departments. Before the crisis, only a quarter of the positions defined in the RWEs' organizational charts and by decree were filled by permanent staff (20% for NLWE, 37% for BMLWE, 23% for BWE, and 12% for SLWE).[64] Part of the shortfall has historically been made up through hiring temporary staff and through contracting. The total number of positions covered through permanent and temporary staff excluding contract staff amounted to 50% on average. The shortfall, as shown by the fact that temporary staff were and are employed, is not only a product of the permanent employment freeze but also of the lack of funding, now exacerbated.

Another problem related to staffing is the mismatch between the qualifications and responsibilities of the employees. Understaffing, and the resultant need to first address operational tasks, leaves management and strategic tasks with too little attention, affecting the development of the RWEs (MEW 2020, p. II C.32). Another related dynamic is the inability of RWEs to compete for talent with the private sector which offers better employment conditions and salaries. This now exacerbated salary difference has already led to expert staff leaving the RWEs.[65]

This loss of expertise coupled with the loss of financial power due to sinking revenues and the concomitant reduction in purchasing power due to inflation foreshadows a deterioration of wastewater infrastructure and, by extension, a reduction of water reuse potential.

Regulating Water Quality

Pollution control and monitoring are responsibilities legally shared between the Ministry of Environment (MoE) and other institutions. These mandates overlap with the MEW's responsibilities to monitor and regulate water and wastewater quality. The MoE has no executive power and no capacity to enforce its regulations while the MEW's ability is limited too. The environmental law 444/2002, which introduced the 'polluter pays' principle, also included a provision for the creation of an 'environmental police' in charge of monitoring and enforcement. The new 'Code de l'Eau' (Water Law) also plans for a 'water police' (police de l'eau). Neither authority has come to be. Similarly, the 'High Council of Water' and the 'High Council of the Environment' have been the object of plans and laws but to-date neither exists. The water law of 2018 was to a large part held up over parliamentary disagreements regarding the presidency of the water council. Should both councils be created, the regulatory overlap and competition between institutions would gain a new layer. It is in this context of regulatory confusion and obfuscation that the discussion of water and wastewater quality needs to be understood.

Of particular relevance to the water reuse discussion is the (in)ability of the RWEs, MEW and MoE to administer a systematic wastewater quality monitoring and testing program. For example, the current testing regime is uneven. Different WWTPs, RWEs, municipalities or the CDR test water according to different quality standards and according to different capacities. An attempt at unifying the standards is underway under the auspices of LIBNOR (the Lebanese Standards Institution) and the IWMI ReWater MENA project. It would represent an important step toward systematic and reliable quality monitoring. As it stands, monitoring remains disjointed and effluent quality targets are derived from different sources.

In addition to these institutional gaps and overlaps, there is the problem of logistical capacities. The larger plants have labs integrated on-site (e.g. Zahleh), and some are connected to donor-funded regional labs operated by the RWEs (the case of BWE). On the other hand, many of the smaller plants (whether municipal or state-managed) often lack full testing capacities. Many municipalities do take the initiative to increase their testing capacities, mostly supported by NGOs which regularly fund the expensive testing material and chemicals (for example, the Ablah and Fourzol plants). Others have their tests done at external labs (Hammana, Araya and Bourj Rahal). In the Chouf, the effluents of 10 small WWTPs operated by BMLWE are tested by one dedicated lab run by one technician in Baadarane. An officer responsible for the WWTP component of a USAID project describes the problems faced by small plants in relation to reuse as follows:

> *"So if you need to use this water you need to make sure that the WWTP is working properly, so you need to train people and make sure the water quality is acceptable…. Small WWTPs are not automated, so they depend on the skills of the operator. There is no preventative maintenance, no testing,*

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[63] For example, an engineer hired as a wastewater expert at BWE on a contractual basis had his salary halved. At SLWE, an engineer responsible for wastewater left for greener pastures in a USAID-funded project with a far superior salary.
[64] This is also a result of the employment freeze maintained by the Civil Service Board on behalf of successive governments to rein in government spending and the spiralling debt.
[65] The development agencies play a role in these dynamics. For example, the engineer responsible for wastewater at SLWE left only recently, due to the financial crisis, to work with the company (Chemonics) contracted by USAID for the management of a technical assistance project in the sector. The loss to the wastewater management department, small and understaffed as it is, can hardly be overstated; the experience and extensive knowledge of local plants and problems built over the almost two years that the engineer had been in charge will not be easy to replace in the current economic conditions.

no emergency response plan; in the case of flooding, all this wastewater would go into the natural stream. Those are small things but they have an impact on the quality of water or the effluent you are getting, which is important for irrigation." [66]

For example, in the Chouf, in Ablah, Fourzol or Aitanit, testing has been reported to occur monthly, and is dependent on the ability and experience of the process engineers. Not all parameters required by FAO are included because of the lack of capacities. The fact that in many places industrial wastewater is not separated from domestic wastewater poses problems for plant operation and treatment reliability. Testing for heavy metals is recommended only once a year by FAO; it is not clear whether the FAO proposal took into consideration the possibility that industrial wastewater is present in numerous areas. Yet, the problem of mixed systems seemed considerable for this engineer responsible for wastewater treatment at an RWE:

"Another problem (is) the combined systems…. We are having a lot of trouble here at the water treatment stations regarding the incoming water. The butchers, for example, the blood, feathers, internal organs… then you also get little pieces of plastic that the plastic factories produce. Those ones give us a lot of trouble here because they are too small and they pass through screens and they get all the way to the clarifiers. After that, we get our staff to go remove them. There is also paint, oils and all that too… We have a big problem with monitoring the networks." [67]

In addition, infiltration of rainwater into combined systems, including stormwater drains, leads to large fluctuations in quantity and quality.[68] Specifically, at the beginning of the rainy season, these waters are highly contaminated with heavy metals, oils and other debris that would have accumulated over the dry summer months and gets washed off with the first rains. Whether or not this affects reuse in irrigation will depend on the need for continued irrigation after the first rains.[69] While the pollution loads are highest in the first rains, debris accumulates over the winter in some plants (at least when regular maintenance does not happen) and can affect operations. Such basic issues as flow measurements are also problematic, especially for the smaller plants, preventing continuous monitoring. A number of operators and engineers pointed to the difficulties of assessing flow volumes. This is the account of one of them:

"I don't have any flow meters to measure the 'in' and 'out' water flows. Here is what I do to know the volume of water being treated; I know that the pump I have has the capacity to pump out 35 m^3 an hour. So I just calculate the volume of water based on how long the motor has been running…. Now I know my motor has the capability to pump up that much water because at some point, I had a tank and I tested my motor to see what it is capable of. With that said, the proper way to measure would be to use a flow meter. We are planning to install flow meters at the 3 stations being renovated right now. I do want to point out though that some of the flow meters I have seen before don't seem to be too accurate in my opinion." [70]

Volumetric data at a number of municipal-scale plants were ambiguous, with two or three different values presented in different reports and by different interviewees. But even in the larger plants, actual flow volumes and treated volumes are not always clear. For the Tripoli plant, for example, the numbers obtained were ambiguous, ranging from 3,000 m^3 to 30,000 m^3, depending on the sources and their interpretation of operational status. This inability to easily produce reliable data affects our calculations of potential, introducing a source of uncertainty. It also affects reuse project planning. A systematic and reliable monitoring of average and peak flow volumes, specifically during the irrigation season, is essential to adequately design reuse system infrastructure and plan water distribution to agricultural plots.

What can be seen from this brief discussion is the sensitivity of wastewater treatment systems to the management of plants and the O&M context. Maintaining effluent quality, and the monitoring and testing needed to guarantee it, will depend on the ability of RWEs and individual municipalities to employ diligent and trained staff for operations and in on-site labs. In turn, this will affect downstream potential for reuse in irrigation according to standards.

[66] Interview, LWP, April 16, 2020.
[67] Interview, SLWE, January 30, 2020.
[68] Interview, Ehden municipality, May 27, 2020; Interview, SLWE, January 30, 2020; Interview, CDR, June 20, 2020.
[69] The systems, including storm water drainage, are affected by the large volumes entering the WWTPs. The risk of washing out the bacteria in constructed wetlands, lagoons and other similar technologies leads operators to open the bypasses for such flows in order to protect WWTP operations. This though is of little consequence for reuse as such instances happen almost exclusively in the rainy season.
[70] Interview, operator, Chouf, June 1, 2020.

Allocation of Treated Effluents and Irrigation Water Rights and Management

Water reuse articulates complex questions of decision-making on water allocation and planning as well as reuse system management. While regional water planning and irrigation management are legally in the hands of the RWEs since 2000, they are still far from implementing those duties. In practice, most irrigation systems in Lebanon are operated by local committees, where historical water rights and local arrangements largely prevail.[71] With their poor financial and technical resources, the RWEs have poor or no authority over and knowledge of the management of surface water and groundwater-based systems and do not monitor irrigation water use. Groundwater use is supposed to be mapped and regulated by MEW, but as seen above, tens of thousands of wells remain undeclared and regulated. The weak governmental knowledge and agency on irrigation management represents a serious barrier to integrated planning of treated effluent use. On the other hand, if community-based distribution mechanisms exist, water allocation conflicts are also widespread and increasing with the reduction of water availability. Treated effluents are desirable for farmers but they represent yet another source of conflict in the absence of water allocation rules.

The Zahleh case study illustrates this well. Different water sources and irrigation systems co-exist within the reuse command area of the Zahleh WWTP, and function independently of the Bekaa Water Establishment. The Berdaouni, Litani and Ghozayel rivers are managed through different infrastructure and according to different forms of formal (legalized) and informal water rights (Annex 9B). The Berdaouni spring is used through an open-canal collective network supplying most of Zahleh's agricultural lands, which are located mostly upstream of the WWTP. The system has historically been managed by two farmer committees according to an ancient system involving the Zahleh municipality, the Mohafaza (regional administration) and farmers.[72] Water allocation occurs proportionate to land size according to old water rights (23% of the flow to the Maalaqa branch, 47% to Haouchlel Oumara and the remainder goes to the El Madina El Sinayia branch and eventually flows into the Litani). A large proportion of land located at the tail-end of the network is irrigated by groundwater (since the 1970s-1980s) through large private networks in the summer when surface water does not cover the water requirement of all lands.

Lands irrigated from the Litani and Ghozayel rivers are located downstream of the WWTP, at the level of Barr Elias village. Water was distributed by gravity until the 1970s when farmers started to use private pumps to irrigate lands not having access to water by gravity. The use of pumps increased the extent of lands drawing on these two sources, and gave rise to new land- and water-use arrangements, which can be described as informal water rights. Yet, when conflicts arise (in cases of water shortage), farmers benefiting from old water rights claim priority over those who do not. Conflicts over water allocation from the Litani and the Ghozayel are frequent in summer, especially during years of drought. Recently, authorities forbade the use of the Litani due to a threatening level of pollution, and users stopped irrigating their land, especially because groundwater was not readily available (Nassif 2016). In this context, the treated effluent from the Zahleh WWTP represents a vital source both to downstream farmers (in Barr Elias) and upstream farmers (Zahleh), where some large landowners are already pumping it from the Litani to reduce their energy costs. While conveying water by gravity to Barr Elias would be less costly and have a higher economic impact, the Zahleh municipality claims exclusivity to the use of the treated effluent. The argument is that sewage is produced and treated in Zahleh and its residents are paying for it while Barr Elias units are not connected to the WWTP. The issue juxtaposes the interests of some of the largest individual agricultural landowners in Lebanon with those of less endowed farmers or tenant farmers (IWMI Forthcoming).

Complex water rights and distribution dynamics can also be observed in the case of the Yammouneh WWTP (Annex 9H). There, the BWE is in charge of managing a large open-canal network implemented during the French mandate that crosses over several villages in North Bekaa. However, the historically developed local power of clans and families, the relative absence of the state, and production patterns centered around cannabis affect the distribution and control of water resources. As in Zahleh, water rights registered during the French mandate still codetermine distribution patterns. Upstream villages such as Yammouneh and Dar al Waasa claim priority over water resources—even where community and sectarian compositions have changed over the last century. The BWE performs its charge of water distribution through water guards who organize irrigation schedules for farmers.[73] According to a BWE employee, there are 15 employees hired by the water establishment for this purpose. The guards are drawn from the local population

[71] Water was legally established as property of the state under the French mandate in 1925, but community and individual rights to irrigation water use were maintained and formalized. These water rights allocated spring flows to one or different village based on geography and sociopolitical relations, and sometimes to specific landowners. Water rights are generally linked to landownership and appear on property titles. Today, these water allocation rules are still in place and serve as reference for communities. But other socio-technical arrangements have also emerged with the proliferation of individual and collective wells and groundwater networks. See Nassif (2016, 2019) for an extensive study on the history of irrigation rights and examples from the Bekaa.

[72] Irrigation is organized in water turns, and farmers pay the water guard a flat-rate fee per dunum (a measure of land, 1 dunum = 1,000 m^2 = 0.1 hectare). These "fees" include organization of the water turns and operating the canal gates accordingly. The municipality contributes to the cost of maintenance of primary and secondary canals and farmers usually pay for the clearing of tertiary channels to their plots.

[73] The Yammouneh water is divided into two main canals. Water allocation is as follows: 30% of the water should theoretically go to Chlifa, Deir El Wessaa, Btedhi, Abou Slaybi and Mrah El Sayed; 70% goes to Flewa, Boudai, Saideh and Chmistar.

and earn a salary, but where their allegiance lies when it comes to conflict is not clear. The power of BWE is limited. The case of BWE proposing a municipal water supply project for downstream villages suffering from severe undersupply illustrates the power of the clans. The initiative was successfully opposed by Dar el Wasaa farmers who mobilized their political power to assert their customary rights to water.

Questions of water distribution recurrently produce conflict. "Under the threat and intermittent use of force, the upstream families maintain effective control over the water from the Yammouneh spring by diverting its supply to their agricultural land," according to a study by Ghanem et al. (2017). The elders of Boudaai village negotiate water transfers when downstream needs become pressing but use their advantageous position to secure their needs first. Boudai families also act as intermediaries for other lowland villages. In a context of relative absence of state intervention, these local power dynamics leave little room for intervention by BWE. The failure of the WWTP project in Yammouneh as well as the problematic water supply further undermines the state authority's position in the area. According to municipal members, pollution from untreated wastewater is a major threat to agriculture; the existing sewer network, which is of inadequate capacity or condition, overflows and wastewater seeps into the groundwater and pollutes the lake, which provides (domestic or irrigation) water to 42 villages. Indicating local dissatisfaction with the work of BWE, one of our interviewees said, "The percentage of pollution in the lake is 1,000%."

The question of customary rights also appears in Iaat, although in a different form. There the WWTP did not start operations until the sewerage network was completed in 2009-2010. Yet, the plant remained inoperable: the minimum wastewater inflow requirement of 2,000 m^3/day was not met because farmers resisted the diversion of raw wastewater to the plant. They repeatedly broke the conveyor to claim what they considered their water, not based on old water rights but rather based on practice-derived claims. Distrust and cost considerations acted as barriers to the adaptation of alternative/new water sources proposed by planners. Reconciliation with farmers took until 2013, yet today farmers in the proximity of the plant (and upstream) still use raw wastewater for irrigation.

In Hammana, the situation is different. Treated water from the WWTP is currently being reused downstream after being discharged into the river. It is diverted from the river into an existing collective irrigation network by farmers of the next downstream village. When WWTP operations were interrupted for maintenance, raw wastewater was allowed to enter the river, resulting in a reduction of water in the irrigation canal. Farmers mobilized their municipality, which in turn submitted a formal complaint to the Mouhafaz denouncing the pollution of the river, leading to a conflict between municipalities. In this case, the fact that the rights to reused water are not regulated caused conflict. The municipality of Hammana carries the cost of treatment but does not profit from the reused water because the WWTP is situated at the lowest point of the village in the valley and like in Zahleh residents and farmers consider that the water rights lie with the municipality and the flows should be used within the village itself.

The case studies outlined above show that there are a multiplicity of interpretations and perceptions of customary or legal rights, which are mobilized to support claims to treated and untreated water. This requires irrigation management to come up with locally specific solutions that take into account the local power dynamics and customary arrangements. To be able to intervene productively in problems, the RWEs will have to go beyond the existing staff profiles. It seems reasonable to suggest that in fact new profiles with new competencies need to be defined to address these challenges which include technical and social skills such as mediation and negotiation. Creative solutions will have to be found to manage the mixture of private and public management arrangements including municipalities and regional authorities, landowners and tenant farmers, local notables and influential families. The importance of the role of the water guardians was clearly articulated in Bater, where their role in maintaining social peace is acknowledged in the public elections held under the purview of the municipality. Finally, who gets—or is denied—access to reused water is a central issue that may appear at the scale of irrigation network management by the water guardian or at an earlier level at the conception of water reuse projects. In one case study, this pitted large landowners owning around 1,000 ha owning their own well against numerous smaller farming enterprises drawing water from multiple sources (Zahleh case study in Annex 9B).

In conclusion, this chapter showed that many questions are yet to be addressed for the water reuse potential to be implemented in practice in Lebanon. While harnessing the WWTPs' potential is indeed needed amidst increasing water shortages in different water basins, one cannot expect it to be successful without a larger national strategy that is focused on bringing solutions to the different institutional, financial and sociopolitical limitations discussed in this section.

Conclusion

Ambitious wastewater treatment and reuse goals were articulated by Lebanon's Ministry of Energy and Water with the publication of the National Water Sector Strategy in 2012. But efforts and experiences in developing water reuse remain limited and wastewater treatment was seriously impaired long before the impact of the current financial crisis which has further weakened the sector. This study hopes to enrich the policy discussion on the topic of water reuse and wastewater treatment at the national scale.

This detailed assessment of the technical potential for water reuse in Lebanon should serve as a useful entry point into the articulation of a reuse strategy at the national level. Our analysis is based on material characteristics such as geography, agricultural area, available water and treatment technology. At this level, it shows that the coastal wastewater treatment plants, which process the highest volumes, have little potential in their immediate surroundings. Only massive investment would allow conveying these waters to agricultural areas.

The selection of plants mentioned in Table 21 combines WWTPs that have relatively large reuse potential areas with those that have relatively small reuse potential areas. It provides a selection of seemingly easier-to-implement and operate potential reuse schemes as well as larger ones that are more complex to implement. It shows that this relatively simple model, on account of having only three criteria, already produces a level of analysis that is useful for different policy orientations and different donor interests. The model further shows that a lot of small plants mostly operating at the level of rural municipalities have or could have high reuse potential.

With the current economic and financial crisis and the accompanying deep political crisis in Lebanon, a rethinking of planning and policy practice is inevitable. The degradation of institutions and existing infrastructure caused by the crisis shows the limits of previous planning approaches. For the foreseeable future, sector development and management will be even more illusory to finance through user fees than it was in the past 30 years. Holding on to a development model that has proven its inability to recover costs will further negatively affect wastewater treatment and water reuse potential.

The failure of the development model of the last 30 years brings with it two implications with regard to potential:

- Materializing potential on a national scale will require a rethinking of developmental approaches on a fundamental level and across sectors. Where user fees do not suffice for RWEs to maintain operations, they will certainly not provide profits to the private sector as originally imagined by sector reform. Recentering the state and state building as goals of development efforts will have to be an essential aspect of future efforts.
- At the level of water reuse and wastewater treatment, projects with lower investment volumes and low maintenance cost will have a higher chance of materializing and operating over the long term.

But other factors will affect project outcomes such as the formulation of a governance framework for the planning, management and monitoring of reuse systems, as well as formulating qualitative standards. One topic particularly identified in our case studies is the issue of decision-making regarding water allocation. Formal and informal water rights will need to be integrated for project acceptance and outcomes. In a similar manner, reuse projects will have to engage with and understand local irrigation management practices. These vary across locations, where they can be communally managed such as in Bater, or privately such as in Zahleh, or through the municipalities in other places. Projects will also have to address questions of distribution and livelihood impacts—who will profit and who will not? Are projects to reinforce existing wealth disparities, or to address poverty and livelihoods?

In a context where RWEs are struggling to make ends meet, both financially and regarding human resources, it will be necessary to further create synergies with local institutions such as municipalities, farmers and farmer associations. The project in Wadi Qanoubine funded by AFD would be an experience to learn from in this regard. The participatory planning and implementation approach implemented in the IWMI ReWater MENA project, of which this study is a part, will hopefully provide valuable lessons to be integrated in an incremental and adaptive approach to reuse planning.

Table 21. Summary numbers for wastewater reuse potential and the main sites with high potential.

	Mm^3/year	Mm^3/season	% of total
Total municipal wastewater generated	273.7-328.5	164.2-198.2	100
Total treated water produced	81.2	48.9	25-30
Total treated water discharged to sea	60.2	36.3	18-22
Total treated water discharged to inland water bodies	20.9	12.6	6.3-7.6
Total direct reuse (2020)	0	0	0
Total indirect reuse	Indirect reuse is widespread as water from rivers is persistently used for irrigation but cannot be quantified because of a lack of water use and water production data.		
Area potentially irrigable with treated water at present	2,208 ha		
Treatment plants with high reuse potential (area)	• Zahleh (527.2 ha), Aitanit (32.6 ha), Ablah (28.6 ha), Fourzol (21.3 ha), Joub Janine (138.9 ha), (Bekaa) • Chabriha (326.3 ha) (Sour) • Tebnine (23.9 ha) (BintJbeil) • Hebarriye (11.2 ha) (Hasbaya) • Ijbaa (87.5 ha), Aintourine (91.9 ha) (Ehden) • Nabaa el Safaa (22.0 ha), Bater (15.6 ha), Barouk (12 ha), Ammantour (9.7 ha) (Chouf) • Hammana (19.5 ha) (Metn) • Qobayat (12.2 ha) (Akkar)		

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Annex 1. Some Characteristics of Lebanese Agriculture.

Lebanon is home to a diversity of agroclimatic zones that support a variety of crops and farming systems. The zones are classified according to environmental factors such as topography, altitude and water availability. For reasons of space, only a simplified description of these zones is presented here for reference, without detailing their respective farming systems, though an understanding of farming systems remains important for assessment of water reuse policy options and project planning.

- *Southern coastal plain*. This zone extends from the southern border to the *caza* (sub-district) of Jbeil (North). Vegetables, bananas and citrus are the main crops here, with greenhouses more widely evident to the north.
- *Northern coastal plain*. Olive plantations are the mainstay in this zone, which extends up to the northern border from Koura to Zgharta. However, tobacco, cereals, potatoes and legumes are also produced in the northern part of the plain.
- *Dry upland plain*. This agroclimatic zone includes the central and southern Bekaa plain. It is the largest and most fertile agricultural region of Lebanon, and the most intensively exploited. The main crops are wheat, potatoes and vines as well as a diversity of fruit trees and vegetables.
- *Arid upland plain*. This zone includes the Northern Bekaa where cereals, forage crops, vegetables and apricots are grown.
- *Lowland mountains*. This agroecological zone is located below 800 meters above sea level (masl), extending from Batroun to Minieh and the Akkar. A variety of fruit trees and vegetables are grown here.
- *Wet upland mountains*. This zone includes most of the Mount Lebanon mountain chain. It is mainly cropped with fruit trees (most important of them being apples) and a diversity of vegetables.
- *Arid upland mountains*. This zone extends from the northern Anti-Lebanon mountain chain, where mostly apricots and cherries are produced, to the slopes of Mount Hermon, where rainfed plantations grow, mainly olives.
- *Dry hills of the South*. This zone counts tobacco and olives as its most important crops.

Farming systems in Lebanon are distinguished according to size of holding, technology, division of labor including gender division, capital requirement, water needs and uses, among others. As farmer livelihoods ought to lie at the center of any strategic consideration of reuse potential, any such analysis can and should be expanded to include a variety of socioeconomic relationships, such as farm market relations, as well.

Larger landholdings in Lebanon are concentrated in the Bekaa, where the average size of a holding is 2.9 ha compared with the average of 1.3 ha for the country as a whole. In the South, coastal plantations of banana and citrus tend to be relatively large too, while in the water-poor southern hills farmers plant tobacco on only a few dunums.

Lebanon's agriculture sector in general is characterized by a high level of concentration of landownership (Table A1). According to the 2010 agricultural census,[74] the top 1.8% of 169,512 landholders own 33% of all arable land. Concentration of irrigated land is even higher, with 42.6% of it held by the top 0.2% of landholders. In contrast, almost 94% of farmers work on less than 4 ha (48.8% of arable land and 39.4% of irrigated land); 70% of them work on less than 1 ha (MoA and FAO 2012).

This uneven distribution is reflected in the representation of small farmers in commodity chains. Markets for inputs are highly monopolistic. A 2003 study (Gaspard 2003)[75] detailed how the market for agricultural inputs is controlled by just five companies with one of them having 59% of the market. Market power downstream is equally concentrated and controlled by wholesalers and powerful traders. While small farm operations have little choice, large farmers profit from vertical integration. In the potato sector, large landowners who have better storage capacities, transportation, on-farm infrastructure and access to capital/credit dominate the market and capture a large part of production from small farmers at low prices.[76]

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[74] The study was published in 2012 but survey conducted in 2010.
[75] For further discussion, see Hamade (2019).
[76] The dynamics of large trader/farmer control of markets regarding potatoes are described in considerable detail for the Akkar region in Wood et al. (2020).

Table A1. Distribution of land by size of holding.

Size of holding (ha)	Number of farmers	Percentage of farmers	Percentage of all arable land	Percentage of all irrigated arable land
< 0.5	118,865	49.1%	8.1%	6.5%
< 1	26,269	70.1%	18.2%	14.2%
< 2	13,977	85.6%	33.0%	26.0%
< 4	7,312	93.9%	48.8%	39.3%
> 10	1,996	1.8%	33.1%	42.60%

Source: Compiled from MoA and FAO 2012.

These dynamics are manifest in the poverty rates: According to the most recent survey, the poverty rate among the agriculturally active population is 40% (CAS and World Bank 2016) while other data show that the poverty rate for agricultural households is approximately 67% (Riachi 2013). Further, the current economic crisis has dramatically boosted poverty. This situation is also reflected by the distribution of poverty rates among governorates where agriculture is an important sector, such as the South where poverty is at 42% (UNDP 2008).[77]

Across the country, about half of the farmer population relies on agriculture as their only source of income while the other half is pluriactive. For most of the latter category of people, pluriactivity is a necessity because incomes or sustenance derived from agricultural activity do not suffice to support their livelihoods. Smallholders are much less likely to own machinery and generators or have access to irrigation and wells.

[77] Extreme poverty rates were measured at 11.64% and an astounding 17.75%. A 2016 UNDP report confirms the average poverty rate but seems to indicate a more even distribution (UNDP 2016).

Annex 2. Database of Existing WWTPs.

#	Wastewater treatment plant	Operational status	Current design capacity (m^3/day)(2019/2020)	Average actual volume treated (m^3/day)	Type of treatment	Design level of treatment	Actual level of treatment	Managing public authority	Wastewater type	Conflicting or unclear information
1	Akkar El-Atika	Built, not operational	260	0	Settlement, sand filtration, extended aeration	Secondary		Municipality (tbc)[78]	Domestic	
2	Aammatour	Operational	900	275	Extended aeration, trickling filters, activated sludge	Tertiary	Tertiary	BMLWE	Domestic	
3	Ablah	Operational	2,000	1,300	Trickling filters	Secondary	Secondary	Municipality	Domestic	
4	Abou Qamha	Built, not operational	90		Anaerobic digestion/ closed settling tank followed by trickling filter	Secondary		Municipality	Domestic	Location precision
5	Ain Horche	Operational	120	50	Oxidation pond – anaerobic digestion, aerobic treatment, settlement, extended aeration	Secondary		Municipality	Domestic	
6	Ain Jarfa	Built, not operational	375	0	Extended aeration	Secondary		Municipality	Domestic	
7	Ain Qenia	Built, not operational	1,100	0	Anaerobic digestion/ pretreatment of olive pressings	Unknown		Municipality	Domestic	Conflicting location
8	Ainbal	Operational	2,200	550		Tertiary	Secondary	CDR	Domestic	

Continued on next page

[78] *Notes*: tbc = To be confirmed. The information for these WWTPs needs to be double checked by direct contact with municipalities. This was not done in the framework of this study.

#	Wastewater treatment plant	Operational status	Current design capacity (m^3/day)(2019/2020)	Average actual volume treated (m^3/day)	Type of treatment	Design level of treatment	Actual level of treatment	Managing public authority	Wastewater type	Conflicting or unclear information
9	Aintourine	Partially operational	3,600	3,600		Tertiary	Secondary	CDR	Domestic	
10	Aitanit/Machghara	Operational	5,000	1,200	Sedimentation tanks, anaerobic digestion, sludge drying beds, trickling filters, chlorination	Secondary	Secondary	Union of Municipalities of Lake Qaraoun	Domestic	
11	Baadarane	Operational	450	250	Activated sludge	Tertiary	Tertiary	BMLWE	Domestic	
12	Bakka 1	Built, not operational	60	0	Anaerobic digestion, extended aeration, non-electromechanical system (anaerobic fermentation – closed reactor, and aerobic treatment – open pond)	Secondary		Municipality	Domestic	
13	Bakka 2	Built, not operational	160	0	Anaerobic digestion, extended aeration, non-electromechanical system (anaerobic fermentation – closed reactor, and aerobic treatment – open pond)	Secondary		Municipality	Domestic	
14	Barouk	Under construction	1,800	0	Primary biofiltration, activated sludge with ultraviolet (UV) disinfection	Tertiary		CDR	Domestic	Conflicting volume
15	Bater	Operational	900	550	Extended aeration/ mixture of trickling filter and activated sludge	Tertiary		BMLWE	Domestic	
16	Bcharre	Under construction	5,000	0		Secondary		CDR	Domestic	

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#	Wastewater treatment plant	Operational status	Current design capacity (m^3/day)(2019/2020)	Average actual volume treated (m^3/day)	Type of treatment	Design level of treatment	Actual level of treatment	Managing public authority	Wastewater type	Conflicting or unclear information
17	Bcharre wetland	Operational				Unknown		Municipality (tbc)	Domestic	
18	Beino	Built, not operational	120	0		Secondary		Municipality (tbc)	Domestic	
19	Beit Menzer	Built, not operational		0		Secondary		Municipality (tbc)	Domestic	Location precision
20	Berti	Operational	195	195	Extended aeration	Secondary		Municipality	Domestic	
21	Bourj Rahal	Operational	300	240	Extended aeration	Tertiary		Municipality	Domestic	
22	Bqerzla	Built, not operational	675	100	Anaerobic digestion, septic tank	Secondary		Municipality	Mixed	
23	Bteddine El-Lekche	Partially operational	400	0	Extended aeration	Secondary		Municipality	Domestic	
24	Chabriha	Under construction	36,000	17,000	Activated sludge	Tertiary		CDR	Mixed	
25	Charbila	Partially operational	237	0	Anaerobic digestion wetland	Secondary		Municipality	Domestic	
26	Charqiye	Operational	10,900	5,000	Oxidation ditch	Tertiary	Tertiary	CDR	Mixed	
27	Chebaa	Built, not operational	900	0	Anaerobic digestion	Secondary		Municipality	Domestic	
28	Chekka	Built, not operational	2,200	0	Extended aeration, activated sludge	Secondary		CDR	Domestic	
29	Chouaya	Built, not operational	50			Secondary		Municipality	Domestic	Unclear operational status
30	Dahr Er Ramli	Built, not operational			Activated sludge	Unknown		Municipality	Domestic	Probably irreparable
31	Daoura	Built, not operational	1,000	0	Trickling filters	Secondary		Municipality	Domestic	Location precision

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#	Wastewater treatment plant	Operational status	Current design capacity (m^3/day)(2019/2020)	Average actual volume treated (m^3/day)	Type of treatment	Design level of treatment	Actual level of treatment	Managing public authority	Wastewater type	Conflicting or unclear information
32	Deir El-Ahmar	Partially operational	525	180	Extended aeration	Secondary	Primary	Municipality	Domestic	
33	Deir Mimas	Operational	200	200	Extended aeration	Tertiary		Municipality	Domestic	
34	Dibbine	Built, not operational	600		Anaerobic digestion	Secondary		Municipality	Domestic	
35	El Aakabe	Under construction	600	0	Trickling filters	Tertiary			Domestic	
36	El Aichye	Built, not operational	150	0	Anaerobic digestion followed by open settling tanks	Secondary		Municipality	Domestic	
37	El Jdeide	Operational	1,350	120	Activated sludge	Tertiary		BMLWE	Domestic	
38	El Meri	Built, not operational	220	0		Secondary		Municipality	Domestic	
39	Fardis	Built, not operational	120	0		Secondary		Municipality	Domestic	
40	Fourzol	Operational	0	1,000	Trickling filters, primary & final clarifiers, chlorination	Secondary		Municipality	Domestic	
41	Ghabbatiyeh	Built, not operational	250	0	Anaerobic digestion, followed by open settling tank	Secondary		Municipality	Domestic	
42	Ghadir	Operational	138,000	60,000	Screening, grinding	Primary		BMLWE	Mixed	
43	Gharifeh	Operational	1,125	0	Activated sludge	Secondary		Municipality (tbc)	Domestic	
44	Halta	Built, not operational	115	0		Unknown		Municipality	Domestic	
45	Hammana	Operational	1,440	900	Extended aeration	Secondary		Municipality	Domestic	
46	Haouch El Qinnabeh	Partially operational	100	0		Secondary		Municipality	Domestic	

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#	Wastewater treatment plant	Operational status	Current design capacity (m^3/day)(2019/2020)	Average actual volume treated (m^3/day)	Type of treatment	Design level of treatment	Actual level of treatment	Managing public authority	Wastewater type	Conflicting or unclear information
47	Hasbaya	Partially operational		0		Unknown		Municipality	Domestic	Conflicting operational status
48	Haytoura	Operational	100		Closed settling tank followed by trickling filters	Secondary		Municipality	Domestic	
49	Hebbariyeh	Operational	920	0	Anaerobic digestion (extended aeration)	Tertiary		Municipality	Domestic	
50	Hmaira	Partially operational	252	126	Anaerobic digestion, upflow anaerobic sludge blanket	Secondary		Municipality	Domestic	
51	Hnaider	Built, not operational	402	0	Advanced septic tank	Unknown		Municipality	Domestic	
52	Iaat	Partially operational	24,000	5,000	Activated sludge, chlorination, oxidation ditches	Tertiary	Secondary	BWE	Mixed	
53	Ijbaa	Partially operational	3,600	3,600		Tertiary	Secondary	CDR	Domestic	
54	Jabboule	Operational	90			Tertiary	Secondary		Domestic	Conflicting operational status
55	Jbaa	Built, not operational	1,050		Consecutive closed settling tanks	Secondary		Municipality	Mixed	
56	JbaaEch-Chouf	Operational	225	175	Trickling filters, activated sludge, chlorination	Tertiary		BMLWE	Domestic	
57	Jbeil	Under construction	10,000	0	Biofiltration	Tertiary		CDR	Mixed	
58	Jebrayel	Built, not operational	120	0	Activated sludge	Secondary		Municipality	Domestic	

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#	Wastewater treatment plant	Operational status	Current design capacity (m^3/day)(2019/2020)	Average actual volume treated (m^3/day)	Type of treatment	Design level of treatment	Actual level of treatment	Managing public authority	Wastewater type	Conflicting or unclear Information
59	Joub Janine	Operational	10,000	6,000	Anaerobic oxidation, disinfection, extended aeration, activated sludge	Tertiary		BWE	Mixed	
60	Kawkaba	Partially operational	135	135		Unknown		Municipality	Domestic	
61	Kfar Fila	Built, not operational	525	0	Consecutive closed settling tanks	Secondary		Municipality	Domestic	
62	KfarHamam	Built, not operational	115	0	Extended aeration	Tertiary		Municipality	Domestic	
63	Kfar Sir	Under construction	1,218	0	Water stabilization pond (WSP)	Tertiary		Municipality	Domestic	
64	Kfarqatra	Operational	250	90	Activated sludge	Secondary		CDR	Domestic	
65	Kfeir	Partially operational	425	0	Activated sludge	Secondary		Municipality	Domestic	
66	Khiam	Built, not operational	6,000	0	Extended aeration - trickling filters	Secondary		Municipality	Domestic	
67	Khreibet Ech-Chouf (El Khreibe)	Operational	450		Trickling filters, activated sludge	Tertiary		BMLWE	Domestic	
68	Knaisse 1	Operational	532	0	Advanced septic tank	Unknown		Municipality	Domestic	
69	Knaisse 2	Operational	532	0	Advanced septic tank	Unknown		Municipality	Domestic	
70	Maasser Ech-Chouf	Operational	450	100	Trickling filters, activated sludge	Tertiary		BMLWE	Domestic	
71	Majdala	Built, not operational	120	0		Secondary		Municipality	Domestic	

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#	Wastewater treatment plant	Operational status	Current design capacity (m³/day)(2019/2020)	Average actual volume treated (m³/day)	Type of treatment	Design level of treatment	Actual level of treatment	Managing public authority	Wastewater type	Conflicting or unclear information
72	Majdel Anjar/ El Marj	Under construction	45,000	0	Activated sludge, biological nitrogen removal, biological and chemical phosphorus removal	Tertiary		CDR	Mixed	
73	Marj Ez-Zouhour	Built, not operational	120	0	Wetland	Secondary		Municipality	Domestic	
74	Marjayoun	Built not operational				Unknown		Municipality	Domestic	
75	Mazraat Balde	Built, not operational		0		Unknown		Municipality	Domestic	
76	Mimes (2)	Partially operational	120	0	Activated sludge	Secondary		Municipality	Domestic	Not clear if existing
77	Moukhtara	Operational	450	175	Trickling filters, activated sludge, chlorination	Tertiary	Tertiary	BMLWE	Domestic	
78	Mristi	Operational	225	90	Trickling filters, activated sludge	Tertiary	Tertiary	BMLWE	Domestic	
79	Nabaa El Safa and Aain Zhalta	Under construction	3,000	0	Activated sludge	Tertiary		CDR	Domestic	
80	Jiyeh (Nabi Younes)	Partially operational	18,400	0	Sludge stabilization biofiltration	Tertiary	Secondary	CDR	Mixed	
81	Qaytoule	Partially operational	980	0	Activated sludge	Unknown		Municipality	Domestic	
82	Qbaiyat Akkar El Gharbie (Andket)	Operational	1,350	0	Extended aeration, trickling filters	Secondary		Municipality	Domestic	
83	Qornayel	Built, not operational	900	0	Extended aeration	Secondary		Municipality	Domestic	Location not verified

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#	Wastewater treatment plant	Operational status	Current design capacity (m^3/day)(2019/2020)	Average actual volume treated (m^3/day)	Type of treatment	Design level of treatment	Actual level of treatment	Managing public authority	Wastewater type	Conflicting or unclear information
84	Rachaiya	Operational	600	0	Trickling filters, aerobic treatment, extended aeration	Secondary		Municipality	Domestic	
85	Rahbe	Built, not operational	300	0	Trickling filters	Secondary		Municipality	Domestic	
86	Rihane (Jezzine)	Partially operational	820	0	Extended aeration	Tertiary			Domestic	
87	Rimhala	Operational		0		Unknown		Municipality	Domestic	No volume information
88	Saghbine	Operational	560	100	Activated sludge, extended aeration with anoxic zone	Secondary	Secondary	CDR	Domestic	
89	Batroun	Operational	3,000	3,000	Extended aeration, activated sludge	Tertiary		CDR	Domestic	Operational status not clear
90	Sayniq	Partially operational	65,000	55,000	Preliminary treatment	Secondary		SLWE	Mixed	
91	Snaya	Partially operational	60	0	Anaerobic digestion followed by open settling tanks	Secondary		Municipality	Domestic	
92	Tebnine	Operational	3,600	0	Oxidation ditch	Tertiary		SLWE	Domestic	
93	Tripoli	Partially operational	35,000	30,000	Activated sludge	Tertiary		CDR	Mixed	
94	Wadi Jezzine	Built, not operational	150	0	Concentric tanks (aerobic treatment and sludge digestion with enzyme)	Secondary		Municipality	Domestic	Location not verified
95	Wazzani	Built, not operational	50	0	Wetland	Unknown		Municipality	Domestic	

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#	Wastewater treatment plant	Operational status	Current design capacity (m^3/day)(2019/2020)	Average actual volume treated (m^3/day)	Type of treatment	Design level of treatment	Actual level of treatment	Managing public authority	Wastewater type	Conflicting or unclear information
96	Yammouneh	Built, not operational	800	50	Extended aeration, activated sludge	Secondary		BWE	Domestic	
97	Yanta 1 (northern)	Partially operational	200	50	Activated sludge, extended aeration, trickling filter	Secondary		Municipality	Domestic	
98	Yanta 2 (southern)	Partially operational	300	50	Activated sludge, extended aeration, trickling filter	Secondary		Municipality	Domestic	
99	Yohmor En Nabatiyeh	Operational	525	210	Water stabilization pond	Tertiary		SLWE	Domestic	
100	Zahleh	Operational	35,000	25,000	Activated sludge, trickling filters, biological nitrogen removal, UV disinfection	Tertiary	Tertiary	CDR	Mixed	
101	Zaoutar Ech-Charqiye	Operational	450	160	Water stabilization pond	Tertiary	Tertiary	SLWE	Domestic	
102	Araya	Operational	400	400	Activated sludge	Secondary		Municipality	Domestic	
103	Qasmiyeh 1	Operational	45	45	Activated sludge	Secondary		Municipality	Domestic	
104	Qasmiyeh 2	Operational	100	100	Activated sludge	Secondary		Municipality	Domestic	

Sources: Compilation based on MEW 2020; FAO 2016a; KREDO 2015a; MEW 2012; MoE 2004; ELARD 2015; GIZ 2009; Triple E 2020. Data for BWE and SLWE were validated by respective officials.

Annex 3. Database of Proposed WWTPs.

ID	Village	Status	WWTP	Capacity (m³/day)	Technology
1	Wadi Faara	Proposed	Wadi Faara	275	NA[a]
2	El Mdaouich	Proposed	El Mdaouich	858	NA
3	El Boustane	Proposed	El Boustane	849	NA
4	Sahel Hermel	Under execution	Sahel Hermel	2,500	Membrane bioreactor
5	Al-QaWadi El-Khanzir	Proposed	Al-QaWadi El-Khanzir	4,917	NA
6	Al-Fakiat	Proposed	Al-Fakiat	17,296	NA
7	Harbta	Proposed	Harbta	11,893	NA
8	Ainata	Proposed	Ainata	618	NA
9	Chlifa	Proposed	Chlifa	0	NA
10	Chlifa	Proposed	Chlifa	4,220	NA
11	Maaraboun	Proposed	Maaraboun	895	NA
12	Jenta	Proposed	Jenta	512	NA
13	Tamnine El-Tahta	Proposed	Tamnine El-Tahta	50,000	NA
14	Tfeil	Proposed	Tfeil	268	NA
15	Bizhel	Proposed	Bizhel	1,550	Membrane bioreactor
16	Mayrouba	Proposed	Mayrouba	5,148	NA
17	Ghazir	Proposed	Ghazir	48,000	NA
18	Aachqout	Proposed	Aachqout	4,477	NA
19	Zouk Mousbeh	Proposed	Zouk Mousbeh	42,000	Membrane bioreactor
20	Ras El Matn	Proposed	Ras El Matn	17,400	Extended aeration activated sludge
21	Aabadiyé	Proposed	Aabadiyé	5,090	NA
22	Aabadiyé	Proposed	Aabadiyé	13,000	NA
23	Hlaliyé Baabda	Proposed	Hlaliyé Baabda	17,400	NA
24	Charoun	Proposed	Charoun	2,253	NA
25	Chaqra	Proposed	Chaqra	1,300	Activated sludge
26	Yaroun	Proposed	Yaroun	6,396	Activated sludge
27	Chourit	Proposed	Chourit	13,000	NA
28	litige	Proposed	litige	10,200	NA
29	Bchtfine	Proposed	Bchtfine	9,152	NA
30	Faouarat Jaafar	Proposed	Faouarat Jaafar	2,353	NA
31	Deir Baba	Proposed	Deir Baba	2,464	Activated sludge
32	BenouatiEch-Chouf	Proposed	BenouatiEch-Chouf	10,780	Biological aerated filter
33	Qreiaa	Proposed	Qreiaa	700	Activated sludge
34	DeirEl-MoukhallesEch-Chouf	Proposed	DeirEl-MoukhallesEch-Chouf	118	NA
35	Hasbaiya	Proposed	Hasbaiya	12,442	
36	Zabbougha	Proposed	Zabbougha	2,000	Membrane bioreactor
37	Zabbougha	Proposed	Zabbougha	2,000	NA
38	Mar Boutros Karm Et-Tine	Proposed	Mar Boutros Karm Et-Tine	5,681	NA
39	Abou Mizane	Proposed	Abou Mizane	1,018	NA
40	Bteghrine	Proposed	Bteghrine	8,432	Activated sludge
41	Aayoun El-Matn	Proposed	Aayoun El-Matn	9,500	Extended aeration activated sludge
42	Beit Meri	Proposed	Beit Meri	4,700	Extended aeration activated sludge
43	Tartij	Proposed	Tartij	402	NA

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ID	Village	Status	WWTP	Capacity (m^3/day)	Technology
44	KharbetJbayl	Proposed	KharbetJbayl	1,480	Low F/M activated sludge with oxidation ditch
45	Ghalboun	Proposed	Ghalboun	1,875	Low F/M activated sludge with oxidation ditch
46	Haqel	Proposed	Haqel	111	NA
47	KfarMashoun	Proposed	KfarMashoun	985	Low F/M activated sludge with oxidation ditch
48	Ferhet	Proposed	Ferhet	2,185	Low F/M activated sludge with oxidation ditch
49	ZibdineEn-Nabatiyeh	Proposed	ZibdineEn-Nabatiyeh	635	Low F/M activated sludge with oxidation ditch
50	Lassa	Proposed	Lassa	0	NA
51	Bisri	Proposed	Bisri	270	Reed bed filter
52	Aazour	Proposed	Aazour	158	Reed bed filter
53	Roum	Proposed	Roum	616	Activated sludge
54	Sfaray	Proposed	Sfaray	402	Reed bed filter
55	Srayri	Proposed	Srayri	2,000	NA
56	Kfar Qouq	Proposed	Kfar Qouq	1,243	NA
57	Deir El-Aachayer	Proposed	Deir El-Aachayer	203	Membrane bioreactor
58	Kfar Lichki	Proposed	Kfar Lichki	482	NA
59	Aaqabet Rachaya	Under construction	Aaqabet Rachaya	12,182	Oxidation ditch (extended aeration)
60	Haouch El Qinnabé Rachaiya	Proposed	Haouch El Qinnabé Rachaiya	5,011	Oxidation ditch (extended aeration)
61	Ghaziyé	Proposed	Ghaziyé	40,221	NA
62	Bourj Hammoud	Proposed	Bourj Hammoud	325,000	NA
63	Bhannine	Proposed	Bhannine	3,920	NA
64	Aslout	Proposed	Aslout	593	Trickling filter
65	ArbetKoshaya	Proposed	ArbetKoshaya	672	Trickling filter
66	Kfarsghab	Proposed	Kfarsghab	587	Trickling filter
67	Zahleh	Proposed	East Zahleh	0	NA
68	Sohmor	Proposed	Sohmor	2,000	NA
69	Kaftoune	Proposed	Kaftoune	3,266	Trickling filter
70	Btaaboura	Proposed	Btaaboura	191	Wetland
71	Behouaita	Proposed	Behouaita	116	Wetland
72	Bchernata	Proposed	Bchernata	132	Wetland
73	Izal	Proposed	Izal	1,258	Trickling filter
74	Qattine	Proposed	Qattine	8,988	Activated sludge
75	Tarane	Proposed	Tarane	993	Trickling filter
76	Beit Zoud	Proposed	Beit Zoud	199	Wetland
77	Beit Haouik	Proposed	Beit Haouik	414	Wetland
78	Qemmamine	Proposed	Qemmamine	215	Wetland
79	Btoumaz	Proposed	Btoumaz	3,413	Trickling filter
80	Beit Haouik	Proposed	Beit Haouik	1,474	Trickling filter
81	Btoumaz	Proposed	Btoumaz	545	Trickling filter

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ID	Village	Status	WWTP	Capacity (m^3/day)	Technology
82	Jairoun	Proposed	Jairoun	248	Wetland
83	Qarn	Proposed	Qarn	80	Wetland
84	Azqey	Proposed	Azqey	83	Wetland
85	Terbol	Proposed	Terbol	72	Wetland
86	Abdine	Proposed	Abdine	7,680	Wetland
87	Knate	Proposed	Knate	624	Rotating biological contractors (RBC)
88	Beit Menzer	Proposed	Beit Menzer	432	Wetland
89	Hadeth-el-Jebbé	Proposed	Hadeth-el-Jebbé	1,728	Activated sludge
90	Brissat	Proposed	Brissat	240	Wetland
91	Mazraet-Beni-Saab	Proposed	Mazraet-Beni-Saab	312	Wetland
92	Mazraet Assaf	Proposed	Mazraet Assaf	240	Wetland
93	Billa	Proposed	Billa	312	Wetland
94	Bane	Proposed	Bane	504	Wetland
95	Hasroune	Proposed	Hasroune	2,592	Activated sludge
96	Bazoune	Proposed	Bazoune	1,128	Rotating biological contractors (RBC)
97	Bkarkacha	Proposed	Bkarkacha	1,272	Rotating biological contractors (RBC)
98	Bikaakafra	Proposed	Bikaakafra	1,680	Activated sludge
99	Berhalioun	Proposed	Berhalioun	720	Wetland
100	El-Dimane	Proposed	El-Dimane	768	Wetland
101	Blaouza	Proposed	Blaouza	312	Wetland
102	Hadchite	Proposed	Hadchite	2,208	Activated sludge
103	Bcharré	Under construction	Bcharré	9,700	Activated sludge with nutrient removal
104	Mugher-el-Ahwel	Proposed	Mugher-el-Ahwel	432	Wetland
105	Blaouza	Proposed	Blaouza	672	Wetland
106	Hasroune	Proposed	Hasroune	384	Wetland
107	Knaiouer	Proposed	Knaiouer	384	Wetland
108	Tourza	Proposed	Tourza	1,493	Wetland
109	Thoum	Planned	Thoum	6,660	Activated sludge
110	KfarHalda	Planned	KfarHalda	3,525	Activated sludge
111	Kour	Planned	Kour	2,146	Activated sludge
112	Chabtine	Planned	Chabtine	1,040	Activated sludge
113	Harare	Proposed	Harare	1,432	Trickling filter
114	Michmiche	Proposed	Michmiche	8,043	Activated sludge
115	Habchite	Proposed	Habchite	584	Trickling filter
116	El-Krayat	Proposed	El-Krayat	508	Trickling filter
117	Chane	Proposed	Chane	1,083	Trickling filter
118	Danbou	Proposed	Danbou	6,769	Trickling filter
119	El-Houaïche	Proposed	El-Houaïche	660	Trickling filter
120	Mimnih	Proposed	Mimnih	575	Trickling filter
121	El-Houaïche	Proposed	El-Houaïche	396	Wetland
122	Jebrâil	Proposed	Jebrâil	17,275	Activated sludge
123	Akkar El-Atika	Proposed	Akkar El-Atika	3,411	Trickling filter
124	KobbetBchamra	Planned	KobbetBchamra	39,010	Activated sludge
125	Akkar El-Atika	Proposed	Akkar El-Atika	4,264	Trickling filter
126	El-Koubayet	Proposed	El-Koubayet	338	Wetland
127	Akroum	Proposed	Akroum	965	Trickling filter
128	Akroum	Proposed	Akroum	965	Trickling filter
129	Akroum	Proposed	Akroum	1,015	Trickling filter
130	SindianetZeidan	Proposed	SindianetZeidan	5,847	Trickling filter
131	Akroum	Proposed	Akroum	1,157	Trickling filter

Continued on next page

ID	Village	Status	WWTP	Capacity (m^3/day)	Technology
132	Douair Adouiyé	Proposed	Douair Adouiyé	2,858	Trickling filter
133	Mazraet-El-Nahrieh	Proposed	Mazraet-El-Nahrieh	626	Trickling filter
134	Akroum	Proposed	Akroum	406	Wetland
135	El-Bardé	Proposed	El-Bardé	102	Wetland
136	Akroum	Proposed	Akroum	534	Trickling filter
137	Mazraet-El-Nahrieh	Proposed	Mazraet-El-Nahrieh	372	Wetland
138	Hnaïder	Proposed	Hnaïder	1,316	Trickling filter
139	Deirine	Proposed	Deirine	435	Wetland
140	Mounjez	Proposed	Mounjez	508	Reed bed filter
141	Cheikh Zennad Tal Bibé	Proposed	Cheikh Zennad Tal Bibé	1,361	Trickling filter
142	Srar	Proposed	Srar	34	Wetland
143	Freidice	Proposed	Freidice	306	Wetland
144	Kachlak	Proposed	Kachlak	575	Trickling filter
145	Chikhlar	Proposed	Chikhlar	203	Wetland
146	Kfarnoune	Proposed	Kfarnoune	406	Wetland
147	Al-Kneissé	Proposed	Al-Kneissé	1,394	Trickling filter
148	Tal Biré	Proposed	Tal Biré	1,185	Trickling filter
149	Noura El-Faouka et Tahta	Proposed	Noura El-Faouka et Tahta	579	Trickling filter
150	Freidice	Proposed	Freidice	220	Wetland
151	Aaouainat	Proposed	Aaouainat	406	Wetland
152	Dabbabiyé Charkié	Proposed	Dabbabiyé Charkié	220	Wetland
153	Cheir Homeirine	Proposed	Cheir Homeirine	5,850	Trickling filter
154	Arida	Proposed	Arida	512	Trickling filter
155	Ouadi Khaled	Proposed	Ouadi Khaled	8,878	Activated sludge
156	Hekrel Dahiri	Proposed	Hekrel Dahiri	981	Trickling filter
157	Al-Semmakié	Proposed	Al-Semmakié	970	Trickling filter
158	Kafrra	Proposed	Kafra Bent Jbeil	NA	NA
159	Heloue	Proposed	Helouet Rachaya	NA	NA
160	Salhani	Proposed	Salhani	11,000	NA
161	Jabal El-Botm	Proposed	Jabal El-Botm	1,500	NA
162	Mansouri Sour	Proposed	Mansouri Sour	3,500	NA
163	Naqoura	Proposed	BorjEn-Naqoura	1,500	NA
164	Jimjim	Proposed	Jimjim	4,500	NA

Source: NWSSU 2020 Geodatabase.

Note: [a]NA = Not available; F/M = Food-to-Mass Ratio.

Annex 4. Code for CMD Area Delimitation.

A schematic overview of the modeling steps is presented here:

Input:

- WWTP location file (with unique ID, elevation, latitude, longitude and WWTP name as attributes)
- DEM (digital elevation model) for Lebanon file
- Flow direction grid for Lebanon (derived from DEM) file
- Irrigation schemes file

Logical steps:

- Read point and elevation of WWTP.
- Set of buffer diameter (maximum distance from WWTP to be irrigated)
- Set maximum elevation (to account for potential pumping).
- Subtract all points higher than maximum elevation from buffer (eliminate all areas higher than pumping maximum elevation).
- From closest point to WWTP at maximum pumping elevation define flow path (it is assumed that after pumping water conveyance occurs by gravity)
- Set buffer for flow path (includes areas from highest point following the terrain going downstream)
- Add irrigated areas.
- Output as GIS layer
- Set counter to next point

The code in R below was used to create command areas of WWTPs. The required inputs are three shape files describing (1) WWTP locations, (2) a digital elevation model .tif file, (3) shape file describing the irrigation perimeters as areas. This code was produced by Naga Manohar Velpuri, senior researcher at the International Water Management Institute.

The point buffer, elevation and stream buffer are the variables for two different modelling scenarios.

```
#install.packages("raster")
library(raster)
#install.packages("rgdal")
library(rgdal)
#install.packages("sf")
library(sf)
#install.packages("dplyr")
library(dplyr)
#install.packages("riverdist")
library(riverdist)
#install.packages("geosphere")
library(geosphere)
#install.packages("maptools")
library(maptools)
#install.packages("rgeos")
library(rgeos)

setwd("/home/.folder path to target folder to save output")

shp_wwtp ← readOGR("/home/ ....input shape file for WWTPS")
dem ← raster("/ /home/ ...dem_30m_fill.tif")
dem_fd ← raster("dem_30m_fill_fd.tif")
irrg_schm ← st_read("/home/....../Irrigation_Schemes.shp")
irrg_schm_dis ← readOGR("Irrigation_Schemes_dis.shp")

lat ← shp_wwtp$Long
long ← shp_wwtp$Lat
name ← shp_wwtp$WWTP
id ← shp_wwtp$ID
elev ← shp_wwtp$Elevation
```

```
for(i in (1:length(id))){
    data ← data.frame(name[i], id[i], lat[i], long[i])
    names(data) ← c(“name”, “id”, “lat”, “long”)
    point_geo ← st_as_sf(data, coords = c(x = “lat”, y = “long”), crs = 4326)
    point_buff ← st_buffer(point_geo, 0.03)
    st_write(point_buff, “point_buff.shp”, delete_layer = TRUE)
    x ← st_join(point_geo, irrg_schm, join = st_within)
    schemeID ← x$OBJECTID
    wwtp_elev ← crop(dem, extent(point_buff))
    maxx ← elev[i] + 50
    wwtp_elev[wwtp_elev > maxx] ← NA
    cmd_irrg ← wwtp_elev

    cmd_low ← cmd_irrg
    cmd_low[cmd_low > min(cmd_low[], na.rm = TRUE)] ← NA
    lowp ← rasterToPoints(cmd_low, spatial=TRUE)

    cmd_hi ← cmd_irrg
    cmd_hi[cmd_hi < max(cmd_hi[], na.rm = TRUE)] ← NA
    hip ← rasterToPoints(cmd_hi, spatial=TRUE)

    loc ← c(x = lat[i], y = long[i])
    fdir_mask ← crop(dem_fd,extent(cmd_irrg))
    path ← flowPath(fdir_mask, loc)
    xy ← xyFromCell(fdir_mask, path)
    stream ← st_linestring(xy)
    wwtp_stream ← st_sfc(stream) #convert stream line object to sf object

    if(is.na(schemeID)){
        buff_dist ← 0.0075              #USE buff distance as 750 m from the stream when high point is unknown and unrealistic.
        streambuff ← st_buffer(wwtp_stream, buff_dist) #generate buffer based on the buff_distance
        stream_buff ← st_sfc(streambuff)    #verify simple feature geometry
    } else {
        xyp ← xyFromCell(dem, coordinates(hip))          #extract xy coordinates from the cell (coordinates of high points)
        coo ← coordinates(hip)              #get coordinates of highest points

        dist ← dist2Line(coo, stream, distfun = distGeo)          #compute distance to line feature
        dis ← sort(dist[,1])                #sort distance from WWTP to higher elevation values

        buff_dist ← quantile(dis[1:(length(dis) * 0.25)], 0.98)  #use closest 25 distance values (from WWTP to highest elevation) to compute buff_dist
        buff_dist ← as.numeric(format(buff_dist, digit = 2))/ 100000    #convert buff_dist to degree decimals
        streambuff ← st_buffer(wwtp_stream, buff_dist)            #generate buffer based on the buff_distance
        stream_buff ← st_sfc(streambuff)    #verify simple feature geometry
    }
    st_write(wwtp_stream, “stream.shp”, delete_layer = TRUE)
    st_write(streambuff, “stream_buff.shp”, delete_layer = TRUE) #write stream buffer to shp file
    streambuffer ← readOGR(“stream_buff.shp”)  #read streambuffer shp file
    wwtp_cmd_area ← mask(cmd_irrg, streambuffer)      #clip elevation cmd area to stream buffer
        polys1 = rasterToPolygons(wwtp_cmd_area)  #convert raster to polygon shp file (usually converts each pixel to one polygon)
    meanelev ← data.frame(mean(polys1$dem_30m, na.rm = TRUE))
    row.names(meanelev) ← c(“0”)
    polys1$dem_30m ← 0 #(change the elevation for each pixel to 0; so that we can dissolve by this column)
    region = unionSpatialPolygons(polys1, IDs = polys1$dem_30m)  #dissolve all the pixel polygons to one single polygon
    cmnd.area.df ← SpatialPolygonsDataFrame(region, meanelev) #convert spatialpolygons to spatialPolygon data.frame

    outfile ← paste(“commandarea_ID_potential_”, id[i], sep = “”)          #generate output file name
    dn ← getwd()                    #get the working directory path
    writeOGR(cmnd.area.df, dn, outfile, driver=”ESRI Shapefile”, overwrite_layer=TRUE) #write spatialPolygonDataFrame to shp file.
    print(i)
```

```
infile ← paste(outfile, ".shp", sep = "")
cmd_area ← readOGR(infile)
irrg ← irrg_schm_dis[,1]
cmd_area2 ← gIntersection(irrg, cmd_area)  #
if(!is.null(cmd_area2)){
        cmd_area2_dem ← mask(dem, cmd_area2)
        cmd_area3 = rasterToPolygons(cmd_area2_dem)  #convert raster to polygon shp file (usually converts
        each pixel to one polygon)
        meanelev ← data.frame(mean(cmd_area3$dem_30m, na.rm = TRUE))
        row.names(meanelev) ← c("0")
        cmd_area3$dem_30m ← 0 #(change the elevation for each pixel to 0; so that we can dissolve by this
        column)
        region = unionSpatialPolygons(cmd_area3, IDs = cmd_area3$dem_30m)  #dissolve all the pixel
        polygons to one single polygon
        cmnd.area3.df ← SpatialPolygonsDataFrame(region, meanelev)
        outfile ← paste("commandarea_ID_irrigation_", id[i], sep = "")                #generate output file name
        dn ← getwd()                                    #get the working directory path
        writeOGR(cmnd.area3.df, dn, outfile, driver="ESRI Shapefile", overwrite_layer=TRUE) #write spatial
        Polygon Data Frame to shp file.
```

Annex 5. Maps for Proposed WWTPs.

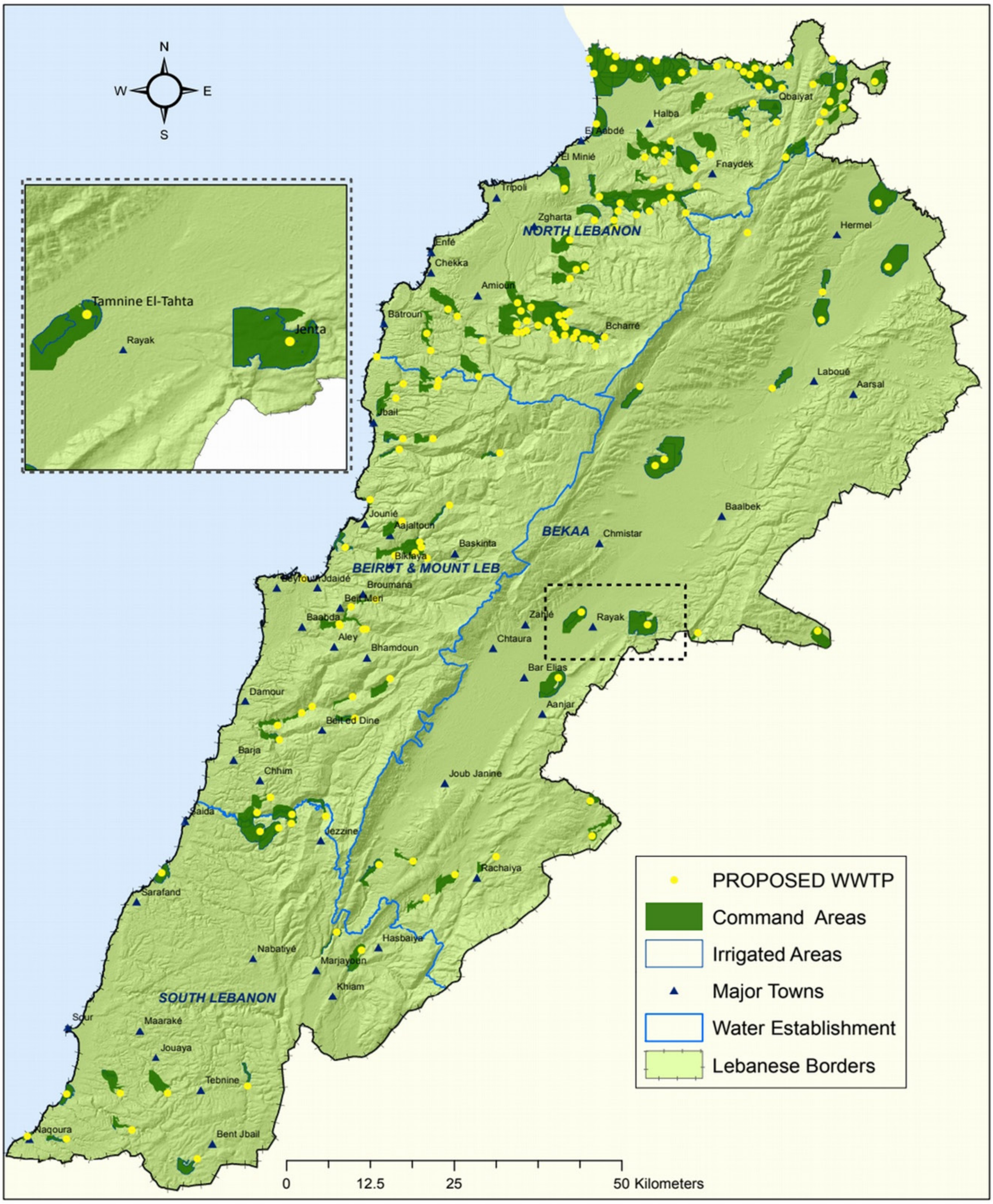

Figure A5.1. Command areas of proposed WWTPs.

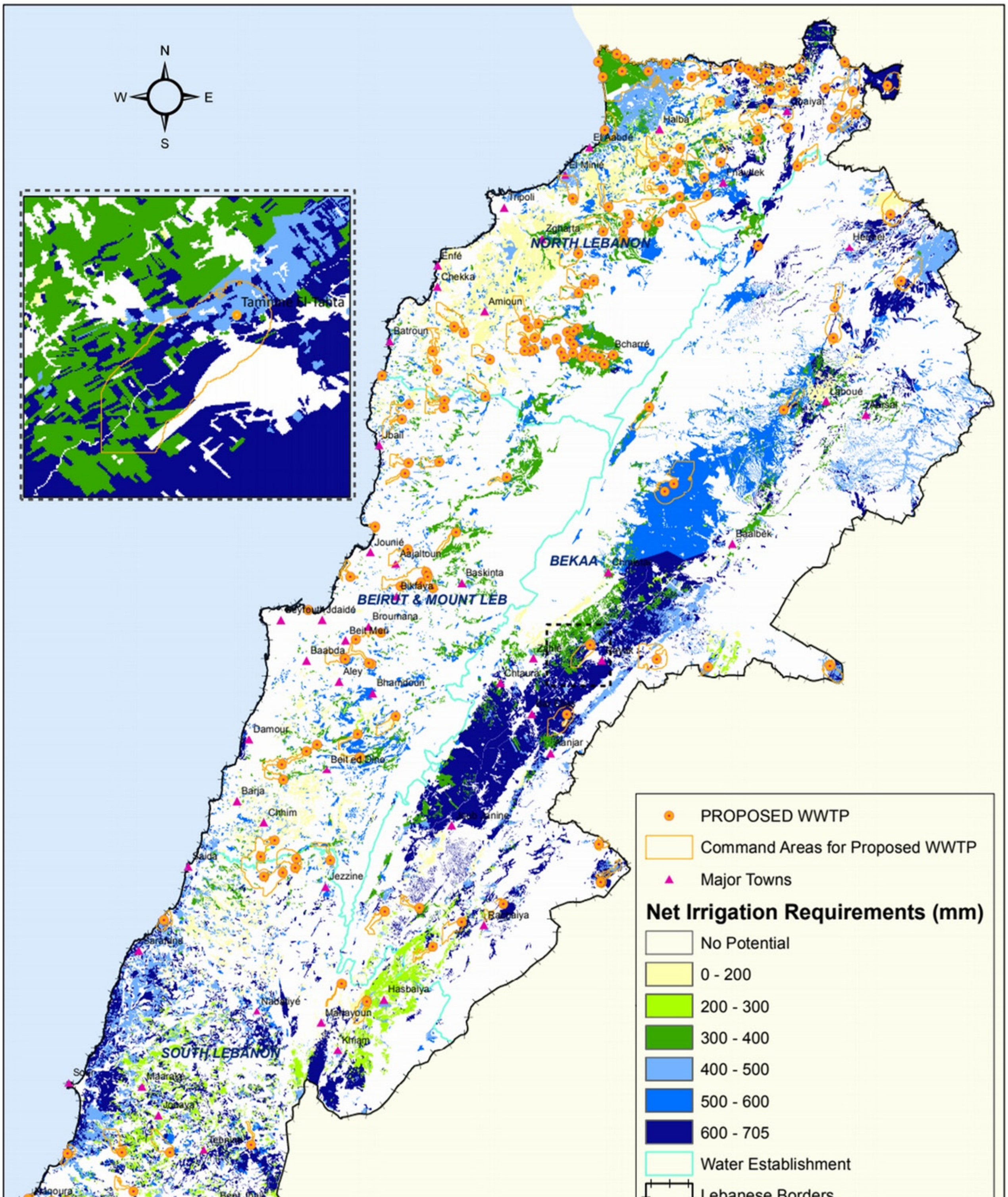

Figure A5.2. Net irrigation requirement for the command areas of proposed WWTPs.

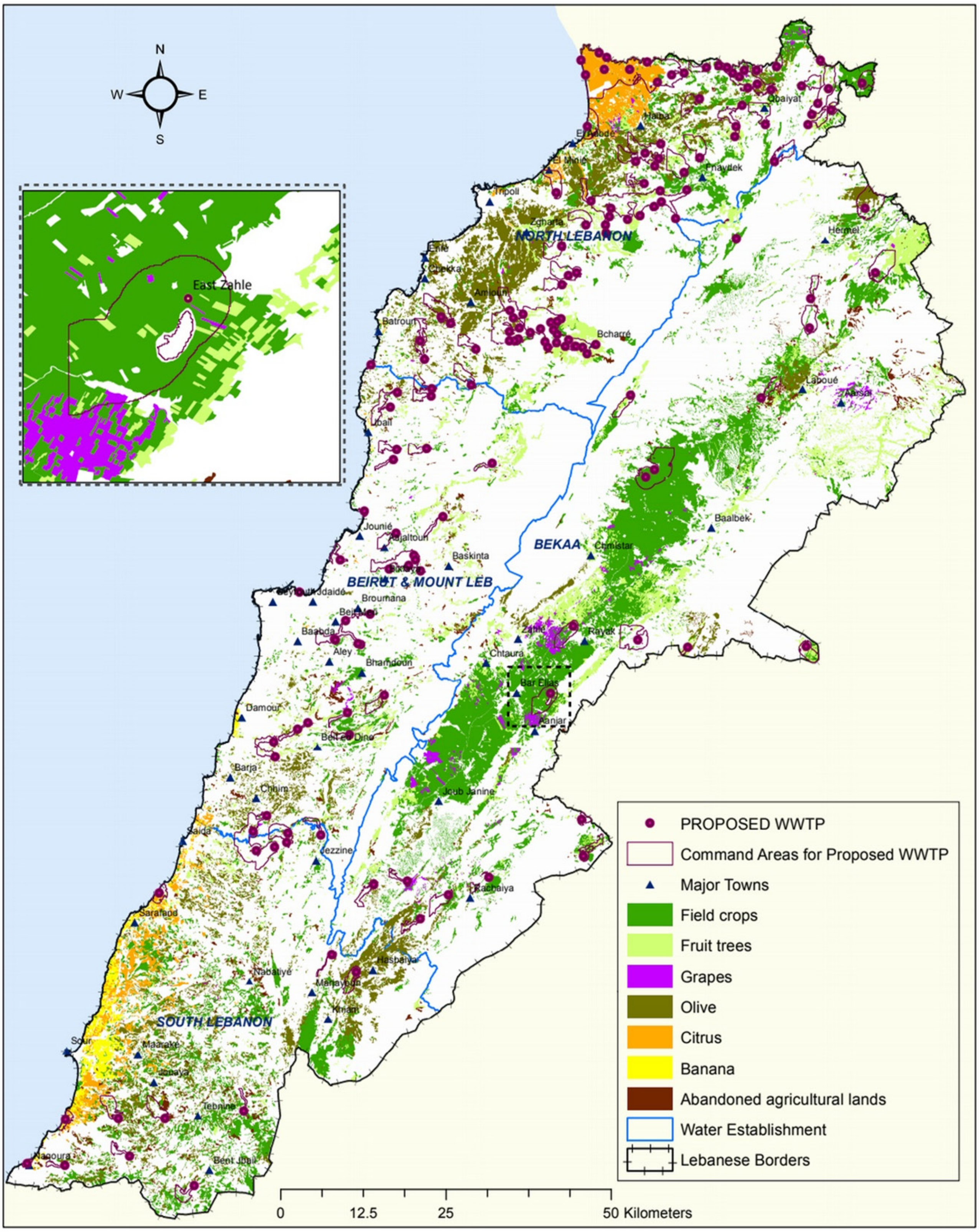

Figure A5.3. Agricultural areas in the command areas of proposed WWTPs.

Annex 6. Sample Water Quality Tests.

WWTP: Zahleh

	Unit	Result in inlet	Result in outlet	Maximum admissible limit[a]
Chemical oxygen demand (COD)	mg/L O_2	800	50	125
Biochemical oxygen demand BOD)	mg/L	450	4	25
Total suspended solids (TSS)	mg/L	500	4	35
Ammonium	mg/L NH_4	45	2	10
Total nitrogen	mg/L TNb	70	8	30
Nitrate	mg/L NO_3	4	6	90
Nitrite	mg/L NO_2	0.3	0.9	90
Total phosphorus	mg/L P	11	3	10
pH		7.5	7.1	6–9
Conductivity	$\mu S.cm^{-1}$	1,800	2,000	
Active chlorine (free Cl_2)	mg/L	0	0	1
Ultraviolet			Yes	
Total coliforms		Too numerous to count	200	0
Fecal coliforms		Too numerous to count	100	0

Note: [a] According to Decision 8/1 and tender document for water discharge in surface water sources.

WWTP: IAAT

Parameter	Unit	Result in inlet	Result in outlet	Maximum admissible limit
Chemical oxygen demand (COD)	mg/L O_2	1,200	180	125
Biochemical oxygen demand (BOD)	mg/L	500	50	25
Total suspended solids (TSS)	mg/L	350	65	50
Ammonium	mg/L NH_4	30	8	10
Total nitrogen	mg/L TNb	40	20	30
Nitrate	mg/L NO_3	2	4	90
Nitrite	mg/L NO_2	0.4	0.5	90
Total phosphorus	mg/L P	8	6	10
pH		7.5	7.3	6–9
Conductivity	$\mu S.cm^{-1}$	800	1,500	
Active chlorine (free Cl_2)	mg/L	0	0.5	1
Total coliforms		Too numerous to count	0	0
Fecal coliforms		Too numerous to count	0	0

WWTP: Tebnine (inlet)

Date			TSS mg/L	TVS mg/L	COD mg/L	BOD_5 mg/L	$N\text{-}NH_4$ mg/L $N\text{-}NH_4$	NTK mg/L N	$N\text{-}NO_3$ mg/L $N\text{-}NO_3$
2019	August	Average	402	346	702	516	49	75	22
		Maximum	607	495	895	586	52	82	45
	September	Average	328	284	588	347	42	72	14
		Maximum	397	345	655	387	46	85	23
	October	Average	373	323	621	392	43	63	15
		Maximum	505	394	770	428	45	69	18
	November	Average	323	273	565	353	48	70	15
		Maximum	431	400	755	374	50	82	22
	December	Average	289	240	534	185	43	58	5
		Maximum	463	389	740	315	50	80	8
2020	January	Average	155	124	273	36	15	26	7
		Maximum	353	252	552	70	26	38	10

WWTP: Tebnine (outlet)

Date			TSS mg/L	COD mg/L	BOD_5 mg/L	$N\text{-}NH_4$ mg/L $N\text{-}NH_4$	NTK mg/L N	$N\text{-}NO_3$ mg/L $N\text{-}NO_3$	Fecal coliforms colonies/100 mL	*E. coli*
2019	August	Average	4	31	3	0.67	2	1.6	26	
		Maximum	7	65	4	1.4	6	3.2	60	
	September	Average	3	39	3	0.32	0.6	2.2	40	
		Maximum	5	60	4	0.43	0.6	3.2	82	
	October	Average	5	32	4	0.83	2.8	2.2	64	
		Maximum	7	60	7	1.68	4.2	3.4	89	
	November	Average	3	29	1	0.84	1.7	3.4	88	79
		Maximum	5	40	1	1.26	2.4	5.6	182	86
	December	Average	3	33	1	1.23	2.6	4.1	103	67
		Maximum	4	55	1	2.24	4.2	5.8	140	99
2020	January	Average	3	30	1	0.42	1.1	5.5	53	37
		Maximum	5	49	1	0.7	1.8	8.6	114	76

Annex 7. Irrigation Potential and Potential Scores of Existing WWTPs.

Scenario		Base					High-cost				
#	WWTP	Irrigation potential (ha) per season (IP[a])	Reuse potential (ha) in command area (IP)	Reuse potential score (IP)	Irrigation potential (ha) per season (AP[b])	Reuse potential score (AP)	Irrigation potential (ha) per season (IP)	Reuse potential (ha) in command area (IP)	Reuse potential score (IP)	Irrigation potential (ha) per season (AP)	Reuse potential score (AP)
1	Akkar El-Atika	8.3	8.3	0.94	0	0	8.1	8.1	0.94	0	0
2	Aammatour	31.7	31.7	0.94	9.7	0.94	27.1	27.1	1	8.3	1
3	Ablah	44.1	44.1	0.94	28.6	0.94	43.7	43.7	0.94	28.4	0.94
4	Abou Qamha	2.7	2.7	0.94	0	0	2.8	2.8	0.94	0	0
5	Ain Horche	3.9	3.9	0.79	1.6	0.79	3.9	3.9	0.79	1.6	0.79
6	Ain Jarfa	14.3	14.3	0.79	0	0	12.7	12.7	0.94	0	0
7	Ain Qenia	32.2	32.2	0.55	0	0	34.7	34.7	0.94	0	0
8	Ainbal	121.2	86	0.4	30.3	0.4	108.6	108.6	0.94	27.2	0.94
9	Aintourine	91.9	91.9	0.79	91.9	0.4	96.3	96.3	1	96.3	0.55
10	Aitanit/ Machghara	136	84	0.94	32.6	0.94	127.4	127.4	1	30.6	0.94
11	Baadarane	12.9	12.9	1	7.1	1	13.9	13.9	1	7.7	1
12	Bakka 1	1	1	0	0	0	1	1	0	0	0
13	Bakka 2	2.6	2.6	0	0	0	2.7	2.7	0.79	0	0
14	Barouk	38.6	38.6	1	12	0.82	45.1	45.1	1	14	0.75
15	Bater	25.4	25.4	1	15.6	1	26.9	26.9	1	16.4	1
16	Bcharre	133.5	16.6	0.55	41.4	0.61	131.1	93.6	0.7	40.6	0.7
17	Bcharre wetland	0	0	0.94	0	0.94	0	0	0.94	0	0.94
18	Beino	3.2	3.2	0.79	0	0	3.3	3.3	0.94	0	0
19	Beit Menzer	0	0	0.79	0	0	0	0	0.79	0	0
20	Berti	7.4	7.4	0.94	7.4	0.94	7.1	7.1	0.94	7.1	0.94
21	Bourj Rahal	6	6	1	4.8	1	6.2	6.2	1	5	1
22	Bqerzla	20.6	20.6	0.69	0	0	18.2	18.2	0.69	0	0
23	Bteddine El-Lekche	12	12	0.94	3.7	0.67	12.1	12.1	0.94	3.8	0.55
24	Chabriha	691	542.5	0.75	326.3	0.57	697.1	697.1	0.75	329.2	0.57
25	Charbila	6.3	6.3	0	2	0	5.8	5.8	0.94	1.8	0.55
26	Charqiye	308.7	8.2	0.69	141.6	0.69	260.6	184.9	0.69	119.5	0.69
27	Chebaa	19.3	8.3	0.7	0	0	29.4	29.4	0.94	0	0
28	Chekka	69.3	68.5	0.4	0	0	67.7	67.7	0.79	0	0
29	Chouaya	1.4	1.4	0.94	0	0	1.6	1.6	0.94	0	0
30	Dahr Er Ramli	0	0	0.94	0	0	0	0	0.94	0	0

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#	WWTP	Irrigation potential (ha) per season (IP[a])	Reuse potential (ha) in command area (IP)	Reuse potential score (IP)	Irrigation potential (ha) per season (AP[b])	Reuse potential score (AP)	Irrigation potential (ha) per season (IP)	Reuse potential (ha) in command area (IP)	Reuse potential score (IP)	Irrigation potential (ha) per season (AP)	Reuse potential score (AP)
31	Daoura	52.2	52.2	0.55	0	0	34	34	0.94	0	0
32	Deir El-Ahmar	10	10	0.55	0	0	10.3	10.3	0.55	0	0
33	Deir Mimas	6.8	6.8	1	6.8	1	5.7	5.7	1	5.7	1
34	Dibbine	15.2	15.2	0.94	0	0	17.3	17.3	0.94	0	0
35	El Aakabe	16.1	16.1	0.85	5	0.67	14.7	14.7	0.85	4.6	0.6
36	El Aichye	4.8	4.8	0.94	0	0	4.1	4.1	0.94	0	0
37	El Jdeide	43.4	43.4	0.94	3.9	0.94	42.9	42.9	1	3.8	1
38	El Meri	5.8	5.8	0.7	0	0	5.3	5.3	0.94	0	0
39	Fardis	3.8	3.8	0.94	0	0	3.8	3.8	0.94	0	0
40	Fourzol	21.3	21.3	0.94	21.3	0.94	21.3	21.3	0.94	21.3	0.94
41	Ghabbatiyeh	6.4	6.4	0.94	0	0	7.1	7.1	0.94	0	0
42	Ghadir	0	0	0	0	0	0	0	0	0	0
43	Gharifeh	60	60	0.55	18.6	0.7	50.5	50.5	0.94	15.6	0.94
44	Halta	3	3	0.7	0	0	2.9	2.9	0.94	0	0
45	Hammana	31.1	31.1	0.7	19.5	0.7	31.2	31.2	0.7	19.5	0.94
46	Haouch El Qinnabeh	4.4	4.4	0.55	1.4	0.52	3.6	3.6	0.79	1.1	0.4
47	Hasbaya	0	0	0.79	0	0.52	0	0	0.94	0	0.55
48	Haytoura	2.4	2.4	0.94	0.7	0.94	2.5	2.5	0.94	0.8	0.94
49	Hebbariyeh	36	36	0.85	11.2	0.85	31.7	31.7	1	9.8	1
50	Hmaira	7.1	7.1	0.94	3.6	0.67	6.8	6.8	0.94	3.4	0.55
51	Hnaider	7.9	7.9	0.79	0	0	7.9	7.9	0.79	0	0
52	Iaat	458.5	458.5	0.69	95.5	0.23	500.3	500.3	0.69	104.2	0.23
53	Ijbaa	86.8	86.8	0.94	86.8	0.67	87.5	87.5	0.94	87.5	0.55
54	Jabboule	2	2	1	0.6	0.94	2	2	1	0.6	0.94
55	Jbaa	36.6	36.6	0.69	0	0	33.4	33.4	0.69	0	0
56	JbaaEch-Chouf	7.4	7.4	1	5.8	1	7.3	7.3	1	5.7	1
57	Jbeil	211	14.2	0.69	65.4	0.53	195.7	45.6	0.69	60.7	0.53
58	Jebrayel	4.4	4.4	0.94	0	0	4	4	0.94	0	0
59	Joub Janine	231.5	231.5	0.69	138.9	0.45	216.3	216.3	0.75	129.8	0.69
60	Kawkaba	4.2	4.2	0.94	4.2	0.67	4.4	4.4	0.94	4.4	0.55
61	Kfar Fila	20.7	20.7	0.55	0	0	17.6	17.6	0.94	0	0
62	KfarHamam	3.9	3.9	0.85	0	0	3.4	3.4	1	0	0
63	Kfar Sir	21.2	0	0.94	6.6	0.78	41.5	41.5	1	12.8	0.75
64	Kfarqatra	6.4	6.4	0.79	2.3	0.79	7.1	7.1	0.79	2.6	0.79

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#	WWTP	Irrigation potential (ha) per season (IP[a])	Reuse potential (ha) in command area (IP)	Reuse potential score (IP)	Irrigation potential (ha) per season (AP[b])	Reuse potential score (AP)	Irrigation potential (ha) per season (IP)	Reuse potential (ha) in command area (IP)	Reuse potential score (IP)	Irrigation potential (ha) per season (AP)	Reuse potential score (AP)
65	Kfeir	12.1	12.1	0.55	3.8	0.52	14.2	14.2	0.94	4.4	0.55
66	Khiam	136	136	0.55	0	0	159.7	159.7	0.94	0	0
67	Khreibet Ech-Chouf (El Khreibe)	18	18	0.94	5.6	0.94	15.2	15.2	1	4.7	1
68	Knaisse 1	9.3	9.3	0.4	2.9	0.4	9.5	9.5	0.79	3	0.79
69	Knaisse 2	9.2	9.2	0.4	2.9	0.4	9.5	9.5	0.79	3	0.79
70	Maasser Ech-Chouf	11.6	11.6	1	2.6	1	12.8	12.8	1	2.8	1
71	Majdala	3.4	3.4	0.94	0	0	3.2	3.2	0.94	0	0
72	Majdel Anjar/ El Marj	933.9	933.9	0.54	289.5	0.38	925.6	925.6	0.54	286.9	0.38
73	Marj Ez-Zouhour	4.7	4.7	0.79	0	0	4.2	4.2	0.94	0	0
74	Marjayoun	0	0	0.94	0	0	0	0	0.94	0	0
75	Mazraat Balde	0	0	0.79	0	0	0	0	0.94	0	0
76	Mimes 2	4.7	4.7	0.55	1.5	0.55	3.7	3.7	0.94	1.1	0.55
77	Moukhtara	14.7	14.7	0.94	5.7	0.94	13.8	13.8	1	5.4	1
78	Mristi	7.7	7.7	1	3.1	1	7.1	7.1	1	2.8	1
79	Nabaa El Safa & Aain Zhalta	71.1	71.1	0.94	22	0.78	69.8	69.8	0.94	21.6	0.7
80	Jiyeh (Nabi Younes)	0	0	0.75	0	0.45	344.7	10.9	0.69	106.9	0.42
81	Qaytoule	24.2	24.2	0.94	7.5	0.67	24	24	0.94	7.4	0.55
82	Qbaiyat Akkar El Gharbie (Andket)	39.4	39.4	0.7	12.2	0.94	34.9	34.9	0.94	10.8	0.94
83	Qornayel	26.3	24.9	0.79	0	0	24.7	24.7	0.79	0	0
84	Rachaiya	16.3	16.3	0.4	5.1	0.55	16	16	0.79	4.9	0.79
85	Rahbe	8.6	8.6	0.94	0	0	8.4	8.4	0.94	0	0
86	Rihane (Jezzine)	14.4	2.4	0.94	4.5	0.67	17.3	17.3	1	5.4	0.58
87	Rimhala	0	0	0.79	0	0.79	0	0	0.79	0	0.79
88	Saghbine	14	14	1	2.5	1	12.9	12.9	1	2.3	1
89	Batroun	0	0	0.85	0	0.85	56.1	2	0.79	56.1	0.79
90	Sayniq	1,360.1	218.6	0.3	0	0	1,466.8	399.9	0.3	0	0
91	Snaya	1.5	1.5	0.94	0.5	0.67	1.7	1.7	0.94	0.5	0.55
92	Tebnine	77.1	51.3	0.94	23.9	0.94	84.7	84.7	1	26.3	1
93	Tripoli	3,011.4	166.3	0.69	0	0	3,036.2	206.3	0.69	0	0
94	Wadi Jezzine	5.2	5.2	0.94	0	0	4.5	4.5	0.94	0	0
95	Wazzani	0.9	0.9	0.94	0	0	0.9	0.9	0.94	0	0
96	Yammouneh	0	0	0.94	0	0	16.8	16.8	0.94	0	0

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#	WWTP	Irrigation potential (ha) per season (IP[a])	Reuse potential (ha) in command area (IP)	Reuse potential score (IP)	Irrigation potential (ha) per season (AP[b])	Reuse potential score (AP)	Irrigation potential (ha) per season (IP)	Reuse potential (ha) in command area (IP)	Reuse potential score (IP)	Irrigation potential (ha) per season (AP)	Reuse potential score (AP)
97	Yanta 1 (Northern)	5.1	5.1	0.79	1.3	0.52	4.5	4.5	0.79	1.1	0.4
98	Yanta 2 (Southern)	4.9	4.9	0	0.8	0	5.1	5.1	0.79	0.8	0.4
99	Yohmor En Nabatiyeh	16.9	16.9	0.94	6.7	0.94	14.6	14.6	1	5.8	1
100	Zahleh	738.1	738.1	0.69	527.2	0.69	738.6	738.6	0.69	527.5	0.69
101	Zaoutar Ech-Charqiye	10.9	10.9	1	3.9	1	11.6	11.6	1	4.1	1
102	Araya	9.5	9.5	0.79	9.5	0.79	9.7	9.7	0.79	9.7	0.79
103	Qasmiyeh 1	0.9	0.9	0.94	0.9	0.94	0.9	0.9	0.94	0.9	0.94
104	Qasmiyeh 2	2	2	0.94	2	0.94	2	2	0.94	2	0.94

Notes: [a] IP = Ideal potential.

[b] AP = Actual potential.

Annex 8. Results for Proposed WWTPs.

WWTP	#	Capacity (m^3/day)	Irrigation potential (ha) per season (IP[a])	Potential area in command area (ha)	Reuse potential score
Wadi Faara	1	275	5.4	5.4	0.93
El Mdaouich	2	858	23.8	5.1	0.93
El Boustane	3	849	15	12.4	0
Sahel Hermel	4	2,500	60.8	60.8	0.65
Al-QaWadi El-Khanzir	5	4,917	100.7	100.7	0.93
Al-Fakiat	6	17,296	314.2	66.1	0.48
Harbta	7	11,893	276.1	252.8	0.48
Ainata	8	618	14.7	14.7	0.93
Chlifa	9	0	0	0	1
Chlifa	10	4,220	81	81	0.48
Maaraboun	11	895	26.8	26.8	1
Jenta	12	512	9.6	9.6	0.93
Tamnine El-Tahta	13	50,000	1,099	609.3	0.48
Tfeil	14	268	5.8	5.8	0.63
Bizhel	15	1,550	0	0	1
Mayrouba	16	5,148	149.2	7.1	0.48
Ghazir	17	48,000	0	0	0.63
Aachqout	18	4,477	99.1	6.5	0.18
Zouk Mousbeh	19	42,000	792	17.1	0
Ras El Matn	20	17,400	0	0	0.63
Aabadiyé	21	5,090	96.2	7.7	0.63
Aabadiyé	22	13,000	245.1	6.8	0
Hlaliyé Baabda	23	17,400	0	0	0.63
Charoun	24	2,253	74.1	74.1	0.63
Chaqra	25	1,300	22	3.9	0
Yaroun	26	6,396	129.9	123.2	0.93
Chourit	27	13,000	258.1	4.2	0.18
litige	28	10,200	343.5	1.8	0.18
Bchtfine	29	9,152	277.6	3.5	0.18
Faouarat Jaafar	30	2,353	62.7	48.2	0.48
Deir Baba	31	2,464	73.8	19.4	0.48
BenouatiEch-Chouf	32	10,780	302.6	35.5	0.48
Qreiaa	33	700	23.3	23.3	0.63
DeirEl-MoukhallesEch-Chouf	34	118	3.6	3.6	0.93
Hasbaiya	35	12,442	379.7	375.5	0.93
Zabbougha	36	2,000	38.1	0.5	0
Zabbougha	37	2,000	43.3	5.4	0.93
Mar Boutros Karm Et-Tine	38	5,681	107.8	5	0
Abou Mizane	39	1,018	0	0	0.63
Bteghrine	40	8,432	195.6	4.7	0.18
Aayoun El-Matn	41	9,500	0	0	0.63
Beit Meri	42	4,700	0	0	0
Tartij	43	402	12.4	12.4	0.63
Kharbet Jbayl	44	1,480	56.1	55.8	0.35

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WWTP	#	Capacity (m³/day)	Irrigation potential (ha) per season (IP[a])	Potential area in command area (ha)	Reuse potential score
Ghalboun	45	1,875	51.4	26	0.18
Haqel	46	111	3	3	0.63
KfarMashoun	47	985	28.2	28.2	0.93
Ferhet	48	2,185	53.5	50.8	0.63
ZibdineEn-Nabatiyeh	49	635	12	1	0.93
Lassa	50	0	0	0	0.93
Bisri	51	270	7.9	7.9	0.93
Aazour	52	158	4.9	4.9	1
Roum	53	616	19.6	17.1	0.48
Sfaray	54	402	9.9	9.9	1
Srayri	55	2,000	0	0	0.93
Kfar Qouq	56	1,243	32.4	32.4	0.63
Deir El-Aachayer	57	203	3.9	3.9	0.63
Kfar Lichki	58	482	9.4	9.4	0.63
Aaqabet Rachaya	59	12,182	381.6	54.7	0.63
Haouch El Qinnabé Rachaiya	60	5,011	221.4	43.9	0
Ghaziyé	61	40,221	764.6	172.4	0.48
Bourj Hammoud	62	325,000	0	0	0.7
Bhannine	63	3,920	102.8	47.9	0.93
Aslout	64	593	13.2	13.2	0.63
Arbet Koshaya	65	672	18.8	18.8	0.93
Kfarsghab	66	587	19.7	11.3	0.65
East Zahleh	67	0	0	0	1
Sohmor	68	2,000	88.6	32.3	0.48
Kaftoune	69	3,266	158.4	158.4	0.18
Btaaboura	70	191	7.7	7.7	0.7
Behouaita	71	116	2.5	2.5	0.63
Bchernata	72	132	3.4	3.4	0.63
Izal	73	1,258	33.1	33.1	0.63
Qattine	74	8,988	274.1	84.9	0.48
Tarane	75	993	36.9	36.9	0.93
Beit Zoud	76	199	6.9	6.9	0.93
Beit Haouik	77	414	12.4	12.4	1
Qemmamine	78	215	4.9	4.9	1
Btoumaz	79	3,413	129.1	129.1	0.65
Beit Haouik	80	1,474	38.4	38.4	0.93
Btoumaz	81	545	22	22	0.93
Jairoun	82	248	6.2	6.2	0.63
Qarn	83	80	2	2	0.93
Azqey	84	83	2.7	2.7	0.93
Terbol	85	72	1.9	1.9	0.93
Abdine	86	7,680	362.9	93.4	0.63
Knate	87	624	18.1	18.1	0.63
Beit Menzer	88	432	11.6	11.6	0.63
Hadeth-el-Jebbé	89	1,728	36.9	36.9	0.48
Brissat	90	240	5.3	5.3	0.93

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WWTP	#	Capacity (m³/day)	Irrigation potential (ha) per season (IP[a])	Potential area in command area (ha)	Reuse potential score
Mazraet-Beni-Saab	91	312	13.9	13.9	0.63
Mazraet Assaf	92	240	10.8	10.8	0.7
Billa	93	312	15.9	15.9	0.63
Bane	94	504	13.7	13.7	0.93
Hasroune	95	2,592	69.7	69.7	0.93
Bazoune	96	1,128	29.7	29.7	0.93
Bkarkacha	97	1,272	34.6	34.6	0.93
Bikaakafra	98	1,680	45.9	45.9	0.93
Berhalioun	99	720	35.6	35.6	0.63
El-Dimane	100	768	19	19	1
Blaouza	101	312	7.7	7.7	1
Hadchite	102	2,208	55	25.9	0.48
Bcharré	103	9,700	259.2	23.1	0.48
Mugher-el-Ahwel	104	432	20.1	20.1	0.35
Blaouza	105	672	15.9	15.9	0.93
Hasroune	106	384	9.9	9.9	0.93
Knaiouer	107	384	10	10	0.93
Tourza	108	1,493	64.2	45.5	0.18
Thoum	109	6,660	389.5	14.8	0
KfarHalda	110	3,525	126.7	28.1	0.48
Kour	111	2,146	93.9	15.5	0.18
Chabtine	112	1,040	49.1	49.1	0.18
Harare	113	1,432	35	35	0.63
Michmiche	114	8,043	146	10.1	0
Habchite	115	584	30.4	30.4	0
El-Krayat	116	508	11.2	11.2	0.93
Chane	117	1,083	29.1	29.1	0.63
Danbou	118	6,769	197	197	0.18
El-Houaïche	119	660	19.4	19.4	0.93
Mimnih	120	575	14.4	14.4	0.63
El-Houaïche	121	396	11.4	11.4	0.93
Jebrâil	122	17,275	564	26.8	0.48
Akkar El-Atika	123	3,411	94.8	78.5	0.65
Kobbet Bchamra	124	39,010	871.1	455.3	0.48
Akkar El-Atika	125	4,264	128.2	52.2	0.48
El-Koubayet	126	338	7.9	7.9	0.93
Akroum	127	965	20.9	20.9	0.63
Akroum	128	965	23.3	23.3	0.63
Akroum	129	1,015	19.8	19.8	0.63
Sindianet Zeidan	130	5,847	160.1	14.1	0.48
Akroum	131	1,157	27.8	27.8	0.93
Douair Adouiyé	132	2,858	91.1	91.1	0.35
Mazraet-El-Nahrieh	133	626	18.7	18.7	0.93
Akroum	134	406	9.9	9.9	0.93
El-Bardé	135	102	2.4	2.4	0.93
Akroum	136	534	10.4	10.4	0.93

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WWTP	#	Capacity (m^3/day)	Irrigation potential (ha) per season (IP[a])	Potential area in command area (ha)	Reuse potential score
Mazraet-El-Nahrieh	137	372	9.2	9.2	0.93
Hnaïder	138	1,316	26.4	26.4	0.63
Deirine	139	435	10.7	10.7	0.93
Mounjez	140	508	10.7	10.7	0.93
Cheikh Zennad Tal Bibé	141	1,361	36.1	36.1	0.93
Srar	142	34	0.8	0.8	0.93
Freidice	143	306	6	6	0.93
Kachlak	144	575	11.2	11.2	0.65
Chikhlar	145	203	4.8	4.8	0.93
Kfarnoune	146	406	9.2	9.2	0.93
Al-Kneissé	147	1,394	38.4	38.4	0.93
Tal Biré	148	1,185	32.1	32.1	0.93
Noura El-Faouka et Tahta	149	579	11.1	11.1	0.65
Freidice	150	220	4.3	4.3	0.65
Aaouainat	151	406	8.6	8.6	0.93
Dabbabiyé Charkié	152	220	4.5	4.5	0.93
Cheir Homeirine	153	5,850	141.5	141.5	0.93
Arida	154	512	13.4	13.4	0.93
Ouadi Khaled	155	8,878	209.4	64.5	0.48
Hekrel Dahiri	156	981	27.5	27.5	0.93
Al-Semmakié	157	970	27	27	0.93
Kafra Bent Jbeil	158		0	0	0.63
Helouet Rachaya	159		0	0	0.63
Salhani	160	11,000	557.2	7.5	0
Jabal El-Botm	161	1,500	32.7	32.7	0.93
Mansouri Sour	162	3,500	66	66	0.93
BorjEn-Naqoura	163	1,500	28	22	0.63
Jimjim	164	4,500	69.7	3.2	0.48

Note: [a] IP = Ideal potential.

Annex 9. Case Studies.

A. Case Study: Ablah WWTP

Characteristics of Ablah WWTP	
Location	On the right bank of Litani River (Figure A9.1), in the Ablah agricultural plain (Figure A9.2)
Design capacity	2,000 m^3/day
Actual average daily flow	1,200–1,500 m^3/day[79]
Treatment technologies	Secondary treatment: Trickling filters; chlorine treatment
Level of treatment	Secondary
Effluent quality	Category 2 according to Lebanese guidelines (FAO 2010)
Effluent discharge location	Litani River
Operation interval	2012–present
Managing institution(s)	Ablah Municipality
O&M expenditure	USD 50,000 per year[80]
Problems	Needs laboratory equipment

Potential for Water Reuse in Irrigation		
Villages included in WWTP command area	Ablah and Fourzol (Figure A9.3)	
Number of farmers	100 (in Ablah)	
Actual reuse potential area	Lower cost scenario	28.6 ha
	Higher cost scenario	28.4 ha
Ideal reuse potential area	Lower cost scenario	44.1 ha
	Higher cost scenario	43.7 ha
Actual reuse potential score	Lower cost scenario	0.94
	Higher cost scenario	0.94
Ideal reuse potential score	Lower cost scenario	0.94
	Higher cost scenario	0.94
Existing agriculture and main crops	Fruit trees (96%), mainly vineyards with some vegetables (Figure A9.4)	
Existing irrigation systems	The main water source is groundwater. Individual pumping from the Litani River used to be practiced but has almost stopped. Private wells with low yields (1-5 L/s) generally used individually. Several wells can be found in one small plot	
Irrigation governance and water rights	Private, mostly individual management of wells. The government (BWE) does not have a role in irrigation management on the ground but is planning a future role in conformity with Law 221.	
Existing water reuse practices (informal reuse)	A collective reuse irrigation system was built in 2014. It serves an area of 20 ha and benefits about 35 farmers. Water is distributed to plots through a pressure network. Drippers are used on the plots. This system operated only for a year and stopped because of a complaint from a resident whose house was next to the storage reservoir. Currently, only 4 farmers use the treated effluent through a direct connection to the WWTP facilitated by the operator.	

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[79] Interview, chief operator of Zahleh WWTP, April 2019.
[80] According to the mayor of Ablah.

Opportunities and obstacles to organized reuse	Opportunities	Obstacles
	• High potential for reuse because of effluent quality, crop types and sustainable management and governance of the treatment and reuse system. • Ablah Municipality ready to manage the system. No conflict with Fourzol even if Fourzol could technically benefit from effluent. • Reuse would reduce the cost of pumping from wells, and alleviate pressure on groundwater • If farmers are willing to pay, reuse could contribute to the cost of treatment.	• The legal conflict between Ablah Municipality and the complaining resident constrains the use of the system. • Absence of a formal wastewater regulatory framework. • The WWTP is also 'informally' managed by Ablah WWTP. By law, it should be under the responsibility of the BWE.

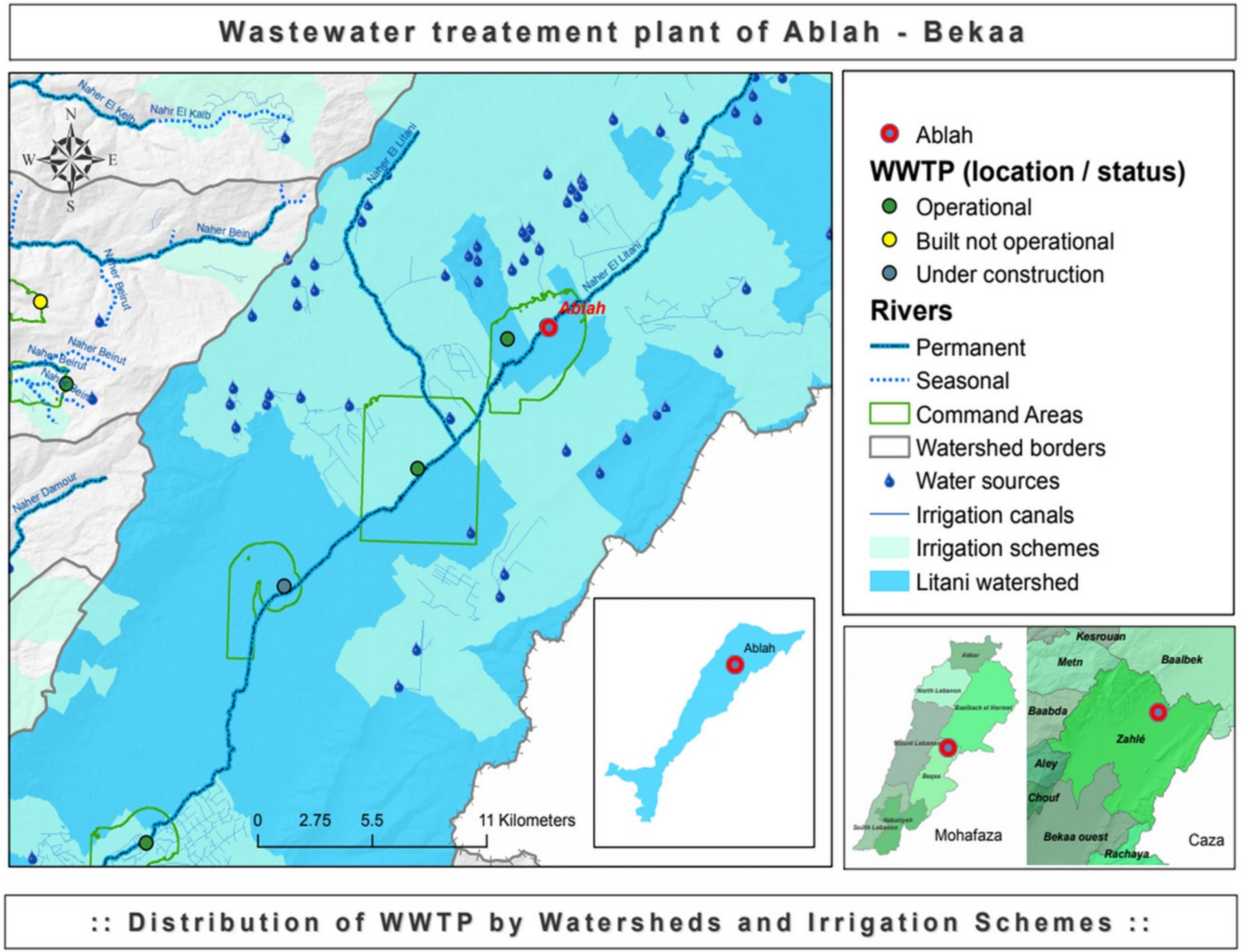

Figure A9.1. Location of the Ablah WWTP.

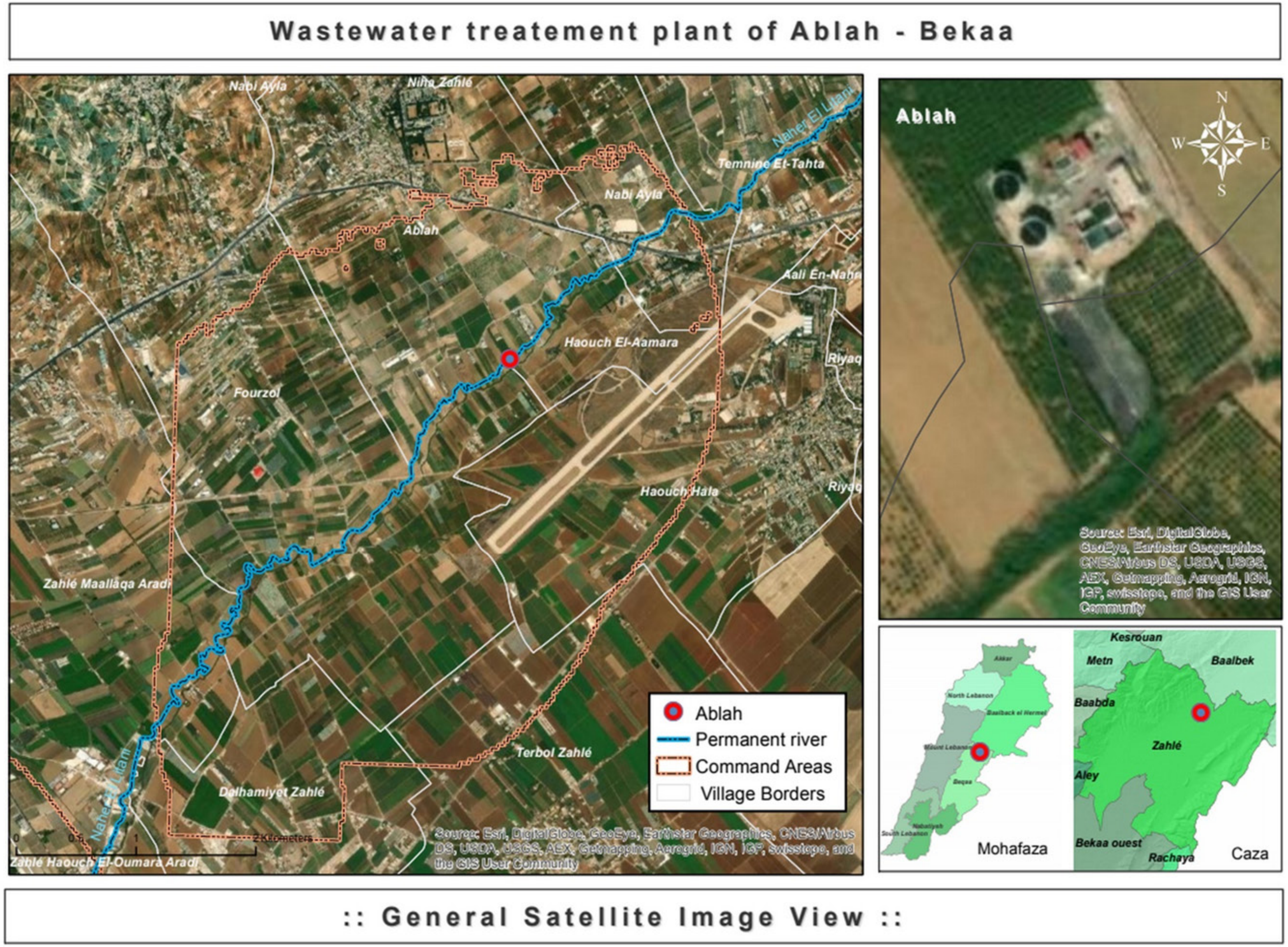

Figure A9.2. Satellite view of the Ablah WWTP command area.

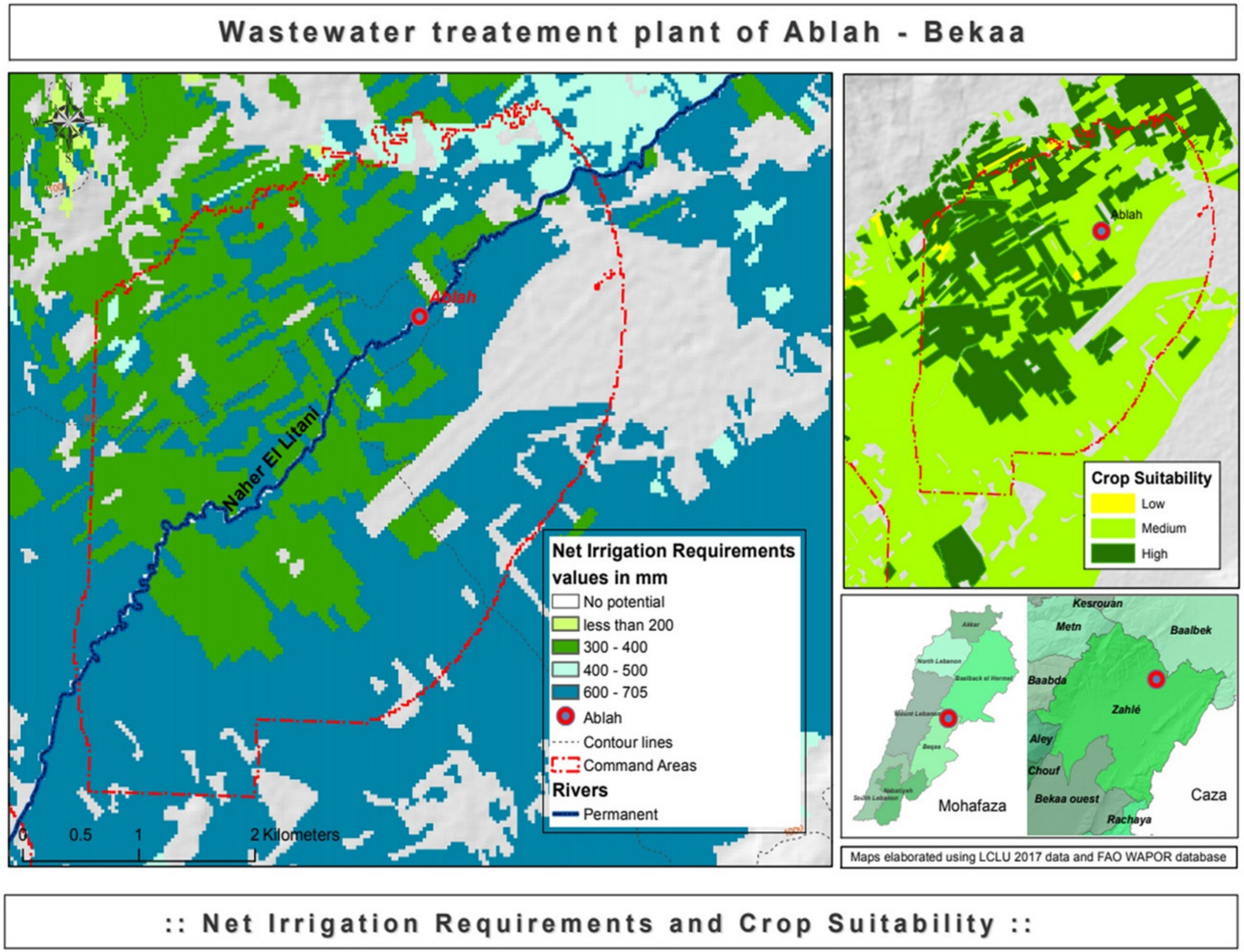

Figure A9.3. Net irrigation requirement map of the Ablah WWTP.

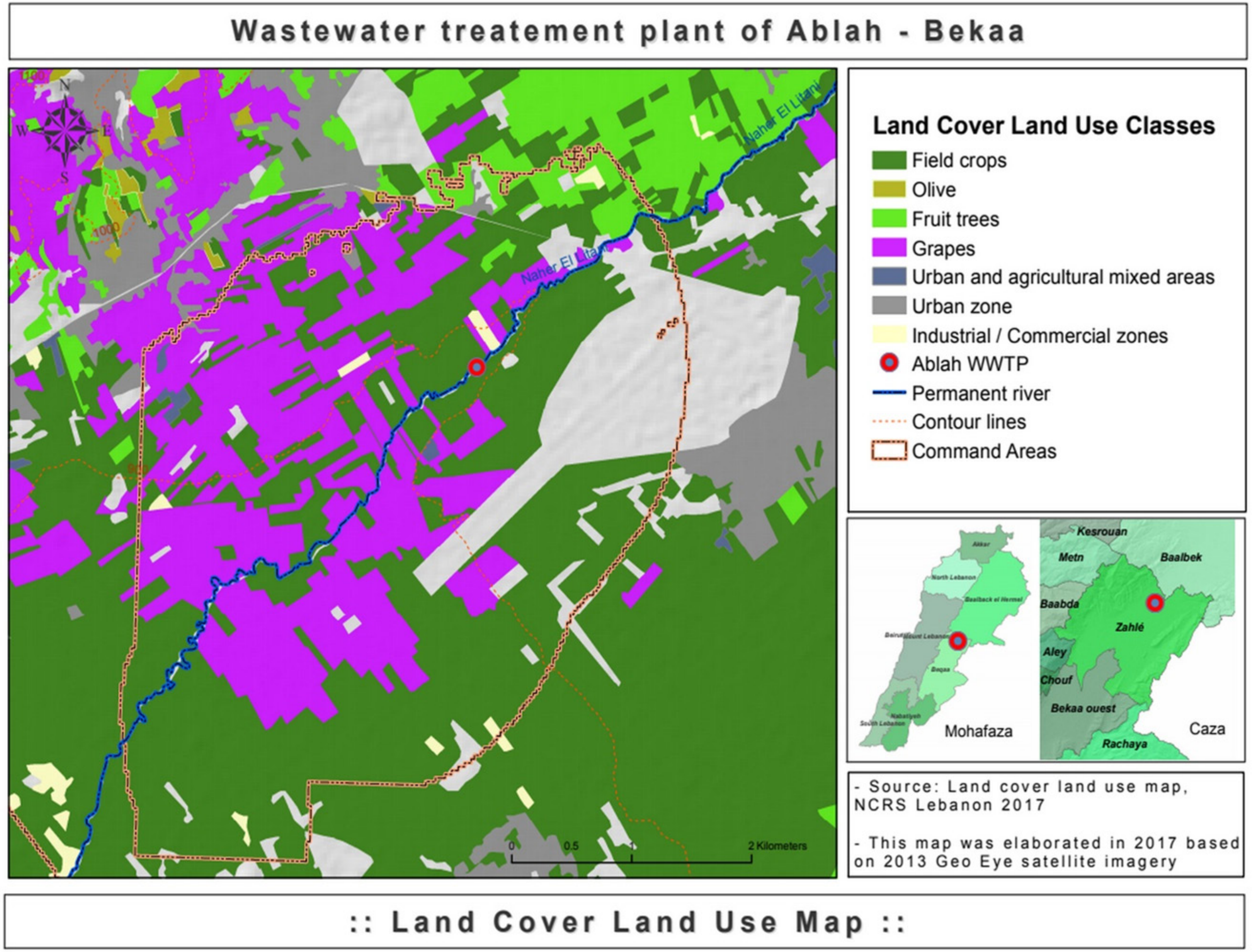

Figure A9.4. LULC map of the vicinity of Ablah WWTP.

B. Case Study: Zahleh WWTP

Characteristics of Zahleh WWTP	
Location	Zahleh, Haouch El Oumara region (Figure A9.5) On the right bank of the Litani River, in the Zahleh agricultural plain, on the frontier of Barr Elias (Figure A9.6)
Operational status	Fully operational
Design capacity	35,000 m^3/day Phase 1: 37,000 m^3/day (implemented) Phase 2: 56,000 m^3/day (planned for 2030)
Actual average daily flow	25,000–28,000 m^3/day[81]
Treatment technologies	Secondary treatment: Activated sludge with biological nitrogen removal. Tertiary treatment: UV technology (operational)
Level of treatment	Tertiary
Effluent quality	Category 1 according to Lebanese guidelines (FAO 2010)
Effluent discharge location	Litani River
Operation interval	October 2017–present
Managing institution(s)	CDR through build-operate-transfer (BOT) contract with SUEZ company. Management was to be transferred to BWE after the end of contract but this has been delayed.
O&M expenditure	Not available
Problems	Serious sludge disposal problem. O&M costs exceeding the capacity of BWE to recover costs.

Potential for Water Reuse in Irrigation		
Villages included in the WWTP command area	Zahleh and Barr Elias (Figure A9.7).	
Number of farmers	400-500	
Actual reuse potential area	Lower cost scenario	572.2 ha
	Higher cost scenario	572.5 ha
Actual reuse potential score	Lower cost scenario	0.69
	Higher cost scenario	0.69
Ideal reuse potential area	Lower cost scenario	738.1 ha
	Higher cost scenario	738. 6 ha
Ideal reuse potential score	Lower cost scenario	0.69
	Higher cost scenario	0.69
Existing agriculture and main crops	Wheat and potato and summer vegetables (tomato, leafy vegetables, onion, garlic, beans and fava beans and others) (Figure A9.8). Alternation on the same plot: Between wheat/potato; potato/potato; wheat/summer vegetables; potato/summer vegetables; wheat/fallow Fruit trees (apple, peach, pear, kaki, almond and others): 8% in Zahleh and 2% in Barr Elias	

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[81] Interview, Chief Operator of Zahleh WWTP, April 2019.

Existing irrigation systems	Diversity of irrigation systems: • 1 collective open canal network supplied by the Berdaouni River (Zahleh) • Collective highly productive wells (40 L/s) in karstic aquifers supplying large plots through double pumping via pipes and ditches (Zahleh) • Individual wells giving medium yields (5-10 L/s) located in quaternary aquifers and supplying medium plots (Zahleh) • Collective pumps on the Ghozayel River supplying large plots through double pumping via pipes and ditches (Barr Elias) • Individual pumps on the Litani supplying medium plots (Barr Elias)	
Irrigation governance and water rights	• Government (BWE) does not have a role in irrigation management on the ground but is planning a future role in accordance with Law 221. • Irrigation systems are chiefly managed by the local communities following customary water rights (legalized) and community arrangements (informal). • The Berdaouni system is managed by the Berdaouni Irrigation Committee supported by the Zahleh Municipality. • Collective wells and pumps are managed following water/land-use arrangements.	
Existing water reuse practices (informal reuse)	There is indirect reuse from the Litani River by farmers in Zahleh and Barr Elias downstream of the WWTP to supplement pumping from wells and the Litani River.	
Obstacles and opportunities to organized reuse	Opportunities	Obstacles
	• Large volume of exceptionally good quality water would allow complementing the use of declining water sources and reduce pressure on groundwater. • Farmers already use the treated water downstream to irrigate vegetables which means that there won't be an issue of social acceptability.	• The financial sustainability of operating Zahleh WWTP is not ensured. • Absence of a formal wastewater regulatory framework (water allocation, management and governance of reuse system, cost-recovery mechanisms, etc.). • Many irrigation systems and water rights exist in the command area. This complicates the design and future management of a reuse system (who should benefit from the system? Who should manage it?)

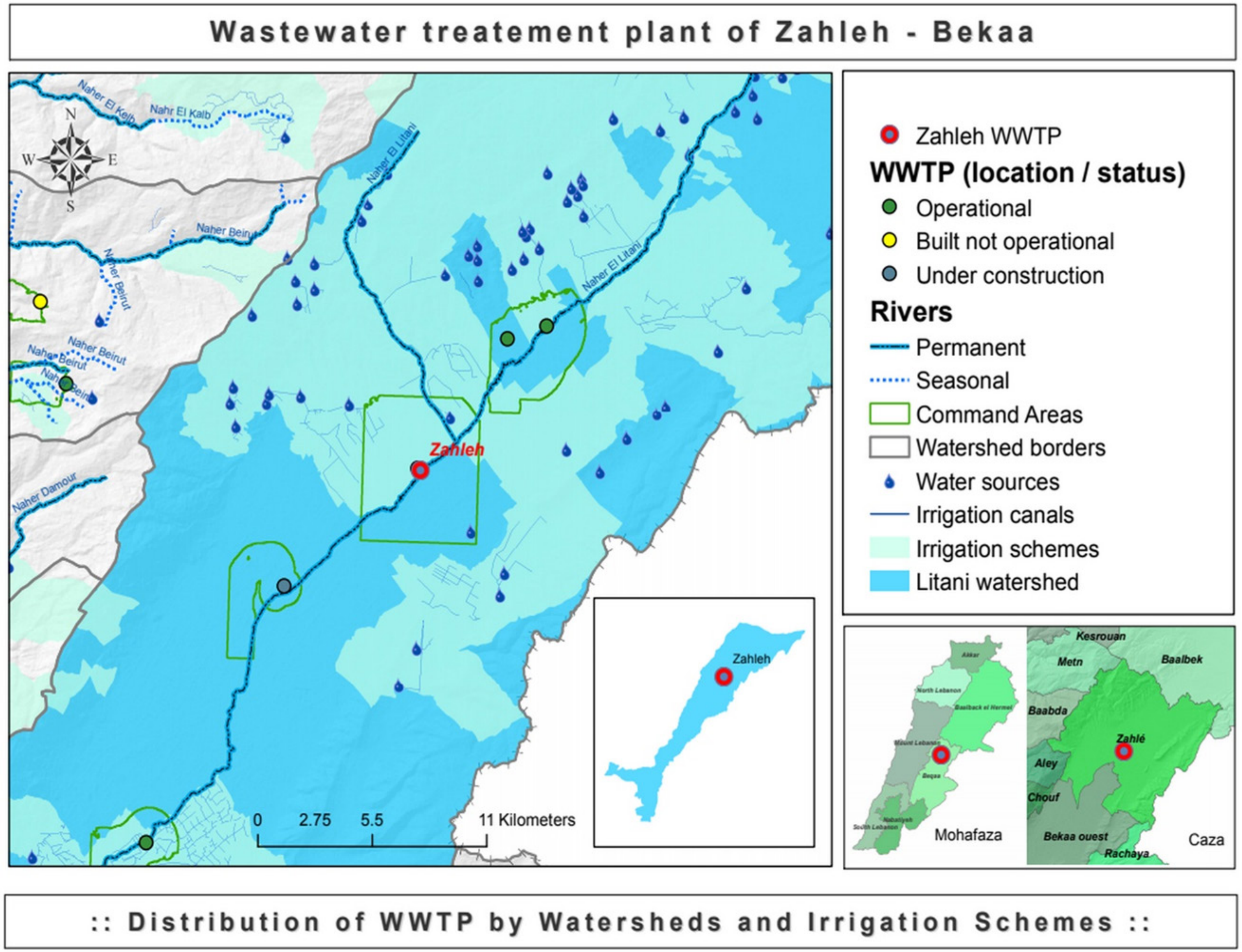

Figure A9.5. Location of the Zahleh WWTP.

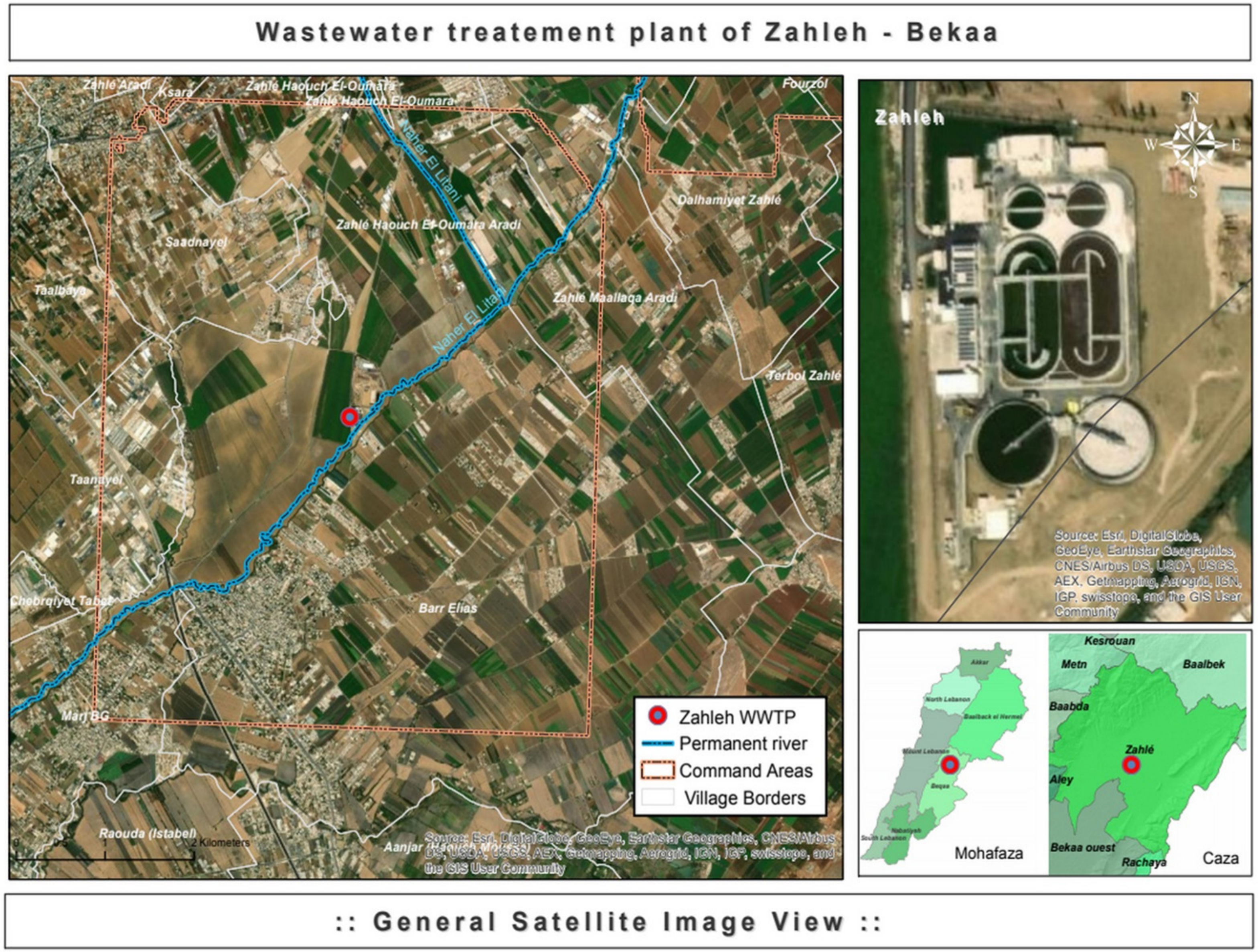

Figure A9.6. Satellite view of the Zahleh WWTP command area.

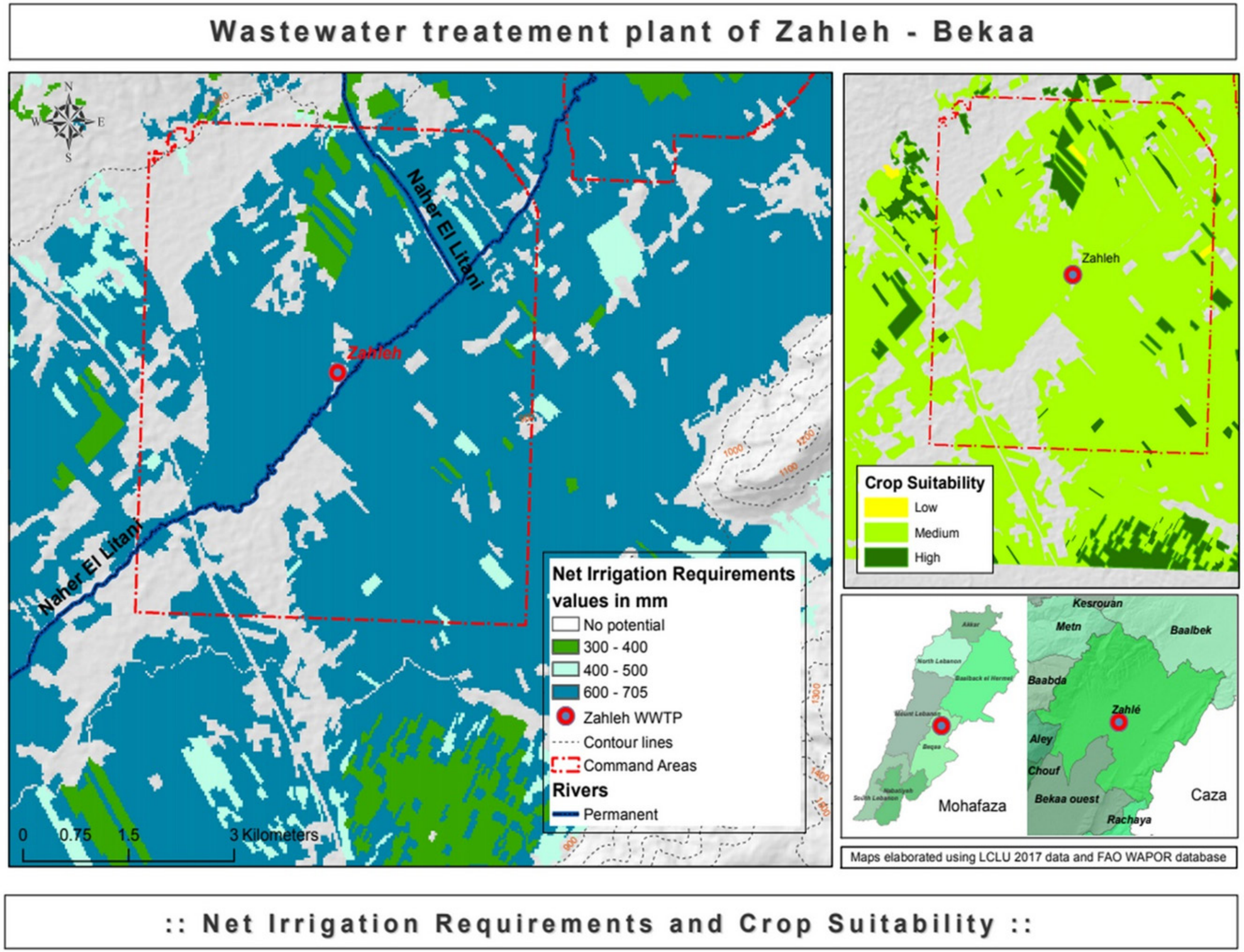

Figure A9.7. The net irrigation requirement of the Zahleh WWTP.

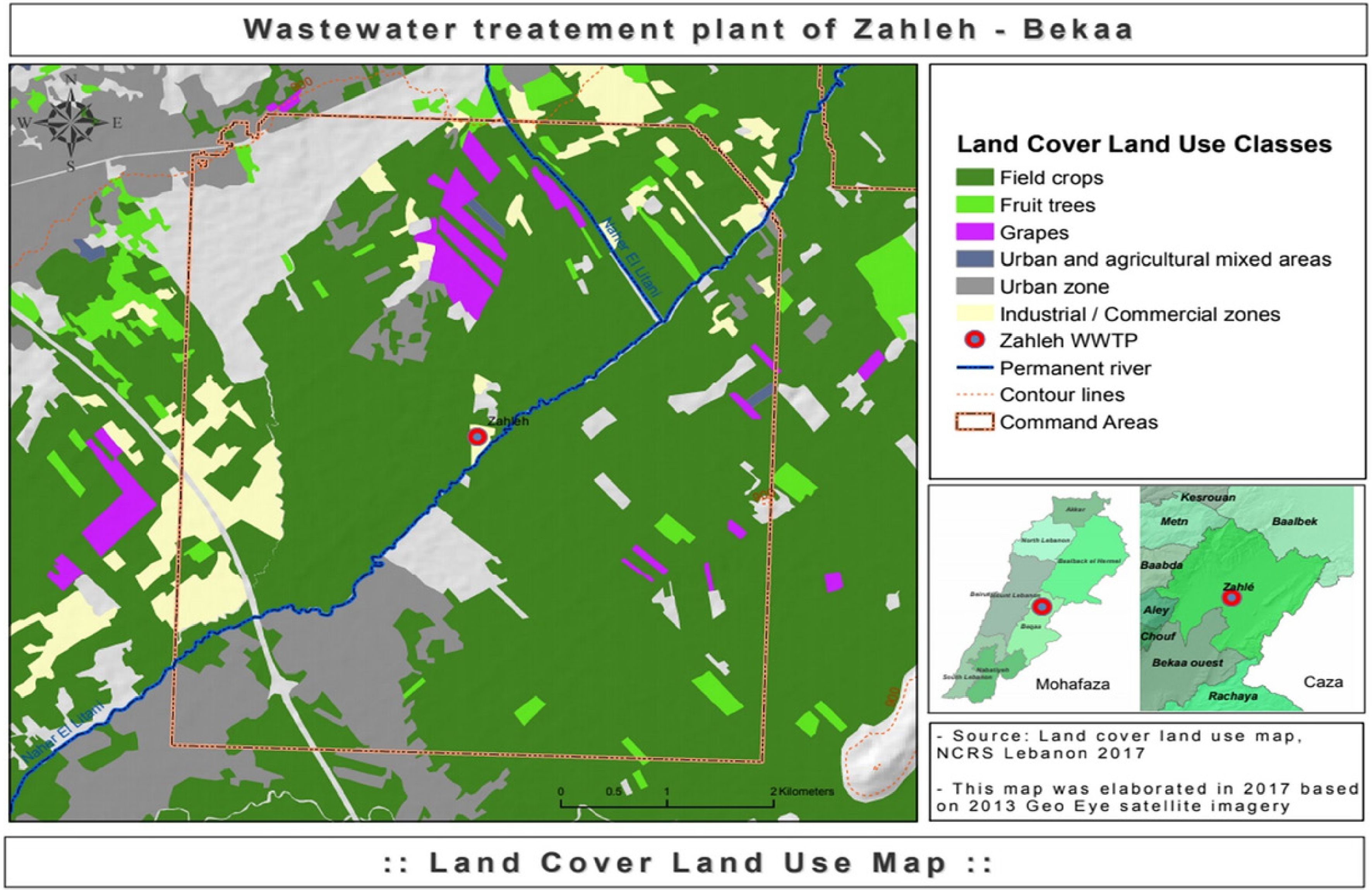

Figure A9.8. LULC map of the vicinity of the Zahleh WWTP.

C. Case Study: Aintourine WWTP

Characteristics of Aintourine WWTP	
Location	Aintourine village (Figures A9.9, A9.10)
Operational status	Partial/Not operational
Design capacity	3,600 m^3/day
Actual average daily flow	3,600 m^3/day
Treatment technologies	Activated sludge
Design level of treatment	Tertiary
Actual level of treatment	Unclear
Effluent quality	Currently untreated
Effluent discharge location	Wastewater overflows without treatment to Wadi Qadisha, and through Arai'er to Bneshai. It is then mixed with stormwater and continues to the Jouiit River, eventually discharging into the Abou Ali River.
Operation interval	Not available
Energy supply	Not available
Managing institution(s)	North Lebanon Water Establishment is responsible according to Law 221 but has not taken operational responsibility yet.
O&M costs and recovery	USD 650,000 to 900,000 per year (for both plants, Ijbaa and Aintourine). CDR covers the costs during the period of operation agreed upon within the loan agreement. NLWE should be able to cover the costs after the transfer through wastewater fees levied on residents. Currently, such fees are not included in the water bill yet.
Problems	• NLWE not able to take over the management of the plant after the end of contract between CDR and the current contracted operator. • Lack of trust from the side of the municipality toward CDR and the operator regarding the state of management and operation of the WWTP. • Dispute between the government and the municipality: The municipality demands to be involved in management since it contributed to the construction of the sewage collection network while government is not responsive.

Potential for Water Reuse in Irrigation		
Villages included in the WWTP command area	Aito, Sebaal, Ijbaa (Figure A9.11)	
Number of farmers	About 200	
Actual reuse potential area	Lower cost scenario	91.9 ha
	Higher cost scenario	96.3 ha
Actual reuse potential score	Lower cost scenario	0.4
	Higher cost scenario	0.55
Ideal reuse potential area	Lower cost scenario	91.9 ha
	Higher cost scenario	96.3 ha
Ideal reuse potential score	Lower cost scenario	0.79
	Higher cost scenario	1
Existing agriculture and main crops	Mainly fruit trees (apple and pear) with some vegetables (Figure A9.12) (MoA and FAO 2012).	
Existing irrigation systems	According to MoA and FAO (2012), around 60% of farmers in Ayto practice irrigation (35% of total cultivated area) while the rest do not. Farmers who irrigate use water from rivers (17%), wells (17%), reservoirs (16%) while others use 'other sources'.	
Irrigation governance and water rights	Individual/community management of existing systems (diversion/pumping from rivers and private wells). The government (NWE) does not have a role in irrigation management on the ground but is planning a future role in conformity with Law 221.[82]	
Existing water reuse practices (informal reuse)	Probably indirect reuse at the level of Ayto and Sebaal but this was not identified during field visits. According to a key informant, farmers tap into raw sewage networks to irrigate their orchards.[83]	
Opportunities and obstacles to organized reuse	Opportunities • If WWTP is operated well, there is high potential for indirect reuse because of effluent quality and crop type. • Municipalities are active in the region, essentially because of a strong political party representing a majority in the Ehden region (one authority). • Existence of know-how and local governance in irrigation	Obstacles • Future management (hence effective operation of WWTP) is unclear. • This valley is steep, which is an obstacle to indirect reuse (without implementing new infrastructure). • Multiplicity of water rights might be an obstacle.

[82] According to KII.
[83] According to KII.

D. Case Study: Ijbaa WWTP

Characteristics of Ijbaa WWTP	
Location	Ayto village (Figures A9.9, A9.10)
Operational status	Partial/not operational
Design capacity	3,600 m^3/day
Actual average daily flow	Unclear
Treatment technologies	Activated sludge
Design level of treatment	Tertiary
Actual level of treatment	Secondary
Effluent quality	Unclear
Effluent discharge location	Nahr Abou Ali
Operation interval	Not available
Energy supply	Not available
Managing institution(s)	North Lebanon Water Establishment is responsible according to Law 221 but has not taken operational responsibility yet.
O&M costs and recovery	USD 650,000 to 900,000 per year (equivalent to LL 1 billion before the economic crisis) for both plants, Ijbaa and Aintourine.
Problems	• NLWE not able to take over management of the plant after the end of contract between CDR and the current contract operator. • Lack of trust from the side of the municipality toward CDR and the operator regarding management and operation. • Dispute between government and municipality: The municipality demands to be involved in management since it contributed to the construction of the sewage collection network while government is not responsive.

Potential for Water Reuse in Irrigation		
Villages included in the WWTP command area	Parts of Aintourine, Kfarsghab, ArbetKoshaya, Bane (Figure A9.11)	
Number of farmers	Around 100	
Actual reuse potential area	Lower cost scenario	86.8 ha
	Higher cost scenario	87.5 ha
Actual reuse potential score	Lower cost scenario	0.67
	Higher cost scenario	0.55
Ideal reuse potential area	Lower cost scenario	86.6 ha
	Higher cost scenario	87.5 ha
Ideal reuse potential score	Lower cost scenario	0.94
	Higher cost scenario	0.94
Existing agriculture and main crops	Mainly fruit trees (apple) with some green leafy vegetables (Figure A9.12).	
Existing irrigation systems	According to the MoA and FAO census of 2010, most farmers in Aintourine practice irrigation with the main source being a river. Gravity irrigation is widely used on the plot.	
Irrigation governance and water rights	Individual/community management of existing systems (diversion/pumping from rivers and private wells).[84] The government (NWE) does not have a role in irrigation management on the ground but is planning a future role in conformity with Law 221.	
Existing water reuse practices (informal reuse)	Probably indirect reuse downstream at the level of Aintourine and other villages but this was not identified during field visits. According to a key informant, farmers tap into raw sewage networks to irrigate their orchards.	
Opportunities and obstacles to organized reuse	Opportunities	Obstacles
	• If WWTP is well operated, there is high potential for indirect reuse because of effluent quality and crop types. • Municipalities are active in the region, essentially because of a strong political party representing the majority in the Ehden region (one authority). • Existence of a local water committee.[85] • Existence of knowhow and local governance in irrigation.	• Future management (hence effective operation of WWTP) is unclear. • Distrust toward CDR from the side of the municipalities. • The valley is steep, which is an obstacle to indirect reuse (without implementing new infrastructure). • Multiplicity of water rights might be an obstacle.

[84] According to key informants.
[85] According to key informants.

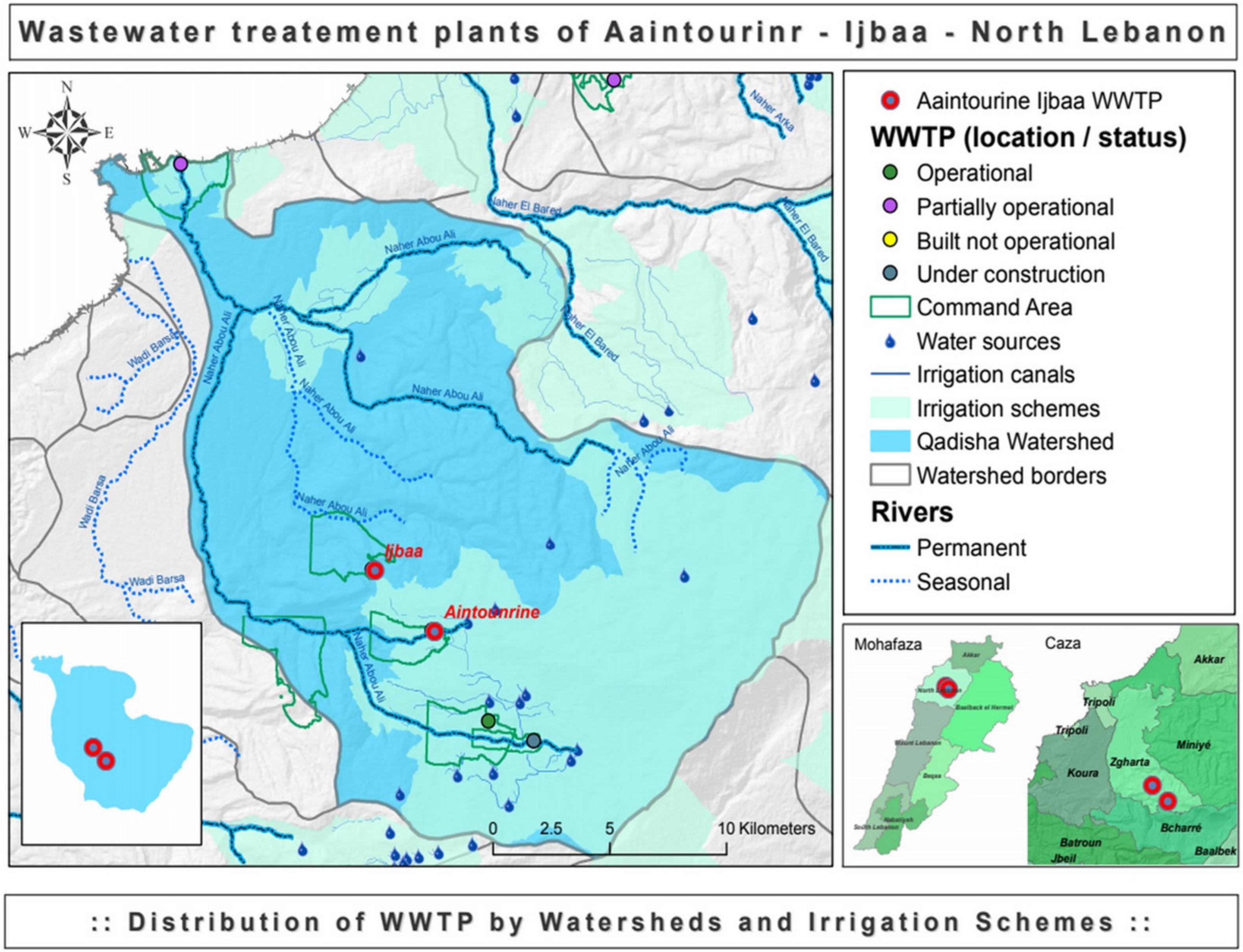

Figure A9.9. The Aintourine and Ijbaa WWTPs.

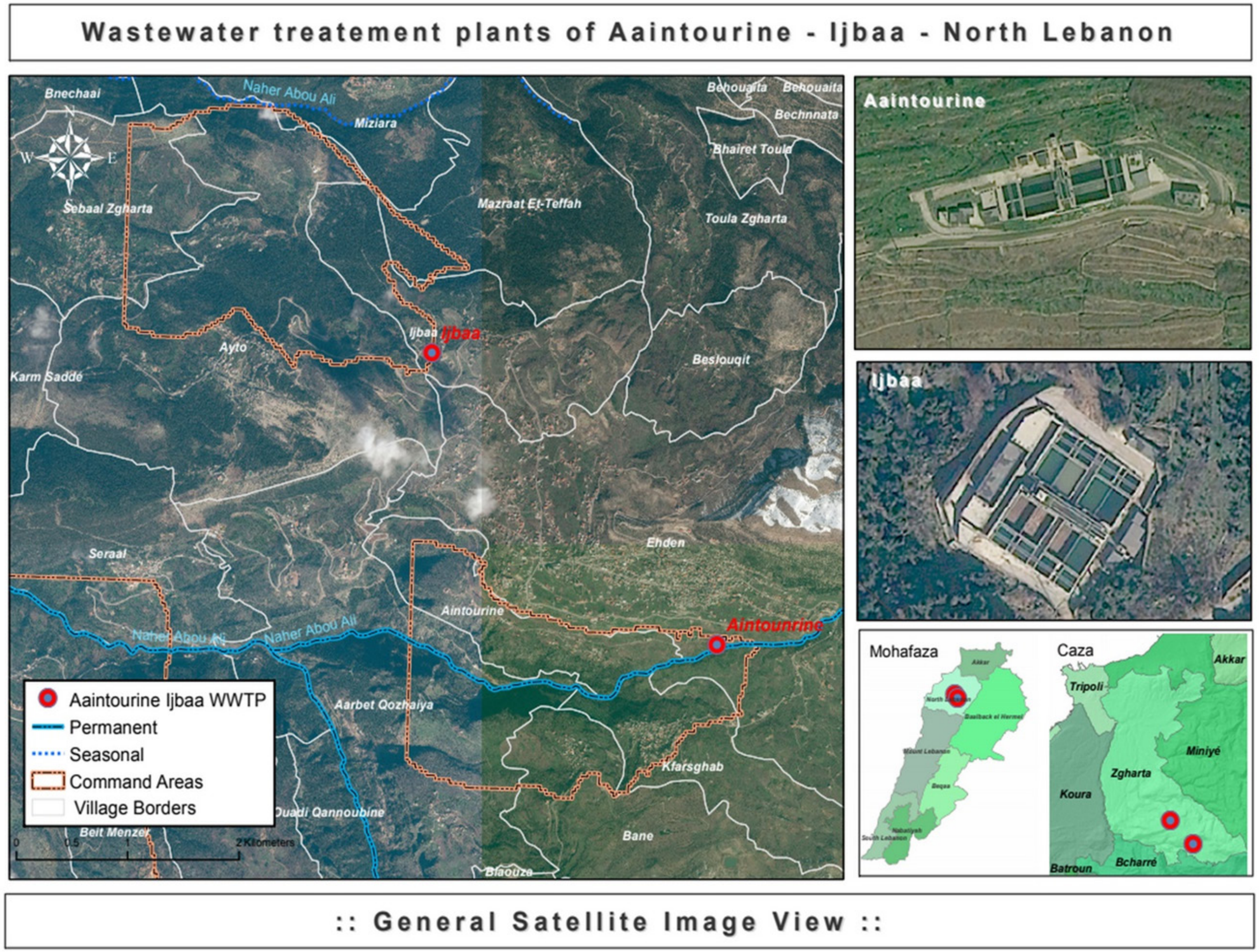

Figure A9.10. Satellite image of the Aintourine-Ijbaa WWTP area.

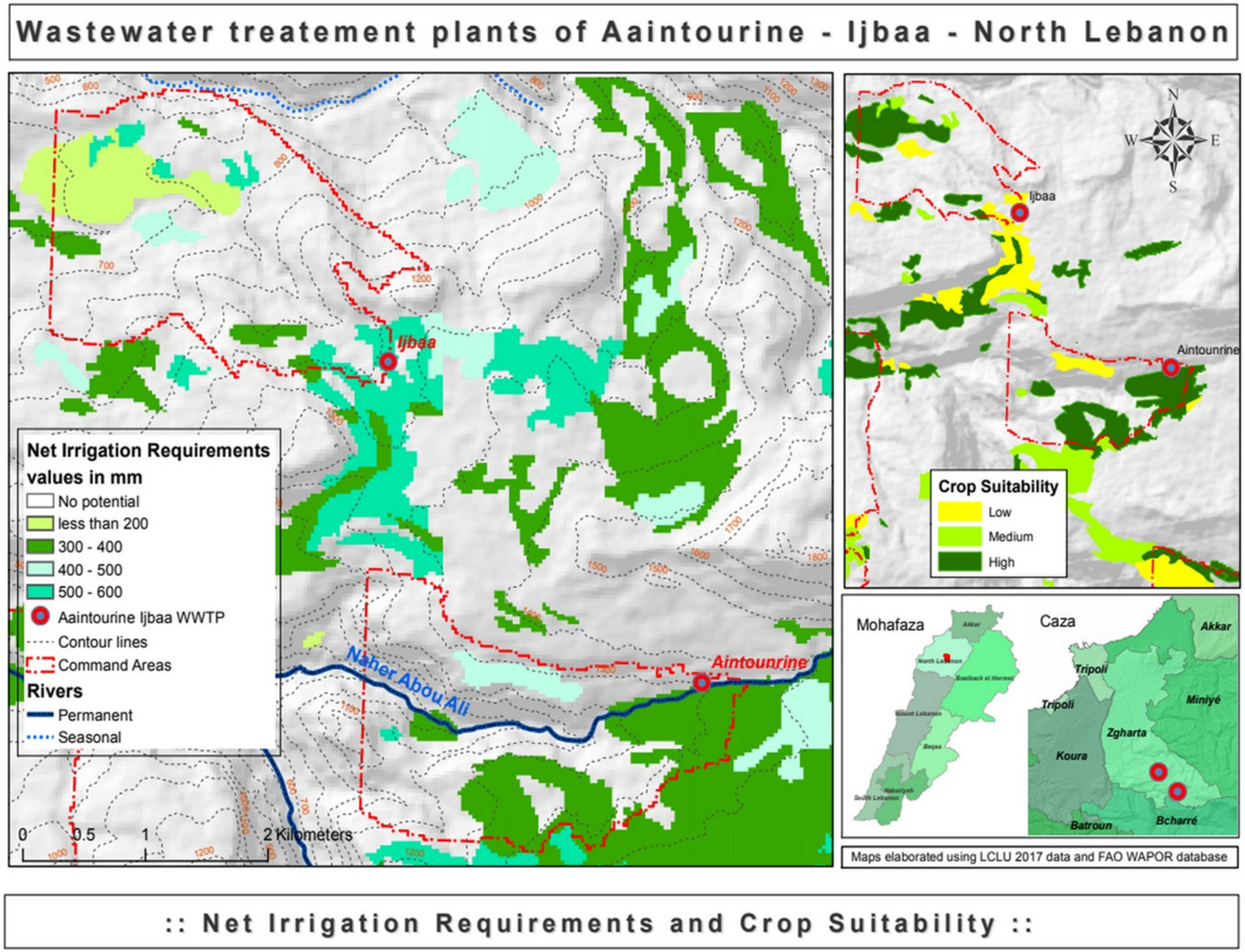

Figure A9.11. Net irrigation requirement in the command areas of the Aintourine and Ijbaa WWTPs.

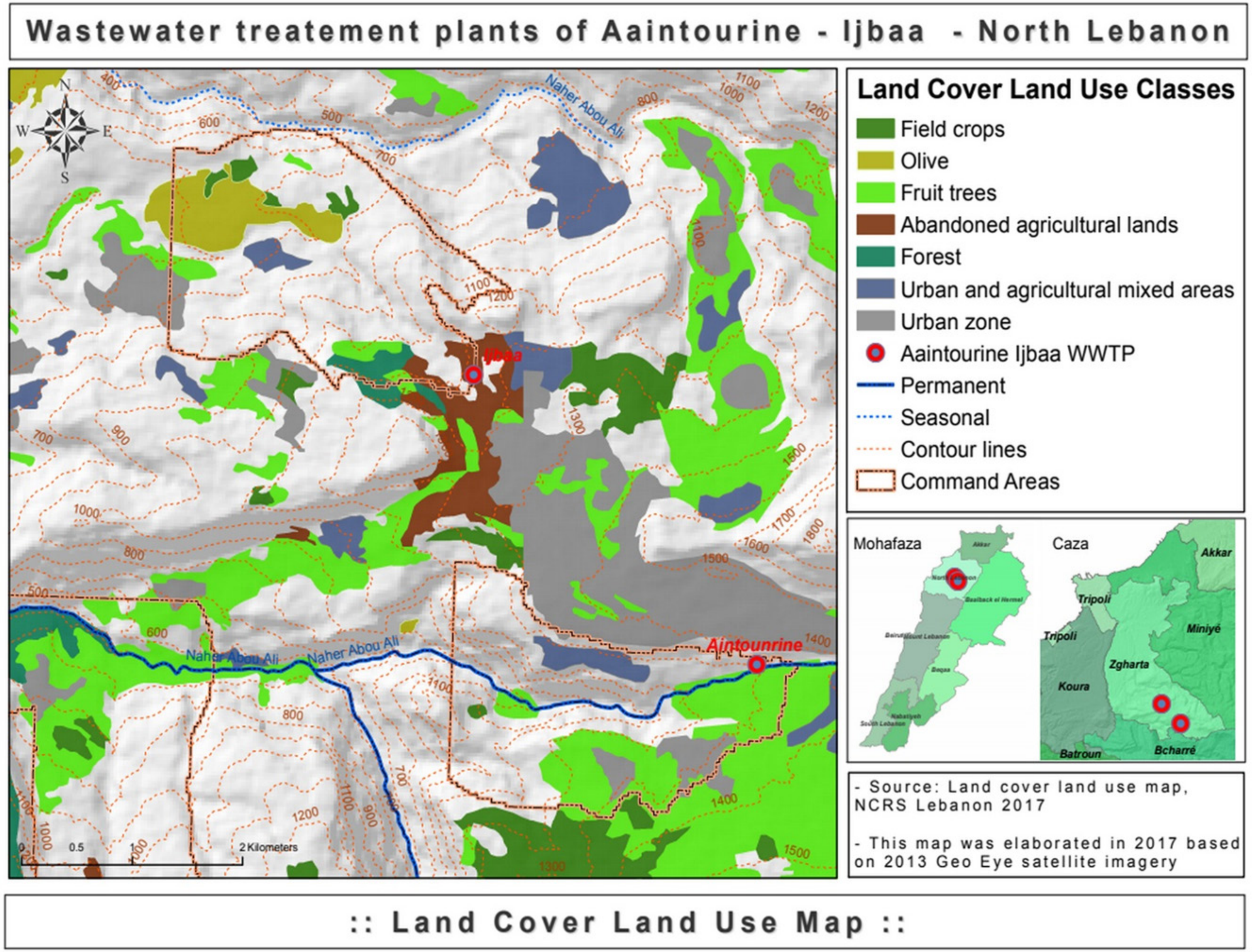

Figure A9.12. LULC map of the vicinity of the Aintourine and Ijbaa WWTPs.

E. Case Study: Chabriha/Sour WWTP

Characteristics of Chabriha WWTP	
Location	Chabriha[86] (Sour) (Figures A9.13, A9.14)
Operational status	Partially operational
Operation interval	Should start operating in the summer 2020[87]
Design capacity	35,000 m^3/day
Actual average daily flow	17,000 m^3/day[88]
Treatment technologies	Activated sludge
Level of treatment	Tertiary (UV treatment)
Effluent quality	Should be of category 1 or 2 since it undergoes tertiary treatment
Effluent discharge location	Mediterranean Sea
Energy supply	Public network (EDL) and private generator. There is a system of biogas production from sludge that should produce 500 KVA. It should cover 25% of the energy needed for operation.[89]
Managing institution(s)	Currently managed by CDR through OTV-Veolia company. The contract is expected to last until 2026. After that, it would be transferred to the SLWE. The SLWE has the authority to follow up on operations, such as performing field visits, to ensure that the process is working properly, requesting water quality tests, etc.
O&M costs and recovery	Not available
Problems	Delay in start of operations

[86] Name given by the locals to this location.
[87] Interview, director of the wastewater program at CDR. Construction started around 10 years ago. The consultant was Cabinet Merlin.
[88] Interview, engineer, SLWE.
[89] Interview, engineer, OTV company.

Potential for Water Reuse in Irrigation		
Villages included in the WWTP command area	Parts of Abbassyeh, Sour and Mheilib are included in the WWTP's command area. However, treated water could be conveyed beyond the limits of the command area through the existing irrigation scheme of Qasmieh Ras-El-Ain (Figure A9.15)	
Number of farmers	To be confirmed	
Actual reuse potential area	Lower cost scenario	326.3 ha
	Higher cost scenario	392.1 ha
Actual reuse potential score	Lower cost scenario	0.57
	Higher cost scenario	0.57
Ideal reuse potential area	Lower cost scenario	542.5 ha
	Higher cost scenario	697.1 ha
Ideal reuse potential score	Lower cost scenario	0.69
	Higher cost scenario	0.69
Existing agriculture and main crops	Banana, citrus trees, and vegetables (Figure A9.16)	
Existing irrigation systems	Open canal irrigation network (Qasmieh Ras-El-Ain) supplied by water from local springs and Lake Qaraoun. Many wells drilled within the system to complement surface water in the summer (Raad 2004).	
Irrigation governance and water rights	The Litani River Authority (LRA) manages the Qasmieh Ras-El-Ain irrigation system and provides water to farmers at a cost. Wells are drilled and managed individually by farmers.	
Existing water reuse practices (informal reuse)	There is no existent use of the effluent. It is discharged into the sea. However, farmers might be tapping into sewage networks.	
Sludge disposal and existing reuse practices	There is a system of biogas production from sludge.	
Opportunities and obstacles to organized reuse	Opportunities	Obstacles
	• High potential for reuse in view of effluent quality, crop types and existence of agricultural areas suffering from water shortage in the summer at the level of the command area. Organized and expanded water reuse could alleviate pressure on irrigation water use. • An irrigation reuse system is planned and partly implemented (pumps and conveyance pipe to be connected to the Qasmieh Ras-El-Ain canals)	• The LRA is currently opposed to the idea of a reuse system and is not ready to consider water exchange between sectors.

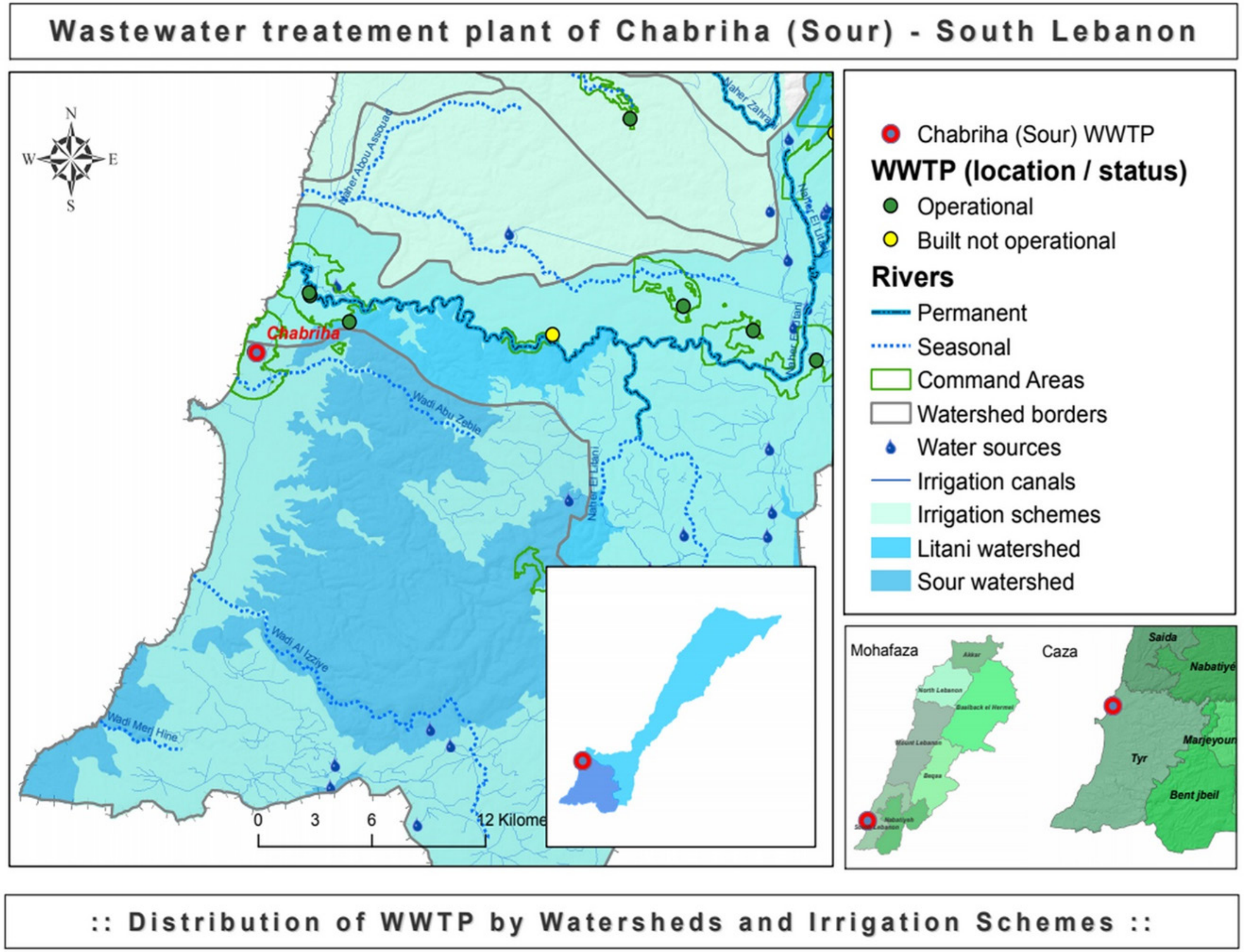

Figure A9.13. The WWTP at Chabriha (Sour).

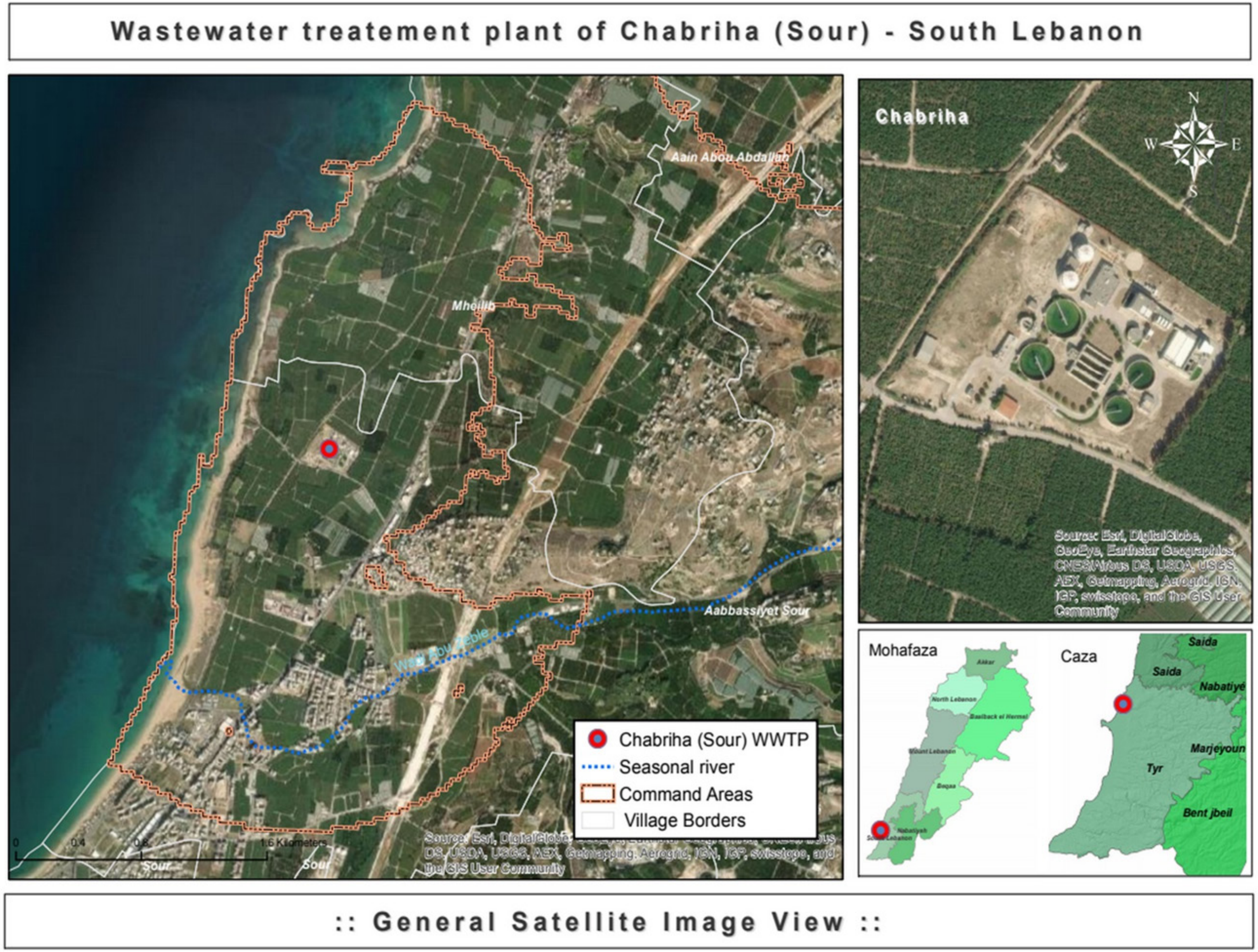

Figure A9.14. Satellite image of the Chabriha (Sour) WWTP.

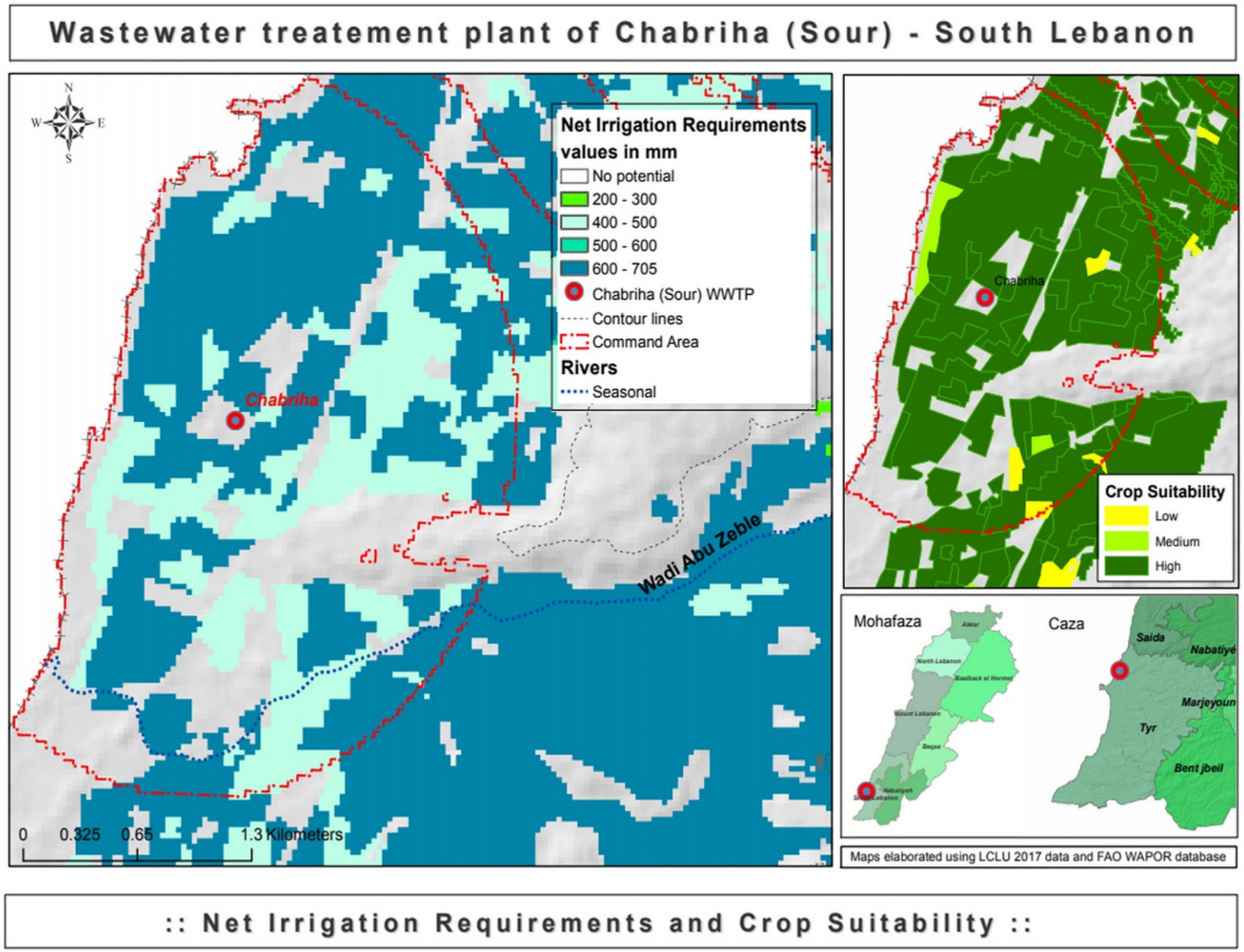

Figure A9.15. Net irrigation requirement at the Chabriha (Sour) WWTP.

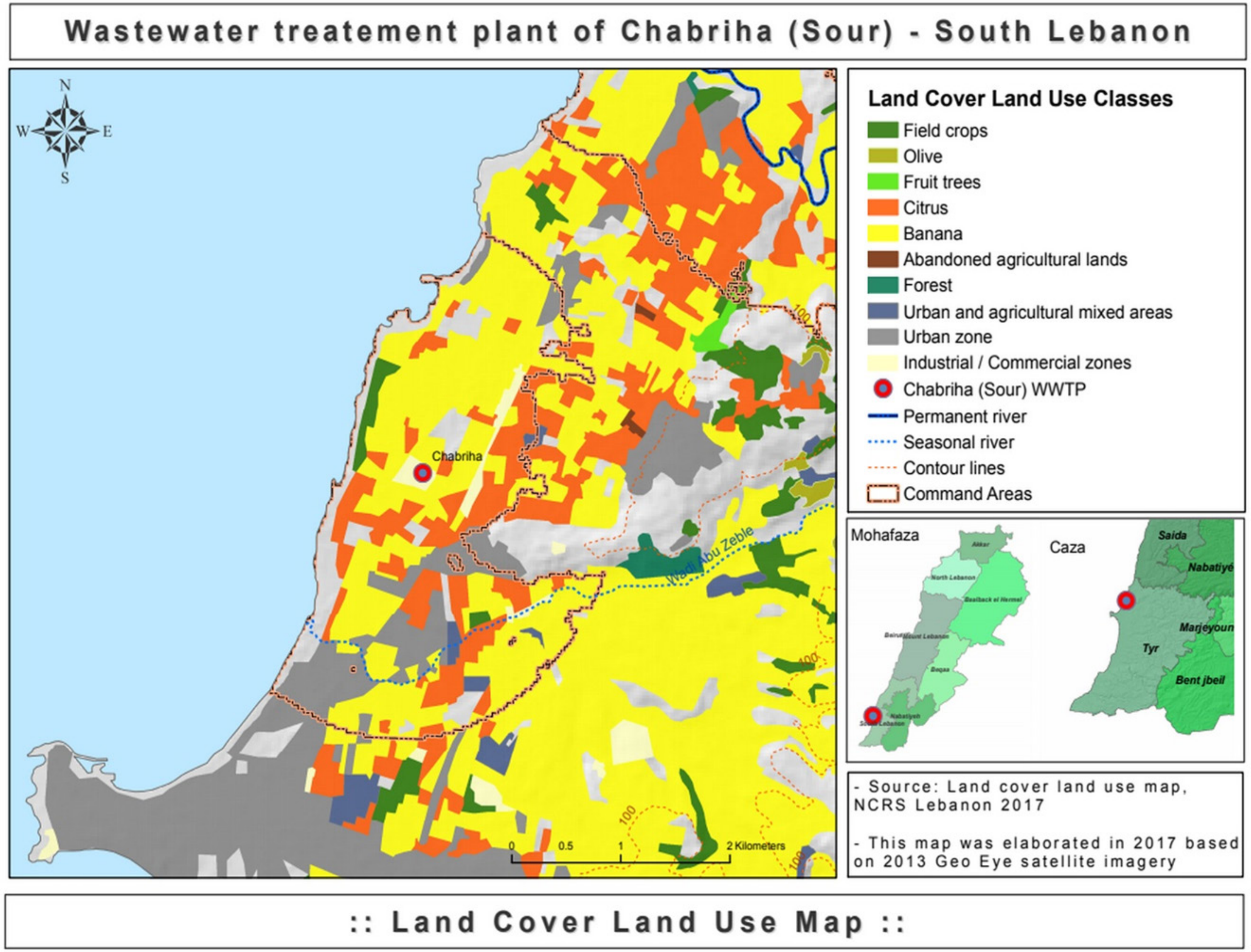

Figure A9.16. LULC map of the vicinity of Chabriha (Sour) WWTP.

F. Case Study: Hammana WWTP

Characteristics of Hammana WWTP

Location	Hammana (Figures A9.17, A9.18)
Operational status	Fully operational
Operation interval	Constructed in 1969, rehabilitated in 2000 and upgraded in 2014
Design capacity	1,000 m^3/day
Actual average daily flow	700 m^3/day (winter) – 1,500 m^3/day (summer)[90]
Treatment technologies	Activated sludge
Design level of treatment	Secondary
Actual level of treatment	Secondary
Effluent quality[91]	Category 2 according to Lebanese guidelines (FAO 2010)
Effluent discharge location	Seasonal river
Energy supply	Three sources: Public network (EDL), private generator and solar panel system
Managing institution(s)	Hammana Municipality contracts an enterprise founded and managed by an engineer from the village[92]
O&M costs and recovery	USD 300,000-333,000/year[93] Paid by Hammana Municipality
Problems	• Wastewater entering the WWTP exceeds design capacity in the summer and disrupts the process. The plant needs to be upgraded to be able to treat 25% more of the current flow during summer.[94] • Additionally, sewage network needs rehabilitation.[95]

[90] Interview, Chief Operator, Hammana WWTP, February 2020.
[91] Water quality testing occurs every 3–6 months for BOD, COD, pH, and sometimes P and N.
[92] The enterprise Triple E operates four other plants in Lebanon. It has implemented many other small- or medium-scale WWTPs appropriate for single municipalities or residential compounds and units. All contractors and subcontractors as well as laborers are locals, as insisted upon by the Mayor because it makes coordination with the municipality easier. The worker is Syrian and has been living and working in Hammana for more than 20 years. He works on a part-time basis in agriculture to supplement his income.
[93] Interviews, Hammana Municipal board members, February 2020.
[94] The municipality has plans to implement another plant/treatment unit. At this stage, only the land for the project has been secured, but no funding is available. The current financial crisis in Lebanon suggests that funding will only become available from external funding/NGO project.
[95] During the CEDRE donor conference in 2018, funds (from Kuwait) were allocated for a regional infrastructure rehabilitation project for the upper Metn. The project envisions a functional sewer network and three WWTPs. Rehabilitation of the Hammana sewage network is part of this project. This Information was obtained from the Hammana Municipality.

Potential for Water Reuse in Irrigation		
Villages included in the WWTP command area	Parts of Hammana, Khraybeh, Bmariam and Chbanieh (Figure A9.19)	
Number of farmers	Around 200 in the whole potential area	
Actual reuse potential area	Lower cost scenario Higher cost scenario	19.5 ha 19.5 ha
Actual reuse potential score	Lower cost scenario Higher cost scenario	0.7 0.94
Ideal reuse potential area	Lower cost scenario Higher cost scenario	31.1 ha 31.2 ha
Ideal reuse potential score	Lower cost scenario Higher cost scenario	0.7 0.94
Existing agriculture and main crops Existing irrigation systems	Mainly fruit trees (apple) with some vegetables (Figure A9.20). Mostly spring and river-based open canal irrigation systems with some reliance on groundwater wells in Hammana.	
Irrigation governance and water rights	Individual/community management of existing systems (diversion/ pumping from rivers and private wells) The government (BMLWE) does not have a role in irrigation management on the ground but is planning a future role in conformity with Law 221.[96]	
Existing water reuse practices (informal reuse)	Indirect reuse downstream at the level of Khraybeh.[97] Farmers divert diluted water into irrigation canals. Reuse was initially considered as part of the WWTP's rehabilitation in 2000, whereby treated water would be pumped to lands in Hammana supplied by the spring area.[98]	
Sludge disposal and existing reuse practices	Local sludge disposal and reuse is unclear The CDR plans to treat and dispose sewage from the whole region, including Hammana at the level of the Bourj Hammoud area.	
Opportunities and obstacles to organized reuse	Opportunities	Obstacles
	• High potential for reuse because of effluent quality, crop types and existence of agricultural areas suffering from water shortage in the summer at the level of the command area.[99] Organized and expanded water reuse could alleviate pressure on irrigation water use. • The functioning of Hammana WWTP seems to be sustainable. The municipality is ready to cover costs and the technical know-how exists. • Installation of solar panels has reduced the cost of energy and has had a positive impact on financial sustainability.	• The plant needs rehabilitation/ upgrading to ensure proper treatment of greater collected volume of wastewater. • Monitoring of treated effluent is not adequate.[100] • A multiplicity of irrigation systems and user groups in the command area might create conflicts over water allocation if an infrastructure is planned. For example, the Hammana Municipality considers it has the right to use the water it is treating while it is already used • Pumping water to Hammana village comes with a financial cost while storing it for use downstream might not be accepted without compensation.[101]

[96] Hammana Municipality also manages its own drinking water system based on an acquired water right linked to the Chaghour spring (effluent of Nahr Beirut).
[97] Interview, worker at WWTP.
[98] This option was never realized because of the cost it entailed. This information was obtained from Hammana municipal board members in February 2020.
[99] This was found to be the case both at the level of Hammana and Khraybeh. In Hammana, increased water shortage as well as reduced water quality was reported after the construction of the Qaysamani dam in the Chaghour spring catchment area.
[100] As compared with the Monitoring Protocol proposed by the FAO guidelines for Lebanon (FAO 2010).
[101] The WWTP operator reported an incident where the interruption of the plant's operation for annual cleaning led to complaints from the downstream municipality of Khraybeh since it compromised farmers' access to irrigation water. "There is no planning or a law or regulation that regulates…it will create clashes at some point," he underlined.

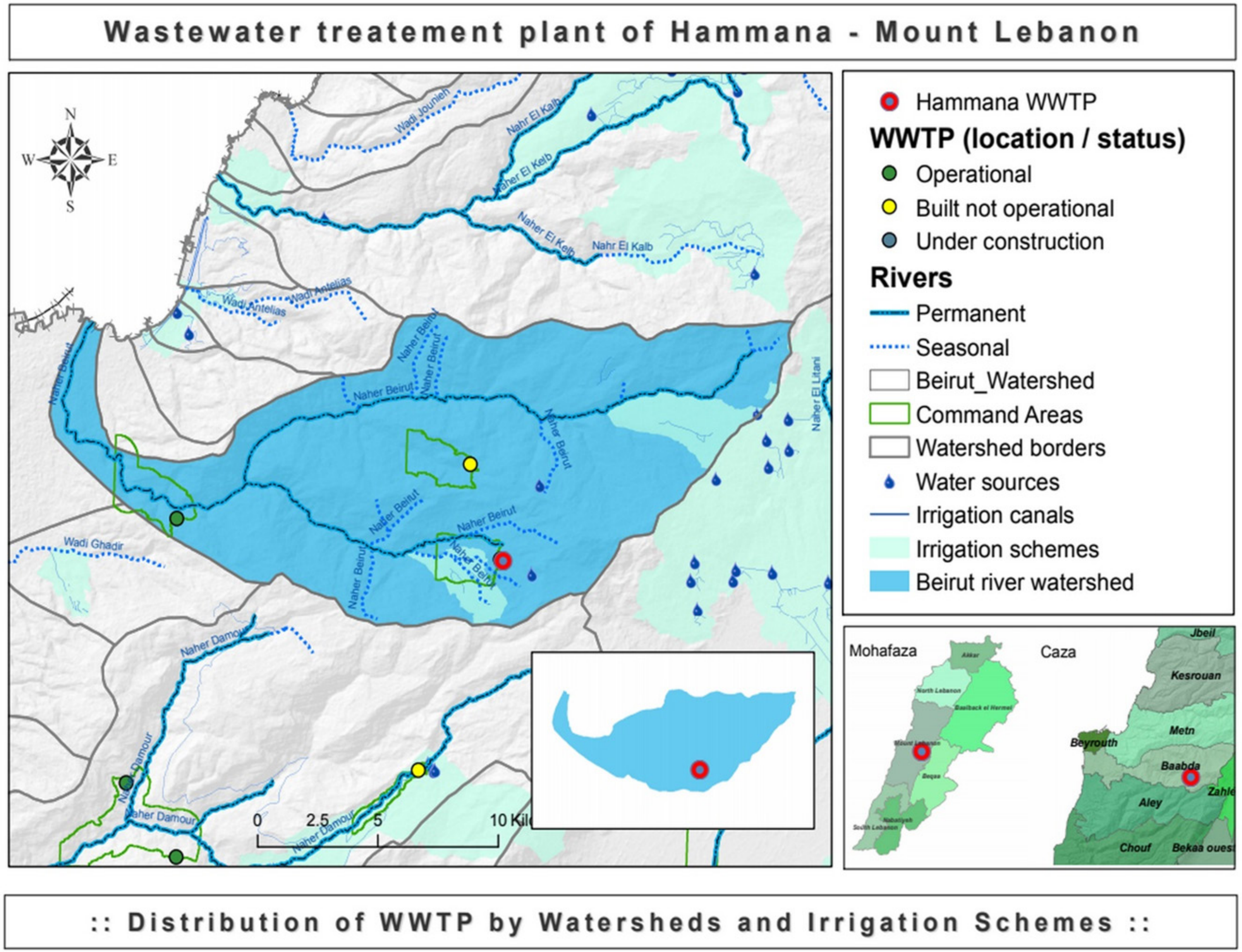

Figure A9.17. Location map of the Hammana WWTP.

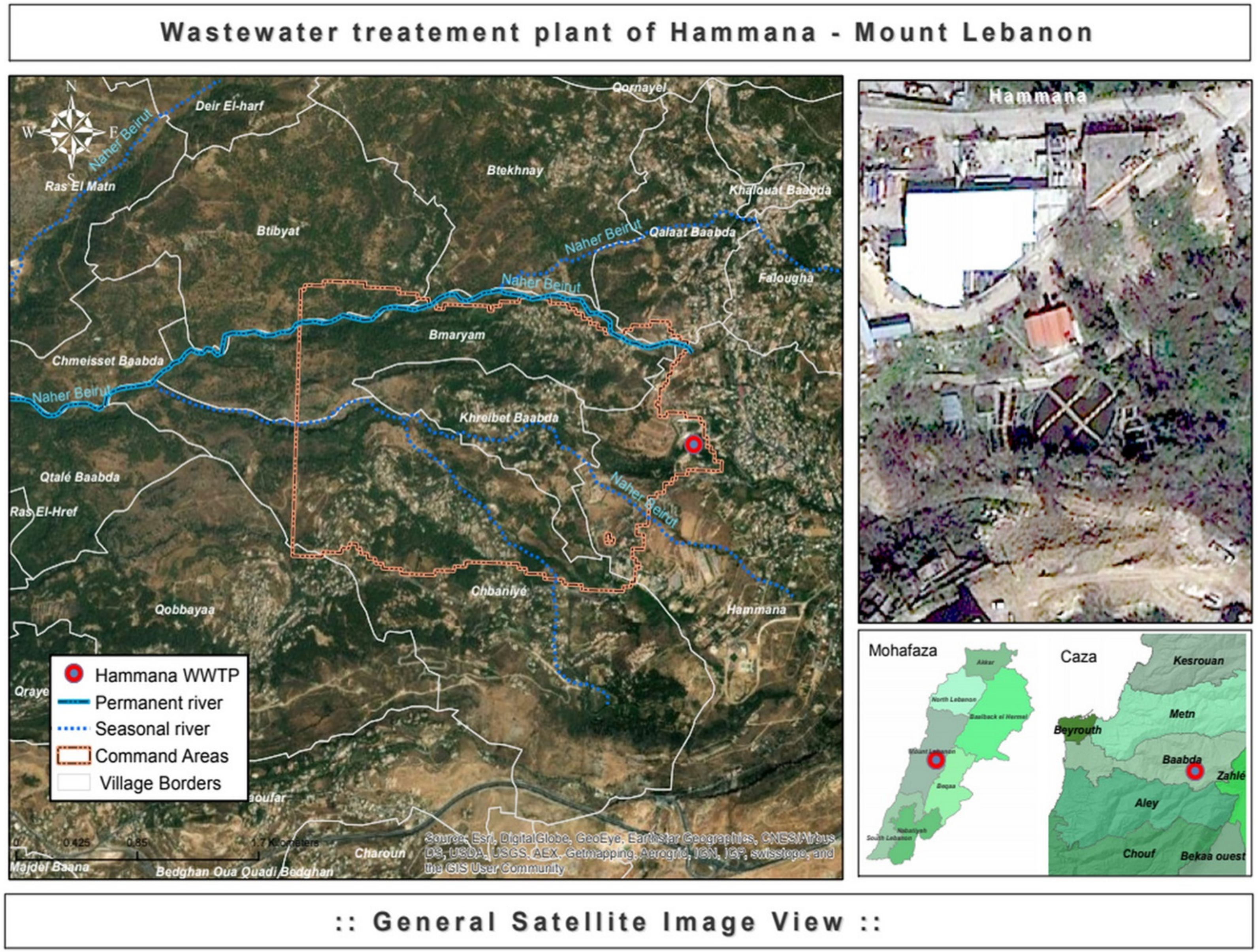

Figure A9.18. Satellite map of the Hammana WWTP.

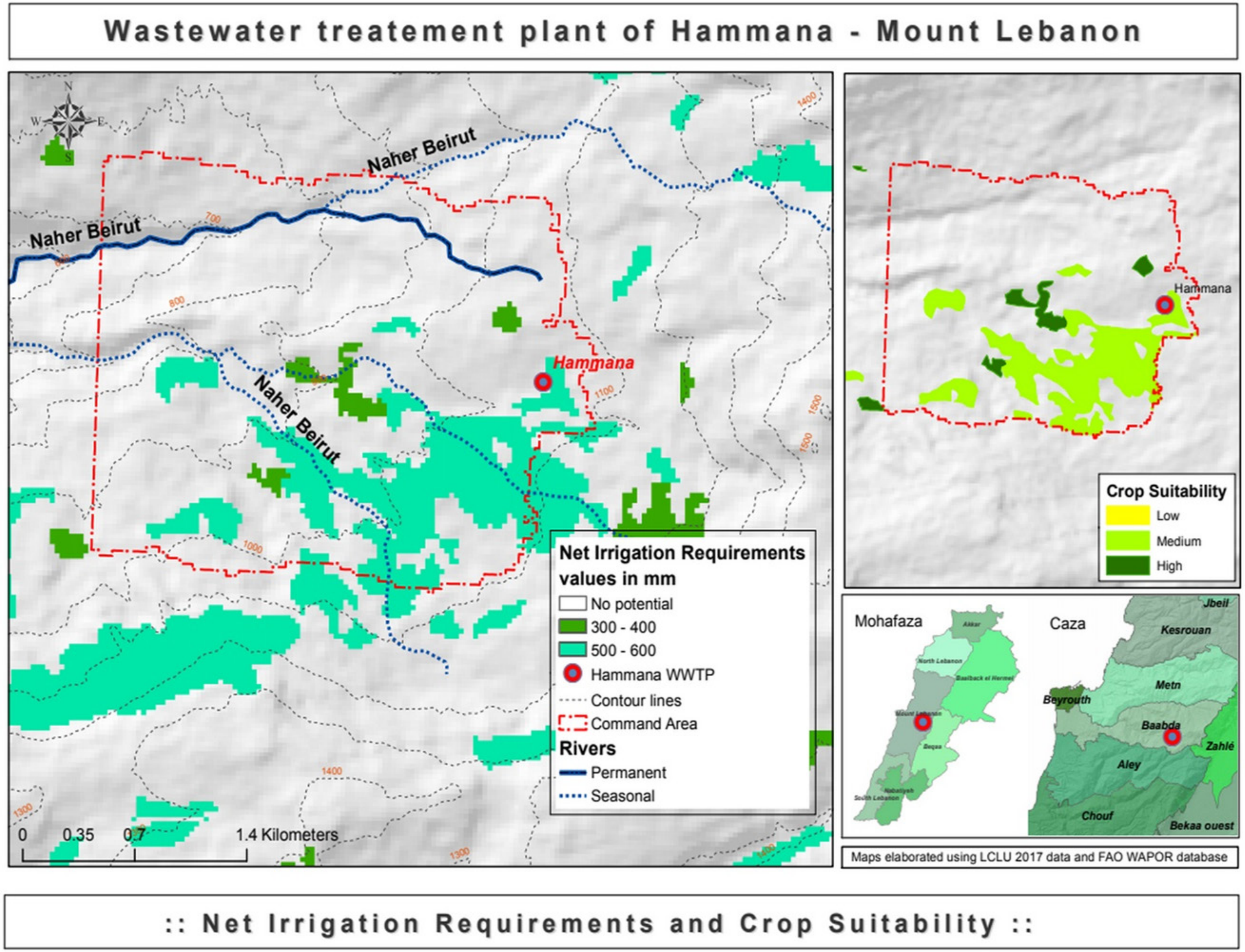

Figure A9.19. Net irrigation requirement of Hammana command area.

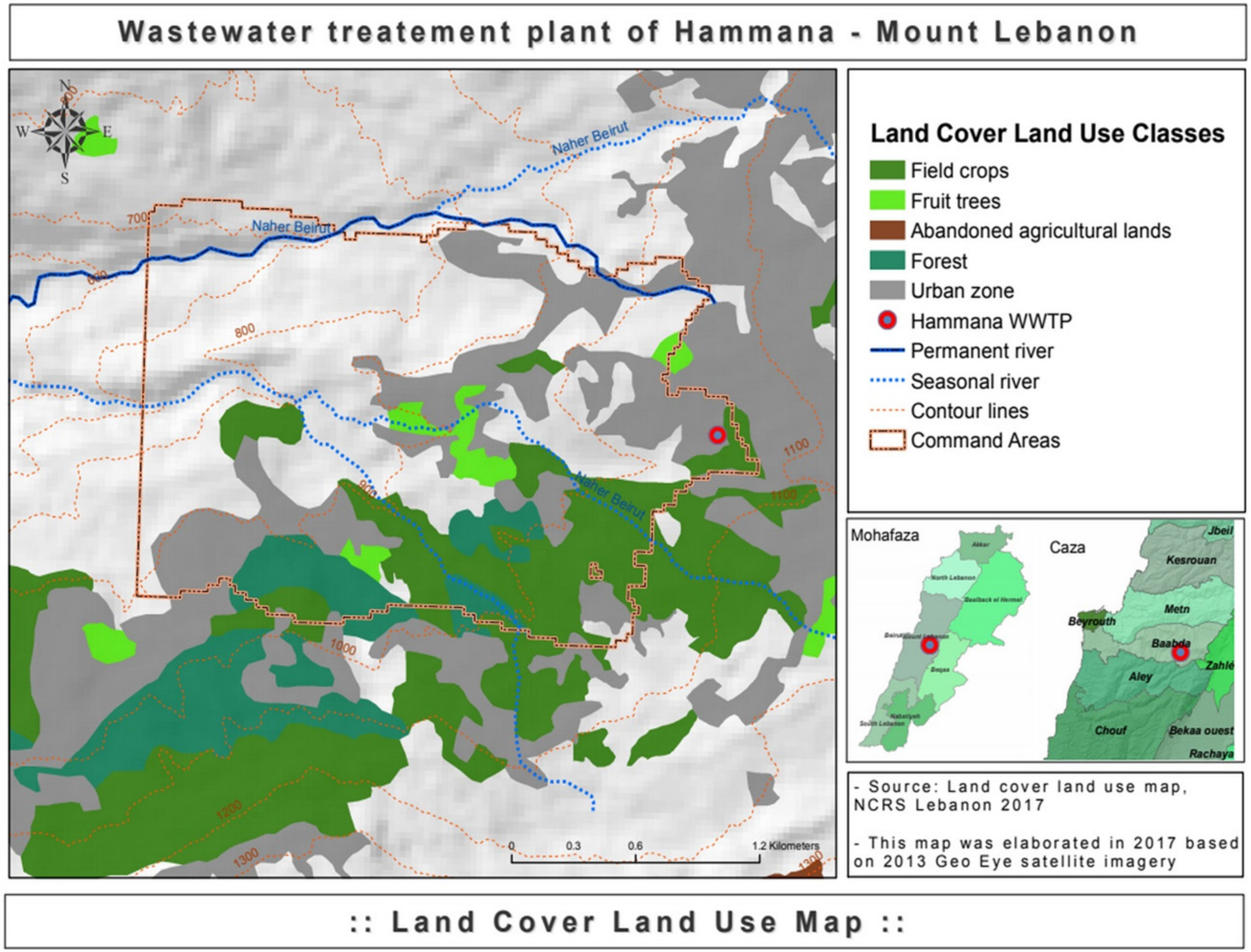

Figure A9.20. LULC map of the vicinity of the Hammana WWTP.

G. Case Study: Iaat WWTP

Characteristics of Iaat WWTP	
Location	Iaat (Figures A9.21, A9.22)
Operational status	Partial/not operational
Operation interval	2011 until today (only partial operation)[102]
Design capacity	Conflicting information[103] (ranging from 5,000 to 24,000 m^3/day)
Actual average daily flow	Less than 1,000 m^3/day in summer because of illegal tapping into the sewage network upstream (FAO 2016b). In winter, more than 16,500 m^3/day since effluent is mixed with stormwater because of heavy rains.[104]
Treatment technologies	Activated sludge + oxidation ditches
Level of treatment	Secondary + disinfection unit
Effluent quality	Not compliant with MoE standards and FAO guidelines
Effluent discharge location	Litani River
Energy supply	Not available
Managing institution(s)	Bekaa Water Establishment
O&M costs and recovery	Estimated at around USD 925,000/year, of which USD 150,888/year goes to power consumption (KREDO 2015b).
Problems	The Iaat WWTP has never operated adequately, and has suffered from chronic management problems caused by different factors: First, the implemented sewage collection networks were not sufficient to convey the minimum amount of effluent needed for operation; second, farmers tapping into the sewage network upstream further decreased the inflow. Another problem is blamed on the operator in charge who failed to ensure proper operation.[105] Today the Iaat plant is in a seriously damaged state due to years of partial operation and lack of maintenance. The MEW is planning to rehabilitate it as part of its national strategy. However, the financial sustainability of the plant is at risk because of the incapacity of BWE to secure funds for its operation.

[102] Although construction was completed by 2007, the Iaat WWTP did not start operating until the sewerage network was established in late 2009. Operations, however, stopped because the plant was only receiving influent quantities of 300-700 m^3/day—too low to meet the operational minimum limit of 2,000 m^3/day needed by a plant designed for 12,000 m^3/day. While all wastewater connections were completed by 2010, an average of only 1,500 m^3/day reached the WWTP.
[103] 5,000 m^3/day (Difaf 2017); 12,000 m^3/day (FAO 2016a); 24,000 m^3/day (KREDO 2015a).
[104] Conflicting information from different reports: 800 m^3/day according to Difaf (2017); 8,000 m^3/day according to World Bank (2012) and FAO (2016a).
[105] According to officials in BWE.

Potential for Water Reuse in Irrigation			
Villages included in the WWTP command area	Mainly in Iaat and part of Chlifa (Figure A9.23)		
Number of farmers	Around 200 in the whole potential area[106]		
Actual reuse potential area	Lower cost scenario Higher cost scenario	95.5 ha 104.2 ha	
Actual reuse potential score	Lower cost scenario Higher cost scenario	0.225 0.23	
Ideal reuse potential area	Lower cost scenario Higher cost scenario	458.5 ha 500.3 ha	
Ideal reuse potential score	Lower cost scenario Higher cost scenario	0.69 0.69	
Existing agriculture and main crops	Mainly potato, wheat and barley (FAO 2016b) (Figure A9.24)		
Existing irrigation systems	Mostly wells used individually or collectively		
Irrigation governance and water rights	Individual/community management of existing systems The government (BMLWE) does not have a role in irrigation management on the ground but is planning a future role in conformity with Law 221.		
Existing wastewater reuse practices (informal reuse)	Farmers use raw and/or treated wastewater for irrigation especially in summer. An FAO project implemented a pilot reuse system, but it was not used by farmers. Treated effluent is discharged into the Assi River and is also used for irrigation (Difaf 2017).		
Sludge disposal and existing reuse practices	Local sludge disposal and reuse is unclear CDR plans to treat and dispose sewage from the whole region, including Hammana at the level of Bourj Hammoud area.		
Opportunities and obstacles to organized reuse	Opportunities		Obstacles
	• An alternative water source is highly needed in this area where farmers tap raw wastewater sewage to save on the pumping costs of groundwater. If granted reliable access, treated water is a good alternative to the use of raw wastewater and/or groundwater which comes with high pumping costs, especially since little or no pumping is required in this area. • A large agricultural area could be irrigated with treated water if the WWTP is rehabilitated and managed properly and sustainably.		• The plant needs costly rehabilitation to become operational, and its financial sustainability is not guaranteed. • Existing irrigation practices with raw wastewater are less costly than accessing treated water. • Governmental authorities are not able to prevent the use of raw sewage.

Sources: Compiled based on Difaf 2017; FAO 2016b; KREDO 2015b; Localiban 2016; World Bank 2012; Mhanna 2016; WaterSUM n.d.

[106] Estimate based on MoA-FAO census of 2010.

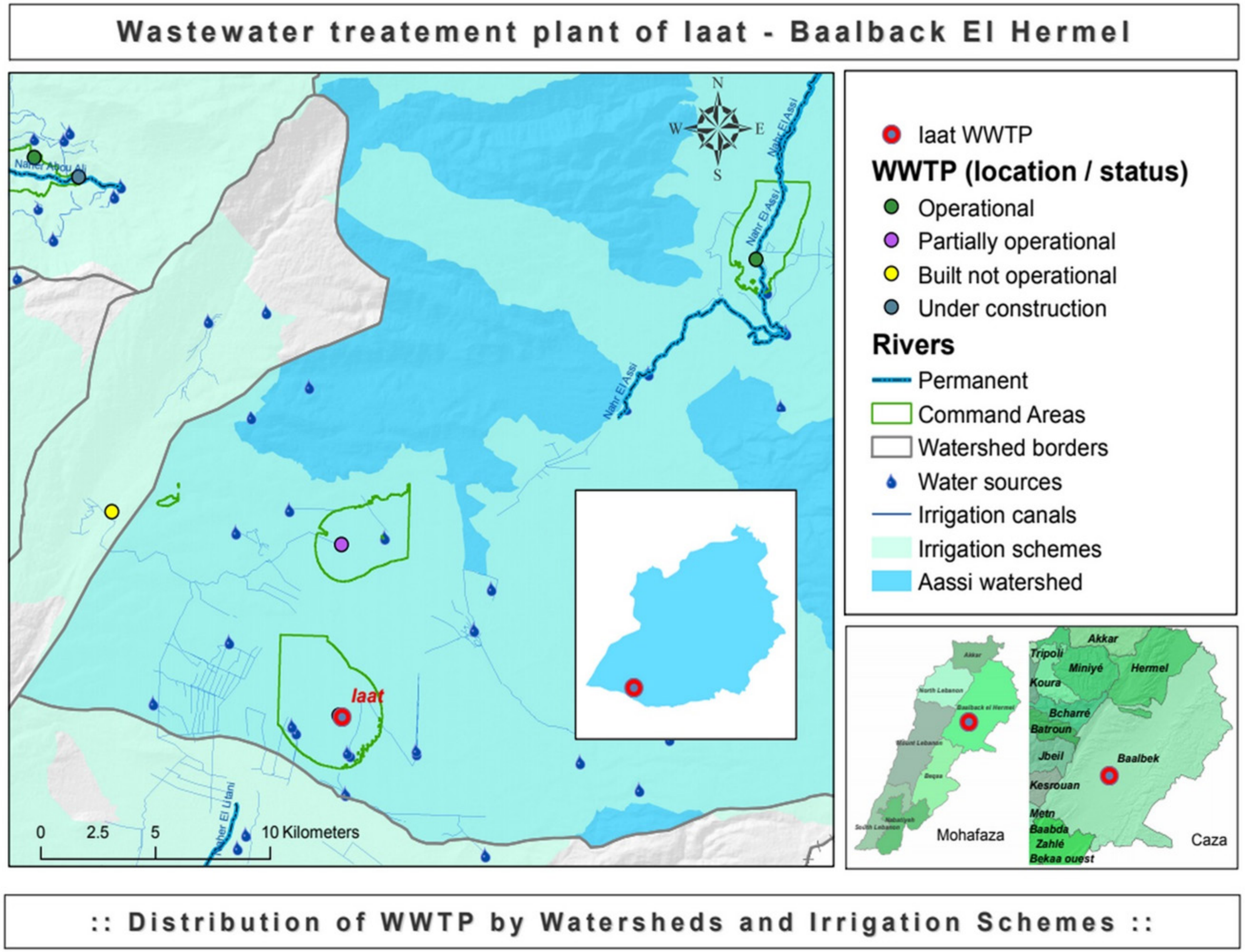

Figure A9.21. Location map of the Iaat WWTP.

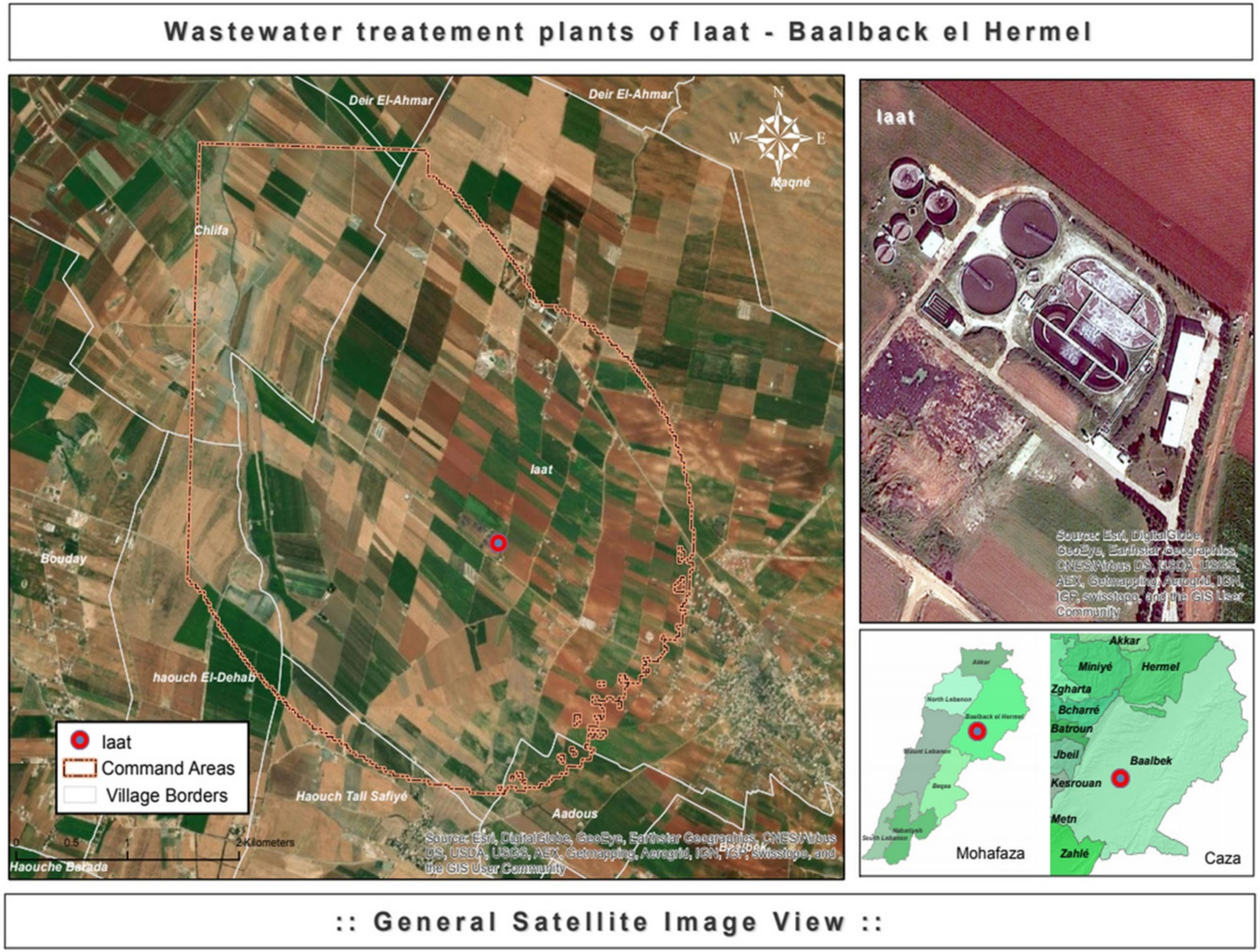

Figure A9.22. Satellite map of the Iaat WWTP.

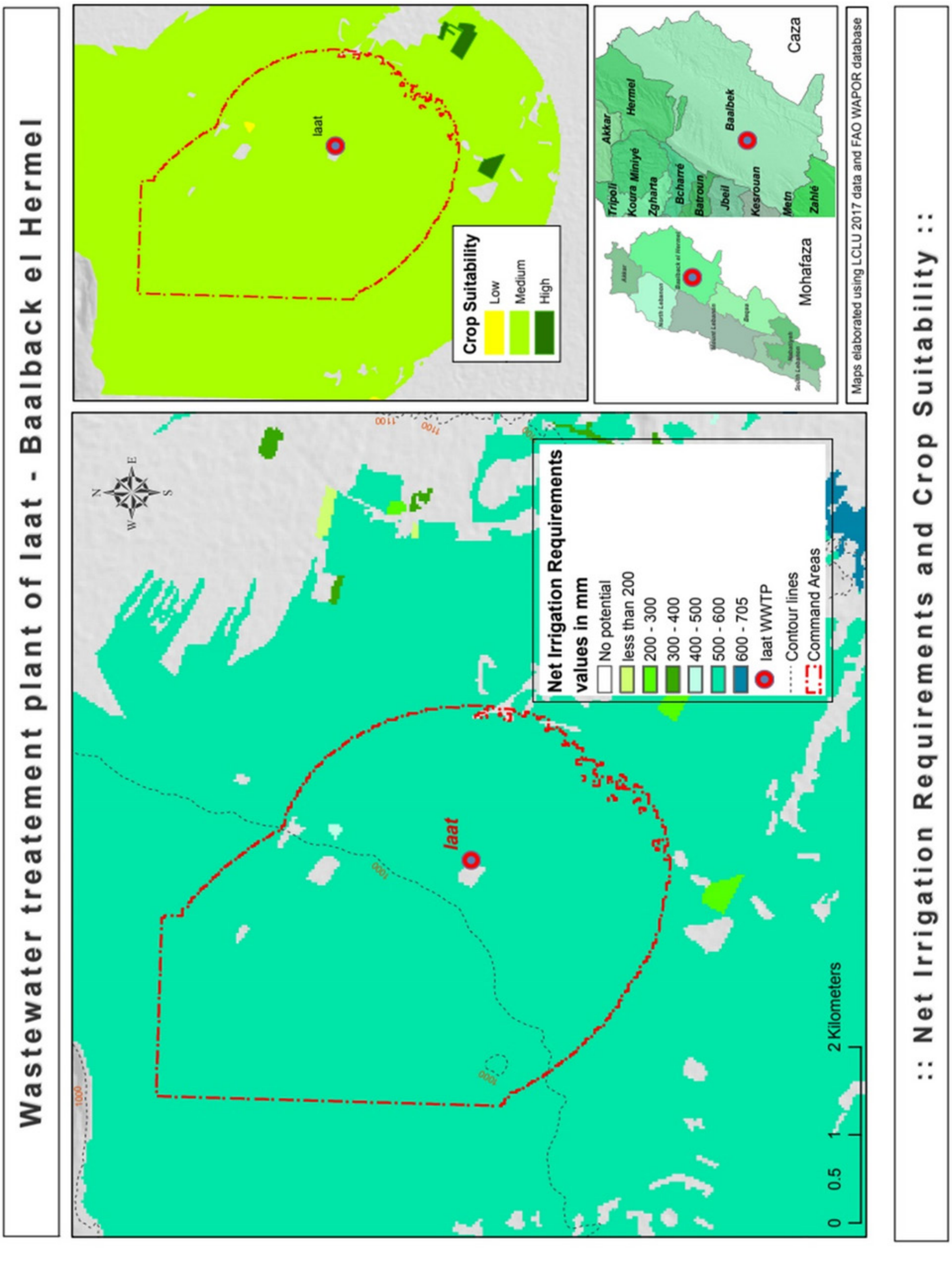

Figure A9.23. Net irrigation requirement at the Iaat WWTP.

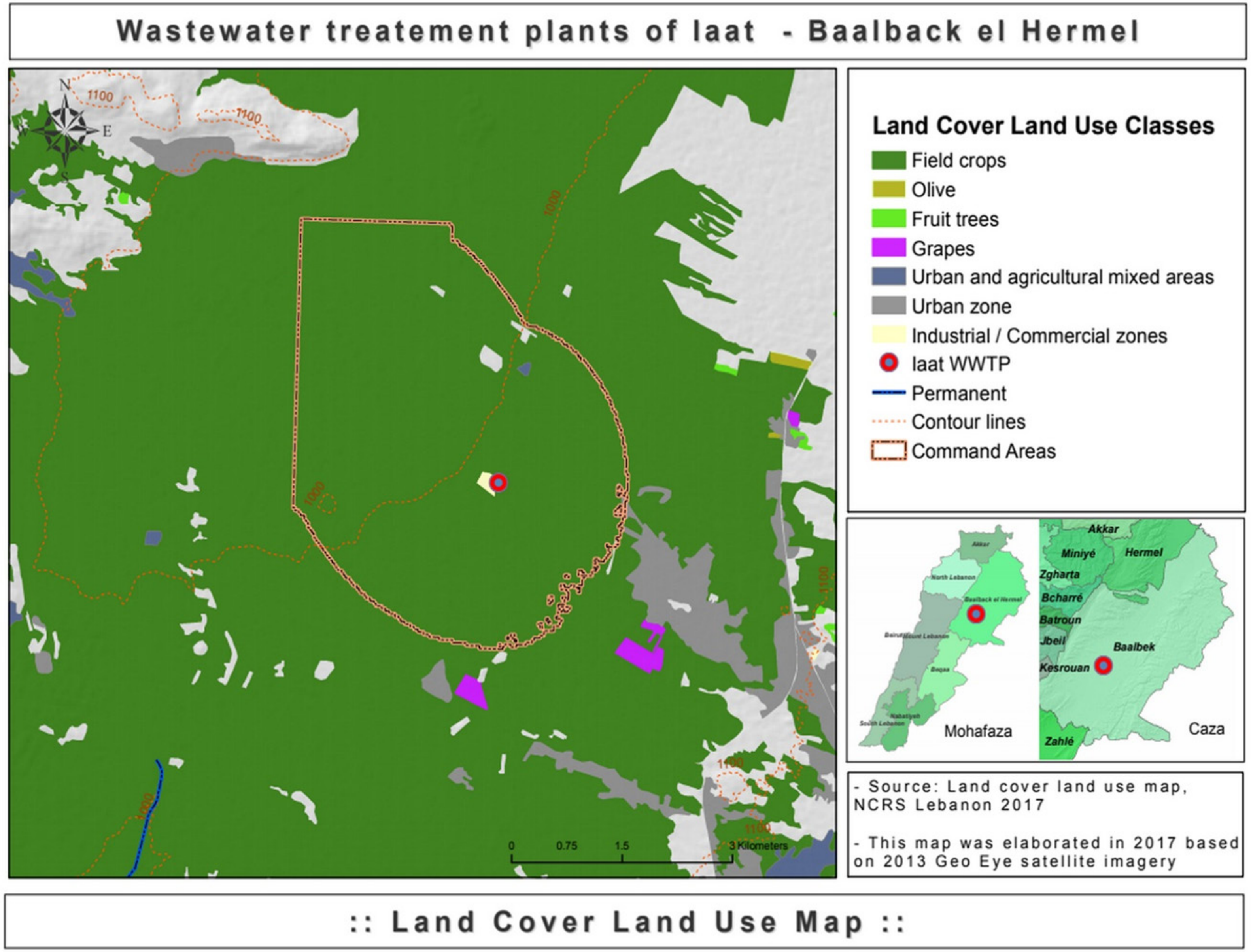

Figure A9.24. LULC map of the vicinity of the Iaat WWTP.

H. Case Study: Yammouneh WWTP

Characteristics of Yammouneh WWTP	
Location	Yammouneh (Figures A9.25, A9.26)
Operational status	Partially operational (only preliminary treatment)
Operation interval	Completed in 2004, operated for two years under CDR before being transferred to BWE.
Design capacity	788 m^3/day (KREDO 2015a)
Actual average daily flow	50 m^3/day[107]
Treatment technologies	Activated sludge
Level of treatment	Secondary
Effluent quality	Not compliant with MoE standards
Effluent discharge location	Yammouneh Lake
Energy supply	Not available
Managing institution(s)	Bekaa Water Establishment[108, 109]
O&M costs and recovery	Not available. Costs should be recovered by the BWE.
Problems	• Many items of equipment of the WWTP are damaged and need to be replaced. • Parts of the sewage collection network are reported to be leaking and contaminating Lake Yammouneh.[110] • BWE is unable to pay for O&M costs. Sustainability of the WWTP is uncertain. • Distrust from Yammouneh Municipality toward the planning, implementation and management of the WWTP by governmental authorities.

[107] This was the average daily flow during the period when it was operational (KREDO 2015a)
[108] Two 'daily workers' from Yammouneh are hired by the BWE.
[109] The Yammouneh Municipality is not directly involved in operating the WWTP but participates in discussions during the preparation phase of upcoming projects (sewers, building of new station, rehabilitation of the existing station) and shares maps and data. The municipality is also involved in the repairs and maintenance of sewer lines even though the vice mayor considers that it is not in the municipality's mandate to carry out such tasks (Interview, February 2020).
[110] Recently, BWE and MEW made plans to rehabilitate the WWTP with an extension of the sewage network. Dar El Handassah Nazih Taleb was asked to perform an assessment and rehabilitation study within a budget of USD 250,000 (according to an interview with BWE in February 2020).

Potential for Water Reuse in Irrigation [111]		
Villages included in the WWTP command area	Two main scenarios are possible: 1) treated water is diverted to the side of Yammouneh to be used in the Yammouneh plain; 2) treated water is diverted to the irrigation canals supplied by Yammouneh Lake through a tunnel dug through the mountain and is used by the villages of Chlifa, Deir El Wessaa, Btedhi, Mrah El Sayeh, Flewa, Boudai, Saideh and Chmistar (Figure A9.27).	
Number of farmers	Around 100 farmers	
Actual reuse potential area	Lower cost scenario Higher cost scenario	0 ha 0 ha
Actual reuse potential score	Lower cost scenario Higher cost scenario	0 0
Ideal reuse potential area	Lower cost scenario Higher cost scenario	16.8 ha 16.8 ha
Ideal reuse potential score	Lower cost scenario Higher cost scenario	0.94 0.94
Existing agriculture and main crops	Wheat, potato, vegetables, and cannabis, which is planted widely in the region (Figure A9.28).	
Existing irrigation systems	• Open canal systems are used to distribute water from local springs in the Yammouneh plain. In the summer, most of the land is irrigated by private wells. • Water collected in the Yammouneh Lake is diverted to the eastern part of the mountain through a tunnel. From there, water goes into two main canals and is distributed to several villages through open-canal networks.[112] Wells are used to complement the use of surface water especially in the villages downstream.	
Irrigation governance and water rights	• At the level of Yammouneh plain, irrigation is managed by the farming community. • The irrigation network supplied by Yammouneh Lake through the mountain tunnel is managed by the BWE.[113] However, local communities and tribal power dynamics influence water allocation.	
Existing wastewater reuse practices (informal reuse)	Wastewater (or partially treated water) is reused indirectly by farmers benefiting from Yammouneh Lake.	
Sludge disposal and existing reuse practices	Unclear	
Opportunities and obstacles to organized reuse	Opportunities	Obstacles
	• Organized reuse could alleviate pressure on irrigation water use from groundwater in the summer. • The municipality of Yammouneh is willing to contribute to planning, implementation and management of a reuse project. The municipality does not seem to mind that treated water is allocated outside the Yammouneh plain.	• The WWTP is currently not operational and its rehabilitation requires large funding. • It is unclear how BWE will be able to financially support the operation of the WWTP. • The multiplicity of irrigation systems and user groups included in the command area might create conflicts over water allocation if infrastructure is planned.

[111] Most of the information in this section was obtained from interviews with BWE employees, the vice-mayor of Yammouneh and farmer/environmental activist Nasser Chreifin, February 2020.
[112] This project was built during the French Mandate with the purpose of irrigating a part of the Northern Bekaa. As per the plan, 30% of the water should go to Chlifa, Deir El Wessaa, Btedhi, Abou Slaybi and Mrah El Sayed, and 70% of the water to Flewa, Boudai, Saideh and Chmistar.
[113] A team of 15 employees working for BWE manage water distribution. Farmers subscribe to the service and pay the following irrigation fees: LL 6,000/hour in winter; LL 7,000/hour in spring; LL 9,000/hour in summer.

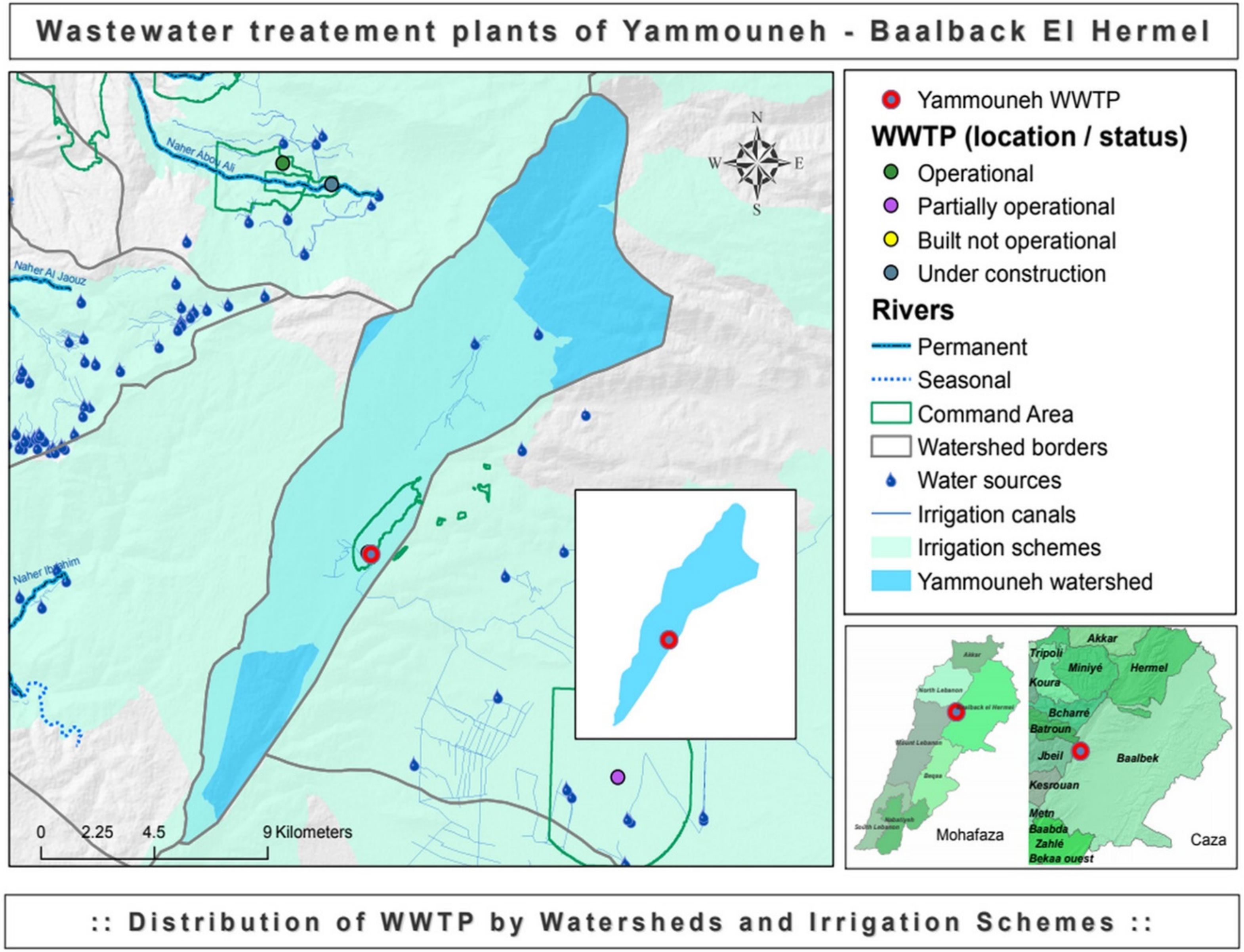

Figure A9.25. Location map of the Yammouneh WWTP.

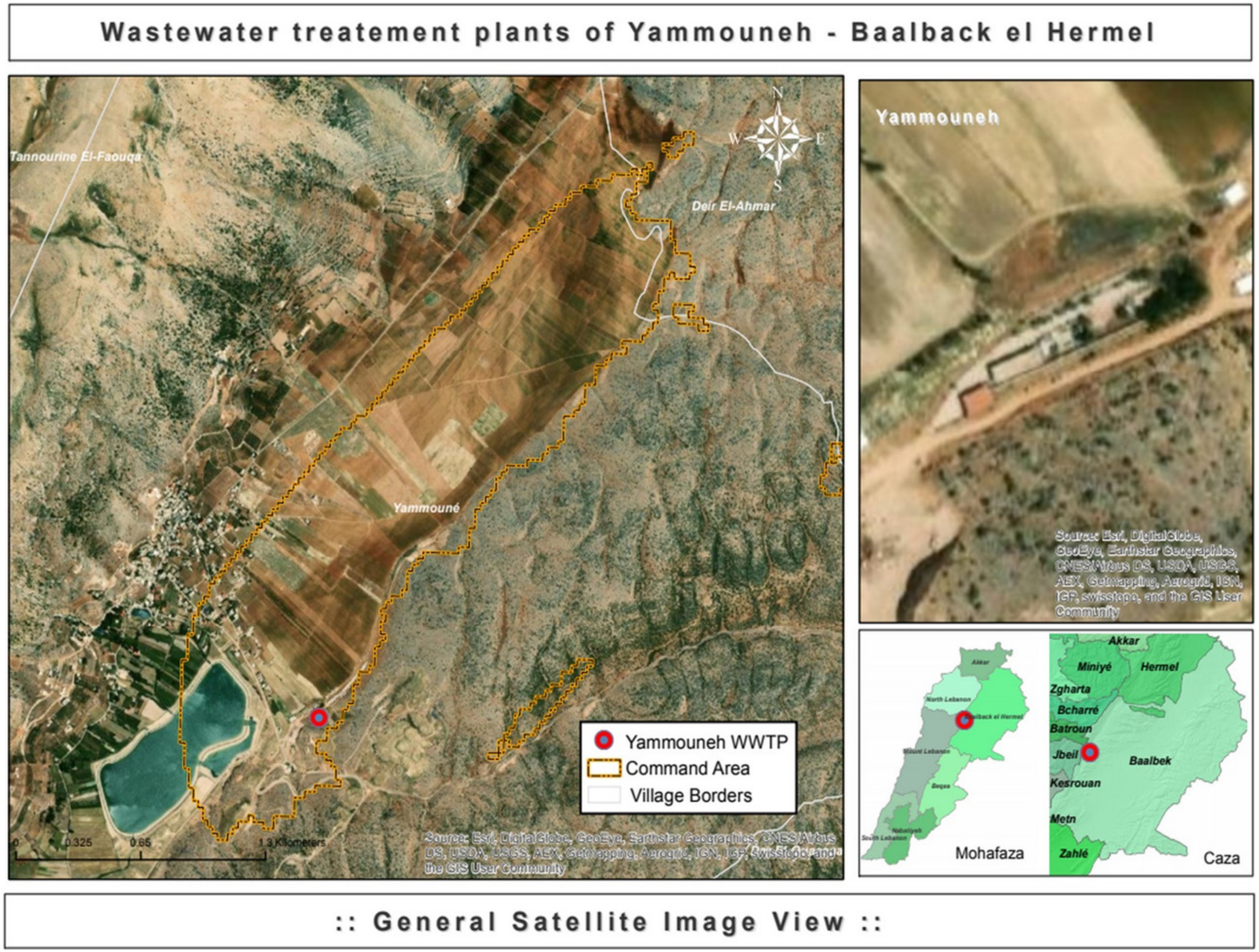

Figure A9.26. Satellite map of the Yammouneh WWTP

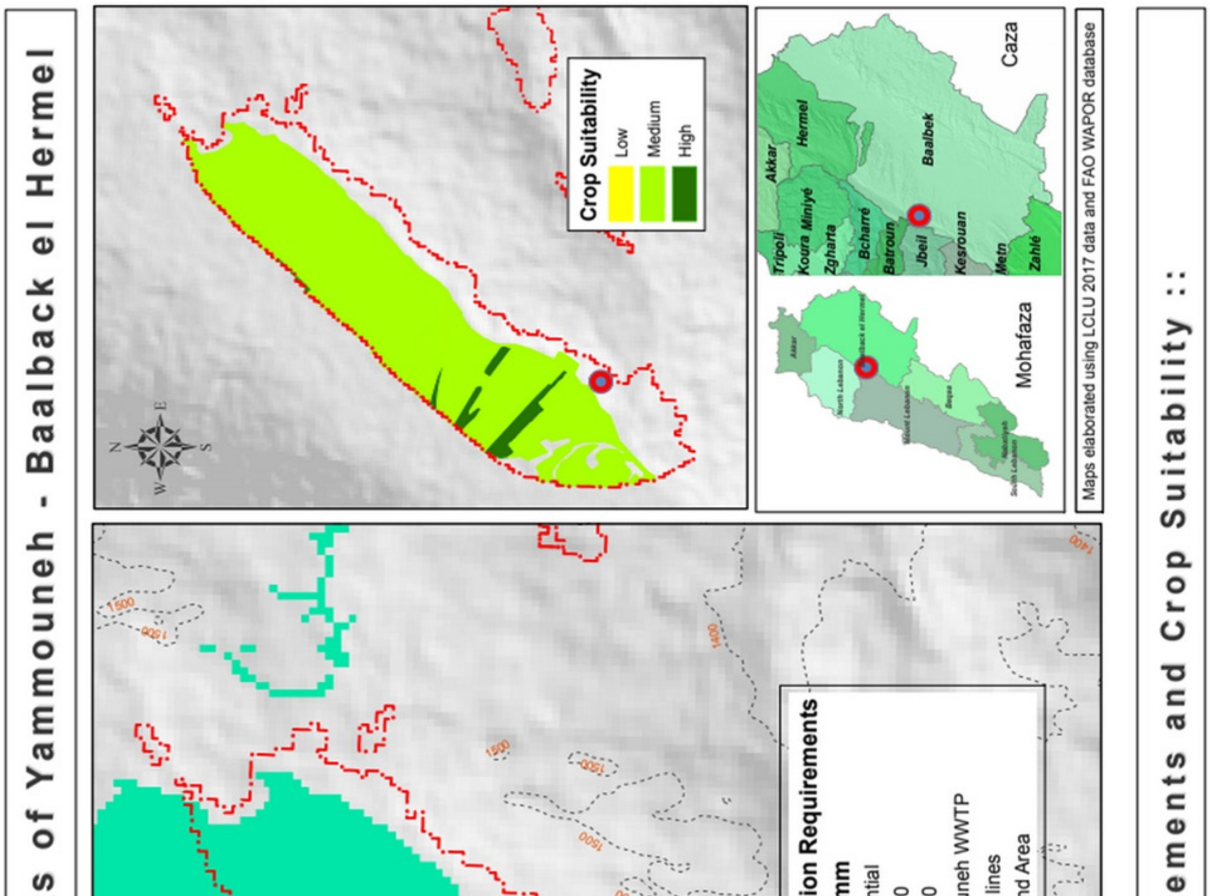

Figure A9.27. Net irrigation requirement at the Yammouneh WWTP.

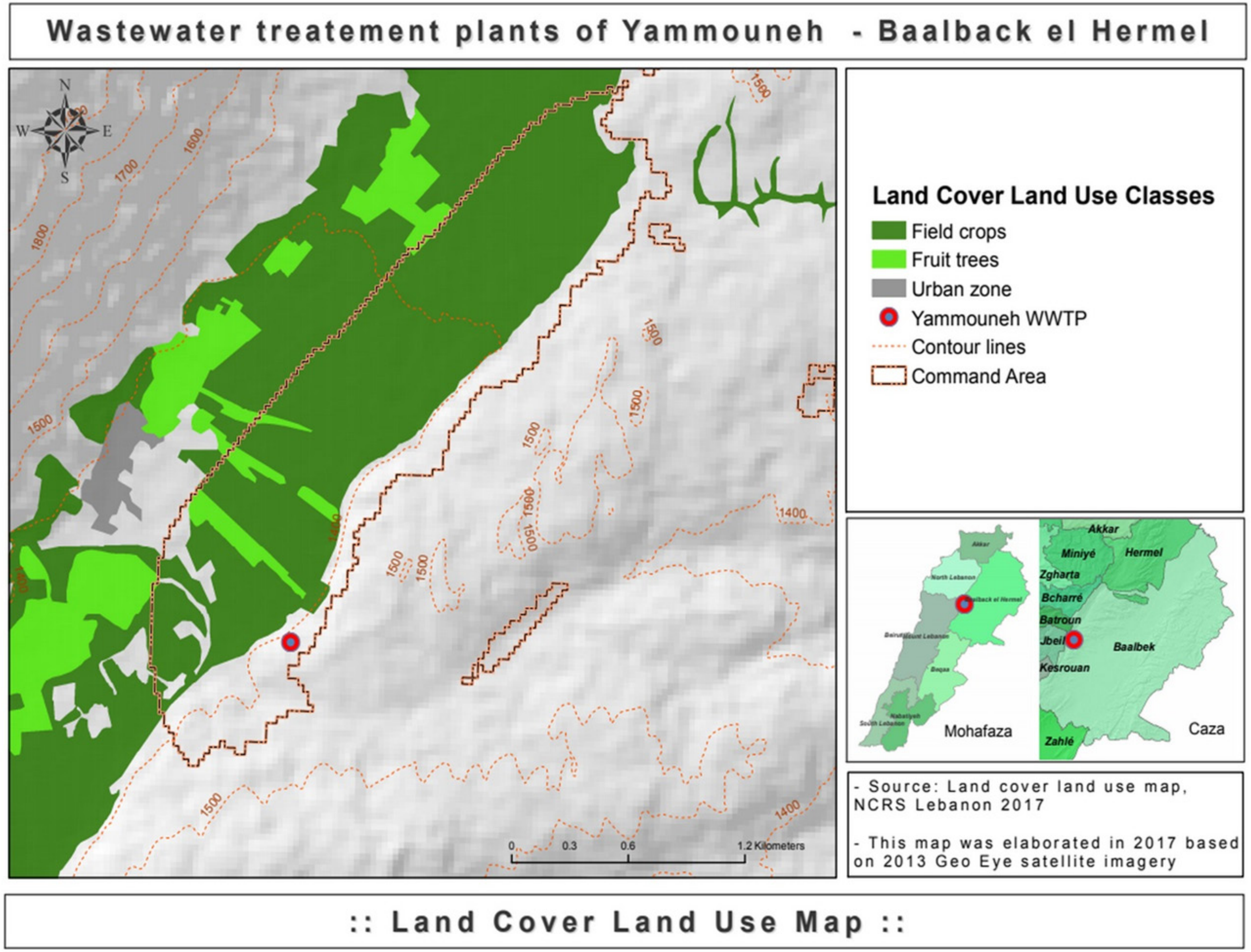

Figure A9.28. LULC map of the Yammouneh WWTP area.

Annex 10. Questionnaire Samples.

Interview Questionnaire for AFD

Introduction

The purpose of this study is to produce a realistic assessment/baseline of the potential for use of treated wastewater (WW) for irrigation. This has a number of dimensions, and talks about the immediate as well as future potential related to existing and planned WWTPs.

Purpose of the Interview

- Understanding AFD's strategy for the wastewater sector, its technical and governance components.
- Understanding AFD's wastewater treatment project for North Lebanon, and if possible, obtaining data about different planned as well as operating plants.
- Understanding the place of wastewater reuse in this project.
- Reaction to the current crisis and planning regarding WW management and reuse (if applicable).

Questions

- We understand that AFD has been funding a project regarding the improvement of wastewater management capacity in the Akkar region. Can you give us more details about the project?
- When did the project start? Who initiated it/how did it come to be? What are the different components of the project? WWTPs? Networks? Capacity building? Technical assistance?
- Would it be possible to share explanatory project documents/designs including locations, technical specs of WWTPs, etc.?
- Which Lebanese institutions are directly involved in the planning and implementation of the project?
- What role do municipalities have? Municipalities seem to have a larger role in this project. Was this strategy suggested by MEW or CDR or is it AFD policy to go for more local participation? And why?
- What role for NLWE?
- What is the planning horizon and project implementation schedule?
- How do you think this project has been impacted by the multiple crises that Lebanon is suffering currently?
- How is sustainability of the project affected by the current economic crisis?
- Is there a role for wastewater reuse in the project?
- If so, what are the main challenges facing the water reuse components of the project? (economic, administrative, social, cultural, political)?
- Does AFD have other experiences with wastewater reuse in Lebanon? If so, what are they and what are the lessons learned from these experiences/projects?
- Do you have other observations on the potential/necessity for wastewater reuse?
- What are the implications of the multiple and recurrent crisis for the water/wastewater sectors and for WW reuse?
- According to your experience, what are the three most important challenges to implementation of (wastewater management and) treated wastewater reuse projects in Lebanon today?
- Which do you think are the three most difficult and most urgent administrative hurdles to overcome? And how do you think this could be achieved?
- What other administrative issues could potentially improve wastewater management and eventually reuse? From past interviews we know that reflections about different types of collaboration between RWEs and municipalities are being considered. Have you encountered similar reflections? What obstacles exist to such a strategy?
- How does AFD plan its development strategy for the Lebanese wastewater sector in the light of these observations?

Interview Questionnaire for MEW

Introduction

The purpose of the study is to produce a realistic assessment/baseline of the potential for treated wastewater reuse for irrigation. This has a number of dimensions, and talks about the immediate as well as future potential related to existing and planned WWTPs.

Topics

- Challenges regarding general planning, implementation and management of the wastewater sector more generally as well as the place of reuse in these plans.
- The mechanics of interdepartmental and interministerial coordination. MEW-CDR-OPM-MoA-MoE/MEW-GD-RWE-LRA. How does this affect planning (for WW reuse)?

Questions

- What are the experiences of MEW with treated WW reuse? Have there been any successful projects MEW has been directly involved with?
- According to your experience, what are the three most important challenges to the implementation of (wastewater management and) treated wastewater reuse projects in Lebanon today? (the law and implementation decrees as well as standards regarding reuse water quality are in the process of production. Have these efforts been coordinated with MEW and if so, how?)
- Water quality management is probably the most important technical issue regarding wastewater reuse. What are the three most important technical issues related to quality management?
- Beyond water quality management, what are the three most important technical challenges to treated wastewater reuse?
- What do you think are the three most difficult and most urgent administrative hurdles to overcome? And how do you think this could be achieved? (Code d'leau—is it law and why is it still under discussion?)
- Specifically, how would you assess the role of CDR in the process? How do you think this could be better managed?
- How does the monitoring of RWEs by MEW work? How do you think the legal relationships between RWE and MEW could and should be improved? Where do you think more decentralization or recentralization could/would be called for? Which responsibilities should be given to RWEs and which should be given to MEW? How would this improve the operation of RWEs and MEW?
- What are the other administrative issues that could potentially improve wastewater management and reuse?
- How do you think WW reuse management responsibilities should be divided among the different actors? More precisely, (1) who should be responsible for water supply to farmers and allocate water within irrigation systems, and (2) who should be responsible of monitoring water quality?
- How do you think cooperation between RWEs and municipalities can be strengthened? What do you think are possibilities to organize cooperation between RWEs and municipalities on WW treatment? What could be the terms of such cooperation? Do you see possibilities to achieve a division of fees that can benefit both? Would such a partnership have to go through the ministry? It was mentioned to us that a similar agreement was discussed with the Union of Municipalities of Lake Qaraoun for the management of the Aitanit WWTP. Can you tell us more about this experience?
- What are the economic challenges that you see facing the wastewater sector?
- Can you identify any social/cultural obstacles that could stand in the way of the implementation of the reuse project? If so, how could they affect such projects directly?
- Can you think of political obstacles that could arise or have arisen in relation to wastewater treatment and water reuse projects?
- How far has the update of the wastewater management master plan progressed?
- Can you share with us the updated wastewater management master plan as well as the corresponding data?
- Does MEW currently plan with wastewater reuse as a component of wastewater resource management and irrigation management?
- The consultant producing the updated WW management plant, Bureau Technique pour le Développement (BTD), seemed to favor large-scale WWTPs over smaller WWTPs citing the failure of small plants. Yet, in the Chouf, in the Bekaa, smaller plants seem to be working whereas none of the larger plants seem to be working at capacity? How has the ministry guided master planning by the consultant?

- The current crises in Lebanon will certainly impact the work of MEW: How is the current health crisis affecting the ministry's work in the sector? How is the financial crisis affecting the work of MEW? With USD shortages affecting numerous projects, what are potential solutions to address the dramatic exchange rate issues?
- Do you think that treated WW reuse could/should or could not/should not be a source of additional funds for RWEs?
- Given the large investment needs of the RWEs and the ministries and the large risks such investments pose for the private sector, how do you think MEW or the government/state could mobilize additional financial resources?
- Do you expect that foreign funding will be forthcoming in the future? What are the dangers to foreign funding that you can identify? In the potential absence of international funding, is MEW exploring other options?
- Coordination and cooperation between ministries and within ministries seem to be problematic at times? As the difficulty of obtaining the GIS data for this study confirmed.
- What do you think would be useful steps to effectively improve these difficulties? Where do you think such reforms should start?
- What are the implications of multiple and recurrent crises for the water/wastewater sectors and for water reuse?

Interview Questionnaire for WWTP Operator/BWE Official

- What is your role at the plant and what tasks are you responsible for?
- How long have you been with BWE or with the company/operator?
- When was the plant built?
- How long has the plant been operational?
- Have there been issues with operations and maintenance?
- Which institutions are responsible for the operations and maintenance of the plant? How is it organized (type of contract)?
- What are the costs associated with O&M? Where does funding/cost recovery come from?
- How many workers are there in the plant?
- How many hours a day does the plant operate?
- What obstacles interfere with the proper operation of the plant?
- What is the role of CDR/MEW/RWE/municipality in the management of the plant?
- Does a wastewater tariff exist? What do you think the best structure for a tariff would be?
- What is the fate of the treated effluent? Does the WWTP incorporate a water reuse system?
- How often are lab tests performed?
- Can we have a copy of the latest lab tests or information about the ranges in which the test fall?
- Is wastewater currently used for irrigation?
- What do you think of treated water reuse in agriculture? What obstacles might impede treated WW reuse? What would make a treated water reuse system successful?
- Do you think farmers should be paying for water in general? And treated wastewater in particular?

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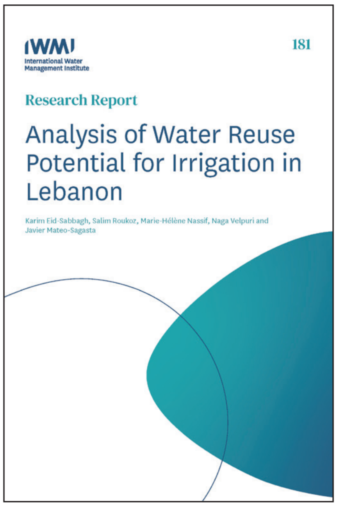

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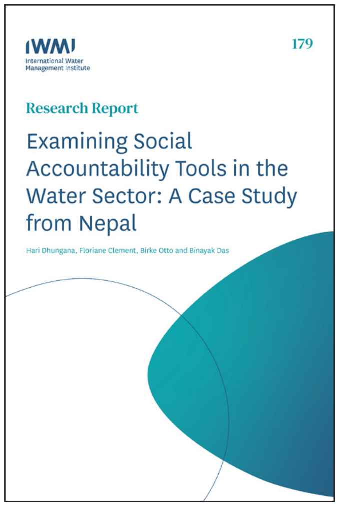

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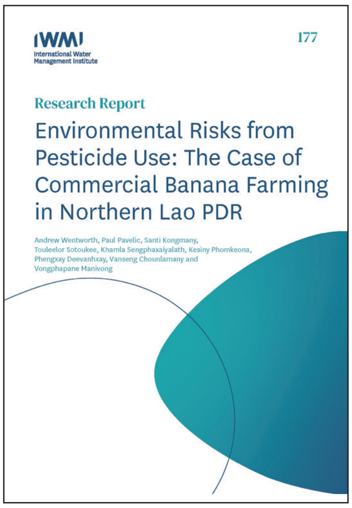

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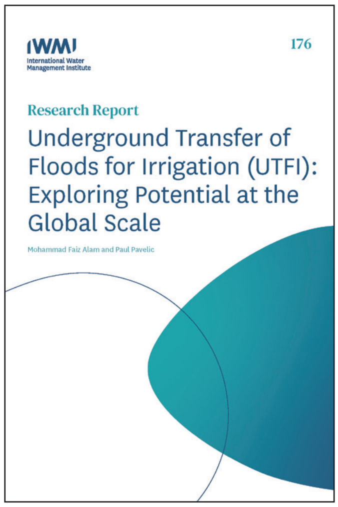

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