TALANOA

- water -

Deliverable 2.2: Water Accounting Database V2.0

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Executive summary

The Water Accounting Database serves as a guide for implementing the Water Accounting Plus (WA+) procedure through the utilization of FAO WaPOR, offering a wealth of resources, including user manuals and step-by-step videos, to support users at every stage of the WA+ process. The report delivers an overview of the status of input data and the adopted methodologies of the tool in each water laboratory. At the project's inception and in the first version of this report, a distinct approach to the WA method was envisioned, combining WaPOR and WA+. However, engagements with stakeholders during science-policy workshops in various water laboratories revealed a preference for adopting and, if needed, enhancing the existing water accounting methodologies already employed in these labs. The report establishes the foundational framework for conducting a WA+ run by first introducing the Water Accounting approach,effectively distinguishing it from the Water Accounting Plus framework, and presenting the essential engines responsible for sourcing a portion of the input requirements, particularly the FAO WaPOR Spatial Database and the Hybrid Surface Energy Balance (HSEB) model for water productivity. This report enables water laboratories to effectively utilize the tool and generate comprehensive WA outputs.

List of Acronyms

Acronym	Definition
AUB	American University of Beirut
BDC	Basin Determined Contribution
BRGM	French Geological Survey
CESBIO	Centre d'Etudes Spatiales de la Biosphère
CMCC	Centro Euro-Mediterraneo sui Cambiamenti Climatici
CONUS	Continental United States
ET	Evapotranspiration
FAO	Food and Agriculture Organization
GEE	Google Earth Engine
GPAI	Green Power for Agriculture and Irrigation
GRACE	Gravity Recovery and Climate Experiment
GRDC	Global Runoff Data Center
GRaND	Global Reservoir and Dam Database
HSEB	Hybrid Surface Energy Balance
IGME	Instituto Geológico y Minero de España
INAT	Institut National Agronomique de Tunisie
INRAE	National Research Institute for Agriculture, Food and the Environment
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
LCC	Land Cover Classification
LRB	Litani River Basin
LPIS	Land Parcel Identification System
LST	Land Surface Temperature
MODIS	Moderate Resolution Imaging Spectroradiometer
MYC	Meet Yazid Canal Command Area
POI	Point of Interest
SMWB	Soil Moisture Water Balance
USAL	Universidad de Salamanca
VIIRS	Visible Infrared Imaging Radiometer Suite

WA	Water Accounting
WA+	Water Accounting Plus
WaPOR	Water Productivity through Open Access of Remotely sensed derived data
WDPA	World Database on Protected Areas
WP	Water Productivity

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1. Introduction to Water Accounting

Water shortage and increased competition for water among various sectors necessitate effective water management techniques and decision-making procedures. An evidence-based grasp of the basin hydrological processes, manageable and unmanageable water flows, the relationship with land use, and options to alleviate the negative consequences of water depletion on communities are all prerequisites to a clear understanding of proper water management. Water availability per capita is decreasing in several water-stressed river basins, many of which are in arid climates (Molden, 2007).

Water Accounting (WA) enables the identification of key issues in river basins, as well as restrictions and potentials for increased climate resilience. WA can be defined as the systematic acquisition, analysis and communication of data and information relating to stocks and fluxes of water in natural, disturbed or heavily engineered environments, within a geographical domain (Steduto, Faurès, Hoogeveen, Winpenny, & Burke, 2012). Water Accounting may go beyond conventional water measurements to address challenges related to uncertainty, accessibility, and governance. WA is becoming more widely promoted as an integral component of Integrated Water Resource Management (IWRM) programs and has become an essential part of any policy or program addressing water scarcity. Water scarcity can only be explained, measured, and/or mapped if there is a thorough understanding of present and projected supply and demand discrepancies, as well as how this affects consumers. Most WA techniques are designed to achieve this goal to describe the effect of water scarcity onwater users.

The International Water Management Institute (IWMI) developed the WA system with the aim of measuring water depletion rather than withdrawals to eliminate errors and account for Evapotranspiration (ET). The method enables the computation of the output per unit of water that has been effectively depleted, while dividing water depletions into beneficial and non-beneficial use. The WA method has been applied in many countries around the world on several irrigation system studies, as well as on the river basin scale (P. Karimi, Bastiaanssen, & Molden, 2013).

1.1. Water Accounting Plus (WA+) Framework

In the original IWMI Water Accounting framework, aspects of information that are crucial on a basin level are not considered. Some of the IWMI Water Accounting components are broad brushes for basin-level analysis. For instance, water depletion is limited to crop evapotranspiration in the irrigation service setting, whereas at the basin scale, it includes an all-inclusive system by considering municipalities, industries, fisheries, forestry, dedicated wetlands, and all other uses.

WA+ is an analytical framework for river basin water resources planning, operation, monitoring, and evaluation that focuses on several aspects of water management and various hydrological processes, and the linkages between them. WA+ considers the impact of diverse land use groups and landscape evapotranspiration on the water cycle while providing explicit spatial information on water depletion and net withdrawal processes in complex river basins (P. Karimi et al., 2013). WA+ was developed by IHE-Delft and its partners FAO and IWMI and is based on the IWMI's early definitions (Molden, 1997), however, some differences with WA are prevalent. WA+ makes the link between land use and ET apparent, hence conveys the influence of changes in land use on exploitable water resources. Besides defining manageable and non-manageable depletions and quantifying the processes, WA+ differentiates between surface and groundwater systems by accounting for their distinct management alternatives and legal requirements. Additionally, WA+ designates benefits from managed water use by computing incremental ET for various land use categories and water user groups. A final significant difference between WA and WA+ is that the latter divides consumed water (ET) into evaporation, transpiration, and interception to evaluate beneficial and non-beneficial ET.

WA+'s primary goal is to make water accounting easier to utilize in terms of available input data and to aid in strategic water resource management decisions. WA+ consists of four sheets that concisely summarize the water management situation in complex river basins (Table 1).

Table 1. Water Accounting Plus (WA+) Sheets (P. Karimi et al., 2013)

Water Sheet	**Purpose**
Resource Base	Hydrological, manageable, utilizable flows, water security, sustainability
Evapotranspiration	Beneficial & non-beneficial flows
Productivity	Biomass returns, carbon sequestration, food security
Withdrawal	Management, regulations, allocations

The Resource Base Sheet is essential for quantifying water volumes, including inflows, processes of water transfer, as well as exploitable water and outflows. The Evapotranspiration Sheet makes a distinction between ET processes that are managed, manageable or non-manageable, and further arranges the processes into beneficial and non-beneficial ET. The Productivity Sheet summarizes the agricultural production (biomass production) per unit of water. While accounting for the four land categories, namely conserved, utilized, and modified land use, as well as managed water use, the productivity sheet communicates water productivity (kg/m3) and biophysical land productivity (kg/ha). The fourth sheet, the Withdrawal Sheet, allows for the quantification of surface water and groundwater and discerns between them. For the purpose of the TALANOA project, Sheet 1 – Resource Base –

is of interest, as it provides average flow values for a river basin over a specific period. The purpose of sheet 1 is to provide a summary on over-exploitation, manageable, unmanageable, exploitable, reserved, utilized, and utilizable flows at river basin scale. Sheet 1 determines the difference between landscape ET and incremental ET and accounts for the evaluation of environmental commitments and legal agreements.

The input data for the WA+ sheets may generally be quantified by satellite measurements, except for the Withdrawal sheet, which is more tied to traditional water accounting techniques. For an effective WA+ procedure, basin outflow and inter-basin transfer flows must be always monitored. Remote sensing is increasingly being used in applications of water performance estimations given its cost-effective advantage and its possibility to derive data at different scales where field measurements are not available (Hellegers, Soppe, Perry, & Bastiaanssen, 2009). Some river basins requiring WA+ procedure may be poorly gauged, or ungauged at all, which necessitates the application of remote sensing in the spatial framework. Additionally, remote sensing techniques are recognized for their low cost of data acquisition, as well as instant data availability. Remote sensing removes the burden of ground and survey data collection, which often demands a large amount of labor for collection and data analysis. Due to its independence of hydro-meteorological measurements, WA+ can be used almost anywhere, allowing researchers and policymakers to gain a finer understanding of the state of water resources on a national, continental, and global scale. WA+ is therefore a useful tool for water resource planning and development, especially in overpopulated catchments where water supplies are at stake.

Despite the many advantages of remote sensing techniques in WA+, there exists some limitations. Since WA+ does not analyze flow from one area to another, but rather summarizes water depletion in a basin, WA+ cannot replace hydrological models. Additionally, since satellites measure hydrological processes indirectly, all satellite data parameters have a level of uncertainty and error that must be considered (P. Karimi et al., 2013).

For implementing the WA+ framework, satellite measurements are not an input requirement for all sheets and can nevertheless be compounded with data from hydrological models and water allocation models (P. Karimi et al., 2013). However, satellite measurements ensure a decreased dependence on local data sources and agencies, hence guarantee standardized and transparent data collection schemes. Under TALANOA, the FAO WaPOR database (WaPOR v2.0), as well as other open-access worldwide databases, are used to carry out the rapid Water Accounting Plus (WA+) modeling approach. For the project, the Lebanese Lab represented by the American University of Beirut will provide ET data for Water Accounting using the Hybrid Surface Energy Balance (HSEB) model in areas where WaPOR data is not available (i.e., Europe) (Jaafar, Mourad, & Schull, 2022).

1.2. FAO WaPOR Spatial Database

WaPOR, the Food and Agriculture Organization of the United Nations (FAO) portal to monitor Water Productivity through Open access of Remotely sensed derived data, provides Water Productivity (WP) data components at varied spatial scales and temporal resolutions for Africa and the Near East (FAO, 2020). The publicly accessible FAO WaPOR database (2009-present) provides near real-time information and uses satellite data and open-source algorithms that allow the monitoring of agricultural water productivity at different scales. Aside from the primary goal of monitoring water productivity, the data available on the portal can be used for a variety of other applications, including: the monitoring of water resources through water accounting; the monitoring of changes in agricultural production, the reporting of water consumption of specific crops, to name a few. Data download of key variables related to water and land productivity evaluations, direct data inquiries, area statistics, and time series analysis are all possible through the portal. Datasets are available at three spatial resolutions: continental (250m), national or basin scale (100m), and sub-national (30m) scales, as well as on various temporal resolutions depending on the investigated layer: daily, dekadal (10-day), monthly (30-day), seasonal, and annual. The WaPOR catalog includes regularly updated raster datasets of Actual Evapotranspiration and Interception (ETIa), Evaporation (E), Transpiration (T), Interception (I), Precipitation, Net Primary Production (NPP), Gross Biomass Water Productivity, Net Biomass Water Productivity, Total Biomass Production (TBP), and Land Cover Classification (LCC), among others.

For the purpose of WA+, WaPOR input data layers are grouped into three categories: 1) climate, namely precipitation at a daily and monthly 5km resolution; 2) land use, namely land cover classification at a yearly 100m resolution; and 3) hydrology, including ETIa and I at a 100m spatial resolution and a monthly and dekadal temporal resolution respectively, as well as Reference ET at a 20km monthly resolution. Since WaPOR data layers are not available for some areas of the world, Europe for instance, WaPOR datasets were compounded with ET data derived from the HSEB model.

1.3. HSEB Model for Water Productivity

The Hybrid Surface Energy Balance (HSEB) model, developed by the Lebanese lab, is a single-source operational global model for monitoring evaporative stress and evaporation at the field-scale. The model is an ET product that minimizes the discrepancy between modeled and actual water use for proper water accounting (Jaafar et al., 2022). HSEB utilizes products from Sentinel-2, Landsat, Visible Infrared Imaging Radiometer Suite (VIIRS) LST (Land Surface Temperature) and Moderate Resolution Imaging Spectroradiometer (MODIS) LST to compute ET. HSEB significantly enhances the temporal and spatial aspects of ET mapping while operating in Google Earth Engine (GEE) as a time series, employing 100m Copernicus land cover data and global atmospheric variables. HSEB was evaluated at the field scale against 29 flux towers in the Continental United States (CONUS), Europe, and Australia. HSEB runs TIR data sharpened with harmonized surface reflectance data from Landsat, Sentinel-2, and digital elevation data in a GEE environment. The sharpening procedure is two-fold and is performed through a random forest sharpener and a TsHarp algorithm. Figure 1 presents the general diagram for the modeling procedure of HSEB (Jaafar et al., 2022).

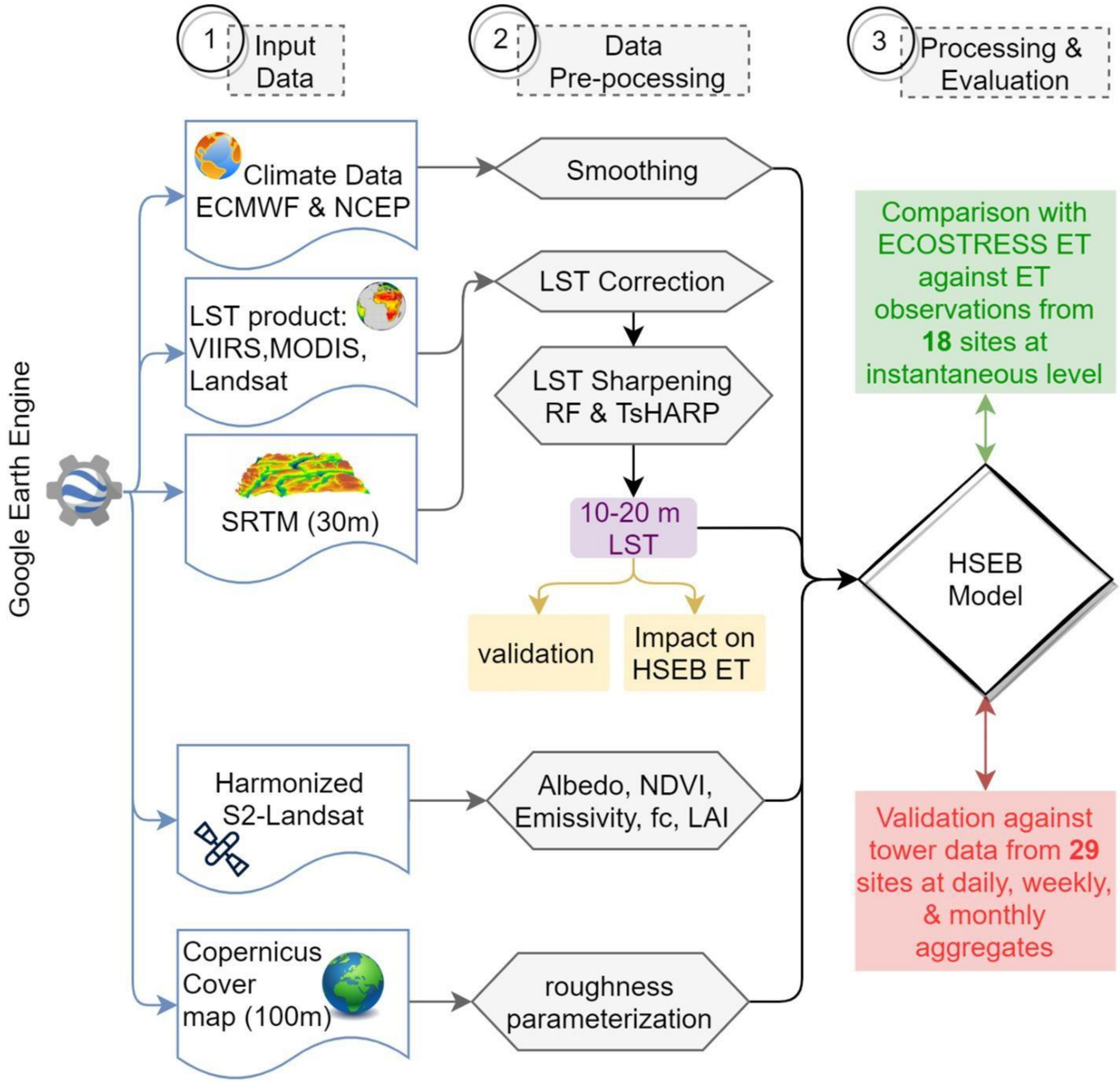

Figure 1. Workflow for the generation of near-daily HSEB-ET (10-20m)

Operating in Google Earth Engine global dataset inputs, HSEB was constructed over target investigated sites (US, EU, and Australia). The workflow exhibits the processing stream flowing into the HSEB model and displays the comparison of HSEB to ECOSTRESS ET and tower flux data. Over fields in Lebanon, sharpened LST data were compared to LST observations and benchmarked with the ECOSTRESS LST product.

As part of the ongoing collaborations between the different water laboratories under TALANOA-WATER, the Spanish water lab represented by Universidad de Salamanca

(USAL) is utilizing ET data derived from HSEB model over the Cega catchment. The Lebanese lab has provided ET time-series data over the Cega catchment in Spain from 1984 to 2020 (Figure 2). ET data is key to perform biophysical modeling, herein identify actual water use, while accounting for illegal water use. Section 3.1 of this report elaborates more on the Spanish Water Accounting Plus use case for transformational adaptation. The Lebanese lab is further looking into prospective collaborations with other water laboratories by providing ET data on their respective basin case studies.

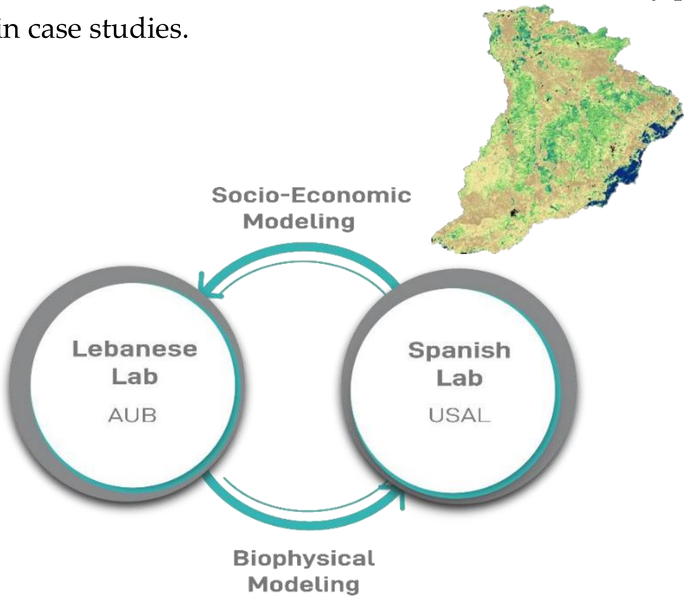

Figure 2. Ongoing collaborations on ET time-series data using HSEB model

2. WA+ General Running Procedure

Running WA+ involves deriving remotely sensed data from the WaPOR database, preparing the data for computations of monthly water balance for WA+ purposes, and performing quality checks such as comparing WaPOR precipitation data with in situ observations, as well as Actual Evapotranspiration (Eta) with other remotely sensed Eta estimates. A workshop on the use of WaPOR data in Water Accounting Plus was earlier organized by the Lebanese lab on January 7, 2022. The workshop explained how to run the Rapid WA+ on a study area and prepared participants for applying WA+ to their basins. Any water laboratory seeking to run the WA+ model over its case study will follow the general procedure of accounting, namely 1) collecting required data (remotely sensed and ground-truth) for the study period, 2) preparing the data for monthly computations of water balance using Python scripting, and most importantly 3) performing several quality checks before employing the data in WA+.

2.1. WA+ Data Inputs and Outputs

Input data for running the WA+ requires datasets derived from WaPOR, as well as global data sourced from several open-access databases (see figure 3). For the purpose of running the WA+ tool, input data derived from WaPOR incorporates monthly actual evapotranspiration and interception, dekadal interception, monthly reference evapotranspiration, daily and monthly precipitation, as well as yearly land cover classification (Table 2).

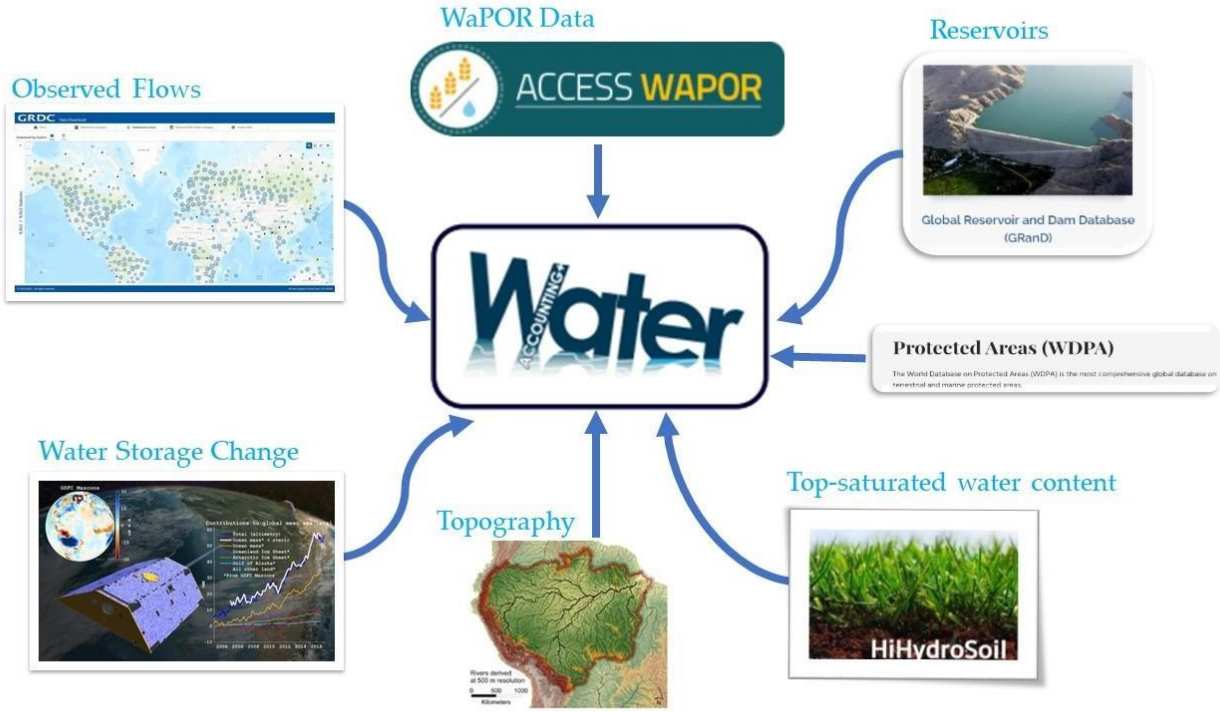

Figure 3. Overview of WA+ input data

Table 2. WaPOR input data layers for running the WA+ model

Data Layer	Temporal Resolution	Spatial Resolution	Data Tag
Precipitation	Daily	5km	CLIMATE
Precipitation	Monthly	5km	CLIMATE
Actual Evapotranspiration and Interception	Monthly	100m	HYDROLOGY
Interception	Dekadal	100m	HYDROLOGY
Land Cover Classification	Yearly	100m	LAND USE
Reference Evapotranspiration	Monthly	20km	HYDROLOGY

The first step needed to complete WA+ is therefore collecting the required data. Water laboratories have collected input data for their WA+ runs, which are accessible through the TALANOA_Sourcebook_Metadata - Google Sheets. This data can be classified into remotely sensed spatial data and the time-series data of ground observations. The remotely sensed data includes data on catchment boundary, land use, precipitation, ET, change in storage, protected areas, and reservoirs. The WA+ modeling approach also includes global data derived from several databases (Table 3). Basin boundary can be obtained from HydroSHEDS (or local authorities or can be delineated from digital elevation models (DEM)).

In WA+, the land-use map divides the basin into four major categories which are Protected Land Use (PLU): areas that have a special nature status and are protected by National Governments or Internationals NGOs, Utilized Land Use (ULU): areas with minimal human influence, and where the water flow is essentially natural, Modified Land Use (MLU): areas where the land use has been modified and water is not diverted, but land use affects all unsaturated zone physical process such as infiltration, storage, percolation and water uptake by roots, and Managed Water Use (MWU): areas where water flow is controlled by humans via irrigation canals, pumps, hydraulic structures, utilities, and drainage systems. Data on terrestrial and marine protected areas can be retrieved from the World Database on Protected Areas (WDPA). Data on reservoirs can be retrieved from the Global Reservoir and Dam Database – GDW: Global Dam Watch (GRaND). Monthly total water storage change can be derived from the Gravity Recovery and Climate Experiment – NASA mission (GRACE). Additionally, data on topsoil saturated water content can be retrieved from HiHydroSoils, and data on monthly observed flows can be obtained from the Global Runoff Data Center (GRDC).

Table 3. Global input data layers and time-series data for running the WA+ model

Data Layer	Resolution	Data Type	Source	Data Tag
Topsoil Saturated Water Content	Static, 5km	Raster	HiHydroSoils	HYDROLOGY
Protected Area	Static	Shapefile	WDPA	LAND USE
Reservoirs	Static	Shapefile	GRaND	HYDROLOGY
Basin Delineation	Static	Shapefile	HydroSHED	HYDROLOGY
Total Water Storage Change	Monthly	Mascon	GRACE	HYDROLOGY
Observed Flows	Monthly	Point	GRDC	HYDROLOGY

Upon the completion of the WA+ runs, viewing and evaluating the results of the water balance model become possible through Sheet 1. Output data layers and time-series of the Rapid Water Accounting Plus runs are presented in Table 4, with WA+ Sheet 1 providing a total overview of the state of the water resources. The WA+ approach hence provides systematic insights on the water cycle of the river basin using the WaPOR and global open-access databases.

Table 4. Output data layers and time-series generated from running the WA+ model

Data	Temporal Resolution	Spatial Resolution	Data Type
Incremental Evapotranspiration	Monthly	100m	netCDF – Data Layer
Incremental Evapotranspiration	Yearly	100m	netCDF – Data Layer

Rainfall Evapotranspiration	Monthly	100m	netCDF – Data Layer
Rainfall Evapotranspiration	Yearly	100m	netCDF – Data Layer
WA+ Sheet 1	Yearly	Basin	Csv – Time-series
P and ET per Land Cover Class	Yearly	LCC	Csv – Time-series
P and ET	Yearly	Basin	Csv – Time-series

2.2. From Data Pre-Processing to WA+ Sheet 1

A workshop on the use of WaPOR data in Water Accounting Plus was earlier organized by the Lebanese lab on January 7, 2022. This section of the report provides an overview of the five main modules presented during the workshop and delivers the resources necessary to perform a complete run of the WA+ model.

Prior to implementing the five modules, various procedures and installations are necessary to lay the groundwork for the accounting measures. These instructions are exhibited via the Pre-workshop Video Tutorials, prepared, and presented by the Lebanese lab (AUB). The preparatory steps are summarized in Table 5. As a first step, the installation of the Anaconda distribution of Pyhton is necessary. A Python distribution is a package that includes a Python implementation as well as several libraries or tools. The Anaconda distribution, a free and open-source distribution of Python, is the most widely used among the scientific community. This is followed by the installation of Python packages that are used in WA+ including Pandas, GeoPandas, Rasterio, and Xarray. To run Python code, Jupyter notebook is activated. Jupyter Notebook is a web-based interactive computational environment for producing and engaging with IPython notebook documents through a web browser. Subsequently, Jupyter notebooks for Water Accounting and Water Productivity using WaPOR are downloaded from GitHub public repositories. Here, Python packages are used to download WaPOR data by reading and running Python codes in the prepared Jupyter notebooks. To collect the WaPOR data, a personal API token is retrieved. As a final step of the preparatory phase, bulk download of WaPOR input data is executed. To automate the download of the WaPOR raster dataset, the Notebook will use a local Python module. The script will automatically adjust the datasets it downloads with WaPOR conversion factor.

Table 5. Preparatory steps and tutorials prior to WA+ runs

Step	Tutorial	Source
1	Install Anaconda Distribution of Python	Link
2	Install Python Packages for the WaPOR WA Runs	Link
3	Use Jupyter Notebook to Run Python Code	Link
4	WaPOR Data Access	Link

5	WaPOR Data Bulk Download	Link

The Pre-workshop Supplementary Instructions Manual offers more technical details on the implementation of the preparatory phase. During the workshop, WA+ runs were performed on the Litani River Basin case study. Figure 4 shows the workflow of WA+, including the data employed in the runs and the generation of the WA+ output sheets. The WA+ framework acts as a reporting mechanism for water fluxes, flows, and stocks that are summarized by means of the WA+ sheet.

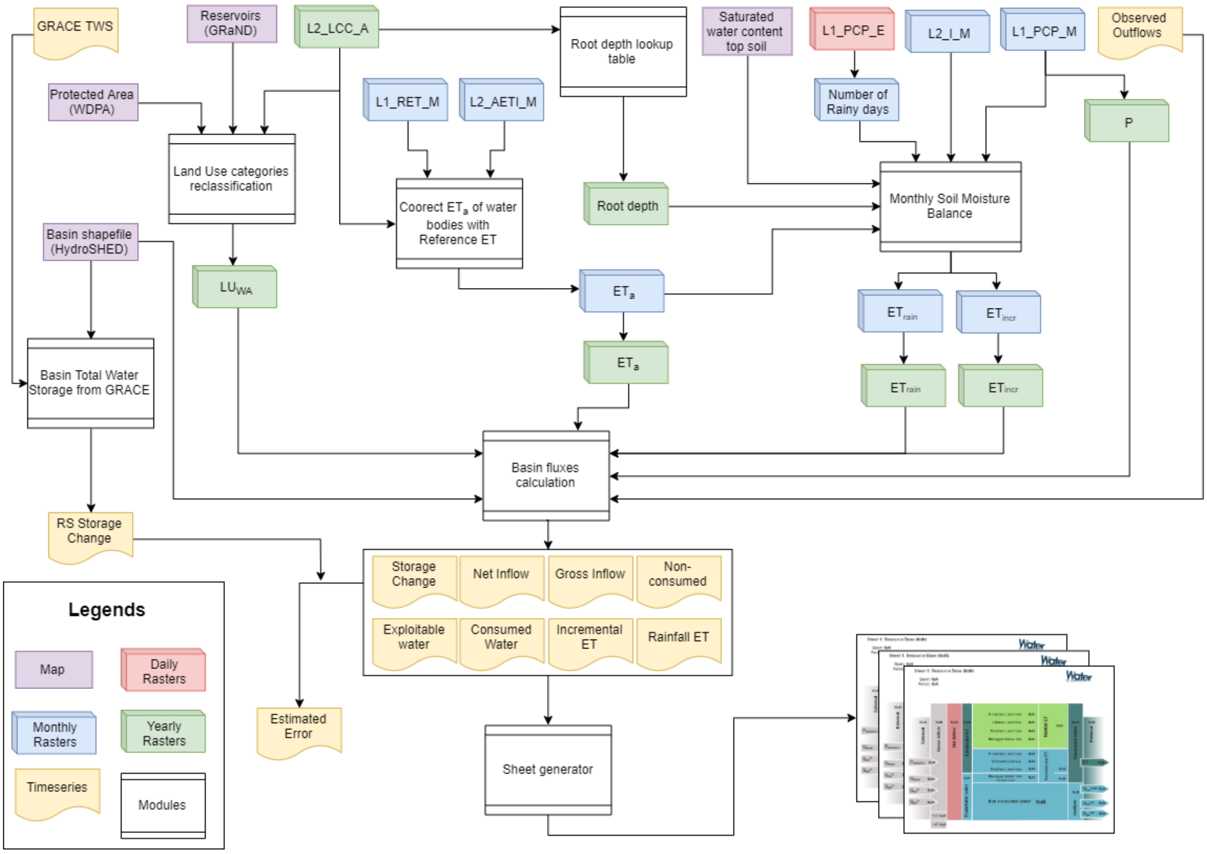

Figure 4. Flow chart of the WA process and the data used to generate the sheets for the Litani River Basin

In essence, the required data is collected for the study period. However, before using the data for the WA+ runs, several quality checks need to be performed including: 1) the comparison of WaPOR precipitation data with in-situ observations, 2) the comparison of WaPOR Eta data with other remotely sensed Eta estimates, 3) the assessment of the difference between WaPOR- derived basin-scale water balance and total water storage from GRACE (the Gravity Recovery and Climate Experiment NASA mission for studying key changes in the planet's waters, ice sheets, and the solid Earth), as well as 5) quality checks of inter-basin diversions, flow measurements, and domestic and industrial water supply.

Now that all preparatory procedure is completed, the scene is set for implementing the five modules presented in Figure 5.

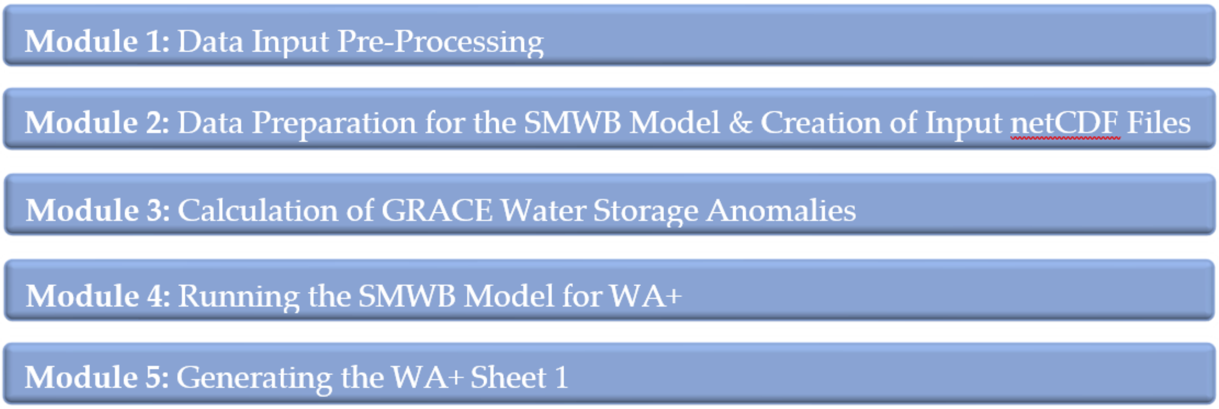

Figure 5. Workshop modules for generating Sheet 1 of WA+

Detailed information on how to execute modules 1 to 5 is available through the Workshop Modules Tutorial Videos, prepared in step-by-step format by the Lebanese lab.
The WaPOR-Based Water Accounting User Manual, which was also presented during the workshop, is a complete and detailed guide on running WaPOR-WA+.

3. Data for Water Accounting Modeling

Within TALANOA-WATER, several water laboratories are implementing the WA+ approach over the respective river basin case studies. Section 3 of this report presents an overview of the status of WA+ modeling in each of the laboratories employing WA+ in their operations, the main use purpose of the tool for transformational adaptation, as well as a display of the input data needed for running the tool on the study area.

3.1. Spain

3.1.1. Status of WA+ Modeling and Use Purpose for Transformational Adaptation

The Spanish Water Lab's case study comprises the Cega River Sub-basin in the Douro River Basin. This sub-basin is one of the few remaining nonregulated catchments in Spain, while harboring one of the most productive agricultural areas in the Douro River Basin (horticultural crops represent nearly 21% of the irrigated area). The main water source of this productive area is the Los Arenales aquifer, which has been overexploited for nearly 40 years triggering not only quantitative issues, but also severe episodes of groundwater pollution affecting urban water supply. Also, widespread water theft has been reported in the area, which is not accounted for in the official water use register. A recent report by WWF estimates that 23, 975 ha of agricultural land are currently irrigated with illegal water uses in Los Arenales aquifer. This additional over-allocation is not accounted for in the official water census, which only provides information on theoretical allocations that often do not match actual uses.
In order to identify actual water use and account for illegal water uses in water policy design, AUB and USAL have collaborated to quantify evapotranspiration using local monitoring data

and remote sensing data, which have been processed using WA+ and Hidromore to estimate irrigation water use and compare actual and theoretical uses. The procedure of the application with WA+ is described in D2.1.

Regarding the application with Hidromore, we have used time series of remote sensing images of Sentinel and Copernicus data and applied classification trees to produce estimates on the disposition of land and irrigated crops across the lab. In parallel, a machine learning algorithm has been set up to identify land use at farm scale. The output of this task has been a land use map for different agronomic years, generated from classification trees and machine learning, and validated with field sampling in the two water labs. We found that this land use classification did not provide significantly different results from those obtained from ITACyL. Next, we tested an operational LST product at a global scale that was recently released by the USGS as part of a new Collection 2 imagery for Landsat series to evaluate the operational use of water stress parameter as a key input in land classification or surface processes related to water use. Since the spatio-temporal resolution of Landsat 8, or coming Landsat 9, did not fully cover the LST spatiotemporal resolution aims in this proposal, recent advances in downscaling techniques were also applied. Sentinel-2 reflectance (10 m resolution) and Sentinel-3 radiances (1 km) were used as kernels to generate high resolution downscaling LST (DLST) boosting the use of the S2-S3 Copernicus tandem. The information above was used to build a water accounting for the water lab.

Quality controls of associated spatial data components were conducted with both WA+ and Hidromore, including uncertainty sampling in the estimation of water use within and across different remote sensing data processing methods. This comparison will allow us to locate users that are using more water than is officially allocated (i.e., theft), and develop adequate compliance strategies. Aside from satellite data, the analysis involved several other hydrology, climate, groundwater, and geographic data sources that are listed in Table 6.

3.1.2. WA+ Data for Case Study

Table 6. WA+ input data of the Cega River Sub-Basin case study in Spain

Type of Data	Format	Location	Time Start	Time End	Time Step	Source
HYDROLOGY AND HYDROGEOLOGY						
Discharge	Time series	Pajares de Pedraza (Segovia)	1912	2016	Daily	CEDEX
River Depth	Time series	Pajares de Pedraza (Segovia)	1912	2016	Daily	CEDEX
Discharge	Time series	Villovela de Piron (Segovia)	1972	2016	Daily	CEDEX
River Depth	Time series	Villovela de Piron (Segovia)	1972	2016	Daily	CEDEX
Dam storage volume	Time series	Castro de las Cogotas (Cardeñosa, Ávila)	1996*	2018*	Daily	CEDEX

Dam Dischargue	Time series	Castro de las Cogotas (Cardeñosa, Ávila)	1996*	2018*	Daily	CEDEX
Dam storage volume	Time series	Ponton Alto (Segovia)	1995*	2018*	Daily	CEDEX
Dam Dischargue	Time series	Ponton Alto (Segovia)	1995*	2018*	Daily	CEDEX
****Hydrological years***						
CLIMATE						
Precipitation	Time series	Segovia	1980	2016	Monthly	
Precipitation	Time series	Pajares de Pedraza (Segovia)	1950	2016	Monthly	Copernicus
Precipitation	Time series	Villovela de Piron (Segovia)	1950	2016	Monthly	Copernicus
Temperature-mean	Time series	Pajares de Pedraza (Segovia)	1950	2016	Monthly	Copernicus
Temperature-mean	Time series	Villovela de Piron (Segovia)	1950	2016	Monthly	Copernicus
Precipitation	Time series	Cega Basin	2001	2021	Daily	ITACyL
ETo (P.Monteith mm)	Time series	Cega Basin	2001	2021	Daily	ITACyL
Temperature-mean	Time series	Cega Basin	2001	2021	Daily	ITACyL
Temperature-minimum	Time series	Cega Basin	2001	2021	Daily	ITACyL
Temperature-maximum	Time series	Cega Basin	2001	2021	Daily	ITACyL
Relative Humidity-mean	Time series	Cega Basin	2001	2021	Daily	ITACyL
Relative Humidity-minimum	Time series	Cega Basin	2001	2021	Daily	ITACyL
Relative Humidity-maximum	Time series	Cega Basin	2001	2021	Daily	ITACyL
Wind Speed-mean	Time series	Cega Basin	2001	2021	Daily	ITACyL
Wind Speed-maximum	Time series	Cega Basin	2001	2021	Daily	ITACyL
Wind direction	Time series	Cega Basin	2001	2021	Daily	ITACyL
Wind direction-maximum gust	Time series	Cega Basin	2001	2021	Daily	ITACyL
WELLS DATA						
Well locations		Segovia, Ávila and Valladolid				IGME (Instituto Geológico y Minero de España)
Well_type		Segovia, Ávila and Valladolid				IGME
Elevation		Segovia, Ávila and Valladolid				IGME
Depth		Segovia, Ávila and Valladolid				IGME

Use		Segovia, Ávila and Valladolid		IGME
GEOGRAPHIC INFORMATION				
DEM	AAIGrid (ASCII)	Cega Basin		IGN
Land use class map	Shapefile	Cega Basin	2017	Corine LandCover
Land use classes table	Table	Cega Basin	2017	Corine LandCover
Soil map	Shapefile	Cega Basin		
Soil map	Table	Cega Basin		
Crop_type map	Shapefile	Cega Basin	2015	ITACyL
Crop_type map	Table	Cega Basin	2015	ITACyL
AWDUs Surface map*	Shapefile	Cega Basin	2015/2021	ITACyL
AWDUs Groundwater map*	Table	Cega Basin	2021	ITACyL
AWDUs Surface table*	Shapefile	Cega Basin	2021	ITACyL
AWDUs Groundwater table*	Table	Cega Basin	2021	ITACyL
Well locations	Shapefile	Cega Basin		IGME
Well locations	Table	Cega Basin		IGME

**Agricultural Water Demand Units*

3.2. France

3.2.1. Status of WA+ Modeling and Use Purpose for Transformational Adaptation

In the French case study, it was not possible to apply the WaPOR modeling approach. First, the WaPOR data are available just for Africa and the Near East countries and obtaining them would have taken resources to develop a database that does not improve the already available information in the lab. In fact, data available on the Aude case study allows us to apply a more detailed modeling approach, and to have a finer analysis of the water consumption due to irrigation. Accordingly, in the French lab we proceed with a water accounting approach to establish the BDC (Basin Determined Contribution) that will be determining the targets of strategies.

One first accounting suggested by the French water management system derives from the water law (transposition of the Water Framework Directive). The water basin management plan refers to an accounting scheme that states that the sum of withdrawals in the low flow periods should be lower or equal to the "volumes prélevables", the "acceptable" withdrawal. These are estimated while stating that the minimum flows need to be let in the natural bed of the river, these must be above a certain threshold that is determined locally (on a study basis, often based on the principle of the "10% of the modulus"). The minimum "reserved flow" is the mandatory minimum flow of water that the owners or managers of a hydraulic structure (lake, body of water, dam, sill, hydroelectric unit, etc.) must reserve for the watercourse and for minimum operations. The local basin water management plan (Plan de Gestion de la Ressource en eau, 2017) also includes a set of aggregated numbers on which actors agreed

upon already, even if years ago (2011). This accounting will be questioned in workshops to explore alternative visions (for instance questioning the minimum flows assumptions) leading to alternative objectives in terms of minimum flows and/or uptake and BDC.
The accounting that we suggest proceeding with is shown in figure 6 below. The idea is to start from two ends: (i) the water needs by crops and conveyance infrastructure (losses/return flow to the environment) and (ii) the hydrological flows at the gauging stations. This scheme will be amended further while developing hydrological accounting and modeling. The data used for this accounting approach are presented in section 3.2.3 of this report.

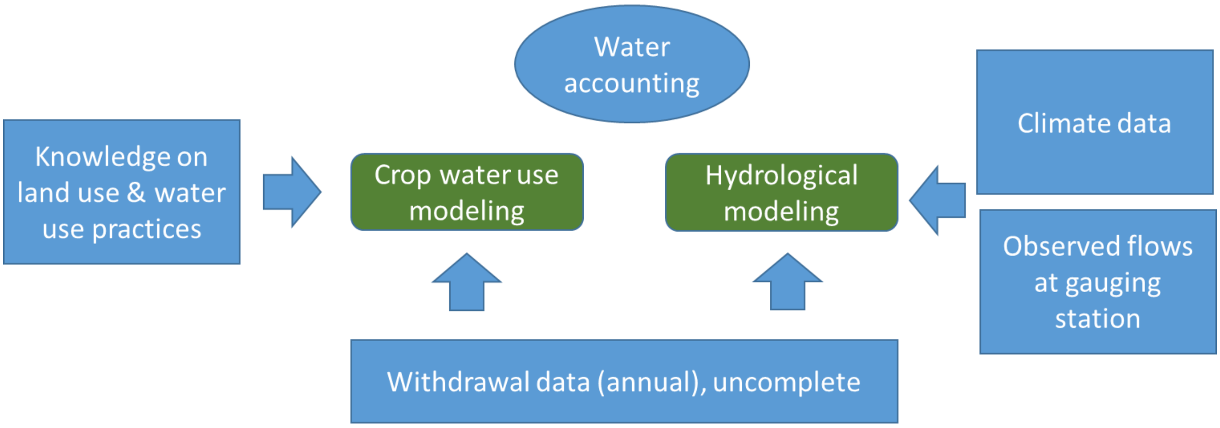

Figure 6. Water accounting approach of the French lab

3.2.1. Hydrological Modeling Approach

The hydrological model will be based on a semi-distributed model consisting of lumped conceptual rainfall-runoff models. The Aude River Basin is a complex system as it includes water conveyance channels that support water supply for navigation, irrigation, and environmental flows. Channels will also be modelled.
The lumped rainfall-runoff model used will be one of the available GR ("Génie Rural")-type models at daily time step in the airGR R package (Coron, Thirel, Delaigue, Perrin, & Andréassian, 2017). The semi-distribution over the whole catchment will be provided by the airGRiwrm package (Dorchies, Delaigue, & Thirel, 2021). This model allows the integration of human influences such as dams and withdrawals. These features will be used to integrate the influence and the management rules of the hydroelectric dams managed by the national hydropower company (EDF) and the withdrawals made by gravity canals for various uses.
The semi-distribution needs to define Points of Interest (POI) in the catchment where the flow is modelled. As POIs, we first use gauging stations' locations which are included in the model for the calibration of the hydrological model parameters of each hydrological unit or sub-catchment delimited by the location of the gauging stations. Then, we add POIs that are required for management (for example for defining withdrawal restriction on an irrigation area) or indicator purpose. The latter points are modelled with hydrological model parameters

derived from the calibrated ones on the first gauging station located downstream the POI. Finally, we add POIs for integrating inflows and outflows managed by human infrastructures (dams, irrigation canal intakes and offtakes...). For each POI, the model uses the mean meteorological data for the considered sub-catchment.

The calibration of the model will use influenced observed flow on the gauging stations located on the Aude River and its tributaries and the calibration will be performed directly on the influenced hydrological model with all the input available: meteorological, hydroelectric dam and withdrawal data (irrigation, drinking water, navigation, environmental flows withdrawals data). As the calibration of parameters of semi-distributed models can be complicated due to the lack of parameter sensibility on downstream intermediate catchments, we will use a regularization of the parameters following the proposed method (De Lavenne, Andréassian, Thirel, Ramos, & Perrin, 2019). Once calibrated, the model will be available to simulate future climates and different scenarios of water management.

The main limitation of this model is that it doesn't contain a groundwater component. So, it will not be able to model the interaction of surface water and groundwater in relation to groundwater withdrawals. Research is underway on the subject but may not be available for this project. Exchanges with BRGM with whom the French partners are in contact should also enable to find options.

3.2.2. Water Needs for Crop Irrigation

For the estimation of the water needs for crop irrigation, we will apply the SIMETAW model (Mancosu, Spano, Orang, Sarreshteh, & Snyder, 2016) (Masia et al., 2021). SIMETAW is based on a soil water balance model, assessing the crop water use and irrigation requirements, and the generated outputs include possible irrigation schedules, which can be adapted to scenarios of full or deficit irrigation. In this sense, the model has been adapted to correct the crop coefficients (Kc) considering water deficit effects, and it can evaluate the consequences of deficit irrigation on evapotranspiration and yield. For this reason, the model can be used for assessing agricultural water management both at local and regional scales. These are the main improvements related to this model compared to the traditional and already diffused water balance model. The model is implemented in R programming language.

3.2.3. WA+ Data for Case Study

Data identified for the French lab is available here [TALANOA Sourcebook Metadata - Google Sheets] (see D1.1), although some of the data inputs provided are still not openly available. Data used for water accounting is shown in Table 7. Other data will be produced by modeling.

Table 7. WA input data of the Aude River Basin case study in France

Type of Data	Location	Time Start	Time End	Time Step	Source
HYDROLOGY AND HYDROGEOLOGY					
Water bodies (superficial & groundwater)	RMC basin	-	-	-	AERMC
List of spring locations and elevations	multiple, points	-	-	-	BRGM
Spring discharges	multiple, points	-	-	-	BRGM/DREAL
Pumped volume - Farming	multiple, points	2009	2020	year	AERMC
Pumped volume -industry	multiple, points	2009	2020	year	AERMC
Pumped volume - drinking water	multiple, points	2009	2020	year	AERMC
Stream flows	all basin	variable	today	1 day	Banque hydro
Inter-basin transfers					(SMMAR, 2017)
CLIMATE					
Precipitation	France	01/08/1958	31/07/2020	1 day	MétéoFrance Safran
Temperature - Daily mean	France	02/08/1958	01/08/2020	1 day	MétéoFrance Safran
Temperature - Daily max	France	02/08/1958	01/08/2020	1 day	MétéoFrance Safran
Temperature - Daily min	France	03/08/1958	02/08/2020	1 day	MétéoFrance Safran
Evaporation	France	04/08/1958	03/08/2020	1 day	MétéoFrance Safran
Relative humidity	France	05/08/1958	04/08/2020	1 day	MétéoFrance Safran
Wind speed	France	06/08/1958	05/08/2020	1 day	MétéoFrance Safran
Solar radiation	France	07/08/1958	06/08/2020	1 day	MétéoFrance Safran
Sunshine hours	France	08/08/1958	07/08/2020	1 day	MétéoFrance Safran
Snowfall	France	09/08/1958	08/08/2020	1 day	MétéoFrance Safran
Precipitation	France	01/08/1958	31/07/2020	1 day	MétéoFrance Safran
Temperature - Daily mean	France	02/08/1958	01/08/2020	1 day	MétéoFrance Safran
Temperature - Daily max	France	02/08/1958	01/08/2020	1 day	MétéoFrance Safran
Temperature - Daily min	France	03/08/1958	02/08/2020	1 day	MétéoFrance Safran
Evaporation	France	04/08/1958	03/08/2020	1 day	MétéoFrance Safran
Relative humidity	France	05/08/1958	04/08/2020	1 day	MétéoFrance Safran
Wind speed	France	06/08/1958	05/08/2020	1 day	MétéoFrance Safran
Solar radiation	France	07/08/1958	06/08/2020	1 day	MétéoFrance Safran
GEOGRAPHIC INFORMATION					
DEM	basin	-	-	-	
Land use class map	table	-	-	-	CESBIO (Centre d'Etudes Spatiales de la Biosphère)
Land use classes table	table	-	-	-	CESBIO
Soil	raster	-	-	-	INRAE

3.2.4. Hydrological Data-Needs

Meteorological data for historical climate will be provided by the SAFRAN reanalysis (Vidal, Martin, Franchistéguy, Baillon, & Soubeyroux, 2010). This database contains all the required data for the hydrological modelling (precipitation, potential evaporation, and temperature) at a daily time-step from 1958 to 2021 on a grid of 8 km by 8 km covering Metropolitan France territory. The runs will also require daily data on gauging stations' flows. Water withdrawals and points of withdrawal will be downscaled from year (water agency data) today.

3.2.2.2. Water Needs for Crop Irrigation Data Needs

In terms of data, ideally a detailed map about crop distribution is needed in order to understand which irrigated crops are present on the study area and what their distribution is. The THEIA service ([Satellite Data – Theia (theia-land.fr)]) furnishes a yearly crop type map from 2018 until 2021. This could be coupled on one side with the LPIS (Land Parcel Identification System) data (RPG data in France), in order to obtain the parcel border and to

have more information about some crops' distribution and on the other side with a map of irrigated areas, that does not exist. Other data from the agricultural census about irrigated crops in each municipality and irrigation methods (which is an input variable for the model in order to understand and estimate the water management) will be mobilized. Moreover, some general information about plant phenology and physiology would be needed, related to planting, and harvesting dates, as well as to rooting depth. In terms of soil data, the model requires as inputs the soil water capacity and the soil depth. Climate data (temperature, solar radiation, rainfall, wind speed and relative humidity) will be acquired from CORDEX regional climate model data (with a resolution of 0.11°), corresponding to around 11 km. CORDEX furnish climate projection as well, and this could allow to estimate possible scenarios of water management for different future climate situations. The French lab decided to work with CORDEX mainly to have a standardized database for the whole Europe and to use the climate projections for the future available from CORDEX. The use of Safran for homogeneity with hydrological modeling is also possible.

3.3. Italy

3.3.1. Status of WA+ Modeling and Use Purpose for Transformational Adaptation

The study area for the Italian Lab is located within the Emilia Romagna Region (RER), and particularly in the provinces of Modena and Reggio Emilia (Emilian part of the Region, figure 7). In this area, the surface resources from the main rivers are exploited by a wide range of users for agriculture, industry, human water consumption, while monitored and controlled by the public bodies to reach the goals of EU environmental policies. All these different instances are well represented in the lab and the involved Stakeholders (essentially Regional Government dealing with water management planning and permitting, private companies/ irrigation consortia who are the main water users, Regional Environmental Agency ARPAE

that manages most of the data of interest for water accounting).
The lab's study area (figure 7) is the upper part of the Emilian Catchment of Secchia river, upstream of the Castellarano Weir (figure 8), where water usages of different sectors crosse (ranging from agriculture to industry to hydropower generation to river bodies surveillance and conservation). Based on stakeholders' early interaction, the spatial scale has been defined (entire catchment with closing section at the weir) while temporal scales of interest (e.g., sub-seasonal, seasonal, annual, decadal or climate change) for the water accounting output need to be defined to start reasoning on co-generation of adaptation strategies.
So far, a consensus has been reached on identifying all users in the platform surface water availability (discharge to the weir) as the core variable of interest. A common ground for lab activities has been indeed in the necessity to provide river discharge projections and preserve water balance in medium to long term perspectives, at the catchment closure, where most stakeholders ("primary users" of water) have some of their withdrawals to feed their respective users downstream (for example farmers for irrigation or ceramic industries for multiutility companies).

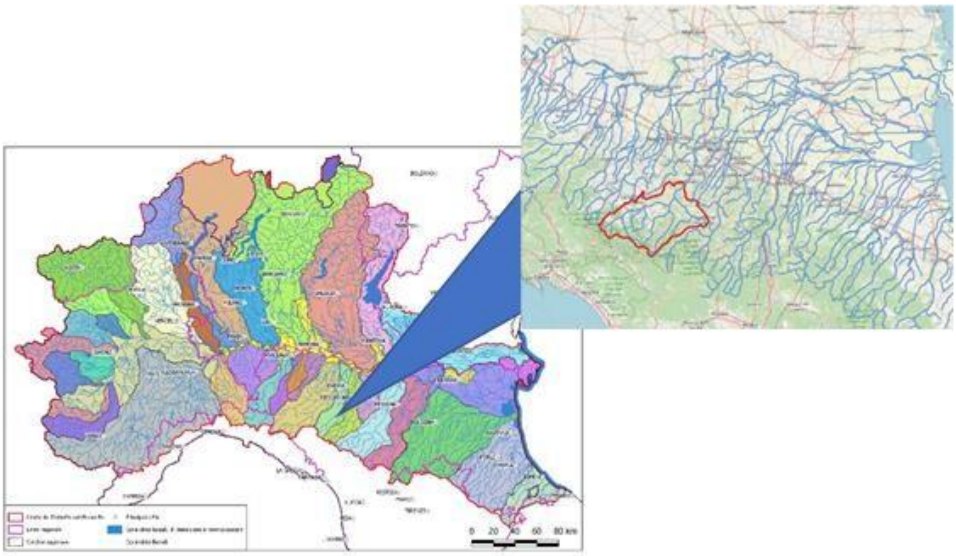

Figure 8. Location of the study area in RER- Italy, south of the Po River District

Figure 7. A view of the Weir at Castellarano along Secchia River

The Regional Government recognizes the variation in water availability as one of the greatest impacts of climate change on the water cycle. Balance between water availability and requests of civil, agri-zootechnical and productive users, is, at present, in precarious equilibrium, with local criticalities, particularly when exploitation occurs, as in the lab area, form surface watercourses with torrential hydrological regimes. Even the hydropower usages (which release back water to the river) are bound to respect the protection objectives for the exploited watercourses, thus facing a reduction in energy production from a climate change perspective. This is due to the concurrence of lower water availability and higher requests for environmental protection. Nevertheless, the reduced impacts of plants that exploit local jumps induced by pre-existing structures (less prone to environmental issues and ecological flow requests) must be recognized. The study area provides good examples of such low impact plants.

Climate change poses well known threats to water balance. A generalized increase in temperature, lowered precipitation (Table 8) and tendential increase in evapotranspiration reduce water availability and increase irrigation needs of crops; less significant are the impacts of an increase in temperatures on civil and industrial needs.

A recent report on regional climate projections for homogeneous areas from ARPAE (3) provides insight for precipitation and temperature that, as seen before, drive water generation and availability. The area of interest for the lab mainly belongs to the "West hill" area of the Region, for which the following table summarizes values for projections.

Table 8. Climatic projections for water availability related variables, emissive scenario RCP4.5 in the area of interest

Ref.Period	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990
Climate projection.	**2021-2050**	**2021-2050**	2021-2050	**2021-2050**	**2021-2050**
Em. Scenario	RCP4.5	RCP4.5	RCP4.5	RCP4.5	RCP4.5
Indicator	**AV. Annual temp.**	**Max Summer temp.**	**heat waves**	**Annual perc.**	**Summer dry days**
Description	average daily	average daily max	numb of consecutive day	total cumulate	Number of consecutive day
			with temp above 90th Percentile		with prec. below 1 mm
Unit of meas.	[°C]	[°C]		[mm]	-

value ref. period	10.9	25.2	3	1020	20
value clim. Project.	12.6	27.7	8	940	26

Based on discussions with stakeholders, correct assessment of actual withdrawals data is a critical lack.

The most recent available public data dates to 2011 and comes from the previous iteration of regional water balance currently under review. Part of this information has been recently updated and part is under review for the next iteration of River water balance by RER. For the sake of framing the context, previous complete data have been used.

Table 9 shows water availability, water needs for ecological river flow (under review as well) and water exploitation. Despite the age of the data (around 2011), the situation in the main catchments in the study area is quite evident in the reduction of water availability compared to climatology, with increasing pressure on water bodies.

Table 9. Synthesis of Water availability, ecological needs, and exploitation for the main catchments in the area

main hydrological quantities restimated with regional models

River	station	Water body	Area (km2)	Hmed	annul precip. (mm/y)			Av. Flow Qm (m^3/s)			Variation of flow '90-01 Vs '32-'90	Variation of flow '02-'11 Vs '32-'90
			(km^2)	m slm	32-90	91-01	02-11	32-90	91-01	02-11		
F. Secchia	Castellar	012000000000 7	952	830	1262	1189	1204	24.6	21.1	20.9	-14%	-15%

Average annual outflows 2002-2011 and resources available at the

BM: mountain basin				Area (km^2)	minimum flow Oct-Apri, May-Sept.			annual flow	max exploitable flow	availble resource (Mm^3/y)	
Asta	Areale	Water body	station		Q_m	DMV_i	DMV_e	(Mm^3/y)	(m^3/s)	Oct-	May-Sept
Secchia	BM	012000000000 7 ER	Castellarano	952	16.5	1.94	1.28	521	7.5	114	28

Main alterations to natural outflows at the exit of the

Water body codes			Catch. Area (km^2)	drained water bod.	Dishcarges (Mm^3/y)		Withdrawals (Mm^3/y)					Hydropower (Mm^3/y)		Changings (m^3/s)	avg. Flow (m^3/s)
Code	Name	station			Civil	Industrial	Civil	Industrial	Irrigatio	farming	others	withd.	release		
012000000000 8	F. Secchia	Valle Sassuolo	1028	31	4	0	-10	-2	-19	0	-2	-1020	1020	-0.91	21.89

No official projections have been published in detail for climate change effects on water availability (river discharge) in the area of interest, and this could be one valuable output of the water balance to provide to the lab. The Regional government can then test resilience strategies and review water budget in such a challenging context (Apennine water course with water scarcity period).

The Regional Government plays a critical role in ensuring water resources to legitimate users including economic relevant sectors such as Hydropower, Agriculture, Industry and preserving (possibly improving) environmental and ecological status of the river.

General projections for the Region are provided in (3). These projections are obtained through the statistical regionalization technique applied to the results of the global climate model of the Euro-Mediterranean Centre on Climate Change (CMCC) for the RCP4.5 emission scenario. The model estimates a reduction over time in the concentration of greenhouse gases following the adoption of mitigation policies; the scenario corresponds to the 2°C global warming goal, identified in the Paris Agreement (2015). The climate scenarios for the Region show significant signs of change:

For the 2021-2050 period compared to the 1971-2000 reference period, in terms of both temperature and rainfall. For the 2021-2050 period, a probable increase in minimum and maximum temperatures of about 1.5 °C in winter, spring, and autumn, and about
2.5 °C in summer.

Probable increase in temperature extremes, of heat waves and tropical nights.

Probable decrease in the amount of precipitation, especially in spring (around 10%) and summer.

Probable increase in total precipitation and extreme events in autumn (about 20%) and increase in the number of consecutive days without precipitation in the summer (about 20%).

There are similar temperature projections for the 2021-2050 period, including in the context of the RCP8.5 emission scenario. As observed in Table 8, similar patterns are present in the homogeneous area inside the region to which the lab study area belongs. Towards the end of the century, from 2071 to 2100, the projections show more intense changes in terms of both temperature and rainfall. With the RCP 4.5 scenario, the expected increase for maximum temperatures during the summer could be around 4.5 °C, while with the RCP 8.5 scenario, which considers the absence of mitigation policies and the increase in greenhouse gas emissions over time, summer temperatures could increase by as much as 8 °C. All these signals for water generation related variables lead to the conclusion that climate change has direct effects on the water system, affecting both needs and hydrological and hydrogeological processes, and the availability of resources.

So far and based on early users' interaction, an updated water accounting model for the upstream Castellarano catchment is still missing, but local knowledge and data can be integrated to foster application of established schemes such as WA+.

Next paragraph will synthesize in a table the actual available data to feed Water Accounting modeling, here follows a brief description of the local knowledge that can be exploited through the lab.

Concerning local knowledge integration, ARPAE can provide relevant local data, in particular historical discharge records (more than 10 years of data) at a river station near the closing section of the catchment. Data are regularly updated up to the end of the previous day (figure 9- left). Grids of meteorological data are updated regularly by ARPAE as well, they produce a meteorological dataset of hourly and daily data for the main meteorological and agrometeorological variables (air temperature, precipitation, relative air humidity, solar radiation, and wind) from 2001 to today. The data are obtained by spatial interpolation on a regular grid starting from the values detected by the network of historical meteorological stations and are downloadable as grid files (figure 9- right).

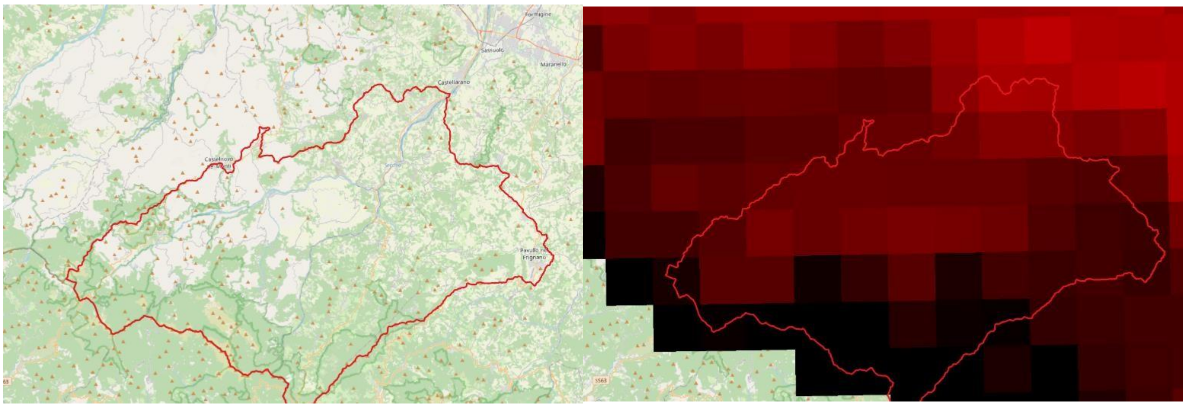

Figure 9. Left-position of discharge refinal monitoring station along Secchia River provided by ARPAE (daily data); right- example of gridded meteorological dataset provided by ARPAE

Other Static datasets to support water balance are generally available through the regional geoportal, and include:

- Digital elevation model and river network (available as rates geotif at 5m pixel size and vector shapefile)
- Soil use vector shape file (year 2017).

Soil map is not available in the regional database for the upstream catchment of interest, a larger scale database such as JRC's EU soil database may be a viable alternative.

As outlined before, this relevant local knowledge shall be integrated in the co-generation process starting from water needs for different usages in different periods and existing conflict for water resources during water scarcity (particularly in summer for the concurrent presence of low resources and higher demand for agriculture) that can be defined in the lab. Effective withdrawals have been identified by most Stakeholders as a potential threat, to be overcome by screening for available direct data from users.

Concerning climate projections to force output of the Water budget in the different climate scenarios, upstream data at coarse resolution from existing operation services (such as Copernicus Climate Dat Store -CDS) could be used, eventually benefiting from local ground station data (or gridded interpolation mentioned above) to downscale climate projections (figure 10).

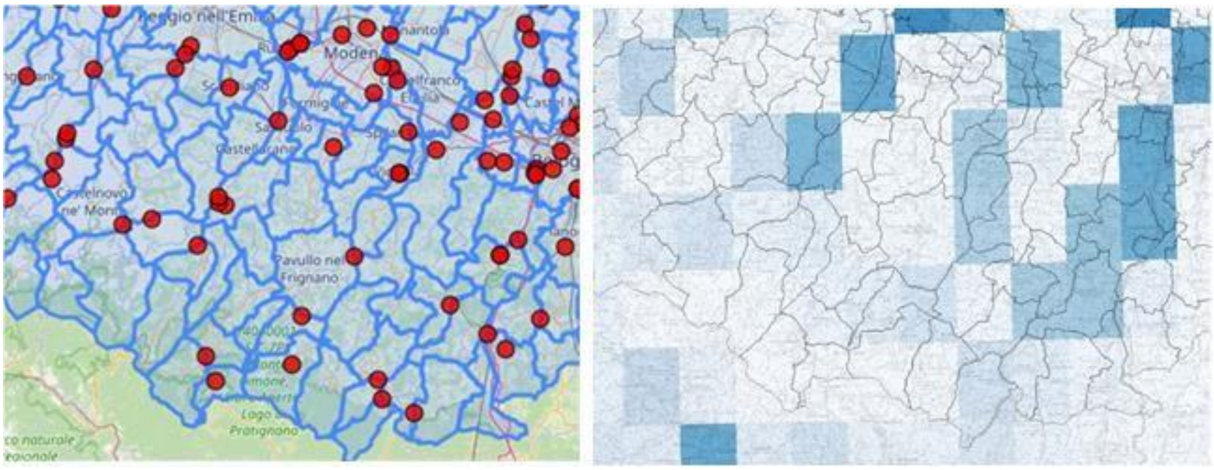

Figure 10. Example of local data from ground hydro meteorological stations (left) and upstream services output (CDS gridded forecasts- right) that could be used to downscale climate projections to the lab area.

3.3.2. WA+ Data for Case Study

Below we present a tabular synthesis (Table 10) of the local data for Water Accounting modeling application in the lab area (available directly through online repositories). Previous paragraphs discuss data and providers.

Table 10. WA+ data input for the upper part of the Emilian Catchment of Secchia river case study in Italy

Type of data	Format	Location	Time Start	Time End	Time step	Source	Resolution	link
River Discharge	csv	station	'90	2021	Daily	ARPAE		https://simc.arpae.it/dext3r/
Precipitation	GRIB	catchment	2001	2021	Hourly-Daily	ARPAE	5 km	https://dati.arpae.it/dataset/erg5-interpolazione-su-griglia-di-dati-meteo
Temperature - Daily max	GRIB	catchment	2001	2021	Hourly-Daily	ARPAE	5 km	https://dati.arpae.it/dataset/erg5-interpolazione-su-griglia-di-dati-meteo
Temperature - Daily min	GRIB	catchment	2001	2021	Hourly-Daily	ARPAE	5 km	https://dati.arpae.it/dataset/erg5-interpolazione-su-griglia-di-dati-meteo
Evapotranspiration	GRIB	catchment	2001	2021	Hourly-Daily	ARPAE	5 km	https://dati.arpae.it/dataset/erg5-interpolazione-su-griglia-di-dati-meteo
Relative humidity	GRIB	catchment	2001	2021	Hourly-Daily	ARPAE	5 km	https://dati.arpae.it/dataset/erg5-interpolazione-su-griglia-di-dati-meteo

Wind speed	GRIB	catchment	2001	2021	Hourly-Daily	ARPAE	5 km	https://dati.arpae.it/dataset/erg5-interpolazione-su-griglia-di-dati-meteo
Solar radiation	GRIB	catchment	2001	2021	Hourly-Daily	ARPAE	5 km	https://dati.arpae.it/dataset/erg5-interpolazione-su-griglia-di-dati-meteo
Soil map	shp	catchment	2001	2001		JRC	1:1,000,00	https://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data
Land use class map	shp	catchment	2017	2017		RER	1:10000	https://geoportale.regione.emilia-romagna.it/download/dati- e-prodotti-cartografici-preconfezionati/pianificazione-e-catasto/uso-del-suolo
Digital elevation model	geotif	catchment	2015	2015	2015	RER	5m	https://geoportale.regione.emilia-romagna.it/catalogo/dati-cartografici/altimetria/layer-2

3.4. Lebanon

3.4.1. Status of WA+ Modeling and Use Purpose for Transformational Adaptation

3.4.1.1 Approach and objectives

This Water Accounting study aims to assess the water availability, consumptive use, and non-consumptive use in the Litani River Basin (LRB) using remote sensing data derived from the FAO WaPOR database and other open access data sources described in section 2.1. It aims to complement the lack of routine water resources data collection and incorporates spatially distributed water consumption. This study implements a rapid WaPOR-based WA+ framework for the 2017-2020 period. It focuses on the basin-wide analyses through the WA+ Resource Base sheet, which represents an initial analysis of the water resources utilization status in the Litani River Basin. After this approach and objective section, the results of the water accounting, including the resource base sheet, key indicators, and data produced in the analysis, including tables and figures, are presented in the following subsections.

3.4.1.2 Preliminary Assessment

i) Basin-Scale Water Balance — GRACE Total Water Change

For the change in storage, we used data from the Gravity Recovery and Climate Experiment (GRACE) (GSFC.glb.200204_202107_RL06v1.0_OBP-ICE6GD). This type of data allows us to assess whether the storage change (delta S), as observed by GRACE, is positive or negative. The water storage for a single GRACE pixel covering Lebanon from 2017 to 2020 may be observed.

We later examined the water balance results derived using WaPOR data layers (P – ETa - ΔS) and GRACE data, compared to the observed discharge at the Al-Markaba tunnel plus the sea mouth outlet. The total discharge measured at the sea mouth outlet and the main water transfer in the Markaba tunnel is compared over the years 2017 to 2020.

3.4.1.3 Water Generation & Consumptive Analysis

The WaPOR data layers for precipitation, actual evapotranspiration and interception, and land cover class were used to identify water generating and consumer land cover types. Land cover classes that satisfy P > ETa is considered water generating areas, while those fulfilling ETa > P are net water consumers (Bastiaanssen et al., 2014). We estimated the mean values of P, ETa, and their difference per land-use class for the 2017-2020 period. As expected, some land cover classes may consume more water than they receive through precipitation, and most land cover classes of the Litani Basin are net water generating areas.

3.4.1.4 Water Accounting Plus Results

i) WA+ Sheet 1 Resource Base

Figure 11 shows the average WA+ Sheet 1 for 2010-2016 as generated by the (FAO & IHE-Delft, 2019) water accounting report. For the 2017-2020 study period, we generated a similar WA+ Sheet 1 that provides a total overview of the state of the water resources in the Litani River Basin. We examined the precipitation amounts consumed through evapotranspiration. Additionally, we reported the outflow in Mm3 /year. We investigated the exploitable and renewable water resources as opposed to the basin storage. We explored the ET shares of the various landscape types across the blue and green ET components.

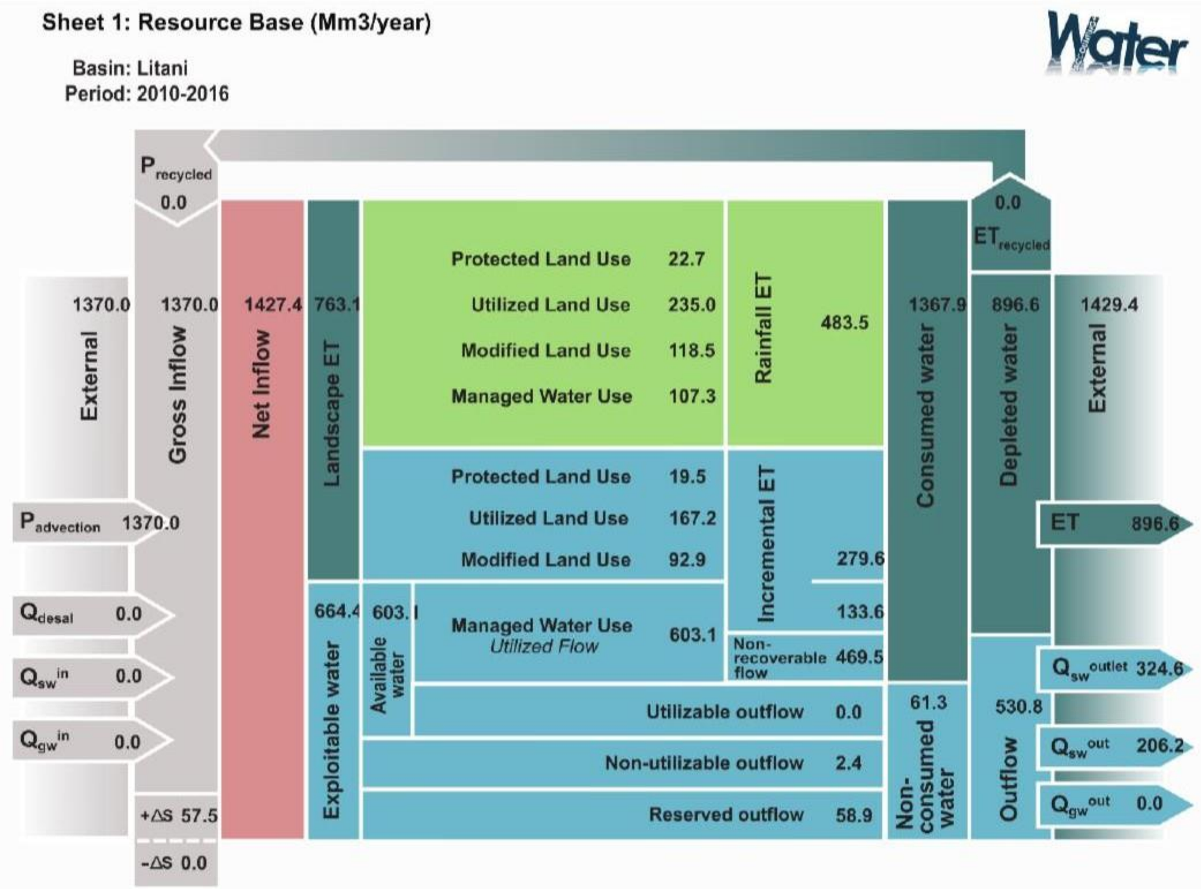

Figure 11. Average WA+ Sheet 1 for the study period 2010-2016 as reported by FAO & IHE- Delft in 2019

ii) WA+ Indicators

The WA+ Sheet 1 Resource Base provides an overview of the water resources utilization per different land use categories. In addition, a set of key performance indicators can be calculated to describe the entire system (see Table 11) (Dost, Obando, Bastiaanssen, & Hoogeveen, 2013). These indicators provide the basin planners and policymakers with data for water management, (re-)allocation, withdrawal permits, flows, soil, and water conservation, among others (P Karimi & Bastiaanssen, 2014).

Table 11. Key performance indicators involved in WA+

Indicator	Definition	How can it be used?
ET fraction	$\frac{ET_a}{P + Q_{in}}$ (%)	Actual ET as a percentage of the total inflow. It shows the proportion of the consumed inflow and the other proportion converted into renewable resources. A value higher than 100% indicates overexploitation or reliance on external

		resources.
Stationarity index	$\frac{\Delta \text{ storage}}{ETa}$ (%)	It indicates the depletion of water. A positive value suggests water is added to the water storage, and a negative value indicates a depletion.
Basin closure	$1 - \frac{\text{outflow}}{P + Q_{in}}$ (%)	Basin closure defines the percentage of total available water which is consumed and/or stored within a basin; a value of 100% indicates that all available water is consumed and/or stored in the basin
Available Water (AW)	Gross inflow – Landscape Evapotranspiration – Reserved Flow (km3/year)	Total amount of water that can be managed
Managed Water (MW)	blue ET of Managed Water Use (km3 /year)	Amount of water abstracted for managed water use
Managed Fraction	$\frac{\text{ManagedWater (MW)}}{\text{AvailableWater (AW)}}$ (%)	Percentage of water that is managed from the total amount of available water

The key performance indicators result of the 2017-2020 study period over the Litani River Basin allow us to describe the average ET fractions, hence, to indicate whether all precipitation is consumed. Stationarity Index (%) and Basin Closure (%) may also be quantified. The key performance indicators may also contribute to the assessment of the shares of water resources consumed, stored in the basin, and/or flows out of the basin. Additionally, the total amount of Available and Managed Water (km3/year) are accounted for.

3.4.2. WA+ Data for Case Study

3.4.2.1 Observed Flows

Apart from the WaPOR observations (described in section 1.2), WA+ requires observed discharge data as an input. Therefore, monthly observed flows (inter-basin transfers and discharge at the basin outlet) were collected for the study area for the period between 2017 and 2020. The main inter-basin transfer is the water diversion from Qaraoun Lake to produce hydropower at the Abd el Al station through the Markaba tunnel. This water is then used for land irrigation outside the watershed of the Litani and urban settlements of Beirut. The discharge capacity of the tunnel is 22 m3/s (Litani River Authority, 2019). We examined the variations of the discharge rates among years. Next to this inter-basin transfer, water is supplied to the Qasimiya irrigation project, which draws water from the Litani River before the basin outlet. The discharge capacity to Qasimiya is approximately 5 m3/s (Litani River Authority, 2019).

Table 12. WA+ input data of the Upper Litani River Basin in Lebanon

Category	Data Type	Data Name	Variables	Data Owner	Time Start	Time End	Time step	Location
	Water Storage Change	GRACE	Total Water Storage Change	GRACE-Gravity Recovery and Climate Experiment - NASA	2017	2020	Monthly	Global
	Reservoirs	GRanD_reservoirs_v1	Global Reservoirs	GDW	2019	-	Static	Global
	Water Content	thetasat_topsoil	Topsoil Saturated Water Content	HiHydroSoils (FutureWater)	2019	-	Static	Global
	Global Runoff	GRDC_runoff	Observed Flows	GRDC	2017	2020	Monthly	Global
	Discharge	Qibt_litani_MarkabaTunnel	Discharge (m3/s)	LRA	2010	2016	Monthly	Markaba Tunnel
	Discharge	Qoutlet_litani_QASMIYE_SeaMouth	Discharge (m3/s)	LRA	2010	2016	Monthly	Qasmiye Seamouth
	Evapotranspiration	L2_AETI_M	Actual Evapotranspiration and Interception	WaPOR	2009	2020	Monthly	Africa and Near East
	Interception	L2_I_D	Interception	WaPOR	2009	2020	Dekadal	Africa and Near East
	Evapotranspiration	L2_RET_M	Reference Evapotranspiration	WaPOR	2009	2020	Monthly	Africa and Near East
	Discharge	Gauge_JobJannine	Discharge (m3/s)	LRA	1998	2017	Monthly	Job Janine Gauge
	Discharge	Gauge_Qasmeyeh	Discharge (m3/s)	LRA	1994	2018	Monthly	Qasmeyeh Gauge
	Discharge	Gauge_Qilaya	Discharge (m3/s)	LRA	2003	2017	Monthly	Qilaya
	Discharge	Gauge_AinelZarqa	Discharge (m3/s)	LRA	2000	2017	Monthly	Ain el Zarqa
HYDRO	Discharge	Gauge_AinelSikeh	Discharge (m3/s)	LRA	1998	2017	Monthly	Ain el Sikeh

	Discharge	Gauge_Anjar	Discharge (m3/s)	LRA	1996	2017	Monthly	Anjar
	Discharge	Gauge_Ammiq	Discharge (m3/s)	LRA	1962	2017	Monthly	Ammiq
	Discharge	Gauge_BerdawniQaaelRim	Discharge (m3/s)	LRA	2008	2017	Monthly	Berdawni Qaa el Rim
	Discharge	Gauge_Chamsine	Discharge (m3/s)	LRA	2001	2016	Monthly	Chamsine
	Discharge	Gauge_Chtoura	Discharge (m3/s)	LRA	2005	2017	Monthly	Chtoura
	Discharge	Gauge_FourkFarzabad	Discharge (m3/s)	LRA	1962	2017	Monthly	Fourk Farzabad
	Discharge	Gauge_Ghelli	Discharge (m3/s)	LRA	2015	2018	Monthly	Ghelli
	Discharge	Gauge_Khrayzat01	Discharge (m3/s)	LRA	1992	2017	Monthly	Khrayzat
	Discharge	Gauge_Khrayzat02	Discharge (m3/s)	LRA	2009	2017	Monthly	Khrayzat
	Discharge	Gauge_RasElAinInterbol	Discharge (m3/s)	LRA	1962	2017	Monthly	Ras El Ain Interbol
	Discharge	Gauge_QaabElias(Delm)	Discharge (m3/s)	LRA	1998	2017	Monthly	Qaab Elias (Delm)
	Discharge	Gauge_Canal900	Discharge (m3/s)	LRA	2002	2016	Monthly	Canal 900
	Discharge	Gauge_QasmeyehIrrigation	Discharge (m3/s)	LRA	2012	2016	Monthly	Qasmeyeh irrigation
	Discharge	Gauge_TransferForHydropower	Discharge (m3/s)	LRA	2012	2016	Monthly	Transfer for hydropower
	Discharge	Gauge_HydroDiversionDemand	Discharge (m3/s)	LRA	2008	2016	Monthly	Hydro diversion demand
	Hydropower production	Gauge_QaraounReservoir01		LRA	2012	2016	Daily	Qaraoun reservoir
	Dam storage volume	Gauge_QaraounReservoir02		LRA	2002	2016	Monthly	Qaraoun reservoir
CLIMATE	Precipitation	L1_PCP_E	Precipitation	WaPOR	2009	2020	Daily	Africa and Near East
	Precipitation	L1_PCP_M	Precipitation	WaPOR	2009	2020	Monthly	Africa and Near East
LAND USE	Protected area	WDPA_CatIandII_17countries	Terrestrial and Marine Protected Areas	WDPA			Static	Global
	Land Cover	L2_LCC_A	Land Cover Classification	WaPOR	2009	2020	Yearly	Africa and Near East
GIS	Basin Delineation	BasinLitani	Boundary	HydroSHED	2021	2021	Static	Litani Basin

3.5. Tunisia

3.5.1. Status of WA+ Modeling and Use Purpose for Transformational Adaptation

The Jeffara of Medenine coastal plain, which is 5500 km² in area (Fig.12), is characterized by a semi-arid climate where the average annual rainfall is about 200 mm. Since the region is facing increasing needs in drinking water, agriculture and tourism activities and groundwater is the main source of water supply, it is critical to assess inflow to the aquifer and its salinity.

Figure 12. Location of the study area

The objectives of this study are to characterize the groundwater table in terms of groundwater balance, storage, and recharge, and geochemically and isotopically, using the results to specify the origin of the salinity, the hydrodynamic of the groundwater and the recharge area. Hydrogeological studies have shown that Jeffara has a multilayered aquifer system composed of four aquifers of the Plio-Quaternary (PQ), the Miocene (M), Jurassic Zeuss-Koutine (ZK) and the sandstone Triassic of Sahel El Ababsa (TSA) (Fig 13). The shallow aquifer has a salinity ranging from 2 to 10 g/L (M.F, 2008).

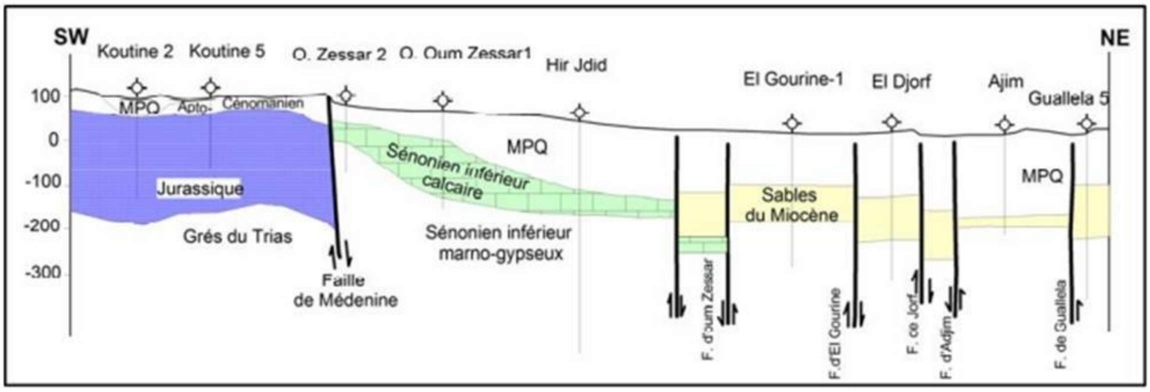

Figure 13. Hydrogeologic cross section across Jeffara region

Surface runoff estimation:

The estimation of surface runoff in the Jeffara coastal plain was based on the physical characteristics of watersheds determined by Kallel (2003). Empirical formulas were used for the estimation of runoff. The formula for calculating the runoff volume most adopted for the Zeuss-Koutine region is that given by Fersi (1985) using the following equation:

$$Vr\ (m3/\ y) = Lr * S$$

With: Lr: rainfall excess in m; S: watershed surface in m2. The rainfall excess is calculated by the formula of Fersi:

$$Lr\ (mm) = 16{,}39 * P * (Ig)^{1/2}$$

Table 12 shows the average runoff volume for Jeffara region using the Fersi method, for an average annual rainfall of 180 mm. Total runoff is estimated at 17.05 Mm3/year. The table includes information on the following variables: Lr: rainfall excess (mm); P: Watershed Average rainfall (m); Ig: Global index of slope (m/km).

Table 13. Runoff and runoff volumes in the Jeffara plain

	Wadi Essed	Wadi Sidi Makhlouf	Wadi Rebaia	Wadi Zeuss	Wadi Oum Zessar	Wadi Elfje	Wadi Smar	Wadi Rmel	Wadi Cheraia	Wadi El Maider	Wadi Bou Hamed
S (m^2)	33,6	49	86,2	166,9	350	447,8	590,8	36,7	19,3	22,1	551,7
Ig (m/km)	1,54	6,934,92	6,09	8,34	7,82	7	3,67	5,81	5,85	4,77	
P (km)	24,2	29,2	50,4	60,5	121	128,5	142	35,8	23	24,3	154,5
Lr(m)	4	8,1	6,4	7,7	8,7	8	7,6	5,8	7	7	5,6
Vr (m^3/y)	0,13	0,4	0,55	1,29	3,05	3,59	4,49	0,21	0,13	0,15	3,06
Total (m^3 /y)	17,05										

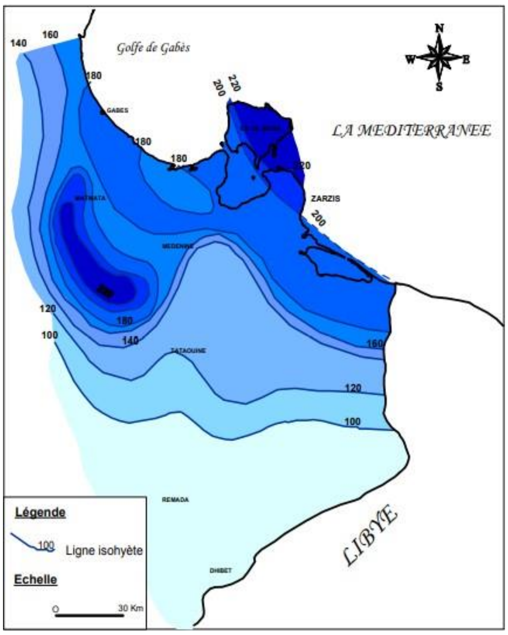

Figure 14. Rainfall distribution map of Jeffara

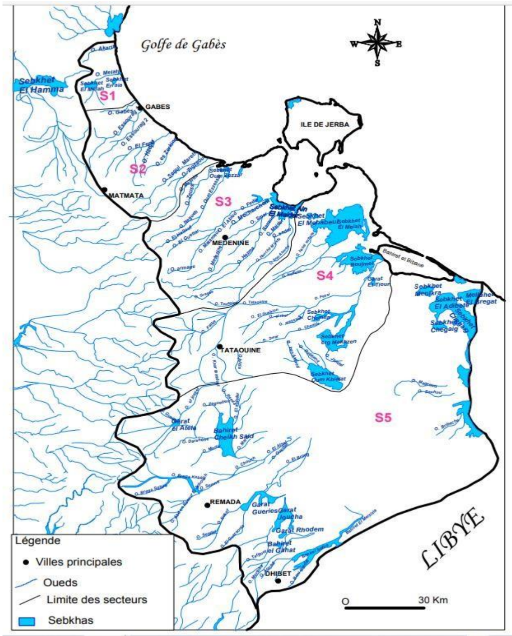

Figure 15. Watershed hydrology of Jeffara

Infiltration

In the Jeffara region, the indirect infiltration of surface water can reach 47% of the runoff volume in the outcrop areas of the Albo-Aptian (Koutine and Ksar Chrarif) and up to 24% in the areas of water and soil conservation (C.E.S) at the level of the main wadis and their outcrops. The infiltration coefficient is very low to the East of the Médenine fault (presence of outcrops formed by gypsum clays or impermeable crusts) (Mansouri, 1985).
The Jeffara of Medenine is characterized by a very dense hydrographic network formed by several streams which originate from the altitudes of the Daher mountain chain and flow towards the Sebkha or depressions and towards the Sea. These runoffs in presence of Soil and water preservation carried out in the main wadis promote groundwater recharge in the Jeffara of Médenine aquifer system.

Piezometry

The piezometry map shows a flow direction controlled by the topography from the Dhaher mountain chain to the sea which forms the downstream hydraulic level. In some places, the piezometric line is below seawater level. In this case we have an inversion of hydraulic gradient due to seawater intrusion.

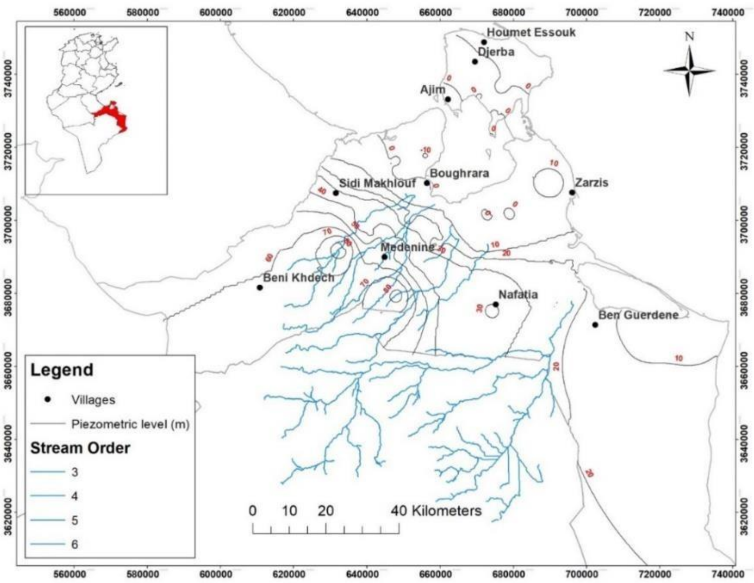

Figure 16. Piezometric map of Jeffara

Salinity map

The salinity measured in groundwater samples from this area is rather high for most samples; the values range between 1 and 10g/l.

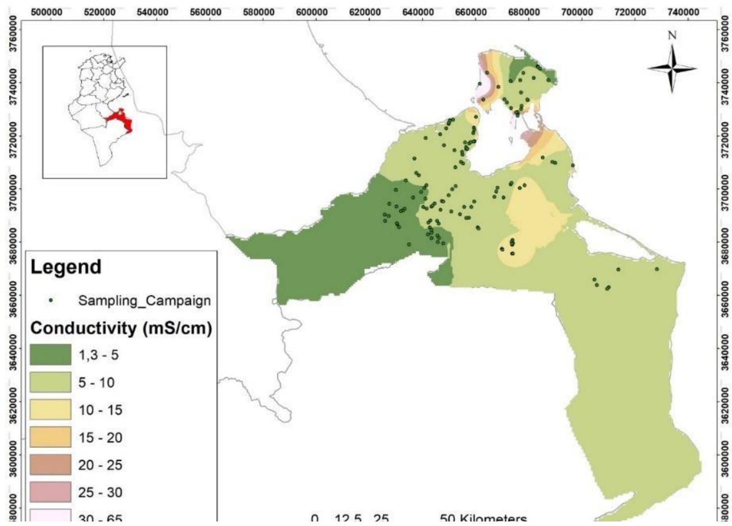

Figure 17. Salinity map 2021 of Jeffara

Hydrodynamic characteristics of the Medenine Jeffara aquifer system

The two essential parameters which define an aquifer from the hydrodynamic point of view are: The transmissivity T expressed in m2/s which characterizes the conductive function of the reservoir and the storage coefficient S which characterizes the storage function.

Transmissivity

This parameter governs the flow rate of water flowing per unit width of an aquifer under the effect of a unit hydraulic gradient. The transmissivity is equal to the product of the permeability and the thickness of the aquifer (Castany, 1982).

Because the exploitation of the shallow aquifer is done by unequipped wells in most regions, there are no precise indications concerning the spatial distribution of the permeability. Available transmissivity values indicate permeability values which are between 0.0125 10-5 and 6.25 10-5m2/s in the plain of El Ouara, El Hamada and Ben Guerdane region. In the regions of Jerba, Zarzis and Médenine the permeability values are between 1.10-4 and 5.10-4 m2/s.

Storage Coefficient

The storage coefficient, denoted by S and without dimension, expresses the ratio of the volume of water released per unit of surface of the aquifer and per unit of variation of the hydraulic head. For an unconfined aquifer, this parameter is equivalent to the effective porosity, and is expressed in %. For a confined aquifer, it is significantly smaller. The value of the mean storage coefficient calculated for the Mio-Plio-Quaternary unconfined aquifer is: 0.1. The hydrodynamic characteristics of the aquifer system of the Jeffara of Medenine are presented in Table 13.

Table 14. Hydrodynamic characteristics of the aquifer system of the Jeffara of Medenine (CRDA, 2016)

Aquifer	Transmissivity m²/s	Storage coefficient (%)	Specific flow rate (L/s/m)
Sandstone of Trias of Sahel El Ababssa	$16*10^{-3}$	0.51	0.82
Jurassic Zeuss Koutine	10^{-3}	0.53	very variable
Miocene	$8.8*10^{-3}$	-	-
Plio-Quaternary	10-3	0.1	0.3

Estimation of the groundwater storage of the Jeffara coastal aquifer

The groundwater storage, W, is evaluated using two pieces of information:

- The volume, V of the section of the aquifer considered (product of the area A and the thickness e).

- The effective porosity of the unconfined aquifer, ne

W= V × ne = A × e × ne

For the Mio-plio-quaternary unconfined aquifer: e = 10 m (average deduced from the thicknesses of the unconfined Mio-Plio-Quaternary aquifer), A = 1903 Km2, ne = 10%

W= 1903.106 m2× 10 m× 0.1 = 1903 106 m3

This theoretical estimation of groundwater storage includes saline and fresh water. The General directorate of water resources in Tunisia (DGRE), estimates that the groundwater resources of fresh water in Jeffara shallow aquifers is: 12,67 106 m3.

Estimation of the annual regulatory groundwater storage of the Jeffara aquifer

The regulating groundwater storage of unconfined aquifers, as in the case of the Mio-Plio-Quaternary, represents the volume of gravity-fed water contained in the fluctuation zone of the interannual piezometric surface. It is calculated by reference to a defined period (annual fluctuation height or annual average). The annual Mio-Plio-Quaternary aquifer reserve estimate was calculated from the equation:

R= h* S* Storage Cœff. (m3)

With:

h: average annual fluctuation of the piezometry for all the piezometers and shallow wells. For the years 2016 and 2017, h varies from 0.1 to 1.08 m (Sahal, 2019).

S: Groundwater surface = 1903 km2 ;

Storage Cœfficient = 0.1

This would give an average annual regulating storage of -19,03 106 m3/year for the years 2016 and 2017.

It should be noted that the estimation for the regulating groundwater storage given by the DGRE (14,37 106 m3) differs from one year to another since it essentially depends on rainfall and a piezometric variation of 1m would generate either an increase or a decrease in the regulating groundwater storage of 190,3 106 m3.

Groundwater exploitation

The groundwater shallow aquifer resources are estimated by (CRDA, 2020) to be around 12.67 106m3/year. The exploitation in 2020 of groundwater in the governorate of Medenine is equal to 14.37 Mm3/year, with a mobilization rate of groundwater of about 113.4%.

In coastal Jefara, Mio-Pliocene clays and marls materialize a semi-permeable screen between the Mio-Plio-Quaternary shallow water tables and the adjacent deep-water tables which are often artesian. Consequently, the water tables of coastal Jefara are mainly supplied by:

- Direct infiltration of rainwater,
- Lateral feeding from adjacent aquifers via the Medenine fault,
- The lateral supply from the interior Sebkhas,
- Upward leakage from deep aquifers.

Within the water tables of coastal Jeffara, superficial aquifer levels of relatively fresh water and underlying aquifer levels of salty water coexist. Under these hydrogeological conditions, any exploitation beyond the renewable resources, a high density of pumped wells, a high pumping rate and deepening wells reaching the level of saltwater lead to homogenization and an increase in salinity.

Table 15. Exploitation of shallow aquifers of governorate of Medenine, December 2020

Aquifer	Code	Number of shallow wells				GW salinity (g/l)		Resources	Exploitation	Available Resources	Deficit	Abstraction rate	Inventory of wells	
		Not equipped	Equipped		Total	Min	Max	(10^6m^3/an)	(10^6m^3/an)	(10^6m^3/an)	(10^6m^3/an)	(%)	Year	Actualization
			GE	GD										
Zeuss-Om Zessar (Aval)	82110	43	69	19	131	4	7	0,79	0,30	0,49		37,97	1995	2020
BV Zeuss-Om Zessar (Hallouf)	82120	28	15	4	47	2,5	4,5	0,16	0,06	0,10		37,50	2000	2020
BV Om Tamar (Amont)	82210	8	152		160	3	5	0,63	0,54	0,09		85,71	1995	2020
Zarzis	82220	110	201	30	341	4	7	0,94	0,87	0,07		92,55	1995	2020
BV Smar (Médenine)	82230	5	810	0	815	3	8	1,39	3,08	0,00	1,69	221,58	1999	2020
BV Om Tamar (Fjé)	82240	12	161	0	173	3,5	7,5	0,47	0,65	0,00	0,18	138,30	1995	2020
Presqu'île de Jorf	82310	195	131	134	460	4	7,5	0,91	1,00	0,00	0,09	109,89	1993	2020
BV Sidi Makhlouf	82320	33	95	0	128	4	8	0,5	0,33	0,17		66,00	1995	2020
BV Hessi Soltane	83210	18	35	5	58	3,5	8	0,22	0,13	0,09		59,09	2006	2020

BV Remel el Maidher	83220	0	57	3	60	4	8	0,66	0,23	0,43		34,85	1991	2020
BV Maleh-Nhil	83230	46	40	18	104	4	8	0,18	0,19	0,00	0,01	105,56	2006	2020
BV Bou Hamed	83250	18	60	17	95	4,5	7	0,47	0,29	0,18		61,70	2009	2020
Ile de Jerba	84110	1306	977	45	2328	2,5	8	3,46	3,88	0,00	0,41	112,14	1995	2020
Ben Guerdane	85110	319	693	53	1065	5	8,5	1,89	2,82	0,00	0,93	149,21	1995	2020
Total		2141	3496	328	5965	3,9	7,4	12,67	14,37	0,00	1,69	113,42	2010	2020

Table 16. Groundwater balance of the Jeffara in steady state in 1950, in m3/s (Trabelsi, 2009)

	Shallow coastal aquifer			Unconfined coastal aquifer			Triassic aquifer		
		Stead ystate (1950)	Stead ystate 1950 (OSS, 2005)		Stead ystate (1950)	Stead ystate 1950 (OSS, 2005)		Stead ystate (1950)	Stead ystate 1950 (OSS, 2005)
Inlet. Inflow	Infiltration	1,71	2,794	Infiltration	0,4	0,427	Infiltration	0,516	0,21
	Inflow CI	1,36	0	Inflow CI	3,04	3,632	Inflow Saharia nbasin	2,27	1,02
	Inseepage Miocene Medenine	1,2	0,701	Inseepage Trias	1, 35	0,742	Inseepag eHigh	0	1,186
	Lateral Inflow south From Libya	0	0,839	Inflow Libya	0	0,084	Inflow Libya	0	0,309
	Inseepage Trias								

		0,8	0						

	Total Inflow	5,07	4,334	**Total Inflow**	4,79	4,885	**Total Inflow**	2,786	1,725
Outlet. Outflow	Outflow Sea	3,89	1,981	Outflow Sea	2,307	1,272	Outflow Sea	0,63	0?802
	Outflow sebkha	1,16	1,973	Inseepage Shallow aquifer	1,2	0,701	Inseepage Shallow aquifer	0,8	0
	Outflow Libya		0,363	Springs	1,21	1,365	Inseepage Medenine Fault	1,35	0,741
	Outflow Gabes		0,016	Inseepage down	0	1,186	Outflow Libya	0	0,185
				Sebkha Hamma	0	0,021			
				Outflow Libya	0	0,132			
				Pumping	0	1,208			
	Total Outflow	5,05	4,333	**Total Outflow**	4,717	4,885	**Total Outflow**	2,78	1,728

Table 17. Groundwater balance of the Jeffara in unsteady state in 2006, in m3/s (Trabelsi, 2009)

	Shallow costal aquifer			Unconfined coastal aquifer			Triassic aquifer		
		Unsteadystate (2006)	Unsteadystate (OSS, 2005)		Unsteadystate (2006)	Unsteadystate (OSS, 2005)		Unsteadystate (2006)	Unsteadystate (OSS, 2005)
Inlet. Inflow	Infiltration	1,71	2,794	Infiltration	0,4	0,427	Infiltration	0,516	0,21
	Inflow CI	0,92	0	Inflow CI	2,03	1,4	Inflow Sahariannbasin	2,329	1,02
	Inseepage Miocene Medenine	1,22	0,428	Inseepage Trias	1,35	0,871	Inseepage High	0	0,125
	Lateral Inflow south From Libya	0	0,84	Inflow Libya	0	0,083	GW Storage	0,285	0,316
	Inseepage Trias	0,85	0	GW Storage	2,1	2,52	Inflow Libya	0	0,309
	Seawater	0,003	0						
	GW storage	0,75	0,857						
	Total Inflow	5,453	4,919	**Total Inflow**	5,88	5,301	**Total Inflow**	3,13	1,98

Outlet. Outflow	Outflow Sea	2,84	1,659	Outflow Sea	0,6107	0,885	Outflow Sea	0,63	0,716
	Outflow sebkha	1,16	1,888	Inseepage Shallow aquifer	1,22	0,428	Inseepage Shallow aquifer	0,85	0
	Abstraction	1,43	1,01	Springs	0,0023	0,112	Inseepage Medenine Fault	1,35	0871
	Outflow Libya	0	0,36	Abstraction	4,05	3,621	Abstraction	0,17	0,21
				Inseepage down	0	0,125	Outflow Libya	0	0,187
				Sebkha Hamma	0	0,013			
				Outflow Libya	0	0,127			
	Total Outflow	5,43	4,917	**Total Outflow**	5,883	5,311	**Total Outflow**	3,002	1,984

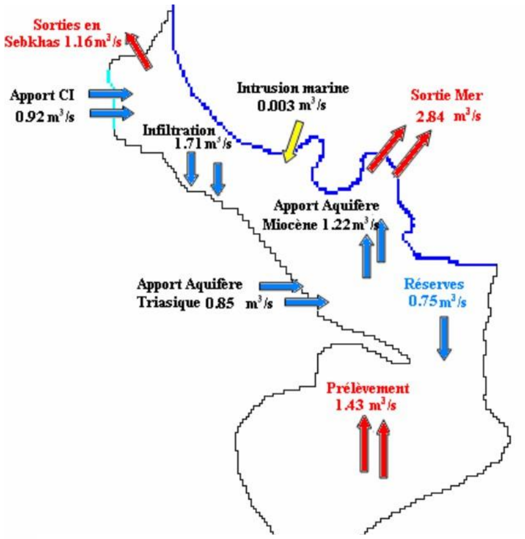

Figure 18. Groundwater Balance of the Jeffara shallow aquifer, (Trabelsi, 2009)

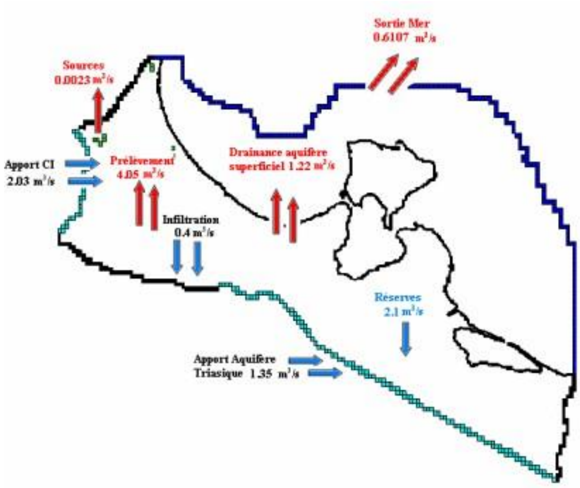

Figure 19. Groundwater Balance of the Jeffara deep aquifer, (Trabelsi, 2009)

Conclusion

The flow model was used in 2009 to estimate the balance of the three aquifers of the Jeffara and to quantify the exchange flows between the different layers in the unsteady state. It showed that Continental Intercalaire CI aquifer inputs decreased from 3.04 to 2.03 m3/s for the deep coastal aquifer and from 1.36 up to 0.92 in the shallow aquifer. However, recharge from rainwater remained constant in the three aquifers, at 1.71 m3/s in the shallow aquifer, 0.4 m3/s in the deep coastal aquifer and 0.5 m3/s.

The exchanges between the three aquifers have remained practically constant. The contributions of Triassic waters in the recharge of the Miocene sands through the faults of Médenine and the shallow aquifer in the plain of El Ouara have been evaluated at 1.35 and 0.85 m3 /s respectively. On the other hand, the vertical drain of the waters of the deep coastal aquifer towards the superficial aquifer of the region of Jerba Zarzis was estimated at 1.2 m3/s (Trabelsi, 2009).

3.5.2. WA+ Data for Case Study

For the Jeffara plain, the water accounting was performed using a classical approach (see previous section), based on statistics of water resources and water demand. Table 17 displays the WA inputs available for the case study.

Table 18. WA+ input data of the Jeffara plain case study in Tunisia

Type of Data	Format	Location	Time Start	Time End	Time Step	Source
HYDROGEOLOGY						
Modflow files	Various	Jeffara, Medenine	2010			INAT
Geologic map	Map	Jeffara, Medenine		1980		ONM, Tunis
List of spring locations	Table and Map	Jeffara, Medenine		2021		CRDA, Medeni

and elevations						ne
Spring discharges	Time series	Jeffara, Medenine		2021		CRDA, Medenine
Well_type	Table	Jeffara, Medenine		2021		CRDA, Medenine
Well Elevation	Table	Jeffara, Medenine		2021		CRDA, Medenine
Well Depth	Table	Jeffara, Medenine		2021		CRDA, Medenine
Well Use	Table	Jeffara, Medenine		2021		CRDA, Medenine
Groundwater levels in monitoring wells	Time series	Jeffara, Medenine		2021		CRDA, Medenine
Locations of monitoring wells	Table and Map	Jeffara, Medenine		2021		CRDA, Medenine
Pumped volume - public wells	Time series	Jeffara, Medenine		2021		CRDA, Medenine
Pumped volume - private wells	Time series	Jeffara, Medenine		2021		CRDA, Medenine
HYDROLO						
Discharge	Time series	Medenine	1980	2021	Daily	CRDA, Medenine
River Depth	Time series	Medenine	1980	2021	Daily	CRDA, Medenine

***Hydrological years**

CLIMATE						
Precipitation	Time series	Medenine meteoric station	1901	2021	Daily	INM, ONAGRI
ETo (P.Monteith mm)	Time series	Medenine meteoric station	1901	2021	Annual	INM
Temperature-mean	Time series	Medenine meteoric station	1901	2021	Daily	INM
Temperature-minimum	Time series	Medenine meteoric station	1901	2021	Daily	INM
Temperature-maximum	Time series	Medenine meteoric station	1901	2021	Daily	INM
Relative Humidity-mean	Time series	Medenine meteoric station	1960	2021	Monthly	INM
Relative Humidity-minimum	Time series	Medenine meteoric station	1960	2021	Monthly	INM
Relative Humidity-maximum	Time series	Medenine meteoric station	1960	2021	Monthly	INM
Wind Speed-mean	Time series	Medenine meteoric station	1960	2021	Daily	INM
Wind	Time series	Medenine meteoric station	1960	2021	Daily	INM

Speed-maximum						
Wind direction	Time series	Medenine meteoric station	1960	2021	Daily	INM
Wind direction-maximum gust	Time series	Medenine meteoric station	1960	2021	Monthly	INM
Solar radiation	Time series	Medenine meteoric station			Monthly	INM
Sunshine hours	Time series	Medenine meteoric station			Daily	INM
WATER QUALITY						
Wastewater plant discharge	Time series	Jeffara, Medenine	2004	2021	Monthly	ONAS, Medenine
Other point source pollution discharges	Time series	Jeffara, Medenine	2004		Monthly	ONAS, Medenine
Locations of point source pollution	Map	Jeffara, Medenine	2004		Annual	ONAS, Medenine
Water quality parameters	Time series	Jeffara, Medenine	1990		Semestrial	CRDA, Medenine
GEOGRAPHIC INFORMATION						
DEM	AAIGrid (ASCII)	Jeffara, Medenine				USGS
Land use class map	Shapefile	Jeffara, Medenine	2003			CRDA, Medenine
Land use classes table	Table	Jeffara, Medenine	2003			CRDA, Medenine
Soil map	Shapefile	Jeffara, Medenine	2003			CRDA, Medenine
Soil map	Table	Jeffara, Medenine	2003			CRDA, Medenine
Crop_type map	Shapefile	Jeffara, Medenine	2003			CRDA, Medenine
Crop_type map	Table	Jeffara, Medenine	2003			

3.6. Egypt

3.6.1. Status of WA+ Modeling and Use Purpose for Transformational Adaptation

3.6.1.1. Description of the study area

The command area known as Meet Yazid (MYC) is situated at the southernmost part of the Middle Delta region. Spanning a length of 63 km, MYC functions as the primary canal that provides water to 60 secondary or branch canals (BCs). The general flow direction of MYC is from north to northwest, terminating just south of El Burullus Lake. Upon crossing Drain 8, MYC continues its course until it reaches the Nashart Drain. At this point, it supplies water to Ganabia Sidi Salim Al-Sharquia, a canal previously fed by the final stretch of the Nashart Drain when it served as a canal. MYC follows the right bank of Ganabia Sidi Salim Al-Sharquia (IWMI and WMRI. 2013).

- Cross regulators are gates that can be raised using a mechanical system, either manually for smaller gates or with a motor for larger ones, and it is called sluice gates. In terms of regulating the Meet Yazid Command (MYC) area, the three successive key regulators are Beltag, Wasat, and Moufti. Most of these structures are in decent to good condition as they undergo regular maintenance and serve their intended purposes. However, there are occasional issues such as leaks (sometimes caused by farmers damaging the gates) or breakages (e.g., the cross-regulator on the Siyak Branch of El Ghabat or a few other unused branches). Some regulators, like the Batata Regulator in the middle of the Zawiya subbranch, are only utilized during winter to increase the water level. The El-Wasat cross regulator underwent complete rehabilitation in 2000.

- The width and flow capacity of MYC gradually decreases from the intake to the tail. Alongside the main canal, an extensive irrigation network is present, consisting of branch canals (secondary canals), mesqas, and marwas (tertiary canals and farm ditches), serving the command area (see Figures 20 and 21). There are five primary types of off-takes from the main canal (IWMI and WMRI. 2013): -
  - Large branch canals that serve areas larger than 15,000 feddans (1 feddan = 4,200 m^2); these can be considered as main canals or extensions thereof, such as El-Zawiya and Shalma canals;
  - Regular branch canals that serve areas between 1,000 and 15,000 feddans; these directly supply mesqas, such as Khadiga and Qahwagi;
  - Ganabias or parallel branch canals; these smaller canals run alongside the main canal and typically serve 500 to 2,000 feddans. They were constructed to avoid direct abstraction from the main canal, enabling better supply control. El-Zawiya canal has 10 successive ganabias along its course;
  - Mesqas (tertiary canals) directly supplied from the Main Canal. MYC has 37 improved direct mesqas under the IIIMP project (IIIMP, 2004) and 40 unimproved mesqas; and
  - Direct lifting (pumping) points located at 120 positions from the head to the El-Wasat cross regulator, serving a command area of approximately 1,154 feddans, with most of them on the left side of the canal. These lifting points typically consist of one or several individual pumps. (Similar lifting points can be found along all the branch canals and along Meet Yazid). A survey conducted by WMRI in 2012-2013 identified a total of 214 abstraction points serving around 10,512 feddans.

Table 19. Direct irrigated areas on Meet Yazid from the head to El-Wasa (adopted from IWMI and WMRI. 2013)

Type	No.	Total area (fed)
Lifting points	120	1,154
Lifting point pumps in Marwas	6	126
Improved Mesqas	37	1,622
Unimproved Mesqas	41	7,610
Large stations	10	
Total	214	10,512

The study encompassed the area up to the Wasat Regulator. Beyond this point, there are additional direct abstraction points, including six large-scale old pumping stations dating back to King Farouk's era. Along the Zawiya Canal, another six pumping stations can be found. Many of these stations still utilize the original British engines and serve areas of a few hundred feddans.

Some of the branch canals, such as Tail-Ruwina or El-Shouka, are relatively small and cater to 500 feddans. Conversely, certain mesqas (tertiary canals) can be lengthy and serve large areas. For instance, at the tail end of the El Ghabat Canal, mesqa No. 5 spans 11 km and serves 1,000 feddans. The distinction between small branch canals and large mesqas can sometimes be arbitrary, and their categorization is primarily based on the legal status of the canal. Branch canals are considered public property with a right of way, while mesqas are situated on community land and owned and maintained by farmers.

As mentioned earlier, MYC boasts two significant branch canals: El-Zawiya, which supplies the northeastern part of the command area (78,000 feddans), and Shalma Canal (20,000 feddans), which can be viewed as an extension or continuation of MYC. These canals can also be considered branches of the main canal as they provide water to secondary canals referred to as branch canals.

It's important to note that the combined storage capacity of Meet Yazid and El-Zawiya canals amounts to approximately 8.0 million m^3, which is equivalent to the average water supply at the canal's head for a single day during the high consumption period of May, June, and July. Branch canals and smaller-level canals contribute additional storage capacity, and the increased supply during the night is typically stored in the canal network. Mesqas are believed to account for 40% of the total storage capacity, highlighting the challenge that arises when they are filled without ensuring continuous flow at the same time, as observed in the IIP/IIIMP projects.

The command area of MYC is served by an extensive drainage network consisting of 24 open drains (main and secondary) with a total length of 400 km, as well as subsurface drains (collectors and laterals). The command area is intersected by four major south-north drainage lines: The Nashart Drain, Main Drain 8, Main Drain 7, Samatay, and Gharbiya (Table 20).

Table 20. Main drains of MYC command area (adopted from IWMI and WMRI. 2013)

Main Drain	Area served in MYC CA (feddans)	Length (km)	Outlet
El Gharbeya main	42,000*	39.5	No.7 east
No.7 lower	85,000	29.4	PS No. 7 to Drain No.7 east
No.8 lower	7,000	22.8	PS No. 8 to Drain No.8
No.7 east	33,000	7.4	No.7
Samatay	26,000*	22.4	Sogaeya PS to Sogaeya Drain
No .9	4,000	37.3	El Burullus Lake
Totals	197,000		

NB. * Also serves areas outside the MYC command area.

The drainage water from the area is directed towards Lake El-Burullus through the El-Gharbiya Drain, although a portion of this drain flows directly to the sea. To protect and separate the reclaimed land in the north of the MYC area from the influence of the sea, an enclosed Moheet Drain (boundary drain) has been established, marking its upper limit. This drain is connected to the lake through outfall drains that are equipped with pumping stations (PSs). These PSs pump drainage water from the Moheet Drain to maintain a difference in water level between the drainage system (kept low for effective land drainage) and the lake (roughly at sea level with some tidal influence). Pumping out all the water discharged into the sea incurs substantial costs. The main drainage PSs are situated along Drains 6, 7, 8, 9, and 11. These stations are operated intermittently to maintain a specific upstream water level in the drain and, at times, to meet the water requirements of the aquaculture area located between the Moheet Drain and the Burullus Lake (IWMI and WMRI. 2013).

IWMI and WMRI (2013) reported that after the construction of the Aswan High Dam in 1970, which eliminated the annual flooding, the cultivation of two to three crops throughout the year became possible. However, the absence of natural soil leaching caused by the floodwaters and the increased water application on the land necessitated the development of an artificial drainage system in the Nile Delta to combat waterlogging and salt accumulation in the root zone. In the 1960s, a national program was initiated, resulting in the installation of subsurface drainage pipes across most of the Nile Delta (Nijland, Croon, & Ritzema, 2005). Although the expected lifespan of this drainage system is 20 years, there have been instances where pipes became clogged after only a few years. The Drainage Authority has acquired machinery to clean the collectors by injecting water under pressure, but this solution has proven to be inadequate. In some cases, the IIIMP project or the farmers themselves have already replaced parts of the drainage network. Lateral pipes, which are subsurface drainpipes, are typically placed at a depth of 1.25 m at the highest point of the field. The spacing between laterals is determined based on soil characteristics, with a minimum spacing of 30 m usually followed, although economic factors may influence this decision. Plastic PVC corrugated tubes with an 80 mm diameter are commonly used for lateral pipes. The water levels in the open drains must align with an average field drainage depth of 1.35 m. Consequently, the bed level of the open drain needs to be at least 2.5 m below the field ground level, taking into account its capacity. In terms of subsurface drainage, the entire command area of MYC has been equipped with subsurface drainage systems over the years. Approximately 18,000 km of laterals, 2,000 km of collectors, and 15,000 concrete manholes have been installed. The ongoing IIIMP project is currently replacing some of the older subsurface drainage networks in the area.

They also stated that the groundwater in the middle Delta is typically part of the Nile Deposit Basin. On average, around 1.57 billion m^3 of groundwater is withdrawn annually, which accounts for about 65% of the annual recharge volume. However, in MYC, only 6 million m^3 (a mere 0.25% of the total) is pumped out (Saleh, 2009). This relatively low value can be attributed to the salinity of the groundwater in most of the MYC area, rendering it unsuitable for domestic use. "The main characteristics of groundwater are: Number of licensed wells: around 35; Average drilling depth: 60 m; Depth of static water table: 2 to 4 m the level over now; Well pumping rate: 700 m^3/day; Salinity: 450-600 ppm; Groundwater potential: high;

Groundwater vulnerability: medium-low; and groundwater quality: $NaHCO_3$."

IWMI and WMRI (2013) mentioned that the water table depth in the field typically ranges from 2 to 4 meters, depending on local drainage conditions and the type of crop being grown (although it can be less than 1 meter during certain periods). Due to the high clay content in the soil, extracting this groundwater through pumping is not feasible. In order to access water from deeper layers with sandier soil, wells are drilled to depths of 40 to 120 meters.

The government primarily abstracts a larger volume of groundwater to supply drinking water to cities. In the Nile Delta, there are several well fields that extract approximately 3 billion m^3 of water per year (Abo Soliman, 2012). Additionally, farmers also drill smaller wells to tap into groundwater as a supplementary resource when the supply of surface water is irregular, uncertain, or insufficient. However, the use of groundwater is limited by its quality and is mostly feasible in the southern part of the Nile Delta. Figure 22 illustrates the iso salinity lines of groundwater, showing that salinity increases as one moves north towards the sea. In practice, groundwater is used up to a line located somewhere north of Tanta City.

3.6.1.2. Water resources developments and challenges in the study area

IWMI and WMRI (2013) indicated that the population residing in the rural and peri-urban areas of the Meet Yazid Canal command area (MYC) is approximately 1.1 million, with 85% of the population living in densely clustered main and satellite villages. The majority of the population is engaged in agriculture, while peri-urban residents are primarily involved in service provision and government employment, with a smaller portion engaged in industrial activities. Fish farming and aquaculture also play a significant role, especially in the northern region of MYC. MYC falls within the administrative boundaries of Gharbiya and Kafr El Sheikh governorates, with Kafr El Sheikh encompassing 71% of the total area. The area is primarily divided into six districts (marakez). Income levels vary among the districts and between rural and peri-urban settlements.

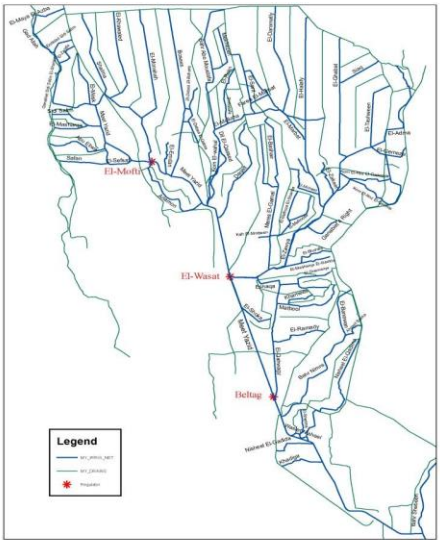

Figure 21. Network of main and secondary irrigation canal (after IWMI and WMRI. 2013)

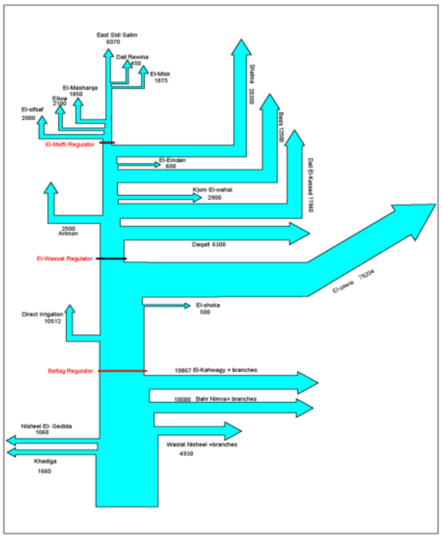

Figure 20. Flow chart of the canal system (the width of arrows is indicative of the flow) (after IWMI and WMRI. 2013)

They also concluded that the Meet Yazid command area (MYC) experiences localized and time-specific water shortages. These shortages are often attributed to one or multiple factors related to supply (such as availability in Aswan Dam and conveyance capacity of certain canals), demand (including increased summer rice cultivation, "illegal" fish farms, and requirements for soil leaching), and poor management (either by farmers or technical staff). Analyzing and identifying the causes of these shortages is complex due to the involvement of multiple factors. However, the result is often an uneven distribution of water between the head and tail reaches of MYC and its branch canals, leading to water shortages being predominantly concentrated at the tail end of the canals.

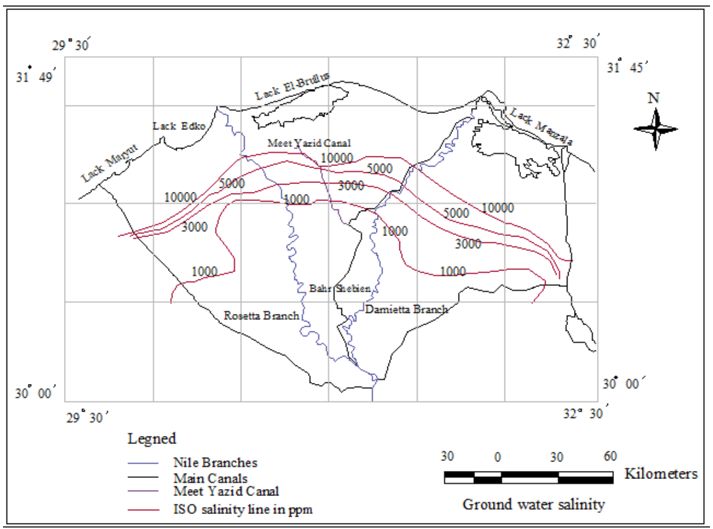

Figure 22. Iso salinity lines of groundwater in the Nile Delta (DRI, 2007)

3.6.1.3. Objective of Water accounting

The objective of this study is to illustrate the utilization of WaPOR data and other Earth observation data sources to generate information that offers insights into major water flows and fluctuations. This information aids in determining water availability, withdrawals, consumptive use, non-consumptive use, as well as the benefits and services derived from it. Specifically, the study aims to address the following inquiries: -

- What is the current availability of water resources in the MYC command area?
- How much water is being consumed by various sectors, particularly agriculture, in the MYC command area?
- What are the recommended limits for water withdrawals in the agricultural sector within the MYC command area? This study presents the necessary inputs for implementing the Water Accounting+ framework in the MYC command area from 2009 to 2022, utilizing WaPOR v2.1.

3.6.2. WA+ Data for Case Study

Type of Data	Format	Location	Time Start	Time End	Time Step	Source
HYDROLOGY						
Discharge	Time series	Meet Yazeid Canal	2018	2021	Monthly	MWRI
Canal Depth	Time series	Meet Yazeid Canal	2018	2021	Monthly	MWRI
CLIMATE						
Precipitation	Time series	The Nile Delta	1991	2021	Monthly	EMA
ETo (P.Monteith mm)	Time series	The Nile Delta	1991	2021	Monthly	EMA
Temperature-mean	Time series	The Nile Delta	1991	2021	Monthly	EMA
Temperature-minimum	Time series	The Nile Delta	1991	2021	Monthly	EMA
Temperature-maximum	Time series	The Nile Delta	1991	2021	Monthly	EMA
Relative Humidity-mean	Time series	The Nile Delta	1991	2021	Monthly	EMA
Relative Humidity-minimum	Time series	The Nile Delta	1991	2021	Monthly	EMA
Relative Humidity-maximum	Time series	The Nile Delta	1991	2021	Monthly	EMA
Wind Speed-mean	Time series	The Nile Delta	1991	2021	Monthly	EMA
Wind Speed-maximum	Time series	The Nile Delta	1991	2021	Monthly	EMA
Wind direction	Time series	The Nile Delta	1991	2021	Monthly	EMA
WELLS DATA						
Well locations	Table	Meet Yazeid Command Area	2021			MWRI
Well_type	Table	Meet Yazeid Command Area	2021			MWRI
Elevation	Table	Meet Yazeid Command Area	2021			MWRI
Depth	Table	Meet Yazeid Command Area	2021			MWRI
Use	Table	Meet Yazeid Command Area	2021			MWRI
GEOGRAPHIC INFORMATION						
Land use classes table	Table	Meet Yazeid Canal	2021			GAD
Soil map	Table	Meet Yazeid Canal	2021			GAD
Crop_type map	Table	Meet Yazeid Canal	2021			GAD
AWDUs Groundwater map*	Table	Meet Yazeid Canal	2021			GAD
AWDUs Groundwater table*	Table	Meet Yazeid Canal	2021			GAD
Well locations	Table	Meet Yazeid Canal	2021			GAD
Agricultural Water Demand Units						

References

Abo Soliman, M. S. (2012). Status and new developments on the use of brackish water for agricultural production in the Near East. Retrieved from

Bastiaanssen, W. G., Karimi, P., Rebelo, L.-M., Duan, Z., Senay, G., Muthuwatte, L., & Smakhtin, V. (2014). Earth observation based assessment of the water production and water consumption of Nile Basin agro-ecosystems. Remote Sensing, 6(11), 10306-10334.

Castany, G. (1982). Hydrogéologie, Principes et méthodes. : Ed Dunod.

Coron, L., Thirel, G., Delaigue, O., Perrin, C., & Andréassian, V. (2017). The Suite of Lumped GR Hydrological Models in an R package. Environmental Modelling & Software. doi:10.1016/j.envsoft.2017.05.002

CRDA. (2016). Etude d'optimisation de l'exploitation des ressources en eaux des nappes de Zeuss Koutine et des

grès du Trias de sahel El Ababssa. Retrieved from

De Lavenne, A., Andréassian, V., Thirel, G., Ramos, M.-H., & Perrin, C. (2019). A Regularization Approach to Improve the Sequential Calibration of a Semidistributed Hydrological Model. Water Resources Research, 55(11), 8821-8839. doi:doi.org/10.1029/2018WR024266

Dorchies, D., Delaigue, O., & Thirel, G. (2021). airGRiwrm: an extension of the airGR R-package for handling Integrated Water Resources Management modeling. doi:10.5194/egusphere-egu21-2190

Dost, R., Obando, E., Bastiaanssen, W., & Hoogeveen, J. (2013). Background Report: Water Accounting+ in the Awash River Basin. Awash River Basin Water Audit (ARBWA) Project.

DRI. (2007). Salinity of groundwater and drainage water in the Nile delta. Retrieved from

FAO. (2020). WaPOR database methodology. Retrieved from Rome: https://doi.org/10.4060/ca9894en

FAO, & IHE-Delft. (2019). Water Accounting in the Litani River Basin – Remote sensing for water productivity.

Retrieved from Rome: https://www.fao.org/3/ca6679en/ca6679en.pdf

Fersi, M. (1985). Etude hydrogéologique de l'Oued Oum Jassar de Koutine. Rapp. Int. Retrieved from DGRE. Tunis:

Hellegers, P., Soppe, R., Perry, C., & Bastiaanssen, W. (2009). Combining remote sensing and economic analysis to support decisions that affect water productivity. Irrigation Science, 27(3), 243-251.

IIIMP. (2004). Environmental Assessment Study (EA). Retrieved from Egypt:

Jaafar, H., Mourad, R., & Schull, M. (2022). A global 30-m ET model (HSEB) using harmonized Landsat and Sentinel-2, MODIS and VIIRS: Comparison to ECOSTRESS ET and LST. Remote Sensing of Environment, 274(112995). doi:https://doi.org/10.1016/j.rse.2022.112995

Kallel, R. (2003). Hydrologie de la Jeffara tunisienne Internal Report. Retrieved from

Karimi, P., & Bastiaanssen, W. (2014). Spatial evapotranspiration, rainfall and land use data in water accounting. Part 1: Review of the accuracy of the remote sensing data. Hydrology and Earth System Sciences Discussions, 11, 2014.

Karimi, P., Bastiaanssen, W. G., & Molden, D. (2013). Water Accounting Plus (WA+)–a water accounting procedure for complex river basins based on satellite measurements. Hydrology and Earth System Sciences, 17(7), 2459-2472.

doi:http://dx.doi.org/10.5194/hess-17-2459-2013
Litani River Authority. (2019). Power Stations and Tunnels. doi:http://www.litani.gov.lb/en/?page_id=95 M.F, B. H. (2008). Hydrogeological, geochimical and Isotopic Approach of the Coastal Aquifers systems of Cap
Bon: Case of the Eastern coastal and El Haouaria aquifer, Tunisia. National Agronomic Institute of Tunisia
Mancosu, N., Spano, D., Orang, M., Sarreshteh, S., & Snyder, R. L. (2016). SIMETAW#-a model for agricultural water demand planning. Water resources management,, 30(2), 541-557.
Mansouri, R. (1985). Projet de recharge de la nappe Zeuss Koutine et Harboub. Retrieved from Tunisia:
Masia, S., Trabucco, A., Spano, D., Snyder, R. L., Sušnik, J., & Marras, S. (2021). A modelling platform for climate change impact on local and regional crop water requirements. Agricultural Water Management, 255(107005). doi:doi.org/10.1016/j.agwat.2021.107005
Molden, D. (1997). Accounting for water use and productivity: IWMI.
Molden, D. (2007). Water for Food, Water for Life: A Comprehensive assessment of water management in agriculture. London: Earthscan.
Nijland, H. J., Croon, F. W., & Ritzema, H. P. (2005). Subsurface drainage practices - Guidelines for the implementation, operation and maintenance of subsurface pipe drainage systems. ILRI publication 60. Part III – Case Study, Egypt. Retrieved from Wageningen, Netherlands:
OSS. (2005). Observatoire du Sahara et du Sahel-Etude sur modèle Mathématique du système aquifère de la Djeffara Tunisio-Lybyenne.
Sahal, S. (2019). Contribution des approches hydrogéologiques, géochimiques et isotopiques à l'étude du système aquifère multicouche de la Jeffara de Médenine. ISSTE, Gabes, Tunisia.
Saleh, W. S. (2009). Environmental management of ground water resources in the Nile delta region. (PhD Thesis).
SMMAR. (2017). Plan de gestion de la resource en eau-AUDE. Retrieved from
Steduto, P., Faurès, J. M., Hoogeveen, J., Winpenny, J., & Burke, J. (2012). Coping with Water Scarcity: An Action Framework for Agriculture and Food Security. Retrieved from Rome: https://www.fao.org/3/i3015e/i3015e.pdf
Trabelsi, R. (2009). aracterisation hydrogeologique et geochimique du systeme aquifere de la djeffara (sud-est tunisien): modelisation et intrusion marine. ENIS, Sfax, Tunisia.
Vidal, J. P., Martin, E., Franchistéguy, L., Baillon, M., & Soubeyroux, J. M. (2010). A 50-year high- resolution atmospheric reanalysis over France with the Safran system. International Journal of Climatology, 30(11), 1627-1644