Report on future scenarios of water availability and demand in the Al Ostuan River Basin, including the performance of different demand management measures and the results of an optimisation process

Consultancy to Facilitate Integrated Water Resource Management (IWRM) in the Al Ostuan Basin

Ref:
PC/11DBH/90D/DTC/B
RT/23-05-2019/001

Date: March 2021

This page is intentionally left blank

ACTED	**Consultancy to Facilitate Integrated Water Resource Management (IWRM) in the Al Ostuan Basin**

Task 4: Development of future water availability and demand scenarios, in the water resources management WEAP model for the Nahr Al Ostuan River Basin, simulation and assessment of the performance of different demand management measures (in WEAP), and selection of an optimal mix based on an optimization process

LDK CONSULTANTS	UNIVERSITY OF BALAMAND
LDK for Management Consulting LLC **LDK Consultants Engineers and Planners SA**	**University of Balamand**

With funding from:	Co-Funded by the European Union بتمويل مشترك من الاتحاد الأوروبي	RÉGION SUD PROVENCE ALPES CÔTE D'AZUR
Date:	31 / 03 / 2021	
Version:	02	
Description:	This report presents the future scenarios for water balance, water availability and demand in the Al Ostuan River Basin in Lebanon, as simulated in the WEAP Al Ostuan Water Resources Management Model, as well as the performance of different demand management measures (also simulated within the WEAP model) and the methodology and results of the optimization process applied for the selection of the optimal mix of measures.	
Status:	Final submittal	

	Name, Company	Position
Prepared by:	Dr. Maggie Kossida Dr. Ioannis Tsoukalas	Senior Consultant, Water Resources Engineer, Technical Project Manager Senior Consultant, Water Resources Engineer
Checked by:	Mr. Costis Nikolopoulos	Head of LDK Group Environment & Water Division General Manager LDK Middle East Region
Approved by:	Mrs. Ciara Noone	Project Manager, ACTED

How to Reference this publication:

Kossida, M., Tsoukalas, I. 2021. Report on future scenarios of water availability and demand in the Al Ostuan River Basin, including the performance of different demand management measures and the results of an optimisation process. Project Deliverable No. 4, Consultancy to Facilitate Integrated Water Resource Management (IWRM) in the Al Ostuan Basin, ACTED, Lebanon.

Acknowledgements:

The authors would like to thank the Lebanese Ministry of Energy and Water (MoEW) for providing valuable information, and in particular Dr. Fadi Georges Comair, Director General of Hydraulic and Electric Resources, MoEW, and Mrs. Mona Fakih, Director of Water, MoEW, SWIM Focal Point (monafakih@hotmail.com) for her important contribution and excellent collaboration.

Additionally, the authors would like to thank Mr. Gaby Nasr, Director of Exploitation, NLWE, Mr. Georges Moussa, NLWE – Qoubayat Branch, and Mr. Youssef Karam, Head of Water, Wastewater and Infrastructure Department CDR for providing information and valuable expert knowledge.

This page is intentionally left blank

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

GW	Groundwater
IWRM	Integrated Water Resources Management
km^2	Square kilometer
m^3	cubic meter
Mm^3	Million cubic meters
mio	Million
MEW	Ministry of Energy and Water
NLWE	North Lebanon Water Establishment
ORB	Al Ostuan River Basin
RB	River Basin
SW	Surface Water
WRMM	Water Resources Management Model
WWT	Wastewater Treatment
WWTP	Wastewater Treatment Plant

This page is intentionally left blank

1 INTRODUCTION

A “Demand Management Policy” is typical based on a bundle of technological, management, regulatory and educational measures which promote water saving and efficiency gains in different economic sectors (urban, agricultural, industrial sectors, etc.) while they can be combined with measures to increase the water supply (e.g. through water reuse, rainwater harvesting, etc.) which do not cause adverse environmental impacts.

Evidence on the impacts of applied response measures is generally limited and no concrete conclusions can be drawn on their effectiveness (Schmidt and Benitez, 2012). It is thus important to simulate response measures (and a bundle of them) against the physical system, in order to test their application and assess their true potential under specific conditions and constraints. The process of testing response measures can be underpinned by their simulation in a physical-based distributed water resources management model (WRMM), which can capture all the salient features of water availability and demand per source and user (Kossida, 2015). To ex-ante assess the impact of these measures, the cost-effectiveness function of water saved (or water gained) versus investment cost must be investigated for each measure and mix of measures. Each measure comes with a potential water saving (or water gain) and an associated investment cost. In parallel, additional socio-economic factors come into interplay, such as the readiness of the technological solution, the social acceptability, the equitability, any constraints related to the implementation of the measures, etc. which can facilitate or impede the uptake and effectiveness of the measure.

The current report investigates a bundle of measures applicable for the domestic and agricultural sectors which aim at introducing water savings (and thus reducing the water demand) or increasing the water supply (i.e. the water available for use) in the Al Ostuan River Basin in Lebanon. These measures have been assessed for their cost-effectiveness function, and have then been simulated through the water resources management model of the Al Ostuan River Basin developed in WEAP21 to further assess their effectiveness against this physical based model. In order to simulate them in WEAP21 new user-defined parameters have been introduced in the model. The resulting water savings and/or water gains, when applying the measures, have been evaluated for the baseline 2003-2018 and for the future 17-year period (2019-2035) across the various demand sites (urban and agriculture nodes) of the model. The future conditions have been modeled assuming an annual population increase, an annual increase in the future domestic agricultural water use rates, and a future climate based on stochastic simulation of the past 2003-2018 climatic variables.

The selection of the measures to be simulated in the Al Ostuan River Basin in order to assess their impact on the water balance of the basin and on the potential reduction of the unmet demand has been done through consultation with relevant stakeholders (the Ministry of Energy and Water, the Ministry of Environment (MEW), the Ministry of Agriculture (MoA), the North Lebanon Water Establishment (NLWE), the Municipalities located within the basin, NGOs).

2 BACKGROUND AND OBJECTIVES

2.1 STATE OF WATER RESOURCES IN THE AL OSTUAN RIVER BASIN: THE CURRENT BASELINE

The Al Ostuan River Basin is located in the Akkar casa in Northern Lebanon and flows from the east (its headwaters originate in Akkar Al Atika and Qoubayat) to the Mediterranean Sea in the Sahel area, with a length of 44 km (the main river). The river's average flow (based on records from 2002-2012) at Embouchure station (close to river's outlet) is about 2.3 m^3/sec. The Al Ostuan River and its 8 sub-catchments drain in total about 145 km^2, with an annual runoff volume of 47 million m^3. A total of 51 villages are located (as a whole or part of) within the Al Ostuan River Basin (ORB) boundaries, with a corresponding population of 105,000 people who rely in the Al Ostuan River Basin water resources . Agriculture is an important activity in the area. The main cultivated crops are field crops in terraces (vegetables, legumes), fruit trees, and olives. The areas under irrigation schemes (~ 30% of the total agricultural area in the basin) are extended in the western and northeastern parts of the basin.

Currently the river suffers from many issues due to its mismanagement. Public water supply is provided by the North Lebanon Water Establishment (NLWE) Qoubayat and Halba Branches, yet it is not covering all the villages in the Al Ostuan River Basin. As a result, a high number of private wells are used in the basin, with no public control over the abstracted volumes, which has led to environmental impacts, such as the degradation of the groundwater resources and declining groundwater levels (SISSAF, 2017). The lack of Wastewater Treatment Plants (WWTP) and the direct discharge of urban wastewater into the river also led to high pollution levels in the river and caused severe environmental damage. Integrated water resources management plans or other policy instruments are lacking, and management is not based on pro-active and preparedness approaches.

The state of the water resources in the Al Ostuan River Basin (ORB) has been assessed for the baseline period 2003-2018, based on the outputs of a detailed Water Resources Management Model (WRMM) developed in WEAP21 software for the Al Ostuan River Bain. This baseline assessment investigated the water availability, water demand, water supply required, and unmet demand (per sector) in the basin during the last 16 years, as well as the current state of surface water pollution based on a recently conducted field survey and sampling.

- **Water availability and water supply:**

The primary water demands in the Al Ostuan basin are for urban and irrigation purposes, accounting for ~35% and ~62% respectively. The urban water demand sums up to ~7 million m^3/year (or 183 lt/cap/day) of which 6.2 million m^3/year are for domestic purposes and 0.8 for industrial purposes, while the irrigation water demand is 11 million m^3/year (average of the 2003-2018 period). The irrigation demand is highly dependent on the precipitation and thus varies across the years from 8 to 13 million m^3/year: during the wet years a larger part of the irrigation needs are covered by precipitation (rainfed) and thus the irrigation demand is lower, as opposed to the drier years where the irrigation water demand is higher. The urban demand is mainly for domestic purposes (90%) and also includes a small share (~10%) for industrial purposes. The water supply requirements are in fact higher than the actual water demand due to network losses and irrigation practices' efficiency (Comair, 2007; NWSS 2020). The losses in the urban water supply network are 30% (SISSAF, 2017; communication with NLWE; NWSS 2020), while the overall combined irrigation efficiency has been estimated at 60% since most irrigation networks are local and individual (according to multiple sources). The efficiency of the collective networks is very low, around 45%, since these are dominantly open channels, while furrow (surface) irrigation is extensively used.

Based on the model results, the balance between demand and availability is negative, resulting in unmet demand in all the 8 sub-catchments of the Al Ostuan River Basin every year. The total annual unmet demand in the Al Ostuan River Basin is, on average, 17 million m^3/year over the 16-year period 2003-2018, and has reached up to 22 million m^3 (in 2010). This basically means that, on average, only about 38% of the water needs are covered by the water availability and supply in Al Ostuan. This unmet demand is mainly attributed to the irrigation: ~13.8 million m^3/year on average, with maximum 16-17.5 million m^3 observed in 2010, 2016 and 2017. Nevertheless, the domestic/ urban sector is also highly affected: the average urban unmet demand is ~3.5 million m^3/year (or 9,620 m3/day, or 92 lt/cap/day), with maximum ~5 million m^3 observed in 2016, 2010, 2017 and 2008.

The villages with the higher urban unmet demand are El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire, Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh (**Figure 2-1**). All these villages are supplied by the NLWE Qoubayat Branch (system of Qoubayat wells 1/3, 2/3, 3/3) Daouce and Charbila lines. It is concluded that the urban water supply provided by the Qoubayat wells cannot meet all the current needs of these villages. The above findings are aligned with the 2020 NWSS Update (NWSS 2020, Volume IV, Appendix IV C5 – Water Balances, pages IV C127 – IV C 148). The calculated balances in the NWSS 2020 have been found negative within the Qobayate distribution systems No. 22 (Charbila, Ain El-Zeit, El-Msalle, Kefr El-Ftouh), No. 23-24-12 (El-Daghle, Kherbet Daoud, El-Bire), No. 17 (El-Kouachra) and No. 13 (Daouce et Baghdadi, Denke et El-Amriyeh).

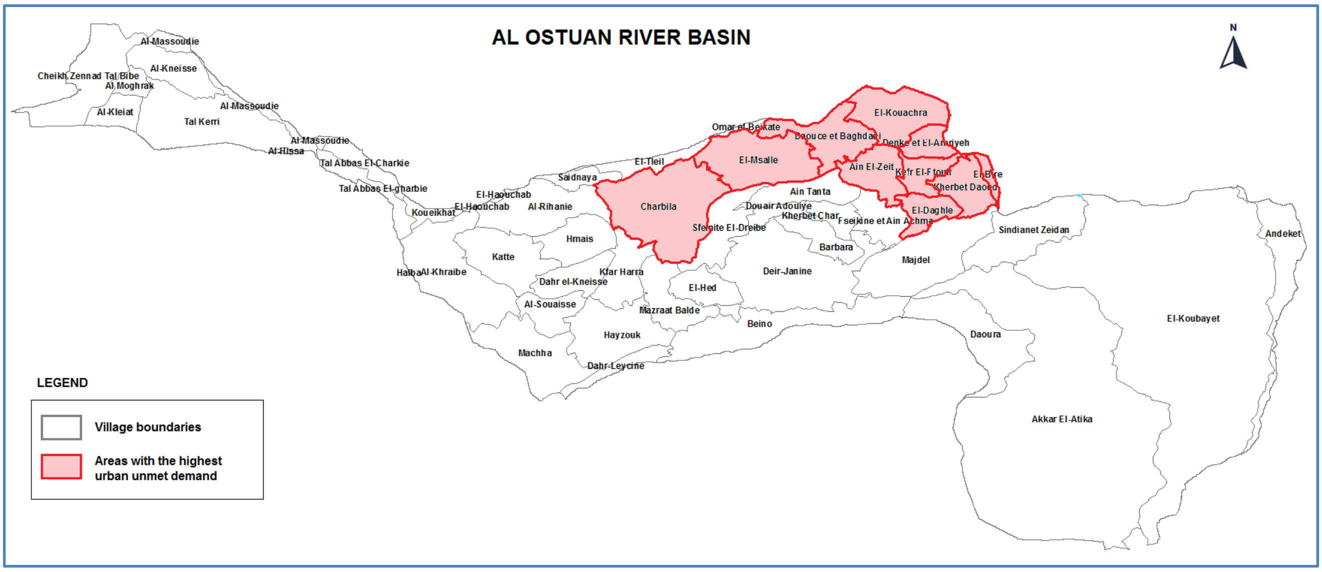


Figure 2-1: Villages with the highest Urban unmet demand (mio m³) per year (from 2003-2018) the Al Ostuan River Basin

The agricultural areas with the highest unmet demand are located in the northern part of the Al Ostuan basin, where extensive irrigation areas of field crops, citrus fruit trees, and olives cover approximately 21 km². The available water cannot cover all these irrigation needs. The farms affected are within the villages of Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie, Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh, El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire, Katte, Al-Rihanie, El-Tleil, Omar el-Beikate, El-Haouchab, Hmais, Saidnaya, Al-Khraibe (**Figure 2-2**).

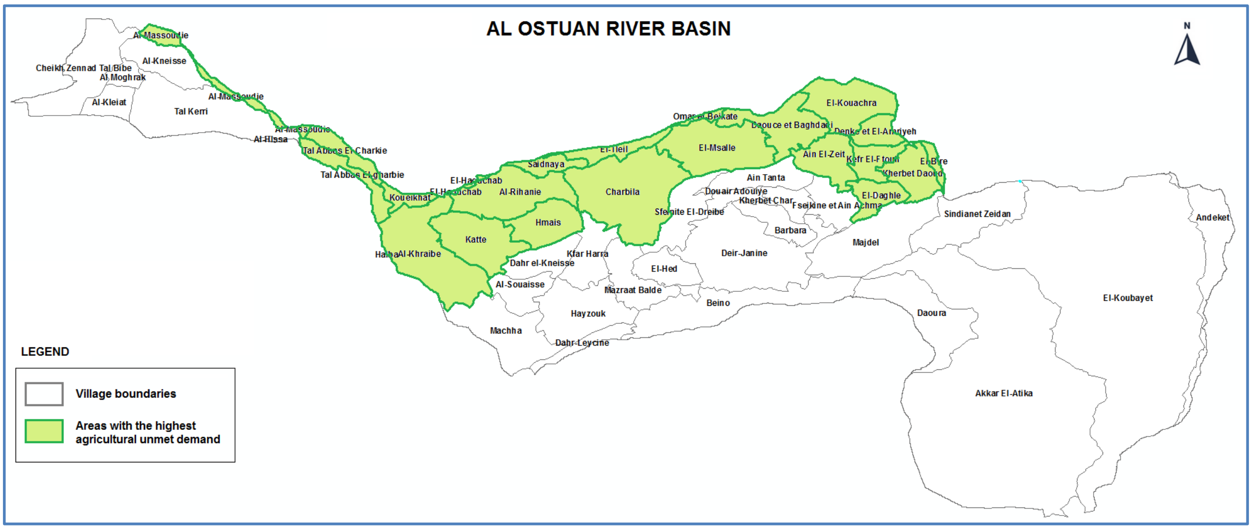


Figure 2-2: Villages with the highest Agricultural unmet demand (mio m³) per year (from 2003-2018) the Al Ostuan River Basin

The Reliability of the system in supplying the requested demand ranges among the uses. Reliability is defined as the percent of the timesteps in which a demand site's demand was fully satisfied. For example, if a demand site has unmet demands in 6 months out of a 10 years, the reliability would be (10 * 12 - 6) / (10 * 12) = 95%. As domestic use is priority 1, the water allocation to this use has an overall higher reliability (60% on average across all the urban demand sites) comparing to the reliability of the irrigation (58% on average across all the agricultural demand sites).

The percent of the time that the urban water demands are fully satisfied (i.e. the so called "water supply reliability") ranges from as low as ~29% in some sites (mainly in the west and southwest areas: Dahr-Leycine, Machha, Hayzouk, Al-Souaisse, Dahr el-Kneisse, Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie), to 100% in others (mainly in the east and central areas: Akkar El-Atika, El-Koubayet, Majdel, Ain Tanta). Overall, within the urban sector, 62% of the users have very low reliability (i.e. <40% reliability) of water supply, while only 38% have very high (i.e. >95% reliability) as summarized in Table 2-1 below.

The reliability in the irrigation water supply ranges from as low as ~22% in some sites (Al-Khraibe, Koueikhat, Tal Abbas El-Charkie, Tal Abbas El-Gharbie, Al-Massoudie, Al-Kleiat, Cheikh Zennad Tal

Bibe, Al-Kneisse, Al Moghrak, Tal Kerri, Al-Hissa, Al-Massoudie), to 100% in others (Ain Tanta, Douair Adouiye, El-Hed, Deir-Janine, Sfeinite El-Dreibe, Kherbet Char, Fseikine et Ain Achma, Barbara, Mazraat Balbe, Beino, Majdel, Andeket, Akkar El-Atika, El-Koubayet). Overall, within the agricultural sector, 50% of the users have very low reliability of water supply (i.e. <40% reliability), 12.5% have low (i.e. 40-60% reliability), while only 37.5% have very high (i.e. >95% reliability) as summarized in **Table 2-1** below.

Table 2-1: Percent (%) of user for each use category (domestic, irrigation) that fall under the 5 reliability classes (very low, low, medium, high, very high) for the 16-year period 2003-2018

Reliability = Likelihood that demand is met	Urban users	Irrigation users
Very High (>95%)	38%	37.50%
High (80-95%)	0%	0%
Medium (60-80%)	0%	0%
Low (40-60%)	0%	12.5%
Very Low (<40%)	62%	50.00%

Concluding the baseline assessment of water resources' availability in the Al Ostuan River Basin for the period 2003-2018, it is observed that the current water supply cannot meet the water demand in the Al Ostuan River Basin, resulting in unmet demands in both the urban and agricultural sector every year. The "exploitable" precipitation in the basin (i.e. total precipitation minus evapotranspiration) is on an annual average basis about 61 mio m^3, of which ~62 mio m^3 becomes surface runoff and the remaining 9 mio m^3 infiltrate to the groundwater. The supply required (including the 30% losses in the urban supply network and 40% in irrigation) on the other hand is ~28 mio m^3 on an annual average basis. This means that the "exploitable" precipitation could in fact cover all demands if adequately captured and exploited, and still leave an adequate volume for the environmental water requirements. Yet, the current supply delivered is only ~10.6 mio m^3 (and fails to cover all demands) simply because only the groundwater is exploited in the basin. The surface water of the river is too polluted to be exploited, especially for drinking purposes. It becomes thus clear, that the water pollution of the river, highly attributed to the direct disposal of sewage waste in the river, impedes the exploitation of the surface water.

- **Water pollution:**

There are multiple sources for the water contamination in the Al Ostuan River Basin, which has been identified as one of the polluted rivers in Akkar region in Northern Lebanon. The direct discharge of untreated wastewater from municipal areas and households has been identified as one of the major causes of environmental pollution. Moreover, outflows from the agricultural and farmlands to the Ostuan River or its tributaries can also be observed and are correlated particularly to the contamination of the water with heavy metals. The lack of correct public networks and waste water treatment plants increase the rate of pollution and contamination in the Al Ostuan River Basin since the untreated waste water is directly released to the river. Thus, the communities living in the Ostuan River basin consider improving the health of the river in parallel to addressing water scarcity as a priority since it directly impacts the health and wellbeing of the communities, the local agriculture, and the tourism sector.

To assess the water quality of the river, two water quality sampling campaign has been conducted in October 2019 (dry season) and February 2021 (wet season), where samples from 17 sites were collected and analyzed in the laboratory of the University of Balamand. These sites were selected to cover the upper area of the river (headwaters), the middle of the river where it is mostly populated (more condensed sampling), as well as the downstream area, near the outflow, where uncontrolled untreated wastewater accumulates.

It has been observed that the physical parameters (temperature, pH, electrical conductivity) were at acceptable levels (lower than the values in the referred standards: Libnor Water Standards). The water samples analysed during the wet period showed higher alkalinity compared to the dry season with pH value ranging between 7.46 and 8.50. As for the chemical parameters, values related to the basic water quality, such as the anions and cations, were all seen to be below the water norms, with the exception of Nitrate and Nitrite (which had high values).These high values of Nitrate and Nitrite are due to the agricultural activities and the uncontrolled use of fertilizers that is related to the crops abundance. Another major factor that influences the high amounts of Nitrate and Nitrite is the lack of wastewater treatment plants that increases their content in surface waters. Finally, the microbiological parameters (fecal coliforms and E.coli) were all found to be above the acceptable limits, since wastewater effluents are discharged in the river, as well as uncontrolled agricultural runoff. **Table 2-2** summarizes the water quality testing findings and the possible sources of pollution, while

Table 2-3 provides an overview of the water pollution (as assessed by the water quality sampling and analysis).

Table 2-2: Possible sources of pollution for the sampled locations

Sampling Sites	Parameters above the Maximum Contaminant Level (MCL)	Possible Source of Pollution
S14,S16, S17	BOD5, High Ecoli, Temperature	Untreated municipal and domestic waste Open dumping
S15	Ecoli, Temperature	
S10	BOD5	
S13	TDS	Leaching of soil Agricultural and urban runoff Discharge of untreated sewage
S1 to S17	DO, Nitrite, Hg, Pb	Discharge of untreated wastewater Open dumping Animal waste Use of fertilizers and chemicals

Table 2-3: Al Ostuan River Basin Water Pollution Overview

Sampling Site	Village (CAD_Name)	Nearby landmark	Temperature	Conductivity	Salinity	TDS	Fluoride	Chloride	Sulfate	Nitrate	Nitrite	Sodium	Potassium	Magnesium	Calcium	pH	DO	Heavy Metals (Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd)	Heavy Metals (Hg, Pb)	E coli	Fecal	BOD
S1	Akkar El-Aatiqa	Crops or animals all around the area																				
S2	Nabaa El Chouh El Ali	Green Area																				
S3	Nabaa El Chouh El Wati	Canal																				
S4	Nabaa El Jaouz	Chicken breading all around																				
S5	Nabaa El Cheikh Jneid																					
S6	Nabaa Omar Kaylo	Tap/ Origin Ain Tayea																				
S7	Ain I Watyeh	Karst																				
S8	Ain I homsiyeh																					
S9	Ain El Abiad																					
S10	Nabaa Hmadeh																					
S11	Ain I Fouar																					
S12	Nabaa El Qolqas																					
S13	Nabaa El Tine																					
S14	Ain Taqiyeh	Mazeret El Baldeh/ In the middle of the river																				
S15	Nabaa Abou Chawkat																					
S16	Ain El Hajal																					
S17	Ain Taba																					

*Note: *Results based on field sampling and analysis conducted on October 3rd, 2019*
***Red** cells show concentration **above** the limits; **Green** cells show a concentration **below** the limits*

The major sources of water pollution in the Ostuan river basin can be described as follows:

- The lack of urban development planning that increases flash flooding and water
- The lack of Wastewater Treatment Plants (WWTPs)
- The direct disposal of domestic sewage into the river without any treatment from municipal councils & villages located near the river

- The uncontrolled solid waste dumping in the river which increases especially microbiological contamination as well as heavy metals
- The re-surfacing of previously deposited pollutants
- The uncontrolled human activities such as large agricultural activities, local farming, livestock breeding, vehicle washing

In order to have a full assessment of the water quality in the Akkar governorate, a broader surface water quality study of the Ostuan River, with major analysis of fertilizers and pesticides availability in the water, should be performed in the near future.

2.2 OBJECTIVES OF THE EX-ANTE EVALUATION OF DEMAND MANAGEMENT MEASURES

Basic Definitions

Demand management: adoption of interventions and measures (technological, legislative, regulatory, financial, etc.) to achieve efficient water use by all sectors of the community (urban/ domestic, agricultural, industrial, tourism, etc.)

Demand reduction/ water saving measures: Measures targeting to reduce demand and/or introduce water conservation *[For example: reduce leakage, install water saving fixtures, increase irrigation conveyance and field application efficiency, create incentives, water tariffs, water markets, taxes, etc.]*

Increase supply measures: Measures targeting to increase water supply and the water available for use. *[For example: greywater and wastewater reuse, water recycling, desalination, rainwater and stormwater harvesting, natural water retention measures].* Caution to potential adverse environmental impacts is important.

A "Demand Management Policy" is typical based on a bundle of technological, management, regulatory and educational measures which promote water saving and efficiency gains in different economic sectors (urban, agricultural, industrial sectors, etc.) while they can be combined with measures to increase the water supply (e.g. through water reuse, rainwater harvesting, etc.) which do not cause adverse environmental impacts.

Evidence on the impacts of applied response measures is generally limited and no concrete conclusions can be drawn on their effectiveness (Schmidt and Benitez, 2012). It is thus important to simulate response measures (and a bundle of them) against the physical system, in order to test their application and assess their true potential under specific conditions and constraints. The process of testing response measures can be underpinned by their simulation in a physical-based distributed water resources management model (WRMM), which can capture all the salient features of water availability and demand per source and user (Kossida, 2015). To ex-ante assess the impact of these measures, the cost-effectiveness function of water saved (or water gained) versus investment cost must be investigated for each measure and mix of measures. Each measure comes with a potential water saving (or water gain) and an associated investment cost. In parallel, additional socio-economic factors come into interplay, such as the readiness of the technological solution, the social acceptability, the equitability, any constraints related to the implementation of the measures, etc. which can facilitate or impede the uptake and effectiveness of the measure.

The current report investigates a bundle of measures applicable for the domestic and agricultural sectors which aim at introducing water savings (and thus reducing the water demand) or increasing the water supply (i.e. the water available for use) in the Al Ostuan River Basin in Lebanon. These measures have been assessed for their cost-effectiveness function, and have then been simulated through the water resources management model of the Al Ostuan River Basin developed in WEAP21 to further assess their effectiveness against this physical based model. In order to simulate them in WEAP21 new user-defined parameters have been introduced in the model. The resulting water savings and/or water gains, when applying the measures, have been evaluated for the baseline 2003-2018 and for the future 17-year period (2019-2035) across the various demand sites (urban and agriculture nodes) of the model. The future conditions have been modeled assuming an annual population increase, an annual increase in the future domestic agricultural water use rates, and a future climate based on stochastic simulation of the past 2003-2018 climatic variables.

The selection of the measures to be simulated in the Al Ostuan River Basin in order to assess their impact on the water balance of the basin and on the potential reduction of the unmet demand has been done through consultation with relevant stakeholders (the Ministry of Energy and Water, the Ministry of Environment (MEW), the Ministry of Agriculture (MoA), the North Lebanon Water Establishment (NLLWE), the Municipalities located within the basin, NGOs). As a result of this participatory approach, the following measures have been selected for simulation, which concern the domestic and agricultural sectors, while their scale of application varies from micro to marco-scale (**Table 2-4**). Some of these measures aim at promoting water conservation and introducing water savings (U1, U3, A1), while others at increasing water supply and water supply reliability(U2, U3).

Table 2-4: Selected measures to be simulated in the Al Ostuan River Basin for the domestic and agricultural sectors

Sector / Scale	Domestic/ Urban	Agriculture
Micro-scale	U1. Low water using fixtures and appliances (low flow taps and shower heads, etc.) (combined with awareness campaigns) U2. Rainwater Harvesting (RWH) on-site (houses, hotels, villages) U3. Domestic Greywater Reuse (GWR) on-site (houses and hotels) in villages	A1. Increase the irrigation efficiency through converting to closed pipes and drip irrigation systems at the farm level A2. Detention basins/ Retention ponds/ Community Hill Lakes in agricultural areas

Meso to Macro-scale	U4. Leakage Reduction in the water supply networks through actions to rehabilitate and modernize the operation of water supply networks	

The bundle of measures investigated could benchmark the effect of an “alternative policy” in the Al Ostuan River Basin focused on the reduction of unmet demand across the main economic sectors. It is yet clear, that simulating each and every measure and technology is a time consuming process, while consensus on the optimal mix of measures requires the additional application of an optimization process, explicitly tuned for the specific water system, as well as the involvement of stakeholders, in order to promote ownership and responsibility, and facilitate the internalization of the Programe of Measures (PoM) in development frameworks.

While this ex-ante assessment is deemed important prior to any decision of implementation of the measures, it bears some uncertainties: socio-economic factors always come into interplay, such as the readiness of the technological solution, the social acceptability, the equitability, constraints related to the implementation of the measures, etc., which can facilitate or impede the uptake and effectiveness of the measures. People’s behavior is also an unpredictable factor, thus it is necessary that the measures are combined with campaigns to increase public awareness and motivation. Finally, it is always recommend it to perform ex-post assessments of the measures based on monitored data after their implementation to evaluate their actual effectiveness and redesign or fine-tune them if needed.

3 FUTURE AL OSTUAN RIVER BASIN

3.1 FUTURE CLIMATE SCENARIOS

Aiming to account for hydroclimatic uncertainty (i.e., natural variability and/or change of hydrological processes) and simulate future climatic conditions in the Al Ostuan basin up to year 2035, stochastic simulation methods for the generation of alternative, yet statistically plausible realizations of Al Ostuan's climate regime have been employed. In detail, in order to evaluate the performance of the Al Ostuan system under future climate conditions we employed a novel, and theoretically sound class of stochastic models to generate long-time series of climatic processes (e.g., precipitation) which represent future climatic scenarios. The employed models are known as Nataf-based models (Tsoukalas et al., 2017, 2018a, 2018b), and are closely associated with the notion of copulas. Key characteristic of this type of models is that they move beyond the typical, and risky, paradigm of moment-based representation of a process to a more complete description based on probability functions and theoretical correlation structures. Furthermore, such models are capable of generating multivariate (i.e., at multiple locations simultaneously) synthetic time series of hydrological processes at sub-annual scales and preserve important statistical properties related with their seasonal and annual characteristics, short-term persistence as well as over-year scaling behavior (i.e., Hurst phenomenon) (Tsoukalas et al., 2019). The above stochastic methods/models are readily available in the form of an open-source R package (R Core Team, 2017), called anySim (Tsoukalas et al. 2020), which has been used in the current study for the generation of future climate scenarios. Herein, using anySim, we generated 100 synthetic datasets (each of 17 years – i.e., 17 x 12 [months] = time steps) for both precipitation and evapotranspiration (hence directly accounted for temperature processes) and for the stations of Fnaidek, Klaiaat, and Qoubayat (i.e., employed a multivariate model for 3 locations and 2 types of processes). As a validation step, **Figure 3-1** compares the mean, standard deviation, and probability of dry interval of the historical and the synthetically generated data (panels a, b and c respectively). Similarly, **Figure 3-2** depicts a comparison among the historical and synthetic monthly lag-1 month-to-month correlation coefficients of the processes (panel a) as well the lag-0 cross-correlation among them (panel a). Both figures validate that the generated datasets exhibit the desired statistical properties and consist statistically plausible realizations of the future climate of the basin.

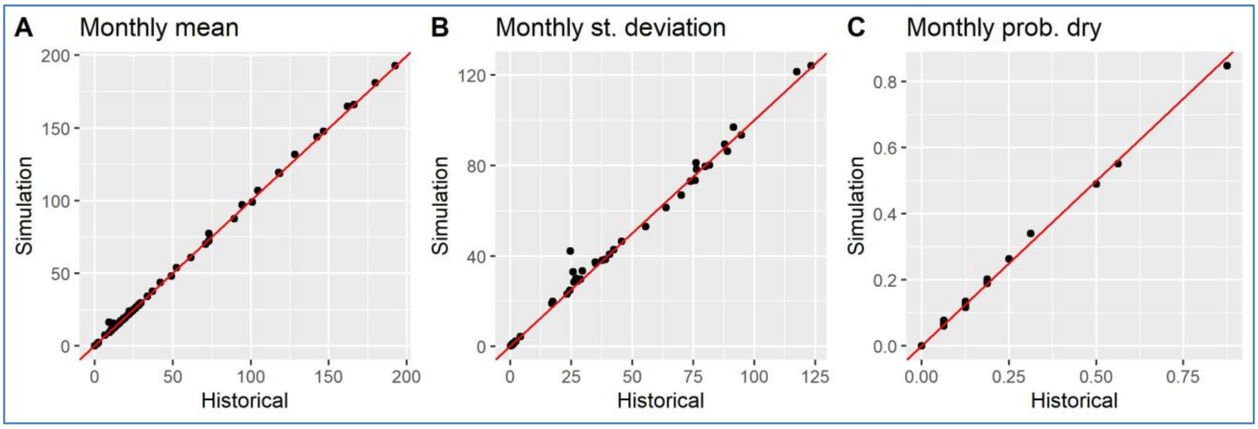


Figure 3-1: Comparison of key statistical quantities of the historical and the synthetic monthly time series. The panels regard the: a) mean, b) standard deviation, and c) probability dry (applicable only for precipitation processes).

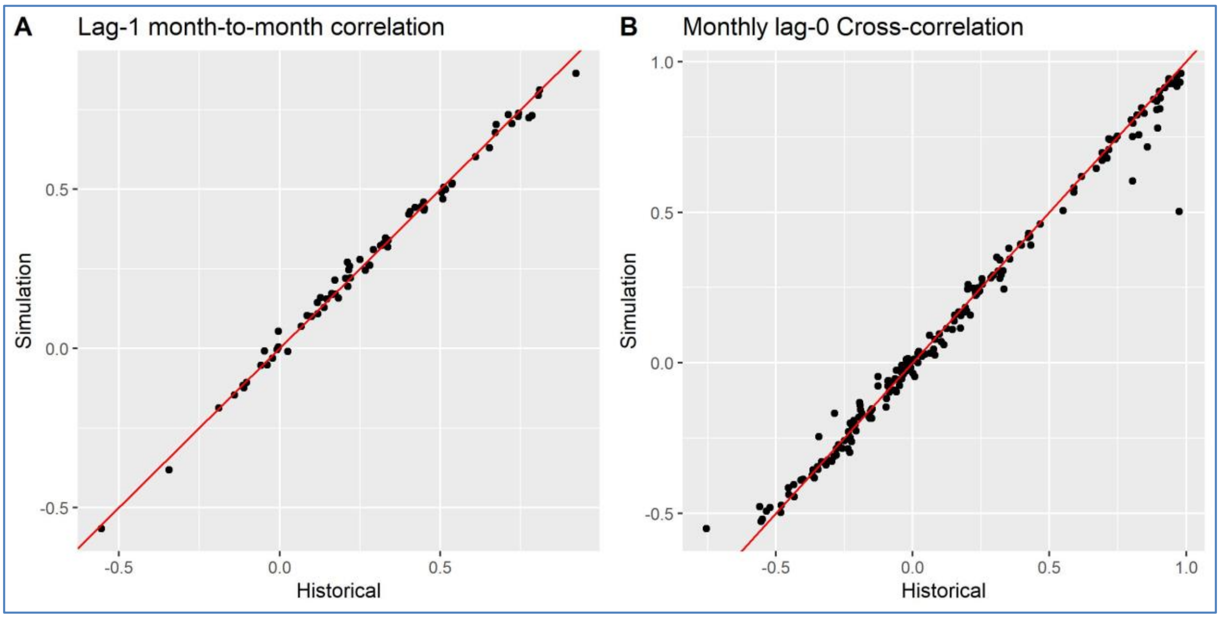


Figure 3-2: Comparison of correlation coefficients of the historical and the synthetic monthly time series. The panels regard the: a) lag-1 month-to-month correlation coefficients and, b) lag-0 correlation coefficients among the processes (3 location x 2 types of processes).

As a next step, and in order to ensure computational tractability (since driving WEAP with all 100 datasets would result in excessive computational load) we selected three representative datasets on the basis of the annual properties of the generated time series. In particular we selected the datasets with the minimum, maximum and average values of mean annual precipitation, as estimated on the basis of all three locations (hereafter referred to as MAX, MIN and MEAN future climate scenarios 2019-2035 respectively). As a final step, the synthetic time series datasets where spatially integrated over the

Al Ostuan River Basin using the method of Thiessen polygons. As an example, **Figure 3-3** and **Figure 3-4** illustrate the synthetically generated annual and monthly precipitation time series for the MEAN future climate scenario 201-2035 respectively, while **Figure 3-5** presents a comparison between the monthly precipitation per catchment for the historical baseline (2003-2018) and the synthetically generated MEAN future climate scenario (2019-2035).

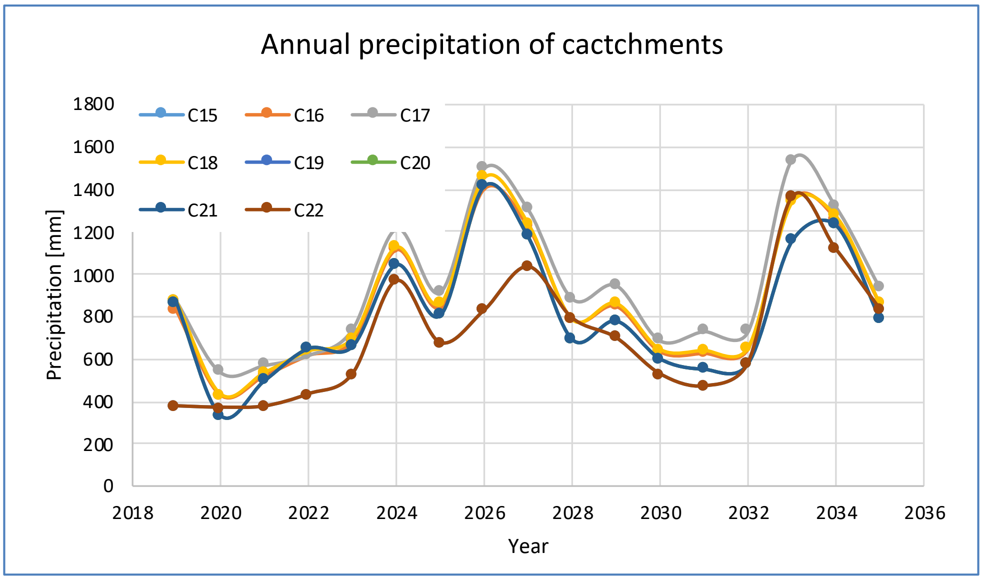


Figure 3-3: Annual precipitation per catchment for the synthetically generated MEAN future climate scenario.

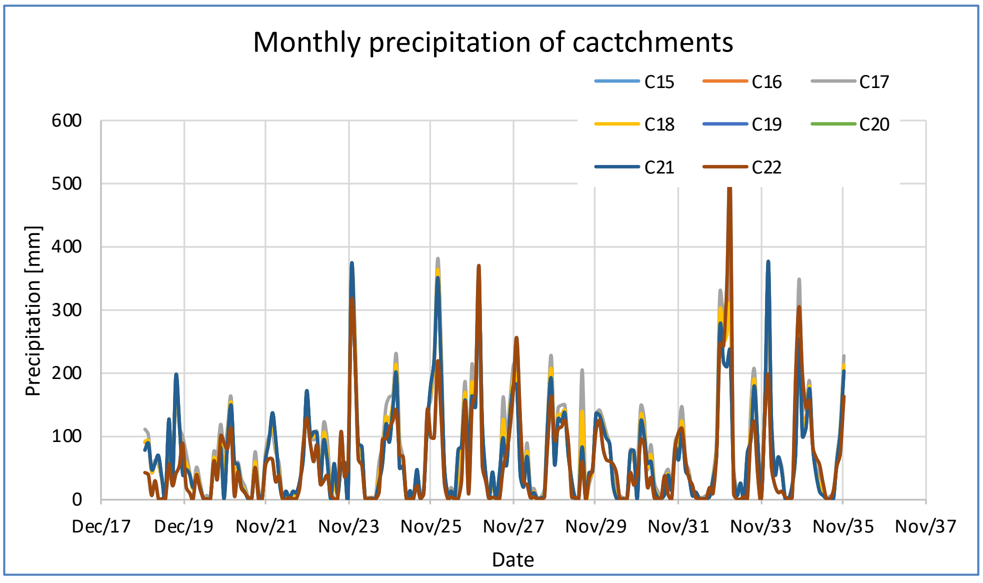


Figure 3-4: Monthly precipitation per catchment for the synthetically generated MEAN future climate scenario.

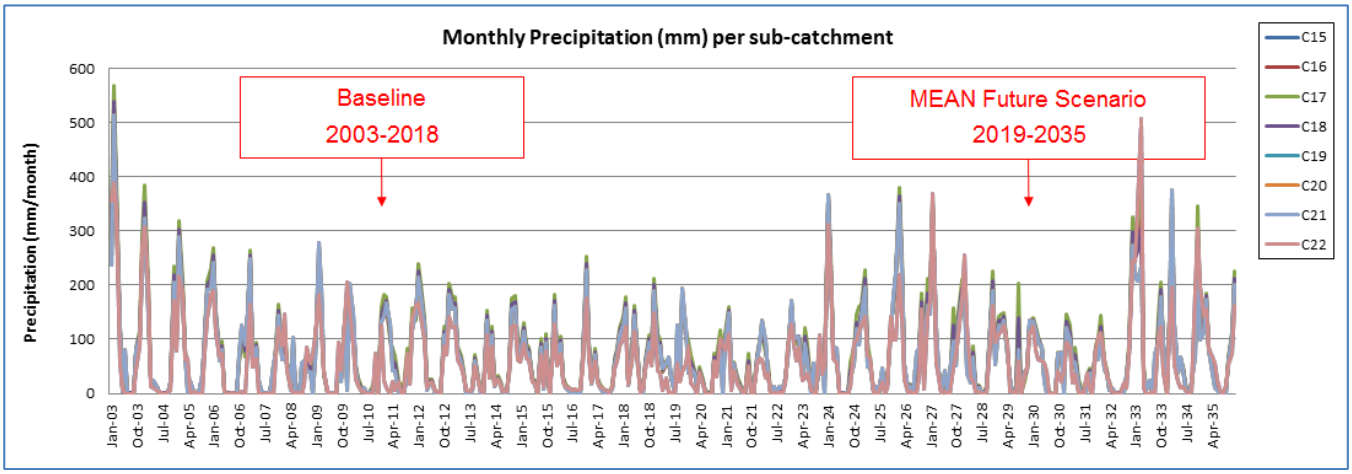
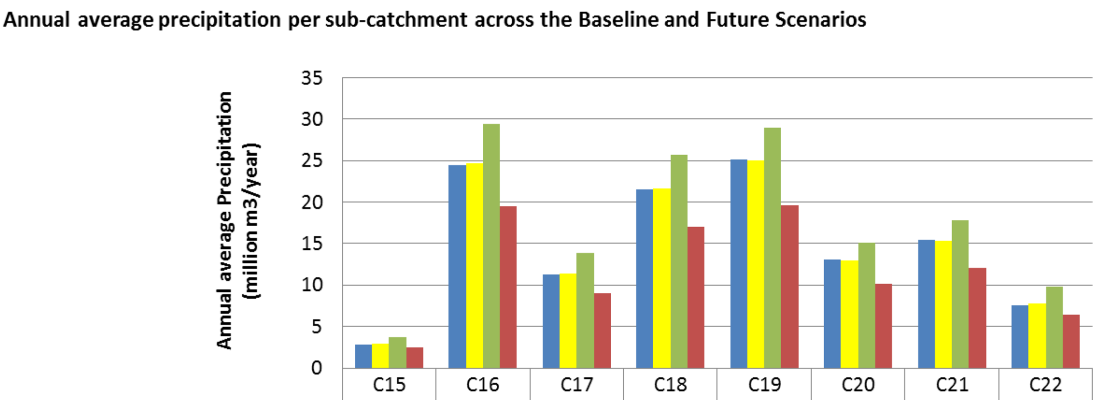


Figure 3-5: Comparison of the monthly precipitation (per catchment) of the historically (baseline) 2003-2018 and the synthetically generated MEAN future climate scenario 2019-2035.

The MEAN, MAX, MIN and future climate scenarios 2019-2035 have been imported in WEAP and subsequent runs were effectuated in the Al Ostuan Water Resources Management Model to obtain the relevant parameters of the future water availability. The results for the various land class inflow and outflows (components of the hydrological cycle) for the three future climate scenarios (MEAN, MAX. MIN) are presented in **Figure 3-6** to **Figure 3-9** below. In **Table 3-1** a comparison of the inflows and outflows (i.e. parameters of the hydrological cycle which depict water availability) between the Baseline 2003-2018 and the 3 future scenarios of the period 2019-2035 is presented. It can be observed that due to the variation in the precipitation and evapotranspiration between the MEAN, MAX and MIN scenarios, the water resources availability (i.e. the total potential volume in surface water and groundwater) fluctuates accordingly.



	C15	C16	C17	C18	C19	C20	C21	C22
Baseline 2003-2018	2.9	24.5	11.2	21.5	25.1	13.1	15.4	7.5
Future 2019-2035 (MEAN Scenario)	3.0	24.7	11.4	21.6	25.0	13.0	15.4	7.8
Future 2019-2035 (MAX Scenario)	3.7	29.5	13.8	25.7	29.0	15.1	17.8	9.9
Future 2019-2035 (MIN Scenario)	2.5	19.5	9.0	17.0	19.6	10.2	12.0	6.5

Figure 3-6: Annual average precipitation per sub-catchment across the Baseline (2003-2018) and Future Scenarios (2019-2035)

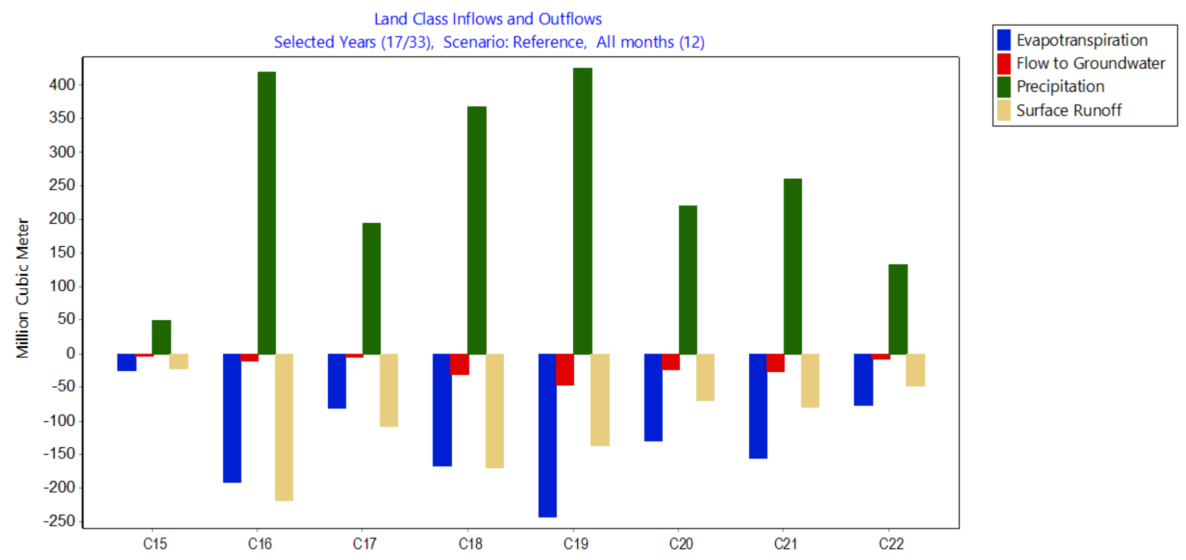


Figure 3-7: Total Land class inflows and outflows (in million m^3) per sub-catchment, for the future 17-year period 2019-2035 under the MEAN future scenario

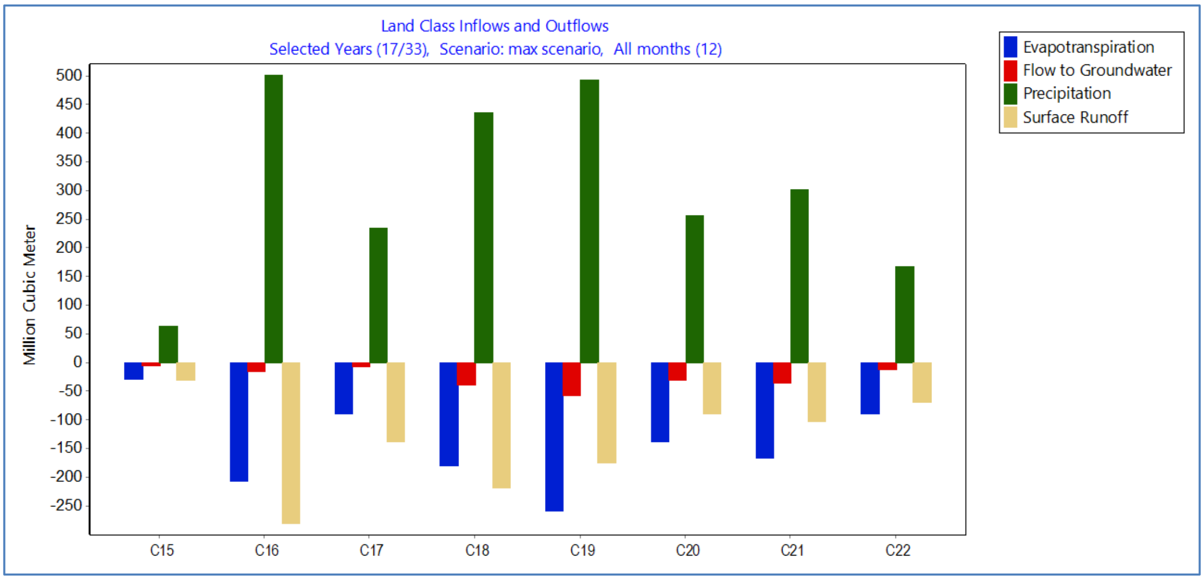


Figure 3-8: Total Land class inflows and outflows (in million m³) per sub-catchment, for the future 17-year period 2019-2035 under the MAX future scenario

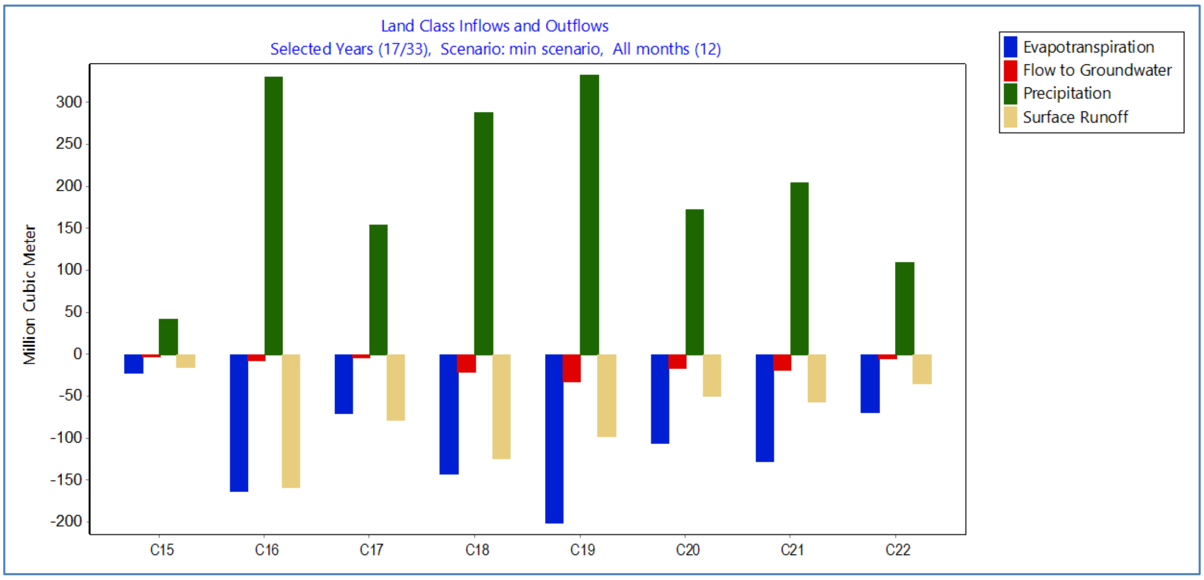


Figure 3-9: Total Land class inflows and outflows (in million m³) per sub-catchment, for the future 17-year period 2019-2035 under the MIN future scenario

Table 3-1: Land class inflows: total values (million m³) in the basin under different future scenarios

Land Class	Baseline 2003-2018	Future 2019-2035 MEAN Scenario	Future 2019-2035 MAX Scenario	Future 2019-2035 MIN Scenario
Precipitation	1,939.49	2,070.79	2,455.93	1,635.55
Evapotranspiration	-960.03	-1,067.58	-1,155.83	-903.44
Surface Runoff	-827.12	-849.62	-1,101.42	-620.51
Flow to Groundwater	-152.35	-153.59	-198.68	-111.60
** All units are in million m³ and refer to the entire Al Ostuan basin*				

3.2 FUTURE SCENARIOS FOR WATER DEMAND

The future water demand scenarios have been based on future socio-economic conditions and modelled assuming an annual population growth rate of 1.5% and a steady agricultural area (i.e. no changes in the number of irrigated hectares or in the crop mix). The following formula has been used:

Pop(year) = Pop(2018) x exp(1.5% x year)

The population increase in each urban demand site in the Al Ostuan from 2019 to 2035 is shown in **Figure 3-10**. The average population for the reference period 2003-2018 is 104,538 inhabitants, while for the future 2019-2035 period is increasing up to 134,888 inhabitants in the year 2035 capita, thus an increase of about 30,360 in this 17-year period (**Table** 3-2). For the future domestic daily water use rate an increase of +35% has been assumed. This has been applied as a linear increase of +2.69% per year until 2031, and then (since the +35% has been reached) it has been kept constant (at +35%, i.e. 216 lt/cap) from 2031-2035. The resulting urban water demand for the period 2018-2035 as compared to the Baseline 2003-2018 is presented in **Figure 3-11**.

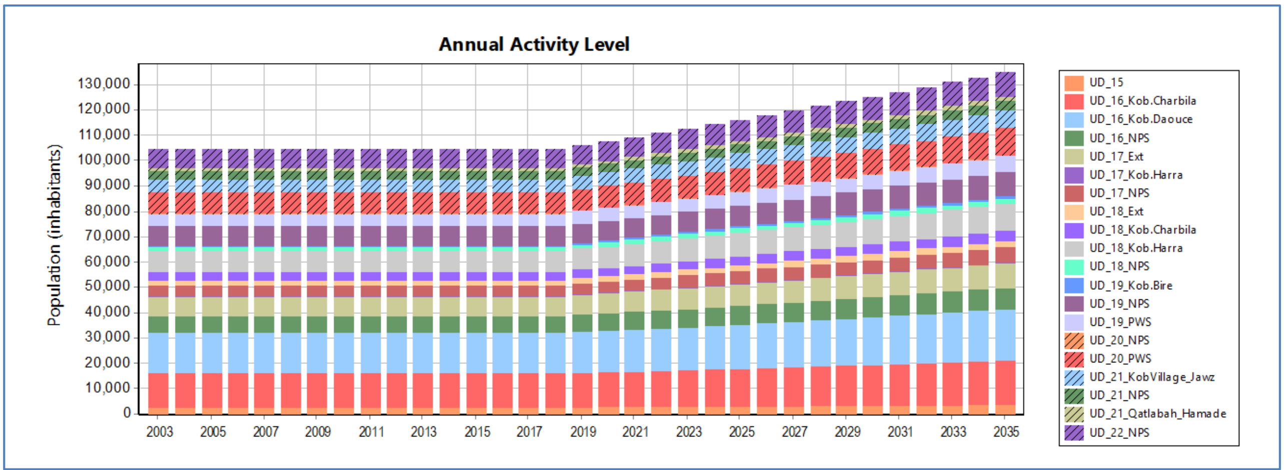


Figure 3-10: Population increase in each urban demand site in the Al Ostuan for the period 2019-2035

Table 3-2: Total population in the Al Ostuan River Basin for the period 2000-2035

Year	Population (capita)
2003	104,538
2018	104,538
2020	107,713
2025	116,099
2030	125,143
2035	134,888
2000-2018 average	104,528
2019-2035 average	119,959

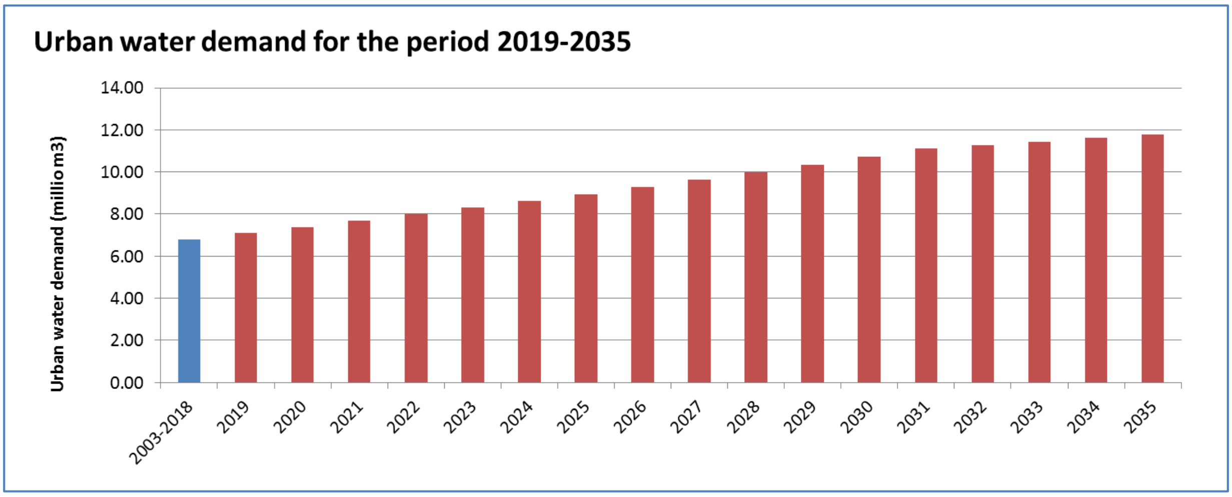


Figure 3-11: Urban water demand in the Al Ostuan for the period 2019-2035 and comparison with the 2003-2018 Baseline

For the future agricultural water use an increase of +22% has been assumed. This has been applied as a linear increase of +1.69% per year until 2031, and then (since the +22% has been reached) it has been kept constant (at +22%) from 2031-2035. The resulting agricultural water demand for the period 2018-2035 as compared to the Baseline 2003-2018 is presented in **Figure 3-12**. It can be observed that the average annual agricultural demand of 11 million m^3/year of the Baseline 2003-2018 is now increased to 12 million m^3/year on average under the MEAN future scenario, with a range from 11.5 to 13 million m^3/year across the MAX and MIN scenarios respectively. The variability in the demand still exists across the years (from 2019-2035) as it is also a function of the meteorological conditions (i.e. effective precipitation and the evapotranspiration).

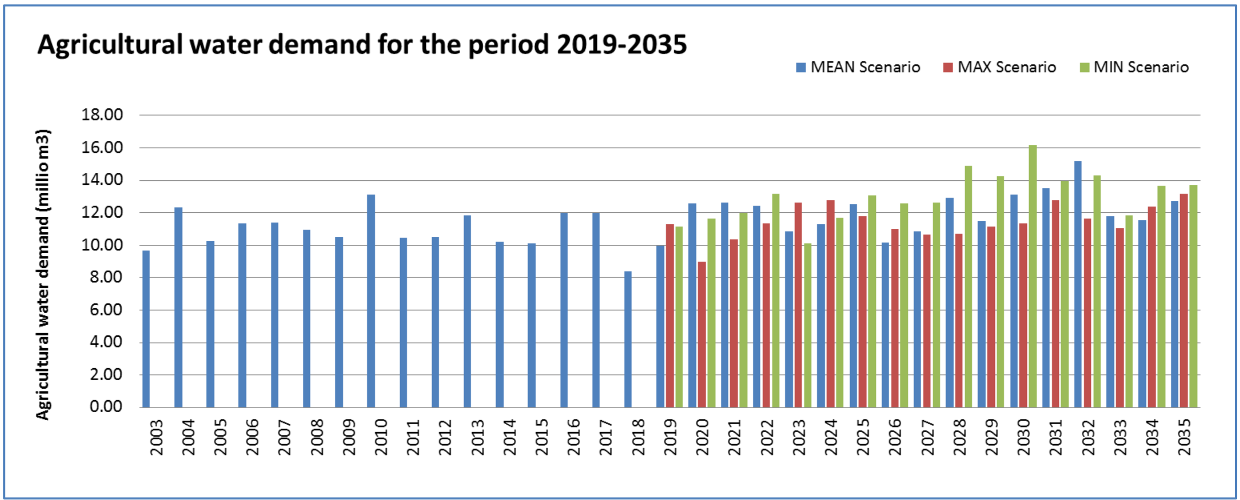


Figure 3-12: Agricultural water demand in the Al Ostuan for the period 2019-2035 and comparison with the 2003-2018 Baseline

Subsequently, the unmet demand has been calculated per sector for each of the 3 future climate scenarios (MEAN, MAX, MIN). The results are presented in the following graphs (

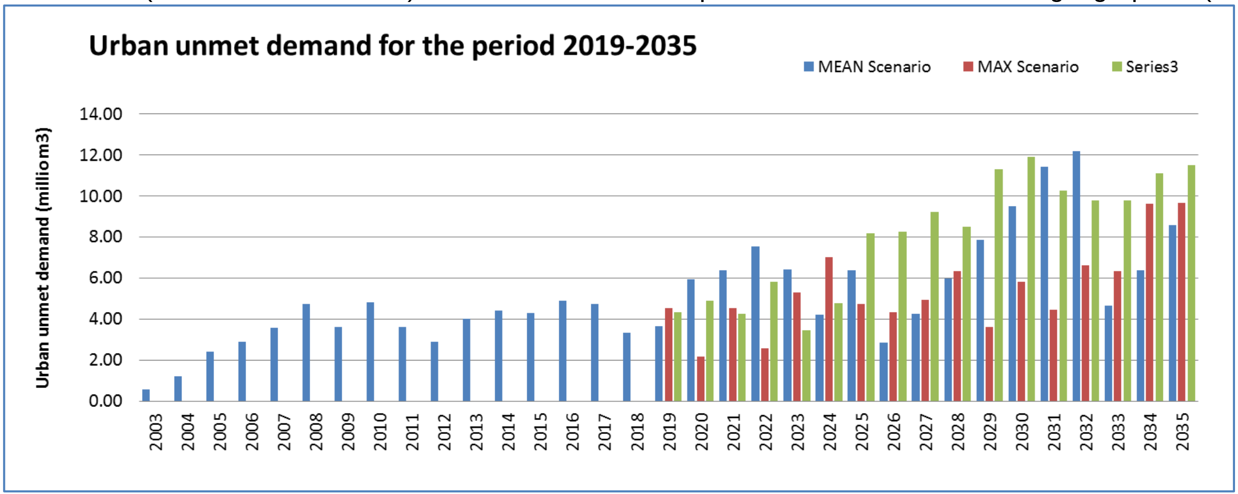


Figure 3-13 to

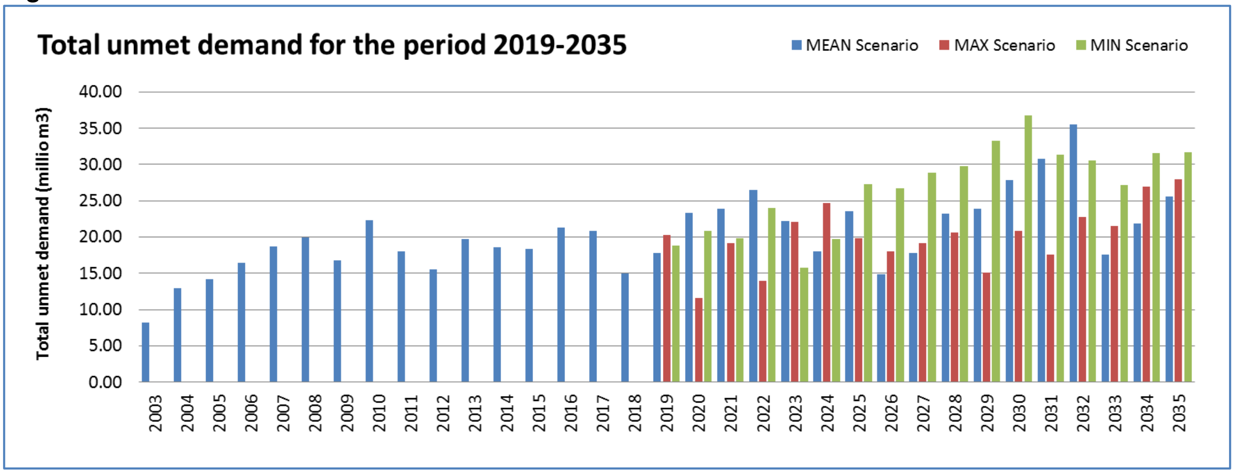


Figure 3-15), while the descriptive statistics (per sector and scenario) are presented in **Table 3-3**. We can observe that the average annual unmet demand increases in all scenarios of the 2019-2035 period as compared to the 2003-2018 Baseline. Under the MEAN scenario 2019-2035, the annual urban unmet demand increases by ~3 million m^3 (i.e. 92% increase), the agricultural by ~2.7 million m^3 (i.e. 19.4% increase), and the total by ~6 million m^3 (i.e. 34% increase). These increases are more pronounced under the MIN climate scenario. Thus, the total unmet demand reaches now 20-27 million m^3 per year, on average (depending on the scenario), as compared to the 17 million m^3 annual average of the 2003-2018 Baseline.

Table 3-3: Unmet demand for the future period 2019-2035 under the three climate scenarios

Scenario	Total (million m^3)	Average annual (million m^3)	Maximum annual (million m^3)	Minimum annual (million m^3)
Urban unmet demand				
Baseline 2003-2018 (16 years)	56.18	3.51	4.90	0.57

Scenario	Total (million m^3)	Average annual (million m^3)	Maximum annual (million m^3)	Minimum annual (million m^3)
Urban unmet demand				
MEAN scenario 2019-2035 (17 years)	114.36	6.73	12.19	2.87
MAX scenario 2019-2035 (17 years)	92.82	5.46	9.69	2.17
MIN scenario 2019-2035 (17 years)	137.64	8.10	11.92	3.47
Agricultural unmet demand				
Baseline 2003-2018	220.90	13.81	17.52	7.61
MEAN scenario 2019-2035	280.13	16.48	23.36	11.97
MAX scenario 2019-2035	249.38	14.67	18.24	9.45
MIN scenario 2019-2035	316.44	18.61	24.86	12.32
Total unmet demand				
Baseline 2003-2018	277.07	17.32	22.33	8.18
MEAN scenario 2019-2035	394.50	23.21	35.55	14.84
MAX scenario 2019-2035	342.21	20.13	27.93	11.61
MIN scenario 2019-2035	454.08	26.71	36.78	15.79

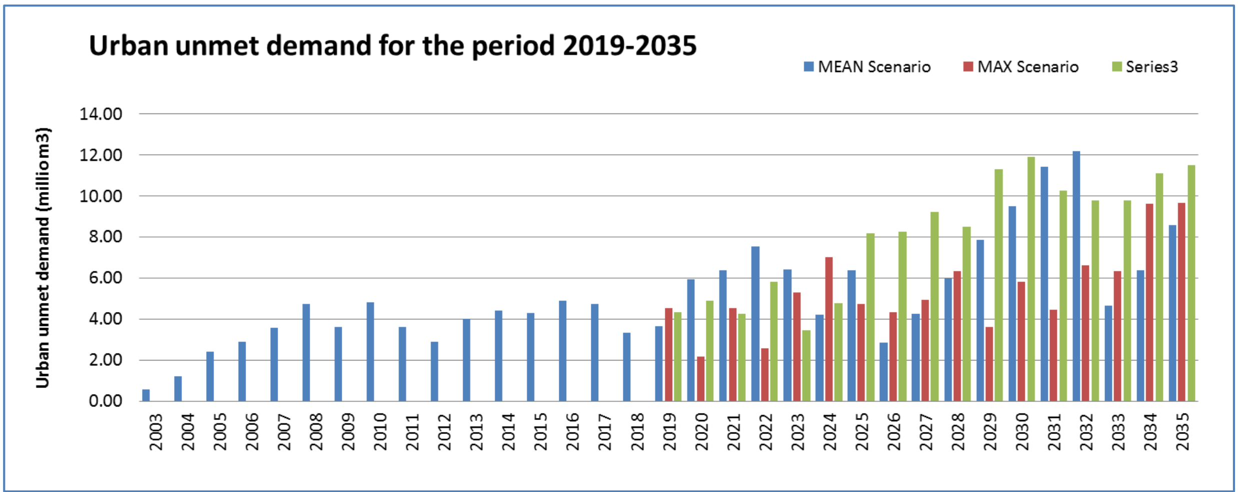


Figure 3-13: Urban unmet demand in the Al Ostuan for the period 2019-2035 and comparison with the 2003-2018 Baseline

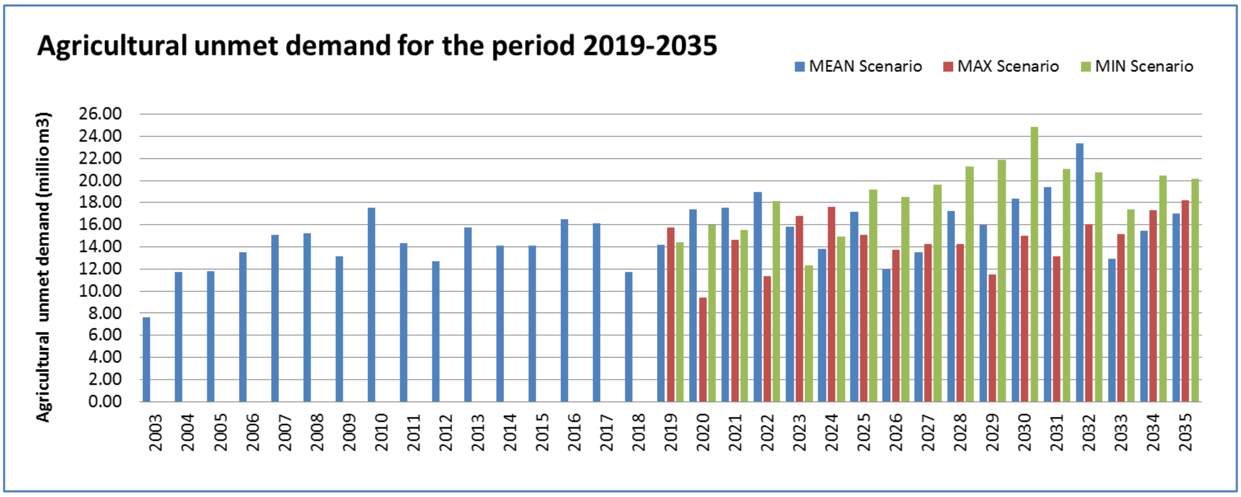


Figure 3-14: Agricultural unmet demand in the Al Ostuan for the period 2019-2035 and comparison with the 2003-2018 Baseline

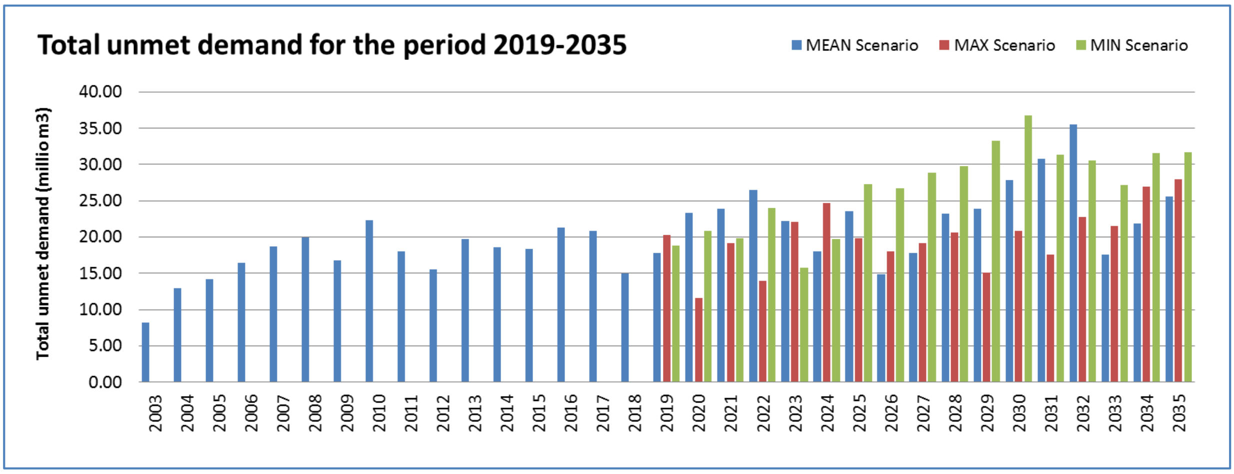
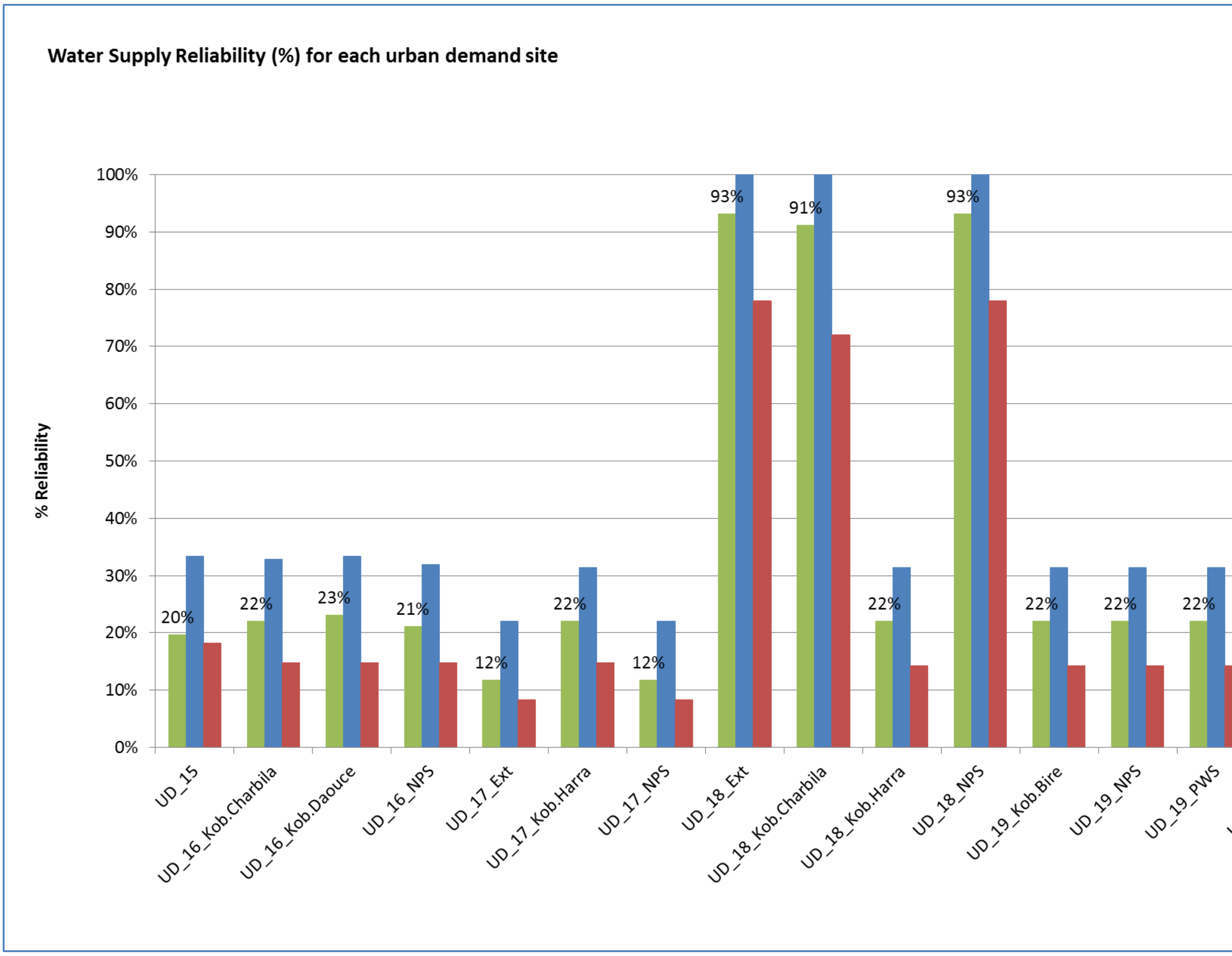


Figure 3-15: Total demand in the Al Ostuan for the period 2019-2035 and comparison with the 2003-2018 Baseline

The Reliability of the system in supplying the requested demand ranges among the uses. Reliability is defined as the percent of the timesteps in which a demand site's demand was fully satisfied. For example, if a demand site has unmet demands in 6 months out of a 10-year scenario, the reliability would be (10 * 12 - 6) / (10 * 12) = 95%.

As domestic use is priority 1, the water allocation to this use has an overall higher reliability comparing to the reliability of the irrigation. The average reliability across all the 21 urban demand nodes is 46% in the MEAN scenario, ranging from as low as ~12% in some sites to 100% in others (



Water Supply Reliability (%) for each urban demand site
% Reliability
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
20%
22%
23%
21%
12%
22%
12%
93%
91%
22%
93%
22%
22%
22%
UD_15
UD_16_Kob.Charbila
UD_16_Kob.Daouce
UD_16_NPS
UD_17_Ext
UD_17_Kob.Harra
UD_17_NPS
UD_18_Ext
UD_18_Kob.Charbila
UD_18_Kob.Harra
UD_18_NPS
UD_19_Kob.Bire
UD_19_NPS
UD_19_PWS

Figure 3-16,

). In the MAX and MIN scenarios the average reliability across all the 21 urban demand nodes is 57% and 36.5% respectively. A significant decrease in the average reliability is thus observed in the future period 2019-2035 as compared to the Baseline 2003-2018 where the average reliability in the urban nodes was 60%.

The nodes with the highest decrease in their water supply reliability are located in the sub-catchmentS C20 and C21 (27% decrease each), and include the villages of Andeket, Akkar El-Atika, and El-Koubayet. It has to be noticed that these nodes had a 100% reliability in the baseline period 2003-2018 which is no longer guaranteed in the future 2019-2035 period (i.e. it has been reduce to 73% reliability). Nodes in the sub-catchments C16, C17, C18, C19 are also expected the have a 16-17% decrease in their water supply reliability, and these include the villages of Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh, El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire, Katte, Al-Rihanie, El-Tleil, Omar el-Beikate, El-Haouchab, Hmais, Saidnaya, Al-Khraibe. Kfar Harra, El-Hed, Deir-Janine, Sfeinite El-Dreibe, Kherbet Char, Fseikine et Ain Achma, Barbara, Mazraat Balde, Majdel, and Daoura. On the contrary, some areas in the sub-catchment C21, i.e. Qatlabah and other parts supplied by the Hamade spring are not expected to be impacted and will maintain their high urban water supply reliability. It is to be noticed that some of these areas are not connected to the public water supply and use private wells.

Table 3-4: Urban water supply reliability per node for the future period 2019-2035
under the three climate scenarios

Urban node	Villages within the node	Water Supply Reliability %			
		Baseline Scenario (2003-2018)	MEAN Scenario (2019-2035)	MAX Scenario (2019-2035)	MIN Scenario (2019-2035)
UD_15	Halba, Tal Abbas El-Gharbie, Koueikhat, Tal Abbas El-Charkie, Al-Massoudie, Al-Khraibe	29%	20%	33%	18%
UD_16_Kob.Charbila	Charbila, Ain El-Zeit, El-Daghle, Kherbet Daoud, El-Msalle, Kefr El-Ftouh	39%	22%	33%	15%
UD_16_Kob.Daouce	El-Kouachra, Daouce et Baghdadi, Denke et El-Amriyeh, El-Bire	39%	23%	33%	15%
UD_16_NPS	Katte, Al-Rihanie, El-Tleil, Omar el-Beikate, El-Haouchab, Hmais, Saidnaya, Al-Khraibe	34%	21%	32%	15%
UD_17_Ext	Dahr-Leycine, Machha, Hayzouk	29%	12%	22%	8%
UD_17_Kob.Harra	Kfar Harra	39%	22%	31%	15%
UD_17_NPS	Al-Souaisse, Dahr el-Kneisse, Al-Khraibe	29%	12%	22%	8%
UD_18_Ext	Beino	100%	93%	100%	78%
UD_18_Kob.Charbila	Ain Tanta, Douair Adouiye	100%	91%	100%	72%
UD_18_Kob.Harra	El-Hed, Deir-Janine, Sfeinite El-Dreibe, Kherbet Char, Fseikine et Ain Achma, Barbara, Mazraat Balde	39%	22%	31%	14%
UD_18_NPS	Majdel	100%	93%	100%	78%
UD_19_Kob.Bire	Sindianet Zeidan	39%	22%	31%	14%
UD_19_NPS	Majdel, Daoura, Andeket, Akkar El-Atika	39%	22%	31%	14%
UD_19_PWS	El-Koubayet	39%	22%	31%	14%
UD_20_NPS	Andeket	100%	73%	98%	52%
UD_20_PWS	Akkar El-Atika	100%	73%	98%	52%
UD_21_KobVillage_Jawz	El-Koubayet	100%	73%	98%	52%
UD_21_NPS	Akkar El-Atika	100%	100%	100%	100%

Table 3-4: Urban water supply reliability per node for the future period 2019-2035 under the three climate scenarios		Water Supply Reliability %			
Urban node	**Villages within the node**	**Baseline Scenario (2003-2018)**	**MEAN Scenario (2019-2035)**	**MAX Scenario (2019-2035)**	**MIN Scenario (2019-2035)**
UD_21_Qatlabah_Hamade	El-Koubayet	100%	100%	100%	100%
UD_22_NPS	Al-Kleiat, Cheikh Zennad, Tal Bibe, Al-Kneisse, Al Moghrak, Tal Kerri, Al-Hissa, Al-Massoudie	29%	20%	36%	16%
Qsair_Danke	Qsair_Danke	39%	22%	31%	14%
Average		**60%**	46%	57%	36.5%

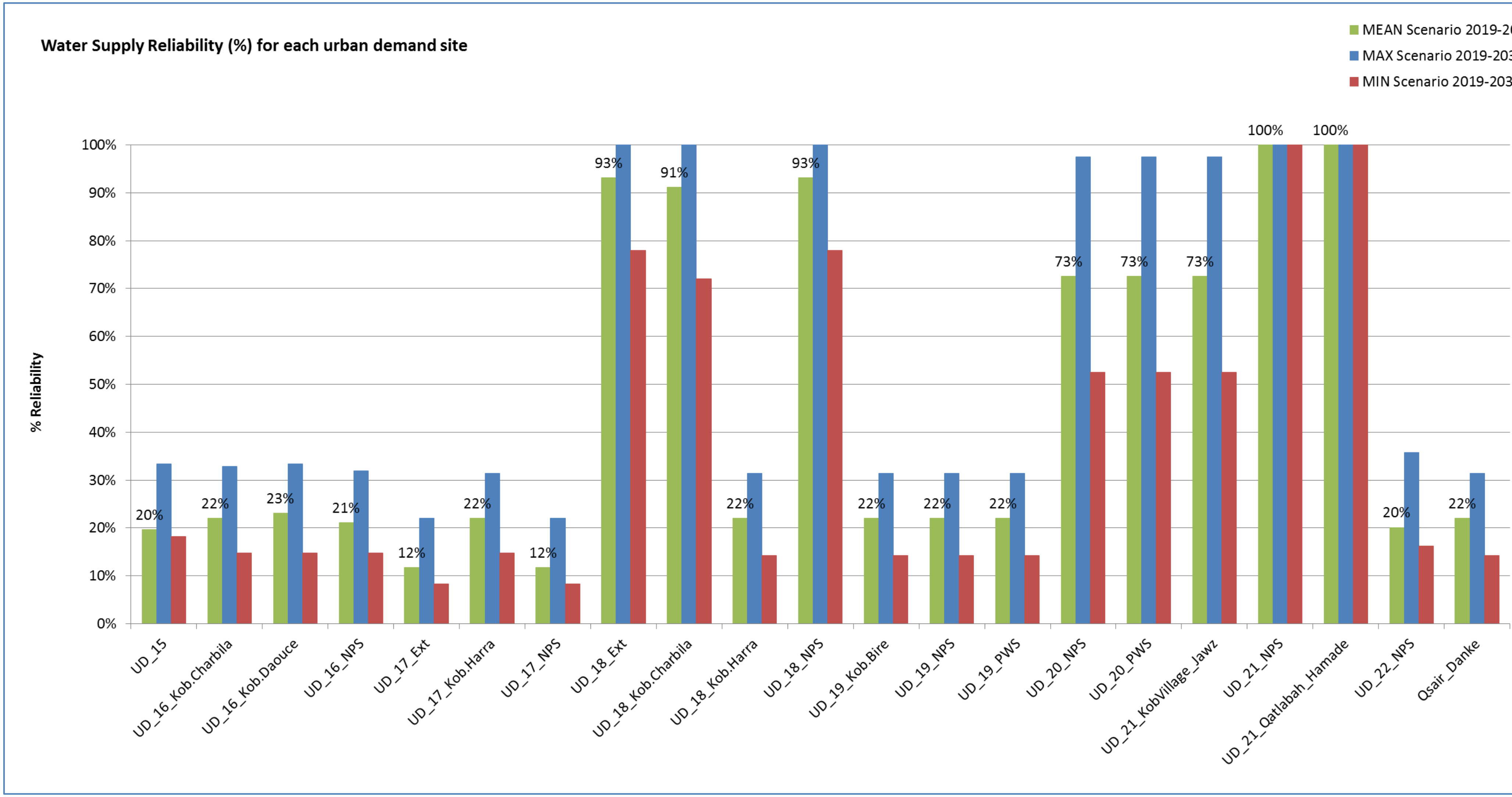


Figure 3-16: Reliability (%) of each urban demand site in the Al Ostuan River Basin under the 3 scenarios for the future period 2019-2035

Regarding the provision of water for irrigation , the average reliability across all the 8 agricultural demand nodes is 51% in the MEAN scenario, ranging from as low as ~21% in some sites to 100% in others (

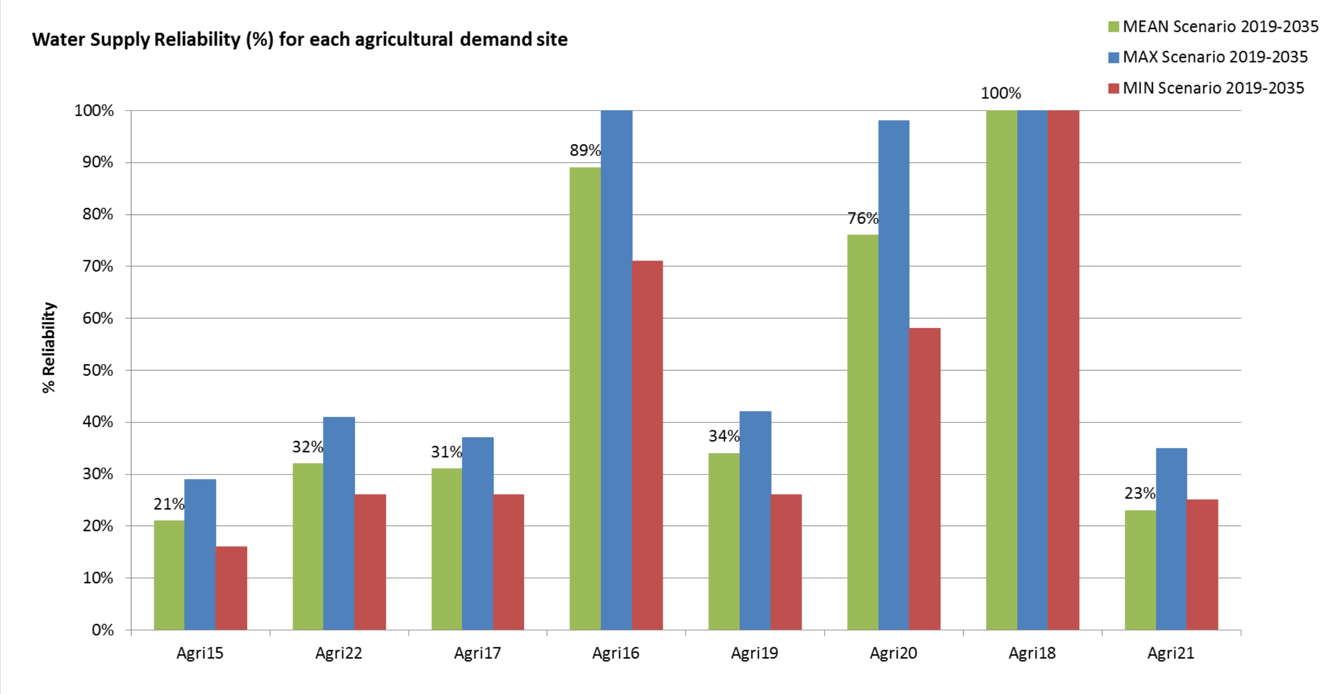


Figure 3-17, **Table 3-5**). In the MAX and MIN scenarios the average reliability across all the 8 irrigation demand nodes is 60% and 43% respectively. A decrease in the average reliability is thus observed in the future period 2019-2035 as compared to the Baseline 2003-2018 where the average reliability in the agricultural nodes was 58%. The nodes with the highest decrease in their water supply reliability are located in the sub-catchments C20 (24% decrease) which includes the village of Akkar El-Atika, C18 (11% decrease) which includes the village of Ain Tanta, Douair Adouiye, El-Hed, Deir-Janine, Sfeinite El-Dreibe, Kherbet Char, Fseikine et Ain Achma, Barbara, Mazraat Balde, Beino, Majdel, and C19 (9% decrease) which includes the north-eastern part of El-Koubayet village, Andeket, Daoura and Sindianet Zeidan. It has to be noticed that the nodes C20 and C18 had a 100% reliability in the baseline period 2003-2018 which is no longer guaranteed in the future 2019-2035 period. On the contrary, some areas in the sub-catchment C21, namely in the southeastern part of the El-Koubayet village, are not expected to be impacted and will maintain their high agricultural water supply reliability.

Table 3-5: Agricultural water supply reliability per node for the future period 2019-2035 under the three climate scenarios

	Water Supply Reliability %			
	Baseline Scenario (2003-2018)	MEAN Scenario (2019-2035)	MAX Scenario (2019-2035)	MIN Scenario (2019-2035)
Agri15	22%	21%	29%	16%
Agri22	38%	32%	41%	26%
Agri17	36%	31%	37%	26%

	Water Supply Reliability %			
	Baseline Scenario (2003-2018)	MEAN Scenario (2019-2035)	MAX Scenario (2019-2035)	MIN Scenario (2019-2035)
Agri16	100%	89%	100%	71%
Agri19	43%	34%	42%	26%
Agri20	100%	76%	98%	58%
Agri18	100%	100%	100%	100%
Agri21	26%	23%	35%	25%
Average	**58%**	**51%**	**60%**	**43%**

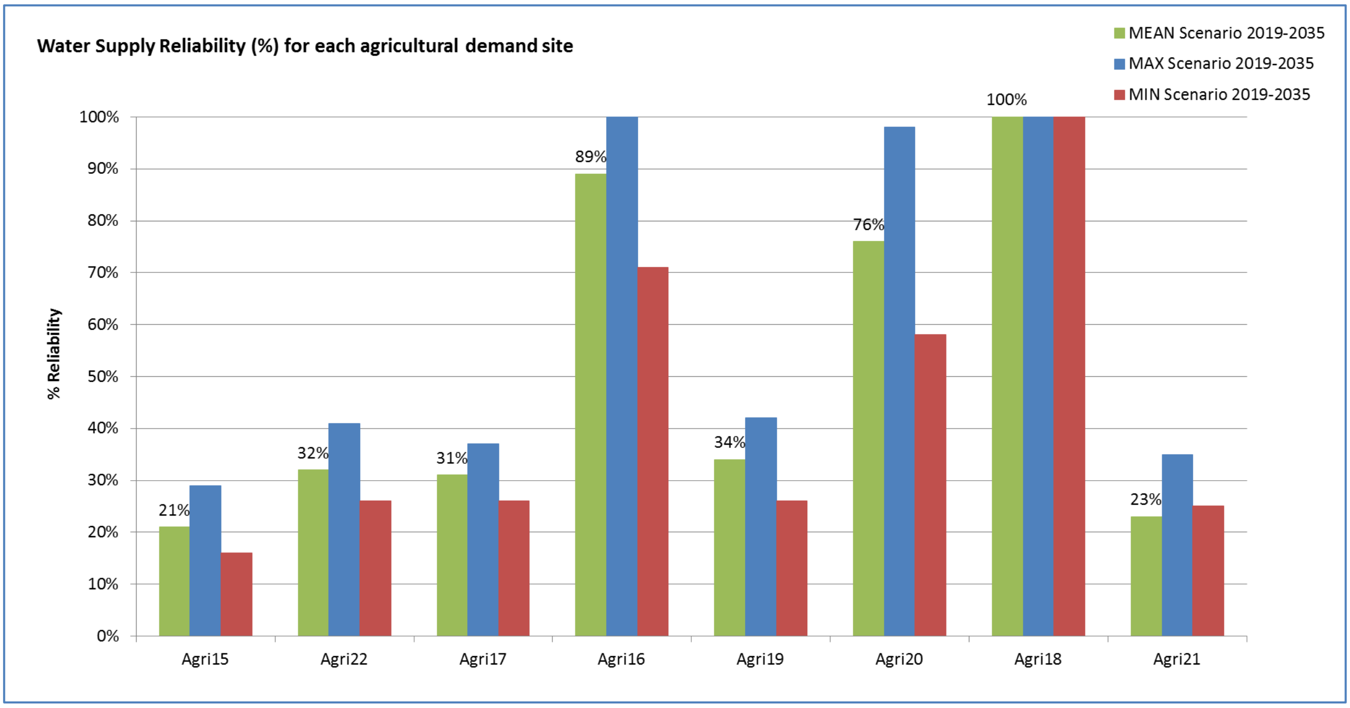


Figure 3-17: Reliability (%) of each agricultural demand site in the Al Ostuan River Basin under the 3 scenarios for the future period 2019-2035

Erreur ! Source du renvoi introuvable. summarizes the number of sites (nodes) per water use that fall under different reliability categories. The reliability categories have been defined as very high (>95%), high (80-95%), medium (60-80%), low (40-60%), and very low (<40%). Within the urban sector, 62% of the users had very low reliability of water supply in the Baseline 2003-2018 period. In the future scenarios for 2019-2035 the percentage in the very low class remains at 62%, which means that the majority of the urban users in the basin will still have very low urban water supply reliability. Yet, the situation is further deteriorating since the 38% of the users which had very high reliability in the baseline is now reduced to 10% (MEAN scenario 2019-2035), while the remaining 28% of the users have been moved down one or classes to the high or medium reliability classes. With regard to the irrigation users, the number of users in the very high reliability class is reduced (from 37.5% in the baseline to 12.5% in the MEAN scenario 2019-2035) while the of users in the very low reliability class is increased (from 50% in the baseline to 62.5% in the MEAN scenario 2019-2035).

Table 3-6: Percent (%) of user for each use category (domestic, irrigation) that fall under the 5 reliability classes (very low, low, medium, high, very high)

Reliability	Baseline Scenario (2003-2018)	MEAN Scenario (2019-2035)	MAX Scenario (2019-2035)	MIN Scenario (2019-2035)
Urban users				
Very High (>95%)	38%	10%	38%	10%
High (80-95%)	0%	14%	0%	0%
Medium (60-80%)	0%	14%	0%	14%
Low (40-60%)	0%	0%	0%	14%
Very Low (<40%)	62%	62%	62%	62%
Irrigation users				
Very High (>95%)	37.5%	12.5%	37.5%	12.5%
High (80-95%)	0.0%	12.5%	0.0%	0.0%
Medium (60-80%)	0.0%	12.5%	0.0%	12.5%
Low (40-60%)	12.5%	0.0%	25.0%	12.5%
Very Low (<40%)	50.0%	62.5%	37.5%	62.5%

4 DEMAND MANAGEMENT MEASURES: AN OVERVIEW

4.1 DEMAND MANAGEMENT MEASURES IN THE URBAN SECTOR

There is a variety of available technologies designed to deliver domestic water saving targeting the different household water uses. These include a range of low water using appliances and retrofitting. On top of that, there are technologies and interventions that can increase the water supply. All these options are analytically presented below

- **<u>Water saving measures</u>**

Toilet flushes, usually accounting for one third of the domestic water use on average can deliver reductions up to 50% of the water used. Common options include the replacement of older style single-flush models (14 lt/flush) with low-flush gravity toilets (6 lt/flush), dual-flush valve operated toilets (4 lt/flush), air-assisted pressurised toilets (2 lt/flush). Evidence exists that flush volumes down to 4 lt do not cause any problems in the drains and sewers in terms of the waste disposal.

Taps and **Showerheads** can be adjusted and render saving by installing water saving devices and inexpensive retrofits. Various options are available for retrofitting kitchen and bathroom taps, which are estimated to account for more than 15% of domestic indoor use, with respective savings of 20-30% and less than 2 years paybacks: fitting of new water efficient tap-ware (spray taps, push taps, etc.), low-flow aerators, durable tap washers, flow restrictors and regulators, automatic shutoff. Showerheads are usually gravity fed, electric or pumped (power showers). The average consumption of showers ranges across the households as it depends on many interrelated factors: frequency of use (from 0.75-2.5 showers/day) average shower time duration (2-5 minutes), type of shower, flow rate (6-16 lt/minute), etc. Yet, evidence exists that showers and baths account for 20-35% of the household water consumption and installing water saving devices (flow restricting devices, low-flow showerheads - aerating or laminar-flow, cut-off valves, etc.) can secure around 30-40% water savings. It worth mentioning that the expected savings from the installation of smart water saving devices in taps and showerheads is also highly influenced by the use patterns and habits of the users.

Washing Machines and **Dishwashers** can be replaced with more efficient ones delivering water and energy savings. Washing of clothes is probably the third largest consumer of domestic water, around 20%. Installing high-efficient washing machines can save up to 40% of the volume need per cycle. Modern washing machines use about 50 lt/cycle or 35 l/cycle for the most efficient ones, as opposed to 150 lt/cycle in the 1990's, due to technological advances (i.e. intelligent sensor systems, advanced and customised washing programmes, improved time functions, etc.). Dishwashers manufactured prior to the year 2000 typically consume 15-50 lt/load, while modern dishwashers consume 7-19 lt/load under normal setting and as low as 8-12 lt/load under the eco-setting, which means average water savings at the range of 40-60% . The share of water use consumed by dishwashers varies from 6-14% as it depends on the cycle time, the frequency of use and their degree of penetration in the households, the latter being influenced by e.g. lack of space, conception that this investment is not necessary due to small load of dishes feasible to be hand-washed, etc.

Water pricing reform usually involves a modification in the rate structure and/or the water tariffs in order to influence the consumers' water use. It often includes the shifting from decreasing block rates to uniform block rates, the shifting from uniform rates to increasing block rates, the increasing of rates during summer months, or the imposing excess-use charges during times of water shortage. This economic instrument needs a very careful design as it can easily raise conflicts among users and trigger many disputes.

- **<u>Increase supply measures</u>**

Greywater is the dilute wastewater, originating from domestic activities such as showering, bathing, washing hands, tooth brushing, dishwashing, washing clothes, cleaning and food preparation, in brief it refers to all household wastewater other than wastewater from toilets (the so called blackwater). This water contains some organic material, yet it can be reused for some uses within the households (e.g. toilet flushing). Greywater from baths, showers and washbasins is less contaminated than that from the kitchen. Reuse in the urban and suburban environment primarily concerns irrigation of green areas, recreation and swimming activities, natural landscaping, fire-fighting, cleaning of streets, and domestic uses with the exception of drinking use. Typical domestic reuse systems collect and store greywater before reusing it to flush the toilet, while more advanced systems treat greywater to a standard that can be used in washing machines and garden irrigation. The most basic systems (i.e. direct reuse systems) simply divert untreated bath water, once cooled, to irrigate the garden. More advanced systems include short retention systems (which apply the very basic treatment of debris skimming and particles settling), basic physical and chemical systems (which use a filter and chemical disinfectants to stop bacterial growth), biological systems (which use bacteria for organic matter removal), bio-mechanical systems (which combine biological and physical treatment). The advantage of onsite domestic reuse of greywater is that the supply is regular and independent of external conditions, such as rainfall. Different systems can be used based on the cross-section of different technologies as previously mentioned, such as filtration and chlorination, advanced oxidation (H_2O_2 + UV), membrane bio-reactor (MBR), biological with media filter, ranging thus in costs (from 1,900-6,500 $ for the equipment purchase and installation, and 36-420 $ for maintenance), and the effluent water quality. Greywater used for flushing toilets can render savings around 20-30% of the average household water use depending on the toilet flash volume. In the UK studies showed water savings from about 5-36% introduced when using greywater reuse systems.

Rainwater Harvesting (RWH) is defined as "the capture, storage and management of water flowing on the roofs of buildings and river basins that exist on the ground with the purpose of growing crops, regeneration of pasture for animal feed production and farming in general, horticulture and domestic use". Typical RWH systems consist of three basic elements: the collection system (area which produces runoff because the surface is impermeable or infiltration is low), the conveyance system (through which the runoff is directed, e.g. by bunds, ditches, channels, pipes) and the storage system (where water is accumulated or held for use). The storage system consists of tanks or impermeable soil and subsoil, as well as larger reservoirs. In the context of urban water cycle, RWH aims to minimize the effects of seasonal variations in water availability due to droughts and dry periods, and to enhance the reliability of domestic water supply and reduce the dependence on the mains water supply. Additional benefits include effective management of surface runoff, mitigation of flooding and soil erosion, increased productivity of domestic crops, reduction of water bills, etc. Nevertheless, there are limitations in implementing RWH techniques or relying on RWH as a source of supply, the main disadvantage being the unpredictable and often irregular supply which results in large storage space requirements. Larger schemes and structures are difficult to implement as they need acceptance by people, political backing and financial support. Finally, as rainwater usually carries small pollutant loads (depended on the location, roof building materials and collection system construction), a main light treatment and disinfection is generally needed for rainwater treatment to non-potable standards. Numerous RWH systems are available with a range of features and varying costs. Costs vary from as low as 2,000 $ to as high as 8,000 $ depending on the size and type of the tank (e.g. 2,000-8,000 lt), the timing of installation (retrofitting vs. installation during construction), the pumping system, additional desired UV treatment, etc. Recently, in 2019, ACTED implemented a Rainwater Harvesting project in the area (MADAD and PACA Funding) where RWH systems have been installed in 33 households and 1 municipal building, and the volumes captured have been monitored (through metering) for 12 weeks from 01/01/2020 to 25/03/2020. The costs of the RWH systems ranged from 1,050$ to 1,950$ (including installation costs). All RWH systems included 2 Double Layer PVC Water Tanks of $2m^3$ capacity each (unit cost of each tank = 212$), a small electrical water pump (Italy made) of 0.5 HP, high pressure up to 12m, and flow rate 35 L/min (unit cost of the pump = 96$), rain water filters (media and micro filter with all needed accessories, supply and installation) (cost = 152$), and 2 valves (5'' two way valves) at the connection between the collection tank and the 5'' PVC pipe from the roof (unit cost = 202$). The total costs ranged depending on the length/number of PVC and HDPE pipes and related accessories (fittings, elbows, connections, etc.) needed to be installed on the external walls of the buildings (cost = 3.5-7 $/m). During the monitoring period from 01/08/2020 to 25/03/2020 (i.e. 12 weeks), a total of 22 rainy days have been registered. The total (cumulative) volumes of rainwater recovered by the installed RWH systems ranged from $20m^3$ to $67m^3$ of rainwater collected (per system), which represents an average of 0.9-2.9 m^3 per rainy day per system/household.

Detention basins are part of the so-called Natural Water Retention Measures (NWRM) and Sustainable Urban Drainage Systems (SUDS). They are vegetated depressions designed to hold runoff from impermeable surfaces and allow the settling of sediments and associated pollutants. Stored water may be slowly drained to a nearby watercourse, using an outlet control structure to control the flow rate. Detention basins do not generally allow infiltration. The capacity to store runoff is dependent on the design of the basin, which can be sized to accommodate any size of rainfall event (CIRIA, 2007 identify up to a 1 in 100 year event as being not uncommon). Detention basins can provide water quality benefits through physical filtration to remove solids/trap sediment, adsorption to the surrounding soil or biochemical degradation of pollutants. Detention basins are landscaped areas that are dry except in periods of heavy rainfall, and may serve other functions (e.g. recreation), hence have the potential to provide ancillary amenity benefits. They are ideal for use as playing fields, recreational areas or public open space. They can be planted with trees, shrubs and other plants, improving their visual appearance and providing habitats for wildlife. A detention basin should be designed to be appropriate for the contributing catchment area (as well as rainfall characteristics). In theory they can be designed to accommodate any volume of runoff, from any catchment area, desired, and CIRIA (2007) states that there is no maximum catchment area. However in general, sustainable drainage principles promote managing runoff close to source, i.e. with a relatively small catchment area, and therefore it is not envisaged that a contributing area greater than 1 km^2 would be likely.

Detention basis are high land-take measures used within the urban environment. The primary cost is therefore the cost of land acquisition or the opportunity cost of not using that land for development. This will depend on the land values at the site under considerations and cannot be generically quantified. Due to the higher costs of land, it is usually more expensive to retrofit these basins to already developed areas as compared to constructing one in an undeveloped region. (Source: NWRM project (http://nwrm.eu/measure/detention-basins; for more information refer to the NWRM Detention Basins Factsheet)

Retention ponds (also including **Hill Lakes**) are part of the so-called Natural Water Retention Measures (NWRM) and Sustainable Urban Drainage Systems (SUDS). They are ponds or pools designed with additional storage capacity to attenuate surface runoff during rainfall events. They consist of a permanent pond area with landscaped banks and surroundings to provide additional storage capacity during rainfall events. They are created by using an existing natural depression, by excavating a new depression, or by constructing embankments. Existing natural water bodies should not be used due to the risk that pollution events and poorer water quality might disturb/damage the natural ecology of the system. Retention ponds can provide both storm water attenuation and water quality treatment by providing additional storage capacity to retain runoff and release this at a controlled rate. Ponds can be designed to control runoff from all storms by storing surface drainage and releasing it slowly once the risk of flooding has passed. Runoff from each rain event is detained and treated in the pond. The retention time and still water promotes pollutant removal through sedimentation, while aquatic vegetation and biological uptake mechanisms offer additional treatment. Retention ponds have good capacity to remove urban pollutants and improve the quality of surface runoff.

Ponds should contain the following zones: (a) a sediment forebay or other form of upstream pre-treatment system (i.e. as part of an upstream management train of sustainable drainage components); (b)a permanent pool which will remain wet throughout the year and is the main treatment zone; (c) a temporary storage volume for flood attenuation, created through landscaped banks to the permanent pool; (d) a shallow zone or aquatic bench which is a shallow area along the edge of the permanent pool to support wetland planting, providing ecology, amenity and safety benefits. Additional pond design features should include an emergency spillway for safe overflow when storage capacity is exceeded, maintenance access, a safety bench, and appropriate landscaping. Well-designed and maintained ponds can offer aesthetic, amenity and ecological benefits to the urban landscape, particularly as part of public open spaces. They are designed to support emergent and submerged aquatic vegetation along their shoreline. They can be effectively incorporated into parks through good landscape design.

The drainage area required to support a retention pond can be as low as 0.03-0.1 km^2 (Environment Agency, 2012), or possible smaller if the retention pond has another resource of water such as a spring. There are no specific constraints on the maximum drainage area for retention ponds, although typically

3-7% of the upstream catchment area will be required for the pond (CIRIA, 2007). Larger retention ponds (>25,000 m^3 volume) require significant impoundment and may be subject to additional inspection and structural requirements (e.g. 1975 Reservoirs Act in UK). Ponds would typically be sited at a low point in the catchment where it can receive drainage by gravity. Several ponds may be required at a large site, split into topographic sub catchments. The position chosen should allow safe routing of flows above the design event for the pond, and the consequence of any pond embankment failure considered.

Retention ponds reduce peak runoff through storage and controlled outflow release. They must be appropriately sized to the catchment area and critical storm depth. They do not infiltrate runoff and therefore provide very little runoff volume reduction (with the exception of evaporation and evapotranspiration, which can be significant in some cases). Typically, retention ponds will be designed to attenuate runoff for events up to at least the 1 in 30 year storm for the drainage area (sometimes greater), with the excess storm volume drained within 24 to 72 hours (CIRIA, 2007).

Retention ponds are high land-take measures used within the urban environment. The primary cost is therefore the cost of land acquisition or the opportunity cost of not using that land for development. This will depend on the land values at the site under considerations and cannot be generically quantified. Due to the higher costs of land, it is usually more expensive to retrofit these basins to already developed areas as compared to constructing one in an undeveloped region. (Source: NWRM project (http://nwrm.eu/measure/detention-basins; for more information refer to the NWRM Retention Ponds Factsheet)

Information on the houshold consumptions per micro-component and water using product, and the expected savings of each of the above mentioned technological interventions has been collected from various literature sources as presented in **The following** methodological steps have been implemented in order to build the cost-effective functions and simulate the selected adaptation measures in the Al Ostuan River Basin:

- Definition of the economic sectors of interest, and selection of relevant measures (per sector) in consultation with local stakeholders
- Adaption of clear definitions for all measures and interventions
- Collection of the input data needed for the cost-effectiveness functions (potential saving, costs)
- Development of the cost-effectiveness curves implementing an optimization process
- Development of the alternative demand management scenarios (based on a mix of the measures) to be simulated
- Investigation on how to simulate the functions in the WEAP21 water resource management model of the Al Ostuan river basin (coding routines)
- Simulation of the alternative demand management scenarios against the baseline scenario (2003-2018), and assessment of their impact and cost-effectiveness on the physical system
- Assessment of the robustness of the alternative demand management scenarios for the future period up to 2035

4.2 ANALYSIS OF THE URBAN MEASURES - DESIGN OF THE COST-EFFECTIVENESS CURVES

Water consumption patterns can vary significantly from house to house, depending on the household occupancy, the social and cultural conditions as well as on the type of the water consuming appliances installed in the houses (Memon and Butler, 2006). However, only a small proportion (approximately 15–20%) of in-house water demand is actually used for purposes requiring drinking water quality (incl. water used for drinking, cooking and cleaning dishes) (refer to **Table 5-1** and **Figure 5-1**).

Table 5-1: Water consumption share of different household micro-components in the industrialized world

Information Sources / **HH Micro-component**	***EU-wide overview***			***Country specific***				
	POST, 2000	*EA, 2007*	*Uihlein and Wolf, 2010 (across the EU)*	*EA, 2010 (in England & Wales for 2009-10)*	*Uihlein and Wolf, 2010 (for Greece)*	*EEA, 2001 (for Switzer-land)*	*Schleich, 2007 (for Germany)*	*Lebano 2020 NW*
WC (toilet flushing)	31 %	30 %	25 %	26 %	25 %	33 %	32 %	30.
Faucets	24 % *(of which 15% kitchen sink, 9% basin)*	20 %	30 % *(of which 5% for drinking and cooking)*	11 %	13 % *(5% for drinking and cooking)*	17 % *(3% for drinking and cooking)*	12 % *(3% for drinking and cooking)*	7.67 some % wahing is inclu together the show *(3.1% drinking cook 4.58% ho clear*
Shower	5 %	35 %	14 %	35 %	34 %	32 %	30 %	41.48% showers was
Bath	15 %		14 %					
Washing Machine	20 %	15 %	13 %	12 %	14 %	16 %	14 %	6.
Dishwasher	1 %		2 %	9 %	8 %		6 %	8.
Outdoor use	4 %		2 %	7 %	6 %	2 %	6 %	5.
Miscellaneous use								
TOTAL	100 %	100 %	100 %	100 %	100 %	100 %	100 %	1
Rainwater Harvesting		Equivalent to: 25% toilet flushing, 25% clothes washing, 22.5% external tap use						
Greywater reuse (GWR)		equivalent tothe water consumed by toilets within the property (i.e. 30%), since						

		GW can be used for this purpose						

Source: Kossida, M., 2015

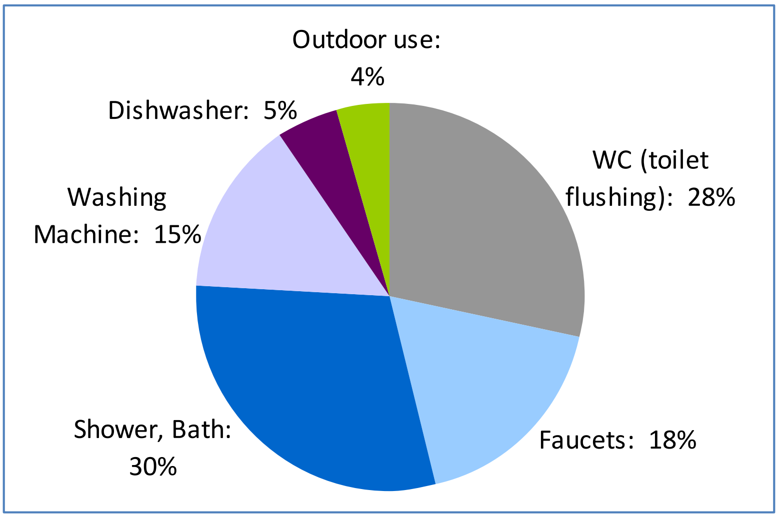


Figure 5-1: Average Water consumption share of different household micro-components in the industrialized world (based on Table **2-4**; Source: Kossida, M., 2015)

For the design of the urban cost-effectivness curve in the Al Ostuan River Basin, 7 demand management measures have been considered (targeting to introduce water savings or increase the supply): istallation of dual flush toilets (1), retrofitting of low flow taps (2), installation of efficient showerheads (3), installation of efficient washing machines (4) and dishwashers (5), istallation of rainwater harvesting (6) and domestic greywater reuse (7) systems. Tier-1 measures comprise of dual flash toilets, low flow taps and showerheads, efficient washing machines and dishwashers, while tier-2 measures additionally include rainwater harvesting and domestic greywater reuse systems. The total potential water saving if applying all tier-1 measures (i.e. creating a “water efficient house”) is estimated to reach 46.5% of the total household consumption (

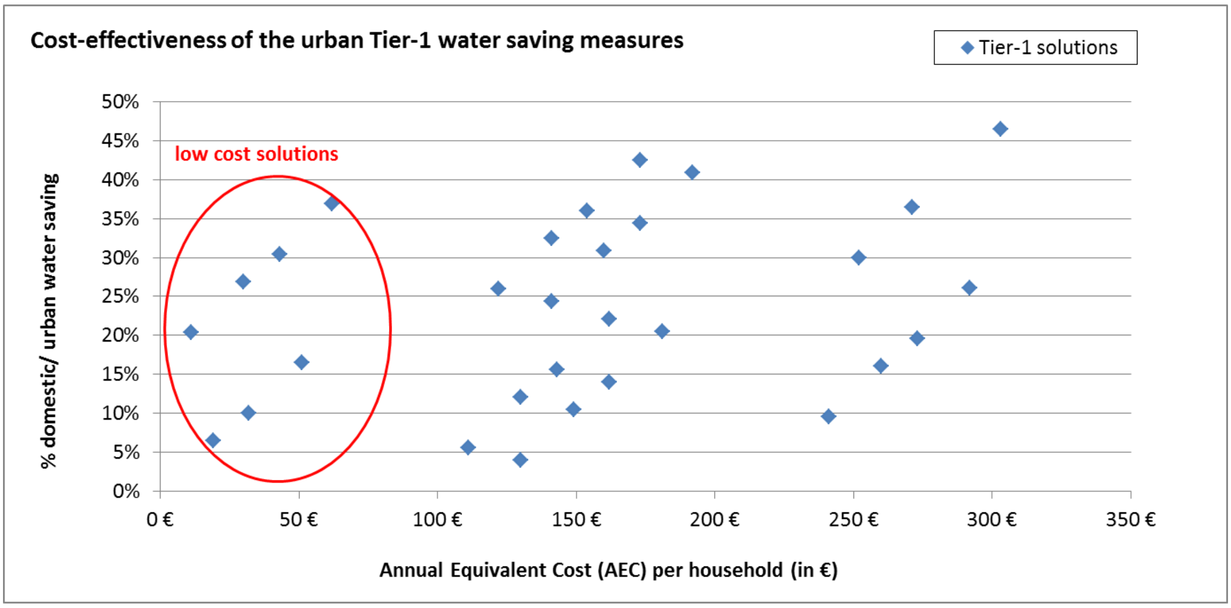


Figure 5-2.

Table 5-3). The application of additional tier-2 measures (rainwater harvesting-RWH, greywater reuse-GWR) on top of the tier-1 measures in a "water efficient" house delivers an additional 16.2% saving, thus a total of 62.7% domestic water saving potential maximum. In reality, since the rainwater harvesting and greywater reuse are expensive measures it is expected that a household would opt them after the tier-1 measures have been pursued. This assumption is considered in the calculations when building the urban cost-benefit curve. For example, the influent to the GWR system (which originates from the showers/ baths and washing machines of the "water efficient house") has been properly adjusted to account for the already achieved water saving of the tier-1 measures, and thus the influent potential volume has been accordingly decreased. As designed in the optimisation problem, the RWH performance is about 40% considering that only the rainy months can provide influent (roughly 4-4.5 months of the year in the area) and can feed this water for toilet flushing, washing clothes and outdoor use (garden irrigation, car washing, etc.). Respectively, GWR reuses the water coming from showers/baths and washing machines, and feeds this volume to toilets for flushing and outdoor use.

If all of the proposed tier-1 measures are applied in a household, the total percentage of water saved is 46.5% per household, or 11.6% per capita (assuming an average household size of 4 persons (CAS, 2012), with a respective total cost of 1,550 $ per household or 388 $ per capita. If the additional tier-2 measures are applied, the total percentage of water saved from the mains is 62.7% per household, or 15.7% per capita (assuming an average household size of 4 persons (CAS, 2012), with a respective total cost of 6,850 $ per household or 1,713 $ per capita. Since all calculations should refer to a mean annual basis (Berbel et al., 2011) the Annual Equivalent Cost (AEC) is also calculated as follows:

$$AEC = \frac{r(1+r)^n}{(1+r)^n - 1} \times Inv + OMC$$

Where, Inv represents the investment costs, OMC are the operational and maintenance costs, r is the discount rate, and n is the useful life of the or measures. A discount rate of 7% and a useful life equal to 3-10 years depending on the measure (as presented in **Table 5-2**) has been considered in the calculations, while the OMC can be ignored. The resulting AEC for each measure is pesented in Table **5-2**.

Table 5-2: Annual Equivalent Cost (AEC) of the urban demand management measures based on a 7% discount rate and their years of useful life

Water Saving Measure	Unit Cost $	r (discount rate)	n (useful life of the or measure in years)	AEC ($)
Dual Flush Toilet	170 $	0.07	7	32 $
Showerheads (1 item)	30 $	0.07	3	11 $
Low flow taps (2 items)	50 $	0.07	3	19 $
Efficient Washing machine	600 $	0.07	7	111 $
Dishwasher	700 $	0.07	7	130 $
Rainwater Harvesting	1,800 $	0.07	10	356 $
Greywater Reuse	3,500 $	0.07	10	498 $

TOTAL *per household (HH):* *per capita (cap):*	**6,850 $** 1,713 $		**1,057 $** 264 $

In order to design the optimum urban water cost-effective curve an optimization procedure was employed. The objective function criteria of the optimization problem at hand regarded a) the maximization of the % of water saving and b) the simulatenoous minimization of the cost (AEC) using a mix of the tier-1 measures (parameters; alternative options/solutions to explore). The cost-effectiveness objectives (i.e. AEC and % expected water saving) that have been used in the optimization are shown below in the last two columns of

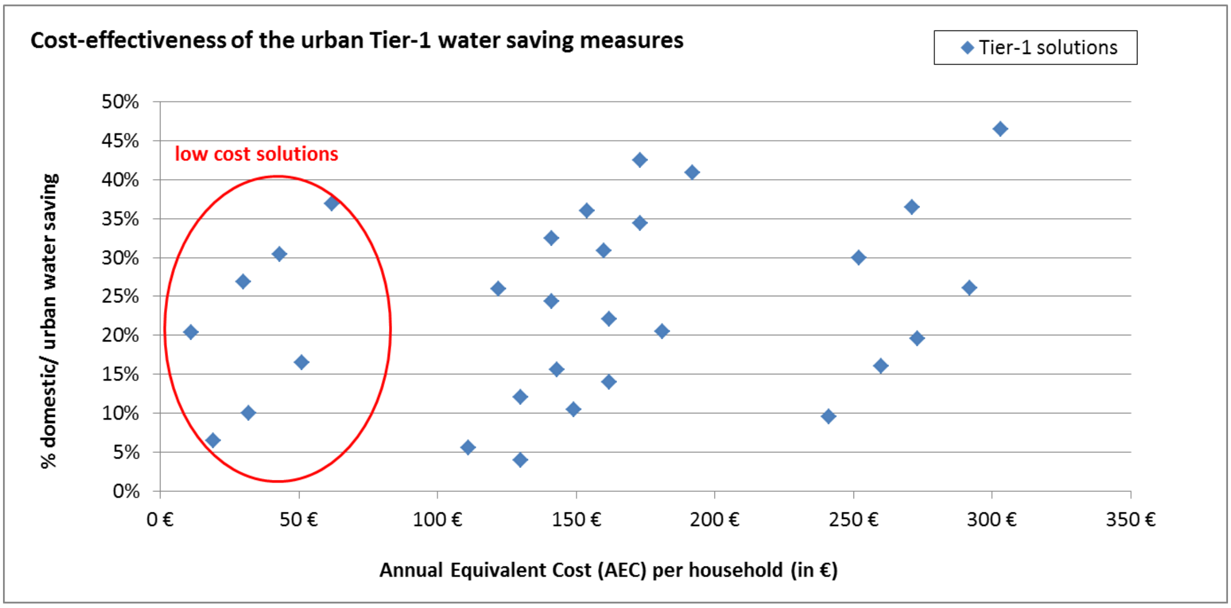


Figure **5-2**.

Table 5-3 (AEC per Household in $; Expected water saving as % of total Household consumption). The results of the optimization analysis (incl. a complete parameter space exploration analysis – i.e., detailing all investated solutions, not just the optimum one(s) identifyed by the algorithm) are presented in detail in

Table 5-4 and

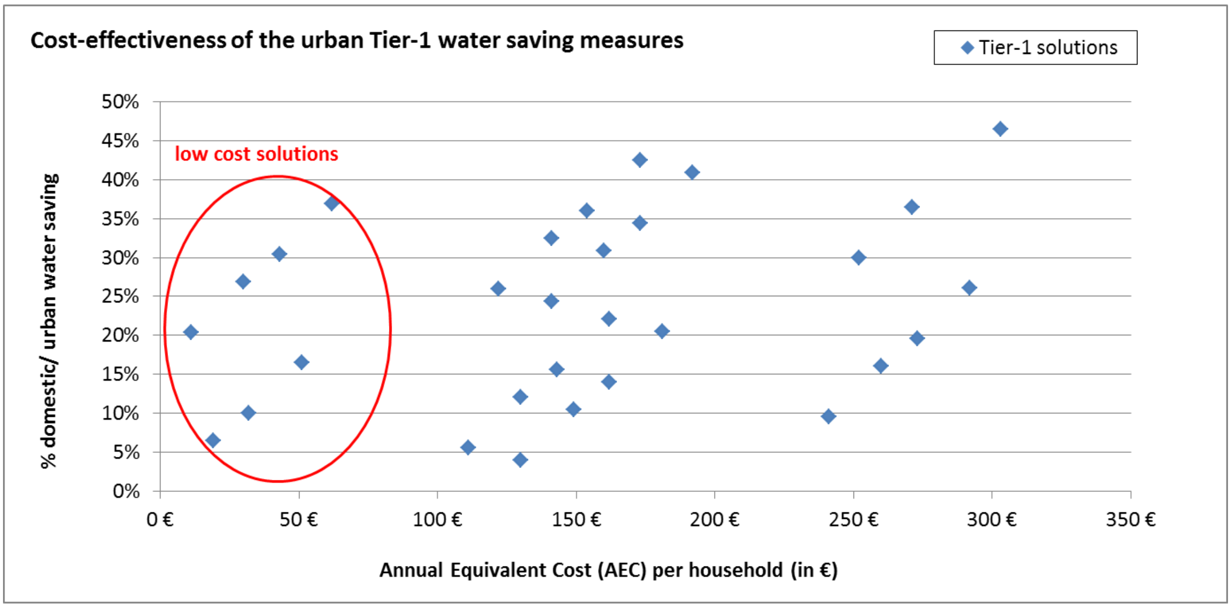


Figure 5-2.

Table 5-3: Cost-effectiveness of the demand management measures per household used in the design of the urban cost-effectiveness curves

	Water Saving Measure	Performance (% water saving per HH)	HH Micro-component targeted	HH Micro-component water consumption share (%)	Unit Cost $	AEC per HH $	Expected water saving as % of total HH consumption
Tier #1	Dual Flush Toilet	40 %	WC	25 %	170 $	32 $	10 %
	Showerheads replacement (1 item)	60 %	Bath + Shower	34 %	30 $	11 $	20.4 %
	Low flow taps (2 items)	50 %	Faucets	13 %	50 $	19 $	6.5 %
	Efficient Washing machine	40 %	Washing Machine	14 %	600 $	111 $	5.6 %
	Dishwasher	50 %	Dishwasher	8 %	700 $	130 $	4 %
			Outdoor use (garden, car washing)	6%			
Tier #1 TOTAL Per household (HH) Per capita (cap)				100 %	1,550 $ 388 $	303 $ 76 $	46.5 % 11.6 %
Tier #2	Rainwater Harvesting *(the effluent goes to: WC, washing machine, outdoor use of the tier #1 "water efficient" house)*	40 % (accounting the rainy months)	WC, washing machine, outdoors	29 %	1,800 $	256 $	11.6 %
	Greywater Reuse *(the influent originates from*	22 % *(potential influent from*	WC , outdoors	21 % (15% WC + 6% outdoors)	3,500 $	498 $	4.6 %

	shower, bath and washing machines , i.e. the 22% of the tier #1 "water efficient house", and the effluent goes to WC and outdoor use)	*shower, bath and washing machine of the "water efficient" house)*					
Tier #2 TOTAL Per household (HH) Per capita (cap)				44 %	 5,300 $ 1,325 $	 754 $ 189 $	 16.2 % 4.1 %
GRAND TOTAL				**Per household (HH) Per capita (cap)**	**6,850 $ 1,713 $**	**1,057 $ 264 $**	**62.7 % 15.7 %**

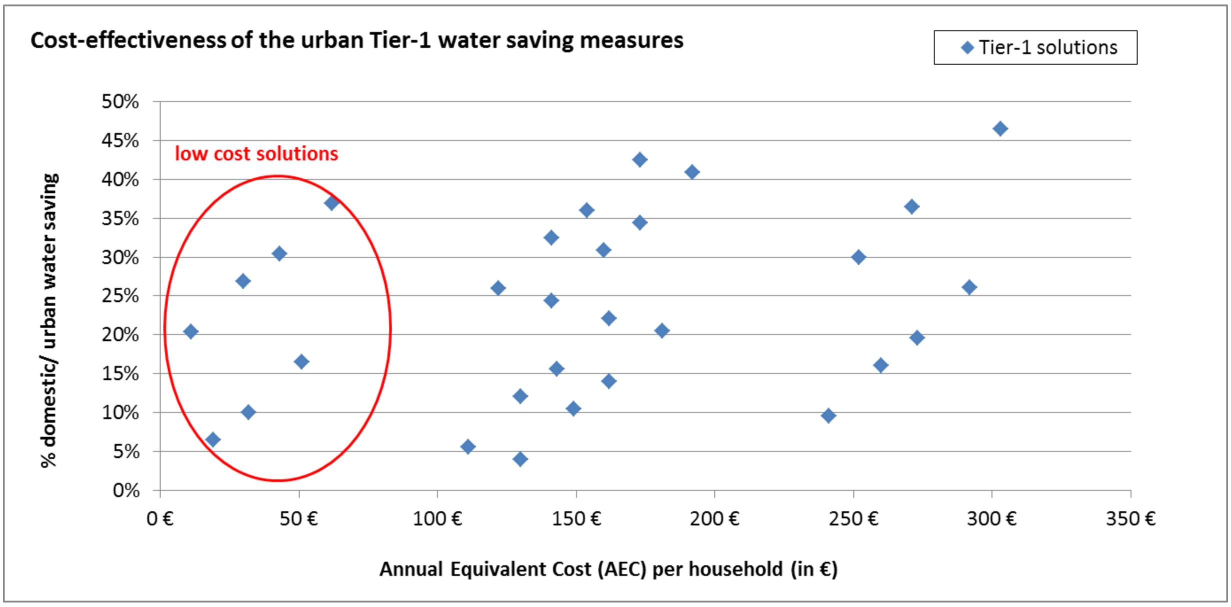


Figure 5-2: Conceptual Cost-effectiveness plot for the simulated urban water saving measures (% water saving vs. AEC per household)

As shown in **Table 5-2** above, it is relatively easy and entails relatively low cost to achieve conservation up to 37% with a cost of approximately 62 $/household AEC (or 250$ initial investment CAPEX). Assuming an average per capita consumption of 160 lt/day (or ~58 m^3 per capita per year) and an average household size of 4 people, this percentage represents a total saving of about 86 m^3 per household per year in the Al Ostuan basin, and results in an AEC unit cost of water saved of ~0.7 $/$m^3$ per household. Above that level of saving, and until the maximum level (46.5%) of water saving that can be achieved with the tier-1 measures, the cost is increasing rapidly (as clearly depicted in

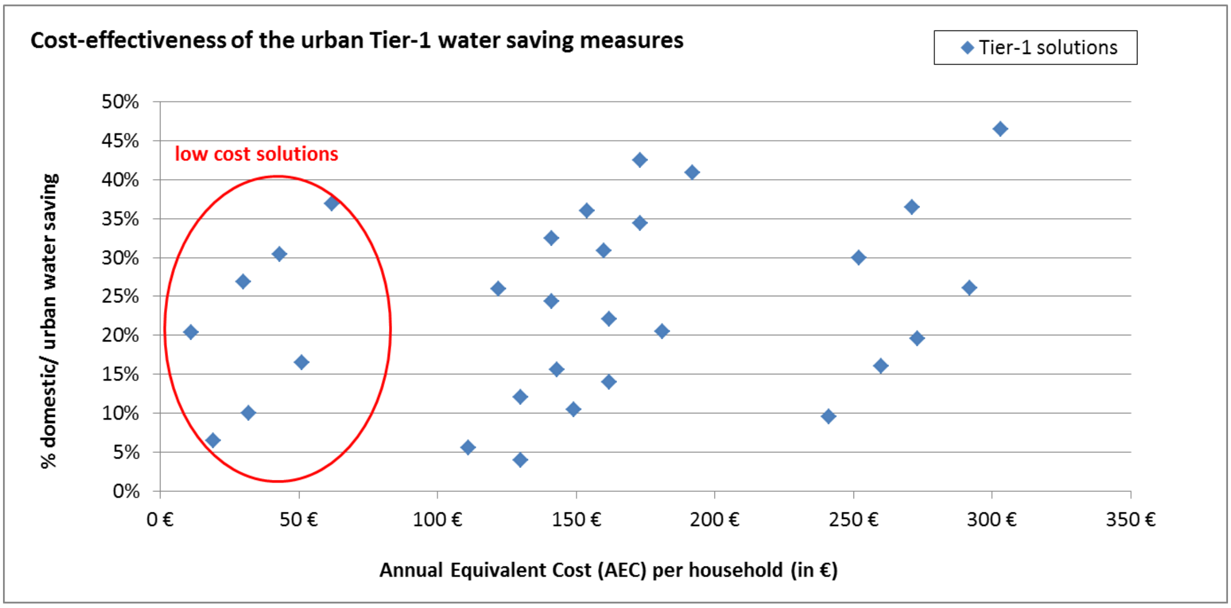


Figure 5-2). This is due to the most expensive tier-1 measures (washing machines, dishwashers). The results of the urban cost-effectiveness analysis are presented in

Table 5-4 below where the most beneficial solutions resulting from the optimization process are highlighted (light blue cells).

Table 5-4: Results of the cost-effectiveness analysis of the urban water saving measures

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m^3) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/$m^3$ of water saved	Total $/$m^3$ of water saved for the basin	Penetration (households adapting the measure)				
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*
1	11 $	30 $	20.40%	2.8 $	5.10%	1.39	0.29	0.78	0.21	0.57		√			
2	19 $	50 $	6.50%	4.8 $	1.63%	0.44	0.50	1.31	1.12	2.96			√		
3	30 $	80 $	26.90%	7.5 $	6.73%	1.83	0.78	2.09	0.43	1.14		√	√		
4	32 $	170 $	10.00%	8.0 $	2.50%	0.68	0.84	4.44	1.23	6.53	√				
5	43 $	200 $	30.40%	10.8 $	7.60%	2.07	1.12	5.23	0.54	2.53	√	√			
6	51 $	220 $	16.50%	12.8 $	4.13%	1.12	1.33	5.75	1.19	5.12	√		√		
7	62 $	250 $	36.90%	15.5 $	9.23%	2.51	1.62	6.53	0.65	2.60	√	√	√		
8	111 $	600 $	5.60%	27.8 $	1.40%	0.38	2.90	15.68	7.62	41.18				√	
9	122 $	630 $	26.00%	30.5 $	6.50%	1.77	3.19	16.47	1.80	9.31		√		√	
10	130 $	600 $	12.10%	32.5 $	3.03%	0.82	3.40	15.68	4.13	19.06			√	√	
11	130 $	700 $	4.00%	32.5 $	1.00%	0.27	3.40	18.29	12.49	67.26					√

12	141 $	680 $	32.50%	35.3 $	8.13%	2.21	3.69	17.77	1.67	8.04		√	√	√	
13	141 $	730 $	24.40%	35.3 $	6.10%	1.66	3.69	19.08	2.22	11.50		√			√
14	143 $	770 $	15.60%	35.8 $	3.90%	1.06	3.74	20.12	3.52	18.97	√			√	
15	149 $	750 $	10.50%	37.3 $	2.63%	0.71	3.89	19.60	5.45	27.45			√		√
16	154 $	800 $	36.00%	38.5 $	9.00%	2.45	4.02	20.91	1.64	8.54	√	√		√	
17	160 $	780 $	30.90%	40.0 $	7.73%	2.10	4.18	20.39	1.99	9.70		√	√		√
18	162 $	800 $	22.10%	40.5 $	5.53%	1.50	4.23	20.91	2.82	13.91	√	√		√	
19	162 $	870 $	14.00%	40.5 $	3.50%	0.95	4.23	22.74	4.45	23.88	√				√
20	173 $	850 $	42.50%	43.3 $	10.63%	2.89	4.52	22.21	1.56	7.69	√	√	√	√	
21	173 $	900 $	34.40%	43.3 $	8.60%	2.34	4.52	23.52	1.93	10.06	√	√			√
22	181 $	920 $	20.50%	45.3 $	5.13%	1.39	4.73	24.04	3.39	17.25	√		√		√
23	192 $	950 $	40.90%	48.0 $	10.23%	2.78	5.02	24.83	1.80	8.93	√	√	√		√
24	241 $	1,300 $	9.60%	60.3 $	2.40%	0.65	6.30	33.98	9.65	52.05				√	√
25	252 $	1,330 $	30.00%	63.0 $	7.50%	2.04	6.59	34.76	3.23	17.04		√		√	√
26	260 $	1,350 $	16.10%	65.0 $	4.03%	1.09	6.80	35.28	6.21	32.23			√	√	√
27	271 $	1,380 $	36.50%	67.8 $	9.13%	2.48	7.08	36.07	2.85	14.53		√	√	√	√
28	273 $	1,470 $	19.60%	68.3 $	4.90%	1.33	7.13	38.42	5.35	28.83	√			√	√
29	292 $	1,520 $	26.10%	73.0 $	6.53%	1.77	7.63	39.73	4.30	22.38	√		√	√	√
30	303 $	1,550 $	46.50%	75.8 $	11.63%	3.16	7.92	40.51	2.50	12.81	√	√	√	√	√

* The total water saving is based on the annual urban water demand in the Al Ostuan basin for the reference period 2003-2018, which sums up at 6.8 million m^3.

* The total AEC is obtained by multiplying the AEC per household (HH) with the total number of households. The later has been estimated to account 26,135 household in the Al Ostuan basin assuming each household is occupied by 4 people on average (number of hh = total population ÷ 4)

The Business as Usual (BaU) represents the current situation, thus no measures are adopted, water saving is 0%, and the unmet demand remains at current levels. With a very low cost, of about 10 $/household AEC, a 20.4% saving of the urban water use can be achieved. This solution (solution No. #1) requires the installation of low-flow showerheads (1 item) in the households in the area. A 27% saving can be achieved with an AEC of 30 $/hh and requires the installation of low-flow showerheads (1 item) and low-flow taps (2 items) in the households in the area (solution No. #3). The total AEC in this case reaches 0.78 million $ with a total water saving of 1.83 mio m^3, thus a unit cost of 0.43 $ AEC/m^3 of water saved. Respectively, with an AEC unit cost of 0.54 $/$m^3$ of water saved (or AEC 43 $/hh) 30.4% of the urban water can be saved (i.e. 2.07 mio m^3 in total) (solution No. #5). The latter requires the penetration of low-flow showerheads (1 item) and dual flush toilets. With a slightly higher AEC of 0.65 $/$m^3$ of water saved (or AEC 62 $/hh) 37% of water can be saved (i.e. 2.51 mio m3 in total and with a respective total cost of AEC 1.6 million $) (solution No. #7). The latter requires the penetration of three technologies, namely dual flush toilets, low-flow showerheads (1 item) and low-flow taps (2 items) in the households in the area. Beyond this level, the annual equivalent unit cost in $/$m^3$ of water saved exceeds 1$ so the solutions cannot be considered as “quick-wins”, while after some point the urban measures become too expensive, possibly more than the actual cost of water (e.g. solutions No. #24 and #26 where the AEC unit costs are higher than 5$/$m^3$ of water saved) which constraints their uptake by the public. An exemption might be solution No. #20, where a high saving of 42.5% (almost equal to the maximum potential saving that can be achieved with tier-1 measures) can be reached with an AEC of 173$ per household (the respective unit AEC is 1.56 $/m^3 of water saved), resulting thus in a total saving of 2.89 million m^3 in the urban sector (i.e.. This solution requires the penetration of four technologies, namely dual flush toilets, low-flow showerheads (1 item), low-flow taps (2 items) and efficient washing machines (1 item) in the households in the area.

It is important to highlight that the unit cost (i.e. the cost required to save 1 m^3 of water) is an important parameter as it can create incentives or disincentives. As the implementation of the urban saving measures depends on the people and their behavior, low unit costs, which are lower than the existing water tariffs, would normally encourage people to implement them. Figure **5-3** presents the annual equivalent unit cost (i.e. $ per m^3 of water saved) of the different solutions plotted against the total potential water saving in the area.

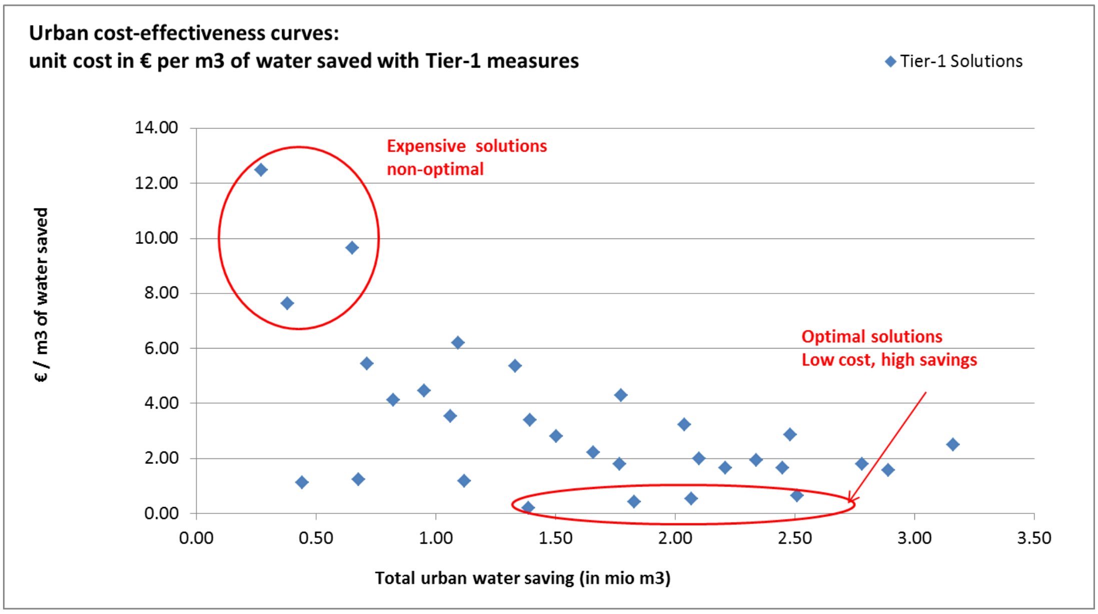


Figure 5-3: Cost-effectiveness curves for the simulated Tier-1 urban measures in $/m^3 of water saved

At the same time, we need of course to consider the capital investment, i.e. the CAPEX which needs to be paid up-front, either by each household or through programmes, incentives, subsidies, etc. Looking at the total investment needed for the basin (CAPEX in mio $), we can observe (as presented in **Table 5-4**) that with CAPEX < 1 million $ (more specifically with 0.78 million $) 20.4% of the domestic water used (i.e. 1.4 mio m^3) could be saved if efficient showerheads are installed in all the households. To achieve 30% savings (i.e. save ~2 mio m^3 in the basin) the necessary CAPEX is about 5.2 million $ and requires the installation of efficient showerheads plus dual flash toilets, while for a 37% saving (i.e. save 2.5 mio m^3 in the basin) the necessary CAPEX is 6.5 million $ (requires the installation of efficient showerheads, dual flash toilets and 2 low flow taps in each household) . A 42.5% saving (i.e. save 2.9 mio m^3 in the basin) can also be achieved but the CAPEX goes up to 22 million $ which is considered disproportionally high in terms of added value as compared to the previous solutions.

Regarding the application of the additional tier-2 measures (rainwater harvesting (RWH) and greywater reuse (GWR)), these have been investigated, as previously mentioned, on top of the tier 1 measures, i.e. in a “water efficient” house. The five tier-1 solutions that have been previously selected as the most beneficial (i.e. solutions No. #1, 3, 5, 7, 20 of

Table **5-4**) have been further examined with the additional application of RWH and GWR. The results are presented in **Table 5-5** below, where the most beneficial solutions are also marked (light blue cells). It can be generally observed (**Table 5-5**, **Figure 5-4**, **Figure 5-5**) that the mixed solutions which contain rainwater harvesting (Tier-1 + RWH) present a better performance as compared the mixed solutions which contain greywater reuse (Tier-1 + GWR), The fully mixed solutions with both rainwater harvesting and greywater reuse (Tier-1 + RWH + GWR) are, as expected, the most expensive, but can deliver up to 59% water saving maximum (with a respective AEC 927 $ per household).

Table 5-5: Results of the cost-effectiveness analysis of the urban increase supply measures

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m³) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/m³ of water saved	Total $/m³ of water saved for the basin	Penetration (households adapting the measure)						
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*	*Rainwater Harvesting (RWH)*	*Greywater Reuse (GWR)*
1r	267 $	1,830 $	32.00%	66.8 $	8.00%	2.18	6.98	47.83	3.21	21.98		√				√	
1w	509 $	3,530 $	25.00%	127.3 $	6.25%	1.70	13.30	92.26	7.83	54.27		√					√
1m	765 $	5,330 $	36.60%	191.3 $	9.15%	2.49	19.99	139.30	8.03	55.97		√				√	√
3r	286 $	1,880 $	38.50%	71.5 $	9.63%	2.62	7.47	49.13	2.86	18.77		√	√			√	
3w	528 $	3,580 $	31.50%	132.0 $	7.88%	2.14	13.80	93.56	6.44	43.68		√	√				√
3m	784 $	5,380 $	43.10%	196.0 $	10.78%	2.93	20.49	140.61	6.99	47.98		√	√			√	√
5r	299 $	2,000 $	42.00%	74.8 $	10.50%	2.86	7.81	52.27	2.74	18.30	√	√				√	
5w	541 $	3,360 $	35.00%	135.3 $	8.75%	2.38	14.14	87.81	5.94	36.90	√	√					√
5m	797 $	5,500 $	46.60%	199.3 $	11.65%	3.17	20.83	143.74	6.57	45.36	√	√				√	√
7r	318 $	2,050 $	48.50%	79.5 $	12.13%	3.30	8.31	53.58	2.52	16.25	√	√	√			√	
7w	560 $	3,750 $	41.50%	140.0 $	10.38%	2.82	14.64	98.01	5.19	34.73	√	√	√				√
7m	816 $	5,550 $	53.10%	204.0 $	13.28%	3.61	21.33	145.05	5.91	40.17	√	√	√			√	√
20r	429 $	2,650 $	54.10%	107.3 $	13.53%	3.68	11.21	69.26	3.05	18.83	√	√	√	√		√	
20w	671 $	4,350 $	47.10%	167.8 $	11.78%	3.20	17.54	113.69	5.48	35.50	√	√	√	√			√
20m	927 $	6,150 $	58.70%	231.8 $	14.68%	3.99	24.23	160.73	6.07	40.27	√	√	√	√		√	√

31	256 $	1,800 $	11.60%	64.0 $	2.90%	0.79	6.69	47.04	8.48	59.64						√	
32	498 $	3,500 $	4.60%	124.5 $	1.15%	0.31	13.02	91.47	41.61	292.43							√
33	754 $	5,300 $	16.20%	188.5 $	4.05%	1.10	19.71	138.52	17.89	125.74						√	√

Note: “r” denotes a solution with rainwater harvesting, “w” with greywater reuse, and “m” with both

* The total water saving is based on the annual urban water demand in the Al Ostuan basin for the reference period 2003-2018, which sums up at 6.8 million m^3.

** The total AEC is obtained by multiplying the AEC per household (HH) with the total number of households. The later has been estimated to account 26,135 household in the Al Ostuan basin assuming each household is occupied by 4 people on average (number of hh = total population ÷ 4)

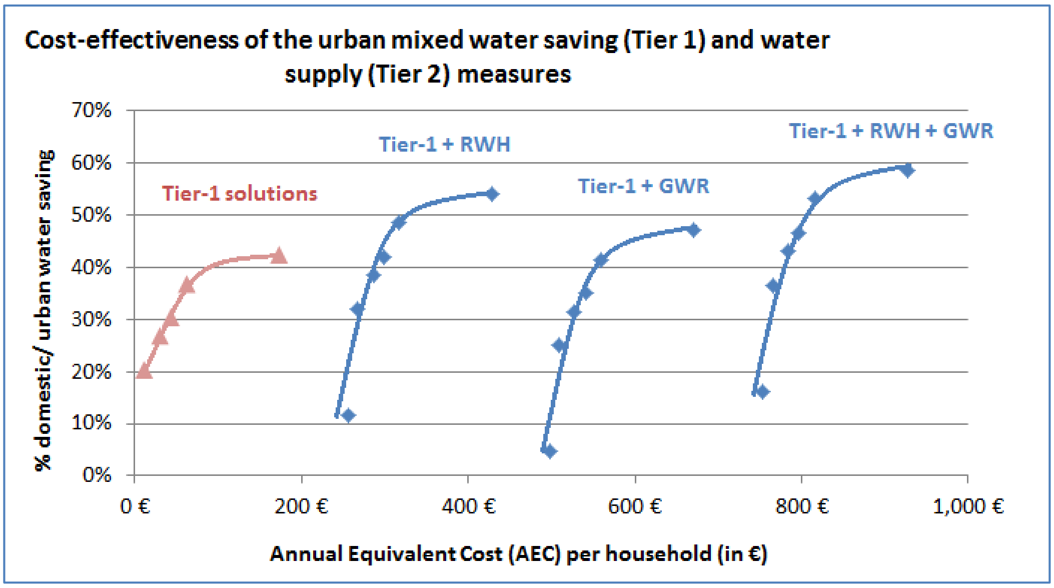


Figure 5-4: Cost-effectiveness plot for the simulated urban increase supply measures (% water saving vs. AEC per household)

The optimal solutions, in terms of cost-effectiveness, are solutions No. 7r and 20r, since they deliver among the highest water savings (48.50% and 54.10% respectively) with the lowest unit costs of AEC 2.52 and 3.05 \$/m^3 of water saved (or AEC 318\$ and 429\$ per household). These measures can render in the basin total water savings of 3.30 and 3.68 million m^3 respectively. For this to be achieved, solution No. 7r requires the penetration of dual flash toilets, low-flow showerheads (1 item), low-flow taps (2 items) and rainwater harvesting in the households in the area, while solution No. 20r also includes the installation of efficient washing machines on top of the aforementioned technologies.

Additional solutions which are considered of good performance are the solutions No. 7w, 20w, and 20m. A 41.5% saving can be achieved with an AEC of 560 \$/hh and requires the installation of dual flash toilets, low-flow showerheads (1 item), low-flow taps (2 items) and greywater reuse in the households in the area (solution No. #7w). The total AEC in this case reaches 14.64 million \$ with a total water saving of 2.82 million m^3, thus a unit AEC of 5.19 \$/m^3 of water saved. This solution is the cheapest among all solutions which contain greywater reuse. A slightly higher total water saving of 3.20 million m^3 (representing 47.1% savings) with a slightly higher unit cost of 5.48 \$/m^3 of water saved (or AEC 671\$/hh) can be achieved with solution No. 20w. This solution requires the penetration of dual flash toilets, low-flow showerheads (1 item), low-flow taps (2 items), efficient washing machine and greywater reuse in the households in the area. Although the solutions 7w and 20w are more expensive than their equivalents 7r and 7w which suggest rainwater harvesting instead of the greywater reuse, we have kept them as options to allow for diversity and flexibility in cases that RWH is not a feasible solution from a technical or social/ cultural perspective. Finally, solution No. 20m which additionally requires the installations of rainwater harvesting on top of all the technologies of the previous 20w solution, brings the maximum water saving potential of 4 million m^3 in the basin (representing 58.7% savings) with a unit AEC of 6 $/$m^3$ of water saved (or AEC 917$/hh). The penetration of the 20m solution in all the households in the basin would require a total AEC of 24 million $.

At the same time, we need also to consider the capital investment for the Tier-2 measures, i.e. the CAPEX which needs to be paid up-front, either by each household or through programmes, incentives, subsidies, etc. Looking at the total investment needed for the basin (CAPEX in mio $), we can observe (as presented in **Table 5-5**) that when we implement the Tier-2 the minimum CAPEX required is about 48 million $. The solution 7r which delivers a total saving of 3.3 million m^3 in the basin requires a CAPEX of 53.6 million $ for the entire basin or 2,050$ per household. To achieve the maximum saving of 4 million m^3 in the basin (representing 58.7% savings) with the solution 20m, the required CAPEX is 160.7 million $ for the entire basin or 6,150$ per household. It is thus clear that all the Tier-2 solutions bear higher costs, especially higher initial investment costs, and might not be considered by the public as the most cost-effective ones, but they bring the additional benefit of reducing the user's dependency from the mains and the public water supply system since the user has a decentralized alternative water supply source.

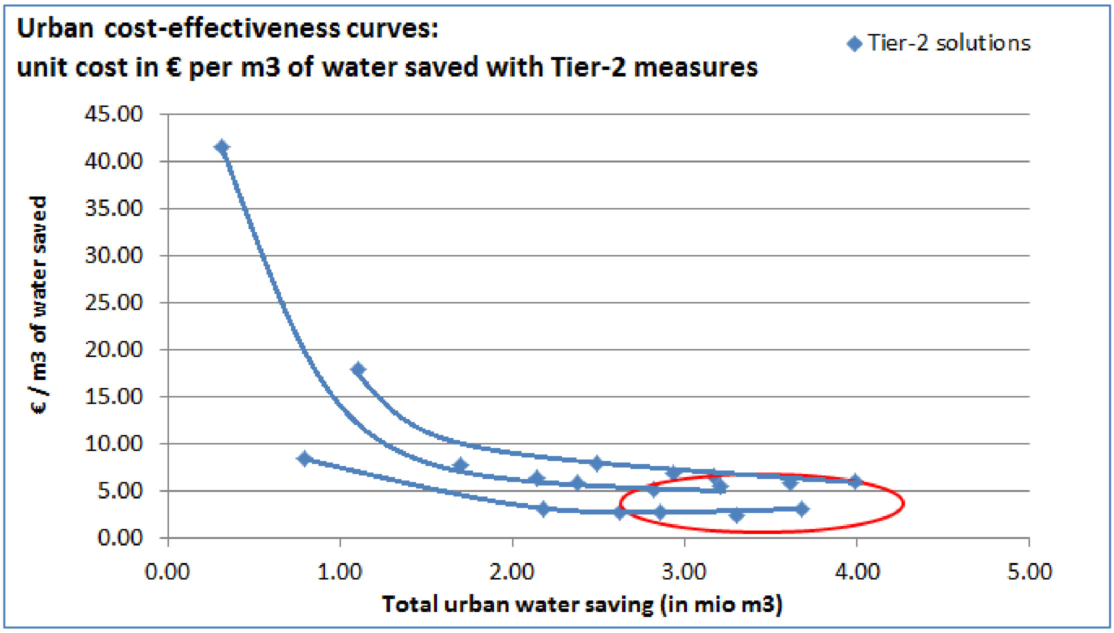


Figure 5-5: Cost-effectiveness curves for the simulated Tier-2 urban measures in $/$m^3$ of water saved

It is also important to notice that for the most successful application of the domestic/ urban measures water metering is essential. In order to pragmatically quantify the water savings delivered by the investigated technologies metering, both prior to and after the implementation of the measures, is important since it will allow the comparison between the two. Additionally, metering helps in detecting leakage which is a very important component of water demand management.

Water leakage from the public supply network has been simulated assuming a 10% reduction in losses (i.e. from the BaU 30% to 20%).

4.3 ANALYSIS OF THE AGRICULTURAL MEASURES - DESIGN OF THE COST-EFFECTIVENESS CURVES

The cost-effective functions for irrigation investigate and try to find the optimum trade-off between various conveyance and field application irrigation methods. The investigation in the Al Ostuan focuses on how much the field application efficiency would be improved in an irrigated area if different irrigation methods are used which can potentially deliver highest efficiency with the minimum possible cost, and if different conveyance methods are used. Two main measures have been considered: (a) converting from furrow (surface) irrigation to drip irrigation, (b) converting from open channels to closed pipes, or from individual to collective networks and improving thus the conveyance efficiency. These transactions from one method to another (field application or conveyance method) are subject of constraints and cannot exceed their initial values. Every transaction from one method to another has a different effectiveness and a different cost. The transactions examined for the Al Ostuan are those aiming to improve both the field application efficiency and the irrigation network conveyance efficiency.

In order to run a scenario-based (i.e., using a discrete state space of solutions) optimisation process the start-up efficiency values have been defined. Typical aggregated values for irrigation efficiency are presented in **Table 5-6**, while the costs for converting to drip irrigation and converting from open canals to closed pipes are presented in **Table 5-7** and **Table 5-8**, and have been defined after a detailed literature review. As seen, the small individual networks (closed pipes) which are drip irrigated have the highest efficiency and that is due to their conveyance efficiency being very high (95%). Regarding the costs, since all calculations should refer to a mean annual basis (Berbel et al., 2011) the Annual Equivalent Cost (AEC) is also calculated (similarly to the urban curve) as follows:

$$AEC = \frac{r(1+r)^n}{(1+r)^n - 1} \times Inv + OMC$$

Where, Inv represents the investment costs, OMC are the operational and maintenance costs, r is the discount rate, and n is the useful life of the or measures. A discount rate of 7% and a useful life equal to 3-50 years depending on the measure has been considered in the calculations, while the OMC can be ignored.

Table 5-6: Typical literature values for aggregated irrigation efficiency (conveyance and fieldapplication)

Irrigation Efficiency	Drip	Sprinkler	Furrow

Closed Pipes	Collective Networks	76.0%	68.0%	52.0%
	Small individual networks	90.3%	80.8%	61.8%
Open Channels	Collective Networks	57.0%	51.0%	39.0%
	Small individual networks	-	-	-

Source: Kossida, M., 2015

Table 5-7: Typical costs associated with converting to drip irrigation

References/ Sources	Cost ($/ha)	Lifespan (yrs)	AEC ($/ha)
Robertson et al., 2006	890	5.5	200
Payero et al., 2005	1,480	20	140
Letey et al., 1990	1,627	8	273
Amosson et al., 2011	2,135	20	202
Lower Arkansas Valley Water Conservancy District (LAVWCD)	2,669	20	252
Kazantzis, 2011	3,068	20	290
Economic calculator for irrigation systems (EconCalc)	3,720	20	351
Guilherme et al, 2015	4,000	20	378
Lamm et al., 2002; Economic comparison tool for Center Pivot and SDI	4,330	20	409
State of Queensland, 2011	5,400	20	510
Economic calculator for irrigation systems (EconCalc)	5,420	20	512
Lourmas et al., 2012	6,886	20	650
Average cost (suggested for the modeling)			**347 $/ha AEC 3,680 $/ha CAPEX**

Source: Kossida, M., 2015

Table 5-8: Typical costs associated with increasing conveyance efficiency (converting from open channels to closed pipes**)**

Cost items	Cost per hectare ($/ha)
Total cost for moving from open channels to closed pipes	6,000
AEC (for a useful life n=50 years, and r=0.07)	435
Savings from slight yield increase of 2-4%	-37
Savings from energy bills (reduced pumping)	-8
Net total cost to converting to closed pipes (suggested for modeling)	**390 $/ha AEC**

Source: Kossida, M., 2015 (adopted from Panagopoulos et al., 2012)

In the Lebanese National Water Sector Strategy (NWSS) update 2020 the conversion from open channels to closed canals to increase the conveyance efficiency has been prioritized as a measure (NWSS page VA4 volume V reference to this priority; NWSS page VB66 volume V reference to specific projects). In the NWSS update 2020, Volume V "Proposed Projects", the following projects are proposed for NLWE (**Table 5-9**). The resulting unit cost per km of concrete pipe (including design and supervision) ranges from ~100,000 $/km to ~255,000 $/km. It is not possible to estimate the equivalent cost per hectare, but if we assume that 3 km of pipe are needed on average per 1km^2 of irrigates land (i.e. per 100 hectares), then the resulting unit cost per hectare is 3,000 – 7,600 $/ha.

Table 5-9: Costs of the planned irrigation projects in the NWSS 2020 (converting from open channels to closed pipes**)**

System	Project Description	Total with design and supervision (USD)	Project Justification
Priority 1			
Omar El Breikat Scheme	18 km Earth channels to concrete	1,821,080	Justified in order to increase canal conveyance efficiency by rehabilitation of existing poorly maintained concrete channels and converting earth canals to concrete structures; by selecting this (these) project(s) negative water balance at farm level will be mitigated
El Koubayat Scheme	- 1.5 km Concrete channels to rehabilitate - 15 km Earth channels to concrete	2,506,993	
Bouqaiaa -Machta Hamoud -Machta Hassan Scheme	42 km Earth channels to concrete	10,687,115	
Priority 3			
Akkar plain Scheme	- 50 m Concrete channels to rehabilitate - 78 km Earth channels to concrete - Extention of Networks to Cover Present Dry Farm Area	29,994,518	Justified in order to increase scheme total area, and direct increase of beneficiaries number. The project(s) will lead to a horizontal expansion since arable land presence is not a limiting factor
Akkar el Atika Scheme	- 2 km Concrete channels to rehabilitate - 29 km Earth channels to concrete - Extention of Networks to Cover Present Dry Farm Area	5,688,774	

In the Al Ostuan basin farmers apply surface irrigation and drip irrigation as indicated by a Survey conducted with 22 Municipalities in the area. The irrigation efficiencies used in the optimisation process for the Al Ostuan, for the combination of various conveyance and irrigation methods, have been formulated as presented in the **Table 5-10** below. The combined efficiency for the Baseline was set to 60%. It has been assumed that 38% of the total irrigated area has collective networks, and the remaining 62% has small individual networks. One percent (1%) of the collective ones are equiped with closed pipes, while 37% has open canals. The dominant irrigation method is furrow (surface) irrigation (in 78% of the areas), followed by sprinklers (155), while only 7% is drip. The current (Baseline) aggregated field application efficiency (considering the above-mentioned assumptions) is thus calculated at ~63%. The coveyance losses are estimated to 10% for the closed-pipe collective networks, 35% for the small individual networks (groundwater wells), and 55% for the open-channel collective networks. Thus, based on the current mix, the aggreagated conveyance efficiency (used in the Baseline) is ~58% (i.e. 42% losses). The areas occupied by each irrigated crop wihtin each subcatchemnt of the Al Ostuan basin are presented in **Table 5-11**.

Table 5-10: Irrigation efficiency assumptions in the Al Ostuan river basin for the Baseline

Conveyance networks and irrigation methods	% coverage of the irrigated area	% losses	% conveyence efficiency
Collective Networks - Closed Pipes	1%	10%	90%
Collective Networks - Open Channels	37%	55%	45%
Small individual networks - Groundwater wells	62%	35%	65%
Aggregated network conveyance efficiency	(1% x 0.9) + (37% x 0.45) + (62% x 0.65) = **57.85% or 42.15% losses**		
Drip irrigation	7%	20%	80%
Sprinklers' irrigation	15%	30%	70%
Furrow irrigation	78%	40%	60%
Aggregated field application efficiency	(7% x 0.8) + (15% x 0.7) + (78% x 0.6) = **62.90% or 37.10% losses**		
Overall combined irrigation efficiency = 60.38%, i.e. 60%			

Note: these figures have been determined in the "Baseline Report on the assessment of the current water resources on the Nahr Al Ostuan Basin" of this study, after investigating multiple sources (as presented in Box 4.3 of the Baseline Report),including the NWSS 2012 and 2020 update, interviews with the NLWE, MEW, MoA, Municipalities, local farmers, agronomists

.

Table 5-11: Irrigated areas per crop type in the Al Ostuan river basin

Catchment	Irrigated crops	irrigated area per crop (km^2)	% of irrigated crop
C15	Field Crops in Medium to Large Terrace	2.08	68%
	Olives	0.03	1%
	Vineyards	0.02	1%
	Fruit Trees	0.02	1%
	Citrus Fruit Trees	0.84	27%
	Protected Agriculture	0.08	3%
C16	Field Crops in Medium to Large Terrace	0.80	35%
	Olives	1.41	62%
	Citrus Fruit Trees	0.01	1%
	Protected Agriculture	0.06	3%
C17	Field Crops in Medium to Large Terrace	0.03	4%
	Olives	0.83	92%
	Fruit Trees	0.04	4%
C18	Field Crops in Medium to Large Terrace	0.42	29%
	Olives	1.01	69%
	Fruit Trees	0.02	1.6%
	Citrus Fruit Trees	0.01	0.4%
C19	Field Crops in Medium to Large Terrace	0.92	47%
	Olives	0.36	18%
	Fruit Trees	0.69	35%

C20	Field Crops in Medium to Large Terrace Olives Fruit Trees	0.01 0.05 0.07	4% 42% 54%
C21	Field Crops in Small Fields/Terrace Olives Fruit Trees	0.36 0.21 0.17	49% 28% 23%
C22	Field Crops in Medium to Large Terrace Citrus Fruit Trees Protected Agriculture	7.32 1.64 0.77	75% 17% 8%
TOTAL =	**20.30 km^2 or 2,030 hectares**		

For the simulation of the agricultural saving measures two scenarios have been considered: a 20% increase in the irrigation efficiency (reaching thus a combined efficiency of 80%) and a 25% increase in the irrigation efficiency (reaching thus a combined efficiency of 85%), by converting a number of hectares to closed pipes and drip irrigation as presented in

Table 5-12. In the first case (i.e. 20% increase) an additional of 1,502 ha need to be conveyed with closed pipes and 1,482 need to convert to drip irrigation from surface. With an AEC of 390 $/ha and 347 $/ha respectively (see **Table 5-8**) the total AEC for this scenario is 1.1 million $, while the total initial investment is 14.5 million $. Similarly, for a 25% increase in the irrigation efficiency, an additional of 1,969 ha need to be conveyed with closed pipes and 1,847 need to convert to drip irrigation from surface, while the required AEC is 1.4 million $ and the CAPEX is 18.6 million $.

Table 5-12: Total hectares per conveyance type and irrigation method in the baseline scenario and under increased efficiency scenarios

Conveyance networks and irrigation methods	Efficiency 60% (Baseline)		Efficiency 80% (+20% increase)		Efficiency 85% (+25% increase)	
Conveyance networks	**% ha**	**ha**	**% ha**	**ha**	**% ha**	**ha**
Collective Networks - Closed Pipes	1%	20.30	75%	1522.50	98%	1989.40
Collective Networks - Open Channels	37%	751.10	5%	101.50	0%	0.00
Small individual networks - Groundwater wells	62%	1258.60	20%	406.00	2%	40.60
Irrigation methods	**%**	**ha**	**%**	**ha**	**%**	**ha**
Drip irrigation	7%	142.10	80%	1624.00	98%	1989.40
Sprinklers' irrigation	15%	304.50	10%	203.00	0%	0.00
Furrow irrigation	78%	1583.40	10%	203.00	2%	40.60
** Total irrigated hectares in the basin = 2,030 ha*						

5 SIMULATION OF THE MEASURES IN THE WEAP21 MODEL OF THE AL OSTUAN RIVER BASIN

5.1 Scenario UrbSav

The Scenario UrbSav focuses on water saving in the domestic/urban sector

Measures included	U1. Low water using fixtures and appliances (including hotels)
Implementation	The measures have been applied in all the 20 urban demand nodes. Node #21 (UD_ Danke-Qsair) is a water export of a fixed volume (7,200 m^3/month) and it was kept constant, assuming that since it is outside the Al Ostuan River Basin the saving measures will not be applied there. The baseline (BaU) was the reference period 2003-2018, where the average annual urban demand was 6.8 million m^3.

Node #	Urban Demand Node	Villages within the Node	Total Node Population in WEAP, ORB
1	UD_22_NPS	Al-Kleiat Cheikh Zennad Tal Bibe Al-Kneisse Al Moghrak Tal Kerri Al-Hissa Al-Massoudie	7,190
2	UD_15	Halba Tal Abbas El-Gharbie Koueikhat Tal Abbas El-Charkie Al-Massoudie Al-Khraibe	3,009
3	UD_16_Kob.Charbila	Charbila Ain El-Zeit El-Daghle Kherbet Daoud El-Msalle Kefr El-Ftouh	13,468
4	UD_16_Kob.Daouce	El-Kouachra Daouce et Baghdadi Denke et El-Amriyeh El-Bire	15,658

	5	UD_16_NPS	Katte Al-Rihanie El-Tleil Omar el-Beikate El-Haouchab Hmais Saidnaya Al-Khraibe	6,652	
	6	UD_17_Ext	Dahr-Leycine Machha Hayzouk	7,614	
	7	UD_17_Kob.Harra	Kfar Harra	270	
	8	UD_17_NPS	Al-Souaisse Dahr el-Kneisse Al-Khraibe	4,401	
	9	UD_18_Kob.Charbila	Ain Tanta Douair Adouiye	3,202	
	10	UD_18_Kob.Harra	El-Hed Deir-Janine Sfeinite El-Dreibe Kherbet Char Fseikine et Ain Achma Barbara Mazraat Balde	8,239	
	11	UD_18_Ext	Beino	2,052	
	12	UD_18_NPS	Majdel	1,601	
	13	UD_19_Kob.Bire	Sindianet Zeidan	744	
	14	UD_19_PWS	El-Koubayet	4,876	
	15	UD_19_NPS	Majdel Daoura Andeket Akkar El-Atika	7,412	
	16	UD_20_NPS	Andeket	168	
	17	UD_20_PWS	Akkar El-Atika	8,304	
	18	UD_21_KobVillage_Jawz	El-Koubayet	5,319	
	19	UD_21_Qatlabah_Hamade	El-Koubayet	1,330	
	20	UD_21_NPS	Akkar El-Atika	3,019	

Simulation parameters

Based on the cost-effectiveness analysis of the urban water saving measures (ref. to Chapter 3.2), the following 5 solutions are considered as optimum (see table below) and have been simulated in WEAP.

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m^3) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/$m^3$ of water saved	Total $/$m^3$ of water saved for the basin	*Penetration (households adapting the measure)*				
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*
1	11 $	30 $	20.40%	2.8 $	5.10%	1.39	0.29	0.78	0.21	0.57		√			
3	30 $	80 $	26.90%	7.5 $	6.73%	1.83	0.78	2.09	0.4	1.14		√	√		
5	43 $	200 $	30.40%	10.8 $	7.60%	2.07	1.12	5.23	0.54	2.53	√	√			
7	62 $	250 $	36.90%	15.5 $	9.23%	2.51	1.62	6.53	0.65	2.60	√	√	√		
20	173 $	850 $	42.50%	43.3 $	10.63%	2.89	4.52	22.21	1.56	7.69	√	√	√	√	

* The total water saving is based on the annual urban water demand in the Al Ostuan basin for the reference period 2003-2018, which sums up at 6.8 million m^3.

* The total AEC is obtained by multiplying the AEC per household (HH) with the total number of households. The later has been estimated to account 26,135 household in the Al Ostuan basin assuming each household is occupied by 4 people on average (number of hh = total population ÷ 4)

These solutions have been simulated In WEAP in the 20 demand sites mentioned above, based on the following formulas:

- Solution No. #1: multiply water demand by (1-0.051) in all 20 sites, or apply DSM saving per capita 5.10% in the tab Demand Sites and Catchments/Demand Management/DSM Savings

	▪ Solution No. #3: multiply water demand by (1-0.0673) in all 20 sites, or apply DSM saving per capita 6.73% in the tab Demand Sites and Catchments/Demand Management/DSM Savings ▪ Solution No. #5: multiply water demand by (1-0.076) in all 20 sites, or apply DSM saving per capita 7.60% in the tab Demand Sites and Catchments/Demand Management/DSM Savings ▪ Solution No. #7: multiply water demand by (1-0.0923) in all 20 sites, or apply DSM saving per capita 9.23% in the tab Demand Sites and Catchments/Demand Management/DSM Savings ▪ Solution No. #20: multiply water demand by (1-0.1063) in all 20 sites, or apply DSM saving per capita 10.63% in the tab Demand Sites and Catchments/Demand Management/DSM Savings For each solution the change in the model results, in terms of unmet demand and potential water excess (resulting from all 20 demand sites as a sum), has been investigated. Since in the WEAP model the resources and supply are interconnected, the reduction in demand in one site may increase water availability in another location.

5.2 Scenario AgrSav

The Scenario AgrSav focuses on water saving in the agricultural sector

<table>
<tr><td>Measures included</td><td>A1. Increase the irrigation efficiency through converting to closed pipes and drip irrigation systems at the farm level</td></tr>
<tr><td>Implementation</td><td>The measures have been applied in all the 8 agricultural demand nodes, i.e. in a total of area of 2,030 irrigated hectares (of which: 1,194 ha Field Crops in Medium to Large Terrace, 390 ha Olives, 351 ha Fruit Trees and Citrus Fruit Trees)
<table>
<tr><th>Conveyance networks and irrigation methods</th><th>% coverage of the irrigated area</th><th>% losses</th><th>% conveyence efficiency</th></tr>
<tr><td>Collective Networks - Closed Pipes</td><td>1%</td><td>10%</td><td>90%</td></tr>
<tr><td>Collective Networks - Open Channels</td><td>37%</td><td>55%</td><td>45%</td></tr>
<tr><td>Small individual networks - Groundwater wells</td><td>62%</td><td>35%</td><td>65%</td></tr>
<tr><td>Aggregated network conveyance efficiency</td><td colspan="3">(1% x 0.9) + (37% x 0.45) + (62% x 0.65) = 57.85% or 42.15% losses</td></tr>
<tr><td>Drip irrigation</td><td>7%</td><td>20%</td><td>80%</td></tr>
<tr><td>Sprinklers’ irrigation</td><td>15%</td><td>30%</td><td>70%</td></tr>
<tr><td>Furrow irrigation</td><td>78%</td><td>40%</td><td>60%</td></tr>
<tr><td>Aggregated field application efficiency</td><td colspan="3">(7% x 0.8) + (15% x 0.7) + (78% x 0.6) = 62.90% or 37.10% losses</td></tr>
<tr><td colspan="4">Overall combined irrigation efficiency = 60.38%, i.e. 60%</td></tr>
</table>
</td></tr>
</table>

Simulation parameters	Based on the analysis of the agricultural water saving measures (ref. to Chapter 5.3), the following 2 solutions have been simulated in WEAP: - **AgrSav80**: Increase the irrigation efficiency to 80% through converting to closed pipes and drip irrigation systems at the farm level: the target is to have 75% of the hectares served by collective networks with closed pipes and only 5% by open channels, while the remaining 20% of the total agricultural area will be served small individual networks connected to individual groundwater wells. At the same time 80% of the total area will be irrigated with drip irrigation, and only 10% with sprinklers and 10% with furrow. These conversions will reduce the combined losses (i.e. conveyance + field application) by 20%. - **AgrSav85:** Increase the irrigation efficiency to 85% through converting to closed pipes and drip irrigation systems at the farm level: the target is to have 98% of the hectares served by collective networks with closed pipes and 0% by open channels, while the remaining 2% of the total agricultural area will be served by small individual networks connected to individual groundwater wells. At the same time 98% of the total area will be irrigated with drip irrigation, and only 2% with furrow. These conversions will reduce the combined losses (i.e. conveyance + field application) by 10%.

Conveyance networks and irrigation methods	Efficiency 60% (Baseline)		Efficiency 80% (+20% increase)		Efficiency 85% (+25% increase)	
Conveyance networks	**% ha**	**ha**	**% ha**	**ha**	**% ha**	**ha**
Collective Networks - Closed Pipes	1%	20.30	75%	1522.50	98%	1989.40
Collective Networks - Open Channels	37%	751.10	5%	101.50	0%	0.00
Small individual networks - Groundwater wells	62%	1258.60	20%	406.00	2%	40.60
Irrigation methods	**%**	**ha**	**%**	**ha**	**%**	**ha**
Drip irrigation	7%	142.10	80%	1624.00	98%	1989.40
Sprinklers' irrigation	15%	304.50	10%	203.00	0%	0.00
Furrow irrigation	78%	1583.40	10%	203.00	2%	40.60
** Total irrigated hectares in the basin = 2,030 ha*						

	Associated costs: ▪ *AgriSav80 (80% efficiency):* Convert 1,502 ha (i.e. 74% of the total) to closed pipes; AEC cost = 1,502 ha * 390$/ha = 0.59 mio $ or 9.1 mio $ CAPEX Switch 1,482 ha (i.e. 73% of the total) to drip irrigation; AEC cost = 1,482 * 347 $/ha = 0.51 mio $ or 5.5 mio $ CAPEX Total AEC cost for mountain areas = 1.1 mio $ or 14.5 mio $ CAPEX ▪ *AgrSav85 (85% efficiency):* Convert 1,969 ha (i.e. 97% of the total) to closed pipes; AEC cost = 1,969 ha * 390$/ha = 0.77 mio $ or 11.8 mio $ CAPEX Switch 1,847 ha (i.e. 91% of the total) to drip irrigation. AEC cost = 1,847 * 347 $/ha = 0.64 mio $ or 6.8 mio $ CAPEX Total AEC cost for mountain areas = 1.41 mio $ or 18.6 mio $ CAPEX

5.3 Scenario MixSav

The Scenario MixSav focuses on water savings across both the urban and the agricultural sectors, and it is a combination on the aforementioned scenarios UrbSav and AgrSav

Measures included	U1. Low water using fixtures and appliances, A1. Increase the irrigation efficiency through converting to closed pipes and drip irrigation systems at the farm level
Implementation	Combination (merging) of the scenarios UrbSav Solution No.1 and AgrSav85 Combination (merging) of the scenarios UrbSav Solution No.1 and AgrSav90 Combination (merging) of the scenarios UrbSav Solution No.3 and AgrSav85 Combination (merging) of the scenarios UrbSav Solution No.3 and AgrSav90 Combination (merging) of the scenarios UrbSav Solution No.20 and AgrSav85 Combination (merging) of the scenarios UrbSav Solution No.20 and AgrSav90
Simulation parameters	Same as in the scenarios UrbSav Solution No.1 and the AgrSav85 scenario Same as in the scenarios UrbSav Solution No.1 and the AgrSav90 scenario Same as in the scenarios UrbSav Solution No.3 and the AgrSav85 scenario Same as in the scenarios UrbSav Solution No.3 and the AgrSav90 scenario Same as in the scenarios UrbSav Solution No.20 and the AgrSav85 scenario Same as in the scenarios UrbSav Solution No.20 and the AgrSav90 scenario

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m^3) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/$m^3$ of water saved	Total $/$m^3$ of water saved for the basin	Penetration (households adapting the measure)				
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*
1	11 $	30 $	20.40%	2.8 $	5.10%	1.39	0.29	0.78	0.21	0.57		√			
3	30 $	80 $	26.90%	7.5 $	6.73%	1.83	0.78	2.09	0.43	1.14		√	√		

20	173 $	850 $	42.50%	43.3 $	10.63%	2.89	4.52	22.21	1.56	7.69	√	√	√	√	

AgriSav80 (80% efficiency):

Convert 1,502 ha (i.e. 74% of the total) to closed pipes; AEC cost = 1,502 ha * 390$/ha = 0.59 mio $ or 9.1 mio $ CAPEX

Switch 1,482 ha (i.e. 73% of the total) to drip irrigation; AEC cost = 1,482 * 347 $/ha = 0.51 mio $ or 5.5 mio $ CAPEX

Total AEC cost for mountain areas = 1.1 mio $ or 14.5 mio $ CAPEX

AgrSav85 (85% efficiency):

Convert 1,969 ha (i.e. 97% of the total) to closed pipes; AEC cost = 1,969 ha * 390$/ha = 0.77 mio $ or 11.8 mio $ CAPEX

Switch 1,847 ha (i.e. 91% of the total) to drip irrigation. AEC cost = 1,847 * 347 $/ha = 0.64 mio $ or 6.8 mio $ CAPEX

Total AEC cost for mountain areas = 1.41 mio $ or 18.6 mio $ CAPEX

Mixed measures costs:

Measures	Total AEC (mio $) per measure	Total CAPEX (mio $) per measure	Grand Total AEC (mio $)	Grand Total CAPEX (mio $)
UrbSav Solution No. 1 AgrSav80	0.29 1.10	0.78 14.47	1.39	15.25
UrbSav Solution No. 1 AgrSav85	0.29 1.41	0.78 18.61	1.7	19.39
UrbSav Solution No. 3 AgrSav80	0.78 1.10	2.09 14.47	1.88	16.56
UrbSav Solution No. 3 AgrSav85	0.78 1.41	2.09 18.61	2.19	20.7
UrbSav Solution No. 20 AgrSav80	4.52 1.10	22.21 14.47	5.62	36.68
UrbSav Solution No. 20 AgrSav85	4.52 1.41	22.21 18.61	5.93	40.82

5.4 Scenario UrbLeak

The Scenario UrbLeak focuses on reducing the leakage of the urban supply network

<table>
<tr><td>Measures included</td><td>U4. Leakage Reduction in the water supply networks through actions to rehabilitate and modernize the operation of water supply networks</td></tr>
<tr><td>Implementation</td><td>This scenario promotes leakage reduction in the urban water supply network and increasing the conveyance efficiency of the network</td></tr>
<tr><td>Simulation parameters</td><td>Reducing % losses by 10% (i.e. from the current 30% to 20%)
In the National Water Sector Strategy (NWSS) update 2020, Volume V “Proposed projects”, the following projects are proposed for NLWE:
<table>
<tr><th rowspan="2">System</th><th rowspan="2">Village</th><th colspan="2">Transmission lines</th><th colspan="2">Distribution networks</th></tr>
<tr><th>Length (km)</th><th>Cost Estimate (USD)</th><th>Length (km)</th><th>Cost Estimate (USD)</th></tr>
<tr><td>System 1</td><td>Akkar El Atika</td><td>8.00</td><td>720,000</td><td>2.00</td><td>160,000</td></tr>
<tr><td>System 11</td><td>Sindianet Zeidan</td><td>4.00</td><td>360,000</td><td>10.00</td><td>800,000</td></tr>
<tr><td>System 17</td><td>El Kouachra</td><td>2.00</td><td>180,000</td><td>-</td><td>-</td></tr>
<tr><td>System 22</td><td>Ain el zeit</td><td>2.00</td><td>180,000</td><td>11.00</td><td>880,000</td></tr>
<tr><td></td><td>Charbila</td><td>-</td><td>-</td><td>10.00</td><td>800,000</td></tr>
<tr><td></td><td>Ain Tanta</td><td>2.00</td><td>180,000</td><td>11.00</td><td>880,000</td></tr>
<tr><td></td><td>Al-Rihanie</td><td>2.00</td><td>180,000</td><td></td><td></td></tr>
<tr><td></td><td>Douair adouiye</td><td></td><td></td><td>10.00</td><td>800,000</td></tr>
<tr><td>System 23,24,12</td><td>Kherbet Daouad</td><td>5.00</td><td>450,000</td><td>10.00</td><td>800,000</td></tr>
<tr><td></td><td>Sfinet El Dreib</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td></td><td>Fseikine et ain achma</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>El daghle</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Kherbet Char</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Majdel</td><td>4.00</td><td>360,000</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Barbara</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Deir Janin</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Knisse</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td></td><td>Mazraat balde</td><td>2.00</td><td>180,000</td><td>-</td><td>-</td></tr>
<tr><td></td><td>El Hed</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Al souaise</td><td>4.00</td><td>360,000</td><td></td><td></td></tr>
<tr><td></td><td>El Bire</td><td>4.00</td><td>360,000</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Kfar Hara</td><td>3.00</td><td>270,000</td><td>10.00</td><td>800,00</td></tr>
</table>
Based on the above information, the estimated cost per km of transmission line is 90,000 $/km, and the cost per km of distribution network is 80,000$
According to the above table, the NWSS prioritizes the infrastructure (rehabilitation or new) of 42 km of transmission lines and 154 km of distribution networks. This would result in total investments of (CAPEX) 158,760 billion $ and 788,480 billion $ respectively. The cost of design and supervision is not included, but ranges from about 6-8% on top of the investment cost.</td></tr>
</table>

	In our scenario we have assumed that a 10% loss reduction is applied uniformly at all 20 urban nodes. Since information of the state of infrastructure, and how many km need to be rehabilitated per node is lacking, the cost of this scenario cannot be estimated; only costs per km can be provided.

5.5 Scenario UrbSup

The Scenario UrbSup focuses on both water saving and increasing supply for the domestic/urban sector (micro-scale)

Measures included	U1. Low water using fixtures and appliances U2. Domestic Greywater Reuse (GWR) on-site (houses, hotels) in villages U3. Rainwater Harvesting (RWH) on-site (houses, hotels, villages)
Implementation	The measures have been applied in all the 20 urban demand nodes. The Tier-2 increase water supply measures have been applied on top of the Tier-1 water saving measures preconditioning thus an already “water efficient” house. Node #21 (UD_ Danke-Qsair) is a water export of a fixed volume (7,200 m^3/month) and it was kept constant, assuming that since it is outside the Al Ostuan River Basin the saving measures will not be applied there. The baseline (BaU) was the reference period 2003-2018, where the average annual urban demand was 6.8 million m^3.
Simulation parameters	Regarding the application of the additional Tier-2 measures (U2 and U3), these have been applied, as previously mentioned in Chapter 3.2, on top of the Tier-1 measure U1, i.e. in a “water efficient” house. Based on the cost-effectiveness analysis of the urban water saving measures (ref. to Chapter 3.2), the following 5 solutions are considered as optimum (see table below) and have been simulated in WEAP.

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m^3) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/$m^3$ of water saved	Total $/$m^3$ of water saved for the basin	Penetration (households adapting the measure)						
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*	*Rainwater Harvesting (RWH)*	*Greywater Reuse (GWR)*
7r	318 $	2,050 $	48.50%	79.5 $	12.13%	3.30	8.31	53.58	2.52	16.25	√	√	√			√	
7w	560 $	3,750 $	41.50%	140. $	10.38%	2.82	14.64	98.01	5.19	34.73	√	√	√				√

20r	429 $	2,650 $	54.10%	107.3 $	13.53%	3.68	11.21	69.26	3.05	18.83	√	√	√	√		√	
20w	671 $	4,350 $	47.10%	167.8 $	11.78%	3.20	17.54	113.69	5.48	35.50	√	√	√	√			√
20m	927 $	6,150 $	58.70%	231.8 $	14.6 %	3. 9	4.23	160.73	6.07	40.27	√	√	√	√		√	√

Note: "r" denotes a solution with rainwater harvesting, "w" with greywater reuse, and "m" with both

* The total water saving is based on the annual urban water demand in the Al Ostuan basin for the reference period 2003-2018, which sums up at 6.8 million m^3.

** The total AEC is obtained by multiplying the AEC per household (HH) with the total number of households. The later has been estimated to account 26,135 household in the Al Ostuan basin assuming each household is occupied by 4 people on average (number of hh = total population ÷ 4)

These solutions have been simulated In WEAP in all the 9 demand sites, based on the following formulas:

- Solution No. #7r: multiply water demand by (1-0.1213) in all 20 sites, or apply DSM saving per capita 12.13% in the tab Demand Sites and Catchments/Demand Management/DSM Savings
- Solution No. #7w: multiply water demand by (1-0.1038) in all 20 sites, or apply DSM saving per capita 10.38% in the tab Demand Sites and Catchments/Demand Management/DSM Savings
- Solution No. #20r: multiply water demand by (1-0.1353) in all 20 sites, or apply DSM saving per capita 13.53% in the tab Demand Sites and Catchments/Demand Management/DSM Savings
- Solution No. #20w: multiply water demand by (1-0.1178) in all 20 sites, or apply DSM saving per capita 11.78% in the tab Demand Sites and Catchments/Demand Management/DSM Savings
- Solution No. #20m: multiply water demand by (1-0.1468) in all 20 sites, or apply DSM saving per capita 14.68% in the tab Demand Sites and Catchments/Demand Management/DSM Savings

For each solution the change in the model results, in terms of unmet demand and potential water excess (resulting from all 9 demand sites as a sum), has been investigated. Since in the WEAP model the resources and supply are interconnected, the reduction in demand in one site may increase water availability in another location.

5.6 Scenario AgrSup

The Scenario AgrSup focuses on increasing supply for the agricultural sector (meso-scale)

Measures included	A3. Detention basins/ Retention ponds/ Community Hill Lakes in agricultural areas
Implementation	This scenario promotes managing runoff close to source (i.e. with a relatively small catchment area) and therefore it is not envisaged that a contributing area greater than 1 km^2 would be likely.
Simulation parameters	Detention basins of 100-150 m^3 capacity have been simulated in WEAP, in sites where the topography is beneficial. The capital costs for the construction of detention basins and/or retention ponds have been fixed at \$30 per m^3 of volume provided for storage. The annual maintenance costs have been fixed between \$3 per m^3 of basin/ pond area. The useful life has been considered 30 years, and thus the resulting AEC is \$5.83/m^3/year.

5.7 Scenario MixSup

The Scenario UrbSup focuses on both water saving and increasing supply for the domestic/urban sector (micro-scale), combined with savings in the agricultural sector.
It is a combination on the aforementioned scenarios UrbSup and AgrSav

Measures included	U1. Low water using fixtures and appliances U3. Rainwater Harvesting (RWH) on-site (houses, hotels, villages) A1. Increase the irrigation efficiency through converting to closed pipes and drip irrigation systems at the farm level
Implementation	Combination (merging) of the scenarios UrbSav Solution No.7r and AgrSav80 Combination (merging) of the scenarios UrbSav Solution No.7r and AgrSav85
Simulation parameters	Same as in the scenarios UrbSav Solution No.7r and the AgrSav80 scenario Same as in the scenarios UrbSav Solution No.7r and the AgrSav85 scenario

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m^3) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/$m^3$ of water saved	Total $/$m^3$ of water saved for the basin	*Penetration (households adapting the measure)*						
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*	*Rainwater Harvesting (RWH)*	*Greywater Reuse (GWR)*
7r	318 $	2,050 $	48.50%	79.5 $	12.13%	3.30	8.31	53.58	2.52	16.25	√	√	√			√	

Note: “r” denotes a solution with rainwater harvesting, “w” with greywater reuse, and “m” with both

* The total water saving is based on the annual urban water demand in the Al Ostuan basin for the reference period 2003-2018, which sums up at 6.8 million m^3.

	** The total AEC is obtained by multiplying the AEC per household (HH) with the total number of households. The later has been estimated to account 26,135 household in the Al Ostuan basin assuming each household is occupied by 4 people on average (number of hh = total population ÷ 4) AgriSav80 (80% efficiency): Convert 1,502 ha (i.e. 74% of the total) to closed pipes; AEC cost = 1,502 ha * 390$/ha = 0.59 mio $ or 9.1 mio $ CAPEX Switch 1,482 ha (i.e. 73% of the total) to drip irrigation; AEC cost = 1,482 * 347 $/ha = 0.51 mio $ or 5.5 mio $ CAPEX Total AEC cost for mountain areas = 1.1 mio $ or 14.5 mio $ CAPEX AgrSav85 (85% efficiency): Convert 1,969 ha (i.e. 97% of the total) to closed pipes; AEC cost = 1,969 ha * 390$/ha = 0.77 mio $ or 11.8 mio $ CAPEX Switch 1,847 ha (i.e. 91% of the total) to drip irrigation. AEC cost = 1,847 * 347 $/ha = 0.64 mio $ or 6.8 mio $ CAPEX Total AEC cost for mountain areas = 1.41 mio $ or 18.6 mio $ CAPEX Mixed measures costs:

Measures	Total AEC (mio $) per measure	Total CAPEX (mio $) per measure	Grand Total AEC (mio $)	Grand Total CAPEX (mio $)
UrbSav Solution No. 7r AgrSav80	8.31 1.10	53.58 14.17	9.41	68.05
UrbSav Solution No. 7r AgrSav85	8.31 1.41	53.58 18.61	9.72	72.19

, **Table 5-2** below. Relevant information on the associated costs has also been collected from various literature sources, as presented in **Table 5-3** and **Table 5-4**. On this basis, the % expected saving and costs have been identified.

Table 5-1: Potential water saving per household (hh) water using product (WuP)

HH Water Using Product (WuP)	Consumption of "traditional" WuPs			Consumption of "efficient" WuPs	Water Saving		
	lt/use	Frequency of use per day	Average consumption in lt/household/day	lt/use	lt/hh	as % of WuP's consumption	As % of total HH consumption
Low flush WC	6-12 lt/flush	7-11.6	101.8	3-4.5 lt/flash	30-170 lt/day	30-50 %	26%
Showerhead	25 lt/min; 25.7-60 lt/shower	0.75-2.5	91.8	6-14 lt/min	25 lt/day	50-70 %	8 %
Faucet aerator	13.5 lt/min; 2.3-5.8 lt/use	10.6-37.9	74.6	2-5 lt/min	12-65 lt/day	40-65 %	7-11,6 %
Dishwasher, AAA class	21.3-47 lt/load	0.5-0.7	24.3	7-19 lt/load	5,000 lt/year	40-60	4 %
Washing Machines, AAA class	39-117 lt/load	0.6-0.8	65.6	40 lt/load	16,000 lt/year	40	12 %

Source: Kossida, M., 2015 (elaboration based on multiple sources: Bio Intelligence Service and Cranfield University, 2009; BIO Intelligence Service, 2012; Cordella et al., 2013)

Information on the frequency of use of the different water using products within the households, and the realted average consumption at household or per capita level is provided in the Lebanese National Water Strategy (NWSS) 2020 update (MEW, 2020), Volume IV, APPENDIX IVC1 "Domestic water demand per capita". A set of assumptions for the basis of the calculation of the domestic water demand are presented in the afforementioned Appendix, as listed in **Table 5-2** below. On the basis of this information a comparison is made between the Average consumption (in lt/household/day) values of **Table 5-1** and the Lebanese estimations (**Table 5-2**). The average daily households consumption fopr flushing is found to be double in Lebanon which probably indicates that the flush appartus used have high unit rates, and thus efficienct low flow flushes would be very beneficial. The same applies for the showers' consumption. Even if we assume that in **Table 5-1** the 92 lt/hh/day corresponf to an average 4-persons household, as opposed to the 5.8-persons in Lebanon, the resulting number would be 133 lt/hh (for the equivalent 5.8-persons household), which is still much lower than the respective 310 lt Lebanese value. This is due to the showehead technology: In Lebanon it is estimated that 75 lt are needed per shower, whereas modern showerheads consume 25 lt/min and the efficient ones 6-14 lt/min. Thus, efficienct showerheads would also be very beneficial. It is difficult to do a similar comparison for the faucets, since the analysis made in the NWSS is not at that level, but indicatively, about 100 lt are consumed per households per day for drinking, cooking, cleaning and watering as compared to 75 lt from faucets in **Table 5-1**. Looking also at the dishwashing consumptions, which in Lebanon is manual and has high consumption rates (i.e. 60 lt/hh/day as opposed to 24lt/hh/day) it is apparent that efficient faucet aerators would also be very beneficial and save a lot of water.

Table 5-2: Calculations of household water consumption in the NWSS 2020 (MEW, 2020)

Micro-components / Water Using Products	Average consumption in lt/ household/ day	Average consumption in lt/ household/ week	Assumptions
Flushing systems	226.6	1,586.4	5.8 persons per household Frequency: 5.5 flushing operations/day/capita and 3 flushings/day/capita for the two persons who are assumed to work outside the study area during a part of the day from Monday to Friday Consuming: 8 lt/flush
Washing and Showers	310.7	2,175	5.8 persons per household Frequency: 5 showers / week / capita Consuming: 75 lt per shower
Dishwashing	60.0	420	5.8 persons per household Frequency (manual dishwashing): 3 times/day Consuming: 20 liters/dishwashing
Laundry	51.4	360	5.8 persons per household Frequency: 4 times/week/household. Consuming: 90 liters/washing
Cooking and drinking	23.2	162.4	5.8 persons per household Consuming: 4 liters / day / capita
House cleaning	34.3	240	5.8 persons per household Consuming: 20 buckets of 12 liters for house cleaning per week
Plants watering	42.9	300	5.8 persons per household Consuming: 300 liters/week
TOTAL *per household (lt/HH/ week):* *per capita (lt/cap/day):*	**749.1 lt/hh/day** **129 lt/ cap/ day**	**5,234.8 lt/ household/ week** **904.1 lt/ capita/ week**	

Costs of different household water appliances and water saving devices and increase supply options

Table 5-3: Costs of different household water appliances and water saving devices and increase supply options

Water appliance/ saving device	*Marshallsay et al., 2007*	*Cordella et al., 2013*	*Lebanese market seatch (2020)*
WC (toilet flushing)	82-337 $		
Taps	- 51 $ (basic mixer tap has no water efficiency features) - 74 $ (monobloc mixer tap with pop up waste and aerator) - 94 $ (monobloc mixer tap with pop up and an Ecotop cartridge)	- 35-50 $ (automatic shut off, push tap) - 160-450 $ (example product with integrated aerators and flow regulators) - 210 $ (tap with water breaks)	

		- 750 $ (water and energy saving tap) - 375 $ (sensor tap, infrared mixer)	
	- 10 $ for attaching a water saving device (6$ for aerator & spray fittings that can be attached to existing taps, + 4$ for the adaptor)	- 5.5 $ for a flow regulator - 25 $ for ecobuttons	- 2$ for an aerator (Assafiri-El Mina-06220704)  - 40,000 LBP = 26.5 $ (MAKHSOUM Lebanon 01-874208, 79-100465)  - 1.87-7.65 for an aerator (Ali Express) + shipping to Lebanon (0-4.51$)
Shower, Bath	- electric shower: 174 – 225 $ - mixer shower: 225 $ (+157$ if a pump is added) - basic bath/shower mixer with hand shower attachment: 31-92 $	- aeration showerhead: 20-120 $ - spray pattern/mechanism showerhead: 60-220 $	- 4$ showerhead (Pexico-Tripoli-06425437)   - 50,000 LBP (Spinneys Lebanon) = 33.14$  - 75,000 LBP = 49.71 $ (Freeshop Lebanon 70376121)  - 11.16$ water saving showerhead 5.5 lt/min 50% saving JOMOO (Ali Express) + shipping to Lebanon (32$) -
	18 $ for attaching an aerated showerhead to a standard mixer shower 31 $ for attaching a pressure reducing valves to a standard mixer shower		
Washing Machine	282-321 $, energy rating A 343-533 $, energy rating A+		

Dishwasher	233-429 $, energy rating A		

Source: Kossida, M., 2015 (elaboration based on multiple sources: Cordella et al., 2013; Marshallsay et al., 2007) and market survey in Lebanon in 2020

Table 5-4: Costs of different increase supply technologies and interventions

Increase supply technologies	Capital Costs	Maintenenace Costs
Rainwater Harvesting	2,451 $ equipment cost + 288-429 $ installation cost (Marshallsay ey al., 2007) 1,050$ to 1,950$ (including installation costs): 2 Double Layer PVC Water Tanks of 2m^3 capacity each (unit cost of each tank = 212$), small electrical water pump (Italy made) of 0.5 HP, high pressure up to 12m, and flow rate 35 L/min (unit cost of the pump = 96$), rain water filters (media and micro filter with all needed accessories, supply and installation) (cost = 152$), and 2 valves (5'' two way valves) at the connection between the collection tank and the 5'' PVC pipe from the roof (unit cost = 202$). The total costs ranged depending on the length/number of PVC and HDPE pipes and related accessories (fittings, elbows, connections, etc.) needed to be installed on the external walls of the buildings (cost = 3.5-7 $/m) (ACTED, 2019)	
Greywater reuse (domestic)	4,534 $ initial cost (Marshallsay ey al., 2007)[1]	additional maintenance costs
Detention basins	Construction costs scale with the storage volume of the detention basin. Costs given in the UK typically range between $20 and $40 per m^3 of storage volume provided: - CIRIA (2007) - $20-$30 / m^3 detention volume - Atkins (2010) - $25-$35 / m^3 detention volume - UK SuDS Cost Calculator (www.uksuds.com) - $20-$40 / m^3 detention volume But others suggest the potential for much higher costs: - Chocat et al (2008) 9 to 90$/$m^3$ detention volume - Certu (2006), 12 to 110 $/$m^3$ detention volume More generally, Environment Agency (2012) indicates that the cost of a "small detention basin will typically be less than $5000". Costs will be higher where additional retaining bunds are required and lower where greater use is made of natural or existing topographic features. Costs for the construction of Hill Lakes in North Lebanon (in Akkar and other regions) are provided in the NWSS 2020 update (MEW, 2020) Volume V "Proposed Projects", Section VA, pages VA65-66. The provided costs are estimated lump sums and range from 400,000$ for Hill Lakes of 0.06 MCM, to 34,000,000$ for Hill Lakes of 1.86 MCM. The unit cost in $ per m^3 of detention volume highly ranges from 1 $/$m^3$ to 35 $/$m^3$ stored.	Ongoing maintenance is essential to maintain the effectiveness of detention basins. Since these basins are long-lived, once in operation only minimal maintenance costs arise. Quarterly inspections of inlets and outlets as well as sediment and trash dredging might be required. Mowing around the basin margins would be possible but it may increase costs. Annual maintenance costs range between $0.5-$5 per m^3 of basin area. - CIRIA (2007), Wilson et al. (2009) - $0.5-$2.5 per m^3 basin area, - UK SuDS Cost Calculator (www.uksuds.com) - $4-$5 per m^3 basin area.

[1] It was not feasible to find costs in Lebanon, necessary to conduct separate study into cost of greywater reuse in Lebanon.

Retention ponds	Retention pond capital costs are typically between \$20- \$40 per m^3 of volume provided for storage. - CIRIA (2007) - \$20-\$30 per m^3 detention volume - UK SuDS Cost Calculator (www.uksuds.com) - \$40 per m^3 attenuation volume - Chocat et al (2008) - \$9-\$60 per m^3 of volume provided for storage More generally, Environment Agency (2012) indicates that "construction costs may increase if lining is required". Requirements for pond lining, or construction on steeper slopes or less stable land may increase construction costs to ensure the integrity of the pond. Costs for the construction of Hill Lakes in North Lebanon (in Akkar and other regions) are provided in the NWSS 2020 update (MEW, 2020) Volume V "Proposed Projects", Section VA, pages VA65-66. The provided costs are estimated lump sums and range from 400,000\$ for Hill Lakes of 0.06 MCM, to 34,000,000\$ for Hill Lakes of 1.86 MCM. The unit cost in \$ per m^3 of detention volume highly ranges from 1 \$/m^3 to 35 \$/m^3 stored.	Annual maintenance costs vary between \$1-\$5 per m^3 of retention pond area. - CIRIA (2007), Wilson et al (2009) - \$1-\$2 per m^3 - UK SuDS cost calculator (www.uksuds.com) - \$4-\$5 per m^3 pond area

5.8 DEMAND MANAGEMENT MEASURES IN THE AGRICULTURAL SECTOR

The main options for reducing irrigation demand are linked to decreasing losses and increasing the irrigation efficiency, i.e. conveyance and field application efficiency. This is generally achieved by replacing open canals with closed pipes, by switching to drip irrigation and/or sprinklers from furrow irrigation systems, by implementing precision agriculture, and by applying deficit irrigation. However, besides the areas of formal collective irrigation networks, additional self-supplied irrigated areas often exist, and in many countries illegal abstractions (illegal wells) might also be a problem. The main options to increase water supply for agricultural purposes is to retain water in detention basins and retention ponds (as described above in Chapter 2.2).

Replacing open canals with closed pipes targets to reduce canal leakage and increase conveyance efficiency. Water conveyance loss consists mainly of operation losses, evaporation, and seepage into the soil from the sloping surfaces and bed of the canal. Open channel networks are usually characterized by high levels of canal seepage, which lead to high water losses, and depends mainly on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals. In large irrigation schemes more water is lost than in small schemes, due to a longer canal system. From canals in sandy soils more water is lost than from canals in heavy clay soils. The losses in canals lined with bricks, plastic or concrete are very small. If canals are badly maintained, bund breaks are not repaired properly and rats dig holes, a lot of water is lost. Indicative values of conveyance efficiency in opens canals range from 60-80% for long (>2,000 m) to short (<200 m) sand earthen canals, from 70-85% for long to short loam earthen canals, from 80-90% for long to short clay earthen canals, and around 95%

for lined canals. These values do not consider the level of maintenance, which, in case of bad maintenance, may lower these values by as much as 50%.

Switching to drip irrigation and/or sprinklers from furrow irrigation systems targets to increase the field application efficiency. The field application efficiency mainly depends on the irrigation method, as well as on the level of the farmers' discipline. Irrigation water losses, illustrated include air losses, canopy losses, soil and water surface evaporation, runoff, and deep percolation. The magnitude of each loss is dependent on the design and operation of each type of irrigation system. Surface irrigation losses (furrow) include runoff, deep percolation, ground evaporation and surface water evaporation. Sprinkler irrigation losses include air losses (drift and droplet evaporation), canopy losses (canopy evaporation and foliage interception) and surface water evaporation. Indicative values of the average field application efficiency are around 60% for surface irrigation (basin, border, furrow), 70% for sprinkler irrigation (traveling gun, center pivot, etc.), and 80% for drip irrigation. Lack of farmers' discipline may lower these values.

Erreur ! Source du renvoi introuvable. presents an overview of different literature values on the efficiency of irrigation methods. The values range, but in all cases it is demonstrated that, when considering single field irrigation efficiencies, sprinkler systems are generally better than furrows, and drip irrigation systems are generally the best. In any case, attainable water application efficiencies vary greatly with irrigation system type, management practices and site characteristics. The analysis of the application efficiency of irrigation systems is thus important to identify potential places where improvements can be made and plan for interventions.

Table 5-5: Field application efficiencies of different irrigation methods

Authors / Methods	Solomon, 1988	Tanji and Hanson, 1991	Morris and Lynne, 2006	Rogers et al., 1997	Howell, 2003	Hanson et al., 1999	Sandoval-Soli et al., 2013
Surface irrigation							*Low/Mean/High*
Furrow	60-75	60-90	60-80	50-90	50-80	70-85	60/73/85
Furrow with tailwater				60-90			
Border	70-85	65-80	55-75	60-90	50-80	70-85	62/73/83
Basin	80-90			60-95	80-65		72/83/93
Sprinkler							
Hand-more or portable	65-75						60/70/80
Periodic move		65-80	60-75	65-80	60-85	70-80	
Continuous move		75-85		70-95	90-98	80-95	
Traveling gun	60-70						
Center pivot	75-90		65-90		75-98		70/80/90
Linear move	75-90		75-90		70-95		73/82/90
Solid set or permanent	70-80	85-90	70-85	70-85		70-80	70/78/85
Drip/Trickle							
Trickle (point source emitters)	75-90						
Subsurcface drip			85-95	70-95	75-95		77/86/95
Microspray			85-90		70-95		
Line source products	70-85						

Source: Kossida, M., 2015 (adopted from Canessa et al., 2011)

Precision agriculture (PA) is a cultivation technique where both irrigation water and fertilizers are provided to the crop at optimum timings and doses. The practice has the purpose to sustain or even increase yields compared to the conventional cultivation ways. Numerous control technologies are available for optimizing irrigation such as evapotranspiration based controllers, soil moisture sensor controllers, and rain sensors. The typical PA system works as follows: infrared sensors are components of a wireless thermal monitoring system (Smart Crop) and identify the timing of application; soil moisture sensors back up the information for the timing while they evaluate the effectiveness of irrigation application, while an evapotranspiration sensor calculates the exact volume of water that has to be applied. Crop yields are also calculated and mapped for the purpose of estimating productivity and environmental performance indicators. All the above mentioned sensors/equipment are very easy to use, while yield maps and productivity indicators are able to demonstrate the sustainability of crop yields produced under this cultivation system and thus convince farmers for the usefulness of these technological innovations. Installation and testing of the PA technologies in the Pinios River Basin in Greece in selected pilot areas (carried out in the framework of the European funded project HYDROSENSE, www.hydrosense.org) showed that water consumption was reduced by 5-35% depending on the local conditions, while yields were increased up to 31%. Precision irrigation and fertilization have considerable costs mainly because of the equipment needed to be installed and operated. One should also consider the cost for installing drip irrigation systems in those farms that are irrigated by different methods.

Deficit irrigation (DI) is defined as the application of water below the ET requirement, and is based on the concept that in areas where water is the most limiting factor, maximizing Crop Water Productivity (CWP) may be economically more profitable for the farmer than maximizing yields. For instance, water saved by DI can be used to irrigate more land (on the same farm or in the water user's community), which, given the high opportunity cost of water, may largely compensate for the economic loss due to yield reduction. The DI practice on the farm has been widely investigated as a valuable and sustainable strategy in dry regions, coming of course with advantages and disadvantages. In general, from a wide application of the practice it can be concluded that it seeks to stabilize, rather than maximize yields and this is usually achieved when water applications are limited to specific drought-sensitive growth stages of each irrigated crop.

Land use/ crop changes involve the changes in the existing crop mix in agricultural areas, either by abandoning some areas under agricultural cultivation, or by changing the mix of existing crops, and planting less water demanding varieties. Form an economic productivity point of view it may be more beneficial to plant crops which are more drought tolerant and do not require excessive irrigation. Such a land reform requires a thorough design process to investigate the full market potential of the new crops, and a long stakeholders' process in order to showcase the benefit of such an intervention and boost its acceptability.

Economic Policy Instruments (**EPIs)** are tools based on incentives and disincentives; they change conditions to enable economic transactions or reduce risk, aiming at delivering environmental and economic benefits. These include for example agricultural subsidies for areas using limited irrigation water, economic incentives for changing land use practices, economic penalties and fines when best management practices for the rational use of water are neglected, groundwater quotas, cap and trade (tradable abstraction permits), volumetric water pricing, cooperation agreements, environmental taxes, agricultural insurance, etc.

Water pricing reform is also an EPI, and usually involves a modification in the rate structure and/or the water tariffs in order to influence the consumers' water use. It often includes the shifting from decreasing block rates to uniform block rates, the shifting from uniform rates to increasing block rates, the increasing of rates during summer months, or the imposing excess-use charges during times of water shortage. In the agricultural sector such as economic reform might be even more challenging than in the domestic sector since farmers in different areas often may not have to pay for water. Thus, this economic instrument needs a very careful design as it can easily raise conflicts among users and trigger many disputes. It is also required that water metering is in place and properly operational prior to applying any water pricing schema.

6 DESIGN OF THE MEASURES (METHODOLOGY, COST-EFFECTIVENESS ANALYSIS)

6.1 METHODOLOGICAL STEPS

The following methodological steps have been implemented in order to build the cost-effective functions and simulate the selected adaptation measures in the Al Ostuan River Basin:

- Definition of the economic sectors of interest, and selection of relevant measures (per sector) in consultation with local stakeholders
- Adaption of clear definitions for all measures and interventions
- Collection of the input data needed for the cost-effectiveness functions (potential saving, costs)
- Development of the cost-effectiveness curves implementing an optimization process
- Development of the alternative demand management scenarios (based on a mix of the measures) to be simulated
- Investigation on how to simulate the functions in the WEAP21 water resource management model of the Al Ostuan river basin (coding routines)
- Simulation of the alternative demand management scenarios against the baseline scenario (2003-2018), and assessment of their impact and cost-effectiveness on the physical system
- Assessment of the robustness of the alternative demand management scenarios for the future period up to 2035

6.2 ANALYSIS OF THE URBAN MEASURES - DESIGN OF THE COST-EFFECTIVENESS CURVES

Water consumption patterns can vary significantly from house to house, depending on the household occupancy, the social and cultural conditions as well as on the type of the water consuming appliances installed in the houses (Memon and Butler, 2006). However, only a small proportion (approximately 15–20%) of in-house water demand is actually used for purposes requiring drinking water quality (incl. water used for drinking, cooking and cleaning dishes) (refer to **Table 5-1** and **Figure 5-1**).

Table 5-1: Water consumption share of different household micro-components in the industrialized world

Information	*EU-wide overview*	*Country specific*	

Sources / **HH Micro-component**	*POST, 2000*	*EA, 2007*	*Uihlein and Wolf, 2010 (across the EU)*	*EA, 2010 (in England & Wales for 2009-10)*	*Uihlein and Wolf, 2010 (for Greece)*	*EEA, 2001 (for Switzer-land)*	*Schleich, 2007 (for Germany)*	*Lebano 2020 NW*
WC (toilet flushing)	31 %	30 %	25 %	26 %	25 %	33 %	32 %	30.
Faucets	24 % *(of which 15% kitchen sink, 9% basin)*	20 %	30 % *(of which 5% for drinking and cooking)*	11 %	13 % *(5% for drinking and cooking)*	17 % *(3% for drinking and cooking)*	12 % *(3% for drinking and cooking)*	7.67 some % wahing is inclu together the show *(3.1% drinking cook 4.58% ho clear*
Shower	5 %	35 %	14 %	35 %	34 %	32 %	30 %	41.48% showers was
Bath	15 %		14 %					
Washing Machine	20 %	15 %	13 %	12 %	14 %	16 %	14 %	6.
Dishwasher	1 %		2 %	9 %	8 %		6 %	8.
Outdoor use	4 %		2 %	7 %	6 %	2 %	6 %	5.
Miscellaneous use								
TOTAL	100 %	100 %	100 %	100 %	100 %	100 %	100 %	1
Rainwater Harvesting		Equivalent to: 25% toilet flushing, 25% clothes washing, 22.5% external tap use						
Greywater reuse (GWR)		equivalent tothe water consumed by toilets within the property (i.e. 30%), since GW can be used for this purpose						

Source: Kossida, M., 2015

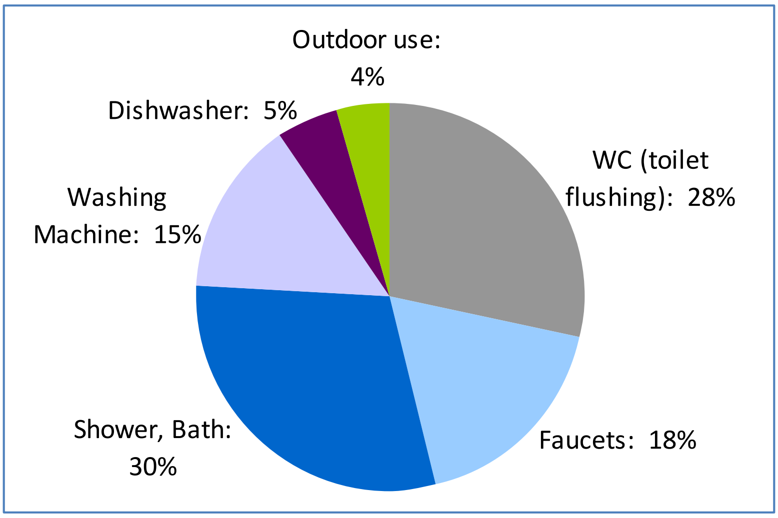


Figure 5-1: Average Water consumption share of different household micro-components in the industrialized world (based on Table **2-4**; Source: Kossida, M., 2015)

For the design of the urban cost-effectivness curve in the Al Ostuan River Basin, 7 demand management measures have been considered (targeting to introduce water savings or increase the supply): istallation of dual flush toilets (1), retrofitting of low flow taps (2), installation of efficient showerheads (3), installation of efficient washing machines (4) and dishwashers (5), istallation of rainwater harvesting (6) and domestic greywater reuse (7) systems. Tier-1 measures comprise of dual flash toilets, low flow taps and showerheads, efficient washing machines and dishwashers, while tier-2 measures additionally include rainwater harvesting and domestic greywater reuse systems. The total potential water saving if applying all tier-1 measures (i.e. creating a "water efficient house") is estimated to reach 46.5% of the total household consumption (

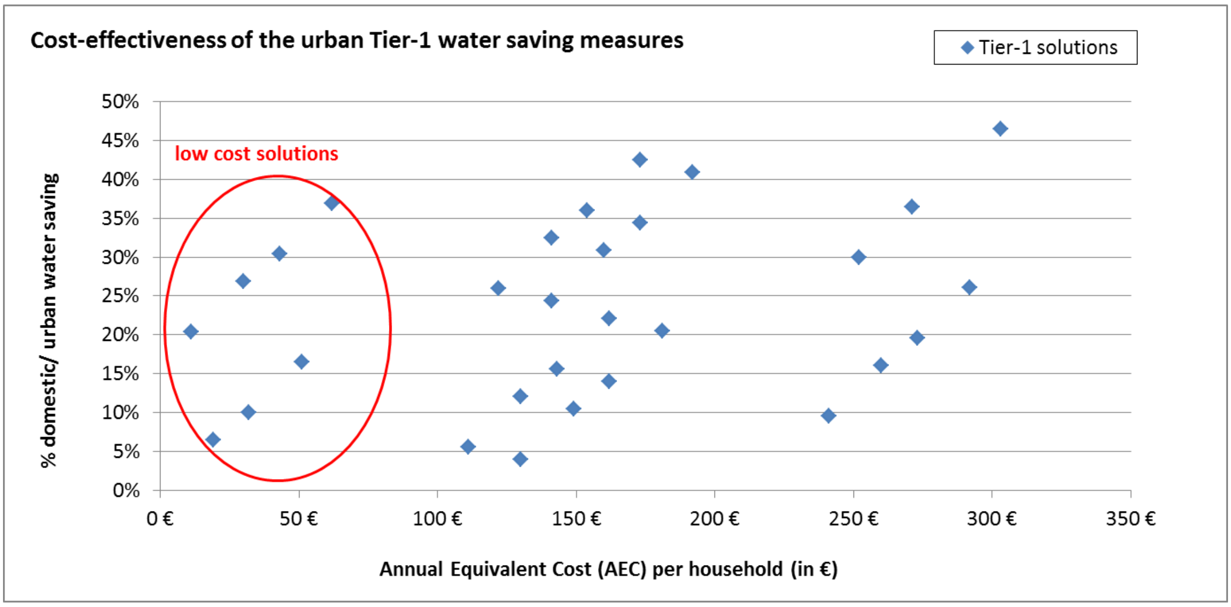


Figure 5-2.

Table 5-3). The application of additional tier-2 measures (rainwater harvesting-RWH, greywater reuse-GWR) on top of the tier-1 measures in a "water efficient" house delivers an additional 16.2% saving, thus a total of 62.7% domestic water saving potential maximum. In reality, since the rainwater harvesting and greywater reuse are expensive measures it is expected that a household would opt them after the tier-1 measures have been pursued. This assumption is considered in the calculations when building the urban cost-benefit curve. For example, the influent to the GWR system (which originates from the showers/ baths and washing machines of the "water efficient house") has been properly adjusted to account for the already achieved water saving of the tier-1 measures, and thus the influent potential volume has been accordingly decreased. As designed in the optimisation problem, the RWH performance is about 40% considering that only the rainy months can provide influent (roughly 4-4.5 months of the year in the area) and can feed this water for toilet flushing, washing clothes and outdoor use (garden irrigation, car washing, etc.). Respectively, GWR reuses the water coming from showers/baths and washing machines, and feeds this volume to toilets for flushing and outdoor use.

If all of the proposed tier-1 measures are applied in a household, the total percentage of water saved is 46.5% per household, or 11.6% per capita (assuming an average household size of 4 persons (CAS, 2012), with a respective total cost of 1,550 $ per household or 388 $ per capita. If the additional tier-2 measures are applied, the total percentage of water saved from the mains is 62.7% per household, or 15.7% per capita (assuming an average household size of 4 persons (CAS, 2012), with a respective total cost of 6,850 $ per household or 1,713 $ per capita. Since all calculations should refer to a mean annual basis (Berbel et al., 2011) the Annual Equivalent Cost (AEC) is also calculated as follows:

$$AEC = \frac{r(1+r)^n}{(1+r)^n - 1} \times Inv + OMC$$

Where, Inv represents the investment costs, OMC are the operational and maintenance costs, r is the discount rate, and n is the useful life of the or measures. A discount rate of 7% and a useful life equal to 3-10 years depending on the measure (as presented in **Table 5-2**) has been considered in the calculations, while the OMC can be ignored. The resulting AEC for each measure is pesented in Table **5-2**.

Table 5-2: Annual Equivalent Cost (AEC) of the urban demand management measures based on a 7% discount rate and their years of useful life

Water Saving Measure	Unit Cost $	r (discount rate)	n (useful life of the or measure in years)	AEC ($)
Dual Flush Toilet	170 $	0.07	7	32 $
Showerheads (1 item)	30 $	0.07	3	11 $
Low flow taps (2 items)	50 $	0.07	3	19 $
Efficient Washing machine	600 $	0.07	7	111 $
Dishwasher	700 $	0.07	7	130 $

Rainwater Harvesting	1,800 $[2]	0.07	10	356 $
Greywater Reuse	3,500 $	0.07	10	498 $
TOTAL *per household (HH):* *per capita (cap):*	 **6,850 $** 1,713 $			 **1,057 $** 264 $

In order to design the optimum urban water cost-effective curve an optimization procedure was employed. The objective function criteria of the optimization problem at hand regarded a) the maximization of the % of water saving and b) the simulatenoous minimization of the cost (AEC) using a mix of the tier-1 measures (parameters; alternative options/solutions to explore). The cost-effectiveness objectives (i.e. AEC and % expected water saving) that have been used in the optimization are shown below in the last two columns of

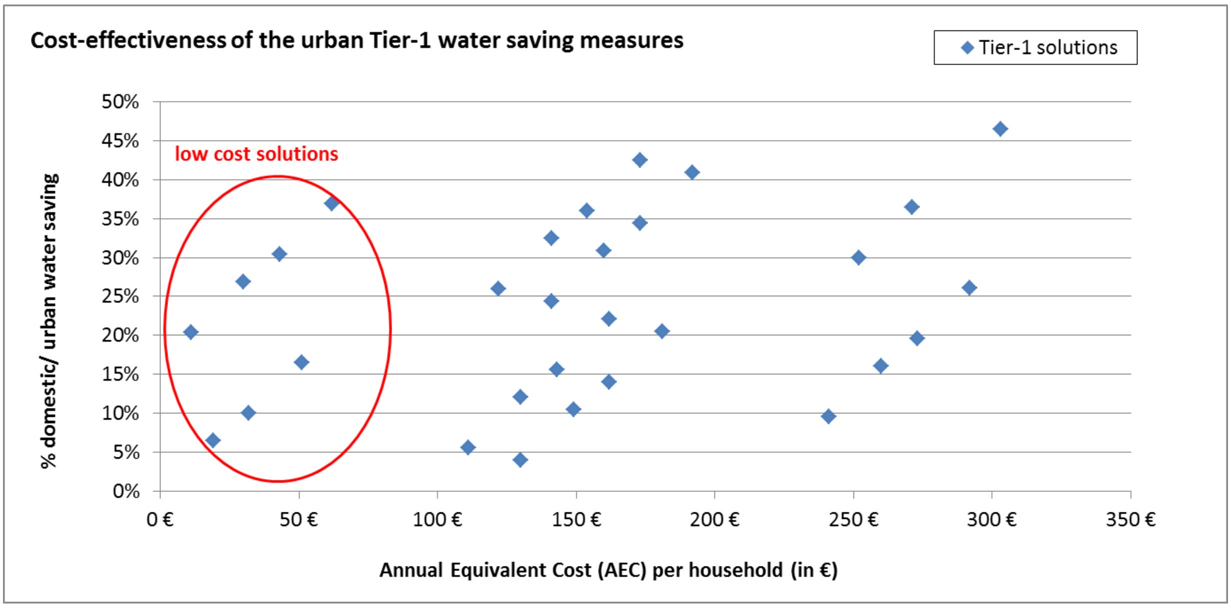


Figure **5-2**.

Table 5-3 (AEC per Household in $; Expected water saving as % of total Household consumption). The results of the optimization analysis (incl. a complete parameter space exploration analysis – i.e., detailing all investated solutions, not just the optimum one(s) identifyed by the algorithm) are presented in detail in

[2] Based on the average cost of the recent Rainwater Harvesting project that has been implemented in the area by ACTED (MADAD and PACA Funding)

Table **5-4** and

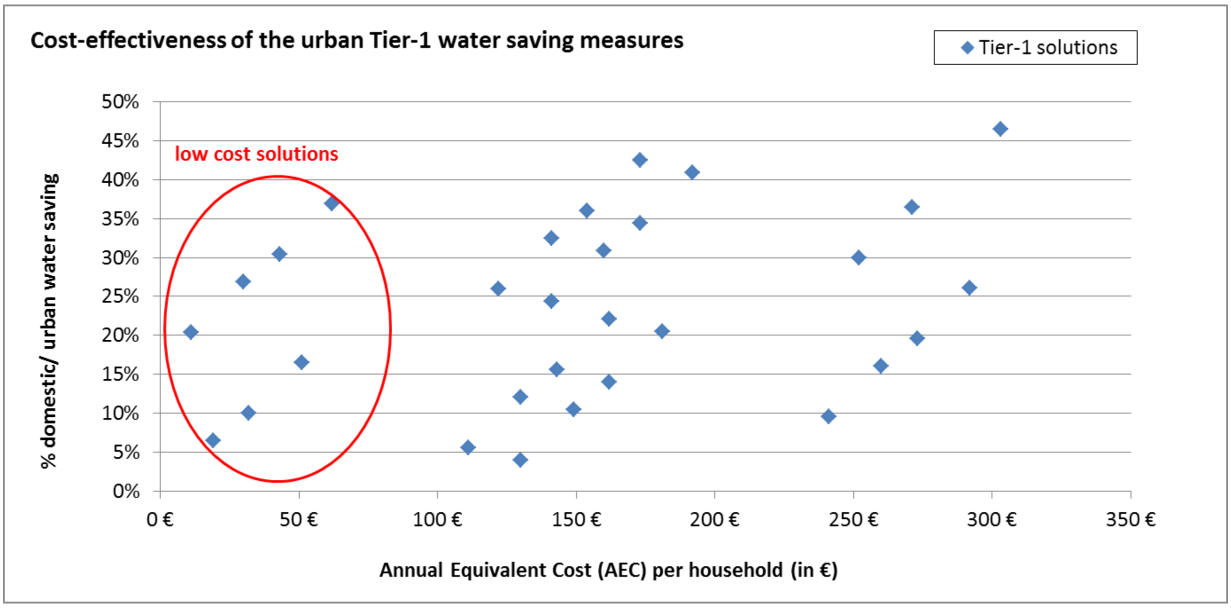


Figure 5-2.

Table 5-3: Cost-effectiveness of the demand management measures per household used in the design of the urban cost-effectiveness curves

	Water Saving Measure	Performance (% water saving per HH)	HH Micro-component targeted	HH Micro-component water consumption share (%)	Unit Cost $	AEC per HH $	Expected water saving as % of total HH consumption
Tier #1	Dual Flush Toilet	40 %	WC	25 %	170 $	32 $	10 %
	Showerheads replacement (1 item)	60 %	Bath + Shower	34 %	30 $	11 $	20.4 %
	Low flow taps (2 items)	50 %	Faucets	13 %	50 $	19 $	6.5 %
	Efficient Washing machine	40 %	Washing Machine	14 %	600 $	111 $	5.6 %
	Dishwasher	50 %	Dishwasher	8 %	700 $	130 $	4 %
			Outdoor use (garden, car washing)	6%			
Tier #1 TOTAL				100 %			
Per household (HH)					1,550 $	303 $	46.5 %
Per capita (cap)					388 $	76 $	11.6 %
Tier #2	Rainwater Harvesting *(the effluent goes to: WC, washing machine, outdoor use of the tier #1 "water efficient" house)*	40 % (accounting the rainy months)	WC, washing machine, outdoors	29 %	1,800 $	256 $	11.6 %

	Greywater Reuse *(the influent originates from shower, bath and washing machines , i.e. the 22% of the tier #1 "water efficient house", and the effluent goes to WC and outdoor use)*	22 % *(potential influent from shower, bath and washing machine of the "water efficient" house)*	WC , outdoors	21 % (15% WC + 6% outdoors)	3,500 $	498 $	4.6 %
Tier #2 TOTAL Per household (HH) Per capita (cap)				44 %	 5,300 $ 1,325 $	 754 $ 189 $	 16.2 % 4.1 %
GRAND TOTAL				**Per household (HH) Per capita (cap)**	**6,850 $ 1,713 $**	**1,057 $ 264 $**	**62.7 % 15.7 %**

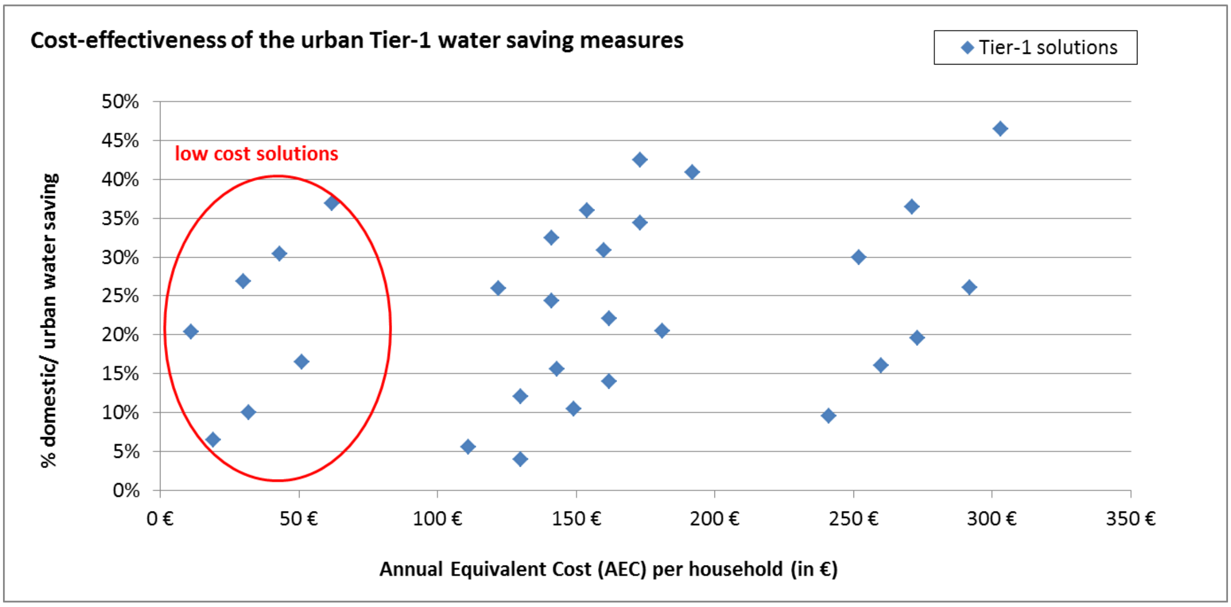


Figure 5-2: Conceptual Cost-effectiveness plot for the simulated urban water saving measures (% water saving vs. AEC per household)

As shown in **Table 5-2** above, it is relatively easy and entails relatively low cost to achieve conservation up to 37% with a cost of approximately 62 $/household AEC (or 250$ initial investment CAPEX). Assuming an average per capita consumption of 160 lt/day (or ~58 m^3 per capita per year) and an average household size of 4 people, this percentage represents a total saving of about 86 m^3 per household per year in the Al Ostuan basin, and results in an AEC unit cost of water saved of ~0.7 $/$m^3$ per household. Above that level of saving, and until the maximum level (46.5%) of water saving that can be achieved with the tier-1 measures, the cost is increasing rapidly (as clearly depicted in

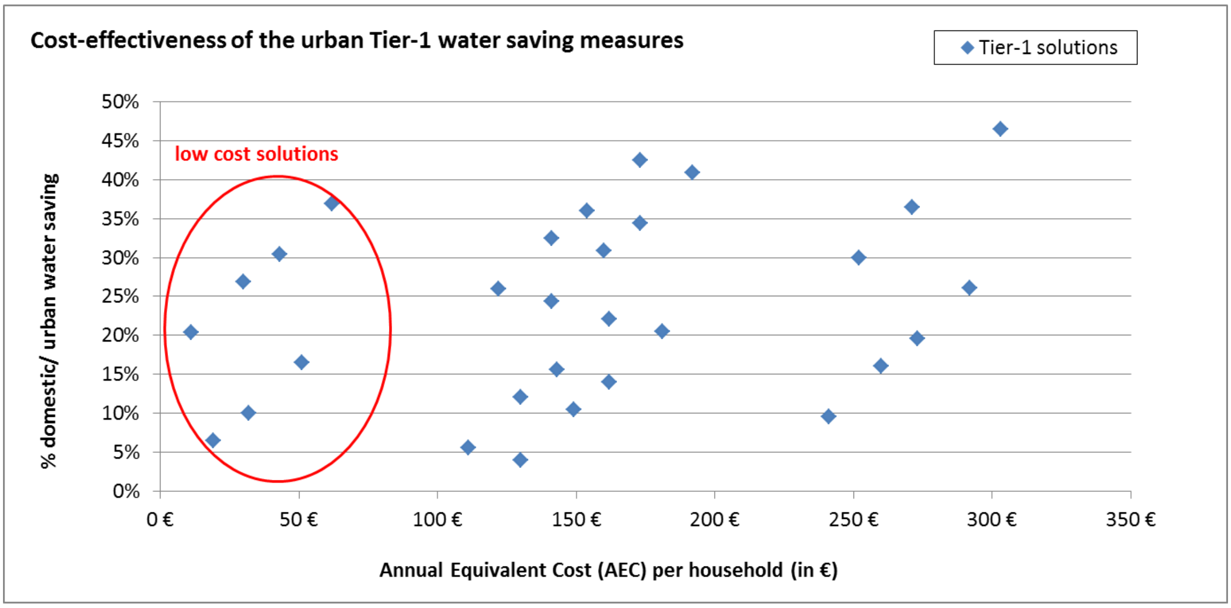


Figure 5-2). This is due to the most expensive tier-1 measures (washing machines, dishwashers). The results of the urban cost-effectiveness analysis are presented in

Table 5-4 below where the most beneficial solutions resulting from the optimization process are highlighted (light blue cells).

Table 5-4: Results of the cost-effectiveness analysis of the urban water saving measures

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m³) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/m³ of water saved	Total $/m³ of water saved for the basin	***Penetration (households adapting the measure)***				
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*
1	11 $	30 $	20.40%	2.8 $	5.10%	1.39	0.29	0.78	0.21	0.57		√			
2	19 $	50 $	6.50%	4.8 $	1.63%	0.44	0.50	1.31	1.12	2.96			√		
3	30 $	80 $	26.90%	7.5 $	6.73%	1.83	0.78	2.09	0.43	1.14		√	√		
4	32 $	170 $	10.00%	8.0 $	2.50%	0.68	0.84	4.44	1.23	6.53	√				
5	43 $	200 $	30.40%	10.8 $	7.60%	2.07	1.12	5.23	0.54	2.53	√	√			
6	51 $	220 $	16.50%	12.8 $	4.13%	1.12	1.33	5.75	1.19	5.12	√		√		
7	62 $	250 $	36.90%	15.5 $	9.23%	2.51	1.62	6.53	0.65	2.60	√	√	√		
8	111 $	600 $	5.60%	27.8 $	1.40%	0.38	2.90	15.68	7.62	41.18				√	
9	122 $	630 $	26.00%	30.5 $	6.50%	1.77	3.19	16.47	1.80	9.31		√		√	
10	130 $	600 $	12.10%	32.5 $	3.03%	0.82	3.40	15.68	4.13	19.06			√	√	

11	130 $	700 $	4.00%	32.5 $	1.00%	0.27	3.40	18.29	12.49	67.26					√
12	141 $	680 $	32.50%	35.3 $	8.13%	2.21	3.69	17.77	1.67	8.04		√	√	√	
13	141 $	730 $	24.40%	35.3 $	6.10%	1.66	3.69	19.08	2.22	11.50		√			√
14	143 $	770 $	15.60%	35.8 $	3.90%	1.06	3.74	20.12	3.52	18.97	√			√	
15	149 $	750 $	10.50%	37.3 $	2.63%	0.71	3.89	19.60	5.45	27.45			√		√
16	154 $	800 $	36.00%	38.5 $	9.00%	2.45	4.02	20.91	1.64	8.54	√	√		√	
17	160 $	780 $	30.90%	40.0 $	7.73%	2.10	4.18	20.39	1.99	9.70		√	√		√
18	162 $	800 $	22.10%	40.5 $	5.53%	1.50	4.23	20.91	2.82	13.91	√	√		√	
19	162 $	870 $	14.00%	40.5 $	3.50%	0.95	4.23	22.74	4.45	23.88	√				√
20	173 $	850 $	42.50%	43.3 $	10.63%	2.89	4.52	22.21	1.56	7.69	√	√	√	√	
21	173 $	900 $	34.40%	43.3 $	8.60%	2.34	4.52	23.52	1.93	10.06	√	√			√
22	181 $	920 $	20.50%	45.3 $	5.13%	1.39	4.73	24.04	3.39	17.25	√		√		√
23	192 $	950 $	40.90%	48.0 $	10.23%	2.78	5.02	24.83	1.80	8.93	√	√	√		√
24	241 $	1,300 $	9.60%	60.3 $	2.40%	0.65	6.30	33.98	9.65	52.05				√	√
25	252 $	1,330 $	30.00%	63.0 $	7.50%	2.04	6.59	34.76	3.23	17.04		√		√	√
26	260 $	1,350 $	16.10%	65.0 $	4.03%	1.09	6.80	35.28	6.21	32.23			√	√	√
27	271 $	1,380 $	36.50%	67.8 $	9.13%	2.48	7.08	36.07	2.85	14.53		√	√	√	√
28	273 $	1,470 $	19.60%	68.3 $	4.90%	1.33	7.13	38.42	5.35	28.83	√			√	√
29	292 $	1,520 $	26.10%	73.0 $	6.53%	1.77	7.63	39.73	4.30	22.38	√		√	√	√
30	303 $	1,550 $	46.50%	75.8 $	11.63%	3.16	7.92	40.51	2.50	12.81	√	√	√	√	√

* The total water saving is based on the annual urban water demand in the Al Ostuan basin for the reference period 2003-2018, which sums up at 6.8 million m^3.

* The total AEC is obtained by multiplying the AEC per household (HH) with the total number of households. The later has been estimated to account 26,135 household in the Al Ostuan basin assuming each household is occupied by 4 people on average (number of hh = total population ÷ 4)

The Business as Usual (BaU) represents the current situation, thus no measures are adopted, water saving is 0%, and the unmet demand remains at current levels. With a very low cost, of about 10 $/household AEC, a 20.4% saving of the urban water use can be achieved. This solution (solution No. #1) requires the installation of low-flow showerheads (1 item) in the households in the area. A 27% saving can be achieved with an AEC of 30 $/hh and requires the installation of low-flow showerheads (1 item) and low-flow taps (2 items) in the households in the area (solution No. #3). The total AEC in this case reaches 0.78 million $ with a total water saving of 1.83 mio m^3, thus a unit cost of 0.43 $ AEC/m^3 of water saved. Respectively, with an AEC unit cost of 0.54 $/$m^3$ of water saved (or AEC 43 $/hh) 30.4% of the urban water can be saved (i.e. 2.07 mio m^3 in total) (solution No. #5). The latter requires the penetration of low-flow showerheads (1 item) and dual flush toilets. With a slightly higher AEC of 0.65 $/$m^3$ of water saved (or AEC 62 $/hh) 37% of water can be saved (i.e. 2.51 mio m3 in total and with a respective total cost of AEC 1.6 million $) (solution No. #7). The latter requires the penetration of three technologies, namely dual flush toilets, low-flow showerheads (1 item) and low-flow taps (2 items) in the households in the area. Beyond this level, the annual equivalent unit cost in $/$m^3$ of water saved exceeds 1$ so the solutions cannot be considered as “quick-wins”, while after some point the urban measures become too expensive, possibly more than the actual cost of water (e.g. solutions No. #24 and #26 where the AEC unit costs are higher than 5$/m^3 of water saved) which constraints their uptake by the public. An exemption might be solution No. #20, where a high saving of 42.5% (almost equal to the maximum potential saving that can be achieved with tier-1 measures) can be reached with an AEC of 173$ per household (the respective unit AEC is 1.56 $/m^3 of water saved), resulting thus in a total saving of 2.89 million m^3 in the urban sector (i.e.. This solution requires the penetration of four technologies, namely dual flush toilets, low-flow showerheads (1 item), low-flow taps (2 items) and efficient washing machines (1 item) in the households in the area.

It is important to highlight that the unit cost (i.e. the cost required to save 1 m^3 of water) is an important parameter as it can create incentives or disincentives. As the implementation of the urban saving measures depends on the people and their behavior, low unit costs, which are lower than the existing water tariffs, would normally encourage people to implement them. Figure **5-3** presents the annual equivalent unit cost (i.e. $ per m^3 of water saved) of the different solutions plotted against the total potential water saving in the area.

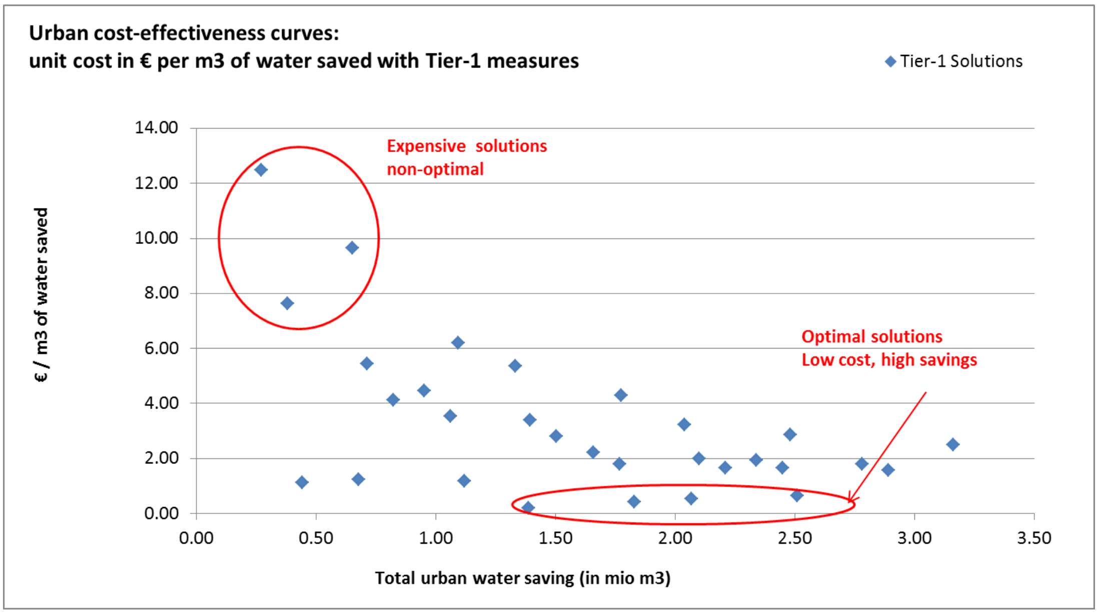


Figure 5-3: Cost-effectiveness curves for the simulated Tier-1 urban measures in $/m^3 of water saved

At the same time, we need of course to consider the capital investment, i.e. the CAPEX which needs to be paid up-front, either by each household or through programmes, incentives, subsidies, etc. Looking at the total investment needed for the basin (CAPEX in mio $), we can observe (as presented in **Table 5-4**) that with CAPEX < 1 million $ (more specifically with 0.78 million $) 20.4% of the domestic water used (i.e. 1.4 mio m^3) could be saved if efficient showerheads are installed in all the households. To achieve 30% savings (i.e. save ~2 mio m^3 in the basin) the necessary CAPEX is about 5.2 million $ and requires the installation of efficient showerheads plus dual flash toilets, while for a 37% saving (i.e. save 2.5 mio m^3 in the basin) the necessary CAPEX is 6.5 million $ (requires the installation of efficient showerheads, dual flash toilets and 2 low flow taps in each household) . A 42.5% saving (i.e. save 2.9 mio m^3 in the basin) can also be achieved but the CAPEX goes up to 22 million $ which is considered disproportionally high in terms of added value as compared to the previous solutions.

Regarding the application of the additional tier-2 measures (rainwater harvesting (RWH) and greywater reuse (GWR)), these have been investigated, as previously mentioned, on top of the tier 1 measures, i.e. in a “water efficient” house. The five tier-1 solutions that have been previously selected as the most beneficial (i.e. solutions No. #1, 3, 5, 7, 20 of

Table **5-4**) have been further examined with the additional application of RWH and GWR. The results are presented in **Table 5-5** below, where the most beneficial solutions are also marked (light blue cells). It can be generally observed (**Table 5-5**, **Figure 5-4**, **Figure 5-5**) that the mixed solutions which contain rainwater harvesting (Tier-1 + RWH) present a better performance as compared the mixed solutions which contain greywater reuse (Tier-1 + GWR), The fully mixed solutions with both rainwater harvesting and greywater reuse (Tier-1 + RWH + GWR) are, as expected, the most expensive, but can deliver up to 59% water saving maximum (with a respective AEC 927 $ per household).

Table 5-5: Results of the cost-effectiveness analysis of the urban increase supply measures

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m^3) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/m^3 of water saved	Total $/m^3 of water saved for the basin	Penetration (households adapting the measure)						
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*	*Rainwater Harvesting (RWH)*	*Greywater Reuse (GWR)*
1r	267 $	1,830 $	32.00%	66.8 $	8.00%	2.18	6.98	47.83	3.21	21.98		√				√	
1w	509 $	3,530 $	25.00%	127.3 $	6.25%	1.70	13.30	92.26	7.83	54.27		√					√
1m	765 $	5,330 $	36.60%	191.3 $	9.15%	2.49	19.99	139.30	8.03	55.97		√				√	√
3r	286 $	1,880 $	38.50%	71.5 $	9.63%	2.62	7.47	49.13	2.86	18.77		√	√			√	
3w	528 $	3,580 $	31.50%	132.0 $	7.88%	2.14	13.80	93.56	6.44	43.68		√	√				√
3m	784 $	5,380 $	43.10%	196.0 $	10.78%	2.93	20.49	140.61	6.99	47.98		√	√			√	√
5r	299 $	2,000 $	42.00%	74.8 $	10.50%	2.86	7.81	52.27	2.74	18.30	√	√				√	
5w	541 $	3,360 $	35.00%	135.3 $	8.75%	2.38	14.14	87.81	5.94	36.90	√	√					√
5m	797 $	5,500 $	46.60%	199.3 $	11.65%	3.17	20.83	143.74	6.57	45.36	√	√				√	√
7r	318 $	2,050 $	48.50%	79.5 $	12.13%	3.30	8.31	53.58	2.52	16.25	√	√	√			√	
7w	560 $	3,750 $	41.50%	140.0 $	10.38%	2.82	14.64	98.01	5.19	34.73	√	√	√				√

7m	816 $	5,550 $	53.10%	204.0 $	13.28%	3.61	21.33	145.05	5.91	40.17	√	√	√			√	√
20r	429 $	2,650 $	54.10%	107.3 $	13.53%	3.68	11.21	69.26	3.05	18.83	√	√	√	√		√	
20w	671 $	4,350 $	47.10%	167.8 $	11.78%	3.20	17.54	113.69	5.48	35.50	√	√	√	√			√
20m	927 $	6,150 $	58.70%	231.8 $	14.68%	3.99	24.23	160.73	6.07	40.27	√	√	√	√		√	√
31	256 $	1,800 $	11.60%	64.0 $	2.90%	0.79	6.69	47.04	8.48	59.64						√	
32	498 $	3,500 $	4.60%	124.5 $	1.15%	0.31	13.02	91.47	41.61	292.43							√
33	754 $	5,300 $	16.20%	188.5 $	4.05%	1.10	19.71	138.52	17.89	125.74						√	√

Note: "r" denotes a solution with rainwater harvesting, "w" with greywater reuse, and "m" with both

* The total water saving is based on the annual urban water demand in the Al Ostuan basin for the reference period 2003-2018, which sums up at 6.8 million m^3.

** The total AEC is obtained by multiplying the AEC per household (HH) with the total number of households. The later has been estimated to account 26,135 household in the Al Ostuan basin assuming each household is occupied by 4 people on average (number of hh = total population ÷ 4)

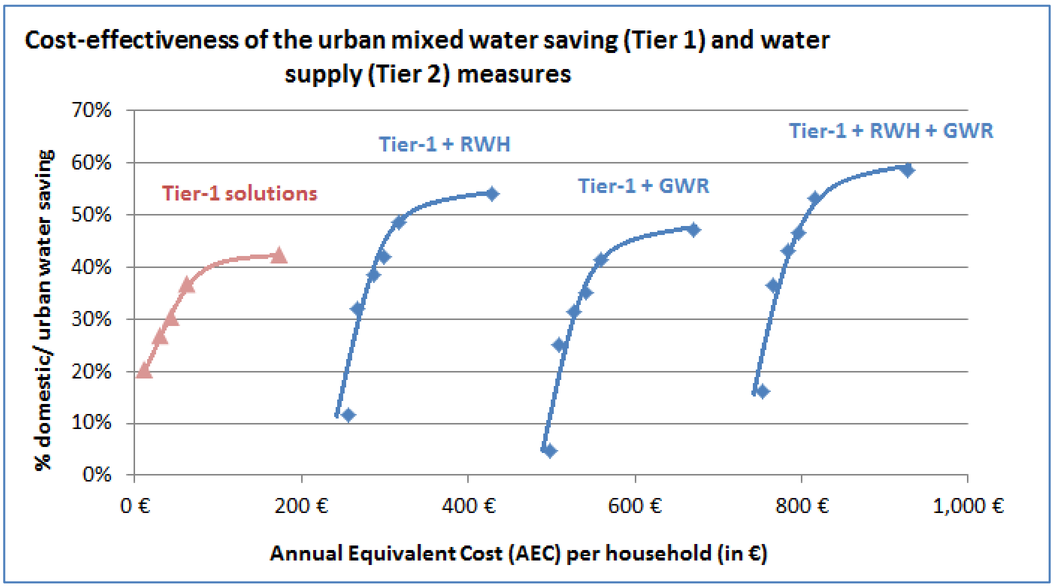


Figure 5-4: Cost-effectiveness plot for the simulated urban increase supply measures (% water saving vs. AEC per household)

The optimal solutions, in terms of cost-effectiveness, are solutions No. 7r and 20r, since they deliver among the highest water savings (48.50% and 54.10% respectively) with the lowest unit costs of AEC 2.52 and 3.05 $/m^3 of water saved (or AEC 318$ and 429$ per household). These measures can render in the basin total water savings of 3.30 and 3.68 million m^3 respectively. For this to be achieved, solution No. 7r requires the penetration of dual flash toilets, low-flow showerheads (1 item), low-flow taps (2 items) and rainwater harvesting in the households in the area, while solution No. 20r also includes the installation of efficient washing machines on top of the aforementioned technologies.

Additional solutions which are considered of good performance are the solutions No. 7w, 20w, and 20m. A 41.5% saving can be achieved with an AEC of 560 $/hh and requires the installation of dual flash toilets, low-flow showerheads (1 item), low-flow taps (2 items) and greywater reuse in the households in the area (solution No. #7w). The total AEC in this case reaches 14.64 million $ with a total water saving of 2.82 million m^3, thus a unit AEC of 5.19 $/$m^3$ of water saved. This solution is the cheapest among all solutions which contain greywater reuse. A slightly higher total water saving of 3.20 million m^3 (representing 47.1% savings) with a slightly higher unit cost of 5.48 $/$m^3$ of water saved (or AEC 671$/hh) can be achieved with solution No. 20w. This solution requires the penetration of dual flash toilets, low-flow showerheads (1 item), low-flow taps (2 items), efficient washing machine and greywater reuse in the households in the area. Although the solutions 7w and 20w are more expensive than their equivalents 7r and 7w which suggest rainwater harvesting instead of the greywater reuse, we have kept them as options to allow for diversity and flexibility in cases that RWH is not a feasible solution from a technical or social/ cultural perspective. Finally, solution No. 20m which additionally requires the installations of rainwater harvesting on top of all the technologies of the previous 20w solution, brings the maximum water saving potential of 4 million m^3 in the basin (representing 58.7% savings) with a unit AEC of 6 $/$m^3$ of water saved (or AEC 917$/hh). The penetration of the 20m solution in all the households in the basin would require a total AEC of 24 million $.

At the same time, we need also to consider the capital investment for the Tier-2 measures, i.e. the CAPEX which needs to be paid up-front, either by each household or through programmes, incentives, subsidies, etc. Looking at the total investment needed for the basin (CAPEX in mio $), we can observe (as presented in **Table 5-5**) that when we implement the Tier-2 the minimum CAPEX required is about 48 million $. The solution 7r which delivers a total saving of 3.3 million m^3 in the basin requires a CAPEX of 53.6 million $ for the entire basin or 2,050$ per household. To achieve the maximum saving of 4 million m^3 in the basin (representing 58.7% savings) with the solution 20m, the required CAPEX is 160.7 million $ for the entire basin or 6,150$ per household. It is thus clear that all the Tier-2 solutions bear higher costs, especially higher initial investment costs, and might not be considered by the public as the most cost-effective ones, but they bring the additional benefit of reducing the user's dependency from the mains and the public water supply system since the user has a decentralized alternative water supply source.

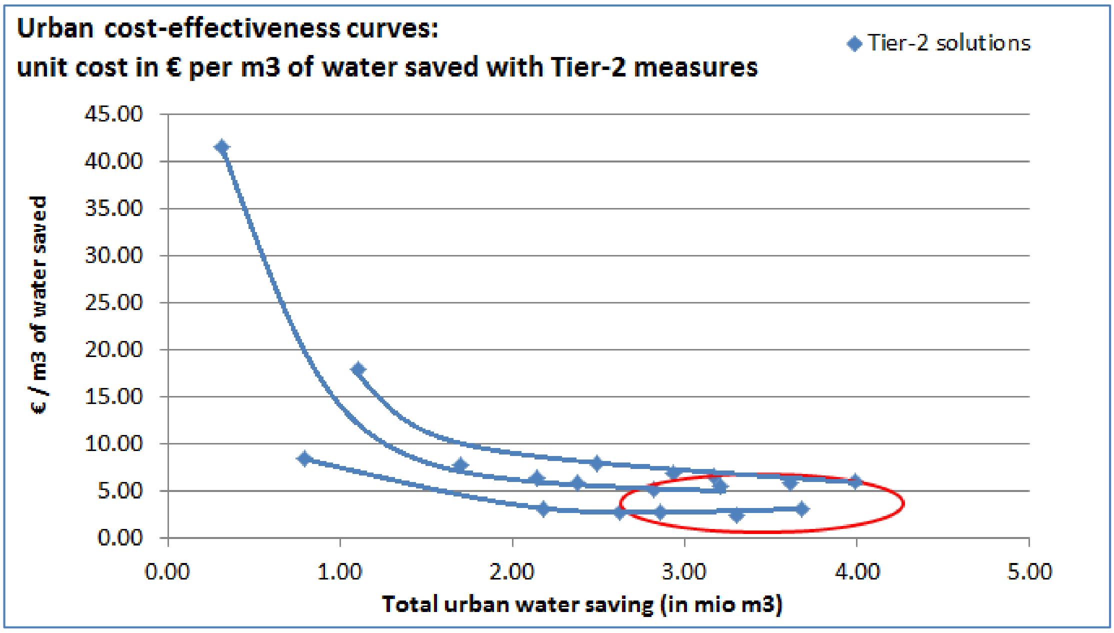


Figure 5-5: Cost-effectiveness curves for the simulated Tier-2 urban measures in $/m^3 of water saved

It is also important to notice that for the most successful application of the domestic/ urban measures water metering is essential. In order to pragmatically quantify the water savings delivered by the investigated technologies metering, both prior to and after the implementation of the measures, is important since it will allow the comparison between the two. Additionally, metering helps in detecting leakage which is a very important component of water demand management.

Water leakage from the public supply network has been simulated assuming a 10% reduction in losses (i.e. from the BaU 30% to 20%).

6.3 ANALYSIS OF THE AGRICULTURAL MEASURES - DESIGN OF THE COST-EFFECTIVENESS CURVES

The cost-effective functions for irrigation investigate and try to find the optimum trade-off between various conveyance and field application irrigation methods. The investigation in the Al Ostuan focuses on how much the field application efficiency would be improved in an irrigated area if different irrigation methods are used which can potentially deliver highest efficiency with the minimum possible cost, and if different conveyance methods are used. Two main measures have been considered: (a) converting from furrow (surface) irrigation to drip irrigation, (b) converting from open channels to closed pipes, or from individual to collective networks and improving thus the conveyance efficiency. These transactions from one method to another (field application or conveyance method) are subject of constraints and cannot exceed their initial values. Every transaction from one method to another has a different effectiveness and a different cost. The transactions examined for the Al Ostuan are those aiming to improve both the field application efficiency and the irrigation network conveyance efficiency.

In order to run a scenario-based (i.e., using a discrete state space of solutions) optimisation process the start-up efficiency values have been defined. Typical aggregated values for irrigation efficiency are presented in **Table 5-6**, while the costs for converting to drip irrigation and converting from open canals to closed pipes are presented in **Table 5-7** and **Table 5-8**, and have been defined after a detailed literature review. As seen, the small individual networks (closed pipes) which are drip irrigated have the highest efficiency and that is due to their conveyance efficiency being very high (95%). Regarding the costs, since all calculations should refer to a mean annual basis (Berbel et al., 2011) the Annual Equivalent Cost (AEC) is also calculated (similarly to the urban curve) as follows:

$$AEC = \frac{r(1+r)^n}{(1+r)^n - 1} \times Inv + OMC$$

Where, Inv represents the investment costs, OMC are the operational and maintenance costs, r is the discount rate, and n is the useful life of the or measures. A discount rate of 7% and a useful life equal to 3-50 years depending on the measure has been considered in the calculations, while the OMC can be ignored.

Table 5-6: Typical literature values for aggregated irrigation efficiency (conveyance and fieldapplication)

Irrigation Efficiency		Drip	Sprinkler	Furrow
Closed Pipes	Collective Networks	76.0%	68.0%	52.0%
	Small individual networks	90.3%	80.8%	61.8%
Open Channels	Collective Networks	57.0%	51.0%	39.0%
	Small individual networks	-	-	-

Source: Kossida, M., 2015

Table 5-7: Typical costs associated with converting to drip irrigation[3]

References/ Sources	Cost ($/ha)	Lifespan (yrs)	AEC ($/ha)
Robertson et al., 2006	890	5.5	200
Payero et al., 2005	1,480	20	140
Letey et al., 1990	1,627	8	273
Amosson et al., 2011	2,135	20	202
Lower Arkansas Valley Water Conservancy District (LAVWCD)	2,669	20	252

[3] Detailed study needed to determine exact costs converting to drip irrigation in Lebanon. Desktop review was conducted to provide estimates.

Kazantzis, 2011	3,068	20	290
Economic calculator for irrigation systems (EconCalc)	3,720	20	351
Guilherme et al, 2015	4,000	20	378
Lamm et al., 2002; Economic comparison tool for Center Pivot and SDI	4,330	20	409
State of Queensland, 2011	5,400	20	510
Economic calculator for irrigation systems (EconCalc)	5,420	20	512
Lourmas et al., 2012	6,886	20	650
Average cost (suggested for the modeling)			**347 $/ha AEC 3,680 $/ha CAPEX**

Source: Kossida, M., 2015

Table 5-8: Typical costs associated with increasing conveyance efficiency (converting from open channels to closed pipes**)**

Cost items	Cost per hectare ($/ha)
Total cost for moving from open channels to closed pipes	6,000
AEC (for a useful life n=50 years, and r=0.07)	435
Savings from slight yield increase of 2-4%	-37
Savings from energy bills (reduced pumping)	-8
Net total cost to converting to closed pipes (suggested for modeling)	**390 $/ha AEC**

Source: Kossida, M., 2015 (adopted from Panagopoulos et al., 2012)

In the Lebanese National Water Sector Strategy (NWSS) update 2020 the conversion from open channels to closed canals to increase the conveyance efficiency has been prioritized as a measure (NWSS page VA4 volume V reference to this priority; NWSS page VB66 volume V reference to specific projects). In the NWSS update 2020, Volume V “Proposed Projects”, the following projects are proposed for NLWE (**Table 5-9**). The resulting unit cost per km of concrete pipe (including design and supervision) ranges from ~100,000 $/km to ~255,000 $/km. It is not possible to estimate the equivalent cost per hectare, but if we assume that 3 km of pipe are needed on average per 1km^2 of irrigates land (i.e. per 100 hectares), then the resulting unit cost per hectare is 3,000 – 7,600 $/ha.

Table 5-9: Costs of the planned irrigation projects in the NWSS 2020 (converting from open channels to closed pipes**)**

System	Project Description	Total with design and supervision (USD)	Project Justification
Priority 1			
Omar El Breikat Scheme	18 km Earth channels to concrete	1,821,080	Justified in order to increase canal conveyance efficiency by

El Koubayat Scheme	- 1.5 km Concrete channels to rehabilitate - 15 km Earth channels to concrete	2,506,993	rehabilitation of existing poorly maintained concrete channels and converting earth canals to concrete structures; by selecting this (these) project(s) negative water balance at farm level will be mitigated
Bouqaiaa -Machta Hamoud -Machta Hassan Scheme	42 km Earth channels to concrete	10,687,115	
Priority 3			
Akkar plain Scheme	- 50 m Concrete channels to rehabilitate - 78 km Earth channels to concrete - Extention of Networks to Cover Present Dry Farm Area	29,994,518	Justified in order to increase scheme total area, and direct increase of beneficiaries number. The project(s) will lead to a horizontal expansion since arable land presence is not a limiting factor
Akkar el Atika Scheme	- 2 km Concrete channels to rehabilitate - 29 km Earth channels to concrete - Extention of Networks to Cover Present Dry Farm Area	5,688,774	

In the Al Ostuan basin farmers apply surface irrigation and drip irrigation as indicated by a Survey conducted with 22 Municipalities in the area. The irrigation efficiencies used in the optimisation process for the Al Ostuan, for the combination of various conveyance and irrigation methods, have been formulated as presented in the **Table 5-10** below. The combined efficiency for the Baseline was set to 60%[4]. It has been assumed that 38% of the total irrigated area has collective networks, and the remaining 62% has small individual networks. One percent (1%) of the collective ones are equiped with closed pipes, while 37% has open canals. The dominant irrigation method is furrow (surface) irrigation (in 78% of the areas), followed by sprinklers (155), while only 7% is drip. The current (Baseline) aggregated field application efficiency (considering the above-mentioned assumptions) is thus calculated at ~63%. The coveyance losses are estimated to 10% for the closed-pipe collective networks, 35% for the small individual networks (groundwater wells), and 55% for the open-channel collective networks. Thus, based on the current mix, the aggreagated conveyance efficiency (used in the Baseline) is ~58% (i.e. 42% losses). The areas occupied by each irrigated crop wihtin each subcatchemnt of the Al Ostuan basin are presented in **Table 5-11**.

Table 5-10: Irrigation efficiency assumptions in the Al Ostuan river basin for the Baseline

[4] In the NWSS 2012 the following percentages are overall reported for Lebanon irrigation methods and efficiencies:
Surface (furrow): 70.4% coverage, 60% efficiency
Sprinklers: 23.4% coverage, 70% efficiency
Drip: 6.2% coverage, 80%
In the NWSS 2020 update, there is no breakdown presented, only a general mention that “under the presently prevailing irrigation conditions, considering network losses and the irrigation practices, the irrigation efficiency is around 50 to 60%” (NWSS 2020, Volume IV, page IV B 4). With regard to the conveyance efficiencies, in the NWSS 2012 it is mentioned that irrigation is the largest water consumer with low efficiencies, as open channels still constitute the majority of the networks. In Karaa et al. (2009), it is mentioned that the actual efficiency of the traditional gravity systems in Lebanon is 45%

Conveyance networks and irrigation methods	% coverage of the irrigated area	% losses	% conveyence efficiency
Collective Networks - Closed Pipes	1%	10%	90%
Collective Networks - Open Channels	37%	55%	45%
Small individual networks - Groundwater wells	62%	35%	65%
Aggregated network conveyance efficiency	(1% x 0.9) + (37% x 0.45) + (62% x 0.65) = **57.85% or 42.15% losses**		
Drip irrigation	7%	20%	80%
Sprinklers' irrigation	15%	30%	70%
Furrow irrigation	78%	40%	60%
Aggregated field application efficiency	(7% x 0.8) + (15% x 0.7) + (78% x 0.6) = **62.90% or 37.10% losses**		
Overall combined irrigation efficiency = 60.38%, i.e. 60%			

Note: these figures have been determined in the "Baseline Report on the assessment of the current water resources on the Nahr Al Ostuan Basin" of this study, after investigating multiple sources (as presented in Box 4.3 of the Baseline Report),including the NWSS 2012 and 2020 update, interviews with the NLWE, MEW, MoA, Municipalities, local farmers, agronomists

.

Table 5-11: Irrigated areas per crop type in the Al Ostuan river basin

Catchment	Irrigated crops	irrigated area per crop (km^2)	% of irrigated crop
C15	Field Crops in Medium to Large Terrace	2.08	68%
	Olives	0.03	1%
	Vineyards	0.02	1%
	Fruit Trees	0.02	1%
	Citrus Fruit Trees	0.84	27%
	Protected Agriculture	0.08	3%
C16	Field Crops in Medium to Large Terrace	0.80	35%
	Olives	1.41	62%
	Citrus Fruit Trees	0.01	1%
	Protected Agriculture	0.06	3%
C17	Field Crops in Medium to Large Terrace	0.03	4%
	Olives	0.83	92%
	Fruit Trees	0.04	4%
C18	Field Crops in Medium to Large Terrace	0.42	29%
	Olives	1.01	69%
	Fruit Trees	0.02	1.6%
	Citrus Fruit Trees	0.01	0.4%
C19	Field Crops in Medium to Large Terrace	0.92	47%
	Olives	0.36	18%
	Fruit Trees	0.69	35%

C20	Field Crops in Medium to Large Terrace Olives Fruit Trees	0.01 0.05 0.07	4% 42% 54%
C21	Field Crops in Small Fields/Terrace Olives Fruit Trees	0.36 0.21 0.17	49% 28% 23%
C22	Field Crops in Medium to Large Terrace Citrus Fruit Trees Protected Agriculture	7.32 1.64 0.77	75% 17% 8%
	TOTAL =	**20.30 km^2 or 2,030 hectares**	

For the simulation of the agricultural saving measures two scenarios have been considered: a 20% increase in the irrigation efficiency (reaching thus a combined efficiency of 80%) and a 25% increase in the irrigation efficiency (reaching thus a combined efficiency of 85%), by converting a number of hectares to closed pipes and drip irrigation as presented in

Table 5-12. In the first case (i.e. 20% increase) an additional of 1,502 ha need to be conveyed with closed pipes and 1,482 need to convert to drip irrigation from surface. With an AEC of 390 $/ha and 347 $/ha respectively (see **Table 5-8**) the total AEC for this scenario is 1.1 million $, while the total initial investment is 14.5 million $. Similarly, for a 25% increase in the irrigation efficiency, an additional of 1,969 ha need to be conveyed with closed pipes and 1,847 need to convert to drip irrigation from surface, while the required AEC is 1.4 million $ and the CAPEX is 18.6 million $.

Table 5-12: Total hectares per conveyance type and irrigation method in the baseline scenario and under increased efficiency scenarios

Conveyance networks and irrigation methods	Efficiency 60% (Baseline)		Efficiency 80% (+20% increase)		Efficiency 85% (+25% increase)	
Conveyance networks	**% ha**	**ha**	**% ha**	**ha**	**% ha**	**ha**
Collective Networks - Closed Pipes	1%	20.30	75%	1522.50	98%	1989.40
Collective Networks - Open Channels	37%	751.10	5%	101.50	0%	0.00
Small individual networks - Groundwater wells	62%	1258.60	20%	406.00	2%	40.60
Irrigation methods	**%**	**ha**	**%**	**ha**	**%**	**ha**
Drip irrigation	7%	142.10	80%	1624.00	98%	1989.40
Sprinklers' irrigation	15%	304.50	10%	203.00	0%	0.00
Furrow irrigation	78%	1583.40	10%	203.00	2%	40.60

** Total irrigated hectares in the basin = 2,030 ha*

7 SIMULATION OF THE MEASURES IN THE WEAP21 MODEL OF THE AL OSTUAN RIVER BASIN

7.1 Scenario UrbSav

The Scenario UrbSav focuses on water saving in the domestic/urban sector

Measures included	U1. Low water using fixtures and appliances (including hotels)
Implementation	The measures have been applied in all the 20 urban demand nodes. Node #21 (UD_ Danke-Qsair) is a water export of a fixed volume (7,200 m^3/month) and it was kept constant, assuming that since it is outside the Al Ostuan River Basin the saving measures will not be applied there. The baseline (BaU) was the reference period 2003-2018, where the average annual urban demand was 6.8 million m^3.

Node #	Urban Demand Node	Villages within the Node	Total Node Population in WEAP, ORB
1	UD_22_NPS	Al-Kleiat Cheikh Zennad Tal Bibe Al-Kneisse Al Moghrak Tal Kerri Al-Hissa Al-Massoudie	7,190
2	UD_15	Halba Tal Abbas El-Gharbie Koueikhat Tal Abbas El-Charkie Al-Massoudie Al-Khraibe	3,009
3	UD_16_Kob.Charbila	Charbila Ain El-Zeit El-Daghle Kherbet Daoud El-Msalle Kefr El-Ftouh	13,468
4	UD_16_Kob.Daouce	El-Kouachra Daouce et Baghdadi Denke et El-Amriyeh El-Bire	15,658

5	UD_16_NPS	Katte Al-Rihanie El-Tleil Omar el-Beikate El-Haouchab Hmais Saidnaya Al-Khraibe	6,652
6	UD_17_Ext	Dahr-Leycine Machha Hayzouk	7,614
7	UD_17_Kob.Harra	Kfar Harra	270
8	UD_17_NPS	Al-Souaisse Dahr el-Kneisse Al-Khraibe	4,401
9	UD_18_Kob.Charbila	Ain Tanta Douair Adouiye	3,202
10	UD_18_Kob.Harra	El-Hed Deir-Janine Sfeinite El-Dreibe Kherbet Char Fseikine et Ain Achma Barbara Mazraat Balde	8,239
11	UD_18_Ext	Beino	2,052
12	UD_18_NPS	Majdel	1,601
13	UD_19_Kob.Bire	Sindianet Zeidan	744
14	UD_19_PWS	El-Koubayet	4,876
15	UD_19_NPS	Majdel Daoura Andeket Akkar El-Atika	7,412
16	UD_20_NPS	Andeket	168
17	UD_20_PWS	Akkar El-Atika	8,304
18	UD_21_KobVillage_Jawz	El-Koubayet	5,319
19	UD_21_Qatlabah_Hamade	El-Koubayet	1,330

20	UD_21_NPS	Akkar El-Atika	3,019

Simulation parameters

Based on the cost-effectiveness analysis of the urban water saving measures (ref. to Chapter 3.2), the following 5 solutions are considered as optimum (see table below) and have been simulated in WEAP.

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m^3) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/$m^3$ of water saved	Total $/$m^3$ of water saved for the basin	*Penetration (households adapting the measure)*				
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*
1	11 $	30 $	20.40%	2.8 $	5.10%	1.39	0.29	0.78	0.21	0.57		√			
3	30 $	80 $	26.90%	7.5 $	6.73%	1.83	0.78	2.09	0.4	1.14		√	√		
5	43 $	200 $	30.40%	10.8 $	7.60%	2.07	1.12	5.23	0.54	2.53	√	√			
7	62 $	250 $	36.90%	15.5 $	9.23%	2.51	1.62	6.53	0.65	2.60	√	√	√		
20	173 $	850 $	42.50%	43.3 $	10.63%	2.89	4.52	22.21	1.56	7.69	√	√	√	√	

* The total water saving is based on the annual urban water demand in the Al Ostuan basin for the reference period 2003-2018, which sums up at 6.8 million m^3.

* The total AEC is obtained by multiplying the AEC per household (HH) with the total number of households. The later has been estimated to account 26,135 household in the Al Ostuan basin assuming each household is occupied by 4 people on average (number of hh = total population ÷ 4)

	These solutions have been simulated In WEAP in the 20 demand sites mentioned above, based on the following formulas: ▪ Solution No. #1: multiply water demand by (1-0.051) in all 20 sites, or apply DSM saving per capita 5.10% in the tab Demand Sites and Catchments/Demand Management/DSM Savings ▪ Solution No. #3: multiply water demand by (1-0.0673) in all 20 sites, or apply DSM saving per capita 6.73% in the tab Demand Sites and Catchments/Demand Management/DSM Savings ▪ Solution No. #5: multiply water demand by (1-0.076) in all 20 sites, or apply DSM saving per capita 7.60% in the tab Demand Sites and Catchments/Demand Management/DSM Savings ▪ Solution No. #7: multiply water demand by (1-0.0923) in all 20 sites, or apply DSM saving per capita 9.23% in the tab Demand Sites and Catchments/Demand Management/DSM Savings ▪ Solution No. #20: multiply water demand by (1-0.1063) in all 20 sites, or apply DSM saving per capita 10.63% in the tab Demand Sites and Catchments/Demand Management/DSM Savings For each solution the change in the model results, in terms of unmet demand and potential water excess (resulting from all 20 demand sites as a sum), has been investigated. Since in the WEAP model the resources and supply are interconnected, the reduction in demand in one site may increase water availability in another location.

7.2 Scenario AgrSav

The Scenario AgrSav focuses on water saving in the agricultural sector

Measures included	A1. Increase the irrigation efficiency through converting to closed pipes and drip irrigation systems at the farm level
Implementation	The measures have been applied in all the 8 agricultural demand nodes, i.e. in a total of area of 2,030 irrigated hectares (of which: 1,194 ha Field Crops in Medium to Large Terrace, 390 ha Olives, 351 ha Fruit Trees and Citrus Fruit Trees)

Conveyance networks and irrigation methods	% coverage of the irrigated area	% losses	% conveyence efficiency
Collective Networks - Closed Pipes	1%	10%	90%
Collective Networks - Open Channels	37%	55%	45%
Small individual networks - Groundwater wells	62%	35%	65%
Aggregated network conveyance efficiency	(1% x 0.9) + (37% x 0.45) + (62% x 0.65) = **57.85% or 42.15% losses**		
Drip irrigation	7%	20%	80%
Sprinklers' irrigation	15%	30%	70%
Furrow irrigation	78%	40%	60%
Aggregated field application efficiency	(7% x 0.8) + (15% x 0.7) + (78% x 0.6) = **62.90% or 37.10% losses**		
Overall combined irrigation efficiency = 60.38%, i.e. 60%			

Simulation parameters	Based on the analysis of the agricultural water saving measures (ref. to Chapter 5.3), the following 2 solutions have been simulated in WEAP: - **AgrSav80**: Increase the irrigation efficiency to 80% through converting to closed pipes and drip irrigation systems at the farm level: the target is to have 75% of the hectares served by collective networks with closed pipes and only 5% by open channels, while the remaining 20% of the total agricultural area will be served small individual networks connected to individual groundwater wells. At the same time 80% of the total area will be irrigated with drip irrigation, and only 10% with sprinklers and 10% with furrow. These conversions will reduce the combined losses (i.e. conveyance + field application) by 20%. - **AgrSav85:** Increase the irrigation efficiency to 85% through converting to closed pipes and drip irrigation systems at the farm level: the target is to have 98% of the hectares served by collective networks with closed pipes and 0% by open channels, while the remaining 2% of the total agricultural area will be served by small individual networks connected to individual groundwater wells. At the same time 98% of the total area will be irrigated with drip irrigation, and only 2% with furrow. These conversions will reduce the combined losses (i.e. conveyance + field application) by 10%.

Conveyance networks and irrigation methods	Efficiency 60% (Baseline)		Efficiency 80% (+20% increase)		Efficiency 85% (+25% increase)	
Conveyance networks	**% ha**	**ha**	**% ha**	**ha**	**% ha**	**ha**
Collective Networks - Closed Pipes	1%	20.30	75%	1522.50	98%	1989.40
Collective Networks - Open Channels	37%	751.10	5%	101.50	0%	0.00
Small individual networks - Groundwater wells	62%	1258.60	20%	406.00	2%	40.60
Irrigation methods	**%**	**ha**	**%**	**ha**	**%**	**ha**
Drip irrigation	7%	142.10	80%	1624.00	98%	1989.40
Sprinklers' irrigation	15%	304.50	10%	203.00	0%	0.00
Furrow irrigation	78%	1583.40	10%	203.00	2%	40.60
** Total irrigated hectares in the basin = 2,030 ha*						

	Associated costs: ▪ *AgriSav80 (80% efficiency):* Convert 1,502 ha (i.e. 74% of the total) to closed pipes; AEC cost = 1,502 ha * 390$/ha = 0.59 mio $ or 9.1 mio $ CAPEX Switch 1,482 ha (i.e. 73% of the total) to drip irrigation; AEC cost = 1,482 * 347 $/ha = 0.51 mio $ or 5.5 mio $ CAPEX Total AEC cost for mountain areas = 1.1 mio $ or 14.5 mio $ CAPEX ▪ *AgrSav85 (85% efficiency):* Convert 1,969 ha (i.e. 97% of the total) to closed pipes; AEC cost = 1,969 ha * 390$/ha = 0.77 mio $ or 11.8 mio $ CAPEX Switch 1,847 ha (i.e. 91% of the total) to drip irrigation. AEC cost = 1,847 * 347 $/ha = 0.64 mio $ or 6.8 mio $ CAPEX Total AEC cost for mountain areas = 1.41 mio $ or 18.6 mio $ CAPEX

7.3 Scenario MixSav

The Scenario MixSav focuses on water savings across both the urban and the agricultural sectors, and it is a combination on the aforementioned scenarios UrbSav and AgrSav

Measures included	U1. Low water using fixtures and appliances, A1. Increase the irrigation efficiency through converting to closed pipes and drip irrigation systems at the farm level
Implementation	Combination (merging) of the scenarios UrbSav Solution No.1 and AgrSav85 Combination (merging) of the scenarios UrbSav Solution No.1 and AgrSav90 Combination (merging) of the scenarios UrbSav Solution No.3 and AgrSav85 Combination (merging) of the scenarios UrbSav Solution No.3 and AgrSav90 Combination (merging) of the scenarios UrbSav Solution No.20 and AgrSav85 Combination (merging) of the scenarios UrbSav Solution No.20 and AgrSav90
Simulation parameters	Same as in the scenarios UrbSav Solution No.1 and the AgrSav85 scenario Same as in the scenarios UrbSav Solution No.1 and the AgrSav90 scenario Same as in the scenarios UrbSav Solution No.3 and the AgrSav85 scenario Same as in the scenarios UrbSav Solution No.3 and the AgrSav90 scenario Same as in the scenarios UrbSav Solution No.20 and the AgrSav85 scenario Same as in the scenarios UrbSav Solution No.20 and the AgrSav90 scenario

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m^3) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/$m^3$ of water saved	Total $/$m^3$ of water saved for the basin	***Penetration (households adapting the measure)***				
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*

1	11 $	30 $	20.40%	2.8 $	5.10%	1.39	0.29	0.78	0.21	0.57		√			
3	30 $	80 $	26.90%	7.5 $	6.73%	1.83	0.78	2.09	0.43	1.14		√	√		
20	173 $	850 $	42.50%	43.3 $	10.63%	2.89	4.52	22.21	1.56	7.69	√	√	√	√	

AgriSav80 (80% efficiency):

Convert 1,502 ha (i.e. 74% of the total) to closed pipes; AEC cost = 1,502 ha * 390$/ha = 0.59 mio $ or 9.1 mio $ CAPEX

Switch 1,482 ha (i.e. 73% of the total) to drip irrigation; AEC cost = 1,482 * 347 $/ha = 0.51 mio $ or 5.5 mio $ CAPEX

Total AEC cost for mountain areas = 1.1 mio $ or 14.5 mio $ CAPEX

AgrSav85 (85% efficiency):

Convert 1,969 ha (i.e. 97% of the total) to closed pipes; AEC cost = 1,969 ha * 390$/ha = 0.77 mio $ or 11.8 mio $ CAPEX

Switch 1,847 ha (i.e. 91% of the total) to drip irrigation. AEC cost = 1,847 * 347 $/ha = 0.64 mio $ or 6.8 mio $ CAPEX

Total AEC cost for mountain areas = 1.41 mio $ or 18.6 mio $ CAPEX

Mixed measures costs:

Measures	Total AEC (mio $) per measure	Total CAPEX (mio $) per measure	Grand Total AEC (mio $)	Grand Total CAPEX (mio $)
UrbSav Solution No. 1 AgrSav80	0.29 1.10	0.78 14.47	1.39	15.25
UrbSav Solution No. 1 AgrSav85	0.29 1.41	0.78 18.61	1.7	19.39
UrbSav Solution No. 3 AgrSav80	0.78 1.10	2.09 14.47	1.88	16.56
UrbSav Solution No. 3 AgrSav85	0.78 1.41	2.09 18.61	2.19	20.7
UrbSav Solution No. 20 AgrSav80	4.52 1.10	22.21 14.47	5.62	36.68

	UrbSav Solution No. 20 AgrSav85	4.52 1.41	22.21 18.61	5.93	40.82	

7.4 Scenario UrbLeak

The Scenario UrbLeak focuses on reducing the leakage of the urban supply network

<table>
<tr><td>Measures included</td><td>U4. Leakage Reduction in the water supply networks through actions to rehabilitate and modernize the operation of water supply networks</td></tr>
<tr><td>Implementation</td><td>This scenario promotes leakage reduction in the urban water supply network and increasing the conveyance efficiency of the network</td></tr>
<tr><td>Simulation parameters</td><td>Reducing % losses by 10% (i.e. from the current 30% to 20%)
In the National Water Sector Strategy (NWSS) update 2020, Volume V “Proposed projects”, the following projects are proposed for NLWE:
<table>
<tr><th rowspan="2">System</th><th rowspan="2">Village</th><th colspan="2">Transmission lines</th><th colspan="2">Distribution networks</th></tr>
<tr><th>Length (km)</th><th>Cost Estimate (USD)</th><th>Length (km)</th><th>Cost Estimate (USD)</th></tr>
<tr><td>System 1</td><td>Akkar El Atika</td><td>8.00</td><td>720,000</td><td>2.00</td><td>160,000</td></tr>
<tr><td>System 11</td><td>Sindianet Zeidan</td><td>4.00</td><td>360,000</td><td>10.00</td><td>800,000</td></tr>
<tr><td>System 17</td><td>El Kouachra</td><td>2.00</td><td>180,000</td><td>-</td><td>-</td></tr>
<tr><td>System 22</td><td>Ain el zeit</td><td>2.00</td><td>180,000</td><td>11.00</td><td>880,000</td></tr>
<tr><td></td><td>Charbila</td><td>-</td><td>-</td><td>10.00</td><td>800,000</td></tr>
<tr><td></td><td>Ain Tanta</td><td>2.00</td><td>180,000</td><td>11.00</td><td>880,000</td></tr>
<tr><td></td><td>Al-Rihanie</td><td>2.00</td><td>180,000</td><td></td><td></td></tr>
<tr><td></td><td>Douair adouiye</td><td></td><td></td><td>10.00</td><td>800,000</td></tr>
<tr><td>System 23,24,12</td><td>Kherbet Daouad</td><td>5.00</td><td>450,000</td><td>10.00</td><td>800,000</td></tr>
<tr><td></td><td>Sfinet El Dreib</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td></td><td>Fseikine et ain achma</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>El daghle</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Kherbet Char</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Majdel</td><td>4.00</td><td>360,000</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Barbara</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Deir Janin</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Knisse</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td></td><td>Mazraat balde</td><td>2.00</td><td>180,000</td><td>-</td><td>-</td></tr>
<tr><td></td><td>El Hed</td><td>-</td><td>-</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Al souaise</td><td>4.00</td><td>360,000</td><td></td><td></td></tr>
<tr><td></td><td>El Bire</td><td>4.00</td><td>360,000</td><td>10.00</td><td>800,00</td></tr>
<tr><td></td><td>Kfar Hara</td><td>3.00</td><td>270,000</td><td>10.00</td><td>800,00</td></tr>
</table>
Based on the above information, the estimated cost per km of transmission line is 90,000 $/km, and the cost per km of distribution network is 80,000$
According to the above table, the NWSS prioritizes the infrastructure (rehabilitation or new) of 42 km of transmission lines and 154 km of distribution networks. This would result in total investments of (CAPEX) 158,760 billion $ and 788,480 billion $</td></tr>
</table>

	respectively[5]. The cost of design and supervision is not included, but ranges from about 6-8% on top of the investment cost. In our scenario we have assumed that a 10% loss reduction[6] is applied uniformly at all 20 urban nodes. Since information of the state of infrastructure, and how many km need to be rehabilitated per node is lacking, the cost of this scenario cannot be estimated; only costs per km can be provided.

7.5 Scenario UrbSup

The Scenario UrbSup focuses on both water saving and increasing supply for the domestic/urban sector (micro-scale)

[5] Cost estimates as per the NWSS, 2020
[6] It is assumed that 30% is the current loss on average

Measures included	U1. Low water using fixtures and appliances U2. Domestic Greywater Reuse (GWR) on-site (houses, hotels) in villages U3. Rainwater Harvesting (RWH) on-site (houses, hotels, villages)
Implementation	The measures have been applied in all the 20 urban demand nodes. The Tier-2 increase water supply measures have been applied on top of the Tier-1 water saving measures preconditioning thus an already “water efficient” house. Node #21 (UD_ Danke-Qsair) is a water export of a fixed volume (7,200 m^3/month) and it was kept constant, assuming that since it is outside the Al Ostuan River Basin the saving measures will not be applied there. The baseline (BaU) was the reference period 2003-2018, where the average annual urban demand was 6.8 million m^3.
Simulation parameters	Regarding the application of the additional Tier-2 measures (U2 and U3), these have been applied, as previously mentioned in Chapter 3.2, on top of the Tier-1 measure U1, i.e. in a “water efficient” house. Based on the cost-effectiveness analysis of the urban water saving measures (ref. to Chapter 3.2), the following 5 solutions are considered as optimum (see table below) and have been simulated in WEAP.

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m^3) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/$m^3$ of water saved	Total $/$m^3$ of water saved for the basin	***Penetration (households adapting the measure)***						
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*	*Rainwater Harvesting (RWH)*	*Greywater Reuse (GWR)*
7r	318 $	2,050 $	48.50%	79.5 $	12.13%	3.30	8.31	53.58	2.52	16.25	√	√	√			√	

7w	560 $	3,750 $	41.50%	140. $	10.38%	2.82	14.64	98.01	5.19	34.73	√	√	√				√
20r	429 $	2,650 $	54.10%	107.3 $	13.53%	3.68	11.21	69.26	3.05	18.83	√	√	√	√		√	
20w	671 $	4,350 $	47.10%	167.8 $	11.78%	3.20	17.54	113.69	5.48	35.50	√	√	√	√			√
20m	927 $	6,150 $	58.70%	231.8 $	14.6 %	3. 9	4.23	160.73	6.07	40.27	√	√	√	√		√	√

Note: “r” denotes a solution with rainwater harvesting, “w” with greywater reuse, and “m” with both

* The total water saving is based on the annual urban water demand in the Al Ostuan basin for the reference period 2003-2018, which sums up at 6.8 million m^3.

** The total AEC is obtained by multiplying the AEC per household (HH) with the total number of households. The later has been estimated to account 26,135 household in the Al Ostuan basin assuming each household is occupied by 4 people on average (number of hh = total population ÷ 4)

These solutions have been simulated In WEAP in all the 9 demand sites, based on the following formulas:

- Solution No. #7r: multiply water demand by (1-0.1213) in all 20 sites, or apply DSM saving per capita 12.13% in the tab Demand Sites and Catchments/Demand Management/DSM Savings
- Solution No. #7w: multiply water demand by (1-0.1038) in all 20 sites, or apply DSM saving per capita 10.38% in the tab Demand Sites and Catchments/Demand Management/DSM Savings
- Solution No. #20r: multiply water demand by (1-0.1353) in all 20 sites, or apply DSM saving per capita 13.53% in the tab Demand Sites and Catchments/Demand Management/DSM Savings
- Solution No. #20w: multiply water demand by (1-0.1178) in all 20 sites, or apply DSM saving per capita 11.78% in the tab Demand Sites and Catchments/Demand Management/DSM Savings
- Solution No. #20m: multiply water demand by (1-0.1468) in all 20 sites, or apply DSM saving per capita 14.68% in the tab Demand Sites and Catchments/Demand Management/DSM Savings

For each solution the change in the model results, in terms of unmet demand and potential water excess (resulting from all 9 demand sites as a sum), has been investigated. Since in the WEAP model the resources and supply are interconnected, the reduction in demand in one site may increase water availability in another location.

7.6 Scenario AgrSup

The Scenario AgrSup focuses on increasing supply for the agricultural sector (meso-scale)

Measures included	A3. Detention basins/ Retention ponds/ Community Hill Lakes in agricultural areas
Implementation	This scenario promotes managing runoff close to source (i.e. with a relatively small catchment area) and therefore it is not envisaged that a contributing area greater than 1 km^2 would be likely.
Simulation parameters	Detention basins of 100-150 m^3 capacity have been simulated in WEAP, in sites where the topography is beneficial. The capital costs for the construction of detention basins and/or retention ponds have been fixed at \$30 per m^3 of volume provided for storage. The annual maintenance costs have been fixed between \$3 per m^3 of basin/ pond area. The useful life has been considered 30 years, and thus the resulting AEC is \$5.83/m^3/year.

7.7 Scenario MixSup

The Scenario UrbSup focuses on both water saving and increasing supply for the domestic/urban sector (micro-scale), combined with savings in the agricultural sector.
It is a combination on the aforementioned scenarios UrbSup and AgrSav

Measures included	U1. Low water using fixtures and appliances U3. Rainwater Harvesting (RWH) on-site (houses, hotels, villages) A1. Increase the irrigation efficiency through converting to closed pipes and drip irrigation systems at the farm level
Implementation	Combination (merging) of the scenarios UrbSav Solution No.7r and AgrSav80 Combination (merging) of the scenarios UrbSav Solution No.7r and AgrSav85
Simulation parameters	Same as in the scenarios UrbSav Solution No.7r and the AgrSav80 scenario Same as in the scenarios UrbSav Solution No.7r and the AgrSav85 scenario

Solution No. #	AEC per HH $	CAPEX per HH	Water Saving % per HH	AEC per capita $	Water Saving % per capita	Total water saving * (mio m³) in the basin	Total AEC** (mio $) for the basin	Total CAPEX (mio $) for the basin	AEC $/m³ of water saved	Total $/m³ of water saved for the basin	***Penetration (households adapting the measure)***						
											Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*	*Rainwater Harvesting (RWH)*	*Greywater Reuse (GWR)*
7r	318 $	2,050 $	48.50%	79.5 $	12.13%	3.30	8.31	53.58	2.52	16.25	√	√	√			√	

Note: “r” denotes a solution with rainwater harvesting, “w” with greywater reuse, and “m” with both

* The total water saving is based on the annual urban water demand in the Al Ostuan basin for the reference period 2003-2018, which sums up at 6.8 million m^3.

** The total AEC is obtained by multiplying the AEC per household (HH) with the total number of households. The later has been estimated to account 26,135 household in the Al Ostuan basin assuming each household is occupied by 4 people on average (number of hh = total population ÷ 4)

AgriSav80 (80% efficiency):

Convert 1,502 ha (i.e. 74% of the total) to closed pipes; AEC cost = 1,502 ha * 390$/ha = 0.59 mio $ or 9.1 mio $ CAPEX

Switch 1,482 ha (i.e. 73% of the total) to drip irrigation; AEC cost = 1,482 * 347 $/ha = 0.51 mio $ or 5.5 mio $ CAPEX

Total AEC cost for mountain areas = 1.1 mio $ or 14.5 mio $ CAPEX

AgrSav85 (85% efficiency):

Convert 1,969 ha (i.e. 97% of the total) to closed pipes; AEC cost = 1,969 ha * 390$/ha = 0.77 mio $ or 11.8 mio $ CAPEX

Switch 1,847 ha (i.e. 91% of the total) to drip irrigation. AEC cost = 1,847 * 347 $/ha = 0.64 mio $ or 6.8 mio $ CAPEX

Total AEC cost for mountain areas = 1.41 mio $ or 18.6 mio $ CAPEX

Mixed measures costs:

Measures	Total AEC (mio $) per measure	Total CAPEX (mio $) per measure	Grand Total AEC (mio $)	Grand Total CAPEX (mio $)
UrbSav Solution No. 7r AgrSav80	8.31 1.10	53.58 14.17	9.41	68.05
UrbSav Solution No. 7r AgrSav85	8.31 1.41	53.58 18.61	9.72	72.19

8 RESULTS AND OUTPUTS OF THE WEAP MODEL

8.1 RESULTS: BAU SCENARIO

The unmet demand in the Al Ostuan River Basin for the future period 2019-2035 has been presented (per sector) in the Chapter 3.2. for the 3 future climate scenarios (MEAN, MAX, MIN). The average annual unmet demand increases in all scenarios of the 2019-2035 period as compared to the 2003-2018 Baseline.

For the purpose of comparing the effects of the different measures, we will select for “Business as Usual (BaU)” the MEAN scenario 2019-2035. Thus, the MEAN scenario represents the future conditions in the basin if NO MEASURES are applied (i.e. BaU = MEAN). As such, the BaU annual average urban unmet demand for the period 2019-2035 is ~7 mio m^3, the agricultural 16.5 mio m^3, and the total unmet demand is ~23 mio m^3 per year on an average basis (**Table 8-1**). These numbers will be used as the reference for comparing the effectiveness of the different measures in reducing unmet demand in the basin.

Table 8-1: Unmet demand for the future period 2019-2035 under the BaU scenario

Scenario	Total (million m^3)	Average annual (million m^3)	Maximum annual (million m^3)	Minimum annual (million m^3)
Urban unmet demand				
Baseline 2003-2018 (16 years)	56.18	3.51	4.90	0.57
BaU scenario 2019-2035 (17 years)	114.36	6.73	12.19	2.87
Agricultural unmet demand				
Baseline 2003-2018	220.90	13.81	17.52	7.61
BaU scenario 2019-2035 (17 years)	280.13	16.48	23.36	11.97
Total unmet demand				
Baseline 2003-2018	277.07	17.32	22.33	8.18
BaU scenario 2019-2035 (17 years)	394.50	23.21	35.55	14.84

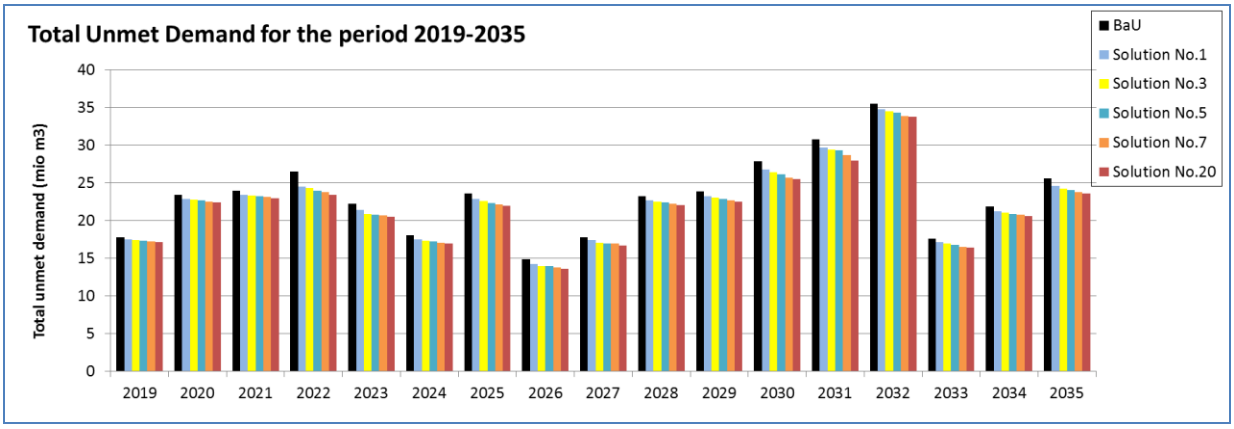
8.2 RESULTS: URBSAV SCENARIO

When implementing the different options of the UrbSav scenario (solutions 1, 3, 5, 7, 20) the urban demand is reduced as a result of the applied water saving measures. This reduction in the urban demand, which basically reflects the relevant water savings, is presented in Table **8-2** below. The mean annual reduction in the total unmet demand varies across the solutions of the UrbSav scenario from 0.7 mio m^3/year (solution No. 1) to 1.6 mio m^3/year (solution No. 20), and the resulting total cumulative unmet demand reductions (savings) for the period 2019-2035 range respectively from 12.5 mio m^3 (solution No. 1) to 26.5 mio m^3 (solution No. 20).

Table 8-2: Reduction in unmet demand after implementation of the UrbSav scenario options as compared to the BaU scenario (period 2019-2035)

Solution #	Unmet demand (annual average, mio m^3)	Reduction in Unmet demand* (annual average, mio m^3)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin
Urban unmet demand				
0 (BaU)	6.73	0	0	0
1	6.08	-0.65	0.29	0.78
3	5.92	-0.81	0.78	2.09
5	5.79	-0.94	1.12	5.23
7	5.60	-1.13	1.62	6.53
20	5.45	-1.28	4.52	22.21
Total unmet demand				
0 (BaU)	23.21	0	0	0
1	22.47	-0.73	0.29	0.78
3	22.22	-0.99	0.78	2.09
5	22.08	-1.12	1.12	5.23
7	21.86	-1.34	1.62	6.53
20	21.65	-1.56	4.52	22.21

* based on the WEAP model outputs



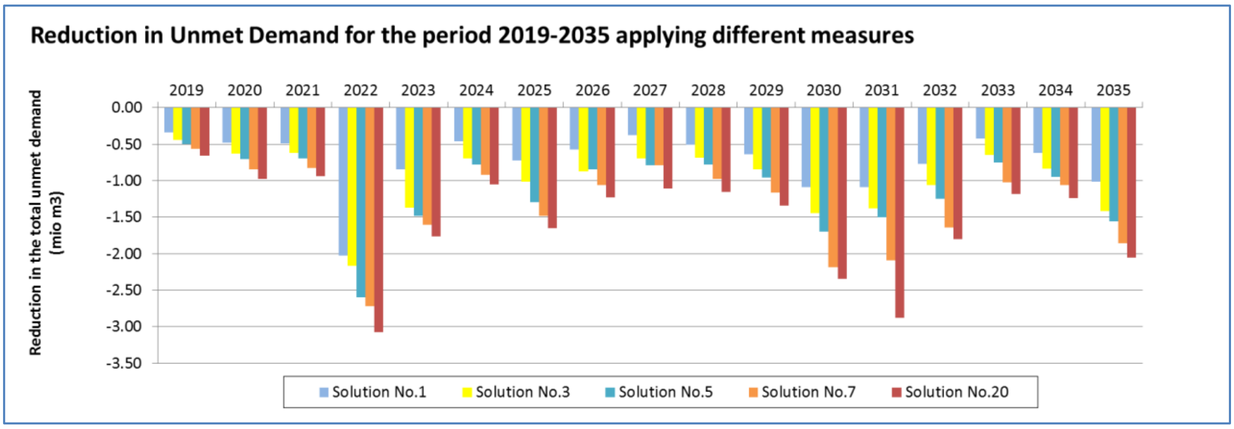


Figure 8-1: Comparison of the unmet demand under the UrbSav scenario options in relation to the BaU scenario (top: unmet demand as compared to the BaU, bottom; net reduction of the unmet demand as compared to the BaU for each option)

8.3 RESULTS: AGRSAV SCENARIO

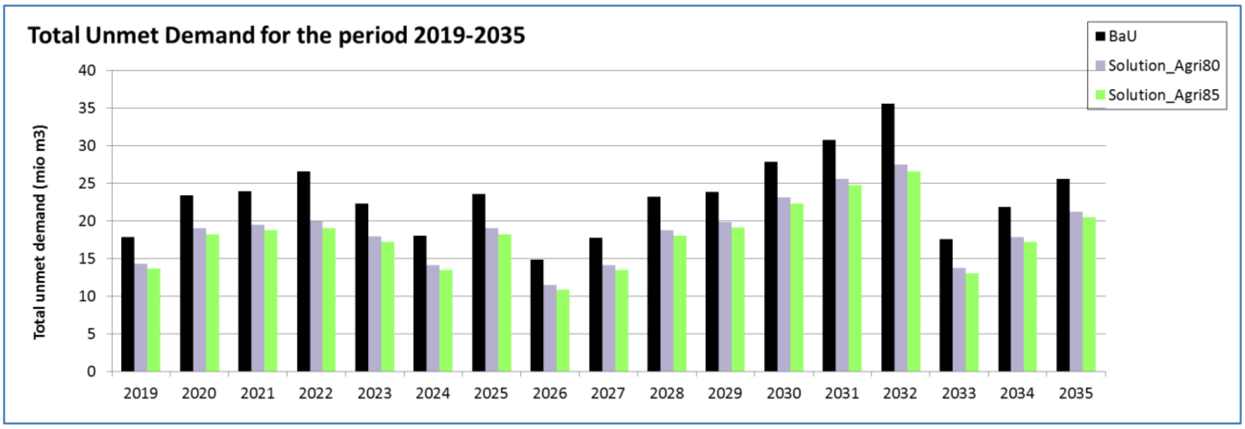
The implementation of the measures of the AgrSav scenario (i.e. reduction of conveyance losses and increase of field application irrigation efficiency) results in a reduction of the unmet demand (**Table 8-3**). The mean annual reduction in the total unmet demand for the 2 scenarios (80% efficiency and 85% efficiency) is 4.6 mio m^3/year and 5.3 mio m^3/year respectively, and the resulting cumulative unmet demand reductions (savings) for the period 2019-2035 amount to 77 mio m^3 and 90 mio m^3 respectively.

Table 8-3: Reduction in unmet demand after implementation of the AgrSav scenario as compared to the BaU scenario

Solution #	Unmet demand (annual average, mio m^3)	Reduction in Unmet demand* (annual average, mio m^3)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin
Agricultural unmet demand				
0 (BaU) *(i.e. efficiency @ 80%)*	16.48	0	0	0
AgrSav_80 *(i.e. +20% from BaU)*	12.08	-4.44	1.10	14.47
AgrSav_85 *(i.e. +25% from BaU)*	11.35	-5.13	1.41	18.61
Total unmet demand				
0 (BaU) *(i.e. eff @ 80%)*	23.21	0	0	0

Solution #	Unmet demand (annual average, mio m^3)	Reduction in Unmet demand* (annual average, mio m^3)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin
Agricultural unmet demand				
AgrSav_80 *(i.e. +20% from BaU)*	18.65	-4.55	1.10	14.47
AgrSav_85 *(i.e. +25% from BaU)*	17.91	-5.30	1.41	18.61

* based on the WEAP model outputs



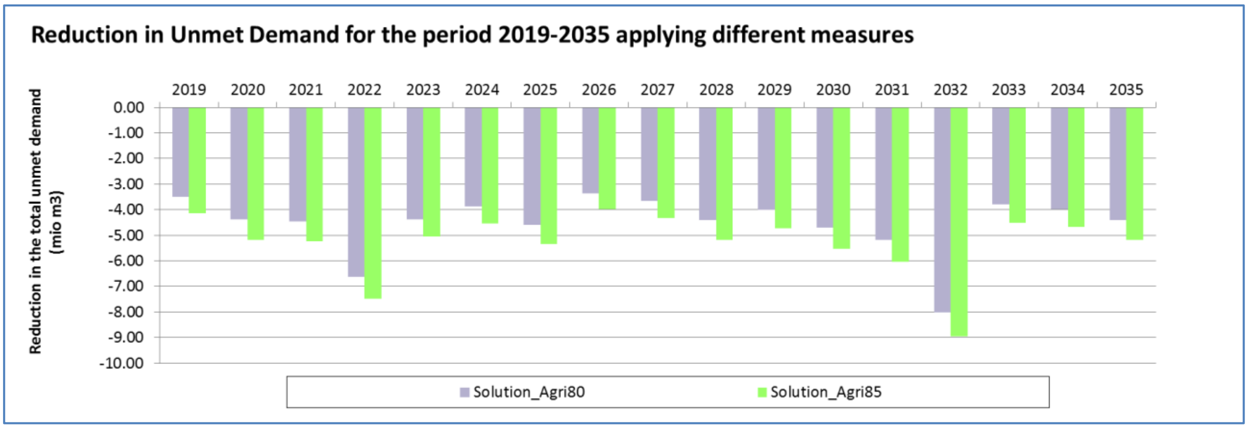


Figure 8-2: Comparison of the unmet demand under the AgrSav scenario in relation to the BaU scenario (top: unmet demand as compared to the BaU; bottom, net reduction of the unmet demand as compared to the BaU)

8.4 RESULTS: MIXSAV SCENARIO

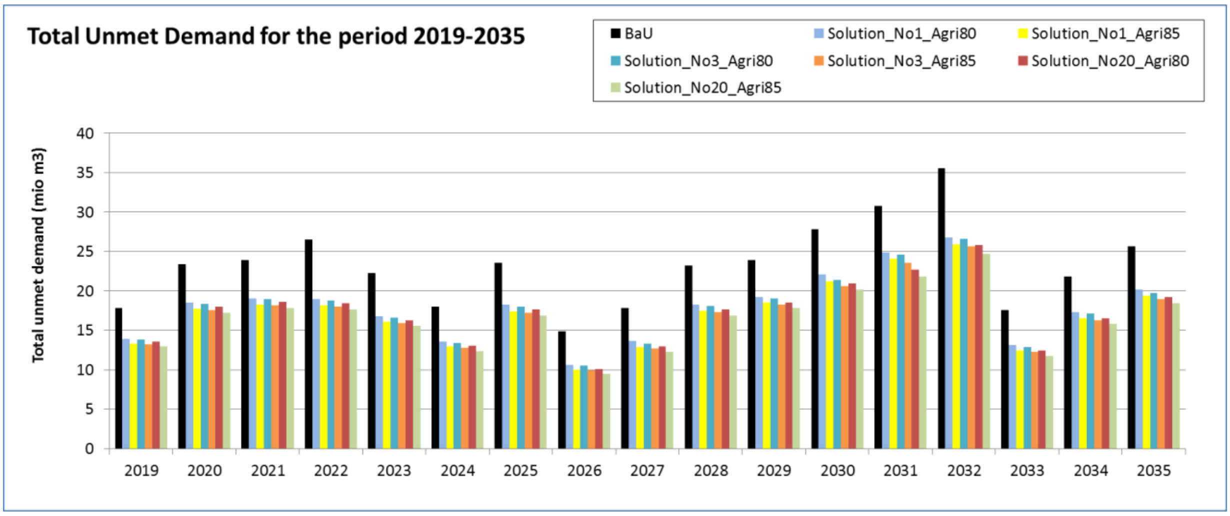
The implementation of the measures of the MixSav scenario (i.e. urban saving solutions No.1, 3, 20, together with increase of irrigation efficiency by +20% and +25%) results in a mean annual reduction in total unmet demand of ~5.3 to 6.8 mio m^3/year depending of the mixed solution (**Table 8-4**), while the resulting cumulative unmet demand reductions (savings) for the period 2019-2035 amount to 89-115 mio m^3 depending of the mixed solution applied.

Table 8-4: Reduction in unmet demand after implementation of the MixSav scenario as compared to the BaU scenario

Solution #	Unmet demand (annual average, mio m^3)	Reduction in Unmet demand* (annual average, mio m^3)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin
Total unmet demand				
0 (BaU)	23.21	0	0	0
UrbSav_No.1 + AgrSav_80	17.95	-5.26	1.39	15.25
UrbSav_No.1 + AgrSav_85	17.19	-6.02	1.70	19.40
UrbSav_No.3 + AgrSav_80	17.72	-5.48	1.88	16.56
UrbSav_No.3 + AgrSav_85	16.97	-6.23	2.19	20.70
UrbSav_No.20 + AgrSav_80	17.20	-6.01	5.62	36.68
UrbSav_No.20 + AgrSav_85	16.46	-6.75	5.93	40.83

* based on the WEAP model outputs

** MixSav includes: UrbSav Solutions No. 1, 3, 20 combined with AgrSav_80 (reduce losses by 20% & increase application efficiency to 80%) and AgrSav_85 (reduce losses by 25% & increase application efficiency to 85%)



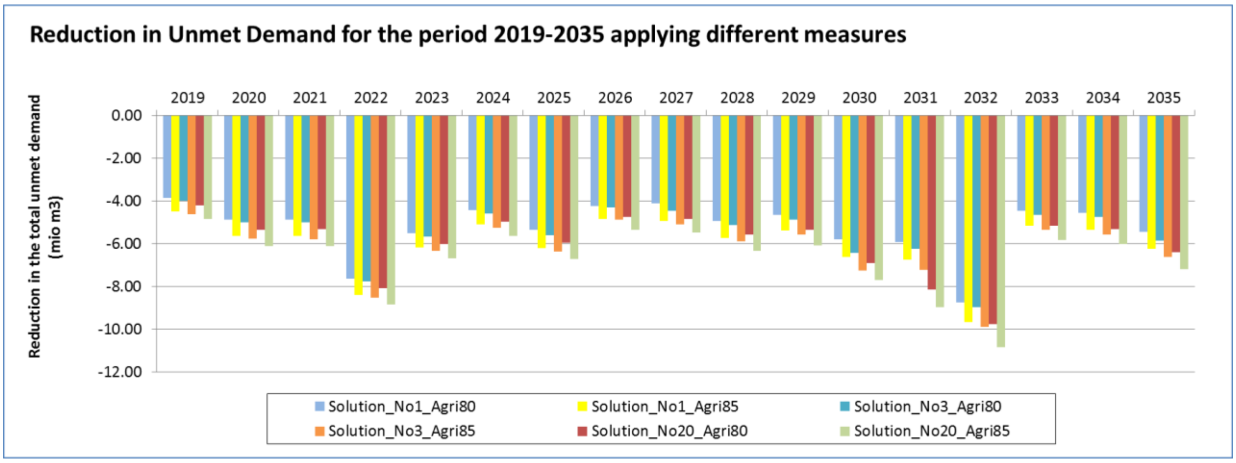


Figure 8-3: Comparison of the unmet demand under the MixSav scenario in relation to the BaU scenario (top: MixSav as compared to the BaU; bottom, net reduction of the unmet demand as compared to the BaU)

8.5 RESULTS: URBLEAK SCENARIO

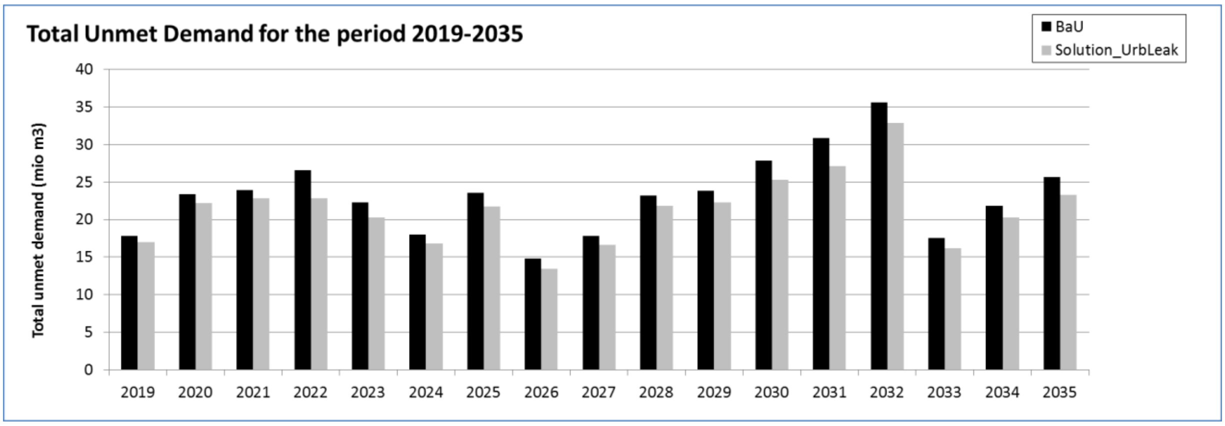
The implementation of the measures of the UrbLeak scenario (i.e. reducing % losses by 10%, i.e. from the current 30% to 20%, through actions to rehabilitate and modernize the operation of water supply networks) results in a mean annual reduction in total unmet demand of 1.9 mio m^3/year (**Table 8-5**), while the resulting cumulative unmet demand reductions (savings) for the period 2019-2035 amount to ~31.5 mio m^3.

Table 8-5: Reduction in unmet demand after implementation of the UrbLeak scenario options as compared to the BaU scenario (period 2019-2035)

Solution #	Unmet demand (annual average, mio m^3)	Reduction in Unmet demand* (annual average, mio m^3)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin
Urban unmet demand				
0 (BaU)	6.73	0	0	0
UrbLeak_20 *(i.e. -10% from BaU)*	5.18	-1.55	n/a	90,000 $/km of transmission line 80,000$/km of distribution
Total unmet demand				
0 (BaU)	23.21	0	0	0
UrbLeak_20 *(i.e. -10% from BaU)*	21.36	-1.85	n/a	90,000 $/km of transmission line

Solution #	Unmet demand (annual average, mio m^3)	Reduction in Unmet demand* (annual average, mio m^3)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin
Urban unmet demand				
				80,000$/km of distribution

* based on the WEAP model outputs



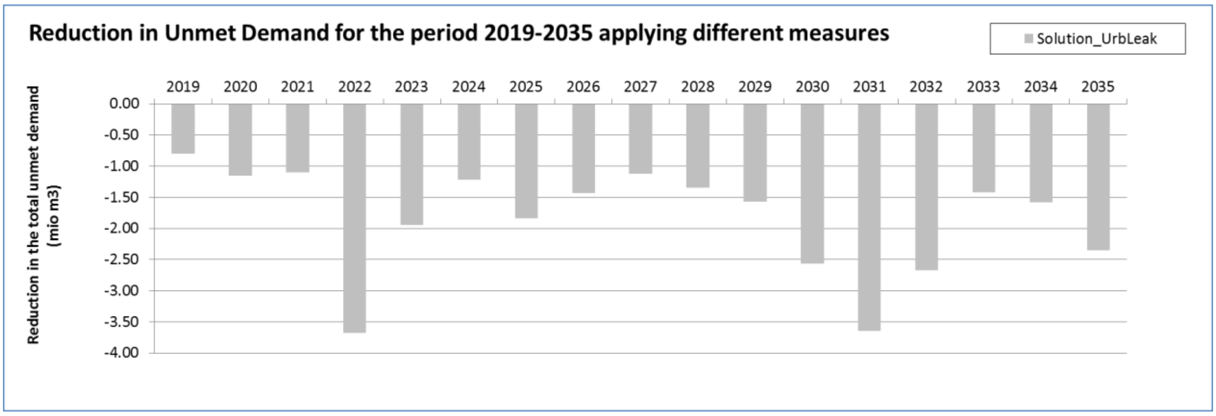


Figure 8-4: Comparison of the unmet demand under the UrbLeak scenario in relation to the BaU scenario (top: UrbLeak as compared to the BaU; bottom, net reduction of the unmet demand as compared to the BaU)

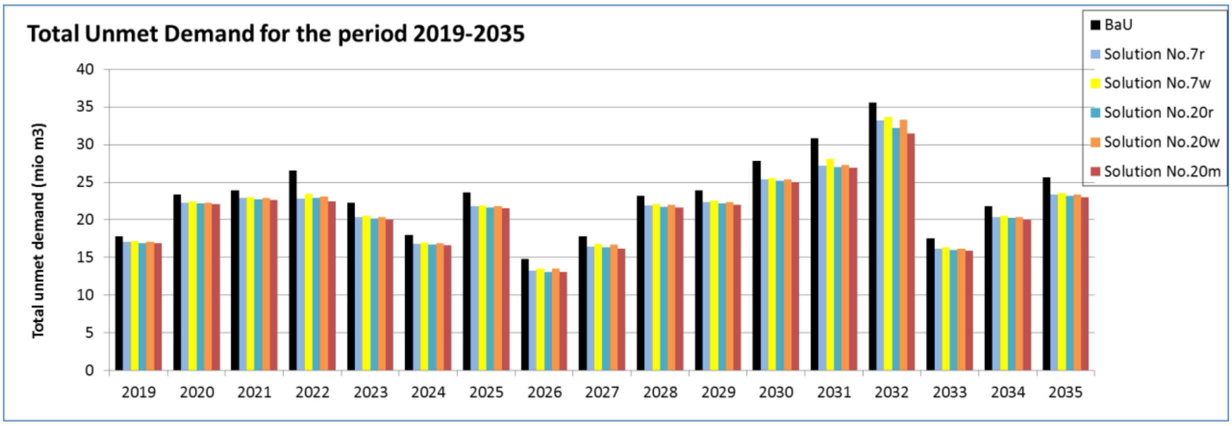
8.6 RESULTS: URBSUP SCENARIO

When implementing the different options of the UrbSup scenario (solutions 7r, 7w, 20r, 20w, 20m) the mean annual reduction in unmet demand varies across the solutions from 1.3 mio m^3/year (solution No. 7w) to ~1.8 mio m^3/year (solution No. 20m) (**Table 8-6**), and the resulting cumulative unmet demand reductions (savings) for the period 2019-2035 (17 years) range respectively from 26 mio m^3 (solution No. 7w) to 37 mio 33m^3 (solution No. 20m).

Table 8-6: Reduction in unmet demand after implementation of the UrbSup scenario options as compared to the BaU scenario

Solution #	Unmet demand (annual average, mio m^3)	Reduction in Unmet demand* (annual average, mio m^3)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin
Urban unmet demand				
0 (BaU)	6.73	0	0	0
7r	5.28	-1.45	8.31	53.58
7w	5.47	-1.26	14.64	98.01
20r	5.09	-1.64	11.21	69.26
20w	5.28	-1.45	17.54	113.69
20m	4.97	-1.76	24.23	160.73
Total unmet demand				
0 (BaU)	23.21	0	0	0
7r	21.38	-1.83	8.31	53.58
7w	21.66	-1.55	14.64	98.01
20r	21.20	-2.01	11.21	69.26
20w	21.47	-1.74	17.54	113.69
20m	21.03	-2.18	24.23	160.73

* based on the WEAP model outputs
Note: “r” denotes a solution with rainwater harvesting, “w” with greywater reuse, and “m” with both



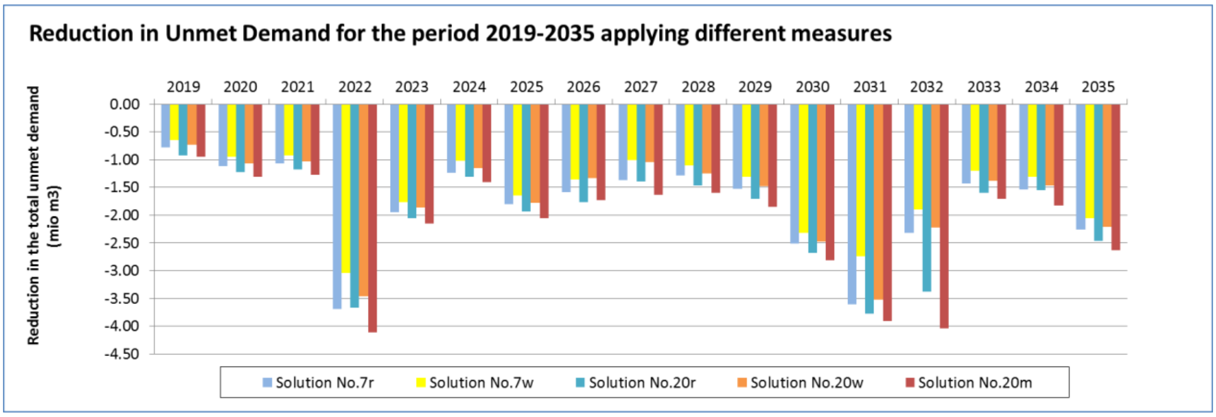


Figure 8-5: Comparison of the unmet demand under the UrbSup scenario options in relation to the BaU scenario (top: UrbSup as compared to the BaU; bottom: net reduction of the unmet demand as compared to the BaU for each option)

8.7 RESULTS: AGRSUP SCENARIO

The proposed detention ponds and Community Hill Lakes of 100-150 m^3 capacity, 1 km^2 drainage area, and a total of around 20 ponds per sub-catchment/demand site, are too small to be captured by the model (the combined total contribution is around less than 0.01% of most demands). The difficulty in implementing the AgrSup scenario is that they ponds are too small to be captured by the model (coarser WEAP resolution) and needs lots of assumptions to account for monthly runoff sources, inflow and servicing area, etc., taking also much of the computational resources and time. On the basin scale and based on the area/retention volume per pond, around 10,000 ponds would be required to see response in the model. Thus, this scenario has not been deemed suitable for simulation, although recommended as a practice for individual use in the agricultural sector mainly.

8.8 RESULTS: MIXSUP SCENARIO

The implementation of the measures of the MixSup scenario (i.e. urban saving/supply solutions No.7r, together with increase of irrigation efficiency by +20% and +25%) results in a mean annual reduction in total unmet demand of ~6 to 7 mio m^3/year depending of the mixed solution (**Table 8-7**), while the resulting cumulative unmet demand reductions (savings) for the period 2019-2035 amount to 105-118 mio m^3 depending of the mixed solution applied.

Table 8-7: Reduction in unmet demand after implementation of the MixSav scenario as compared to the BaU scenario

Solution #	Unmet demand (annual average, mio m^3)	Reduction in Unmet demand* (annual average, mio m^3)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin
Total unmet demand				
0 (BaU)	23.21	0	0	0
UrbSav_No.7r + AgrSav_80	17.01	-6.20	9.41	68.04
UrbSav_No.7r + AgrSav_85	16.26	-6.94	9.72	72.19

* based on the WEAP model outputs

** MixSup includes: UrbSup Solution No. 7r combined with AgrSav_80 (reduce losses by 20% & increase application efficiency to 80%) and AgrSav_85 (reduce losses by 25% & increase application efficiency to 85%)

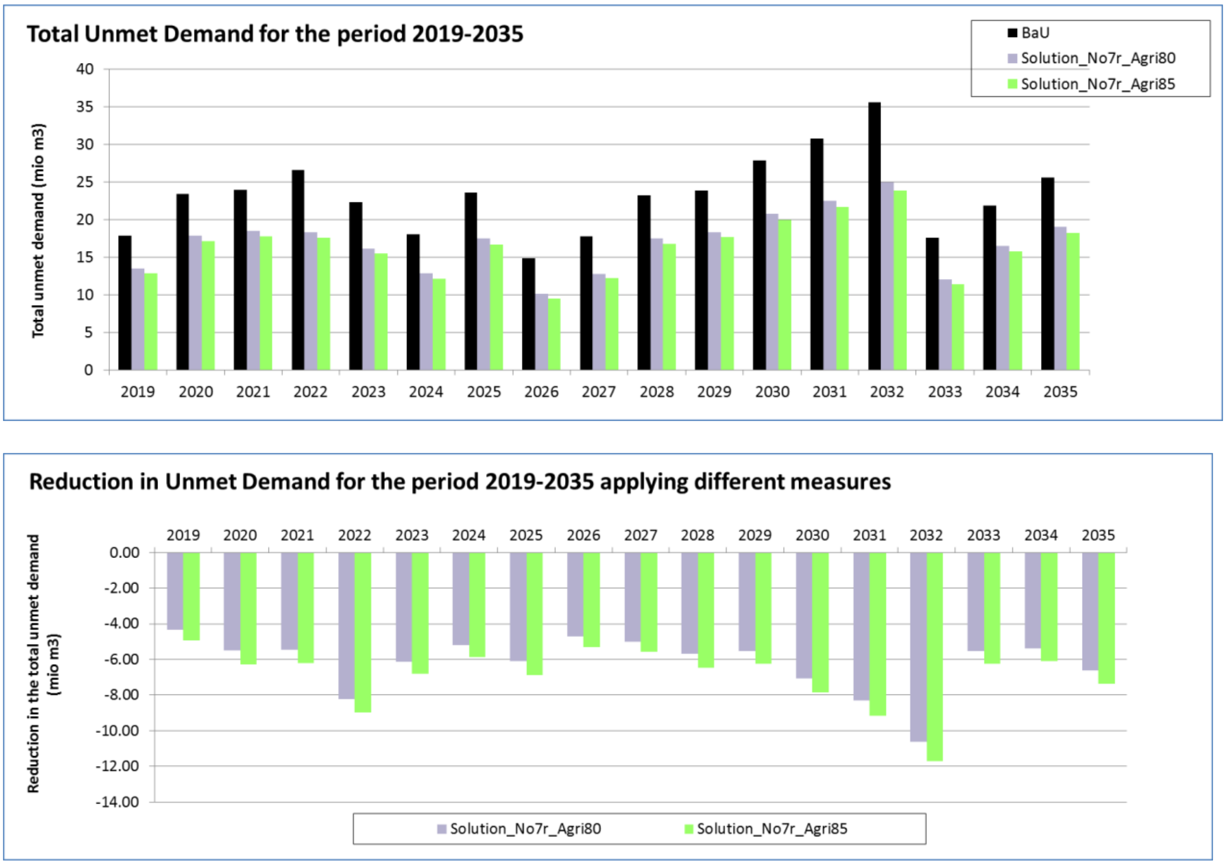


Figure 8-6: Comparison of the unmet demand under the MixSup scenario in relation to the BaU scenario (top: MixSup as compared to the BaU; bottom, net reduction of the unmet demand as compared to the BaU)

9 CONCLUSIONS

All the proposed solutions (of the different scenarios) have the potential to reduce unmet water demand in the Al Ostuan basin, ranging from ~1 mio m^3 reduction (Solution UrbSav_No.1, No.3, No.5) up to ~7 mio m^3 reduction (Solution_No20_Agri85, Solution_No7r_Agri85), or from 12.5-118 mio m^3 reduction for the entire period 2019-2035 (**Table 9-1**).Yet, some of the solutions come with a high investment cost (CAPEX) and are not considered the best tradeoffs. **Table 9-1** below presents all solutions ranked according to the reduction in unmet demand that they can achieve (from the highest to the lowest reduction), while **Table 9-2** presents all solutions ranked according to the needed CAPEX (from smaller to higher).

The cheapest solution is UrbSav_No.1 which requires a CAPEX of 0.78 million $ and reduces unmet demand by 0.8 mio m^3/year on average (i.e. 12.5 mio m^3 during the entire period 2019-2035) corresponding to a 3.2% reduction in the total unmet demand in the basin just by installing efficient Shower-heads (1 item) in all the households. The most expensive solution is UrbSup_No.20m which requires a CAPEX of ~161 mio $ and results in annual reduction of unmet demand by 2.2 m^3/year on average (i.e. 37 mio m^3 during the entire period 2019-2035) corresponding to a 9.4% reduction in the total unmet demand. This solution requires to install all water saving fixture in the households (1 dual flash toilet, 1 efficiency showerhead, 2 low flow taps, 1 efficient washing machine) as well as a Rainwater Harvesting System and a Greywater Reuse System, and this is why it is so expensive. This solution is sub-optimal and not preferred since there are other cheaper solutions which deliver higher savings.

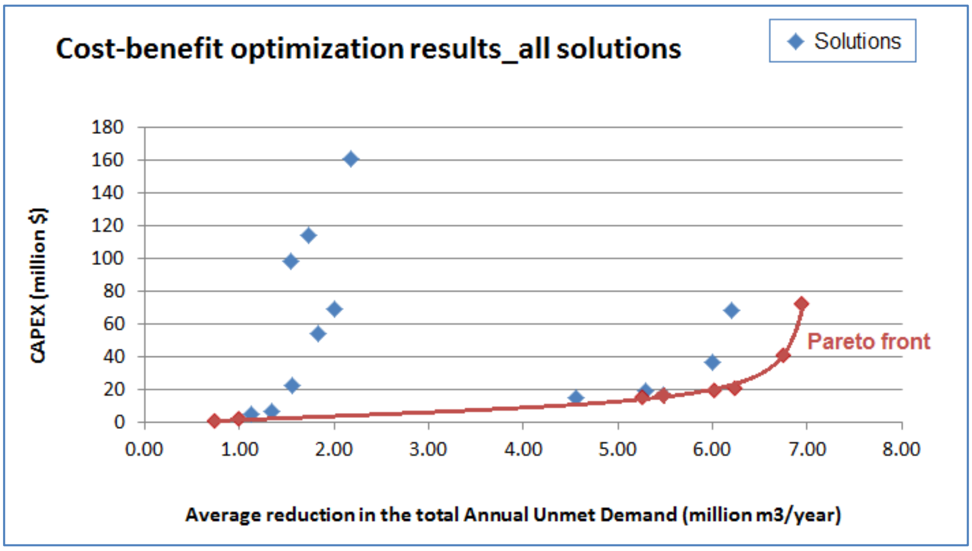


Figure 9-1 presents all solutions cross-compared in terms of reduction in unmet demand vs. CAPEX (cost-benefit) in a pareto front, in order to identify the optimal ones. Eight solutions are the optimal ones in terms of cost-benefit (the benefit being to maximize the reduction of unmet demand and deliver the highest savings), as presented in **Table 9-3**.

Overall, it is observed that 6 out of 8 of the optimal solutions are a mix of urban and agricultural saving measures, one of these solutions also suggesting the installation in households of rainwater harvesting (i.e. Solution_No7r_Agri90). This solution can deliver the maximum reduction in unmet demand (30%), yet with a high CAPEX of 72 mio $ or an AEC of 9.7 mio $/year for about 7.4 years. The cheapest solutions amongst the optimal ones are Solution No. 1 and Solution No.3 and include only the installation of water saving fixtures (1 efficient showerhead and 1 efficient showerhead + 2 low flow taps respectively in all households), rendering reductions of the unmet demand of 3.2% and 4.3% respectively. On the basis of these 8 optimal solutions, **Table 9-4** suggests options per investment budget increments (i.e. what can we do with less than 1 mio $, with 2 mio $, 4 mio $ and so on…).

Table 9-1: Summary table of all solutions (ranked from the solution which results the largest reduction in total unmet demand, to the lowest reduction)

Solution** #	Solution description	Annual average unmet demand (mio m3)	Reduction in Unmet demand* COMPARING TO THE BaU		Reduction in Unmet demand* (total 2019-2035, mio m^3)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin	Unit CAPEX of unmet demand reduction/ saving ($/m3 saved)
			(annual average, mio m^3)	(annual average, %)				
Solution_No7r_Agri85	UrbSup_No.7r + AgrSav_85	16.26	-6.94	29.90%	-118.00	9.72	72.19	0.61
Solution_No20_Agri85	UrbSav_No.20 + AgrSav_85	16.46	-6.75	29.07%	-114.71	5.93	40.83	0.36
Solution_No3_Agri85	UrbSav_No.3 + AgrSav_85	16.97	-6.23	26.86%	-105.98	2.19	20.70	0.20
Solution_No7r_Agri80	UrbSup_No.7r + AgrSav_80	17.01	-6.20	26.72%	-105.41	9.41	68.04	0.65
Solution_No1_Agri85	UrbSav_No.1 + AgrSav_85	17.19	-6.02	25.92%	-102.29	1.70	19.40	0.19
Solution_No20_Agri80	UrbSav_No.20 + AgrSav_80	17.20	-6.01	25.87%	-102.09	5.62	36.68	0.36
Solution_No3_Agri80	UrbSav_No.3 + AgrSav_80	17.72	-5.48	23.62%	-93.21	1.88	16.56	0.18
Solution_Agri85	AgrSav_85	17.91	-5.30	22.83%	-90.08	1.41	18.61	0.21
Solution_No1_Agri80	UrbSav_No.1 + AgrSav_80	17.95	-5.26	22.65%	-89.35	1.39	15.25	0.17
Solution_Agri80	AgrSav_80	18.65	-4.55	19.61%	-77.36	1.10	14.47	0.19
Solution_No20	UrbSav_No.20	21.65	-1.56	6.71%	-26.46	4.52	22.21	0.84
Solution_No7	UrbSav_No.7	21.86	-1.34	5.78%	-22.82	1.62	6.53	0.29
Solution_No5	UrbSav_No.5	22.08	-1.12	4.84%	-19.11	1.12	5.23	0.27

Solution** #	Solution description	Annual average unmet demand (mio m3)	Reduction in Unmet demand* COMPARING TO THE BaU		Reduction in Unmet demand* (total 2019-2035, mio m^3)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin	Unit CAPEX of unmet demand reduction/ saving ($/m3 saved)
			(annual average, mio m^3)	(annual average, %)				
Solution_No3	UrbSav_No.3	22.22	-0.99	4.27%	-16.83	0.78	2.09	0.12
Solution_No20m	UrbSup_No.20m	21.03	-0.95	4.08%	-37.02	24.23	160.73	4.34
Solution_No20r	UrbSup_No.20r	21.20	-0.92	3.96%	-34.09	11.21	69.26	2.03
Solution_No7r	UrbSup_No.7r	21.38	-0.78	3.35%	-31.11	8.31	53.58	1.72
Solution_No20w	UrbSup_No.20w	21.47	-0.74	3.18%	-29.53	17.54	113.69	3.85
Solution_No1	UrbSav_No.1	22.47	-0.73	3.17%	-12.49	0.29	0.78	0.06
Solution_No7w	UrbSup_No.7w	21.66	-0.64	2.77%	-26.30	14.64	98.01	3.73

* based on the WEAP model outputs

**Note: The Solutions UrbLeak which has been analyzed in Section 7.5 is not included in this Table since the lack of data on the actual costs (which depends on the analysis of the current network needs and was not within the technical scope of this study) could not allow its comparisons/ ranking

Table 9-2: Summary table of all solutions (ranked from the solution which results the lowest required CAPEX, to the highest)

Solution** #	Solution description	Annual average unmet demand (mio m3)	Reduction in Unmet demand* COMPARING TO THE BaU		Reduction in Unmet demand* (total 2019-2035, mio m^3)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin	Unit CAPEX of unmet demand reduction/ saving ($/m3 saved)
			(annual average, mio m^3)	(annual average, %)				
Solution_No1	UrbSav_No.1	22.47	-0.73	3.17%	-12.49	0.29	0.78	0.06
Solution_No3	UrbSav_No.3	22.22	-0.99	4.27%	-16.83	0.78	2.09	0.12

Solution** #	Solution description	Annual average unmet demand (mio m3)	Reduction in Unmet demand* COMPARING TO THE BaU		Reduction in Unmet demand* (total 2019-2035, mio m³)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin	Unit CAPEX of unmet demand reduction/ saving ($/m3 saved)
			(annual average, mio m³)	(annual average, %)				
Solution_No5	UrbSav_No.5	22.08	-1.12	4.84%	-19.11	1.12	5.23	0.27
Solution_No7	UrbSav_No.7	21.86	-1.34	5.78%	-22.82	1.62	6.53	0.29
Solution_Agri80	AgrSav_80	18.65	-4.55	19.61%	-77.36	1.10	14.47	0.19
Solution_No1_Agri80	UrbSav_No.1 + AgrSav_80	17.95	-5.26	22.65%	-89.35	1.39	15.25	0.17
Solution_No3_Agri80	UrbSav_No.3 + AgrSav_80	17.72	-5.48	23.62%	-93.21	1.88	16.56	0.18
Solution_Agri85	AgrSav_85	17.91	-5.30	22.83%	-90.08	1.41	18.61	0.21
Solution_No1_Agri85	UrbSav_No.1 + AgrSav_85	17.19	-6.02	25.92%	-102.29	1.70	19.40	0.19
Solution_No3_Agri85	UrbSav_No.3 + AgrSav_85	16.97	-6.23	26.86%	-105.98	2.19	20.70	0.20
Solution_No20	UrbSav_No.20	21.65	-1.56	6.71%	-26.46	4.52	22.21	0.84
Solution_No20_Agri80	UrbSav_No.20 + AgrSav_80	17.20	-6.01	25.87%	-102.09	5.62	36.68	0.36
Solution_No20_Agri85	UrbSav_No.20 + AgrSav_85	16.46	-6.75	29.07%	-114.71	5.93	40.83	0.36
Solution_No7r	UrbSup_No.7r	21.38	-0.78	3.35%	-31.11	8.31	53.58	1.72
Solution_No7r_Agri80	UrbSup_No.7r + AgrSav_80	17.01	-6.20	26.72%	-105.41	9.41	68.04	0.65
Solution_No20r	UrbSup_No.20r	21.20	-0.92	3.96%	-34.09	11.21	69.26	2.03
Solution_No7r_Agri85	UrbSup_No.7r + AgrSav_85	16.26	-6.94	29.90%	-118.00	9.72	72.19	0.61
Solution_No7w	UrbSup_No.7w	21.66	-0.64	2.77%	-26.30	14.64	98.01	3.73
Solution_No20w	UrbSup_No.20w	21.47	-0.74	3.18%	-29.53	17.54	113.69	3.85
Solution_No20m	UrbSup_No.20m	21.03	-0.95	4.08%	-37.02	24.23	160.73	4.34

* based on the WEAP model outputs

**Note: The Solutions UrbLeak which has been analysed in Section 7.5 is not included in this Table since the lack of data on the actual costs (which depends on the analysis of the current network needs and was not within the technical scope of this study) could not allow its comparisons/ ranking

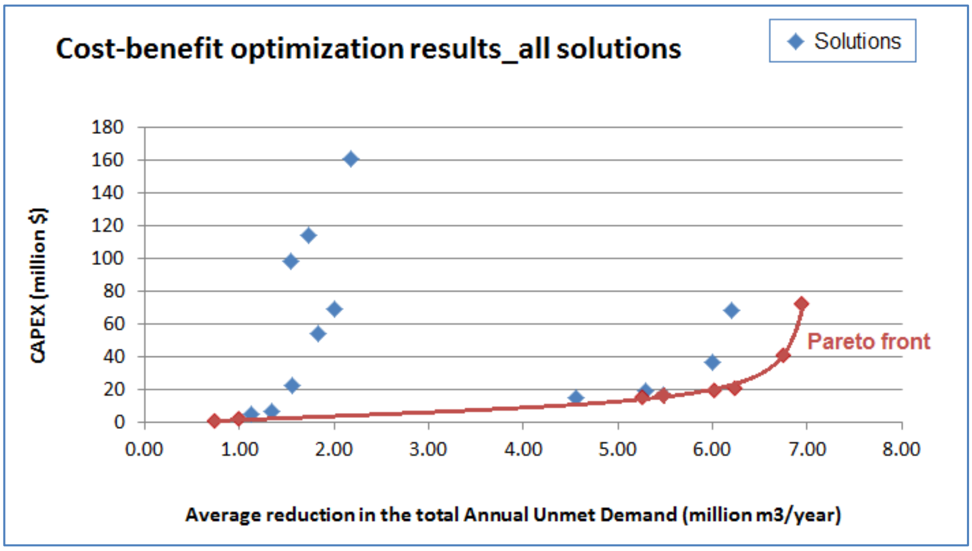


Figure 9-1: Comparison of all solutions in terms of reduction in unmet demand vs. CAPEX (cost-benefit) in a pareto front

Table 9-3: Optimal solutions in terms of cost-benefit

Solution #	Annual average unmet demand (mio m3)	Reduction in Unmet demand* COMPARING TO THE BaU (annual average, mio m³)	Reduction in Unmet demand* COMPARING TO THE BaU (annual average, %)	Reduction in Unmet demand* (total 2019-2035, mio m³)	Total AEC (mio $) for the basin	Total CAPEX (mio $) for the basin	Unit CAPEX of unmet demand reduction / saving ($/m3 saved)
Solution_No1	22.47	-0.73	-3.17%	-12.49	0.29	0.78	0.06
Solution_No3	22.22	-0.99	-4.27%	-16.83	0.78	2.09	0.12
Solution_No1_Agri80	17.95	-5.26	-22.65%	-89.35	1.39	15.25	0.17
Solution_No3_Agri80	17.72	-5.48	-23.62%	-93.21	1.88	16.56	0.18
Solution_No1_Agri85	17.19	-6.02	-25.92%	-102.29	1.70	19.40	0.19
Solution_No3_Agri85	16.97	-6.23	-26.86%	-105.98	2.19	20.70	0.20
Solution_No20_Agri85	16.46	-6.75	-29.07%	-114.71	5.93	40.83	0.36
Solution_No7r_Agri85	16.26	-6.94	-29.90%	-118.00	9.72	72.19	0.61

LDK CONSULTANTS

Contact Name for this Assignment:
Mr. Costis Nicolopoulos
TEL: +30-210-8196753
EMAIL: cni@ldk.gr

HEADQUARTERS
Off 21, Thivaidos St., GR-145 64 Kifissia, GREECE
Tel: +30 210 8196700, Fax: +30 210 8196709
email: main@ldk.gr
www.ldk.gr

Table 9-4: Suggested solutions per investment budget increments

Investment	Unmet Demand	mio m3 / %	What should be applied?
< 1 mio $ CAPEX *or* 290,000 $/yr for 2.7 years	Annual average:	22.5	Solution_No1: *1 efficient showerhead in all households*
	Reduction from BaU (annual average):	0.7	
	% Reduction from BaU:	**3.2%**	
	Total Reduction 2019-2027:	12.5	
~2 mio $ *or* 780,000 $/yr for 2.7 years	Annual average:	22.2	Solution_No3: *1 efficient showerhead and 2 low flow taps*
	Reduction from BaU (annual average):	1	
	% Reduction from BaU:	**4.3%**	
	Total Reduction 2019-2027:	16.8	
~15 mio $ *or* 1.4 mio $/yr for 11 years	Annual average:	18	Solution_No1_Agri80: *1 efficient showerhead in all households, and increasing irrigation efficiency by +20%, by converting 1,502 ha (i.e. 74% of the total) to closed in all households pipes and switching 1,482 ha (i.e. 73% of the total) to drip irrigation*
	Reduction from BaU (annual average):	5.3	
	% Reduction from BaU:	**22.7%**	
	Total Reduction 2019-2027:	89.4	
~20 mio $ *or* 2.2 mio$/yr for 9.4 years	Annual average:	17	Solution_No3_Agri85: *1 efficient showerhead and 2 low flow taps in all households, and increasing irrigation efficiency by +25%, by converting 1,969 ha (i.e. 97% of the total) to closed pipes and switching 1,847 ha (i.e. 91% of the total) to drip irrigation*
	Reduction from BaU (annual average):	6.2	
	% Reduction from BaU:	**27%**	
	Total Reduction 2019-2027:	106	
	Reduction from BaU (annual average):	6.8	
	% Reduction from BaU:	29%	
	Total Reduction 2019-2027:	114.7	

Contact Name for this Assignment:
Mr. Costis Nicolopoulos
TEL: +30-210-8196753
EMAIL: cni@ldk.gr

HEADQUARTERS
Off 21, Thivaidos St., GR-145 64 Kifissia, GREECE
Tel: +30 210 8196700, Fax: +30 210 8196709
email: main@ldk.gr
www.ldk.gr

10 LIST OF REFERENCES

Atkins (2010). **Bath and North East Somerset Flood Risk Management Strategy Report** (www.bathnes.gov.uk)

Berbel, J., Martin-Ortega, J. and Mesa, P. (2011). **A Cost-Effectiveness Analysis of Water- Saving Measures for the Water Framework Directive: the Case of the Guadalquivir River Basin in Southern Spain.** Water Resources Management, 2011, 25, 623- 640.

BIO Intelligence Service (2012). **Water Performance of Buildings**. Final Report Prepared for the European Commission, DG Environment. 2012. Available online: http://ec.europa.eu/environment/water/quantity/pdf/BIO_WaterPerformanceBuildings.pdf

BIO Intelligence Service and Cranfield University (2009). **Water Performance of Buildings**. Report for the European Commission (DG Environment), 2009. Available at: http://ec.europa.eu/environment/water/quantity/pdf/Water%20Performance%20of%20Buildings_Study2009.pdf

Canessa, P., Green, S., and Zoldoske, D. (2011). **Agricultural Water Use in California: A 2011 Update**. Norum, K., ed. Center for Irrigation Technology, California State University, Fresno, Fresno CA.

Central Administration of Statistics, CAS (2012). **Population and Housing in Lebanon, ‚Statistics In Focus (SIF)**. Central Administration of Statistics (CAS), Lebanon, issue number 2, April 2012. Available online: http://www.cas.gov.lb/images/PDFs/SIF/CAS_Population_and_housing_In_Lebanon_SIF2.pdf

CERTU (Ministère de l'Ecologie, du développement et de l'aménagement durables) (2008). **L'assainissement pluvial intégré dans l'aménagement.**

Chocat, Abirached, Delage, Faby (2008). **Etat de l'art sur la gestion urbaine des eaux pluviales et leur valorisation, Tendances d'évolution et technologies en développement.** ONEMA, OIEau

Cordella, M., Garbarino, E., Kaps, R., Wolf, O. (2013). **Developing an evidence base and related products policy measures for "Taps and Showers"**. (Working Draft in progress). Technical Report by the Joint Research Centre of the European Commission, June, 2013. Available online:

Contact Name for this Assignment:
Mr. Costis Nicolopoulos
TEL: +30-210-8196753
EMAIL: cni@ldk.gr

HEADQUARTERS
Off 21, Thivaidos St., GR-145 64 Kifissia, GREECE
Tel: +30 210 8196700, Fax: +30 210 8196709
email: main@ldk.gr
www.ldk.gr

http://susproc.jrc.ec.europa.eu/taps_and_showers/docs/T&S_KO_27June2013_Working_document.pdf

Detention basins Factsheet, U10 Detention Basins. Natural Water Retention Measures (NWRM) project, 2013.

Environment Agency (2012). **Rural Sustainable Drainage Systems (RSuDS)**

Environment Agency, EA (2007). **Conserving water in buildings: a practical guide**. Environment Agency, November 2007. Available at : http://cdn.environment-agency.gov.uk/geho1107bnjr-e-e.pdf (accessed March 2014)

Environment Agency, EA (2010). **Harvesting rainwater for domestic uses: an information guide**. Environment Agency, May 2011. Available online: http://cdn.environment-agency.gov.uk/geho1110bten-e-e.pdf

EU Natural Water Retention Measures (NWRM) Platfrom, http://nwrm.eu/

European Environment Agency, EEA (2001). **Environmental issue report No 19, Sustainable water use in Europe - Part 2: Demand management**. EEA, Copenhagen

Hanson, B., Schwankl, L., Fulton, A, (1999). **Scheduling Irrigations: When and How Much Water to Apply**. Div of Ag and Natural Resources publication 3396. UC Irrigation Program. UC Davis, 1999.

Howell, T. A., 2003. **Irrigation efficiency**. pp. 467-472. In: B. A. Stewart and T. A Howell (eds.) Encyclopedia of Water Science, Marcel-Dekker, Inc.

Kossida, M. (2015). **Methods and tools supporting operational drought risk management in water stressed areas**. PhD Dissertation, National Technical University of Athens (NTUA), http://hdl.handle.net/10442/hedi/43161

Kossida, M., Fayad, A. 2019. **Report on the assessment of the water resources/ balance in Al OstuanRiver Basin, based on the outputs of the WEAP model (under current and future scenarios), including a brief on the scenarios**. Project Deliverable D1.2 & D.1.3, SWIM-H2020 SM Expert Facility Activity EFS-LB-1, Task 1, SWIM-H2020 Project, February 2019.

Kossida, M., Tsoukalas, I., Gerges, N., Saba, M., Jabaly, J., Iaaly, A. 2020. **Baseline Report on the assessment of the current water resources on the Nahr Al Ostuan Basin**. Project Deliverable

Contact Name for this Assignment:
Mr. Costis Nicolopoulos
TEL: +30-210-8196753
EMAIL: cni@ldk.gr

HEADQUARTERS
Off 21, Thivaidos St., GR-145 64 Kifissia, GREECE
Tel: +30 210 8196700, Fax: +30 210 8196709
email: main@ldk.gr
www.ldk.gr

No. 2, Consultancy to Facilitate Integrated Water Resource Management (IWRM) in the Al Ostuan Basin, ACTED, Lebanon.

Kossieris, P., Makropoulos, C., 2020. **Simulation of Non-Gaussian Correlated Random Variables, Stochastic Processes and Random Fields: Introducing the anySim R-Package for Environmental Applications and Beyond**. Water 12, 1645, doi: 10.3390/w12061645.

Marshallsay, D., Trew, J., Waylen, C. (2007). A**ssessing the cost of compliance with the code for sustainable homes.** Environment Agency, UK, 2007.

Ministry of Energy and Water (MEW), 2020. **National Water Sector Strategy Update – 2020: Volume I: Executive Summary**: Volume II: Water Sector Governance; Volume III: Water Resources Management; Volume IV: water sector current situation; Volume V: proposed projects; Volume VI: drawings

Morris, M., Lynne, V., 2006. **Measuring and Conserving Irrigation Water.** National Center for Appropriate Technology. Butte, MT. 2006.

Panagopoulos, Y., Makropoulos, C., Kossida, M., Mimikou, M. (2012). **Surface Water Hydrologic Model Development and Development of Tools Supporting Appropriate Technologies Selection and Placement**. Final Report. Deliverable for the Task E1 & F1 of the Project i-adapt: Innovative Approaches to Halt Desertification in Pinios, DG Environment, April 2012.

POST (2000). **Water efficiency in the home**. Parliamentary Office of Science and Technology Note 135, March 2000.

R Core Team, 2017. **R Development Core Team**. R A Lang. Environ. Stat. Comput., 55, 275–286.

Retention ponds Factsheet, U11 Retention Ponds. Natural Water Retention Measures (NWRM) project, 2013.

Rogers, D.H., Lamm, F.R., Alam, M., Trooien, T.P., Clark, G.A., Barnes, P.L., Mankin, K.L., 1997. **Efficiencies and water losses of irrigation systems**. Kansas State Research and Extension. Irrigation Management Series. MF-2243.

Sandoval-Solis, S., Orang, M., Snyder, R.L., Orloff, S., Williams,K.E., Rodriguez,J.M., 2013. **Spatial and Temporal Analysis of Application Efficiencies in Irrigation Systems for the State of California**. Report prepared for the United States Geological Survey and California Institute for

Contact Name for this Assignment:
Mr. Costis Nicolopoulos
TEL: +30-210-8196753
EMAIL: cni@ldk.gr

HEADQUARTERS
Off 21, Thivaidos St., GR-145 64 Kifissia, GREECE
Tel: +30 210 8196700, Fax: +30 210 8196709
email: main@ldk.gr
www.ldk.gr

Water, July 2013.UC Davis Water Management Research Group, Water Management Research Laboratory, University of California, Davis.

Schleich, J. and Hillenbrand, T. (2007). **Determinants of Residential Water Demand in Germany**. Working Paper Sustainability and Innovation No. S 3/2007. Fraunhofer, Institute Systems and Innovation Research

Schmidt, G. and Benítez, C. (2012). **Topic Report on Water Scarcity and Droughts Aspects in a selection of European Union River Basin Management Plans**, Topic Report, Version 3.0. Service contract for the support to the follow-up of the Communication on Water Scarcity and Droughts. European Commission, Intecsa-Inarsa S.A. and Typsa. Avaialble at: http://ec.europa.eu/environment/water/quantity/pdf/Assessment%20WSD.pdf (accessed March 2014).

SISSAF, 2017. **Water Supply Master Plan for North Lebanon, Chapter 10 Akkar Water Master Plan**.

SISSAF, 2017. **Water Supply Master Plan for North Lebanon, Chapter 12 Socioeconomic Study**.

Solomon, K., 1988. **Irrigation Systems and Water Application Efficiencies**. Center for Irrigation Technology Irrigation Notes, January 1988, California State University, Fresno, California 93740-0018.

Stockholm Environment Institute (SEI), 2015. **WEAP Water Evaluation And Planning System. User Guide for WEAP 2015**, SEI, August 2015.

SuDS Construction and Maintenance Costs Calculator, http://geoservergisweb2.hrwallingford.co.uk/uksd/costintro.aspx

Tanji, K.K., Hanson, B.R., 1990. **Drainage and Return Flows in Relation to Irrigation Management**, in: B.A. Stewart & D.N. Nielsen, eds. Irrigation of Agricultural Crops, Agronomy Monograph No. 30. Madison, WI, USA. American Society of Agronomy.

Tegos, A., Malamos, N., Efstratiadis, A., Tsoukalas, I., Karanasios, A., & Koutsoyiannis, D., 2017. **Parametric Modelling of Potential Evapotranspiration: A Global Survey**. Water, 9(12), 795. https://doi.org/10.3390/w9100795

Tsoukalas, I., 2019. **Modelling and simulation of non-Gaussian stochastic processes for optimization of water-systems under uncertainty**. PhD Thesis, Department of Water Resources

Contact Name for this Assignment:
Mr. Costis Nicolopoulos
TEL: +30-210-8196753
EMAIL: cni@ldk.gr

HEADQUARTERS
Off 21, Thivaidos St., GR-145 64 Kifissia, GREECE
Tel: +30 210 8196700, Fax: +30 210 8196709
email: main@ldk.gr
www.ldk.gr

and Environmental Engineering, National Technical University of Athens (Defense date: 20 December 2018).

Tsoukalas, I., A. Efstratiadis, and Makropoulos, C., 2017. **Stochastic simulation of periodic processes with arbitrary marginal distributions**. 15th International Conference on Environmental Science and Technology. CEST 2017., Rhodes, Greece.

Tsoukalas, I., A. Efstratiadis, and Makropoulos, C., 2018. **Stochastic Periodic Autoregressive to Anything (SPARTA): Modeling and simulation of cyclostationary processes with arbitrary marginal distributions**. Water Resour. Res., 54(1), 161–185, doi:10.1002/2017WR021394.

Tsoukalas, I., Efstratiadis, A., & Makropoulos, C, 2019. **Building a puzzle to solve a riddle: A multi-scale disaggregation approach for multivariate stochastic processes with any marginal distribution and correlation structure**. Journal of Hydrology, 575, 354–380. https://doi.org/10.1016/j.jhydrol.2019.05.017

Tsoukalas, I., Makropoulos, C., & Koutsoyiannis, D., 2018. **Simulation of stochastic processes exhibiting any-range dependence and arbitrary marginal distributions**. Water Resources Research. https://doi.org/10.1029/2017WR022462

Uihlein, A., and Wolf, O. (2010). ECOTAPWARE. **Development of a background report for water using products (WuP) – Identification of suitable product groups, Draft**. Joint Research Centre, JRC IPTS, February 2010. Availabe at: http://susproc.jrc.ec.europa.eu/ecotapware/docs/Scoping%20document_WuP_100217.pdf(accessed March 2014)

UK SuDS website, www.uksuds.com

Wilson, S, Bray, B, Neesam, S, Bunn, S and Flanagan, E (2009). **Sustainable Drainage: Cambridge Design and Adoption Guide**

Woods-Ballard, B, Kellagher, R, Martin, P, Jefferies, C, Bray, R and Shaffer, P (CIRIA) (2007). **The SuDS Manual**. CIRIA C697.

LDK CONSULTANTS

Contact Name for this Assignment:
Mr. Costis Nicolopoulos
TEL: +30-210-8196753
EMAIL: cni@ldk.gr

HEADQUARTERS
Off 21, Thivaidos St., GR-145 64 Kifissia, GREECE
Tel: +30 210 8196700, Fax: +30 210 8196709
email: main@ldk.gr
www.ldk.gr