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REMOTE SENSING FOR WATER PRODUCTIVITY

WATER ACCOUNTING SERIES

Water Accounting in the Litani River Basin

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All maps and figures used in the report originates from this study, unless explicitly mentioned.

Abbreviations and acronyms

AETI	Actual Evapotranspiration and Interception
CHIRPS	Climate Hazards Group InfraRed Precipitation with Stations
CNRS	National Council for Scientific Research (Lebanon)
DGIS	Ministry of Foreign Affairs of the Government of The Netherlands
E	Evaporation (from soil)
EWR	Environmental water requirements
ETa	Actual Evapotranspiration
FAO	Food and Agricultural Organization of the United Nations
GBWS	Greater Beirut Water Supply project
GIS	Geographical Information System
GWF	Global Grey Water Footprint
GRACE	Gravity Recovery And Climate Experiment
I	Interception
IWMI	International Water Management Institute
LAI	Leaf Area Index
LARI	Lebanese Agricultural Research Institute
LRBMS	Litani River Basin Management Support Program
LCC	Land Cover Classification
LRA	Litani River Authority
MoEW	Lebanese Ministry of Energy and Water
NGO	Non-government organization
NPP	Net Primary Production
P	Precipitation
T	Transpiration
UNDP	United Nations Development Programme
USGS	United States Geological Survey
WA+	Water Accounting Plus
WaPOR	FAO portal to monitor Water Productivity through Open access of remotely sensed derived data
WDPA	World Database on Protected Areas
WP	Water Productivity

Executive summary

This report provides the water accounting study for Litani River basin in Lebanon carried out by IHE Delft using the Water Productivity (WaPOR) data portal of the Food and Agricultural Organization (FAO). The Litani River basin is one of the key river basins in Lebanon and it is experiencing water scarcity with the annual renewable water resources being 606.9 Mm^3/yr. With an estimated population of 375,000 in 2010 and doubled by 2016 due to the Syrian refugee crisis, the total per capita water availability is around 800 m^3/cap/year indicating water shortage. Increasing challenges such as growing population, climate change, groundwater over-exploitation and inter-basin transfers have put the available water resources in the basin under stress. The completeness and quality of the hydro-meteorological records are insufficient to draw an appropriate picture of the water resources conditions. However, the Water Accounting Plus (WA+) system designed by IHE Delft with its partners FAO and IWMI has been applied to gain full insights into the state of the water resources in the basin for the period 2010 to 2016. The WA+ framework is a reporting mechanism for water flows, fluxes and stocks that are summarized by means of WA+ sheets. The role of land use and land cover on producing and consuming water is described explicitly.

WaPOR version 1.0 level 2 (100m resolution) data for rainfall, actual and reference evapotranspiration, the breakdown of ET into T, E and I, as well as the Net Primary Production and above-ground biomass production data layers were used for WA+ analyses. In addition, WA+ requires other open access data to make specific computations feasible. The water balance comparison between remotely sensed total outflow (P-ET-ΔS) and the measured discharge to the Mediterranean Sea and records of the main inter-basin transfer showed reasonable agreement for the period of analysis (36% deviation). The lack of information on smaller inter-basin transfer in combination with significant changes in storage makes an accurate assessment of the monthly water balance impossible. The consistency check shows that WaPOR data can be used for the WA+ analyses.

The Litani basin has a considerable outflow of 530 Mm^3/yr. A large component of the water resources (206 Mm^3/year) goes via hydropower tunnels as inter-basin transfer to Beirut. The majority of the outflow (88%) is polluted (Mekonnen and Hoekstra, 2015), and is therefore classified as non-recoverable flow (469.5 Mm^3/year). The estimated groundwater over-exploitation (57.5 Mm^3/year) is in line with the report by UNDP (2014) on the assessment of the groundwater resources, which estimates groundwater decline in the Litani basin of 45.7 Mm^3/yr.

Sustainable utilisation of the water resources in the Litani is critical. Current pollution levels in the river are so high that utilisable flow is zero in all years. Further utilisation of the water resources requires a systematic approach to treating wastewater. Other priority demands are also unmet (for example, environmental flow requirement). When treating wastewater, more water could become available for agriculture, as well as reducing the over-exploitation of groundwater. Considering current irrigation, environmental flow requirements and inter-basin transfers as priority, an additional 71 Mm^3/year could be used for agriculture.

The water productivity for rainfed crops is generally higher than for irrigated crops. The crop water productivity was found to be below the global standard (36% lower for wheat; 48% lower for potatoes), therefore there is room for improving the water productivity. This should be supported by better water management policies. The irrigation efficiency (77 %) and beneficial fraction (T/ET around 0.74) are good.

The WA+ was implemented in collaboration with local partners in Lebanon, including the Lebanese Ministry of Energy and Water (MoEW), the Litani River Authority (LRA), the National Council for Scientific Research (CNRS), the Lebanese Agricultural Research Institute (LARI), and the Green Plan. They have been exposed to the WA+ results and provided validation data for improvement of the WA+ sheets. A selection of staff members of these institutes received training in the processing of the spatial data and compilation of the WA+ sheets. As the Litani is a highly utilised basin, these line agencies could utilize the actual water withdrawals per sector as provided by WA+ for sustainable management of the water resources of the Litani river basin. They can then make better alternative water allocation plans as a preparation of Lebanon’s national water policy agenda.

1 Introduction

The overall objective of the 'Using Remote Sensing in support of solutions to reduce agricultural water productivity gaps' project of the Food and Agricultural Organization (FAO) supported by the Ministry of Foreign Affairs of the Netherlands (DGIS) is to achieve future food security with less water, while using water resources in a sustainable manner. Agriculture is a key water user and a careful monitoring of water productivity in agriculture is a necessity. The FAO Water Productivity Open Access portal (WaPOR) provides new opportunities to exploit spatial information related to water consumption in agriculture and water productivity for Africa and Near East. Assessing sustainable use of water resources is evaluated using the water accounting framework, utilising a combination of remote sensing data (in this case the WaPOR database) open access global datasets and complemented with local measurements on weather conditions and river flows.

The Litani River basin is one of the selected pilot basins for making a more comprehensive assessment of the multiple water user situation (see Figure 1 for location of the Litani basin). The assessment would contribute to better understanding the possible consequences of water productivity increases on other water users. A secondary objective is to demonstrate the value of the WaPOR database in preparing water accounts for river basins.

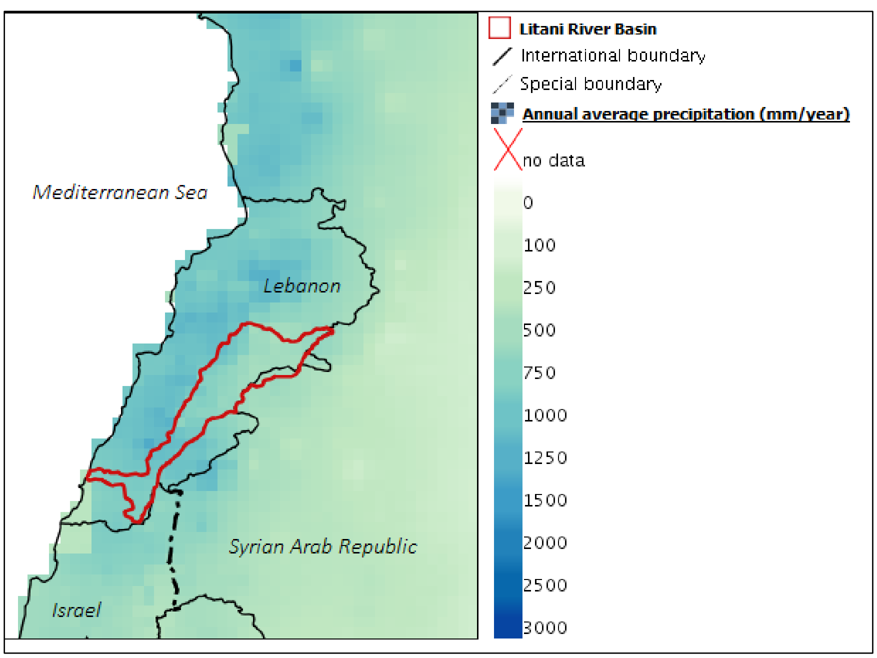


Figure 1: Location of the Litani River Basin and annual precipitation from WaPOR

The Litani river basin covers an area of 2,176 km^2, the Litani River is one of the most important rivers in Lebanon, and it originates from the mountains surrounding the Bekaa valley at 850m altitude. Agriculture in the Bekaa valley is the largest water consumer in the basin. The Litani also provides water for hydropower and domestic water use for Beirut. The Litani river basin is experiencing water shortages and is representative for many other river basins in the Near East and North Africa region. Increasing challenges such as growing population, climate change, agricultural water consumption by irrigated crops and industrial pollution, have put the available water resources in the basin under stress. Future plans to provide more domestic water to Beirut and an inter-basin transfer for irrigation (canal 800) (LBRMS, 2016; Matar, 2019), the vicinity of the Syrian border and the provision of drinking water to Syrian refugees are additional challenges.

In addition to the water resources challenges, there is also a challenge of getting good quality data. Flow measurements in the Litani basin are available at various locations, but there are few stations with long term records of good quality data, providing only a glimpse of the available water resources. Due to the high utilisation and distributed character of water use, information on actual abstractions (groundwater and surface water) is even scarcer. Withdrawals from river and groundwater abstractions are monitored only at selected places. The longer term water resources planning is hampered by a good information system. A system referred to as Water Accounting Plus (WA+) has been designed by IHE Delft with its partners FAO and IWMI to acquire spatial data from earth observations and various other open-access databases. It complements the lack of routine water resources data collection and incorporates spatially distributed water consumption. The WA+ framework is a reporting mechanism that summarizes the state of the water resources conditions by means of customized sheets (www.wateraccounting.org). While the WaPOR database does not contain all the input data required for fully implementing the WA+ framework, key data is provided, such as precipitation, actual evapotranspiration, the breakdown between transpiration, evaporation and interception, reference evapotranspiration, net primary production and above ground biomass production (FAO, 2018).

The purpose of this study is to get additional insights in water availability, withdrawals, consumptive use, non-consumptive use and the benefits and services rendered from it, using WaPOR data in conjunction with other data sources. In particular, the study seeks to investigate:

- What are the safe caps of water withdrawals for the agricultural sector in Litani?
- What are the benefits of crop water consumption and can the water productivity be improved?

Local partners in Lebanon have joined this demonstration project to develop the water accounts for the Litani basin. These local partners are: the Lebanese Ministry of Energy and Water (MoEW), the Litani River Authority (LRA), and the National Council for Scientific Research (CNRS), the Lebanese Agricultural Research Institute (LARI), and the Green Plan.

The present study shows the results of the implementation of the Water Accounting+ framework in the Litani basin for the period 2010 to 2016 using WaPOR data, identifying the current water challenges, the sustainable water withdrawals, and the key areas where future actions can have a profound impact.

2 Methodology

2.1 WaPOR database

The WaPOR v1.0 database contains information at three different spatial resolutions. At continental level, data is available at 250m resolution (Level 1). For selected countries and basins, data is available at 100m resolution (Level 2). For detailed crop water productivity analyses for selected irrigation systems, 30m resolution data is available (Level 3). For this study we used the Level 2 (100m resolution) data. Before using the data for the Water Accounts, various checks of the data were performed such as 1) precipitation data was compared with observed rainfall data 2) water balance of the basin using WaPOR data and 3) identification of source and sink per land use classification.

2.1.1 Precipitation

Figure 2 shows WaPOR average annual precipitation (*P*) for the period 2010-2016. WaPOR rainfall data is based on the CHIRPS database created by the United States Geological Survey (Funk et al., 2015; FAO, 2018). Additional local validation of the precipitation was done based on observed rainfall data in the basin at Zahle and Tal Amara (Figure 2).

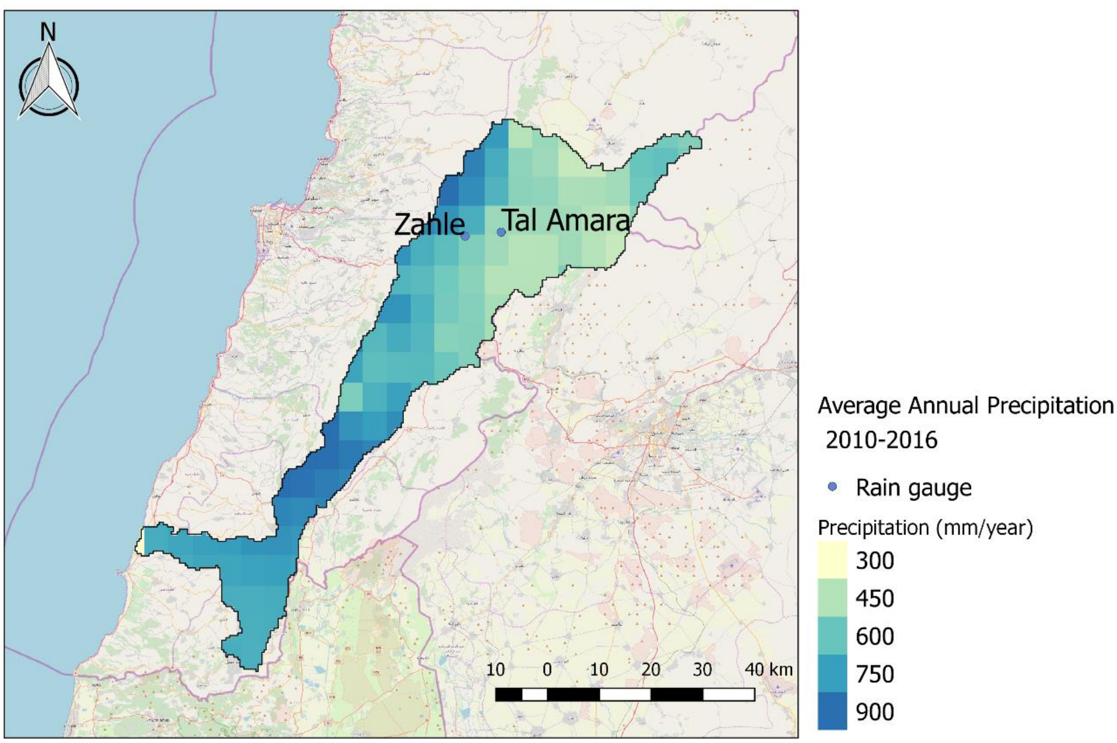


Figure 2: WaPOR annual precipitation (mm/yr) for the Litani River basin averaged for 2010-2016 (on OpenStreet Map background)

The Zahle and Tal Amara meteorological stations are located in the Bekaa valley and therefore represent the climatic conditions of the Bekaa valley. The Zahle station contains observations for the period of January 1981 to March 2014. The Tal Amara station covers the period of September 1997 to August 2014. Figure 3 shows a comparison between the station data and CHIRPS for monthly and annual precipitation amounts. The CHIRPS data has been downloaded from the USGS website because data from WaPOR starts in 2009. The historic CHIRPS data shows good agreement with the station data. CHIRPS slightly under-predicts (8% annually; 11% monthly) the measured precipitation, but two stations are not sufficient for conducting a bias correction, especially when considering the scale mismatch between a single CHIRPS pixel (5 km x 5 km) and a point location in the form of a rain gauge. Hence, WaPOR precipitation has been used further in the analyses without any bias correction.

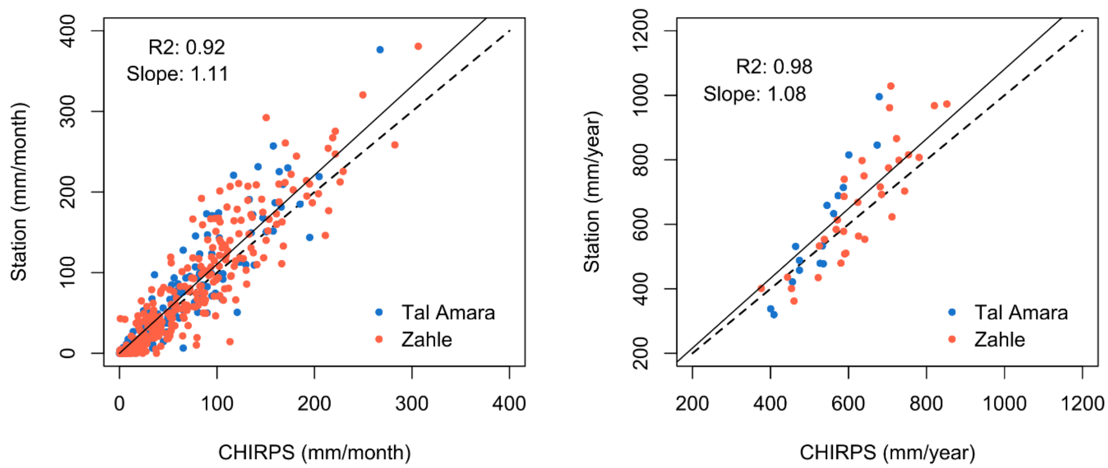
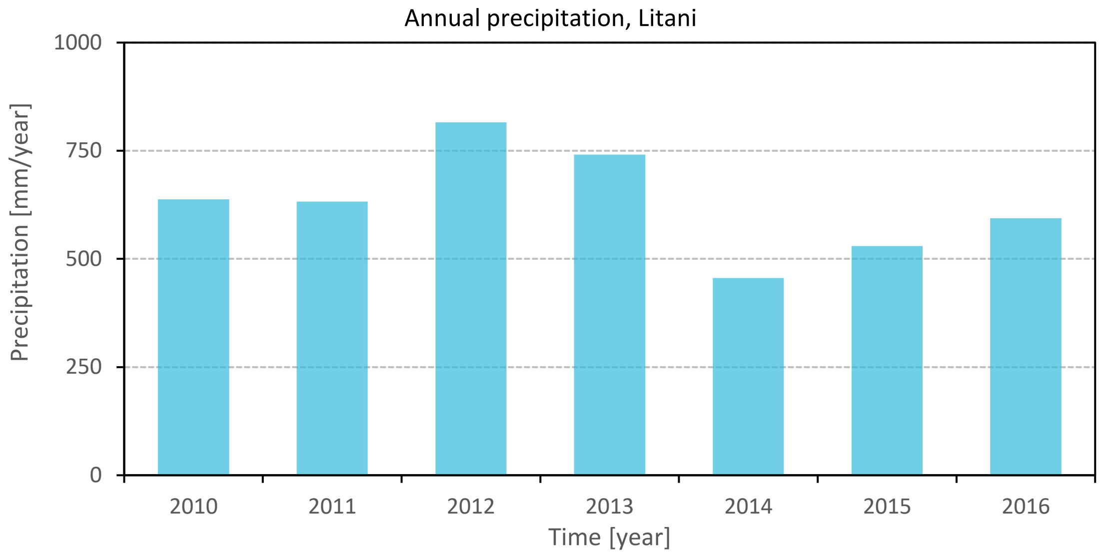


Figure 3: Monthly (left) and annual (right) precipitation from CHIRPS compared with rain gauges in the Northern Bekaa Valley for a period of 30 years (Zahle)

The average annual precipitation in the basin for this period was 630 mm/year (Table 1), which is higher than the country average, and in line with data reported by other sources (e.g. Dragan et al., 2005). The mountains at the western edge of the Litani basin receive an annual amount up to 900 mm/yr. The north-eastern part near Baalbek receives less than 400 mm/year annually, confirming a clear gradient with declining rainfall amounts when moving in the direction of Syria. The variability of rainfall has a great impact on the provision of water resources. For example, the period 2014-2016 received 26% less rainfall compared to the period 2010-2014 (Figure 4a). Hence, inter-variability of rainfall can be 26% or more. The average rainfall in 2012 was 816 mm/year while the year 2014 received only 456 mm/yr. Figure 4b shows a clear mono/modal rainy season, with little to no rainfall observed during the months from June to September. Provision of water during this period requires redistribution of water from the rainy season through storage. Some natural storage is provided by snow and groundwater. In addition, the Qaraoun reservoir stores 220 Mm^3 (source: LRA), but this is located downstream of the Bekaa valley where most agricultural activities are taking place.



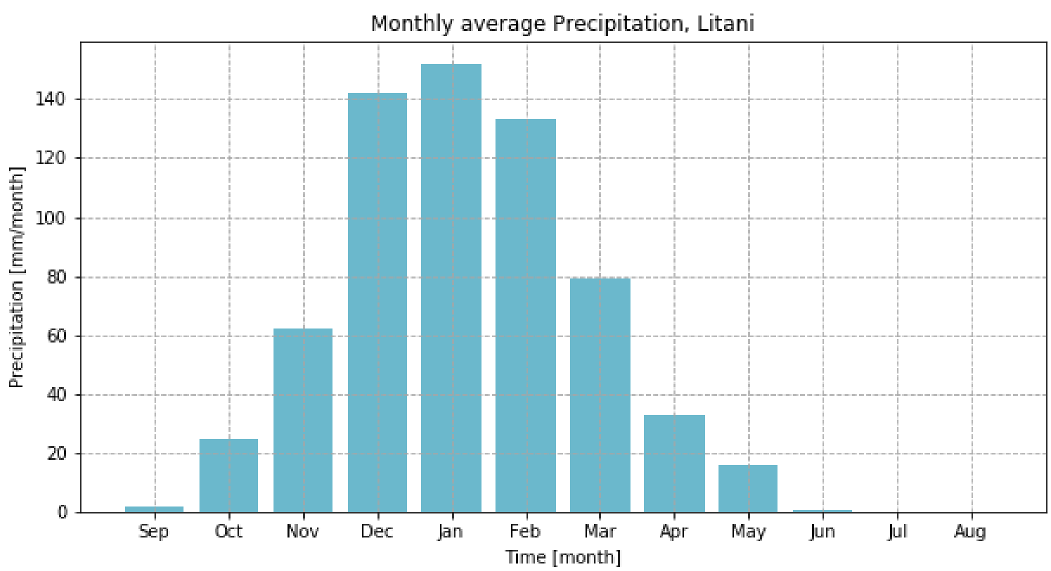


Figure 4: Annual (upper) and monthly average (lower) Precipitation in Litani basin for a period of 9 years (2009 to 2017)

2.1.2 Actual evapotranspiration and interception

The WaPOR evapotranspiration (ET_a) layer estimates the total evaporation, including interception. The ET_a values are related to P for getting more insights in the balance between P and ET_a (Table 1 and Annex I). In the Northern part of Litani basin, ET_a values more or less follow the patterns of the P values (Figure 5). The ET_a in the desert landscape varies between 100 to 400 mm/year, depending on the intensity of local shrubs. The ET_a in the irrigated valley can be 1,000 to 1,200 mm/year depending on crop rotations and local water availability. Farmers apply conjunctive use of surface and groundwater resources. The delta of the Litani seems to be permanently wet, with ET_a values going up as high as 1,200 to 1,500 mm/year.

Table 1: Comparison of WaPOR annual P and ET_a values for the entire Litani Basin.

Year	*P* (mm/yr)	*P* (Mm³/yr)	ET_a (mm/yr)	ET_a (Mm³/yr)	$P - ET_a$ (mm/yr)	$P - ET_a$ (Mm³/yr)
2010	638	1,387	482	1,049	155	338
2011	633	1,377	426	928	206	449
2012	816	1,776	429	933	388	843
2013	741	1,612	478	1,039	263	573
2014	456	992	328	714	128	279
2015	530	1,153	381	830	149	323
2016	594	1,293	361	786	233	507
AVERAGE	**630**	**1,370**	**412**	**897**	**217**	**473**

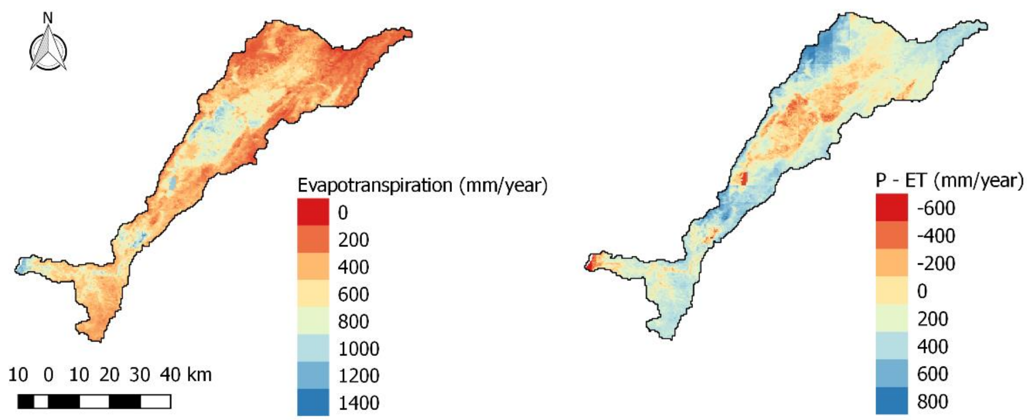


Figure 5: The average ET_a and the average difference P-ET_a of the period 2010-2016

The *P-*ET_a difference is added for quickly spotting source areas ($P>ET_a$) and sink areas, where more water is consumed compared to rainfall ($P<ET_a$). The north-western part of Litani is a clear source area (see Figure 5) with surplus levels reaching 500 to 600 mm/yr. This is the main source of irrigation water supply to the Bekaa Valley (a sink area). Also the southern part downstream of Qaraoun Lake exhibits positive *P-*ET_a values, which can be attributed to higher rainfall in the mountains (see Figure 2). This is the main source of water for the downstream part of Litani.

2.1.3 Basin scale water balance

The conservation of mass should be fulfilled at basin level, therefore, $P - ET_a$ should be identical to the total outflow *Q*, after storage corrections *ΔS*. This can be considered as a quality check of the WaPOR ET_a

data for the total river basin (see also Mul and Bastiaanssen, 2019). WaPOR ET_a has therefore been gauged as $P - ET_a$ - ΔS against Q, where P is from WaPOR, ΔS is estimated from GRACE satellite data for the basin. The outflow records at the mouth of the river have been acquired from the Litani River Authority (LRA). In addition information on inter-basin transfers were collected from local partners.

The longer term trend in storage change (ΔS) as observed by GRACE is negative (see Figure 6). The trend of water storage for a single GRACE pixel that covers central Lebanon from 2009 to 2016 is -2.1 mm/year, which is translated into -4.6 Mm^3/year. Note that only two third of the pixel is located on land, so the GRACE values should be used with caution. Nevertheless, the temporal changes provide an independent signal that groundwater resources are depleted and that years such as 2014 accelerate the process of depletion.

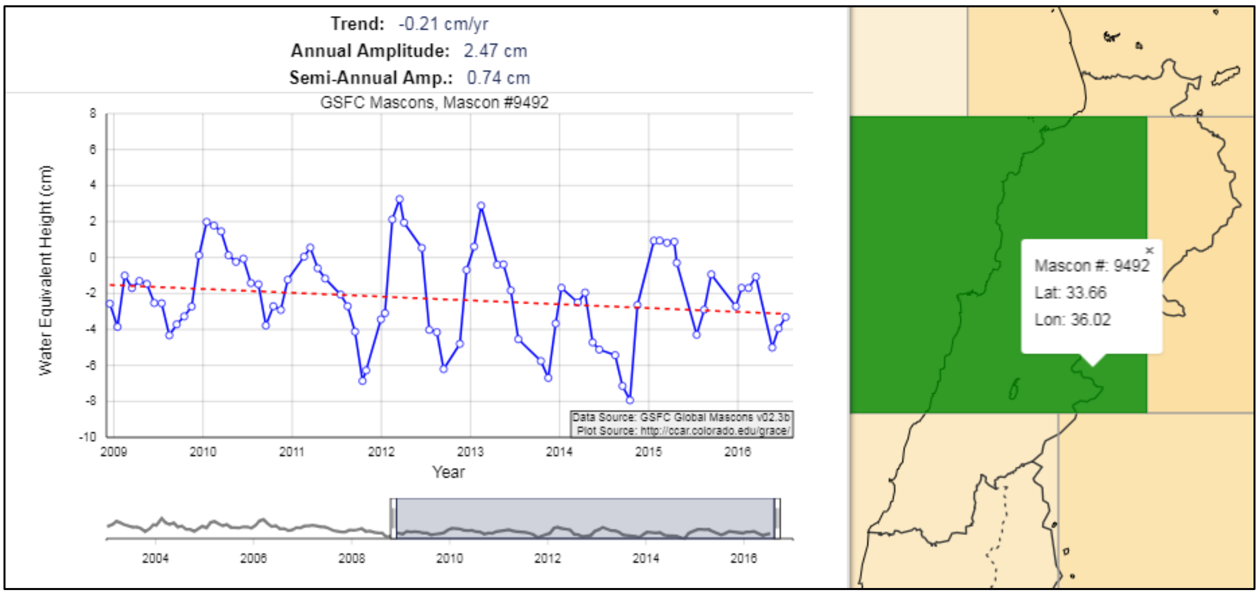


Figure 6: Longer term trend of declining water storage in Lebanon based on GRACE gravity measurements (source: https://ccar.colorado.edu/grace/gsfc.html)

The main inter-basin transfer is the water drawn from Qaraoun Lake to produce hydropower at the Abd el Al station through Markaba and Awali tunnels. This water is later used by the urban settlements of Beirut and irrigated land outside the watershed of the Litani. The discharge capacity of the tunnels is 22 m^3/s (LRA, 2019a). However, the discharge in this tunnel, as reported by the Litani River Authority, varies greatly between years (Figure 6). The average discharge is 206 Mm^3/year from 2012-2016. It should be noted that the reported data is not complete for all the months of the years 2014-2016, which means the actual discharge can be higher for these years than shown in Figure 6.

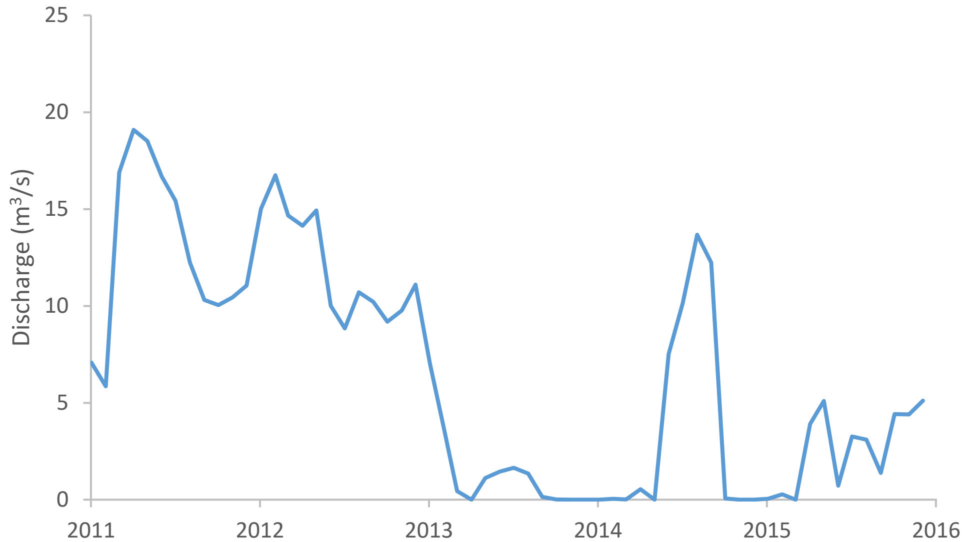


Figure 7: Discharge in Markaba tunnel after hydropower turbines at Abd el Al station. We believe that data for certain years are incomplete.

Next to this inter-basin transfer, water is supplied to the Hasbani River that lies in the Israeli-declared South Lebanon Security Zone, and to Marjayoun. The Qasimiya and Ras Al Ain irrigation project, which is one of the most important irrigation projects in Lebanon, draws water from the Litani River before the basin outlet. The discharge capacity to Qasimiya and Ras Al Ain is approximately 5 m^3/s. The water is conveyed to villages in Sidon and Maachouk, both are outside of the basin (LRA, 2019b). Since monthly discharge by these several inter-basin water allocation projects are not reported, it is not feasible to quantify the total inter-basin transfer on a month-by-month basis.

Figure 8 shows the results of the water balance compared to the observed discharge plus the known inter-basin transfers (using both WaPOR Level 1 and Level 2). The total discharge measured at the sea mouth outlet and the main water transfer in Markaba tunnel is approximately equal to $P - ET_a - \Delta S$ for 2010 – 2013 (Figure 8). The period from 2014 to 2016 shows a larger difference. Also the WaPOR Level 2 data shows larger deviation compared to WaPOR Level 1[1]. Without the full information on other inter basin transfers, the WaPOR water balance $P\text{-}ET_a\text{-}\Delta S$ is considered in reasonable agreement with outflow (Table 2). The total observed outflow is 36% lower than WaPOR Level 2 water balance. The average $P\text{-}ET_a\text{-}\Delta S$ is 139 Mm^3/year (Table 2) higher than the sum of flow at outlet and Markaba tunnel. The largest difference is found in dry years (2014 and 2016), which might be attributed to other unaccounted inter-basin transfers.

[1] Before 2014, Level 2 was resampled from Level 1 data, after 2014, Level 2 uses different input data (Proba-V)

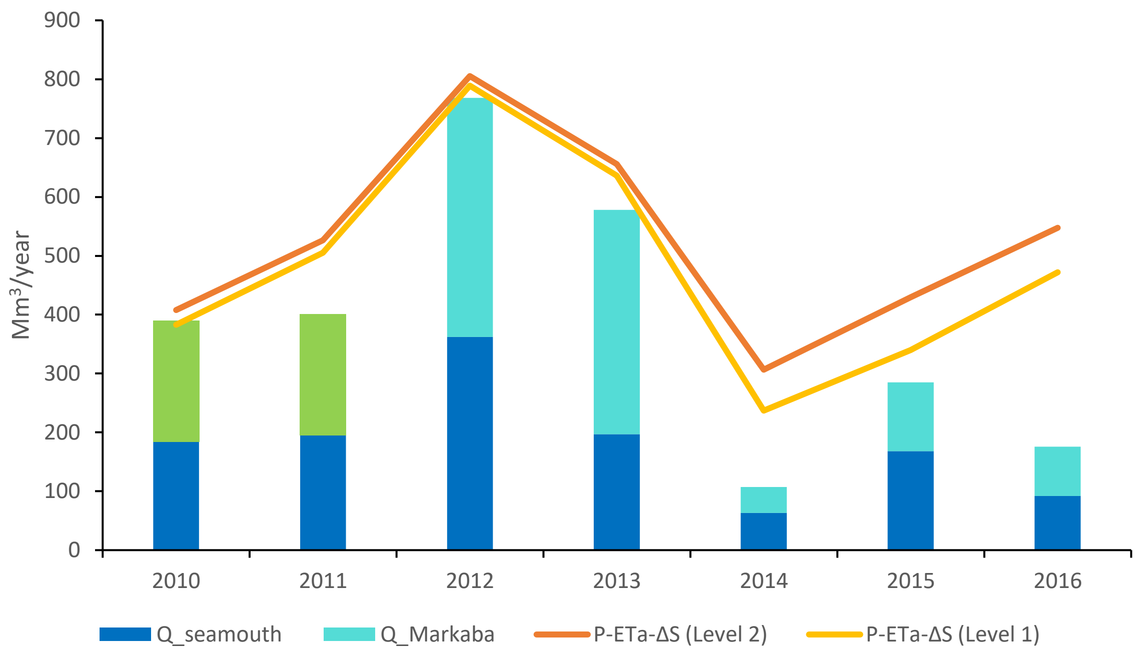


Figure 8: Total discharge from Litani River outlet at sea mouth and Markaba tunnel compared with P – ET_a – dS. Green bars indicates average inter-basin transfers in replacement of no data values.

Table 2: The average P-ET-ΔS (using WaPOR Level 2 AETI data) of the Litani basin. Q is the sum of discharge at basin outlet in sea mouth ($Q_{seamouth}$) and inter-basin transfer discharge in Markaba tunnel ($Q_{Markaba}$) (unit: Mm^3/year)[2]

Year	$Q_{seamouth}$	$Q_{Markaba}$	P	ΔS	ET_a	P-ET_a-ΔS	Q	Diff	%Difference
2010	184	206	1,387	-70	1,049	408	390	18	5
2011	195	206	1,377	-77	928	526	401	125	31
2012	362	406	1,776	38	933	805	768	37	5
2013	197	381	1,612	-83	1,039	656	578	78	13
2014	63	44	992	-28	714	307	107	200	186
2015	168	117	1,153	-106	830	429	285	144	51
2016	92	84	1,293	-41	786	548	176	372	211
Average	**180**	**206**	**1,370**	**-52**	**897**	**526**	**387**	**139**	**36**

2.1.4 Land use analysis

The land use map forms the basis for dividing the basin landscape into the four main categories (PLU, ULU, MLU, MWU). Four main categories of land and water uses are distinguished:

- Protected Land Use (PLU); areas that have a special nature status and are protected by National Governments or Internationals NGO's

[2] Information using WaPOR Level 1 data is provided in Annex II

- Utilized Land Use (ULU); areas that have a light utilization with a minimum anthropogenic influence. The water flow is essentially natural
- Modified Land Use (MLU); areas where the land use has been modified. Water is not diverted but land use affects all unsaturated zone physical process such as infiltration, storage, percolation and water uptake by roots; this affects the vertical soil water balance
- Managed Water Use (MWU); areas where water flows are regulated by humans via irrigation canals, pumps, hydraulic structures, utilities, drainage systems, ponds etc.

The underlying reason for framing these 4 land use categories is that their management options widely differ from keeping them pristine to planning hourly water flows. The land use map (Figure 9) is based on existing land cover map of the year 2013 kindly made available by the National Council for Scientific Research (CNRS) of Lebanon. This existing map was further updated and extended by IHE Delft to include the most essential WA+ land use classes. Protected Land Use class was updated using the World Database on Protected Areas (WDPA). The differentiation between rainfed and irrigated crops was based on the WaPOR Level 2 Land Cover Class (L2_LCC) layer of the same year. Additional data of different crop type classes in Bekaa Valley were collected from WaPOR Level 3 dekadal Land Cover Class (L3_LCC) layers of the same year. To simplify crop rotation in Bekaa valley, the most common crop type in each pixel was considered to determine its WA+ land use class. The legend of this land use map follows the standard WA+ PLU, ULU, MLU and MWU categories. This facilitates the presentation of the results in the standard WA+ sheets. The irrigated fields in the Bekaa Valley can be seen in the MWU zone, which is about 20% of the total basin area (Figure 10). The result is a land use map with a spatial resolution of 100 m.

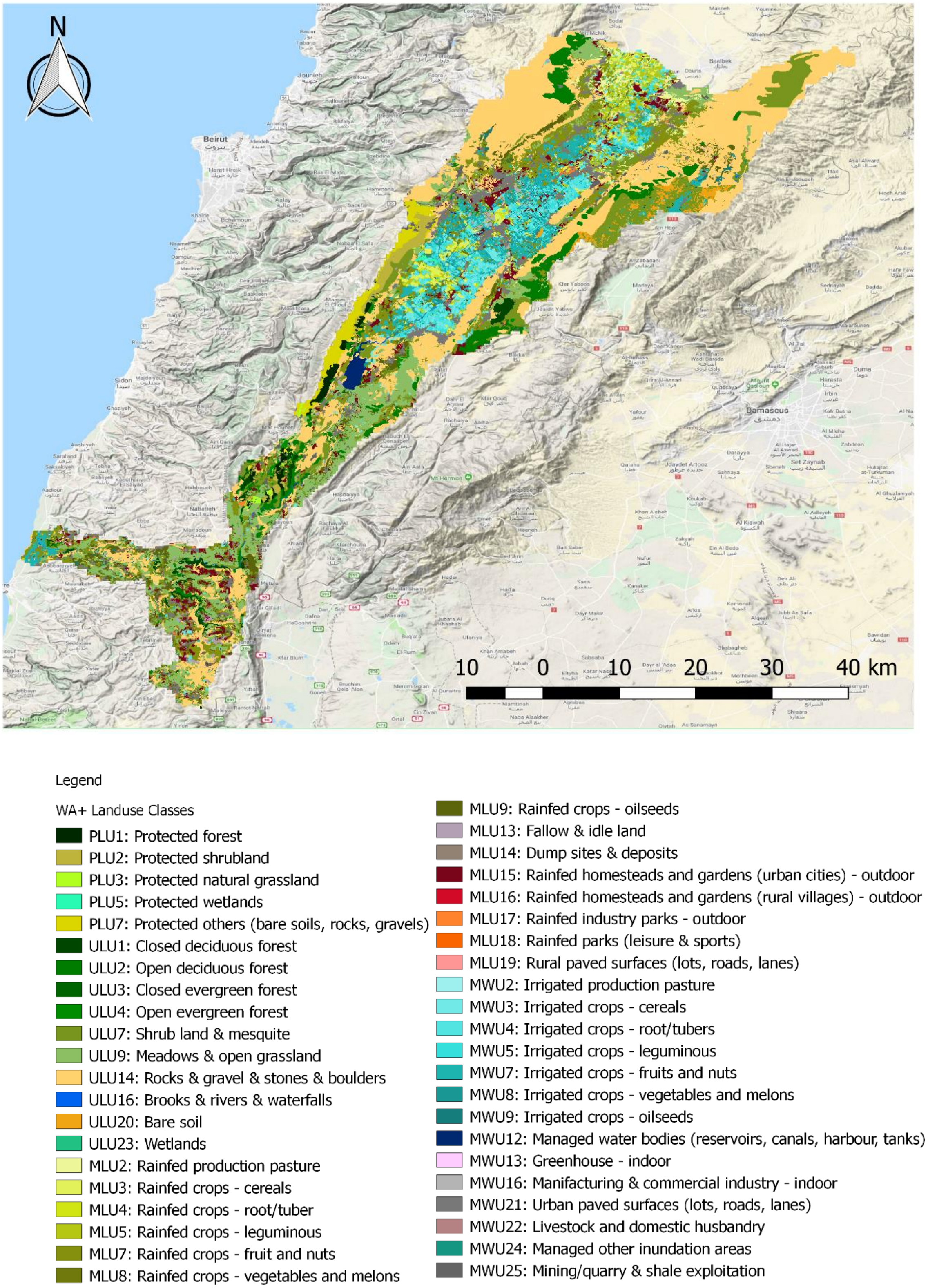


Figure 9: Land use map of the Litani Basin using the standard Water Accounting + (WA+) classification.

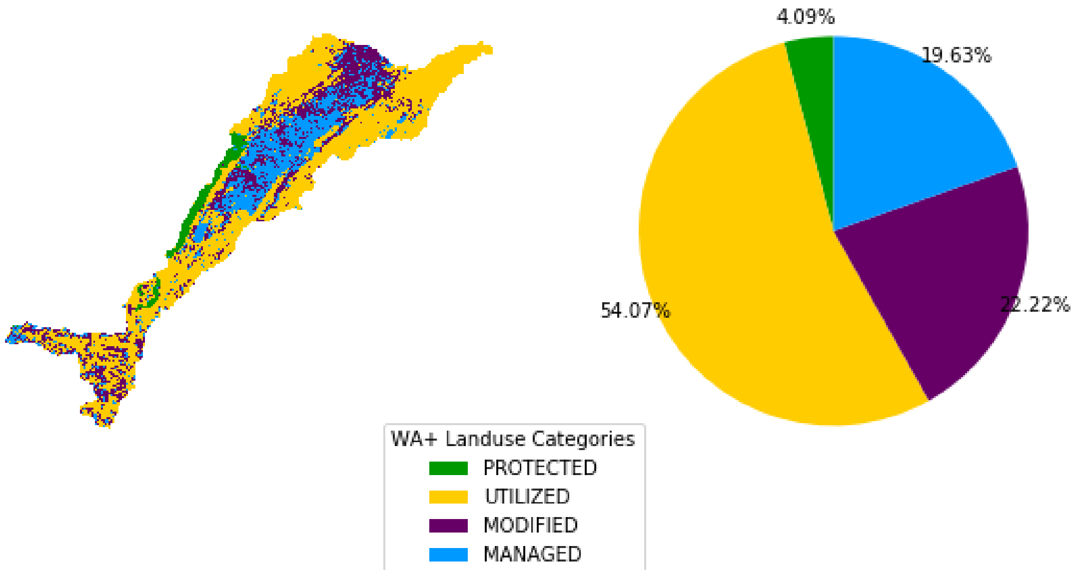


Figure 10: Area percentage of WA+ Land Use categories in Litani River basin

As expected the MWU land use classes are generally the ones that consume water and the PLU, ULU and MLU land use classes are the ones that generate runoff (Table 3). However, the arid character with long and dry summers dictate that natural water bodies (ULU16 and ULU17) and PLU7 (protected others) consume blue water resources as well. For MWU4 (irrigated- roots and tubers) there is also an unexpected surplus reported, which may be a result of fallow land being present in the vicinity of rainfed and irrigated agriculture practices. Mean values of *P*, ET_a and their difference per each land use class is provided in Table 3.

Table 3: P and ET data presented by land use class. The average value for the period 2010 to 2016 is taken into consideration.

Code	Land Use Class Description	Area (km^2)	*P* (mm/year)	ET_a (mm/year)	$P - ET_a$ (mm/year)
PLU1	Protected forest	17.5	582	758	176
PLU2	Protected shrubland	25.6	601	736	135
PLU3	Protected natural grasslands	3.3	528	858	330
PLU5	Protected wetlands	1.4	979	741	-239
PLU7	Protected other (bare soils)	41.1	329	705	375
ULU1	Closed deciduous forest	25.1	572	718	146
ULU2	Open deciduous forest	104.1	409	637	228
ULU3	Closed evergreen forest	1.3	724	809	85
ULU4	Open evergreen forest	8.4	469	779	309
ULU7	Shrubland and mesquite	186.4	389	609	219
ULU9	Meadows and open grassland	232.7	405	717	312
ULU14	Rocks and gravel	591.7	277	635	358
ULU16	Brooks and rivers	6.3	626	663	37

Code	Land Use Class Description	Area (km^2)	*P* (mm/year)	*ET_a* (mm/year)	*$P - ET_a$* (mm/year)
ULU20	Bare soil	20.6	264	467	203
ULU23	Wetland	0.0	523	788	265
MLU2	Rainfed production pastures	37.0	284	494	210
MLU3	Rainfed crops - cereals	31.5	589	594	5
MLU4	Rainfed crops - root/tuber	6.8	650	631	-19
MLU5	Rainfed crops - leguminous	49.1	442	521	79
MLU7	Rainfed crops - fruit and nuts	181.8	429	603	175
MLU8	Rainfed crops - vegetables and melons	12.9	629	594	-35
MLU9	Rainfed crops - oilseed	73.6	440	699	259
MLU13	Fallow & idle land	11.6	401	676	275
MLU14	Dump sites & deposits	0.3	503	640	137
MLU15	Rainfed homesteads and gardens (urban cities) - outdoor	70.3	426	640	214
MLU16	Rainfed homesteads and gardens (rural villages) - outdoor	0.3	436	504	68
MLU17	Rainfed industry parks - outdoor	7.6	430	624	194
MLU18	Rainfed parks (leisure & sports)	0.1	485	712	226
MLU19	Rural paved surfaces (lots, roads, lanes)	0.7	499	542	43
MWU2	Irrigated production pastures	4.0	422	499	77
MWU3	Irrigated crops - cereals	66.3	612	584	-28
MWU4	Irrigated crops - root/tubers	33.0	598	579	-19
MWU5	Irrigated crops - leguminous	54.9	631	555	-76
MWU7	Irrigated crops - fruit and nuts	86.0	665	551	-114
MWU8	Irrigated crops - vegetables and melons	37.3	674	572	-102
MWU9	Irrigated crops - Oilseed	5.1	460	624	164
MWU12	Managed water bodies (reservoirs, canals, harbours, tanks)	11.4	727	611	-116
MWU13	Greenhouses - indoor	1.7	601	617	16
MWU16	Manufacturing & commercial industry - indoor	7.4	476	566	90
MWU21	Urban paved Surface (lots, roads, lanes)	101.5	404	611	206
MWU22	Livestock and domestic husbandry	1.2	374	521	148
MWU24	Managed other inundation areas	0.1	365	297	-68
MWU25	Mining/ quarry & shale exploitation	17.4	318	688	370

2.1.5 Conclusion

The analyses show that the WaPOR 1.0 Level 2 data provides reasonable estimates *of P, ET_a* at basin scale, general spatial distribution and analyses for different land use classes were also consistent. Some further investigation is necessary to understand the discrepancy between WaPOR Level 1 and Level 2 ET_a data.

2.2 Water Accounting Plus (WA+)

The longer term planning process of water and environmental resources in river basins requires a measurement – reporting – monitoring system in place. The Water Accounting Plus (WA+) framework is based on the early water accounting work of Molden (1997) focussing on agriculture and irrigation systems. WA+ was further developed by Karimi et al. (2015) for river basin analyses and incorporating of all water use sectors. Further developments include more hydrological and water management processes and focus on specific land uses.

It also separates ET from rainfall (ET_g) and incremental ET (ET_{inc}), all categories utilise rainfall, while several of them also utilise blue water for incremental ET. WA+ includes thus the hydrology of natural watersheds that provide the mains source of water in streams and aquifers, as well as quantifying water consumption. The core analysis of Litani WA+ is based on the WaPOR v1.0 Level 2 data (100 m resolution).

The output of WA+ exists of a number of sheets and supporting spatial maps. Remote sensing, GIS and spatial models form the core methodology, so all data has a spatial context. The accounts are prepared monthly and are reported on an annual basis, as WA+ is meant for longer term planning. For simplicity, we show in this report only the annual accounts averaged for 2010 to 2016. Monthly and annual accounts per reporting year are displayed on the website www.wateraccounting.org. Software tools have been developed that automatically collect and download open access input data. The models and scripts for the creation of the water accounts and the elaboration of the reports are available on GitHub under the Water Accounting account[3]. The WA+ framework is public and open for all users.

2.2.1 Pixel scale analysis

The water accounting framework distinguishes between a vertical and horizontal water balance. A vertical water balance is made for the unsaturated root zone of every pixel and describes the exchanges between land and atmosphere (i.e. rainfall and evapotranspiration) as well as the partitioning into infiltration and surface runoff. Percolation and water supply are also computed for every pixel, to facilitate attributing water supply and consumption to each land use class.

The WaterPix model calculates for each pixel the vertical soil water balance (See Figure 2 and described below). Rainfall ET (ET_g) and incremental ET (ET_{inc}) are separated by keeping track of the soil moisture balance and determining if ET is satisfied only from rainfall or stored in the soil moisture or additional source (supply) is required. The main inputs into WaterPix are provided in Table 4 and the outputs are

[3] https://github.com/wateraccounting

provided in Table 5. Each parameter is calculated at the model resolution of 100m and available for monthly and annual time steps.

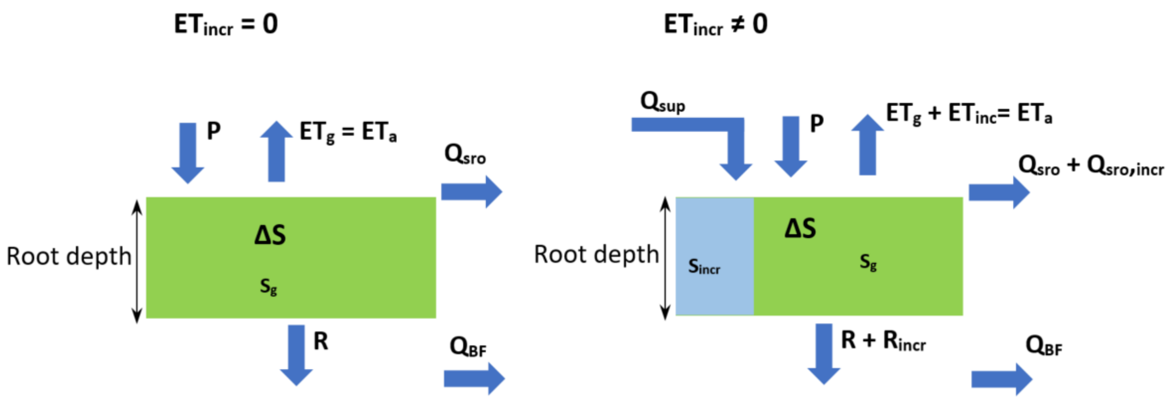


Figure 11: Main schematization of the flows and fluxes in the WaterPix model

Table 4: Inputs of WaterPix

Variable	Parameter	Source	Spatial Resolution	Temporal resolution
Precipitation	*P*	WaPOR	5,000 m	Daily
Actual Evapotranspiration	ET_a	WaPOR	100 m	Decadal
Interception	*I*	WaPOR	100m	Decadal
Land use land cover	LULC	CNRS map	100 m	Static
Saturated Water Content	θ_{SAT}	HiHydroSoil	0.008333 degree (about 900m at the equator)	Static

Table 5: Outputs of the water balance model at pixel level (for S, ET, Q_s, Q_b, and R subscript g denotes natural fluxes and stocks, whereas subscript inc denotes the incremental fluxes and stocks due to supply)

Variable	***Calculation step***	***Definition***
S	1	Soil Moisture
Q_{sro}	1,4	Surface Runoff
R	1,4	Recharge
ET	2	ET
Q_{sup}	3	Supply
Q_b	5	Base flow
Q_t	5	Total runoff

Step 1 Compute soil moisture

The soil moisture ($S_{g,t}$) is computed as the soil moisture storage at the end of the previous timestep ($S_{g,t-1}$) plus the effective rainfall (*P-I*) minus recharge (R_g) and surface runoff (Q_s)(eq 1):

$$S_{g,av} = S_{g,t-1} + P - I - R_g - Q_{sro} \qquad \text{Eq.1}$$

Where the surface runoff (Q_{sro}) is calculated using an adjusted version of the Soil Conservation Service runoff method. The adjusted version replaces the classical Curve Numbers by a dynamic soil moisture deficit term that better reflects the dry and wet season infiltration vs. runoff behaviour (see Schaake et al., 1996; Choudhury & DiGirolamo, 1998). As the Curve Number method is developed for event based runoff, we calculated Q_{sro} based on daily basis, dividing the effective rainfall by the number of rainy days (n) and a calibration parameter f to account for the soil moisture variation due to drying up and filling with in a month. The total surface runoff for a month is then multiplied by n:

$$Q_{sro} = \begin{cases} 0 \; if \; P = 0 \\ \dfrac{\left(\frac{P-I}{n}\right)^2}{\frac{P-I}{n} + f\left(S_{sat} - S_{g,t-1}\right)} * n \; if \; P \neq 0 \end{cases} \quad \text{Eq.2}$$

Then R_g is calculated as exponential function of the soil moisture. If the soil moisture is above a certain percentage (calibration parameter) of the saturated content, the percolation will be computed using the following simple exponential function:

$$R_g = S_{g,t-1} * \exp\left(-\frac{1}{S_{t-1}}\right) \quad \text{Eq.3}$$

Step 2 Separate ET_a into ET_g and ET_{inc} and update S

To compute the rainfall and incremental component of ET, ET_a is subtracted from $S_{g,t}$. When $S_{g,t}$ is insufficient for ET_a, the difference will be supplied by surface or groundwater uptake. The rainfall ET (ET_g) becomes the amount which can be supplied by the soil moisture, whereas the difference will become incremental ET (ET_{inc}):

$$ET_g = \text{if}\left(S_{g,av} > ET_a, ET_a, S_{g,av}\right) \quad \text{Eq.4}$$

$$ET_{inc} = ET_a - ET_g \quad \text{Eq.5}$$

The new soil moisture storage then becomes:

$$S_{g,t} = S_{g,av} - ET_g \quad \text{Eq.6}$$

Step 3 Estimation of water supply

The amount of water supplied to each pixel is a function of ET_{incr} and the so called consumed fraction (f_c).

$$Q_{sup} = f(ET_b, LU) = \frac{ET_b}{f_c} \quad \text{Eq.7}$$

f_c is dependent on the land use class and was suggested to replace the classical irrigation efficiencies (Molden, 1997; Simons et al., 2016). The consumed fractions applied in this study are specified in Table 6.

Table 6: Consumed fraction per land use class

Land use class	Consumed fraction (f_c)
Natural land use classes	1.00
Rainfed crops	1.00
Irrigated crops	0.80
Greenhouses	0.95

Step 4 Estimating incremental soil moisture

A separate soil moisture storage (Blue area in Figure 11) is added to store Q_{sup} and calculate incremental recharge and runoff as follows:

$$S_{incr,t} = S_{incr,t-1} + Q_{supply} - ET_{inc} - R_{inc} - Q_{sro,inc} \qquad \text{Eq.8}$$

And total soil moisture storage (S_t) becomes:

$$S_t = S_{g,t} + S_{incr,t} \qquad \text{Eq.9}$$

Then total recharge (R_t) becomes

$$R_t = S_t * \exp\left(-\frac{1}{S_t}\right) \qquad \text{Eq.10}$$

And the incremental recharge (R_{inc}) becomes:

$$R_{inc} = R_t - R_g \qquad \text{Eq.11}$$

With

$$Q_{sro\ tot} = \begin{cases} 0 \ if \ P = 0 \\ \dfrac{\left(\frac{P + Q_{sup} - I}{n}\right)^2}{\frac{P + Q_{sup} - I}{n} + f\left(S_{sat} - \left(S_{g,t} + S_{inc}\right)\right)} * n \ if \ P \neq 0 \ or \ Q_{sup} \neq 0 \end{cases} \qquad \text{Eq.12}$$

The incremental surface runoff ($Q_{sro,\ inc}$)is then computed as:

$$Q_{sro,incr} = Q_{sro,tot} - Q_{sro,g} \qquad \text{Eq.13}$$

Step 5 Estimate base flow

The base flow is estimated based on the basin level total outflow (Q_b) using the following basin scale formula (assuming surface storage change is negligible at annual timescale):

$$Q_b = P - ET - \Delta S = Q_{sro} + Q_{bf} - Q_{sup,sw} \qquad \text{Eq.14}$$

Where

$$Q_{sup,sw} = f(Q_{sup}, LU) = Q_{sup} * f_x \quad \text{Eq.15}$$

Where f_x is the ratio of surface water withdrawal to total withdrawal. It is assumed that for non-irrigated and non-water body land uses, the supply is only from groundwater, f_x then becomes 0, and for water bodies, the supply is completely from surface water, f_x becomes 0.95. For irrigated area, the ratio of $Q_{sup,sw}/Q_{sup,\text{ tot}}$ is based on the percentage of area equipped with irrigation from surface water (FAO, 2016).

The ratio of baseflow and surface runoff at annual scale at basin level is calculated as follows:

$$\mathrm{r} = \frac{Q_b + Q_{sup,sw} - Q_{sro}}{Q_{sro}} \quad \text{Eq.16}$$

This ratio is used to calculate baseflow at monthly timesteps per pixel using the following formula:

$$Q_{bf} = r * Q_{sro} \quad \text{Eq.17}$$

2.2.2 Water Accounting Plus sheets

The water accounts provide an overview of the water resources and its current utilisation per different land use classes (WA+ sheet 1). In addition to withdrawals and consumptive use, the return flow must be assessed for quantifying reuse and recycling. As part of the return flow is polluted and contaminated (fertilized irrigation, aquaculture, residential, etc.), therefore non-recoverable flow must be addressed explicitly in water accounting. For MWU class, the non-recoverable fraction of the return flow is taken from the grey water footprint map (Mekonnen and Hoekstra, 2015). The total consumed water is the sum of water depleted by evapotranspiration and the non-recoverable flow. Some water needs to be reserved for the environment, this is estimated based on the total environmental water requirements (EWR) global distribution map by Smakhtin et al. (2004).

The total consumed water per land use class is provided in WA+ sheet 2. This is split up into the beneficial (transpiration) and non-beneficial ET (soil evaporation and interception). We evaluated WA+ sheet 2 using the WaPOR ET split into T, E and I as well as the WA+ approach for splitting T, E and I (see Annex III for details).

WA+ sheet 3 provides insights in the agricultural production system. It utilises WaPOR Net Primary Production (NPP) and the seasonality of the growing season obtained from information on the ground, typical harvest index and moisture content to estimated yield:

$$Y_{c,season} = \frac{HI_c \times B_{c,season}}{1-M_c} \quad \text{Eq. 18}$$

where: $Y_{c,season}$ is Crop yield (kg/ha/season)
HI_c is Harvest Index (%), percentage of dry mass production that is harvested
$B_{c,season}$ is net dry biomass production (kg/ha/season)
M_c is Moisture content of the crop (%)
c is the crop under consideration

Whereby the net dry biomass production is a function of WaPOR NPP as follows (FAO, 2018):

$$B_{c,season} = NPP * 0.01444 \quad \text{Eq. 19}$$

The water productivity is calculated using the following formula:

$$WP = \frac{Y_{c,season}}{ET_{a,season}} \quad \text{Eq. 20}$$

The yield and water productivity have been used to assess whether consumed water is used wisely in Litani.

WA+ sheet 4 summarises the utilised flow from groundwater and surface water (Q_{sup}) as well as the return flows (R_{inc} and $Q_{sro,\ inc}$) to groundwater and surface water per land use class respectively. For land use classes categorized as residential areas, additional water demand and supply are estimated based on the global population map (Gaughan et al., 2013) and the reported water consumption per capita per day in the area.

$$Q_{supply,residential} = \frac{w_{average} \times n_t \times N_{population}}{10^6 \times A} \quad \text{Eq. 21}$$

$$Q_{demand,residential} = \frac{w_{min} \times n_t \times N_{population}}{10^6 \times A} \quad \text{Eq. 22}$$

where:

$Q_{supply,residential}$ [mm/month] is the additional supply of blue-water for residential area
$Q_{demand,residential}$ [mm/month] is the additional demand of blue-water for residential area
$w_{average}$ [litres/person/day] is the average water consumption per capita
w_{min} [litres/person/day] is the minimal required water consumption per capita
$N_{population}$ [Persons] is the number of people per pixel
n_t is the number of days in the month
A [km^2] is the area of residential land use.

WA+ sheet 5 summarises the source and withdrawal from surface water per sub-basin and per land use category. Similarly, WA+ sheet 6 summarises the groundwater fluxes per land use type.

The additional data used for the river basin analyses and for the creation of the water accounts for the Litani River Basin is presented in Table 7. The input data sets are based on remote sensing data, GIS layers, techniques and global hydrological models. Most sources are publicly available online.

Table 7: Specification of additional (non WaPOR) data sets for estimating productive use of water resources

Variable(s)	Source	Reference	Used for
Environmental flows requirements	International Water Management Institute (IWMI)	Smakhtin et al., 2004	WA+ sheet 1
Grey water footprint	University of Twente	Mekonnen and Hoekstra, 2015	WA+ sheet 1
Population	WorldPop	Gaughan et al., 2013	WA+ sheet 4

2.3 Consistency check

The total outflow is a result from WA+ sheet 5 on surface water (Section 3.5), which is the residual of surface runoff after subtracting water withdrawals for irrigation and other purposes, their return flows and surface water storage change of Lake Qaraoun. Figure 12 shows low flows (near zero) during the dry summer season, which is correct. The flows during the winter months are higher than observed. This may be as a result of snow not being incorporated in the current WaterPix conceptualisation. At annual timescale, WA total outflow consistently exceeds the measured discharge to sea and inter-basin transfers, which could indicate that the inter-basin transfers may not be well captured.

The inter-basin transfer is of the same order of magnitude as the outflow to the Mediterranean Sea. As this particular sink of water is not always properly reported as mentioned in previous chapters, this makes it difficult to reasonably explain the difference between observed outflow and WA+ result especially for the period from 2014 to 2016. The difference between WA+ output and the observation could be a reasonable estimate of the inter-basin transfer, which is not captured.

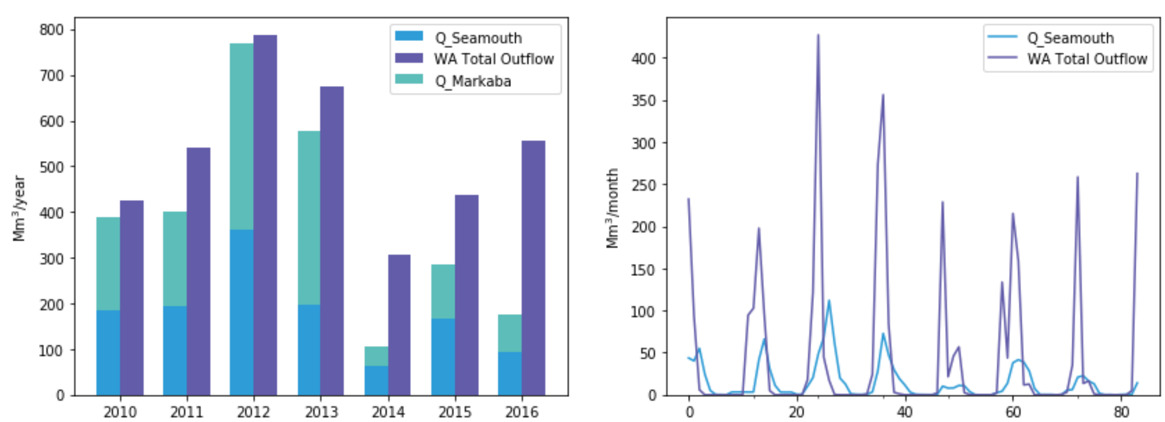


Figure 12: Annually (left) and monthly (right) total outflows estimated by WA+ solely from remote sensing data vs. measured discharges at the outlet (Sea mouth) and Markaba tunnel from 2010-2016.

The average difference is approximately 139 Mm^3/year for the whole period and about 238 Mm^3/year for the last three years. During 2012 and 2013, the inter-basin transfer through Markaba tunnel is 350 to 400 Mm^3/year, this was reduced significantly during the 2014 drought, however it is not likely that the inter-basin transfer ceased completely. Most of this water is supplied to the capital city in Beirut which has a high priority. During the dry years, the observation records are incomplete (no data points, but it is unclear if this is because there is no flow or this was not recorded). Therefore, we will use the observed average transfer of 206 Mm^3/yr.

Another check is the internal consistency of the Resource Base sheet (WA+ sheet 1). The results reveal that the average WaPOR total outflow ($P\text{-}ET_a\text{-}\Delta S$) is 526 Mm^3/year while WA+ estimated average outflow to be 530.8 Mm^3/year. More precisely, the average total outflow of 530.8 Mm^3/year has a breakdown of discharge to sea being 324.6 Mm^3/year and inter-basin transfer 206.2 Mm^3/yr. This means that the results of local soil water balance computations including surface runoff and water withdrawals computed from WaterPix are consistent with the basin scale water balance (see Figure 13).

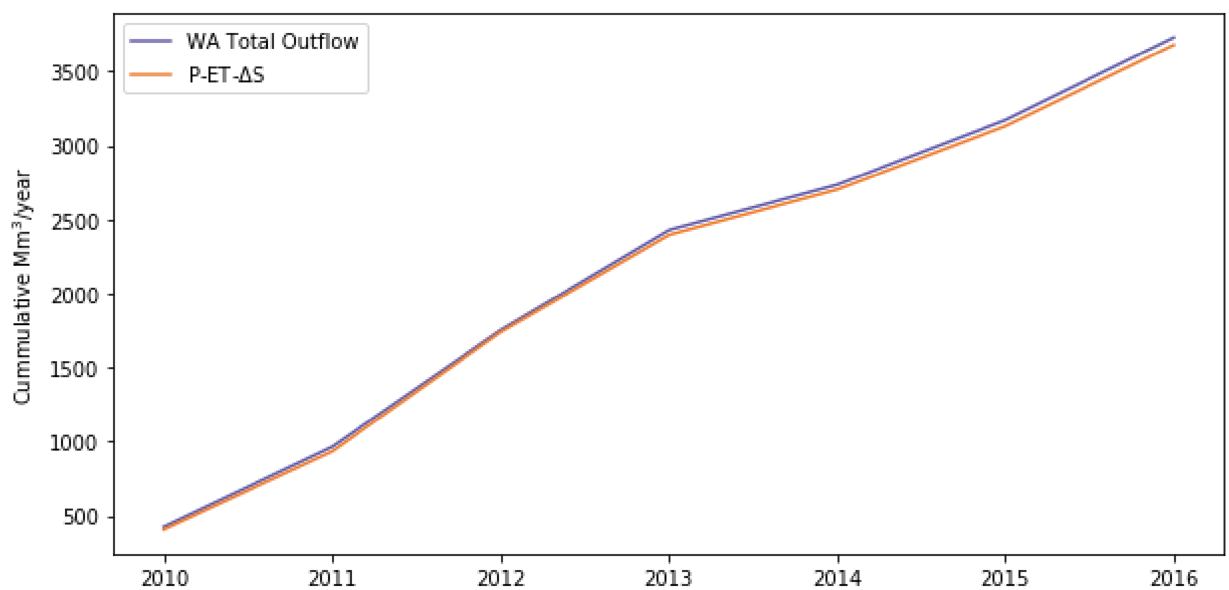


Figure 13: Cumulative WA+ simulated total outflow and the residual $P\text{-}ET_a\text{-}\Delta S$

The estimated total outflow makes it feasible to back calculate the storage changes ΔS with a monthly time step. These storage changes relate to changes in lakes, reservoirs and sinks as well as aquifers and changes of water in the vadose zone. The annually average ΔS estimated in WA+ sheet 1 is +57.5 Mm^3/year (Figure 14) which means in terms of WA+ terminology that a net depletion occurs. Decrease in groundwater level in Litani area is attributed to the over-exploitation of the aquifers. According to the assessment of groundwater resources (UNDP, 2014), the Southern Bekaa Neogene-Quaternary aquifer shows an annual deficit of 45.7 Mm^3/yr. The latter value is in good agreement with our water balance. The GRACE measurements are with -4.6 Mm^3 one order of magnitude different, but the single GRACE pixel does not match the Litani river basin area as explained before. The GRACE storage changes also include soil moisture changes, besides lakes, reservoirs and aquifers and there could be compensating factors that increases the gravity, besides the inclusion of the Mediterranean Sea are in the single GRACE pixel.

Overall, the output of the WaterPix model and WA+ framework provide reasonable estimations of various stocks and fluxes in the Litani Basin.

3 Results

3.1 WA+ sheet 1: Resource base

WA+ sheet 1 provides a total overview of the state of the water resources (Figure 14).

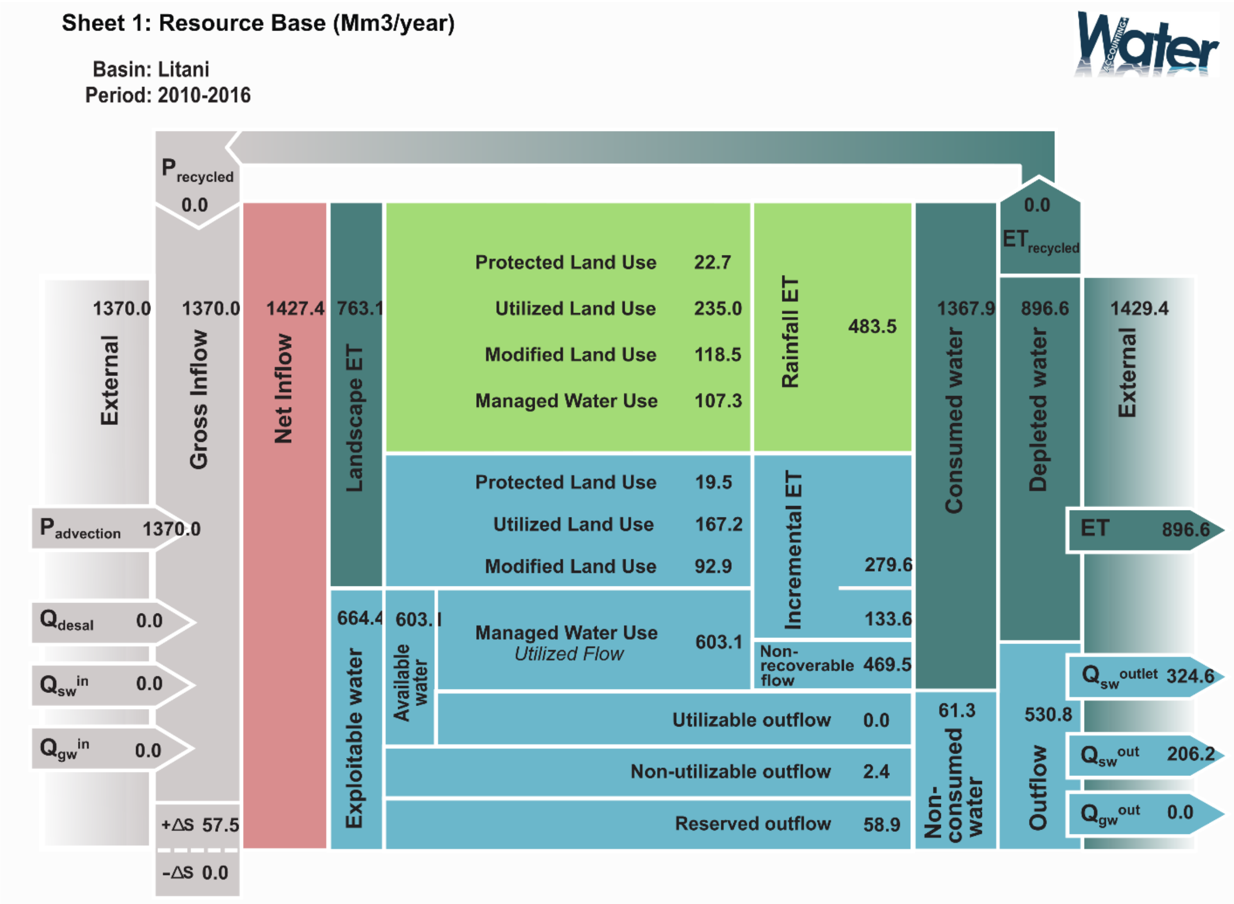


Figure 14: WA+ sheet 1 for the Litani Basin containing average flow values for the period 2010 – 2016. Yearly Resource Base Sheets are included in Annex IV.

The exploitable water resources in the Litani basin are 664.4 Mm^3/yr. The renewable water resources are lower (606.9 Mm^3/year), due to a decrease of the basin storage by 57.5 Mm^3/yr. In 2010, the population of Litani was 375,000 inhabitants, which after the Syrian crisis likely doubled. The per capita water availability in 2010 was approximately 1,600 m^3/cap/year, and with the estimated doubling of the population it has reduced to 800 m^3/cap/year which indicates water shortage. However, about 50% of the surface water resources are utilised outside of the basin, leaving less water available for the population inside the basin. Due to the high estimated water pollution level of 88% (Mekonnen and Hoekstra, 2015), a large part of the remaining water resources are considered non-recoverable. The remaining flow is non-utilizable outflow during storm events (2.4 Mm^3/year). This leaves insufficient amount of water for the environmental flow requirement of 27% of the basin outflow which is about 143 Mm^3/year (Smakthin et al., 2004).

The available exploitable water is 664.4 Mm^3/year out of which 458.2 Mm^3/year is utilized within the basin (69 %) and 206.2 Mm^3/year (31 %) is transferred out. The non-recoverable water due to pollution is based on Mekonnen and Hoekstra (2015) and estimated to be 88 percent of the outflow (469.5 Mm^3/year) and incremental ET (133 Mm^3/year), which is all of the available water. After subtracting non-utilizable out flow of 2.4 Mm^3/year, the amount remaining for environmental flow is just 58.9 Mm^3/year, which is 84 Mm^3/year less than the requirement.

Not all utilized flow contributes to the economy. The majority of ET_{inc} (total volume 413.2 Mm^3/year) originates from natural withdrawals (279.6 Mm^3/year) and less from human-made withdrawals (133.6 Mm^3/year), meaning that the majority of the available water resources goes to Utilized Land Use (ULU) and Modified Land Use (MLU). Rarely this usage of blue water appears in water allocation plans, because this consumption occurs naturally and is out of sight from water managers. Groundwater dependent ecosystems such as bushland and forests tap into shallow aquifers and intercept drainage flows. Indeed many of the Lebanese cedar trees get very old (hundreds of years) and root deep (10 to 30 m). Also seepage in valleys and outcrops of groundwater in hill torrents are an important source of water to natural vegetation. This appears all during the dry summer months when the natural ecosystem has to survive.

Majority of the utilized water, 90% (603.1 Mm^3/year), is attributed to Managed Water Use, which for a large part can be attributed to high pollution levels. The fact that natural land use classes utilize blue water can be explained by capillary rise and some complementary irrigation practices during periods of drought. Certain crops and orchards are basically rainfed, but during specific events they will get supply with mobile irrigation equipment (hoses and sprinklers). It remains an unresolved dispute whether these fields should be classified as rainfed or irrigated.

An initial way to assessing a safe cap for water consumption in irrigated agriculture is based on sustainable utilisation of the water resources. The current abstraction for agriculture is 110 Mm^3/year, which over-exploits the groundwater resources by 50 Mm^3/yr. When wastewater treatment is improved, about 470 Mm^3/year additional water could become available, however 206 Mm^3/year is reserved for the inter-basin transfer (average amount from 2012-2016) for hydropower and Beirut (even though a better estimation of the actual demand is the transfer during wet years, about 380-400 Mm^3/year). In addition, 143 Mm^3/year should be reserved for the environment according to Smakhtin et al. (2004). This potentially provides an additional 121 Mm^3/yr. If the current water consumption for agriculture remains the same (but is supplied by surface water), 71 Mm^3/year is available for irrigation expansion.

3.2 WA+ sheet 2: Evapotranspiration

WA+ sheet 2 quantifies the consumption of water per land use class and summarizes the relationship between beneficial and non-beneficial *ET* (Figure 15). Irrigated crops evaporate 181.1 Mm^3/year and this exceeds the *ET* volume of rainfed crops (172.9 Mm^3/year). The extensive manageable natural areas in the mountains and foothills of the Litani basin can be hold responsible for the large *ET* of 402.2 Mm^3/yr. One interim conclusion is that the *ET* volume from all cropland (354 Mm^3/year) is similar to the *ET* of ULU land use (402.2 Mm^3/year).

The *ET* components (*T*, *E*, *I*) presented in WA+ sheet 2 are based on WaPOR dataset. *T* is with 636 Mm^3/year (71 %) far more than *E* (246 Mm^3/year; 27.4%) and *I* (7 Mm^3/year; 0.8 %). As a consequence, the vast majority of the water resources is used beneficially (72%) and this is a very positive observation, provided that the WaPOR partitioning of ET_a is reliable.

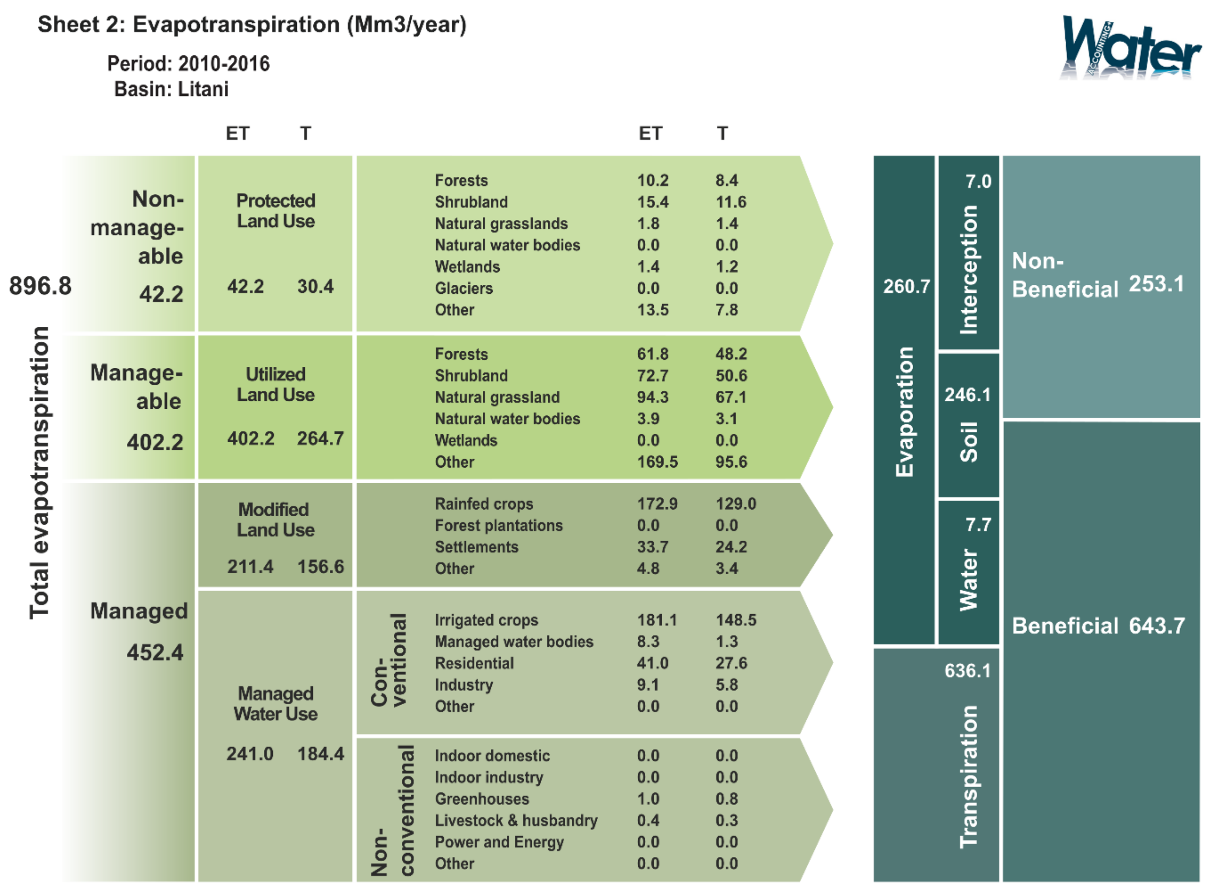


Figure 15: WA+ sheet 2 for the Litani Basin and average flow values for the period 2010– 2016 (using WaPOR data)

The comparison between the WaPOR and WA+ ET split is provided in Figure 16. It shows the proportion of ET_a components following both methods. There is a substantial difference between *T* and *E* components generated by WaPOR at the one hand and the WA+ algorithm at the other hand (Figure 17). WaPOR generally estimates substantially high *T* compared to the WA+ split algorithm (71% for WaPOR compared to 27% for WA+) (Figure 16). This affects the estimation of beneficial vs non beneficial water consumption as shown in Figure 17. Mul and Bastiaanssen (2019) also remarked that the WaPOR split of ET_a favours *T,* and that *T* in reality is likely to be lower.

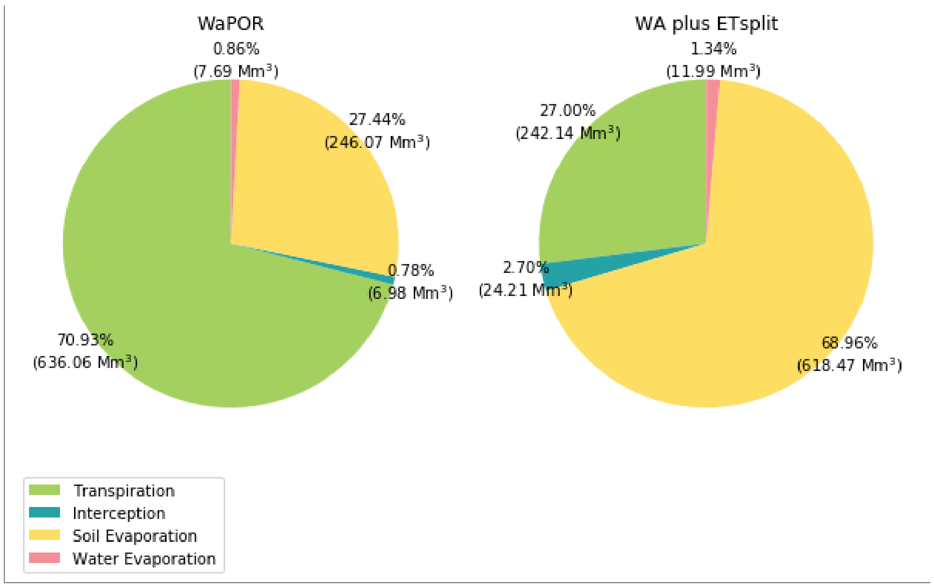


Figure 16: Comparison between the average Evaporation, Transpiration, and Interception components (2010-2016) of WaPOR data and an internal procedure developed by the water accounting team

Agriculture consumes 39.5% of ET_a (Figure 17) and a fraction of 45% of the beneficial consumed water. Agriculture is largest consumer of water in the class Managed Water Use, which has the highest *T/ET* ratio (0.77). Agriculture is also largest consumer in the class Managed Land Use, and the *T/ET* ratio (0,74) is high as well.

3.3 WA+ sheet 3: Agricultural services

WA+ sheet 3 assesses agricultural water consumption, production and water productivity. The main purpose is to demonstrate to what extent water in the agricultural sector is used productively. The first part of WA+ sheet 3 (Figure 18) describes consumptive water use by agriculture while the second part (20) describes Land and Water productivity (See Section 3.3.2).

3.3.1 Part 1: Agricultural water consumption

Consumptive water use for agriculture means evapotranspiration by crops. The grey water consumption due to agro-chemicals and over-fertilization is not considered here, to comply with the international standard measure of crop water productivity (Y/ET_a). As we did not have information on consumptive water use by non-crops agricultural services (e.g. aquaculture, timber) in the Litani basin, thus were considered negligible. The evapotranspiration of irrigated crops (181.1 Mm^3/year) and rainfed crops (172.9 Mm^3/year) shown in WA+ sheet 2 (Figure 15) is the total evapotranspiration of these land-use classes through the whole year. In WA+ sheet 3 (Figure 17), water consumption through evapotranspiration is considered during the crop season alone. Since some of the crop types are only cultivated for a limited period of the year and then fallowed for the rest, the water consumption of the irrigated and rainfed crop classes for agriculture can be lower than that for the whole year. For irrigated crops, the crop season can be as long as the whole year thanks to water supply, thus, the agricultural water consumption (176.15 Mm^3/year) is only 2.7% less than total evapotranspiration of the land. As rainfed crops often have shorter season, the water consumption that is beneficial for agriculture (125.96 Mm^3/year) is much less than the annual evapotranspiration (about 27%).

The difference of water consumption between irrigated and rainfed area (Figure 17) depends greatly on the evapotranspiration and land-use classification. From agricultural water consumption (Figure 18), the crop classes that are mostly irrigated are cereals, root/ tuber, leguminous, and vegetables & melons. Meanwhile, oil crop (olives) is mostly under rainfed conditions. Fruit & nuts crop class consists of several crop types: banana, citrus, grapes, and other fruit trees. About half of agriculture water consumption of the fruits and nuts is from rainfed area (55.49 Mm^3/year). It is often forgotten that irrigated crop also consume water from rainfall. Roughly speaking, 44% of evapotranspiration from irrigated crop area can be ascribed to rainfall (Figure 17), which is mainly from precipitation during rainy season.

Sheet 3: Agricultural services
Part 1: Agricultural water consumption (Mm3/year)

Basin: Litani
Period: 2010-2016

Agricultural water consumption: 302.11

Crop: Cereals	Non-cereals: Root / tuber crops	Non-cereals: Leguminous crops	Non-cereals: Sugar crops	Non-cereals: Merged	Fruit & vegetables: Vegetables & melons	Fruit & vegetables: Fruits & nuts	Fruit & vegetables: Merged	Oil-seeds	Feed crops	Beverage crops	Other crops			
15.28	3.64	17.54	-	-	5.85	55.49	-	28.16	-	-	-	ET	rainfed	125.96
16.29	8.18	13.74	-	-	9.82	28.55	-	1.46	-	-	-	ET from rainfall	irrigated	78.04
23.22	11.14	19.94	-	-	14.68	28.27	-	0.87	-	-	-	Incremental ET	irrigated	98.11
39.51	19.32	33.67	-	-	24.50	56.82	-	2.33	-	-	-	Total ET	irrigated	176.15

Figure 17: WA+ sheet 3a for the Litani Basin and average values for the period 2010-2016

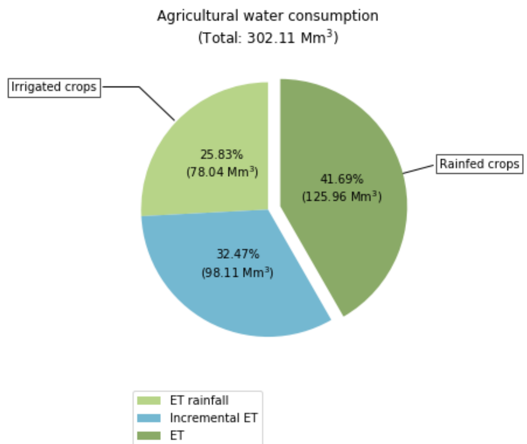


Figure 18: Percentage of agriculture water consumption by Rainfed crops and Irrigated crops

3.3.2 Part 2: Land productivity and water productivity

In order to compute the fresh crop yield for each of the agricultural crop classes, a representative crop or crops have been selected. The representative crops are wheat for cereals, potatoes for tuber/root crops, chickpea for leguminous crops, onion and sugar beet are combined into vegetables & melons crops, and olives for oil crops. For fruit & nuts class, there are four major crops: banana, citrus, grapes, and other fruit trees (orchard). The crop-specific coefficients (harvest indices and water contents) required to convert total dry matter production to crop yield have been applied. Water productivity is then calculated based on the consumed water (evapotranspiration).

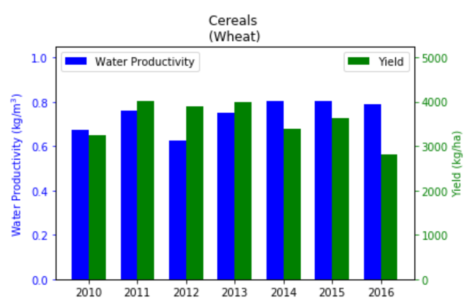
Sheet 3: Agricultural services
Part 2: Land productivity (kg/ha/year) and water productivity (kg/m3)

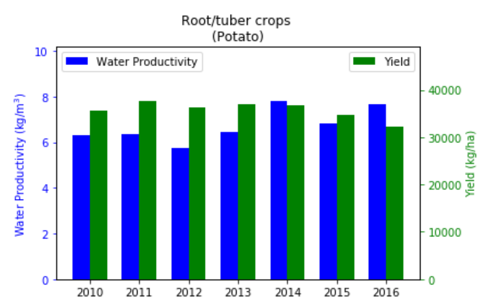
Basin: Litani
Period: 2010-2016

Crop	Cereals	Non-cereals				Fruit & vegetables			Oil-seeds	Feed crops	Beverage crops	Other crops		
		Root / tuber crops	Leguminous crops	Sugar crops	Merged	Vegetables & melons	Fruits & nuts	Merged						
Land productivity	3568	35767	2492	-	-	21795	11989	-	99	-	-	-	Yield	rainfed
	2061	18508	1864	-	-	14627	10740	-	79	-	-	-	Yield from rainfall	irrigated
	2062	17916	2046	-	-	15899	11256	-	29	-	-	-	Incremental yield	irrigated
	4123	36423	3910	-	-	30526	22009	-	107	-	-	-	Total yield	irrigated
Water productivity	0.74	6.74	0.72	-	-	4.86	4.31	-	0.03	-	-	-	WP	rainfed
	0.84	7.45	0.75	-	-	5.55	3.16	-	0.03	-	-	-	WP from rainfall	irrigated
	0.60	5.37	0.57	-	-	4.11	2.66	-	0.02	-	-	-	Incremental WP	irrigated
	0.70	6.30	0.65	-	-	4.70	2.91	-	0.02	-	-	-	Total WP	irrigated

Figure 19: WA+ sheet 3b for the Litani Basin and average values for the period 2010-2016

On average of the 2010-2016 period, the oil crop (olives) has the lowest land and water productivity, the tuber/root crop (potato) has the highest land and water productivity in the basin, following by fruit & vegetables groups. This can be explained mainly by the high moisture content of root/tuber, fruit and vegetable crops. In general, irrigated crop areas have higher land productivity than rainfed crop areas, and their yield is greatly enhanced by irrigation (Figure 19). This can be understood by the fact that irrigation is supplied during the dry months, when rainfed crop area is often fallowed, which helps produce more crop per land area. However, water productivity of the irrigated crop area is lower than that of rainfed crop area in general, which means the irrigated area actually consumes more drop per crop than the rainfed area. This suggests that to improve water productivity in the basin, more effort should be dedicated to improve irrigation efficiency in the irrigated area.





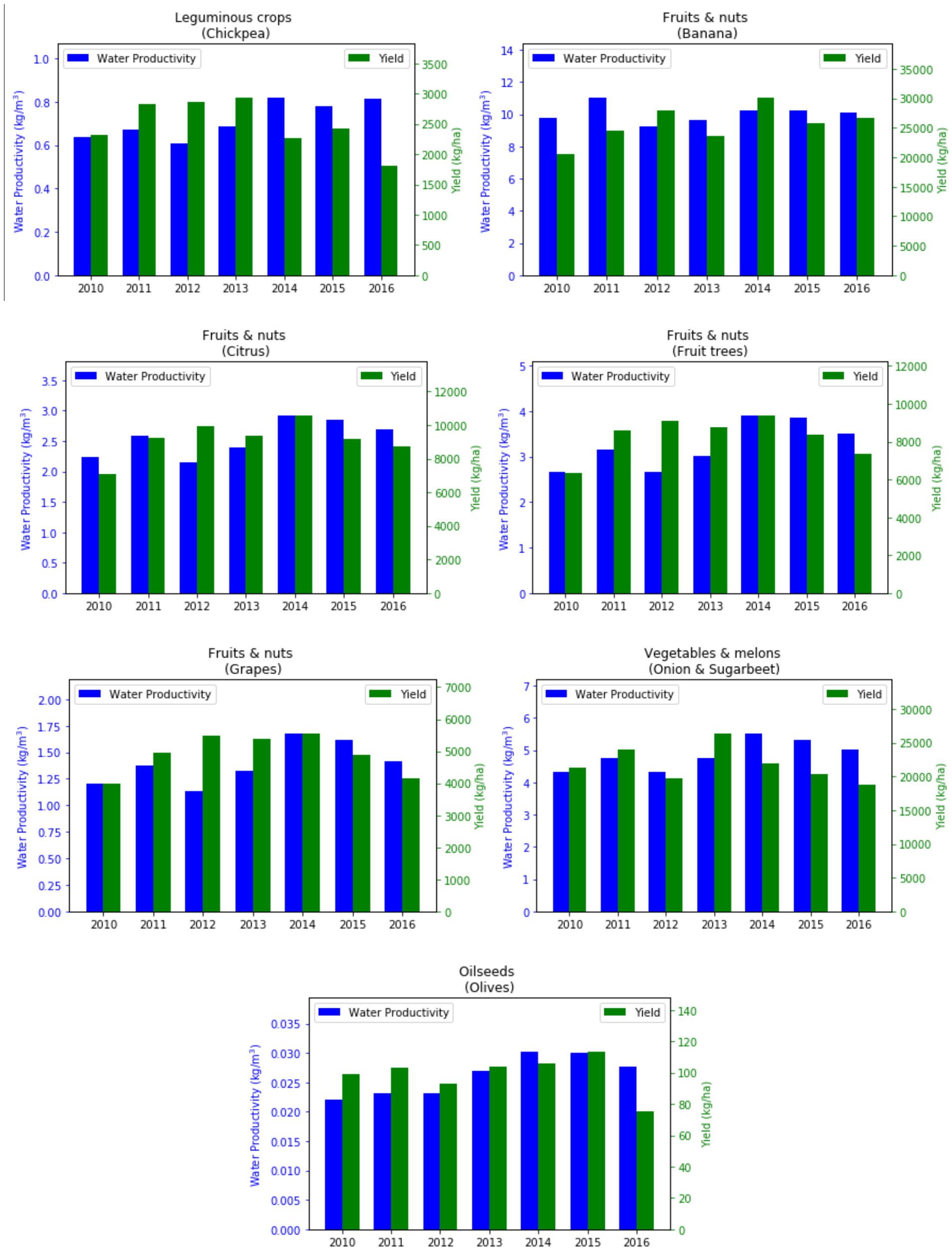


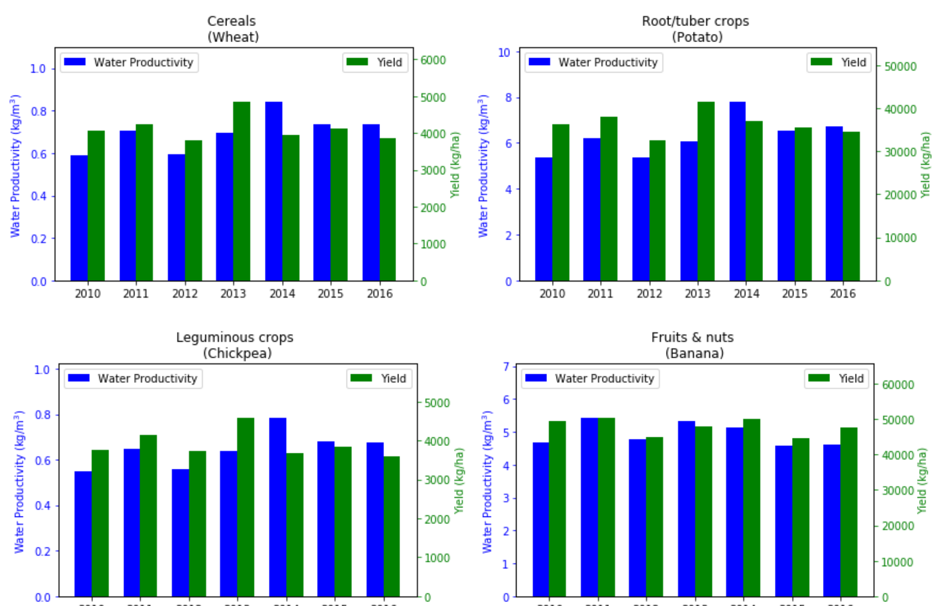
Figure 20: The annual land and water productivity of Rainfed crops from 2010 to 2016

Figure 20 and Figure 21 show the evolution of land productivity (kg/ha) and the water productivity (kg/m^3) per main crop class in the Litani Basin during the period of 2010-2016.

The year 2014, which is considered the driest year in the period as it has lowest $P - ET_a$ (Table 1), has shown changes in land and water productivity. Land productivity for some crops in the Litani Basin shows a decrease in 2014 in respect to 2012 that can be explained by drier conditions. Meanwhile, water productivity has increased for most crop classes since the crops consume less water. For Litani basin, the increase is approximately 2.9% per year. This process could be accelerated by organizing extra agronomic efforts, in conjunction with better water storage and distribution of scarce water resources. With sufficient irrigation water supply, the yield during below-average rainfall years should not be affected. Accurate irrigation practices in the fields with sensors can help to prevent production falling back during dry years. The required infrastructure on storage and canals should be in place to provide the water when needed by the thirsty crops.

The water productivity of irrigated wheat in the Bekaa Valley is on average 0.7 kg/m^3, which is below the global average of 1.1 kg/m^3 (Bastiaanssen and Steduto, 2017), and there is thus lots of opportunities to grow more wheat with less water resources. A similar conclusion can be drawn for potatoes. While the Litani basin show a water productivity from 6.3 to 6.7 kg/m^3, compared to the global average of 8.9 kg/m^3 (Blatchford et al., 2018). The interim conclusion is that WP could be improved realistically to global standard levels with 36% and 48% for wheat and potato respectively.

Livestock production is also an important agricultural activity, especially in the Northern area of the Litani basin where soil fertility is low. Unfortunately, agricultural statistics are not specified for the hydrological basin as they are reported according to administrative division (MoA and FAO, 2010). Though there are few studies on the nutrient balance and number of livestock animals in the Upper Litani River basin in 2015, the reported figure cannot represent the total livestock production in the whole basin and the trend through years. Due to the lack of this information, water consumption by livestock animals was not estimated for this water accounting report.



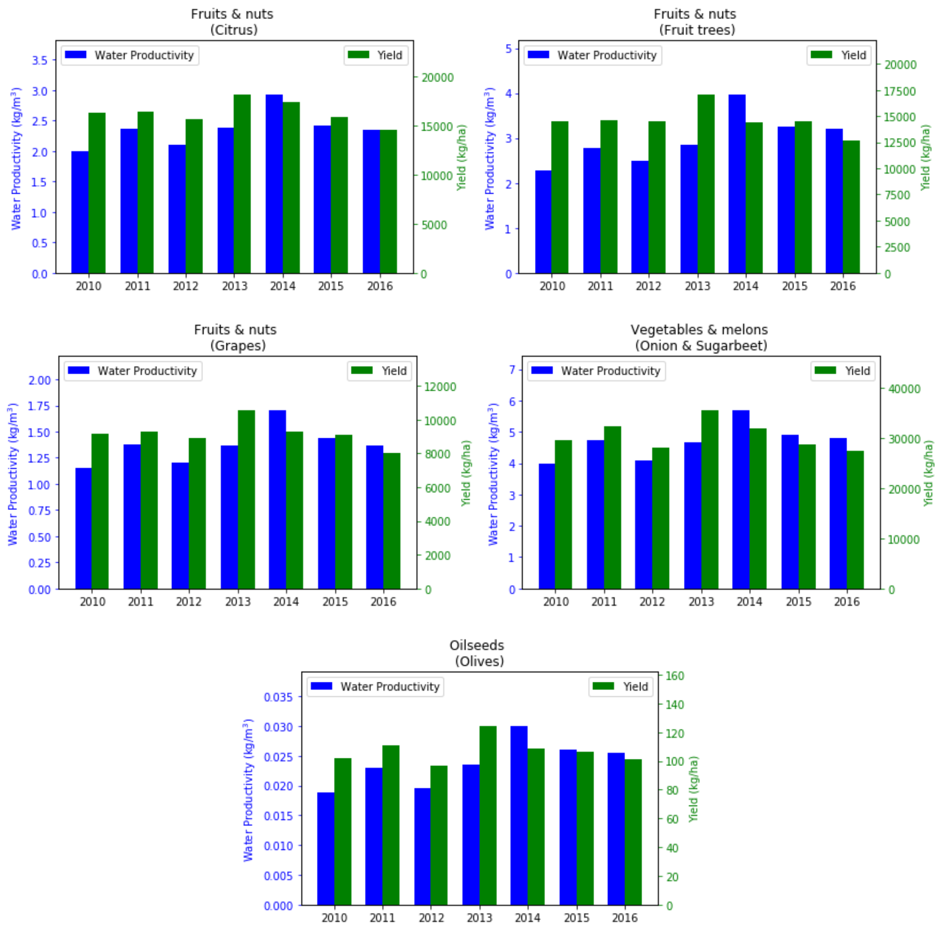


Figure 21: The yearly land and water productivity of Irrigated crops from 2010 to 2016

3.4 WA+ sheet 4: Utilized flow

The average exploitable water is 664.4 Mm^3/year, out of which an amount of 603.1 Mm^3/year is utilized (see Figure 14). WA+ sheet 4 describes in more detail how this water resources are currently utilized. A distinction between human-made (Figure 22) and natural land-use withdrawals (Figure 23) is made. The gross human induced withdrawal is the sum of supplied water computed by WaterPix, which is 145.22 Mm^3/yr. This is the total amount from all the pixels that are identified to have a certain minimum period of time during which extra water is supplied (in addition to rainfall). A fraction of 60% is assumed to originate from groundwater, as groundwater is the major source of water management applications.

The Litani River Basin is located within the region of Bekaa Water Establishment and the South Lebanon Water Establishment. In these establishments, the total groundwater abstraction of public wells is estimated to range from 50 to 70 Mm^3/year (MoEW & UNDP, 2014). The total volume of groundwater abstraction is likely to be underestimated due to ill-defined number of private wells and inaccurate abstraction rates from public wells. Namely, only 25% of over 80,000 wells in Lebanon are registered and a very few of them (300) are metered (Molle et al., 2017). Therefore, the groundwater withdrawals in WA+ sheet 4 of 85.74 Mm^3/year can be closer to the actual groundwater abstraction.

WA+ sheet 4a shows that the incremental ET – the depleted due to water supply is 133.6 Mm^3/year and that 108.68 Mm^3/year goes to irrigated crops land-use. The non-depleted part of the utilized water return to groundwater and surface water as the incremental surface runoff (7.62 Mm^3/year) and incremental percolation (2.54 Mm^3/year). A part of the return flow can be contaminated with agrochemicals applied on crop land. If the concentration in the water exceeds the maximum acceptable concentration, it is considered non-recoverable water. Based on the global grey water footprint (GWF) (Mekonnen & Hoekstra, 2015), the water pollution level of Litani basin is about 0.88, which means the fraction of the total GWF to the actual runoff from that catchment is 88%. In WA+ sheet 4, the non-recoverable flow is estimated based on return flow from supplied water (i.e. through irrigation), which is 8.74 Mm^3/yeaer in addition to the 1.42 Mm^3/year recoverable return flow. The non-recoverable flow presented in WA+ sheet 1 is 496.5 Mm^3/year, which is 88% of the total outflow of the catchment, to include all the polluted water from industrial and domestic use in the basin.

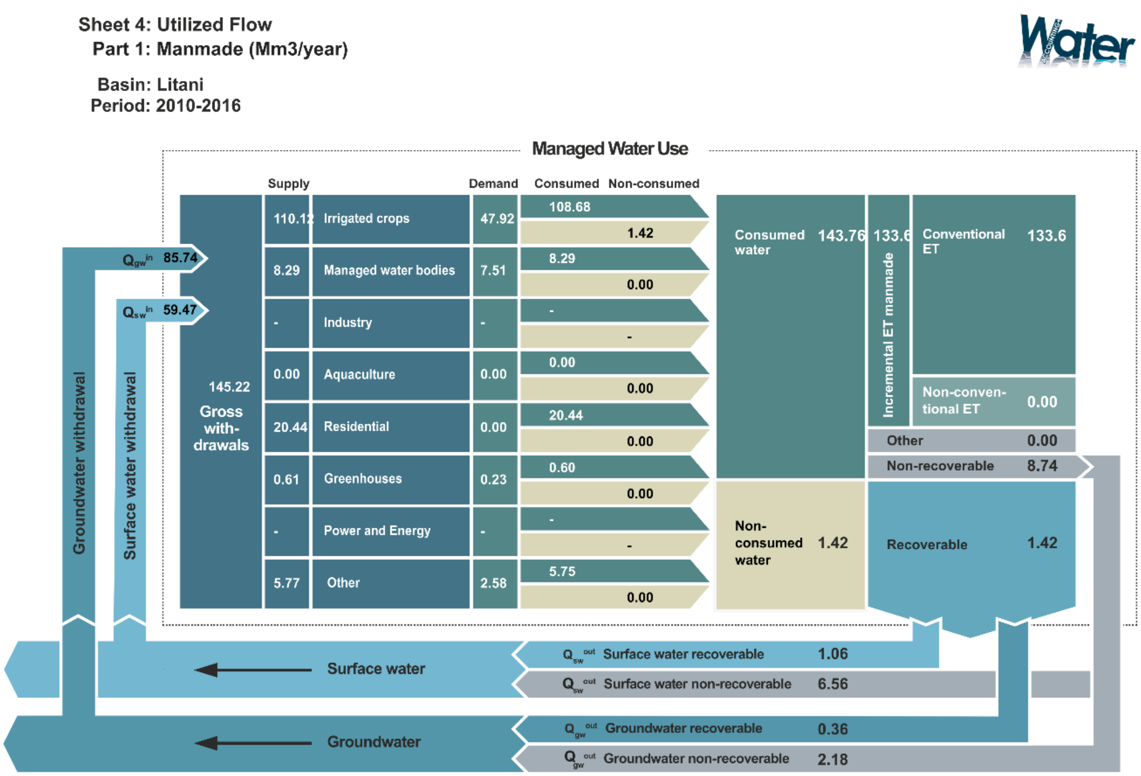


Figure 22: WA+ sheet 4 – part 1 for the Litani Basin and the average values for the period 2010-2016

The managed water body is Lake Qaraoun and other reservoirs that together evaporate an amount of 8.3 Mm^3/yr. For a more explicit recognition, inter-basin transfer is kept out of the Utilized Flow sheet (WA+ sheet 4). If portrayed under Power and Energy, the non-consumed outflow from the turbines would have to go to the surface or groundwater system of Litani (which is not the case because it is a real sink). For this reason the cells of Power and Energy are kept intentionally blank.

As discussed before, the large areas of Utilized Land Use and their interception of exploitable water in a natural manner due to various mechanisms for longer or shorter periods is manifested in a total natural gross withdrawal of 279.58 Mm^3/year (Figure 23). In other words, the *ET* of savannah and forests cannot be explained by rainfall only, and their *ET* in summer and fall relies on underground water availability.

Because of the character of natural withdrawals, which is that vegetation withdraw only the amount of water it requires, all supplied water is consumed. The land use class "other" seems to have a significant influence on the natural utilized flows. This is mainly ULU14 being the mountains in the upstream part of Litani (legend reads as "rocks & gravel & stones & boulders").

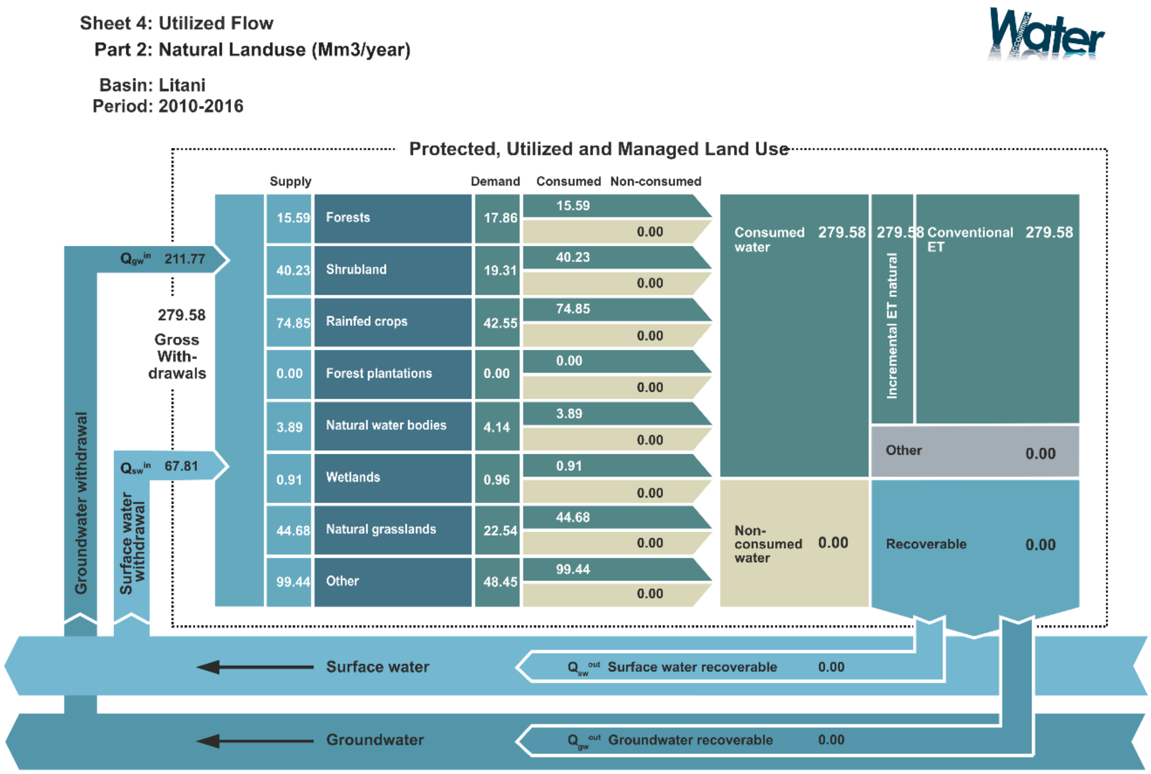


Figure 23: WA+ sheet 4 – part 2 for the Litani Basin and the average values for the period 2010-2016

The spatial patterns of supply can be seen in Figure 24. The values of incremental ET are forming the fundament for such type of analysis. The annual values for a given year are presented. In dry year 2014, the supply from irrigation in the Bekaa valley was significantly higher than the wet year 2012. Since $P - ET_a$ is the highest in 2012 (Table 1), there is less requirement for supplied water. The difference is especially significant in the Bekaa Valley where most of the irrigation activity occurs.

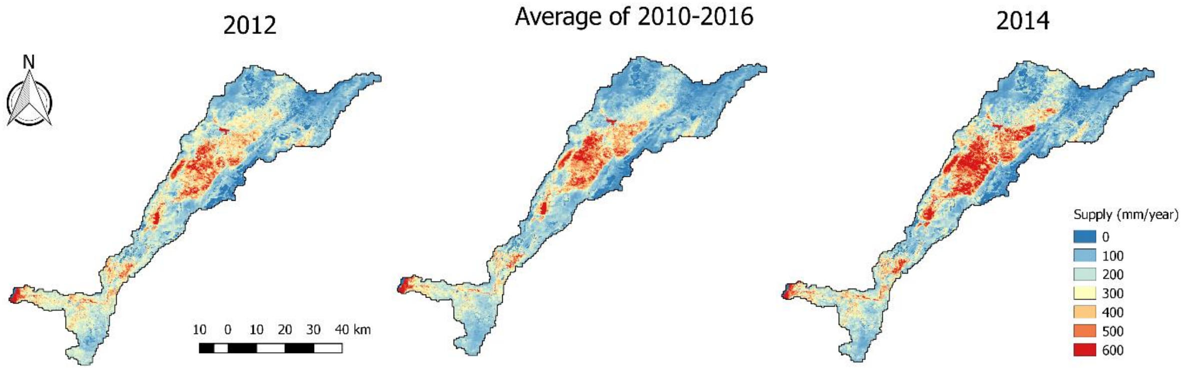


Figure 24: Estimated total water supply from surface water and groundwater sources in the Litani Basin, annual values for 2012 (wet year), 2014 (dry year) and the average of 2010-2016.

3.5 WA+ sheet 5: Surface water

WA+ sheet 5 shows the natural and actual river flow; it accounts for the total runoff (Q_t), withdrawals of surface water ($Q_{sup,\ sw}$), return flows (R_{incr} and $Q_{sro,\ incr}$) and inter-basin transfers (Figure 25. The schematization of Litani is simple. The upper basin is sub-basin 1 up to Lake Qaraoun. Branch 2 covers the area downstream of this reservoir. The total inflow from streams and baseflow together is 654.6 Mm^3/yr or 20.7 m^3/s, of which about 80% is surface runoff (Q_{sro}) and about 20% is baseflow (Q_{bf}). The total basin outflow is 530.8 Mm^3/year including the estimated 206.2 Mm^3/year for the Markaba tunnel.

While a large volume of surface water are abstracted (127.3 Mm^3/year) for incremental *ET*, a part becomes return flow (7.6 Mm^3/year) as incremental runoff (3.1 Mm^3/year) and incremental recharge (4.6 Mm^3/year). The non-recoverable flow in WA+ sheet 5 (469.5 Mm^3/year), which is also consistent with WA+ sheet 1, is mainly due to high water pollution level of the basin (Mekonnen and Hoekstra, 2015). Since water is presented as volume in the current version of water accounting sheets, the pollution load of water cannot be explicitly reported in the sheets. Therefore, the non-recoverable flow should only be seen as an indicator of pollution level of the total outflow, not the actual volume. In fact, with high technology of waste and wastewater treatment, it is possible to recover and reuse this water in the basin. It should also be noted that the uncertainty range of the global GWF is of -33% to +60% (Mekonnen and Hoekstra, 2015).

Sheet 5: Surface Water (Mm3/year)

Basin: Litani

Period: 2010-2016

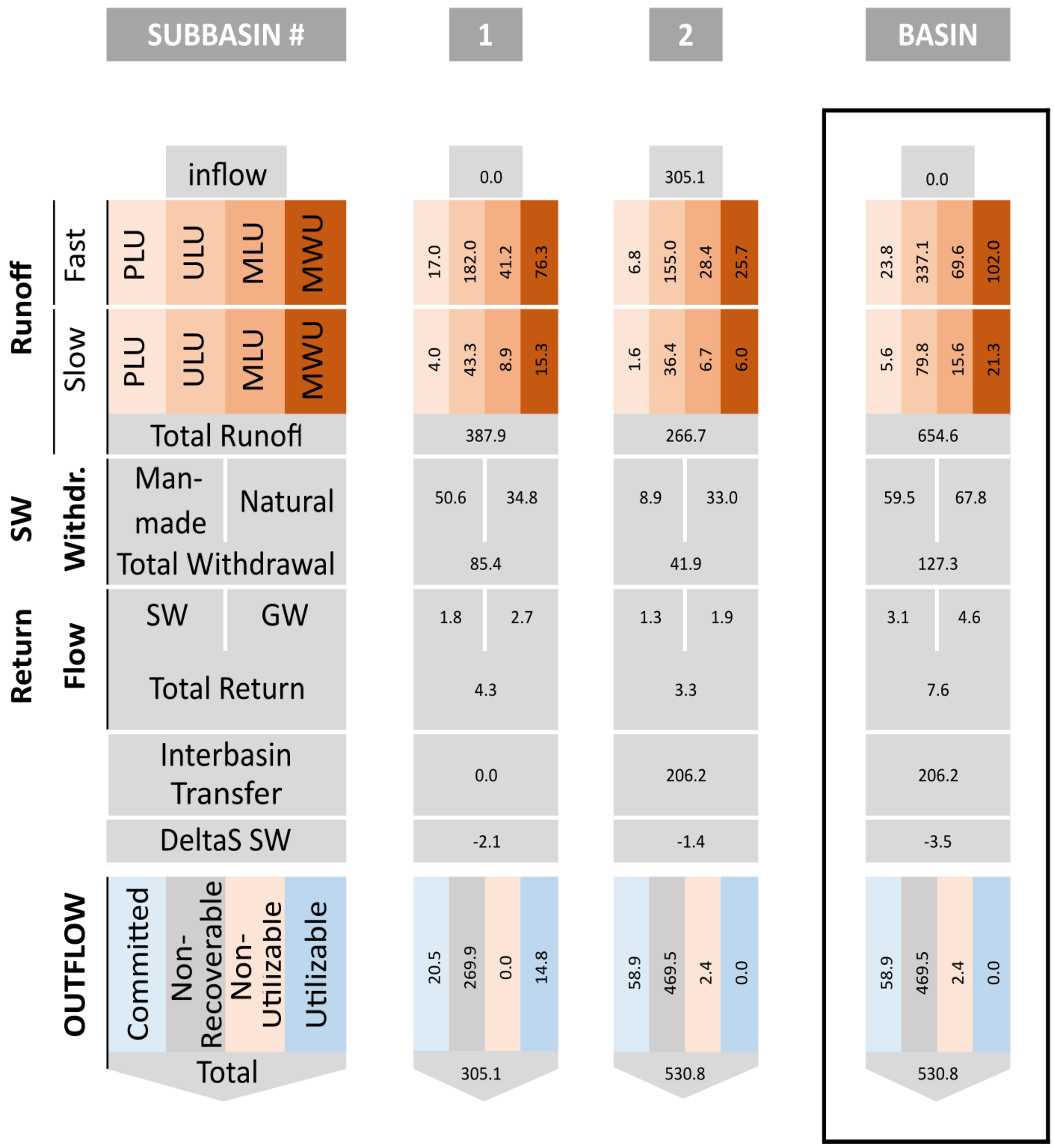


Figure 25: WA+ sheet 5 for the Litani Basin and the average values for the period 2010-2016

3.6 WA+ sheet 6: Groundwater

WA+ sheet 6 is the result of all previous accounts (Figure 26). Groundwater abstractions and return flow of recoverable and non-recoverable water resources are presented before in WA+ sheet 4. Recharge (R_g) in WA+ sheet 6 is calculated by WaterPix. The total recharge of 366.2 Mm^3/year is substantial. Natural grasslands and shrubland contribute with the higher volumes than the forest. Most of the natural recharge is however abstracted again by wells (211.8 Mm^3/year) and by natural land use classes (85.7 Mm^3/year) and subsequently evaporated or turned into return flow. The total return flow from groundwater abstractions in the irrigation systems is estimated to be 1.52 Mm^3/year and recharge from surface water flows and diversions also known as "the leaking fields and managed water bodies" add up to a total volume of 1.02 Mm^3/yr. The total (1.52+1.02 Mm^3/year) is the recoverable (0.36 Mm^3/year) and non-recoverable (2.18 Mm^3/year) return flows in WA+ sheet 4.

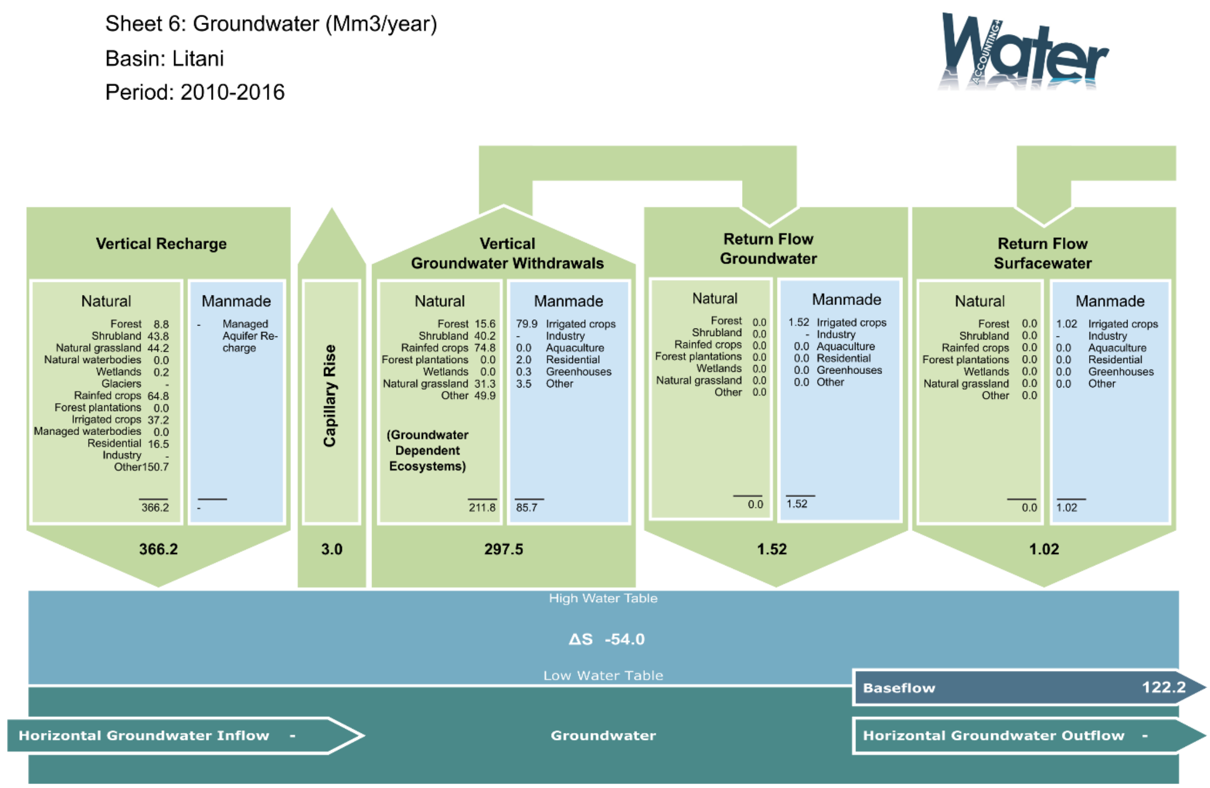


Figure 26: WA+ sheet 6 for the Litani Basin and the average values for the period 2010-2016.

The WA+ approach allows to assess groundwater withdrawals at the basin scale without available records on local well abstractions. The annual average groundwater withdrawal for irrigated land is estimated to be 80 Mm^3/year, which is more than the reported value of public wells (50-70 Mm^3/year). The total irrigation supply is 110 Mm^3/year (WA+ sheet 4), hence the difference 110 – 80 Mm^3/year comes from canal water supply (30 Mm^3/year). The percentage of irrigated area over total cultivated area was above 60% in the upper basin and about 40-60% in the lower basin during 2010 (MoA and FAO, 2010). The share of groundwater in irrigation sources, as illustrated by the Ministry of Agriculture, was approximately 65% in the Upper basin (Zahle and Joub Jannine districts) some 10 years ago (MoA and FAO, 2010). This is similar to the 72% estimated by FAO (2016) for the entire country. Groundwater depletion in the Litani River Basin is thus greatly impacted by water abstraction for irrigation, and this aspect requires proper attention when defining safe water caps for achieving sustainability.

The average annual baseflow is estimated to be 122.2 Mm^3/year. The current WaterPix model estimates total baseflow to match total outflow with the residual $P - ET_a - \Delta S$ at the basin scale so that the total water balance is kept. It is also assumed that there is no aquifer transfer in Litani basin, thus, no horizontal groundwater flows. For subsequent study, it is important to have groundwater survey and modelling to improve this groundwater accounting sheet (WA+ sheet 6) for application in groundwater management.

4 Conclusions

The Litani River basin is facing various challenges related to over-exploitation of the water resources. Ground water resources are depleted by 57.5 Mm^3/year high level of pollution results in non-recoverable water (469.5 Mm^3/year), and environmental flow requirement is unmet (84 Mm^3/year). Based on the estimated water availability, the inhabitants are facing severe water shortage (800 m^3/cap/year), while 39% of the water resources are exported from the basin as inter-basin transfers. In addition, water is exported from the basin through virtual water contained in crops, as the Bekaa valley is one of the key areas for food production in Lebanon. The actual water availability for inhabitants of the Litani River basin is therefore much lower.

While the inflow into the network of streams and rivers is 655 Mm^3/year and groundwater recharge is 366 Mm^3/year, the distribution in space and time as well as across natural land use and irrigation systems is skewed. This is caused by the dry summers and small storage facilities, located downstream of the main water users. The Litani River basin has an exploitable water resources of 664 Mm^3/year, which for 88% are utilised, either through incremental ET (133.6 Mm^3/year) or through pollution (469.5 Mm^3/year). Despite the water scarcity and high pollution level within the basin, about one third of this exploitable water resources is transferred out of the basin for hydropower production and to the urban area in Beirut every year. As a result, the recommended environmental flow requirement is unmet, which leads to zero utilizable water remaining in the river.

Even with an assumption of 80% irrigation efficiency, the amount of abstracted water estimated to satisfy incremental evapotranspiration, mostly during dry months, is still significantly high compared to natural flows. It is estimated that the water storage of the basin is decreasing about 50 Mm^3/yr. The estimated groundwater withdrawal for irrigated crops alone is about 80 Mm^3/year (about 72% of the total withdrawal for irrigated crops 110 Mm^3/year). Given the situation of unregistered groundwater abstraction wells in the basin, more study in groundwater accounting is recommended for the basin to define sustainable water caps.

Rainfed cropping, which is the traditional agricultural system in the basin, showed lower yield but higher water productivity than irrigated area in general. Therefore, it might be still suitable for the economic utilization of water resources and food security of Lebanon. The future water allocation to irrigated cropland depends on a number of possible strategies. One strategy is to invest more in water treatment plants that recovers (part of) the current non-recoverable flow (470 Mm^3/year). Another strategy to reduce groundwater storage depletion (50 Mm^3/year) is to invest in rain harvesting and/or storage during rainy season to tackle the seasonal mismatch of supply and demand. It is also recommended that an increase in reserved flow for environmental flow requirement (about 85 Mm^3/year) should be considered to conserve the ecosystem.

Considerations for improving agricultural water management in the Litani River basin:

- Increase Water Productivity by 25% to safeguard crop production but at a lower crop water consumption rate
- Decrease the over-exploitation of the aquifer by stopping excessive pumping and reduce groundwater dependency to 50%
- Reduce the non-recoverable water through water treatment plants. Re-use treated water to reduce groundwater extractions
- Apply deficit irrigation and more efficient practices

An initial way to assessing a safe cap for water consumption in irrigated agriculture is based on sustainable utilisation of the water resources. The current abstraction for agriculture is 110 Mm^3/year, which over-exploits the groundwater resources by 50 Mm^3/yr. When wastewater treatment is improved, about 470 Mm^3/year additional water could become available, however 206 Mm^3/year is reserved for the inter-basin transfer (average amount from 2012-2016) for hydropower and Beirut. In addition, 143 Mm^3/year should be reserved for the environment. This potentially provides an additional 121 Mm^3/year available. If the current water consumption for agriculture remains the same, 71 Mm^3/year is available. The analyses do not include the proposed plans for the South Lebanon irrigation project and domestic water supply (Canal 800) with an estimated supply of 110 Mm^3/year or the Greater Beirut Water Supply project (GBWS) with a proposed supply of 40 Mm^3/yr. The water accounts show there is not enough water available for these proposed projects in the Litani basin.

This study provides some new and systematic insights in the water cycle of Litani River basin using the WaPOR database. The consistency checks show that the WaPOR database is a good source of information for the water accounts.

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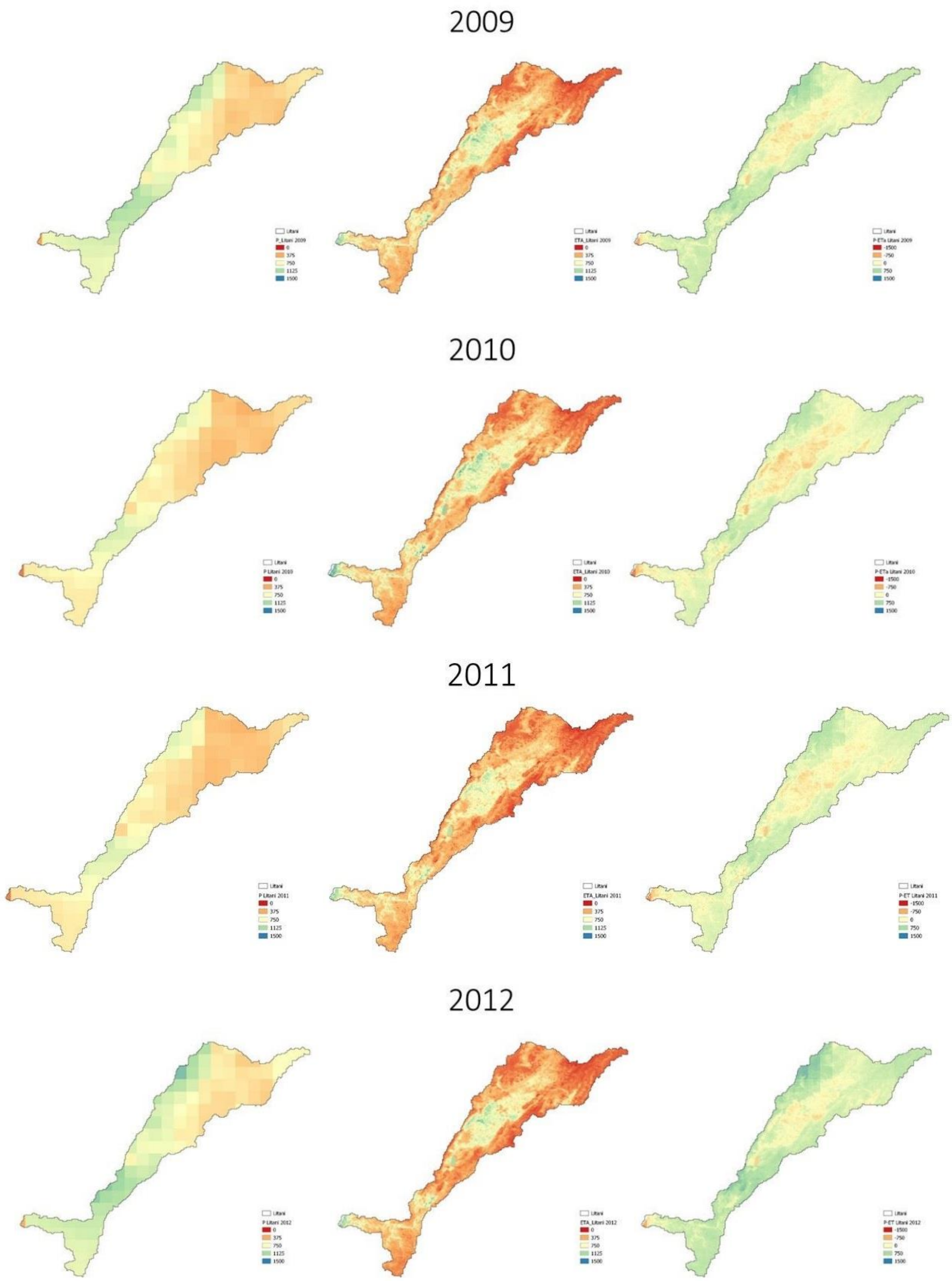
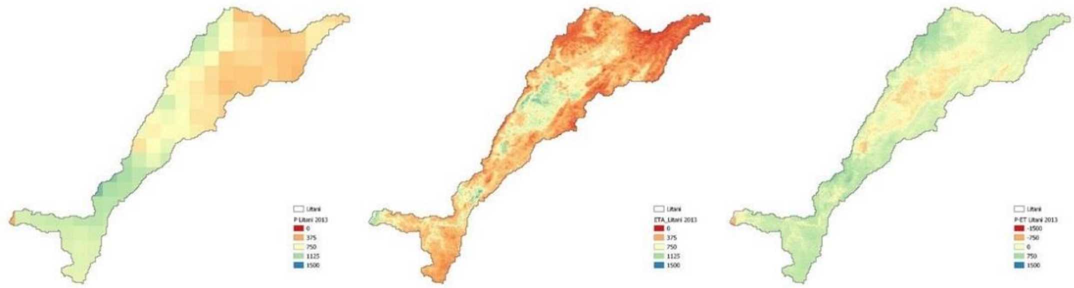
Annexes

Annex I: Spatial distribution of precipitation P and evapotranspiration ET_a.

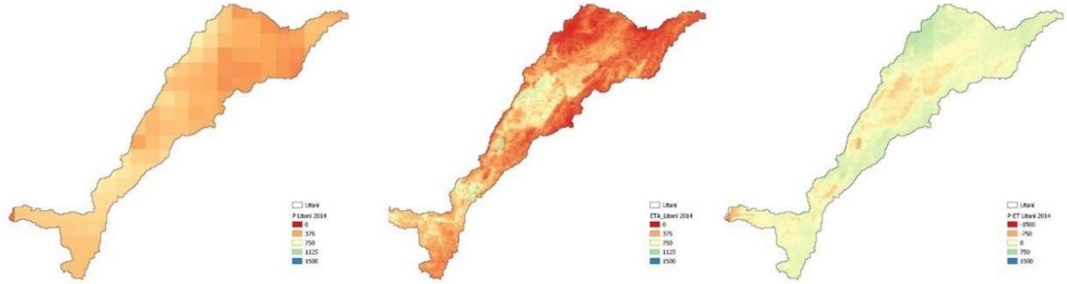
Figure I.1. Spatial distribution of P and ET_a and P-ET_a for 2009-2016



2013



2014



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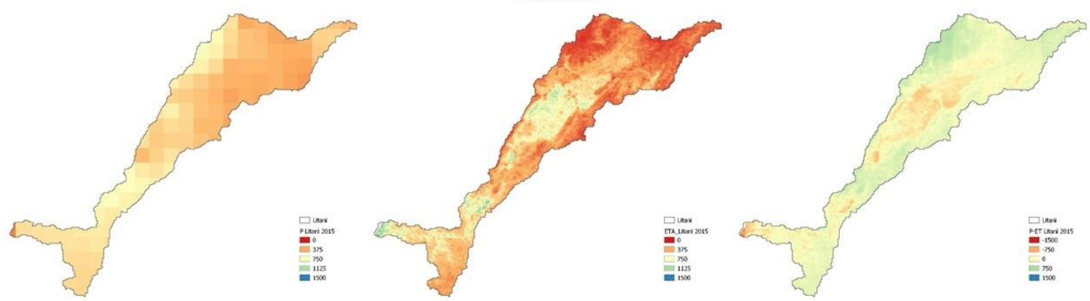
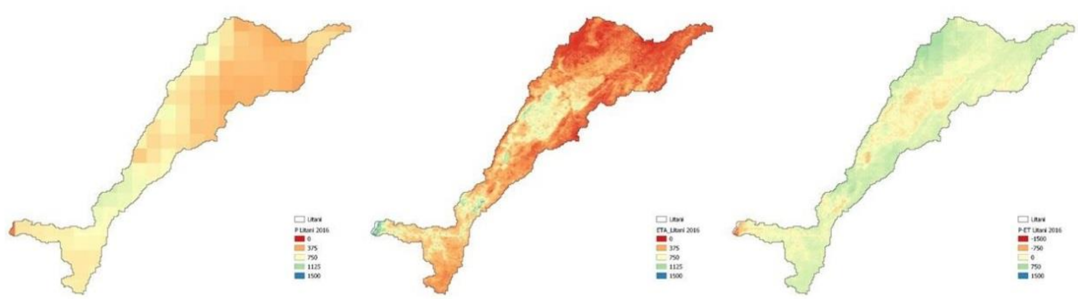


2016



Annex II: Basin scale water balance using WaPOR Level 1 data

Table II.1. The average P-ET-ΔS (using WaPOR Level 1 AETI data) of the Litani basin. Q is the sum of discharge at basin outlet in sea mouth ($Q_{seamouth}$) and inter-basin transfer discharge in Markaba tunnel ($Q_{Markaba}$) (unit: Mm^3/year)

Year	$Q_{seamouth}$	$Q_{Markaba}$	P	ΔS	ET_a	P-ET_a-ΔS	Q	Diff	%Diff
2010	184	206	1,402	-70	1,089	383	390	-7	-2
2011	195	206	1,392	-77	964	505	401	104	26
2012	362	406	1,795	38	968	789	768	21	3
2013	197	381	1,631	-83	1,078	636	578	58	10
2014	63	44	1,003	-28	794	237	107	130	121
2015	168	117	1,166	-106	932	340	285	55	19
2016	92	84	1,307	-41	876	472	176	296	168
Average	**180**	**206**	**1,374**	**-52**	**951**	**480**	**387**	**93**	**24**

Annex III: WA+ method: separation of ET into interception, evaporation and transpiration

In case the Interception, Evaporation and Transpiration spatial data are not available, an additional step to separate the total actual evapotranspiration into these 3 components is needed to estimate beneficial and non-beneficial components of total $ET_{a.}$

Interception

Monthly LAI maps were aggregated from MODI15 8-daily LAI products. Interception maps were computed with the formula proposed by Von Hoyningen-Hüne (1983) and Braden (1985) as described in Kroes et al., (2009)

$$I_t = \left(1 - \frac{1}{1+\frac{P_t}{rd_t}\cdot(1-\exp^{-0.5\cdot LAI_t})\cdot\frac{1}{LAI_t}}\right)\cdot LAI_t \cdot rd_t \qquad \text{(III.1)}$$

where:

I is the Interception $[mm/month]$
P is the Precipitation $[mm/month]$
rd is the number of rainy days $[days/month]$
LAI is the Leaf-Area-Index $[-]$
t is the month $[-]$

Transpiration

Monthly Net-Primary-Production was downloaded from WaPOR Level 2 products to calculate monthly Net-Dry-Mass:

$$NDM_t = a \cdot 22.222 \cdot NPP_t \qquad \text{(III.2)}$$

where:

NPP_t is the monthly Net-Primary-Production [gC/m^2/month]
NDM_t is the Net-Dry-Matter [kg/ha/month]
a equals to 1 for C3 crops and 1.8 for C4 crops

The average and maximum monthly Net-Dry-Mass were then calculated following the formulas:

$$\overline{NDM}_M = \frac{1}{n} \cdot \sum_{t_M=M}^{n} NDM_t \qquad \text{(III.3)}$$

where:

$\overline{NDM}$ is the average monthly NDM [kg/ha/month]
NDM is the Net-Dry-Matter [kg/ha/month]
M is the month, $M = [1,\ldots,12]$ $[-]$
n is the total number of available dates for month M $[-]$

$$\sigma_M = \sqrt{\frac{1}{n} \cdot \sum_{t_M=M}^{n} (NDM_t - \overline{NDM}_M)^2} \qquad \text{(III.4)}$$

where:

$\sigma_{M,i,j}$ is the standard deviation of the NDM [kg/ha/month]

$$NDM_{max,M} = \overline{NDM}_M + 2 \cdot \sigma_M \tag{III.5}$$

where:

NDM_{max} is the per pixel monthly maximum NDM [kg/ha/month]

$$NDM_{MAX,M,i,j} = \max(\{NDM_{max,M,I,J}: I = i - k, \ldots, i, \ldots, i + k, J = j - k, \ldots, j, \ldots, j + k\}) \tag{III.6}$$

where:

NDM_{MAX} is the regional monthly maximum NDM [kg/ha/month]

I is a range of columns around i [−]

J is a range of rows around j [−]

k is the length of the ranges of I and J [−]

Based on the linear relation between biomass production and transpiration, as described by Steduto et al. (2007), transpiration was computed as a function of Net-Dry-Mass and maximum transpiration, which is 0.95 (AETI- I):

$$T_t = \min \begin{cases} \frac{NDM_t}{NDM_{MAX,t_M}} \cdot (AETI_t - I_t) \\ 0.95 \cdot (AETI_t - I_t) \end{cases} \tag{III.7}$$

where:

T is the Transpiration $[mm/month]$

$AETI$ is the Actual Evapotranspiration and Interception $[mm/month]$

Evaporation

Finally, evaporation was computed as the residual of AETI.

$$E_t = AETI_t - I_t - T_t \tag{III.8}$$

where:

E is the Evaporation $[mm/month]$

The original NDM_{MAX} per month was calculated as:

$$NDM_{MAX,M} = \frac{0.95}{\max(\overline{NDM}_M)} \tag{III.9}$$

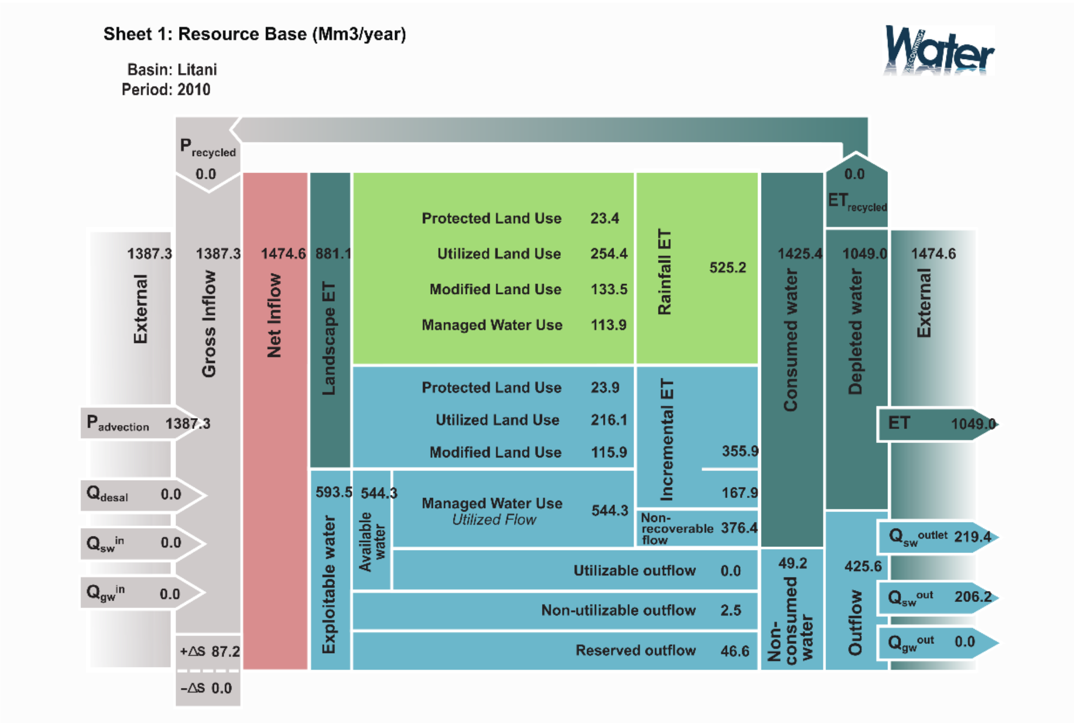
References

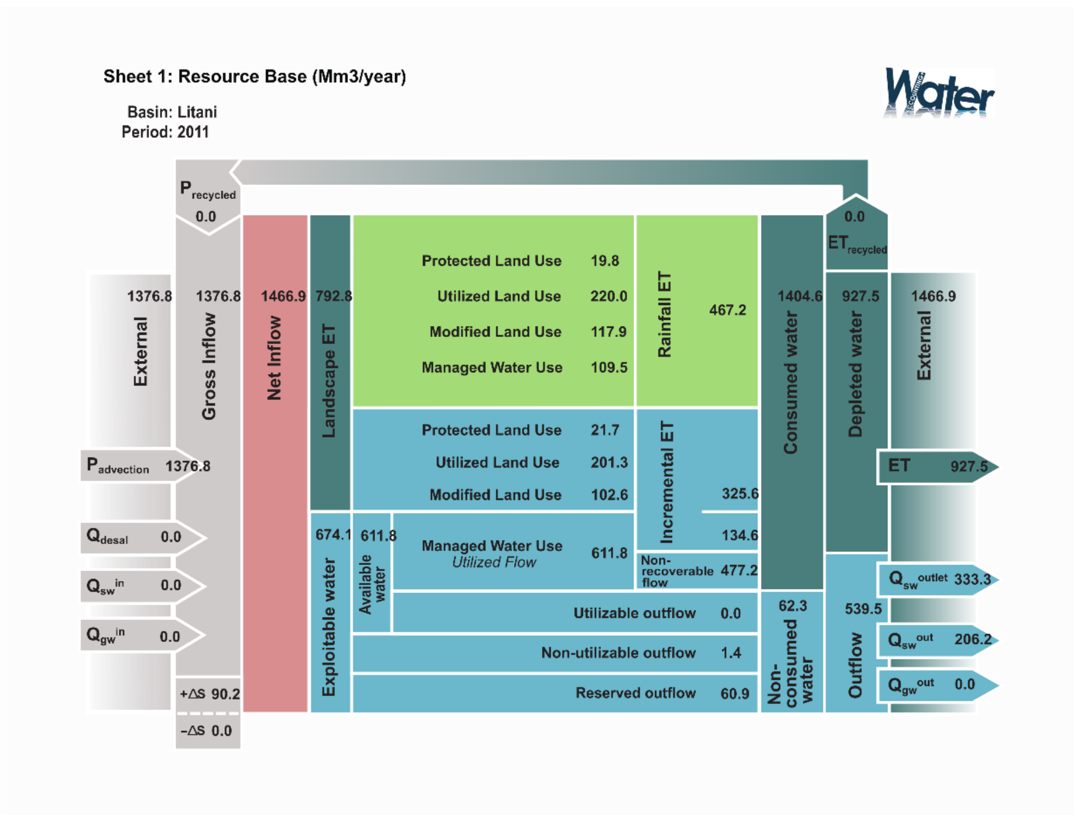
Braden, H., 1985. Ein Energiehaushalts- und Verdunstungsmodell for Wasser und Stoffhaushaltsuntersuchungen landwirtschaftlich genutzer Einzugsgebiete. Mittelungen Deutsche Bodenkundliche Geselschaft, 42, 294-299.

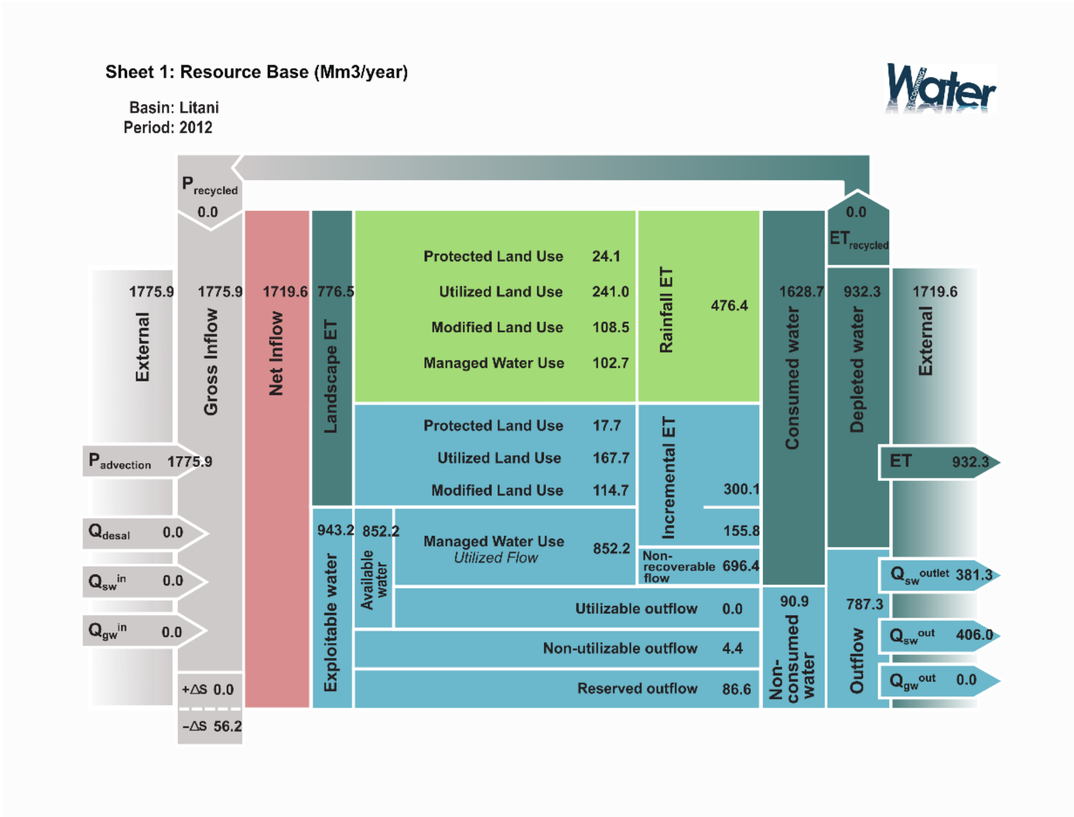
Kroes, J.G., Groenendijk, P., Hendriks, R.F.A., Jacobs, C.M.J., 2009. SWAP version 3.2 Theory description and user manual.

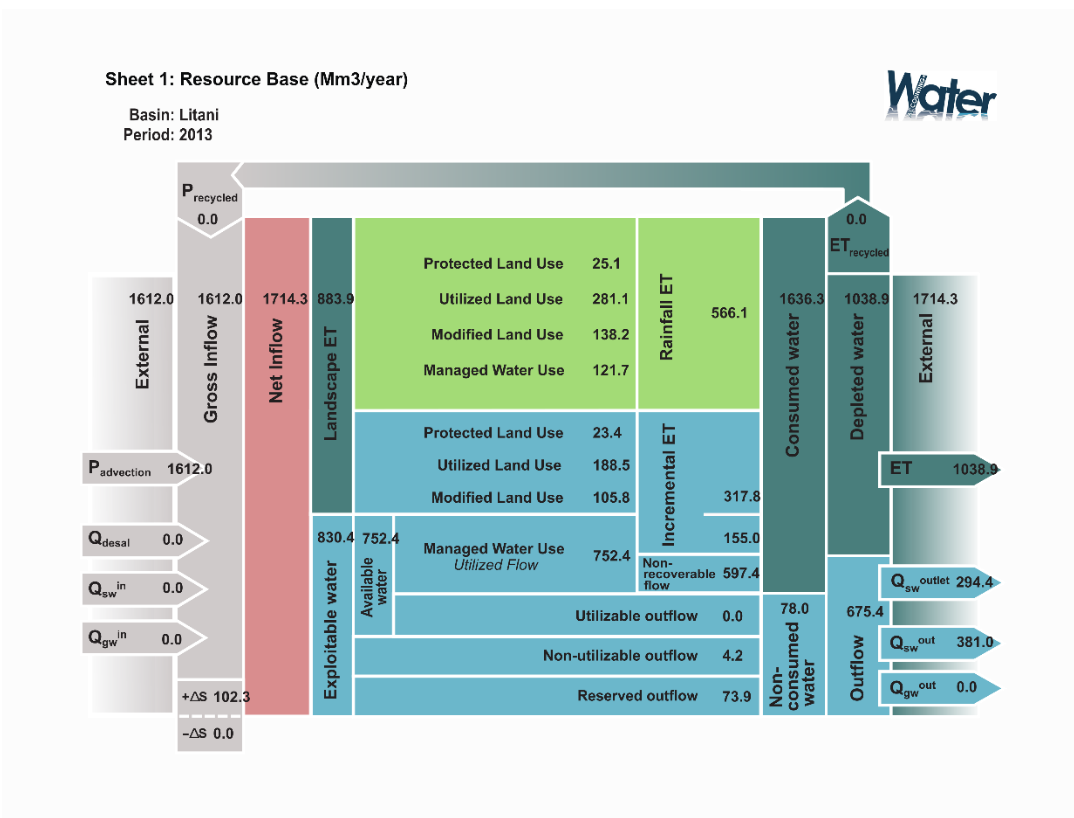
Von Hoyningen-Hüne, J., 1983. Die Interception des Niederschlags in landwirtschaftlichen Beständen. Schriftenreihe des DVWK 57, 1-53

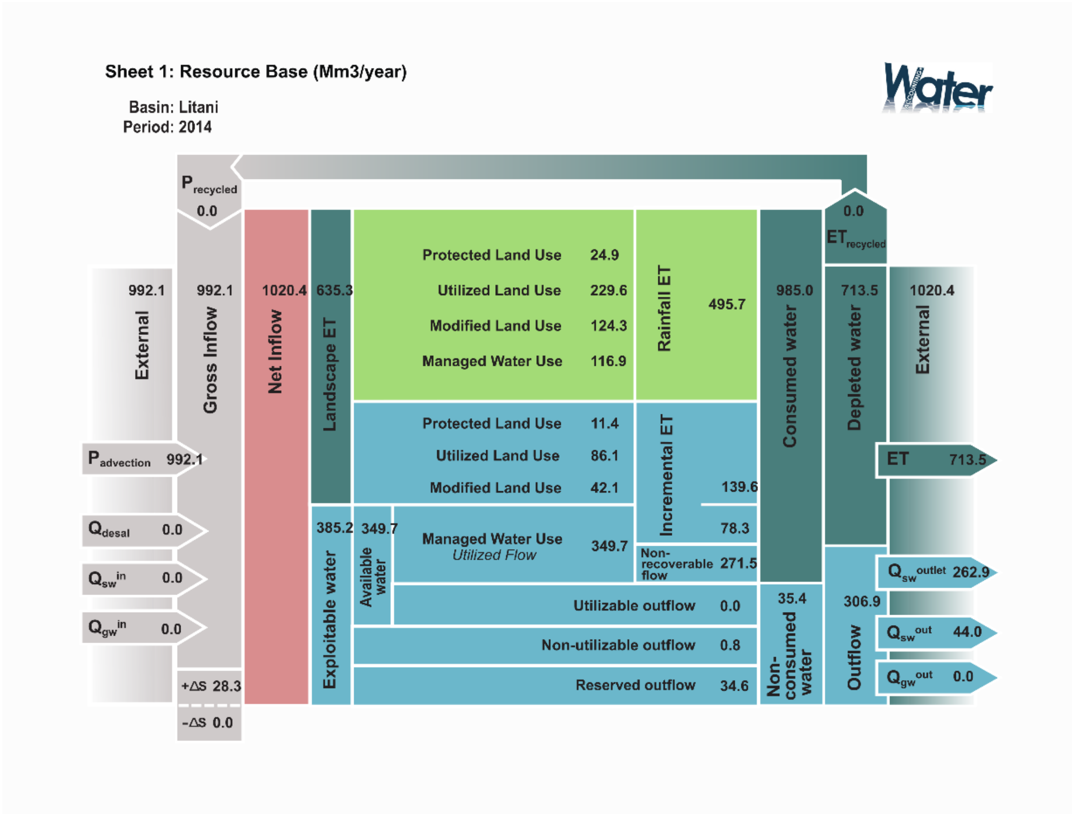
Annex IV: Resource base sheets of all the years

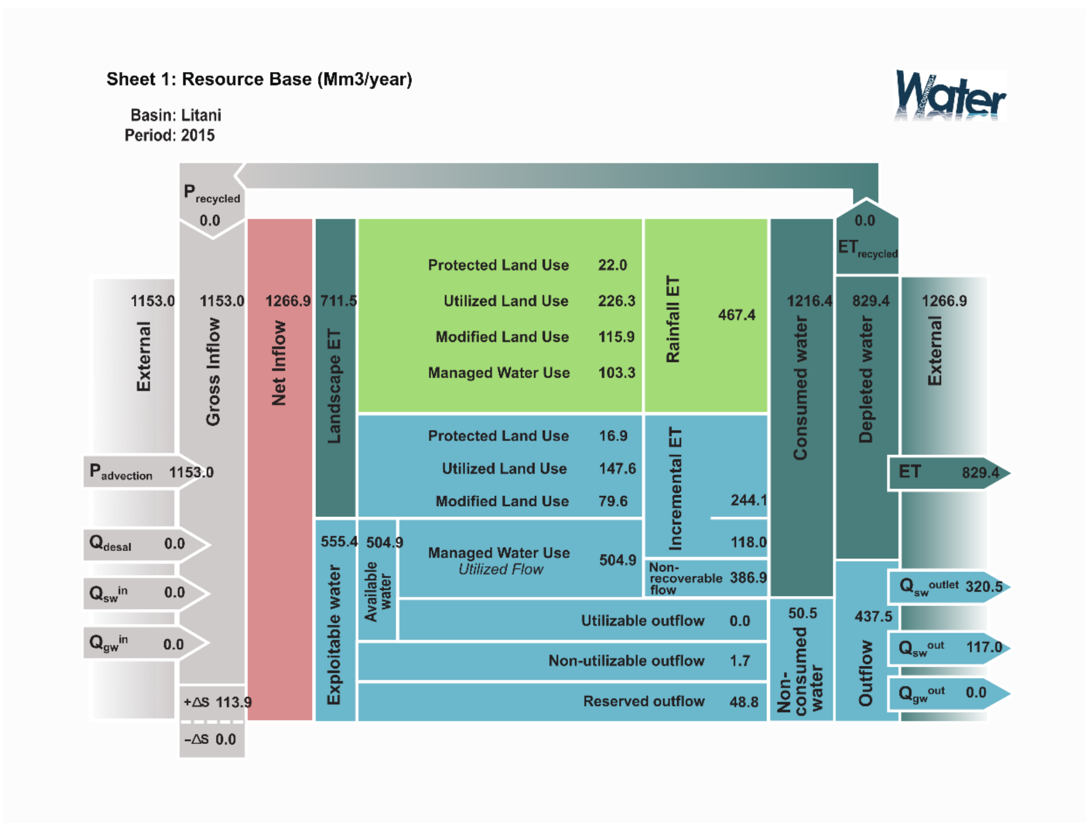


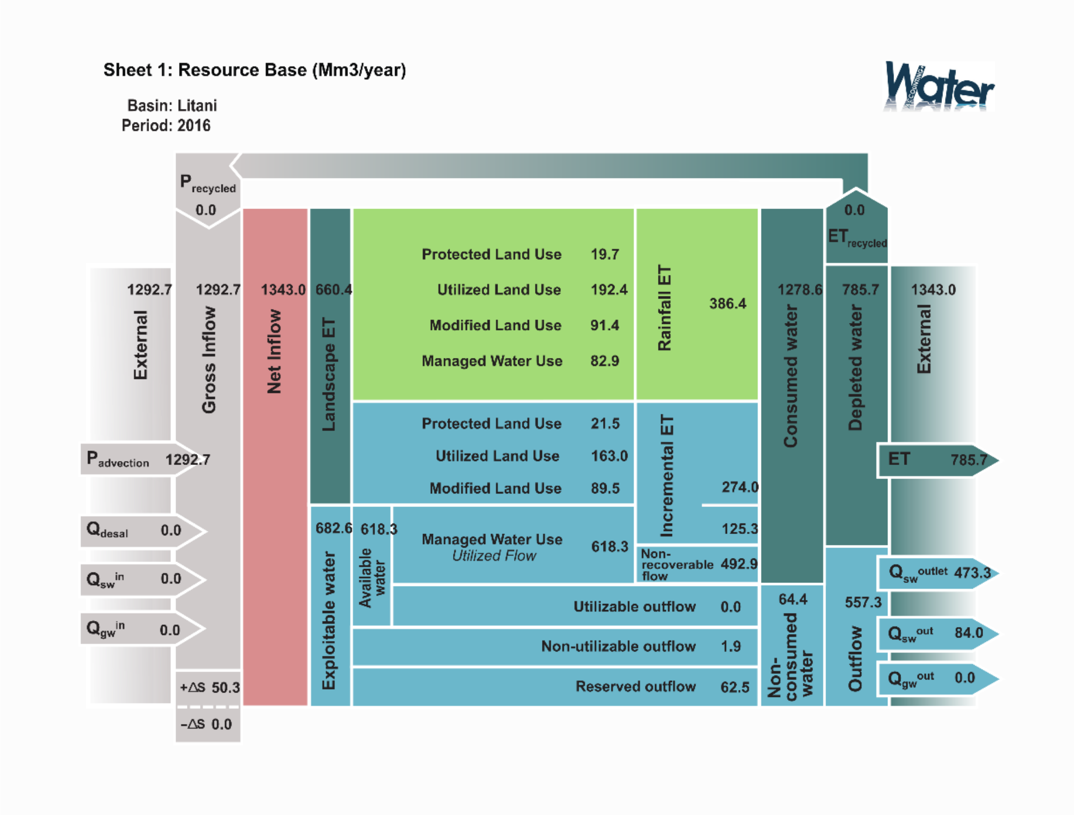



Sheet 1: Resource Base (Mm3/year)
Basin: Litani
Period: 2012
Water
P recycled 0.0
External 1775.9
Gross Inflow 1775.9
Net Inflow 1719.6
Landscape ET 776.5
Protected Land Use 24.1
Utilized Land Use 241.0
Modified Land Use 108.5
Managed Water Use 102.7
Rainfall ET 476.4
Protected Land Use 17.7
Utilized Land Use 167.7
Modified Land Use 114.7
Incremental ET 300.1
155.8
Managed Water Use
Utilized Flow
852.2
Non-recoverable flow 696.4
P advection 1775.9
Q desal 0.0
Q sw in 0.0
Q gw in 0.0
943.2
852.2
Exploitable water
Available water
Utilizable outflow 0.0
Non-utilizable outflow 4.4
Reserved outflow 86.6
+ΔS 0.0
-ΔS 56.2
Consumed water 1628.7
0.0
ET recycled
Depleted water 932.3
External 1719.6
ET 932.3
90.9
Non-consumed water
787.3
Outflow
Q sw outlet 381.3
Q sw out 406.0
Q gw out 0.0


Sheet 1: Resource Base (Mm3/year)
Basin: Litani
Period: 2013
Water
P recycled 0.0
External 1612.0
Gross Inflow 1612.0
Net Inflow 1714.3
Landscape ET 883.9
Protected Land Use 25.1
Utilized Land Use 281.1
Modified Land Use 138.2
Managed Water Use 121.7
Rainfall ET 566.1
Protected Land Use 23.4
Utilized Land Use 188.5
Modified Land Use 105.8
Incremental ET 317.8
155.0
Managed Water Use
Utilized Flow
752.4
Non-recoverable flow 597.4
P advection 1612.0
Q desal 0.0
Q sw in 0.0
Q gw in 0.0
830.4
752.4
Exploitable water
Available water
Utilizable outflow 0.0
Non-utilizable outflow 4.2
Reserved outflow 73.9
+ΔS 102.3
-ΔS 0.0
Consumed water 1636.3
0.0
ET recycled
Depleted water 1038.9
External 1714.3
ET 1038.9
78.0
Non-consumed water
675.4
Outflow
Q sw outlet 294.4
Q sw out 381.0
Q gw out 0.0


Sheet 1: Resource Base (Mm3/year)
Water
Basin: Litani
Period: 2014
$P_{recycled}$ 0.0
0.0
$ET_{recycled}$
External 992.1
Gross Inflow 992.1
Net Inflow 1020.4
Landscape ET 635.3
Protected Land Use 24.9
Utilized Land Use 229.6
Modified Land Use 124.3
Managed Water Use 116.9
Rainfall ET 495.7
Consumed water 985.0
Depleted water 713.5
External 1020.4
$P_{advection}$ 992.1
Protected Land Use 11.4
Utilized Land Use 86.1
Modified Land Use 42.1
Incremental ET 139.6
78.3
ET 713.5
Q_{desal} 0.0
385.2
349.7
Exploitable water
Available water
Managed Water Use
Utilized Flow
349.7
Non-recoverable flow 271.5
Q_{sw}^{in} 0.0
Q_{sw}^{outlet} 262.9
Utilizable outflow 0.0
35.4
306.9
Q_{gw}^{in} 0.0
Non-utilizable outflow 0.8
Q_{sw}^{out} 44.0
Reserved outflow 34.6
Non-consumed water
Outflow
Q_{gw}^{out} 0.0
+ΔS 28.3
-ΔS 0.0


Sheet 1: Resource Base (Mm3/year)
Water
Basin: Litani
Period: 2015
$P_{recycled}$ 0.0
0.0
$ET_{recycled}$
External 1153.0
Gross Inflow 1153.0
Net Inflow 1266.9
Landscape ET 711.5
Protected Land Use 22.0
Utilized Land Use 226.3
Modified Land Use 115.9
Managed Water Use 103.3
Rainfall ET 467.4
Consumed water 1216.4
Depleted water 829.4
External 1266.9
$P_{advection}$ 1153.0
Protected Land Use 16.9
Utilized Land Use 147.6
Modified Land Use 79.6
Incremental ET 244.1
118.0
ET 829.4
Q_{desal} 0.0
555.4
504.9
Exploitable water
Available water
Managed Water Use
Utilized Flow
504.9
Non-recoverable flow 386.9
Q_{sw}^{in} 0.0
Q_{sw}^{outlet} 320.5
Utilizable outflow 0.0
50.5
437.5
Q_{gw}^{in} 0.0
Non-utilizable outflow 1.7
Q_{sw}^{out} 117.0
Reserved outflow 48.8
Non-consumed water
Outflow
Q_{gw}^{out} 0.0
+ΔS 113.9
-ΔS 0.0



Sheet 1: Resource Base (Mm3/year)
Basin: Litani
Period: 2016
Water
P recycled 0.0
0.0
ET recycled
External 1292.7
Gross Inflow 1292.7
Net Inflow 1343.0
Landscape ET 660.4
Protected Land Use 19.7
Utilized Land Use 192.4
Modified Land Use 91.4
Managed Water Use 82.9
Rainfall ET 386.4
Consumed water 1278.6
Depleted water 785.7
External 1343.0
Protected Land Use 21.5
Utilized Land Use 163.0
Modified Land Use 89.5
Incremental ET 274.0
P advection 1292.7
ET 785.7
Q desal 0.0
Exploitable water 682.6
Available water 618.3
Managed Water Use Utilized Flow 618.3
125.3
Non-recoverable flow 492.9
Q sw outlet 473.3
Q sw in 0.0
Utilizable outflow 0.0
64.4
557.3
Q gw in 0.0
Non-utilizable outflow 1.9
Non-consumed water
Outflow
Q sw out 84.0
+ΔS 50.3
Reserved outflow 62.5
Q gw out 0.0
-ΔS 0.0

Water Accounting in the Litani River Basin

This report provides the water accounting study for Litani River basin in Lebanon carried out by IHE Delft using the Water Productivity (WaPOR) data portal of the Food and Agricultural Organization (FAO). The Litani River basin is one of the key river basins in Lebanon and it is experiencing water scarcity with the annual renewable water resources being 606.9 Mm^3/yr. With an estimated population of 375,000 in 2010 and doubled by 2016 due to the Syrian refugee crisis, the total per capita water availability is around 800 m3/cap/year indicating water shortage. Increasing challenges such as growing population, climate change, groundwater over-exploitation and inter-basin transfers have put the available water resources in the basin under stress. The completeness and quality of the hydro-meteorological records are insufficient to draw an appropriate picture of the water resources conditions. However, the Water Accounting Plus (WA+) system designed by IHE Delft with its partners FAO and IWMI has been applied to gain full insights into the state of the water resources in the basin for the period 2010 to 2016. The WA+ framework is a reporting mechanism for water flows, fluxes and stocks that are summarized by means of WA+ sheets. The role of land use and land cover on producing and consuming water is described explicitly.

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