# Report on the performance of demand management measures in the Nahr El-Kelb River Basin

SWIM and Horizon 2020 Support Mechanism

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| 1 | Report on the performance of demand management measures in the Nahr El-Kelb River Basin | Maggie Kossida, Non-Key expert Programmes of Measures | Suzan Taha, Key water expert |

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# DISCLAIMER:

# ABBREVIATIONS

| | |
|---|---|
| BaU | Business as Usual |
| m.s.l. | Mean Sea Level |
| MCM | Million Cubic Meters |
| Mm3 | Million Cubic Meters |
| MoEW | Ministry of Energy and Water |
| RWH | Rainwater Harvesting |
| GWR | Greywater Reuse |
| WWTP | Wastewater Treatment Plan |

# EXECUTIVE SUMMARY

The current work is related to the SWIM-H2020 SM expert facility activity EFS-LB-1: “IWRM at the river basin scale, with a focus on capacity building and implementation aspects” and builds on the respective Project Identity Form (PIF). The activity falls under the SWIM theme “Decentralized water management and Growth” and aspires overall to support aspects of policy development and reform, and to provide institutional training, technical assistance and capacity building, through a series of sub-activities. 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 Nahr El-Kelb River Basin in Lebanon, in order to mitigate the problem of unmet demand.

The demand management measures investigated in the report have been selected through a Consultation Workshop with relevant stakeholders. Cost-effectiveness functions have been developed for each measure, and following an optimization process the optimum measures have been subsequently simulated in the physical-based water resources management model of the Nahr El-Kelb River Basin developed in WEAP, in order to ex-ante assess their performance. The resulting water savings and/or water gains, when applying the measures have been evaluated for the future 2020-2040 period across the various demand sites (urban and agriculture nodes) of the model. The future baseline socio-economic conditions have been modelled assuming an annual population increase of 2.6% and a future climate based on a statistical reproduction, following a random distribution, of the past 2000-2017 climatic variables (i.e. accounting for Mediterranean variability and assuming no climate climate).

The measures selected for simulation included options for the urban sector, namely the installation of low water using fixtures and appliances (low flow taps and shower heads, etc.), on-site Domestic Greywater Reuse (GWR) and on-site Rainwater Harvesting (houses, hotels, villages), as well as options for the agricultural sector, namely the transition to drip irrigation systems and to closed pipes. Additional measures have been selected for increasing supply at the meso-scale and the marco-scale, namely the investigation of building detention/ retention ponds and dams. Based on the mix of these measures (selected through the optimization process), 7 alternative scenarios have been formulated and simulated in WEAP. Their results have been compared against the current Business as Usual scenario (BaU scenario). Three scenarios (UrbSav, AgrSav, MixSav) focus solely on introducing water savings in the urban and agricultural sectors, another two scenarios (UrbSup2, AgrSup2) focus solely on increasing supply at the meso-scale level in the urban and agricultural sectors (through construction of detention basins/ retention ponds), while one scenario (UrbSup) focuses both on water saving and increasing supply for the domestic/urban sector at the micro-scale level. Finally, scenario MoEW investigates increasing water supply at the macro-level and cross-cuts across all sectors. An overview of the scenarios is presented in the Table I below.

**Table I: Alternative scenarios for the Nahr El-Kelb river basin**

| Scenario Name | Scenario Focus | Measures included in the scenarios |
|---|---|---|
| **BaU** | Business as Usual, no measures applied, population change included (2.6% increase) | - |
| **UrbSav** | Water saving in the domestic/urban sector | U1. Installation of low water using fixtures and appliances (dual-flush toilets, efficient showerheads, low-flow taps, efficient washing machines, dishwashers) |
| **AgrSav** | Water saving in the agricultural sector | A1. Increase network conveyance efficiency (converting to closed pipes and thus reduce conveyance losses to 15.5%)<br>A2. Increase field application efficiency (changing irrigation method to drip, and thus increase application efficiency to 84%) |
| **MixSav** | Water saving across all sectors (urban + agriculture) | U1. Low water using fixtures and appliances (dual-flush toilets, efficient showerheads, low-flow taps, efficient washing machines, dishwashers)<br>A1. Increase network conveyance efficiency (converting to closed pipes and thus reduce conveyance losses to 15.5%)<br>A2. Increase field application efficiency (changing irrigation method to drip, and thus increase application efficiency to 84%) |
| **UrbSup** | Water saving and increasing supply for the domestic/urban sector (micro-scale) | U1. Low water using fixtures and appliances (dual-flush toilets, efficient showerheads, low-flow taps, efficient washing machines, dishwashers)<br>U2. Domestic Greywater Reuse (GWR) on-site (houses, hotels) in villages<br>U3. Rainwater Harvesting (RWH) on-site (houses, hotels, villages) |
| **UrbSup2** | Increasing supply for the domestic/urban sector (meso-scale) | U5. Detention basins/ Retention ponds in urban areas |
| **AgrSup2** | Increasing supply for the agricultural sector (meso-scale) | A3. Detention basins/ Retention ponds in agricultural areas |
| **MoEW** | Focus on increasing supply across all sectors (macro-scale) | C1. Implementation of the Boqataa Dam |

The results of the model indicated that under the BaU scenario, where no measures are applied and population is projected to increase annually by 2.6%, the unmet demand in the future period 2020-2040 will increase from 3.7 Mm3/year (i.e. average unmet demand of the 2000-2017 reference period) to about 6 Mm3/year on average, i.e. a 62% increase (ranging from 1.4 to 15.4 Mm3/year), with the highest unmet demands occurring in July-September. The highest increase, about 135%, is expected in the urban unmet demand which will reach 2.5 Mm3/year on average. The unmet demand in the urban sector was about 0.96 Mm3 in 2018. The maximum projected for the future, under the BaU scenario, is to reach 6.10 Mm3 in the year 2036. The Hardoun area experienced the highest unmet demands in the reference period (about 0.79 Mm3/year in 2018). Yet, the greatest % increase in the unmet demand in the future is expected to occur in the Beit Chabeb and Coastal areas, which had almost zero unmet demand so far. The month with the highest increase in urban unmet demand in the future (as compared to the reference 2000-2017) is June, where 166% increase in unmet demand is expected in the future as compared to the current reference period. The agricultural unmet demand will increase about 33%, reaching 3.5 Mm3/year on average. The unmet demand in the agricultural sector was about 4.5 Mm3 in 2018. The maximum projected for the future, under the BaU scenario, is to reach 9.7 Mm3 in the year 2037. The Coastal South and Mountain South agricultural areas experienced the highest unmet demands in the reference period 2000-2017 (about 1 Mm3/year and 1.3 Mm3/year respectively). Yet, the greatest % increase in the unmet demand in the future is expected to occur in the Mountain North agricultural area, which had almost no unmet demand so far. Regarding the monthly distribution of the agricultural unmet demand, this is mostly occurring in May-September. The month with the highest increase in unmet demand in the future (as compared to the baseline) is April, where 70% increase in unmet demand is expected in the future as compared to the reference period where the unmet demand was almost zero.

When implementing the UrbSav, UrbSup and AgrSav scenarios, the unmet demand of the future 2020-2040 period is reduced as a result of the applied Tier-1 water saving measures (installation of dual-flush toilets, efficient showerheads, low-flow taps, efficient washing machines), the additional Tier-2 water supply measures (rainwater harvesting, domestic greywater reuse), and the agricultural water saving measures (reduction of conveyance losses and increase of field application irrigation efficiency) respectively. The same applies when implementing the scenario MixSav, which is basically the combination of the UrbSav and AgrSav scenarios. With regard to the UrbSup2 and AgrSup2, the proposed detention ponds of 100-150 m2 capacity, 1 km2 drainage area, and a total of around 20 ponds per sub-catchment/demand site. is 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 UrbSup2 and AgrSup2 scenarios is that they 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, these scenarios have not been deemed suitable for simulation, although recommended as a practice for individual use in the agricultural sector mainly. Concluding, the different scenarios (UrbSav, UrbSup and AgrSav, MixSav) that have been simulated in WEAP demonstrated a good potential to reduce unmet demand, at various rates and costs, depending on the measures embedded in each scenario. A comparison of all scenarios across them and against the BaU is presented in Figure I below. The scenario with the lowest unit cost (i.e. € spent per m3 of unmet demand reduction in Annual Equivalent Cost - AEC) is the AgrSav (0.08 €/m3 AEC), followed by the MixSav (0.29 €/m3 AEC) and the UrbSav (0.49 €/m3 AEC). All these three scenarios can introduce savings with less than 0.5 €/m3 AEC, while the UrbSup scenario requires a respective AEC of more than 2€/m3. Table II summarises the expected reductions in unmet demand after implementation of the different scenario ((UrbSav, UrbSup and AgrSav, MixSav) as compared to the BaU scenario, along with the associated costs.

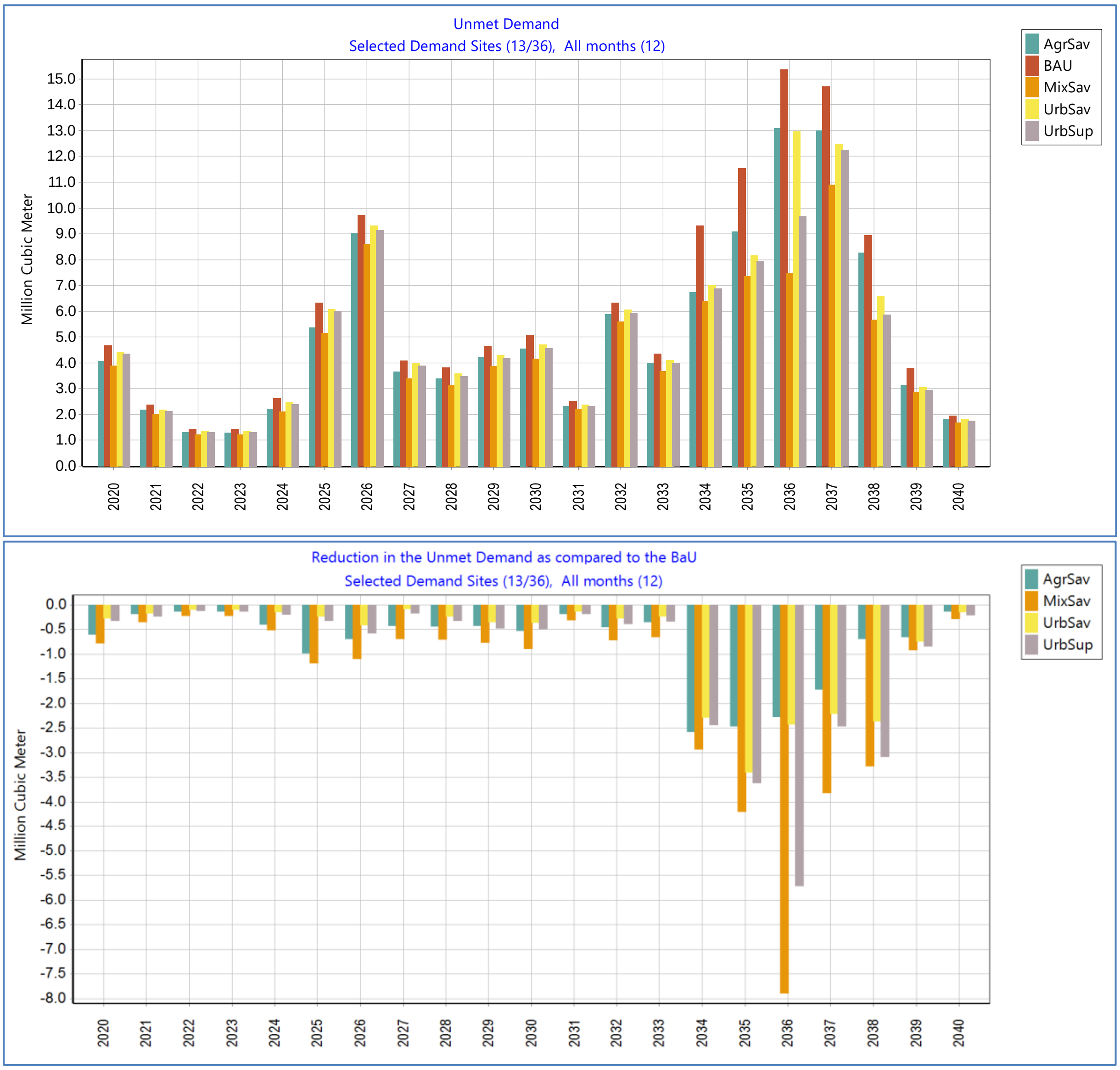



**Figure I: Expected reductions in the annual unmet demand (as estimated by the WEAP model) in all the demand sites (lump sum) in the Nahr El-Kelb basin for the period 2000-2040, when applying the different demand management scenarios (UrbSav, UrbSup, AgrSav, MixSav) as compared to the BaU scenario (top: all scenarios as compared to the BaU, bottom: net reduction of the unmet demand as compared to the BaU for each scenario)**

**Table II: Reduction in unmet demand after implementation of the different scenario as compared to the BaU scenario**

| Solution | Total reduction in unmet demand* (Mm3) in the basin for 2020-2040 | Mean annual reduction in unmet demand* (Mm3/year) | Maximum annual reduction in unmet demand* (Mm3/year) | Minimum annual water reduction in unmet demand* (Mm3/year) | Total AEC (mio €) for the basin | Unit AEC of unmet demand reduction/ saving (€/m3) |
|---|---|---|---|---|---|---|
| 0 (BaU) | 0 | 0 | 0 | 0 | 0 | 0 |
| UrbSav** | 16.62 | 0.89 | 3.39 | 0.08 | 8.12 | 0.49 |
| UrbSup** | 22.59 | 1.08 | 5.71 | 0.12 | 48.24 | 2.14 |
| AgrSav | 16.37 | 0.78 | 2.57 | 0.13 | 1.26 | 0.08 |
| MixSav*** | 32.37 | 1.57 | 7.89 | 0.22 | 9.38 | 0.29 |

* based on the WEAP model outputs

** The UrbSav and UrbSup scenarios here refer to the Solutions No.20 and No. 20m respectively which are the ones that deliver the maximum savings among the different options. Solution No. 20 contains the installation of 1 dual-flush toilet, 1 efficient showerheads, 2 low-flow taps, and 1 efficient washing machine in every household in the basin. Solution No. 20m contains the installation of a rainwater harvesting system and a domestic grewater reuse system additionally to the aforementioned measures of Solution No. 20.

*** MixSav includes: UrbSav Solution No. 20 and AgrSav (reduce losses to 15.5% & increase application efficiency to 84%)

The implementation of the different demand management measures as simulated in the UrbSav, UrbSup, AgrSav, MixSav can meaningfully contribute to the reduction of unmet demand, yet they cannot fully eliminate the problem as there still remains a portion of demand which cannot be covered by the existing water supply sources, especially under the future conditions. For example, the total annual unmet demand in the urban sector in the year 2018 reached 0.96 Mm3. Under the future population projection and climate variability simulation this unmet demand can reach 2.4 Mm3/year in 2030 and even 6.1 Mm3/year in 2036 if we experience some dry years. The simulated demand management measures of scenarios UrbSav, UrbSup, AgrSav, MixSav can reduce this unmet demand by 0.8-1.5 Mm3/year on average (depending on the scenario) and with a max potential reduction of 2.6-7.9 Mm3/year (during some years). It is thus understood that the problem cannot be eliminated by applying demand management measures alone, and some increase in water supply is also necessary. The implementation of the Boqaata Dam has been simulated under the MoEW scenario (to be operational in 2025), and is has been calculated by the model that the Boqaata Dam can deliver a water supply of about 7.5-10.5 MCM/year (depending on the climatic conditions of the year) (ref. Figure II below).

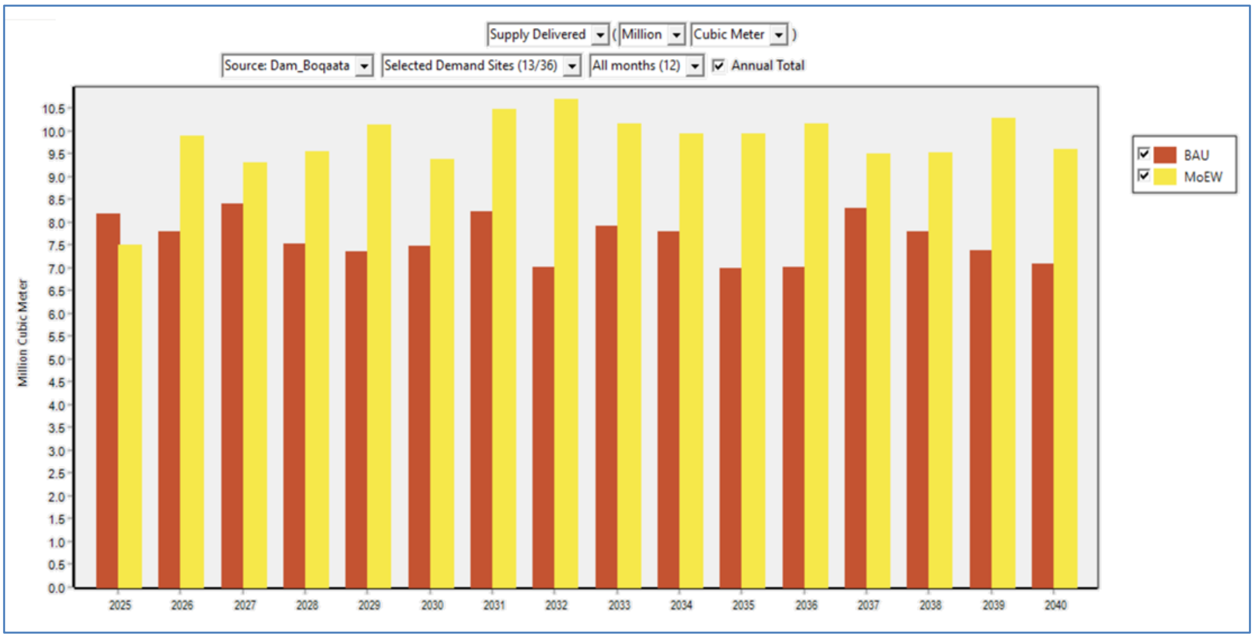



**Figure II: Expected increase in the annual water supply (as estimated by the WEAP model) in the Nahr El-Kelb basin for the period 2025-2040, with the operation of the Boqaata Dam (scenario MoEW) as compared to the to the BaU scenario**

# 1. INTRODUCTION

A "Demand Management Policy" is typical based on a bundle of technological, management and regulatory 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 Nahr El-Kelb 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 Nahr El-Kelb 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 a future 20-year period (2020-2040) across the various demand sites (urban and agriculture nodes) of the model. The future conditions have been modeled assuming an annual population increase of 2.6% and a future climate based on a statistical reproduction, following a random distribution, of the past 2000-2018 climatic variables (i.e. accounting for Mediterranean variability and assuming no climate climate).

The selection of the measures to be simulated in the Nahr El-Kelb River Basin has been done through a Consultation Workshop with relevant stakeholders, held on 06/07/2018 in the Ministry of Energy and Water in Beirut, in order to safeguard their relevance and acceptability. Participants from the Ministry of Energy and Water (MoEW), the Ministry of Environment (MoE), the Ministry of Agriculture (MoA), the Beirut-Mount Lebanon Water Establishment (BMLWE) and the SWIM-H2020 SM team engaged in an interactive discussion and reached a consensus regarding the adaptation measures (reduce demand and increase supply measures) which would be meaningful to simulate in the Nahr El-Kelb basin in order to assess their impact on the water balance of the basin and on the potential reduction of the unmet demand. 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 1-1). Some of these measures aim at introducing water savings (U1, A1, A2), while others at increasing supply (U2, U3, U4, U5, U6, A3, C1).

**Table 1-1: Selected measures to be simulated in the Nahr El-Kelb River Basin for the domestic and agricultural sectors**

| Sector / Scale | Domestic/ Urban | Agriculture | Cross-Cutting |
|---|---|---|---|
| **Micro-scale** | U1. Low water using fixtures and appliances (low flow taps and shower heads, etc.) (combined with awareness campaigns)<br>U2. Domestic Greywater Reuse (GWR) on-site (houses and hotels) in villages<br>U3. Rainwater Harvesting (RWH) on-site (houses, hotels, villages) | A1. Precision agriculture at the farm level (combined with education on crop productivity)<br>A2. Drip irrigation at the farm level | |
| **Meso-scale** | U4. Detention/ Retention ponds (small damming and RWH) in urban areas<br>U5. The WWTP of Bourj Hammoud is quite downstream so this water | A3. Detention/ Retention ponds (small damming and RWH) in agricultural areas | |

| | | | |
|---|---|---|---|
| | cannot be reused (needs to be pumped up). Maybe divert it to Beirut for some re-use? | | |
| **Macro-scale** | | | C1. Dams |

The bundle of measures investigated could benchmark the effect of an "alternative policy" in the Nahr El-Kelb 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.

# 2. BACKROUND AND BASIC DEFINITIONS

**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.

## 2.1 THE STUDY AREA: THE NAHR EL-KELB RIVER BASIN

The Nahr El-Kelb River Basin is located on the windward part of Mount Lebanon. The Basin has an area of 287 $km^2$. Elevation ranges from 0 m.s.l. (mean sea level) at the basin outflow in the Mediterranean Sea to 2,626 m.s.l. at Mnt. Sannine. Climate is typical Mediterranean with precipitation falling between October and May. Most precipitation is observed between December and March. Precipitation above 1,200 m.s.l. (mean sea level) falls as snow. Precipitation is enhanced topographically and has a high spatial and inter-annual variability. The average estimated annual precipitation for the time period 2000-2017 ranged from 570 mm in the coastal part to 2,750 in the mountain regions.

The major land cover in the basin is woodland (34% of the basin total area) followed by grassland (27%). Agriculture land use is 10.6%, urban areas occupy around 10%, while the remainder of the basin area is bare rocks and soils.

The basin is managed by the Beirut and Mount Lebanon Water Establishment (BMLWE). Population estimates for 2017 are about 190,000 inhabitants. Water from the Jeita springs, at 60 m.s.l. (mean sea level), supplies approximately 60% of Beirut's fresh water demand, which makes this basin of major source of water for around 2 million people (around 35% of Lebanon's total population).

The main challenges in the basin with regards to water management can be summarized as follow:

- Water availability is dependent on the seasonal precipitation and the high karstification which has an impact on the discharge of most springs. Spring discharge has a high seasonal variability ranging from 0-3.7 $m^3$/sec during the dry season (June - November) to 1.9 - 9.6 $m^3$/sec between February and May.
- Water demand increases during the summer months with increasing demands from urban areas and agricultural lands. Water stress is more frequent during dry years. There is a limitation in the quantification of water demand, water supply, and water consumption which limits the proper assessment of the water imbalance (i.e. the difference between water demand and water availability).
- Water contamination increases with the increase of urban and agricultural activities at mid-elevation to lowland areas and impacts the usability of water in downstream areas. There is a limited competition between water users due to the limited agricultural practices in the basin. The major impacts are related to the water available for transfer to the Beirut area from the Spring of Jeita.

A water balance model was developed for the El-Kelb basin for the years 2000-2017, for 19 sub-catchments and 15 demand sites in the basin, in order to assess water balance in the basin and identify the percentage unmet demand (i.e. the water demand that fails to be satisfied by the existing water availability). The model revealed that the total annual unmet demand ranges between 0.3 -1.5 million $m^3$ in the urban sector (excluding Beirut), and between 0.7-4.2 million $m^3$ in the agricultural sector depending if the year is wet or dry.

Water shortages were observed at the southern part of the basin (Sannine, Hardoun) between June and November with coverage reaching as low as 30% during summer months and even 0% during August sometimes. Unmet demand for agricultural activities at the southern sites ranged between

10%-20% (March -June) and 30%-60% during summer (July - September). Water supply for the Beirut area is the most affected given that water is transferred from the lower spring at Jeita. Water coverage (i.e. water met) for Beirut ranged from 62% during winter season to less than 25% in the summer season. More detailed information about the El-Kelb water balance model and the results can be found in the SWIM-H2020 SM Report “Documentation of the Nahr El-Kelb WEAP21 model”.

## 2.2 OPTIONS FOR 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

- **Water saving measures**

**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.

- **Increase supply measures**

**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.

**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** 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 expected savings and costs of each of the above mentioned technological interventions has been collected from various literature sources as presented in Table 2-1 to Table 2-3 below. On this basis, the % expected saving and costs have been identified.

**Table 2-1: Potential water saving per household water using product (WuP).**

| HH Water Using Product (WuP) | Consumption of "traditional" WuPs | | | Cnsumption of "efficient" WuPs | Water Saving | | |
|---|---|---|---|---|---|---|---|
| | lt/use | Frequency of use per day | Average consumption in lt/hh/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)

**Table 2-2: Costs of different household water appliances and water saving devices and increase supply options**

| Water appliance/ saving device | *Marshallsay et al., 2007 (convereted from £ to €)* | *Cordella et al., 2013* |
|---|---|---|
| WC (toilet flushing) | 82-337 € | |
| Taps | - 51 € (basic mixer tap has no water efficiency features)<br>- 74 € (monobloc mixer tap with pop up waste and aerator)<br>- 94 € (monobloc mixer tap with pop up and an Ecotop cartridge) | - 35-50 € (automatic shut off, push tap)<br>- 160-450 € (example product with integrated aerators and flow regulators)<br>- 210 € (tap with water breaks)<br>- 750 € (water and energy saving tap)<br>- 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<br>- 25 € for ecobuttons |
| Shower, Bath | - electric shower: 174 – 225 €<br>- mixer shower: 225 € (+157€ if a pump is added)<br>- basic bath/shower mixer with hand shower attachment: 31-92 € | - aeration showerhead: 20-120 €<br>- spray pattern/mechanism showerhead: 60-220 € |
| | 18 € for attaching an aerated showerhead to a standard mixer shower<br>31 € for attaching a pressure reducing valves to a standard mixer shower | |
| Washing Machine | 282-321 €, energy rating A<br>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)

**Table 2-3: 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) | |
| Greywater reuse (domestic) | 4,534 € initial cost (Marshallsay ey al., 2007) | additional maintenance costs |
| Detention basins | Construction costs scale with the storage volume of the detention basin.<br><br>Costs given in the UK typically range between €20 and €40 per $m^3$ of storage volume provided:<br>- CIRIA (2007) - €20-€30 / m3 detention volume<br>- Atkins (2010) - €25-€35 / m3 detention volume<br>- UK SuDS Cost Calculator (www.uksuds.com) - €20-€40 / m3 detention volume<br>But others suggest the potential for much higher costs:<br>- Chocat et al (2008) 9 to 90€/m3 detention volume<br>- Certu (2006), 12 to 110 €/m3 detention volume<br><br>More generally, Environment Agency (2012) indicates that the cost of a “small detention basin will typically be less than €5000”.<br>Costs will be higher where additional retaining bunds are required and lower where greater use is made of natural or existing topographic features. | 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.<br><br>Annual maintenance costs range between €0.5-€5 per $m^2$ of basin area.<br>- CIRIA (2007), Wilson et al. (2009) - €0.5-€2.5 per $m^2$ basin area,<br>- UK SuDS Cost Calculator (www.uksuds.com) - €4-€5 per $m^2$ basin area. |
| Retention ponds | Retention pond capital costs are typically between €20- €40 per $m^3$ of volume provided for storage.<br>- CIRIA (2007) - €20-€30 per $m^3$ detention volume<br>- UK SuDS Cost Calculator (www.uksuds.com) - €40 per $m^3$ attenuation volume<br>- Chocat et al (2008) - €9-€60 per $m^3$ of volume provided for storage<br><br>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. | Annual maintenance costs vary between €1-€5 per $m^2$ of retention pond area.<br><br>- CIRIA (2007), Wilson et al (2009) - €1-€2 per $m^2$<br>- UK SuDS cost calculator (www.uksuds.com) - €4-€5 per $m^2$ pond area |

## 2.3 OPTIONS FOR 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). Treated wastewater from the Bourj Hammoud Wastewater Treatment Plan (BH WWTP) could be also diverted and used in agriculture, but since the site is located quite downstream this use presents limitations since water would need to be pumped-up upstream and needs further investigation.

**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.

**Error! Reference source not found.** 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 2-4: 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 | | | | | | |
| Subsurfcace 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.

# 3. DESIGN OF THE MEASURES (METHODOLOGY, COST-EFFECTIVENESS ANALYSIS)

## 3.1 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 Nahr El-Kelb 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 scenarios (based on a mix of the measures)
- Investigation on how to simulate the functions in the WEAP21 water resource management model of the Nahr El-Kelb river basin (coding routines)
- Simulation of the alternative scenarios against a baseline scenario, and assessment of their impact and cost-effectiveness on the physical system

## 3.2 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 3-1 and **Error! Reference source not found.**).

**Table 3-1: 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 )* |
| WC (toilet flushing) | 31 % | 30 % | 25 % | 26 % | 25 % | 33 % | 32 % |
| 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)* |
| Shower | 5 % | 35 % | 14 % | 35 % | 34 % | 32 % | 30 % |
| Bath | 15 % | | 14 % | | | | |
| Washing Machine | 20 % | 15 % | 13 % | 12 % | 14 % | 16 % | 14 % |
| Dishwasher | 1 % | | 2 % | 9 % | 8 % | | 6 % |
| Outdoor use | 4 % | | 2 % | 7 % | 6 % | 2 % | 6 % |
| Miscellaneous use | | | | | | | |
| TOTAL | 100 % | 100 % | 100 % | 100 % | 100 % | 100 % | 100 % |
| Rainwater Harvesting | | Equivalent to: 25% toilet flushing, 25% clothes washing, 22.5% external tap use | | | | | |
| Greywater reuse | | equivalent to 30% of the water consumed by toilets within the property | | | | | |

Source: Kossida, M., 2015

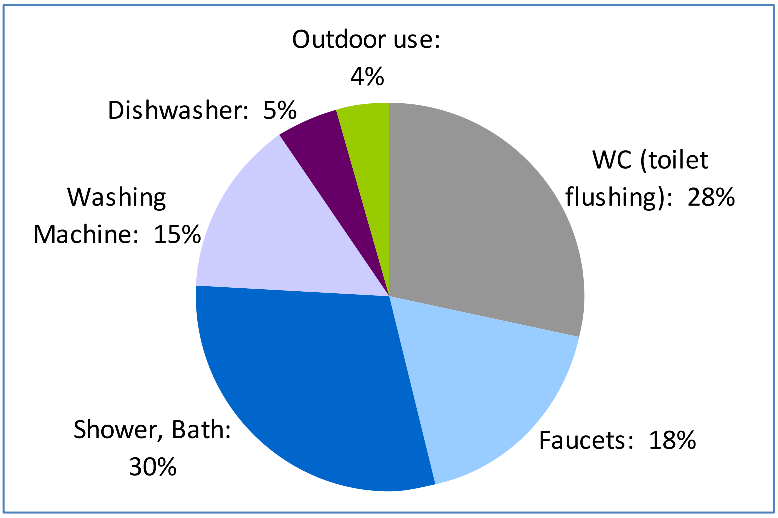



**Figure 3-1: Average Water consumption share of different household micro-components in the industrialized world** (based on Table 1-1; Source: Kossida, M., 2015)

For the design of the urban cost-effectivness curve in the Nahr El-Kelb 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) and 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 (

). 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 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 7,550 € per household or 1,888 € 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 3-2) has been considered in the calculations, while the OMC can be ignored. The resulting AEC for each measure is pesented in Table 3-2.

**Table 3-2: Annual Equivalent Cost (AEC) of the urban demand managagement 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 | 2,500 € | 0.07 | 10 | 356 € |
| Greywater Reuse | 3,500 € | 0.07 | 10 | 498 € |
| **TOTAL**<br>*per household (HH):*<br>*per capita (cap):* | **7,550 €**<br>1,888 € | | | **1,158 €**<br>290 € |

In order to design the optimum urban water cost-effective curve an optimization process was employed. The objective function of the optimization was to maximize the % water saving while minimizing the cost (AEC) using a mix of the tier-1 measures. The cost-effectiveness parameters (i.e. AEC and % expected water saving) that have been used in the optimization are shown below in the last two columns of Table 3-3. The results are presented in

Table **3-4** and **Error! Reference source not found.**.

**Table 3-3: 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<br>Per household (HH)<br>Per capita (cap) | | | | 100 % | 1,550 €<br>388 € | 303 €<br>76 € | 46.5 %<br>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 % | 2,500 € | 356 € | 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<br>Per household (HH)<br>Per capita (cap) | | | | 44 % | 6,000 €<br>1,500 € | 854 €<br>214 € | 16.2 %<br>4.1 % |
| **GRAND TOTAL** | | **Per household (HH)<br>Per capita (cap)** | | | **7,550 €<br>1,888 €** | **1,158 €<br>290 €** | **62.7 %<br>15.7 %** |

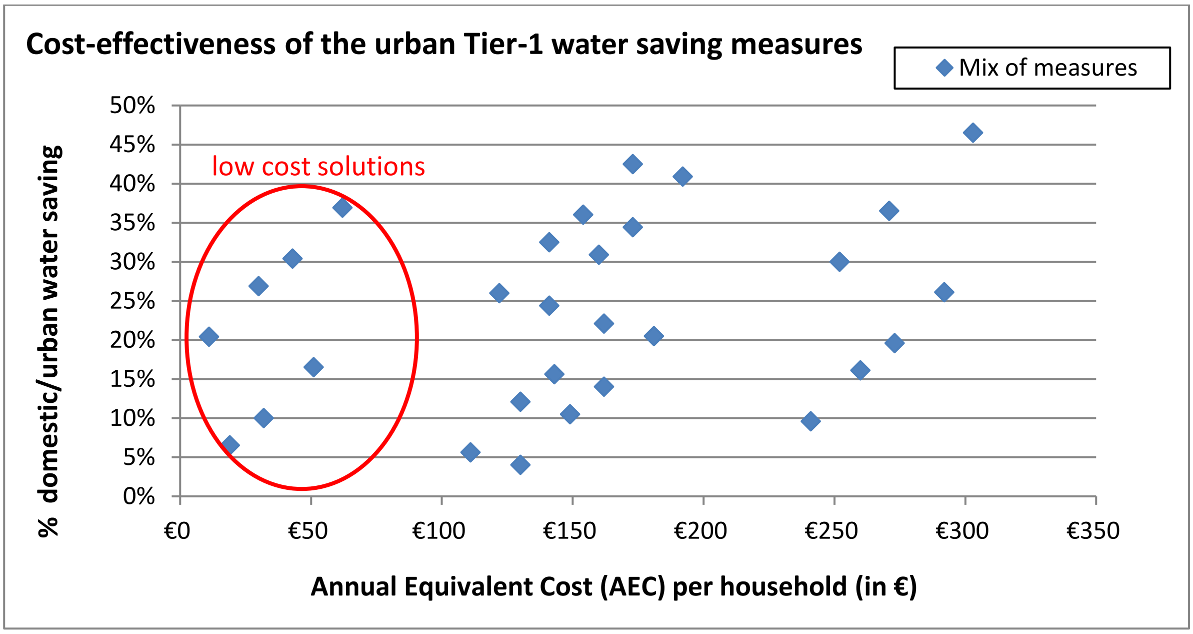



**Figure 3-2: Conceptual Cost-effectiveness plot for the simulated urban water saving measures (% water saving vs. AEC per household)**

As shown in Table 3-2 above, it is relatively easy and entails relatively low cost to achieve conservation up to 37% with a cost of approximately 62 €/household AEC. Assuming an average per capita consumption of 140 lt/day (or 51.10 $m^3$ per capita per year) and an average household size of 2.8 people, this percentage represents a total saving of about 53 $m^3$ per household per year in the Nahr El-Kelb basin, and results in an AEC unit cost of water saved of 1.17 €/m3 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 3-2) until the maximum cost of 14.93 million € per year for the entire basin. 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 **3-4** below where the most beneficial solutions are also marked (light blue cells).

**Table 3-4: Results of the cost-effectiveness analysis of the urban water saving measures**

| Solution No. # | AEC per HH € | Water Saving % per HH | AEC per capita € | Water Saving % per capita | Total water saving * (Mm3) in the basin | Total AEC** (mio €) for the basin | €/m3 of water saved | *Penetration (households adapting the measure)* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | *Dual flush toilet* | *Shower-heads (1 item)* | *Low flow taps (2 items)* | *Efficient Washing Machine* | *Dish-washer* |
| 0 (BaU) | 0 € | 0.00% | 0 € | 0.00% | 0 | 0 | 0 | | | | | |
| 1 | 11 € | 20.40% | 2.8 € | 5.10% | 3.07 | 0.52 | 0.17 | | √ | | | |
| 2 | 19 € | 6.50% | 4.8 € | 1.63% | 0.98 | 0.89 | 0.91 | | | √ | | |
| 3 | 30 € | 26.90% | 7.5 € | 6.73% | 4.04 | 1.41 | 0.35 | | √ | √ | | |
| 4 | 32 € | 10.00% | 8.0 € | 2.50% | 1.50 | 1.50 | 1.00 | √ | | | | |
| 5 | 43 € | 30.40% | 10.8 € | 7.60% | 4.57 | 2.02 | 0.44 | √ | √ | | | |
| 6 | 51 € | 16.50% | 12.8 € | 4.13% | 2.48 | 2.40 | 0.97 | √ | | √ | | |
| 7 | 62 € | 36.90% | 15.5 € | 9.23% | 5.55 | 2.91 | 0.52 | √ | √ | √ | | |
| 8 | 111 € | 5.60% | 27.8 € | 1.40% | 0.84 | 5.21 | 6.19 | | | | √ | |
| 9 | 122 € | 26.00% | 30.5 € | 6.50% | 3.91 | 5.73 | 1.47 | | √ | | √ | |
| 10 | 130 € | 12.10% | 32.5 € | 3.03% | 1.82 | 6.11 | 3.36 | | | √ | √ | |
| 11 | 130 € | 4.00% | 32.5 € | 1.00% | 0.60 | 6.11 | 10.15 | | | | | √ |
| 12 | 141 € | 32.50% | 35.3 € | 8.13% | 4.88 | 6.62 | 1.36 | | √ | √ | √ | |
| 13 | 141 € | 24.40% | 35.3 € | 6.10% | 3.67 | 6.62 | 1.81 | | √ | | | √ |
| 14 | 143 € | 15.60% | 35.8 € | 3.90% | 2.34 | 6.72 | 2.86 | √ | | | √ | |
| 15 | 149 € | 10.50% | 37.3 € | 2.63% | 1.58 | 7.00 | 4.43 | | | √ | | √ |
| 16 | 154 € | 36.00% | 38.5 € | 9.00% | 5.41 | 7.23 | 1.34 | √ | √ | | √ | |
| 17 | 160 € | 30.90% | 40.0 € | 7.73% | 4.64 | 7.51 | 1.62 | | √ | √ | | √ |
| 18 | 162 € | 22.10% | 40.5 € | 5.53% | 3.32 | 7.61 | 2.29 | √ | √ | | √ | |
| 19 | 162 € | 14.00% | 40.5 € | 3.50% | 2.10 | 7.61 | 3.62 | √ | | | | √ |
| 20 | 173 € | 42.50% | 43.3 € | 10.63% | 6.39 | 8.12 | 1.27 | √ | √ | √ | √ | |
| 21 | 173 € | 34.40% | 43.3 € | 8.60% | 5.17 | 8.12 | 1.57 | √ | √ | | | √ |
| 22 | 181 € | 20.50% | 45.3 € | 5.13% | 3.08 | 8.50 | 2.76 | √ | | √ | | √ |
| 23 | 192 € | 40.90% | 48.0 € | 10.23% | 6.15 | 9.02 | 1.47 | √ | √ | √ | | √ |
| 24 | 241 € | 9.60% | 60.3 € | 2.40% | 1.44 | 11.32 | 7.84 | | | | √ | √ |
| 25 | 252 € | 30.00% | 63.0 € | 7.50% | 4.51 | 11.83 | 2.62 | | √ | | √ | √ |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 260 € | 16.10% | 65.0 € | 4.03% | 2.42 | 12.21 | 5.05 | | | √ | √ | √ |
| 27 | 271 € | 36.50% | 67.8 € | 9.13% | 5.49 | 12.73 | 2.32 | | √ | √ | √ | √ |
| 28 | 273 € | 19.60% | 68.3 € | 4.90% | 2.95 | 12.82 | 4.35 | √ | | | √ | √ |
| 29 | 292 € | 26.10% | 73.0 € | 6.53% | 3.92 | 13.71 | 3.50 | √ | | √ | √ | √ |
| 30 | 303 € | 46.50% | 75.8 € | 11.63% | 6.99 | 14.23 | 2.04 | √ | √ | √ | √ | √ |

* The total water saving is based on the annual urban water demand in the Nahr El-Kelb basin (excluding the water transferred to Beirut) for the reference year 2000, which sums up at 15.03 Mm3.

* 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 46,962 household in the Nahr El-Kelb basin (Beirut is not included), 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 about 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) 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 1.4 million € with a total water saving of 4 Mm3, thus a unit cost of 0.35 €/m$^3$ of water saved. Respectively, with a unit cost of 0.44 €/m$^3$ of water saved (or AEC 43 €/hh) 30.4% of the urban water can be saved (i.e. 4.57 Mm3 in total) (solution No. #5). The latter requires the penetration of low-flow showerheads (1 item) and dual flush toilets. With a slightly higher unit cost of 0.52 €/m$^3$ of water saved (or AEC 62 €/hh) 37% of water can be saved (i.e. 5.55 Mm3 in total and with a respective total cost of AEC 2.9 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 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 cost is 1.27 €/m$^3$ of water saved), resulting thus in a total saving of 8.12 million m$^3$ in the urban sector. 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 3-3 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.

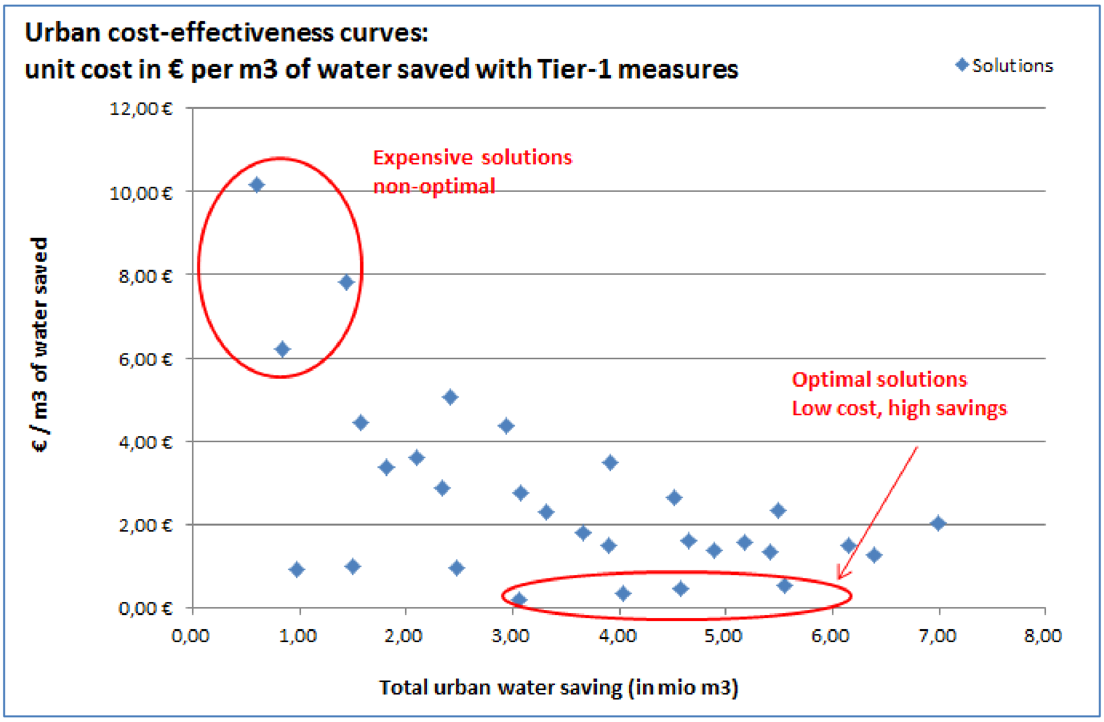



**Figure 3-3: Cost-effectiveness curves for the simulated Tier-1 urban measures in €/m3 of water saved**

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 **3-4**) have been further examined with the additional application of RWH and GWR. The results are presented in Table 3-5 below, where the most beneficial solutions are also marked (light blue cells). It can be generally observed (Table 3-5, Figure 3-4, Figure 3-5) 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), i.e. they offer higher savings with lower costs. The mixed solutions which contain 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 1,027 € per household).

**Table 3-5: Results of the cost-effectiveness analysis of the urban increase supply measures**

| Solution No. # | AEC per HH € | Water Saving % per HH | AEC per capita € | Water Saving % per capita | Total water saving * (Mm3) in the basin | Total AEC** (mio €) for the basin | €/m³ of water saved | Penetration (households adapting the measure) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Dual flush toilet | Shower-heads (1 item) | Low flow taps (2 items) | Efficient Washing Machine | Dish-washer | Rainwater Harvesting | Greywater Reuse |
| 1r | 367 € | 32.00% | 91.8 € | 8.00% | 4.81 | 17.24 | 3.58 | | √ | | | | √ | |
| 1w | 509 € | 25.00% | 127.3 € | 6.25% | 3.76 | 23.90 | 6.36 | | √ | | | | | √ |
| 1m | 865 € | 36.60% | 216.3 € | 9.15% | 5.50 | 40.62 | 7.38 | | √ | | | | √ | √ |
| 3r | 386 € | 38.50% | 96.5 € | 9.63% | 5.79 | 18.13 | 3.13 | | √ | √ | | | √ | |
| 3w | 528 € | 31.50% | 132.0 € | 7.88% | 4.73 | 24.80 | 5.24 | | √ | √ | | | | √ |
| 3m | 884 € | 43.10% | 221.0 € | 10.78% | 6.48 | 41.51 | 6.41 | | √ | √ | | | √ | √ |
| 5r | 399 € | 42.00% | 99.8 € | 10.50% | 6.31 | 18.74 | 2.97 | √ | √ | | | | √ | |
| 5w | 541 € | 35.00% | 135.3 € | 8.75% | 5.26 | 25.41 | 4.83 | √ | √ | | | | | √ |
| 5m | 897 € | 46.60% | 224.3 € | 11.65% | 7.00 | 42.12 | 6.01 | √ | √ | | | | √ | √ |
| 7r | 418 € | 48.50% | 104.5 € | 12.13% | 7.29 | 19.63 | 2.69 | √ | √ | √ | | | √ | |
| 7w | 560 € | 41.50% | 140.0 € | 10.38% | 6.24 | 26.30 | 4.22 | √ | √ | √ | | | | √ |
| 7m | 916 € | 53.10% | 229.0 € | 13.28% | 7.98 | 43.02 | 5.39 | √ | √ | √ | | | √ | √ |
| 20r | 529 € | 54.10% | 132.3 € | 13.53% | 8.13 | 24.84 | 3.06 | √ | √ | √ | √ | | √ | |
| 20w | 671 € | 47.10% | 167.8 € | 11.78% | 7.08 | 31.51 | 4.45 | √ | √ | √ | √ | | | √ |
| 20m | 1,027 € | 58.70% | 256.8 € | 14.68% | 8.82 | 48.23 | 5.47 | √ | √ | √ | √ | | √ | √ |
| 31 | 356 € | 11.60% | 89.0 € | 2.90% | 1.74 | 16.72 | 9.59 | | | | | | √ | |
| 32 | 498 € | 4.60% | 124.5 € | 1.15% | 0.69 | 23.39 | 33.83 | | | | | | | √ |
| 33 | 854 € | 16.20% | 213.5 € | 4.05% | 2.43 | 40.11 | 16.47 | | | | | | √ | √ |

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

* The total water saving is based (on the average annual urban water demand in the Nahr El-Kelb basin (excluding the water transferred to Beirut) which sum up at 15.03 Mm3 on average.

* The total AEC is obtained by multiplying the AEC per household (HH) with the total number of households. The later estimated to account for 46,962 household in the Nahr El-Kelb basin (Beirut is not included), assuming each household is occupied by 4 people on average (number of hh = total population / 4)

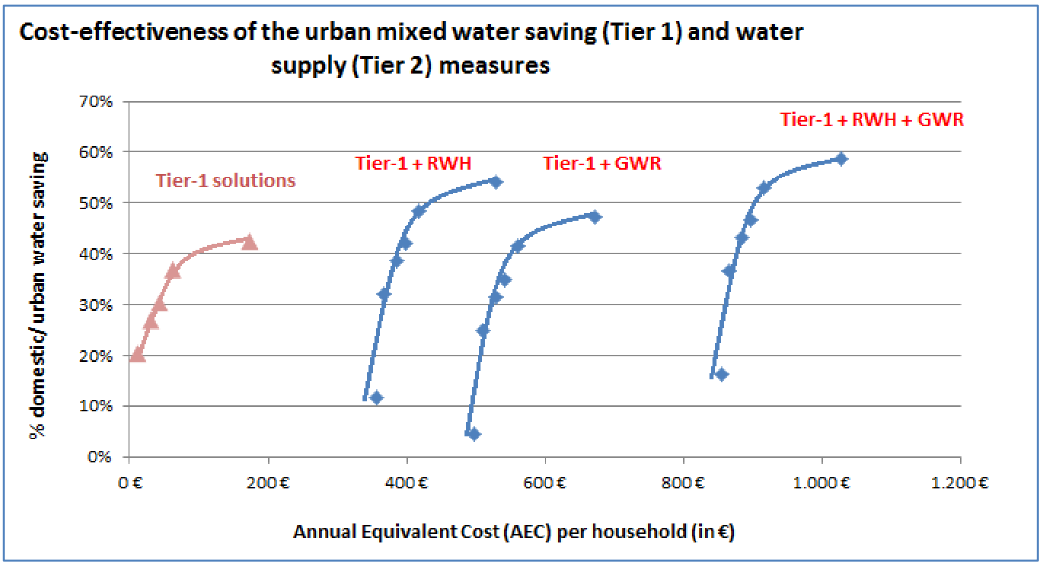



**Figure 3-4: Cost-effectiveness plot for the simulated urban increase supply measures (% water saving vs. AEC per household)**

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 2.69 and 3.06 €/m$^3$ of water saved (or AEC 418€ and 529€ per household ). These measures can render in the area total water savings of 7.29 and 8.13 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 26.3 million € with a total water saving of 6.24 Mm3, thus a unit cost of 4.22 €/m3 of water saved. This solution is the cheapest among all solutions which contain greywater reuse. A slightly higher total water saving of 7.08 Mm3 (representing 47.1% savings) with a slightly higher unit cost of 4.45 €/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. 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 8.82 million m$^3$ in the area (representing 58.7% savings) with a unit cost of 5.47 €/m$^3$ of water saved (or AEC 1,027€/hh). The penetration of the 20m solution in all the households in the area would require a total AEC of 48.2 million €. It has to be notice that all the Tier-2 solutions have bear higher 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.

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 prior 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 is not addressed in the current report since it requires an explicit study to correctly identify the magnitude of the problem and correctly identify the associated repairing costs.

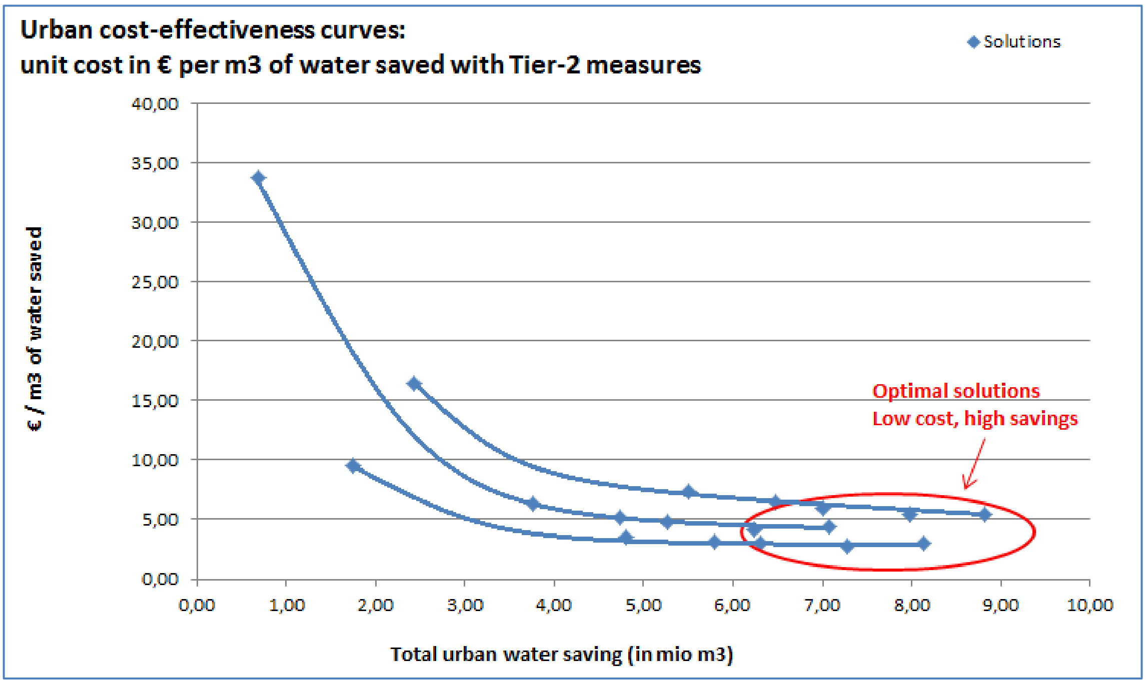



**Figure 3-5: Cost-effectiveness curves for the simulated Tier-2 urban measures in €/m3 of water saved**

## 3.3 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 Nahr El-Kelb 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. The following measures have been considered: converting from furrow irrigation to drip irrigation, converting from sprinklers to drip irrigation, applying precision agriculture (which also requires the installation of drip irrigation systems if they do not already exist). Improvements in the conveyance efficiency, e.g. converting from open channels to closed pipes, or from individual to collective networks have not been examined in the current report since this requires an explicit study to correctly identify the efficiency of the water supply network and correctly identify losses, leaks and associated repairing costs. Yet, it is acknowledged that converting from open channels to closed pipes brings conveyance efficiency gains.

Figure 3-6 provides a schematic representation of the overall optimization, including all possible transactions that can improve both the conveyance and the filed application efficiencies. The transactions from one method to one other (colored lines in the graph) are subject of constraints and cannot exceed their initial value. Every transaction from one method to another has a different effectiveness and a different cost. The transactions examined for the Nahr El-Kelb are those which could improve the field application efficiency, i.e. transactions Z3 and Z2 to Z1, and transactions associated with the irrigation network (replacement from open channels to closed pipes.), i.e. transactions Z4, Z5 and Z2 to Z1, Z2 and Z3 respectively.

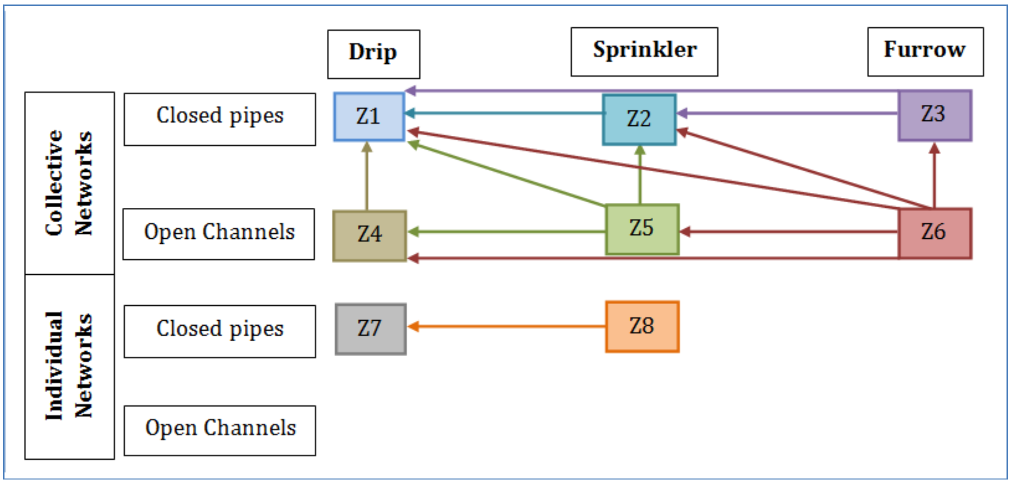



**Figure 3-6: Schematic representation of the optimization process**

In order to run the optimisation process the start-up efficiency values have been defined. Typical aggregated values for irrigation efficiency are presented in Table 3-6, while the costs for converting to drip irrigation and converting from open canals to closed pipes are presented in Table 3-7and Table 3-8, 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 3-6: Literature values for aggregated irrigation efficiency (conveyance and field application)**

| 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 3-7: 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** |

Source: Kossida, M., 2015

**Table 3-8: 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** |

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

In the Nahr El-Kelb basin, irrigation water is distributed via two irrigation canals (Schuler and Margane, 2013). Only a negligible share of irrigation water is contributed by Chabrouh dam (approximately 0.5 MCM per year) (Schuler and Margane, 2013). As irrigation technique, farmers apply surface irrigation and drip irrigation (AVSI, 2009), which has been empirical validated by field research. According to unpublished data, irrigation efficiency is expected to be 75% (Schuler and Margane, 2013). The irrigation efficiencies used in the optimisation process for the Nahr El-Kelb, for the combination of various conveyance and irrigation methods, have been formulated as presented in the Table 3-9 below. For the mountain areas, it has been assumed that 60% of the total irrigated area has collective networks, and the remaining 40% has small individual networks. The collective ones are equiped with open canals and closed pipes (30% in each category). The dominant irrigation method is drip irrigation (in 40% of the areas), closely followed by sprinklers and furrow (surface irrigation) (in 30% of the areac each). The current aggregated field application efficiency (considering the above-mentioned assumptions) in the mountain areas is calculated at 77%. The coveyance losses are estimated to 10% for the closed-pipe collective networks, 25% for the small individual networks (groundwater wells), and 35% for the open-channel collective networks. Thus, based on the current mix for the mountainous areas, the aggreagated conveyance efficiency is 77% (i.e. 23% losses). Similarly, for the coastal aera, it has been assumed that 40% of the total irrigated area has collective networks, and the remaining 60% has small individual networks. The collective ones are mostly equiped with open canals (30% of the area). The dominant irrigation methods are sprinklers and furrow (in 30% of the area each), while drip irrigation prevalis in 20% of the area. The current aggregated field application efficiency (considering the above-mentioned assumptions) in the coastal areas is calculated at 20% and the conveyance efficiency at 73.5% (i.e. 26.5% losses)

**Table 3-9: Irrigation efficiency assumptions in the Nahr El-Kelb river basins**

| *Irrigation Efficiency in the Mountain areas* | % coverage | % losses | % conveyence efficiency |
|---|---|---|---|
| Collective Networks - Closed Pipes | 30% | 10% | 90% |
| Collective Networks - Open Channels | 30% | 35% | 65% |
| Small individual networks - Groundwater wells | 40% | 25% | 75% |
| **Aggregated network conveyance efficiency** | (30% x 0.9) + (30% x 0.65) + (40% x 0.75) = **76.5% or 23.5% losses** | | |
| Drip irrigation | 40% | 10% | 90% |
| Sprinklers' irrigation | 30% | 25% | 75% |
| Furrow irrigation | 30% | 40% | 60% |
| **Aggregated field application efficiency** | (40% x 0.9) + (30% x 0.75) + (30% x 0.6) = **76.5%** | | |
| *Irrigation Efficiency in the Coastal areas* | **% coverage** | **% losses** | **% conveyence efficiency** |
| Collective Networks - Closed Pipes | 10% | 10% | 90% |
| Collective Networks - Open Channels | 30% | 35% | 65% |
| Small individual networks - Groundwater wells | 60% | 25% | 75% |
| **Aggregated network conveyance efficiency** | (10% x 0.9) + (30% x 0.65) + (60% x 0.75) = **73.5% or 26.5% losses** | | |
| Drip irrigation | 20% | 10% | 90% |
| Sprinklers' irrigation | 40% | 25% | 75% |
| Furrow irrigation | 40% | 40% | 60% |
| **Aggregated field application efficiency** | (20% x 0.9) + (40% x 0.75) + (40% x 0.6) = **74%** | | |

**Table 3-10: Irrigated areas in the Nahr El-Kelb river basin**

| Site | Irrigated area (ha) | Crop mix | Annual water use rate | Water use (m3/year) |
|---|---|---|---|---|
| Agri_Mountain_North | 1,330 | 85% fruit trees<br>15% vegetables | Fruit trees: 5,200 m3/ha/year<br>Vegetables: 6,100 m3/ha/year | 5,878,600<br>1,216,950 |
| Agri_Mountain_South | 539 | 75% fruit trees<br>25% vegetables | Fruit trees: 5,200 m3/ha/year<br>Vegetables: 6,100 m3/ha/year | 2,102,100<br>821,975 |
| Agri_Coastal_North | 1,490 | 60% fruit trees<br>40% vegetables | Fruit trees: 5,900 m3/ha/year<br>Vegetables: 6,500 m3/ha/year | 5,274,600<br>3,874,000 |

| | | | | |
|---|---|---|---|---|
| Agri_Coastal_South | 440 | 50% fruit trees<br>50% vegetables | Fruit trees: 5,900 m3/ha/year<br>Vegetables: 6,500 m3/ha/year | 1,298,000<br>1,430,000 |
| **Total** | 3,799 | 2,648.75 ha fruit trees<br>1,150.25 ha vegetables | Average annual water use rate:<br>Fruit trees: 5,550 m3/ha/year<br>Vegetables: 6,300 m3/ha/year | 21,896,225<br>or<br>**21.90 MCM/year** |

**Table 3-11: Costs and benefits of the different possible transactions simulated in the optimization process**

| Option | Measure | Relevant transactions (from Frigure 3.6) | Increase in Irrigation efficiency | Cost (€/ha) |
|---|---|---|---|---|
| Increase field application efficiency<br>(individual networks, closed pipes) | Converting from sprinkler to drip irrigation (without changing network system) | Z8 → Z7 | 75% → 90% | 1,200 €/ha |
| Increase field application efficiency<br>(collective networks, closed pipes) | Converting from sprinkler to drip irrigation (without changing network system) | Z2 → Z1 | 75% → 90% | 1,200 €/ha |
| Increase field application efficiency (collective networks, open channels) | Converting from furrow or sprinkler to drip irrigation (without changing network system) | Z6 → Z4<br>Z5 → Z4 | 60% → 90%<br>75% → 90% | 1,200 €/ha<br>1,200 €/ha |

# 4. SIMULATION OF THE MEASURES IN THE WEAP21 MODEL OF THE NAHR EL-KELB RIVER BASIN

It is often a problem that water use cannot be directly measured for all sectors, and thus different water use estimates require integrating data of mixed quality that are collected by other agencies for other purposes and that are derived from data collection protocols generally neither controlled nor

Based on the mix of measures that have been selected through the optimization process, 7 alternative scenarios have been formulated and simulated in WEAP. Their results have been compared against the current Business as Usual scenario (BaU scenario). The focus of the alternative scenarios is presented in Table 4.1 below. Three scenarios (UrbSav, AgrSav, MixSav) focus solely on introducing water savings in the urban and agricultural sectors, another two scenarios (UrbSup2, AgrSup2) focus solely on increasing supply at the meso-scale level in the urban and agricultural sectors, while one scenario (UrbSup) focuses both on water saving and increasing supply for the domestic/urban sector at the micro-scale level. Finally, scenario MoEW investigates increasing water supply at the macro-level and cross-cuts across all sectors.

**Table 4-1: Alternative scenarios for the Nahr El-Kelb river basin**

| Scenario Name | Scenario Focus | Measures included in the scenarios |
|---|---|---|
| **BaU** | Business as Usual, no measures applied, population change included (2.6% increase) | - |
| **UrbSav** | Water saving in the domestic/urban sector | U1. Low water using fixtures and appliances |
| **AgrSav** | Water saving in the agricultural sector | A1. Increase network conveyance efficiency (converting to closed pipes)<br>A2. Increase field application efficiency (changing irrigation method) |
| **MixSav** | Water saving across all sectors (urban + agriculture) | U1. Low water using fixtures and appliances<br>A1. Increase network conveyance efficiency (converting to closed pipes)<br>A2. Increase field application efficiency (changing irrigation method) |
| **UrbSup** | Water saving and increasing supply for the domestic/urban sector (micro-scale) | U1. Low water using fixtures and appliances<br>U2. Domestic Greywater Reuse (GWR) on-site (houses, hotels) in villages<br>U3. Rainwater Harvesting (RWH) on-site (houses, hotels, villages) |
| **UrbSup2** | Increasing supply for the domestic/urban sector (meso-scale) | U5. Detention basins/ Retention ponds in urban areas |
| **AgrSup2** | Increasing supply for the agricultural sector (meso-scale) | A3. Detention basins/ Retention ponds in agricultural areas |
| **MoEW** | Focus on increasing supply across all sectors (macro-scale) | C1. Implementation of the Boqataa Dam |

The detail analysis of the scenarios and the methodology that has been used for their simulation in the WEAP Nahr El-Kelb model is presented the sections below.

## 4.1 SCENARIO URBSAV

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

<table>
<tr><td>Measures included</td><td>U1. Low water using fixtures and appliances (including hotels)</td></tr>
<tr><td>Implementation</td><td>The measures have been applied in all the 9 urban demand nodes. The measures have not been implemented in Beirut, since the target is to save water from the El-Kelb basin consumption so that more water is available for Beirut.
<table>
<tr><th>Domestic water demand nodes in WEAP</th><th>Site</th><th>Activity level (Persons)</th><th>Number of Households (assuming 4 persons per hh)</th><th>Water Demand (m3/person/year)</th><th>Seasonal variations</th></tr>
<tr><td>DS1_Hrajel</td><td>Hrajel</td><td>15,200</td><td>5,429</td><td>80</td><td>yes</td></tr>
<tr><td>DS2_Kfardebian</td><td>Kfardebian</td><td>11,150</td><td>3,982</td><td>80</td><td>yes</td></tr>
<tr><td>DS3_Ayoun_esSimane</td><td>Ayoun esSimane</td><td>3,475</td><td>869</td><td>80</td><td>yes</td></tr>
<tr><td>DS4_Baskinta</td><td>Baskinta</td><td>14,950</td><td>5,339</td><td>80</td><td>yes</td></tr>
<tr><td>DS5_Sannine</td><td>Sannine</td><td>1,250</td><td>313</td><td>80</td><td>Yes</td></tr>
<tr><td>DS6_Hardoun</td><td>Hardoun</td><td>27,225</td><td>9,723</td><td>80</td><td>yes</td></tr>
<tr><td>DS7_Ballouneh</td><td>Ballouneh</td><td>48,924</td><td>17,473</td><td>80</td><td>yes</td></tr>
<tr><td>DS8_Beit Chabeb</td><td>Beit Chabeb</td><td>49,125</td><td>17,545</td><td>80</td><td>yes</td></tr>
<tr><td>DS9_Coastal</td><td>Coastal</td><td>16,550</td><td>5,911</td><td>80</td><td>yes</td></tr>
<tr><td>TOTAL</td><td>9 sites</td><td>187,849</td><td>46,962</td><td>80</td><td></td></tr>
</table>
</td></tr>
<tr><td>Simulation parameters</td><td>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.</td></tr>
</table>

| Solution No. # | Annual Equivalent Cost (AEC) per capita € | Water Saving per capita % | Potential water saving per year* (Mm3) | Total AEC** (mio €) | €/m3 of water saved | *Penetration (households adapting the measure* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *Dual flush toilet* | *Shower-heads (1 item)* | *Low flow taps (2 items)* | *Efficient Washing Machine* | *Dish-washer* |
| 1 | 2.8 € | 5.10% | 3.07 | 0.52 | 0.17 | | √ | | | |
| 3 | 7.5 € | 6.73% | 4.04 | 1.41 | 0.35 | | √ | √ | | |
| 5 | 10.8 € | 7.60% | 4.57 | 2.02 | 0.44 | √ | √ | | | |
| 7 | 15.5 € | 9.23% | 5.55 | 2.91 | 0.52 | √ | √ | √ | | |
| 20 | 43.3 € | 10.63% | 6.39 | 8.12 | 1.27 | √ | √ | √ | √ | |

* The total potential water saving is based on the annual urban water demand in the Nahr El-Kelb basin (excluding the water transferred to Beirut) for the reference year 2000, which sums up at 15.03 Mm3

** The total AEC is obtained by multiplying the AEC per capita with the number of people for the reference year 2000: (187,849) x AEC per capita.

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

- Solution No. #1: multiply water demand by (1-0.051) in all 9 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 9 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 9 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 9 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 9 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 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.

## 4.2 SCENARIO AGRSAV

The Scenario AgrSav focuses on water saving in the agricultural sector

| | |
|---|---|
| Measures included | A1. Increase network conveyance efficiency (converting to closed pipes)<br>A2. Increase field application efficiency (changing irrigation method) |
| Implementation | The measures have been applied in all the 4 agricultural demand nodes (mountain South, mountain North, coastal South, coastal North), i.e. in a total of area of 3,799 irrigated hectares (of which: 2,648.75 ha fruit trees and 1,150.25 ha vegetables) |

| Irrigation areas | Conveyance network (current) | Conveyance network (to be achieved) in 2020-2040 | % change | Total AEC (mio €) |
|---|---|---|---|---|
| **Mountain** | Collective – closed pipes: 30% | Collective – closed pipes: 70% | +40%<br>*1,869*0.4 = 747.6 ha* | (747.6 ha) * 390€/ha = **0.29 mio €** |
| | Collective – open canals: 30% | Collective – open canals: 10% | -20%<br>*1,869*0.2 = 373.8 ha* | |
| | Individual – Groundwater wells: 40% | Individual – Groundwater wells: 20% | -20%<br>1,869*0.2 = 373.8 ha | |
| | Aggregated Losses: 23.5% | Aggregated Losses: 15.5% | -8% | |
| **Coastal** | Collective – closed pipes: 10% | Collective – closed pipes: 70% | +60%<br>*1,930*0.6 = 1,158 ha* | (1,158 ha) * 390€/ha = **0.45 mio €** |
| | Collective – open canals: 30% | Collective – open canals: 10% | -20%<br>*1,930*0.2 = 386 ha* | |
| | Individual – Groundwater wells: 60% | Individual – Groundwater wells: 20% | -40%<br>*1,930*0.4 = 772 ha* | |
| | Aggregated Losses: 26.5% | Aggregated Losses: 15.5% | -11% | |
| | | | **Total Cost**<br>**Losses Reduction** | **0.74 mio €**<br>**8 - 11%** |

| Irrigation areas | Irrigation methods (current) | Irrigation methods (to be achieved) in 2020-2040 | % change | Total AEC (mio €) |
|---|---|---|---|---|
| **Mountain** | Drip: 40% | Drip: 70% | +30%<br>*+1,869*0.3 = 560.7 ha* | (560.7 ha) * 347€/ha = **0.19 mio €** |
| | Sprinklers: 30% | Sprinklers: 20% | -10%<br>*1,869*0.1 = 186.9 ha* | |
| | Furrow: 30% | Furrow: 10% | -20%<br>1,869*0.2 = 373.8 ha | |

| | | | | |
|---|---|---|---|---|
| | Aggregated field application efficiency: 76.5% | Aggregated field application efficiency: 84% | +7.5% | |
| **Coastal** | Drip: 20% | Drip: 70% | +50%<br>*+1,930*0.5 = 965 ha* | (965 ha) * 347€/ha =<br>**0.33 mio €** |
| | Sprinklers: 40% | Sprinklers: 20% | -20%<br>*-1,930*0.2 = 386 ha* | |
| | Furrow: 40% | Furrow: 10% | -30%<br>*-1,930*0.3 = 579 ha* | |
| | Aggregated field application efficiency: 74% | Aggregated field application efficiency: 84% | +10% | |
| | | | **Total Cost**<br>**Efficiency Increase** | **0.52 mio €**<br>**7.5 - 10%** |

| | |
|---|---|
| Simulation parameters | Based on the analysis of the agricultural water saving measures (ref. to Chapter 3.3), the following 2 solutions have been simulated in WEAP:<br>- Increase the irrigation network conveyance efficiency by converting to closed pipes: target to have 70% closed pipes in both the mountain and coastal areas' networks. This conversion will reduce leakage by 8-11% depending on the area, and increase the aggregated conveyance efficiency to 84%.<br>- Increase the irrigation field application efficiency by switching to the drip irrigation method: target to have 70% of drip irrigation methods in in both the mountain and coastal areas' networks. This conversion will increase the field application efficiency by 7.5-10% to 84%.<br>Associated costs:<br>▪ *Mountain areas:*<br>Convert 747.6 ha (i.e. 40% of the total) to closed pipes; AEC cost = 747.6 ha * 390€/ha = 0.29 mio €<br>Switch 560.7 ha (i.e. 30% of the total) to drip irrigation; AEC cost = 560.7 * 347 €/ha = 0.19 mio €<br>Total AEC cost for mountain areas = 0.48 mio €<br>▪ *Coastal areas:*<br>Convert 1,158 ha (i.e. 60% of the total) to closed pipes; AEC cost = 1,158 ha * 390€/ha = 0.45 mio €<br>Switch 965 ha (i.e. 50% of the total) to drip irrigation. AEC cost = 965 * 347 €/ha = 0.33 mio €<br>Total AEC cost for mountain areas = 0.78 mio € |

## 4.3 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

<table>
<tr><td>Measures included</td><td>U1. Low water using fixtures and appliances,<br>A1. Increase network conveyance efficiency (converting to closed pipes)<br>A2. Increase field application efficiency (changing irrigation method)</td></tr>
<tr><td>Implementation</td><td>Combination (merging) of the scenarios UrbSav Solution No.20 and AgrSav</td></tr>
<tr><td>Simulation parameters</td><td>Same as in the scenarios UrbSav Solution No.20 and the AgrSav scenario

<table>
<tr><th rowspan="2">Solution No. #</th><th rowspan="2">Annual Equivalent Cost (AEC) per capita €</th><th rowspan="2">Water Saving per capita %</th><th rowspan="2">Potential water saving per year* (Mm3)</th><th rowspan="2">Total AEC** (mio €)</th><th rowspan="2">€/m3 of water saved</th><th colspan="5">Penetration (households adapting the measure</th></tr>
<tr><th>Dual flush toilet</th><th>Shower-heads (1 item)</th><th>Low flo t ps (2 items)</th><th>Efficient Washing Machine</th><th>Dish-washer</th></tr>
<tr><td>20</td><td>43.3 €</td><td>10.63%</td><td>6.39</td><td>8.12</td><td>1.27</td><td>√</td><td>√</td><td>√</td><td>√</td><td></td></tr>
</table>

Mountain: Reduce network losses to 16% (i.e. 8% reduction) by converting 1,158 ha (i.e. 60% of the total) to closed pipes; AEC cost = 1,158 ha * 390€/ha = 0.45 mio €<br>
Mountain: Increase field application efficiency to 84% (i.e. 7.5% increase) by switching 965 ha (i.e. 50% of the total) to drip irrigation. AEC cost = 965 * 347 €/ha = 0.33 mio €<br>
Coastal: Reduce network losses by 11% by converting 747.6 ha (i.e. 40% of the total) to closed pipes; AEC cost = 747.6 ha * 390€/ha = 0.29 mio €<br>
Coastal: Increase field application efficiency to 84% (i.e. 10% increase) by switching 560.7 ha (i.e. 30% of the total) to drip irrigation; AEC cost = 560.7 * 347 €/ha = 0.19 mio €

<table>
<tr><th>Measure</th><th>Total AEC (mio €)</th></tr>
<tr><td>UrbSav Solution No. 20</td><td>8.12</td></tr>
<tr><td>Convert to 70% closed pipes</td><td>0.74</td></tr>
<tr><td>Switch to 70% drip irrigation</td><td>0.52</td></tr>
<tr><td>Total AEC</td><td>9.38</td></tr>
</table>
</td></tr>
</table>

## 4.4 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<br>U2. Domestic Greywater Reuse (GWR) on-site (houses, hotels) in villages<br>U3. Rainwater Harvesting (RWH) on-site (houses, hotels, villages) |
| Implementation | The measures have been applied in all the 9 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. The measures have not been implemented in Beirut, since the target is to save water from the El-Kelb basin consumption so that more water is available for Beirut. |
| 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. # | Annual Equivalent Cost (AEC) per capita € | Water Saving per capita % | Potential water saving per year* (Mm3) | Total AEC** (mio €) | €/m$^3$ of water saved | *Penetration (households adapting the measure)* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *D al flush toilet* | *Showerheads ( item)* | *Low flow tap (2 items)* | *Efficient Washing Machine* | *Dishwasher* | *Rainwater Harve ting* | *Greywater Reuse* |
| 7r | 104.5 € | 12.13% | 7.29 | 19.63 | 2.69 | √ | √ | √ | | | √ | |
| 7w | 140.0 € | 10.38% | 6.24 | 26.30 | 4.22 | √ | √ | √ | | | | √ |
| 20r | 132.3 € | 1.53% | 8.13 | 24. 4 | .06 | √ | √ | √ | √ | | √ | |
| 20w | 167.8 € | 11.78% | 7.08 | 31.51 | 4.45 | √ | √ | √ | √ | | | √ |
| 20m | 256.8 € | 14.68% | 8.82 | 48.23 | 5.47 | √ | √ | √ | √ | | √ | √ |

| | |
|---|---|
| | * The total potential water saving is based on the annual urban water demand in the Nahr El-Kelb basin (excluding the water transferred to Beirut) for the reference year 2000, which sums up at 15.03 Mm3<br>** The total AEC is obtained by multiplying the AEC per capita with the number of people for the reference year 2000: (187,849) x AEC per capita.<br><br>These solutions have been simulated In WEAP in all the 9 demand sites, based on the following formulas:<br>▪ Solution No. #7r: multiply water demand by (1-0.1213) in all 9 sites, or apply DSM saving per capita 12.13% in the tab Demand Sites and Catchments/Demand Management/DSM Savings<br>▪ Solution No. #7w: multiply water demand by (1-0.1038) in all 9 sites, or apply DSM saving per capita 10.38% in the tab Demand Sites and Catchments/Demand Management/DSM Savings<br>▪ Solution No. #20r: multiply water demand by (1-0.1353) in all 9 sites, or apply DSM saving per capita 13.53% in the tab Demand Sites and Catchments/Demand Management/DSM Savings<br>▪ Solution No. #20w: multiply water demand by (1-0.1178) in all 9 sites, or apply DSM saving per capita 11.78% in the tab Demand Sites and Catchments/Demand Management/DSM Savings<br>▪ Solution No. #20m: multiply water demand by (1-0.1468) in all 9 sites, or apply DSM saving per capita 14.68% in the tab Demand Sites and Catchments/Demand Management/DSM Savings<br><br>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. |

## 4.5 SCENARIO URBSUP2

The Scenario UrbSup2 focuses on increasing supply for the domestic/urban sector (meso-scale)

| | |
|---|---|
| Measures included | U5. Detention basins/ Retention ponds in urban 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.<br>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 $m^2$ of basin/ pond area. The useful life has been considered 30 years, and thus the resulting AEC is €5.83/m3/year. |

## 4.6 SCENARIO AGRSUP2

The Scenario AgrSup2 focuses on increasing supply for the agricultural sector (meso-scale)

| | |
|---|---|
| Measures included | A3. Detention basins/ Retention ponds 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 km2 would be likely. |
| Simulation parameters | Detention basins of 100-150 m3 capacity have been simulated in WEAP, in sites where the topography is beneficial.<br>The capital costs for the construction of detention basins and/or retention ponds have been fixed at €30 per m3 of volume provided for storage. The annual maintenance costs have been fixed between €3 per m2 of basin/ pond area. The useful life has been considered 30 years, and thus the resulting AEC is €5.83/m3/year. |

## 4.7 SCENARIO MOEW

The Scenario AgrSup2 focuses on increasing water supply across all sectors (macro-scale)

| | |
|---|---|
| Measures | C1. Implementation of the Boqaata Dam |

| | |
|---|---|
| included | |
| Implementation | Operation of the new planned Boqaata Dam in the Nahr El-Kelb basin |
| Simulation parameters | The Boqaata Dam is set to be operational in the model in 2025.<br>Storage capacity: 6 Mm3<br>Expected supply: 5-10 Mm3 per year |

# 5. RESULTS

## 5.1 RESULTS: BAU SCENARIO

The urban water demand in the Nahr-El Kelb for the entire simulation period 2000-2040 is presented in the Figure 5-1 below per urban demand node and year. It demonstrates a 2.6% increase every year, proportional to the projected population increase, thus currently reaching 24 Mm3 in 2018 and projected to reach 42.52 Mm3/year in 2040 based on the BaU scenario. The agricultural water demand in the Nahr-El Kelb for the entire simulation period 2000-2040 is presented in Figure 5-2 below per agricultural demand node and year. It is constant at 21.9 Mm3/year as no changes in the irrigated areas or crop mix have been assumed for the future. The annual total demand (urban and agriculture) reaches 46.53 Mm3 in 2019, and is expected to reach 64.4 Mm3 in 2040.

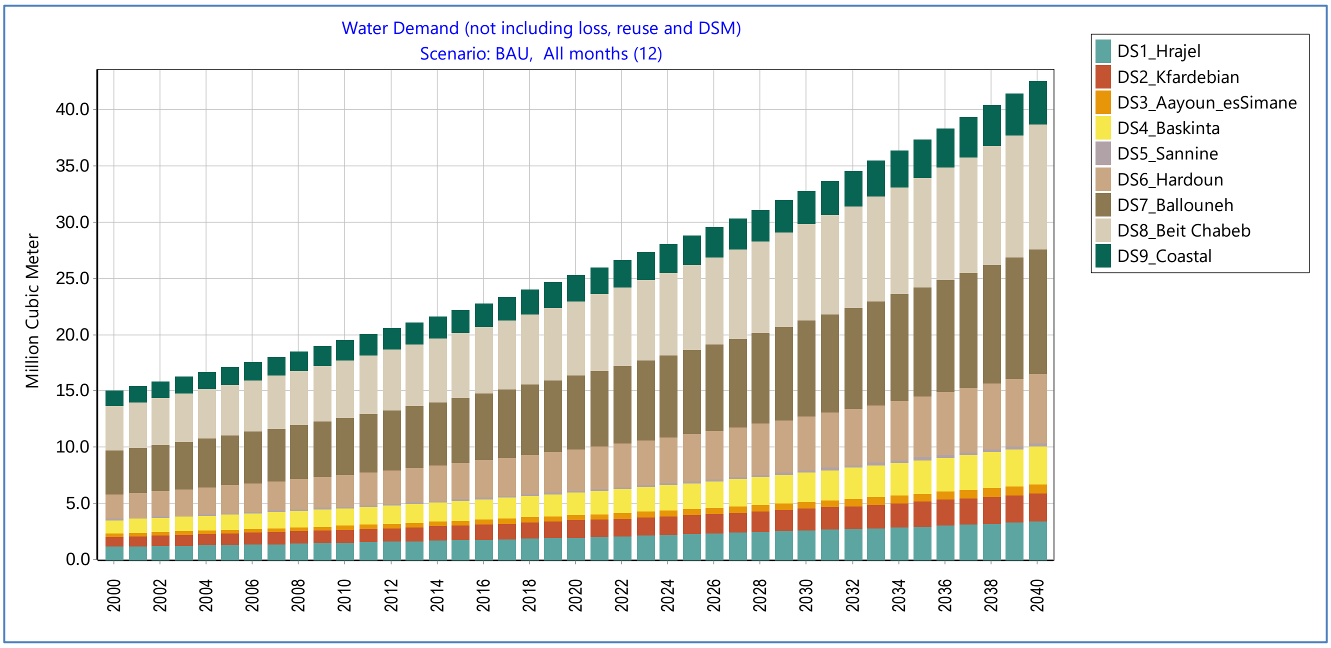



**Figure 5-1: Urban water demand in the Nahr-El Kelb for the entire simulation period 2000-2040 under the BaU scenario**

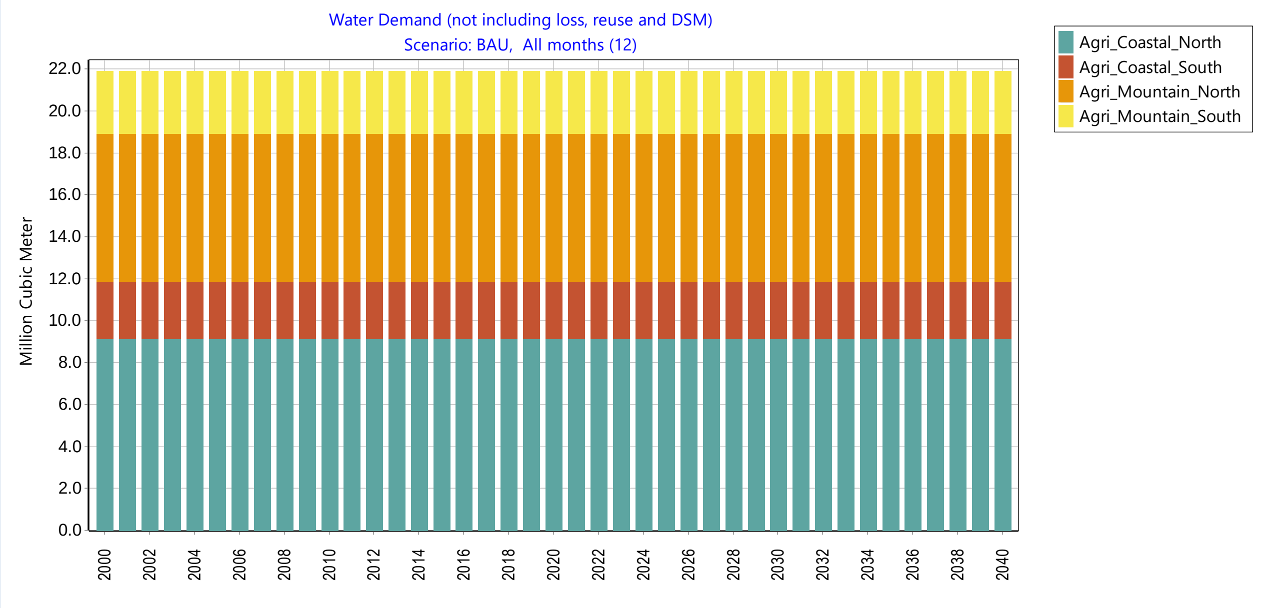



**Figure 5-2: Agricultural water demand in the Nahr-El Kelb for the entire simulation period 2000-2040 under the BaU scenario**

The unmet demand in the urban sector was about 0.96 Mm3 in 2018. The maximum projected for the future, under the BaU scenario, is to reach 6.10 Mm3 in the year 2036 under the BaU scenario (see Figure 5-3). The Hardoun area experienced the highest unmet demands in the reference period (about 0.79 Mm3/year in 2018). Yet, the greatest % increase in the unmet demand in the future is expected to occur in the Beit Chabeb and Coastal areas, which had almost zero unmet demand so far. Regarding the monthly distribution of the urban unmet demand, this is mostly occurring in July-October for the reference period 2000-2018 as well as for the future 2020-2040 period. Yet, there is an increase of the urban unmet demand in every month in the future. The month with the highest increase in urban unmet demand in the future (as compared to the reference) is June, where 166% increase in unmet demand is expected in the future as compared to the current reference period.

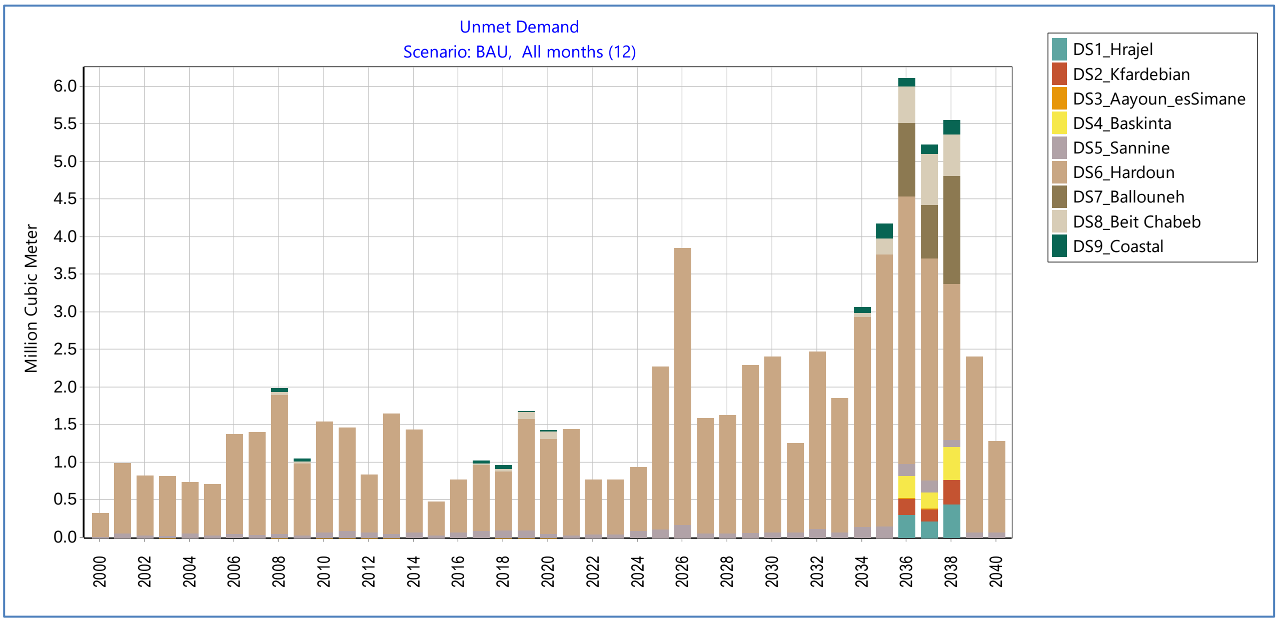



**Figure 5-3: Urban unmet demand in the Nahr-El Kelb for the entire simulation period 2000-2040 under the BaU scenario**

The unmet demand in the agricultural sector was about 4.5 MCM in 2018. The maximum projected for the future, under the BaU scenario, is to reach 9.7 Mm3 in the year 2037 (see Figure 5-4). The Coastal South and Mountain South agricultural areas experienced the highest unmet demands in the reference period (about 1 Mm3/year and 1.3 Mm3/year respectively). Yet, the greatest % increase in the unmet demand in the future is expected to occur in the Mountain North agricultural area, which had almost no unmet demand so far. Regarding the monthly distribution of the agricultural unmet demand, this is mostly occurring in May-September for the reference period 2000-2018, as well as for the future 2018-2040 period. Yet, there is an increase of the agricultural unmet demand in every month in the future. The month with the highest increase in unmet demand in the future (as compared to the baseline) is April, where 70% increase in unmet demand is expected in the future as compared to the reference period where the unmet demand was almost zero.

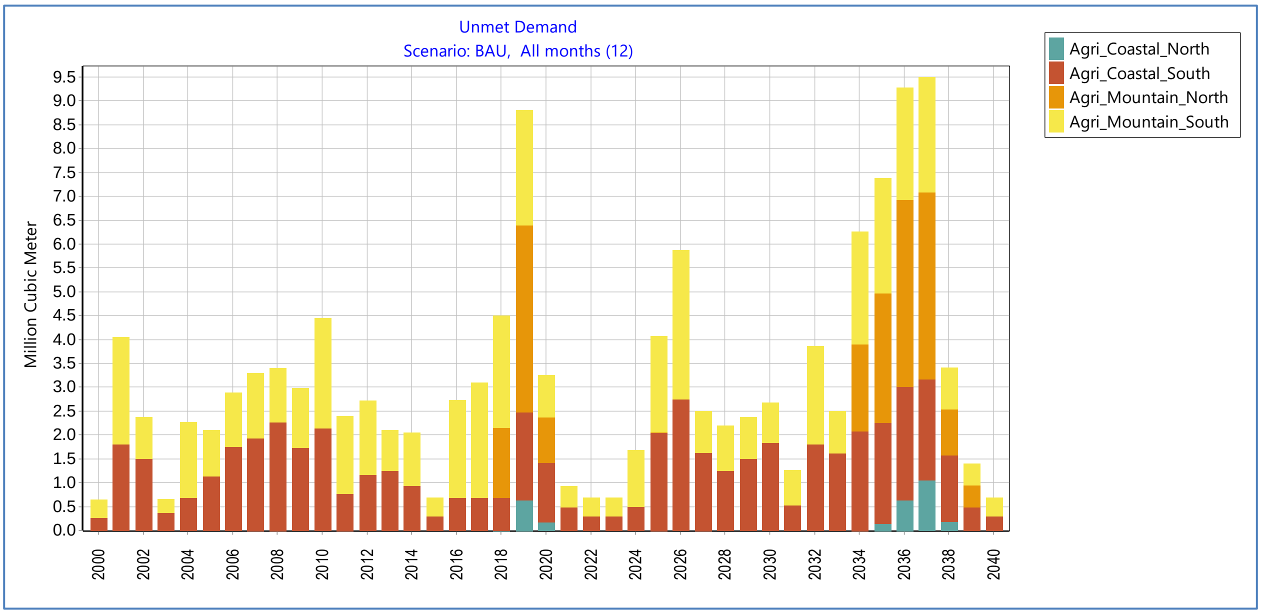



**Figure 5-4: Agricultural unmet demand in the Nahr-El Kelb for the entire simulation period 2000-2040 under the BaU scenario**

The total annual unmet demand (urban and agriculture) was currently 5.46 Mm3 in 2018. The maximum projected for the future, under the BaU scenario, is to reach 15.38 Mm3 in the year 2036 (see Figure 5-5). It has to be notice that the increased unmet demands observed in the future period 2034-2038 coincide with a hydrological dry period simulated in the model, which depicts a future climate of increased drought conditions. During that period, the low precipitation in the agricultural sector coupled with the population increase lead to more severe water stress conditions.

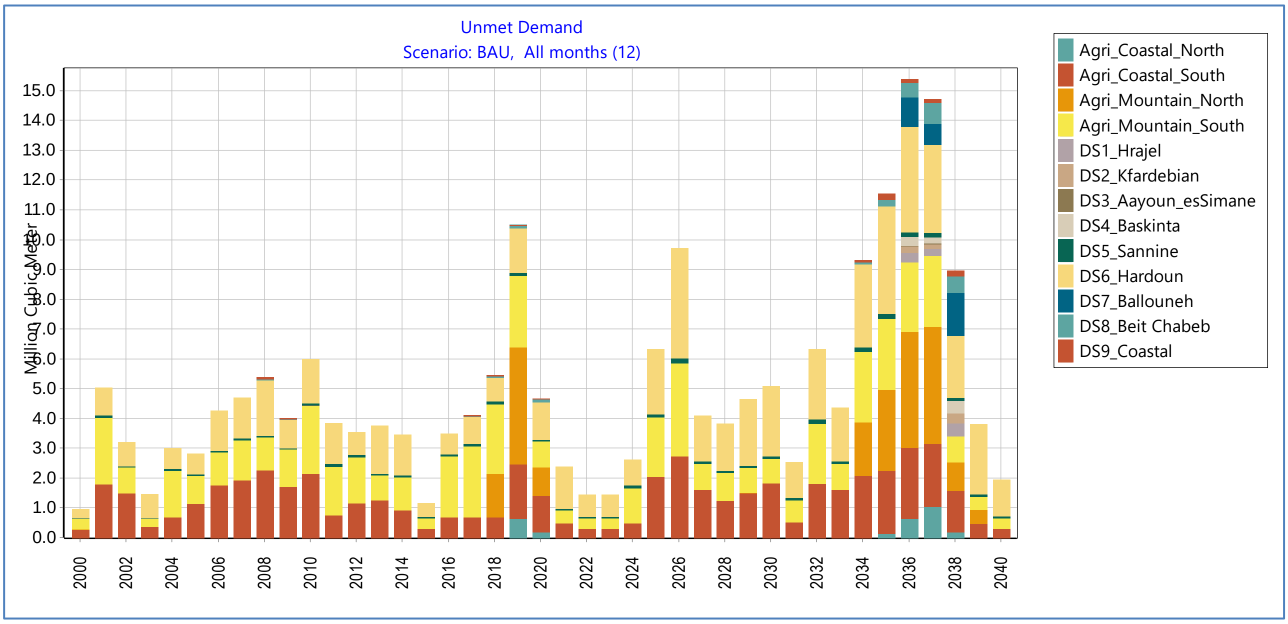



**Figure 5-5: Total unmet demand in the Nahr-El Kelb for the entire simulation period 2000-2040 under the BaU scenario**

## 5.2 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 5-1 below. The mean annual water savings vary across the solutions of the UrbSav scenario from 1.7 Mm3/year (solution No. 1) to 3.5 Mm3/year (solution No. 20), and the resulting cumulative savings for the period 2020-2040 (21 years) range respectively from 35.5 Mm3 (solution No. 1) to 74.1 Mm3 (solution No. 20). These savings in the urban sector consequently lead in a reduction of the unmet demand as well (Table 5-3). The mean annual reduction in unmet demand vary across the solutions of the UrbSav scenario from 0.4 Mm3/year (solution No. 3) to 0.9 Mm3/year (solution No. 20), and the resulting cumulative unmet demand reductions (savings) for the period 2020-2040 (21 years) range respectively from 8.5 Mm3 (solution No. 3) to 16.6 Mm3 (solution No. 20). When investigating the results of  these simulated solutions in the WEAP Nahr El-Kelb model, we concluded that Solutions No.5 and No.1 are the best since they have a low unit cost (euros per m3 of reduced unmet demand) of 0.14 and 0.06 €/m3 and can deliver good reductions of about 0.5-0.7 Mm3 per year. Solution No.20 is also good, as it delivers the highest reduction in unmet demand (0.9 Mm3/year on average) which comes though with a bit higher unit cost of 0.49 €/m3 of unmet demand reduced.

**Table 5-1: Reduction in urban water demand after implementation of the UrbSav scenario options as compared to the BaU scenario**

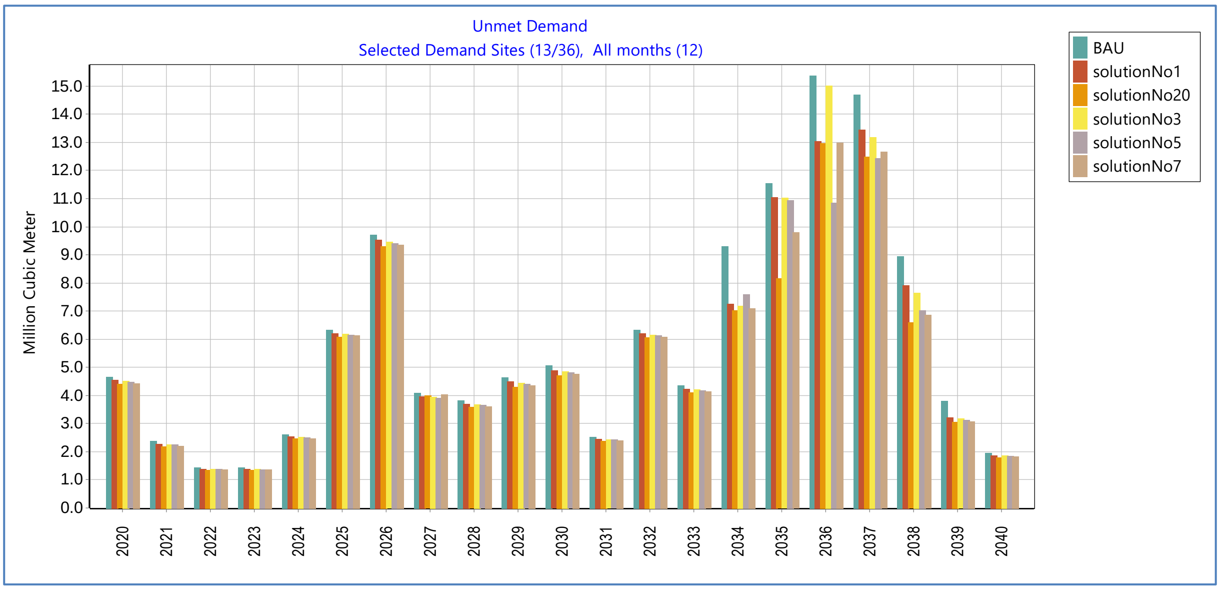
| Solution No. # | Total cumulative water saving* (Mm3) in the basin for 2020-2040 | Mean annual water saving* (Mm3/year) | Maximum annual water saving* (Mm3/year) – observed in year 2040 | Minimum annual water saving* (Mm3/year) - observed in year 2020 | Total AEC (mio €) for the basin | Unit AEC of total water saved (€/m3) |
|---|---|---|---|---|---|---|
| 0 (BaU) | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 35.5 | 1.7 | 2.2 | 1.3 | 0.52 | 0.01 |
| 3 | 44.4 | 2.1 | 2.7 | 1.6 | 1.41 | 0.03 |
| 5 | 53.0 | 2.5 | 3.2 | 1.9 | 2.02 | 0.04 |
| 7 | 64.3 | 3.1 | 3.9 | 2.3 | 2.91 | 0.05 |
| 20 | 74.1 | 3.5 | 4.5 | 2.7 | 8.12 | 0.11 |

* based on the WEAP model outputs

**Table 5-2: Reduction in unmet demand after implementation of the UrbSav scenario options as compared to the BaU scenario**

| Solution No. # | Total reduction in unmet demand* (Mm3) in the basin for 2020-2040 | Mean annual reduction in unmet demand* (Mm3/year) | Maximum annual reduction in unmet demand* (Mm3/year) | Minimum annual water reduction in unmet demand* (Mm3/year) | Total AEC (mio €) for the basin | Unit AEC of unmet demand reduction/ saving (€/m3) |
|---|---|---|---|---|---|---|
| 0 (BaU) | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 9.39 | 0.45 | 2.33 | 0.04 | 0.52 | 0.06 |
| 3 | 8.47 | 0.40 | 2.12 | 0.05 | 1.41 | 0.14 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | 14.09 | 0.67 | 4.52 | 0.06 | 2.02 | 0.14 |
| 7 | 14.01 | 0.67 | 2.38 | 0.05 | 2.91 | 0.21 |
| 20 | 16.62 | 0.89 | 3.39 | 0.08 | 8.12 | 0.49 |



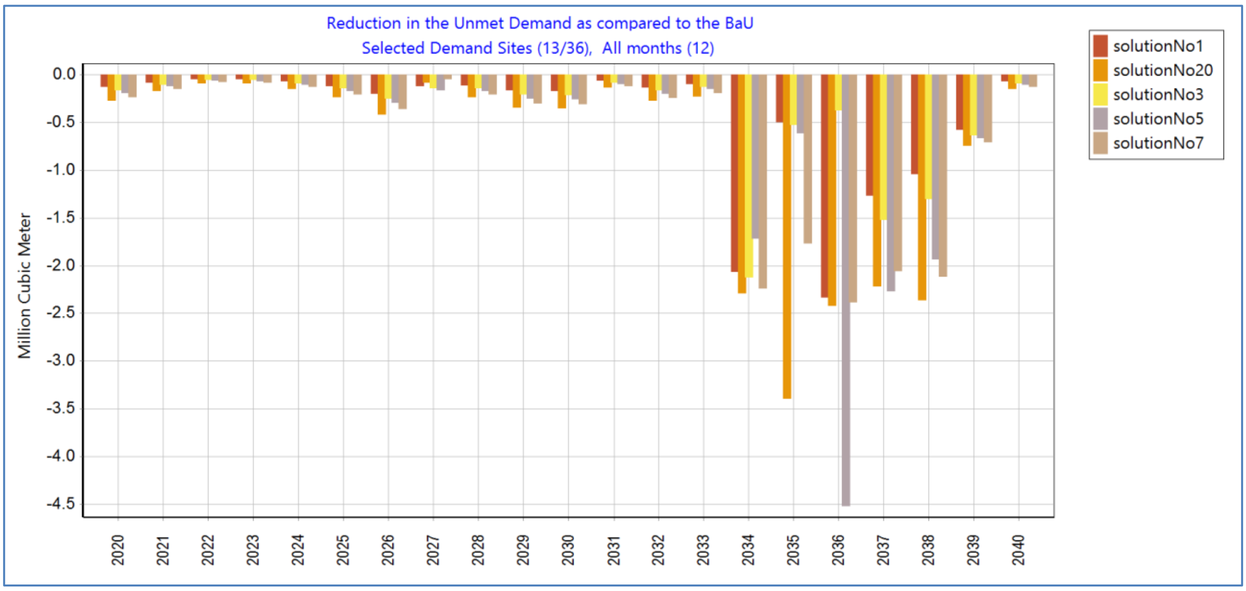




**Figure 5-6: Comparison of the unmet demand under the UrbSav scenario options in relation to the BaU scenario (top: all options as compared to the BaU, bottom: net reduction of the unmet demand as compared to the BaU for each option)**

## 5.3 RESULTS: URBSUP SCENARIO

When implementing the different options of the UrbSup scenario (solutions 7r, 7w, 20r, 20w, 20m) the urban demand is reduced as a result of the applied water saving Tier-1 measures and the additional Tier-2 water supply measures (rainwater harvesting, domestic greywater reuse). This reduction in the urban demand, which basically reflects the relevant water savings, is presented in Table 5-3 below.

The mean annual water savings vary across the solutions of the UrbSup scenario from 3.5 Mm3/year (solution No. 7w) to 4.9 Mm3/year (solution No. 20m), and the resulting cumulative savings for the period 2020-2040 (21 years) range respectively from 72.4 Mm3 (solution No. 7w) to 102.3 Mm3 (solution No. 20m). These savings in the urban sector consequently lead in a reduction of the unmet demand as well (Table 5-4). The mean annual reduction in unmet demand vary across the solutions of the UrbSav scenario from 0.8 Mm3/year (solution No. 7w) to 1.1 Mm3/year (solution No. 20m), and the resulting cumulative unmet demand reductions (savings) for the period 2020-2040 (21 years) range respectively from 16 Mm3 (solution No. 7w) to 22.6 Mm3 (solution No. 20m). When investigating the results of these simulated solutions in the WEAP Nahr El-Kelb model, we concluded that solutions No. 20r, and 7r are the best since they have a low unit cost (euros per m3 of unmet demand reduced) of 1 – 1.2 €/m3 and can deliver good savings of about 0.9 Mm3 per year. Solution No.20m is also good, as it delivers the highest reduction in unmet demand (1.1 Mm3/year on average) which comes though with a bit higher unit cost of 2.14 €/m3 of unmet demand reduced.

**Table 5-3: Reduction in urban water demand after implementation of the UrbSup scenario options as compared to the BaU scenario**

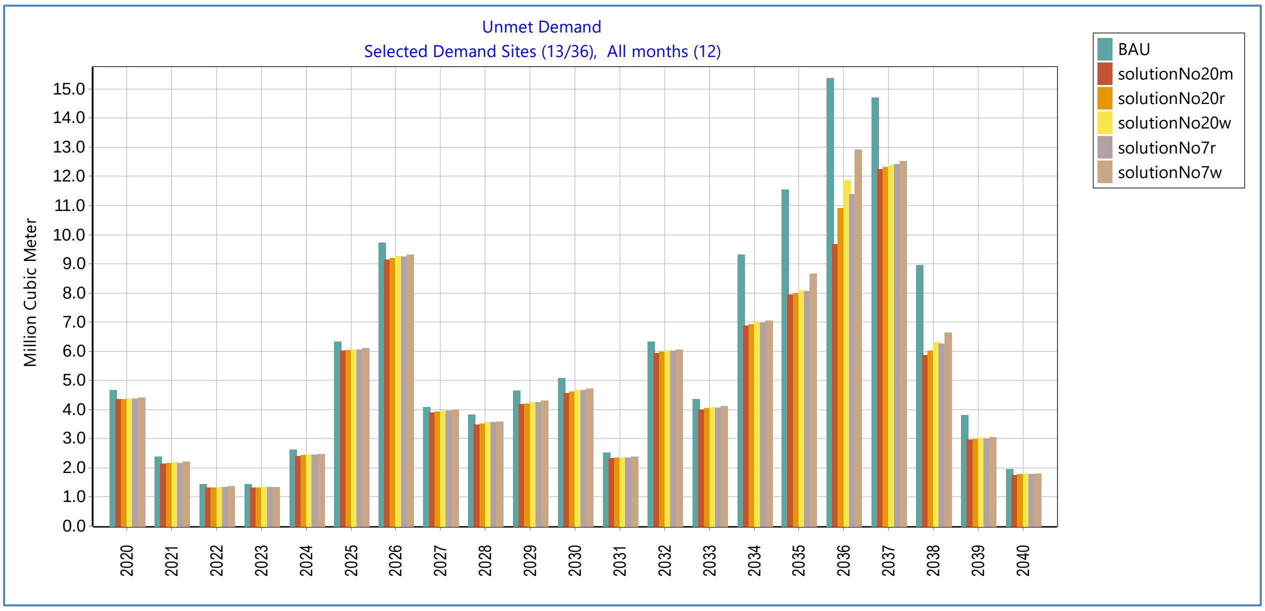
| Solution No. # | Total cumulative water saving* (Mm3) in the basin for 2020-2040 | Mean annual water saving (Mm3/year) | Maximum annual water saving (Mm3/year) – observed in year 2040 | Minimum annual water saving (Mm3/year) - observed in year 2020 | Total AEC (mio €) for the basin | Unit AEC of total water saved (€/m3) |
|---|---|---|---|---|---|---|
| 0 (BaU) | 0 | 0 | 0 | 0 | 0 | 0 |
| 7r | 84.5 | 4.03 | 5.16 | 3.07 | 19.63 | 0.23 |
| 7w | 72.4 | 3.45 | 4.41 | 2.62 | 26.30 | 0.36 |
| 20r | 94.3 | 4.49 | 5.75 | 3.42 | 24.84 | 0.26 |
| 20w | 82.1 | 3.91 | 5.01 | 2.98 | 31.51 | 0.38 |
| 20m | 102.3 | 4.87 | 6.24 | 3.71 | 48.23 | 0.47 |

* based on the WEAP model outputs

**Table 5-4: Reduction in unmet demand after implementation of the UrbSup scenario options as compared to the BaU scenario**

| Solution No. # | Total reduction in unmet demand* (Mm3) in the basin for 2020-2040 | Mean annual reduction in unmet demand* (Mm3/year) | Maximum annual reduction in unmet demand* (Mm3/year) | Minimum annual water reduction in unmet demand* (Mm3/year) | Total AEC (mio €) for the basin | Unit AEC of unmet demand reduction/ saving (€/m3) |
|---|---|---|---|---|---|---|
| 0 (BaU) | 0 | 0 | 0 | 0 | 0 | 0 |
| 7r | 19.30 | 0.92 | 4.01 | 0.10 | 19.63 | 1.02 |
| 7w | 15.99 | 0.76 | 2.89 | 0.07 | 26.30 | 1.64 |
| 20r | 20.66 | 0.98 | 4.47 | 0.11 | 24.85 | 1.20 |
| 20w | 18.61 | 0.89 | 3.50 | 0.10 | 31.52 | 1.69 |
| 20m | 22.59 | 1.08 | 5.71 | 0.12 | 48.24 | 2.14 |

* based on the WEAP model outputs



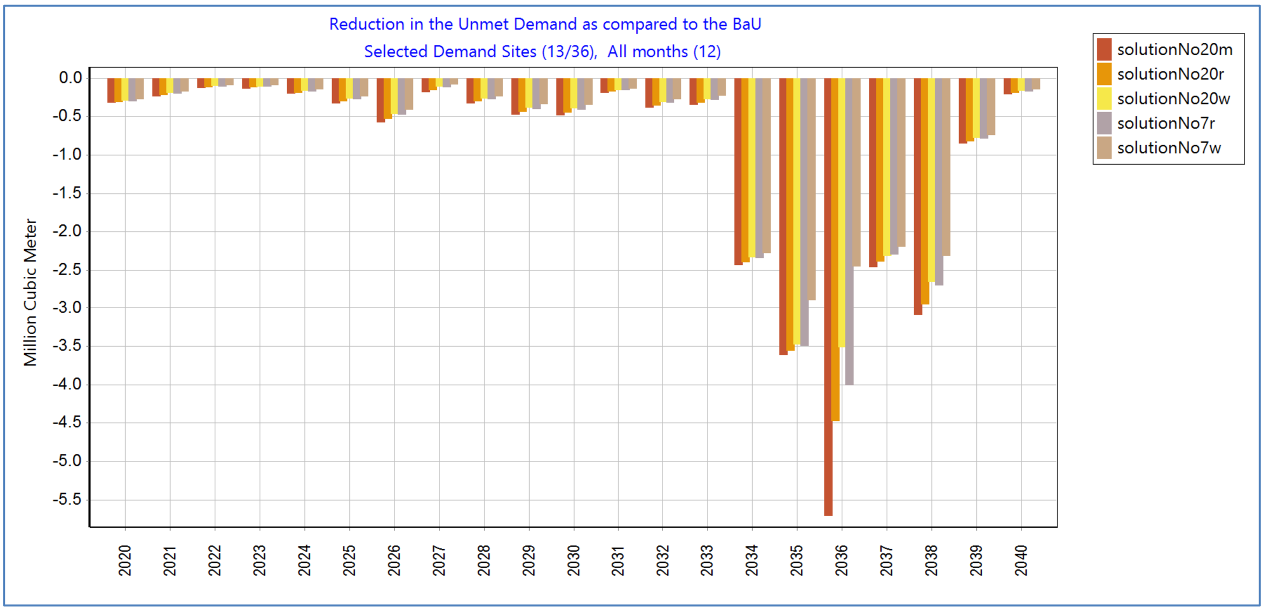




**Figure 5-7: Comparison of the unmet demand under the UrbSup scenario options in relation to the BaU scenario (top: all options as compared to the BaU, bottom: net reduction of the unmet demand as compared to the BaU for each option)**

## 5.4 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 agricultural water supply requirement by 3.44 Mm3 every year, i.e. a total of about 72 Mm3 for the entire period 2020-2040.This volume can be considered as savings coming from the application of the aforementioned agricultural measures. The actual reduction in the agricultural supply delivered, which basically reflects the actual operational water savings as compared to the BaU, is presented in Table 5-5 below.

These savings in the agricultural sector consequently lead in a reduction of the unmet demand as well (Table 5-6). The mean annual reduction in unmet demand is 0.78 Mm3/year, and the resulting cumulative unmet demand reductions (savings) for the period 2020-2040 amount to 16.37 Mm3. To reduce the unmet demand by 1 m3 an AEC of 0.08€ (unit cost) is required.

**Table 5-5: Reduction in agricultural water supply delivered after implementation of the AgrSav scenario as compared to the BaU scenario**

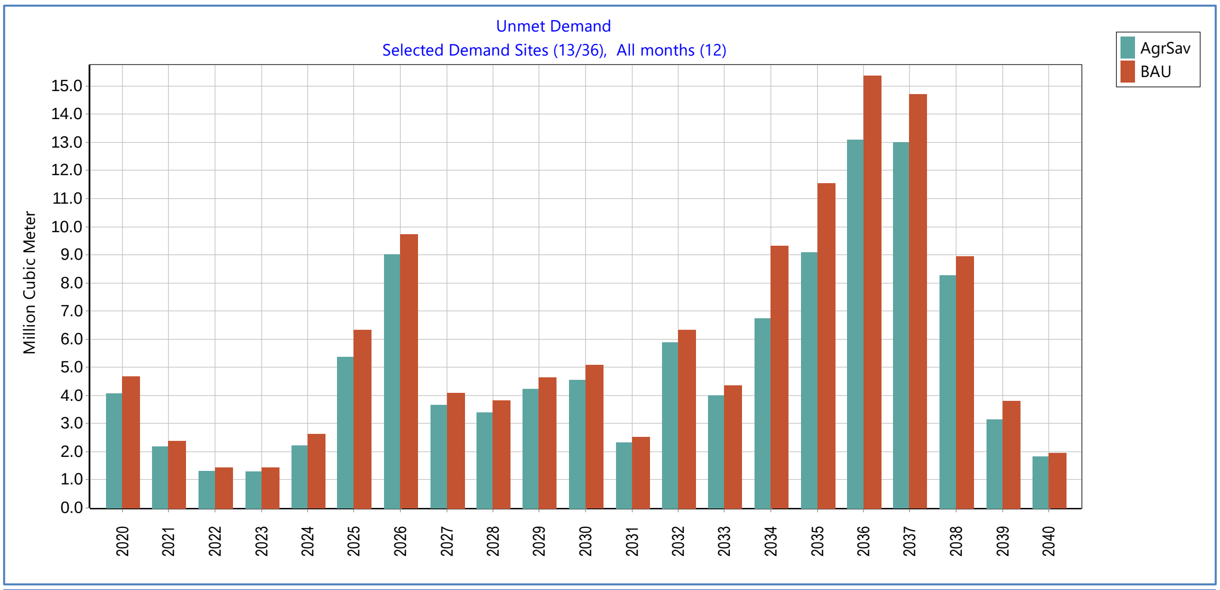
| Solution | Total cumulative water saving* (Mm3) in the basin for 2020-2040 | Mean annual water saving (Mm3/year) | Maximum annual water saving (Mm3/year) – observed in year 2023 | Minimum annual water saving (Mm3/year) - observed in year 2034 | Total AEC (mio €) for the basin | Unit AEC of total water saved (€/m3) |
|---|---|---|---|---|---|---|
| 0 (BaU) | 0 | 0 | 0 | 0 | 0 | 0 |
| Reduce losses to 15.5% & increase application efficiency to 84% | 59.18 | 2.82 | 3.32 | 1.00 | 1.26 | 0.02 |

* based on the WEAP model outputs

**Table 5-6: Reduction in unmet demand after implementation of the AgrSav scenario as compared to the BaU scenario**

| Solution | Total reduction in unmet demand* (Mm3) in the basin for 2020-2040 | Mean annual reduction in unmet demand* (Mm3/year) | Maximum annual reduction in unmet demand* (Mm3/year) | Minimum annual water reduction in unmet demand* (Mm3/year) | Total AEC (mio €) for the basin | Unit AEC of unmet demand reduction/ saving (€/m3) |
|---|---|---|---|---|---|---|
| 0 (BaU) | 0 | 0 | 0 | 0 | 0 | 0 |
| Reduce losses to 15.5% & increase application efficiency to 84% | 16.37 | 0.78 | 2.57 | 0.13 | 1.26 | 0.08 |

* based on the WEAP model outputs



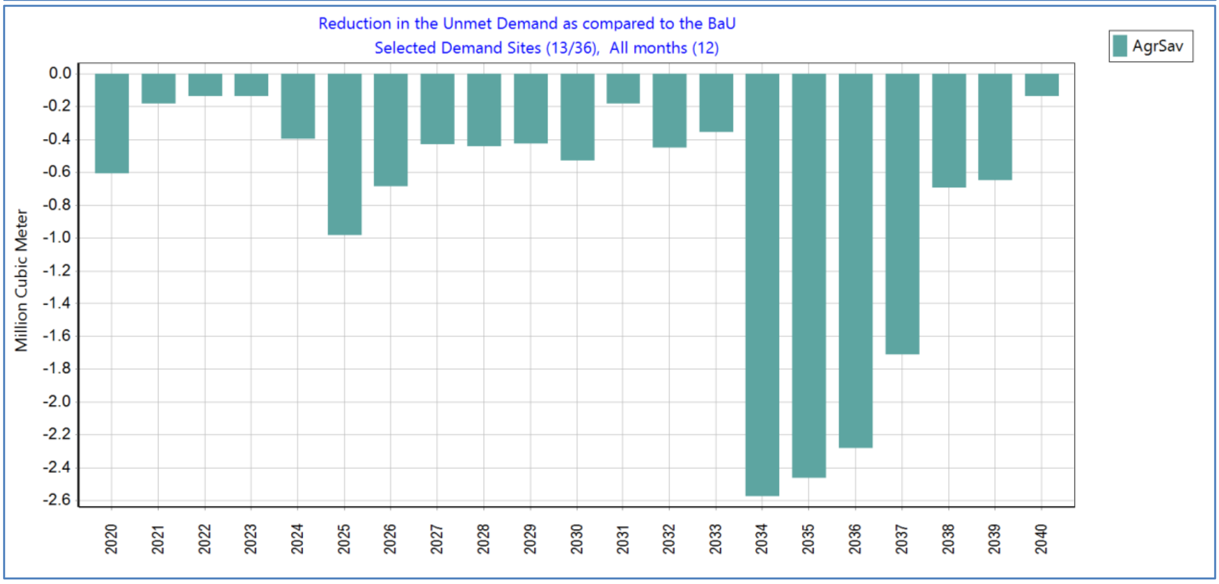




**Figure 5-8: Comparison of the unmet demand under the AgrSav scenario in relation to the BaU scenario (top: AgrSav as compared to the BaU, bottom: net reduction of the unmet demand as compared to the BaU)**

## 5.5 RESULTS: MIXSAV SCENARIO

The implementation of the measures of the MixSav scenario (i.e. urban saving solution No.20, together with reduction of conveyance losses and increase of field application irrigation efficiency) results in a reduction of the water supply requirement (urban + agriculture) by 9.86 Mm3 every year, i.e. a total of about 207 Mm3 for the entire period 2020-2040 (Table 5-7).This volume can be considered as savings coming from the application of the aforementioned mix of measures. These savings sector consequently lead in a reduction of the unmet demand as well (Table 5-8). The mean annual reduction in unmet demand is 1.57 Mm3/year, and the resulting cumulative unmet demand reductions (savings) for the period 2020-2040 amount to 32.37 Mm3. To reduce the unmet demand by 1 m3 an AEC of 0.29€ (unit cost) is required.

**Table 5-7: Reduction in the water supply requirements (urban + agriculture) after implementation of the MixSav scenario as compared to the BaU scenario**

| Solution | Total cumulative water saving* (Mm3) in the basin for 2020-2040 | Mean annual water saving* (Mm3/year) | Maximum annual water saving* (Mm3/year) – observed in year 2040 | Minimum annual water saving* (Mm3/year) - observed in year 2020 | Total AEC (mio €) for the basin | Unit AEC of total water saved (€/m3) |
|---|---|---|---|---|---|---|
| 0 (BaU) | 0 | 0 | 0 | 0 | 0 | 0 |
| MixSav | 206.97 | 9.86 | 11.66 | 8.33 | 9.38 | 0.045 |

* based on the WEAP model outputs

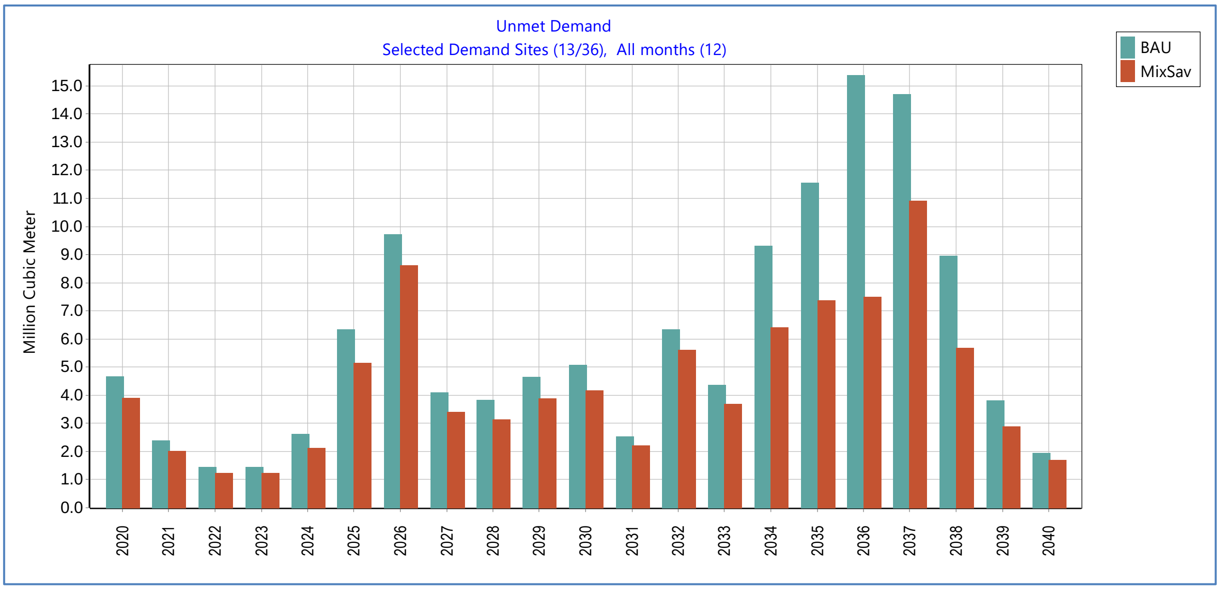
** MixSav includes: UrbSav Solution No. 20 and AgrSav (reduce losses to 15.5% & increase application efficiency to 84%)

**Table 5-8: Reduction in unmet demand after implementation of the MixSav scenario as compared to the BaU scenario**

| Solution | Total reduction in unmet demand* (Mm3) in the basin for 2020-2040 | Mean annual reduction in unmet demand* (Mm3/year) | Maximum annual reduction in unmet demand* (Mm3/year) | Minimum annual water reduction in unmet demand* (Mm3/year) | Total AEC (mio €) for the basin | Unit AEC of unmet demand reduction/ saving (€/m3) |
|---|---|---|---|---|---|---|
| 0 (BaU) | 0 | 0 | 0 | 0 | 0 | 0 |
| MixSav** | 32.37 | 1.57 | 7.89 | 0.22 | 9.38 | 0.29 |

* based on the WEAP model outputs

** MixSav includes: UrbSav Solution No. 20 and AgrSav (reduce losses to 15.5% & increase application efficiency to 84%)



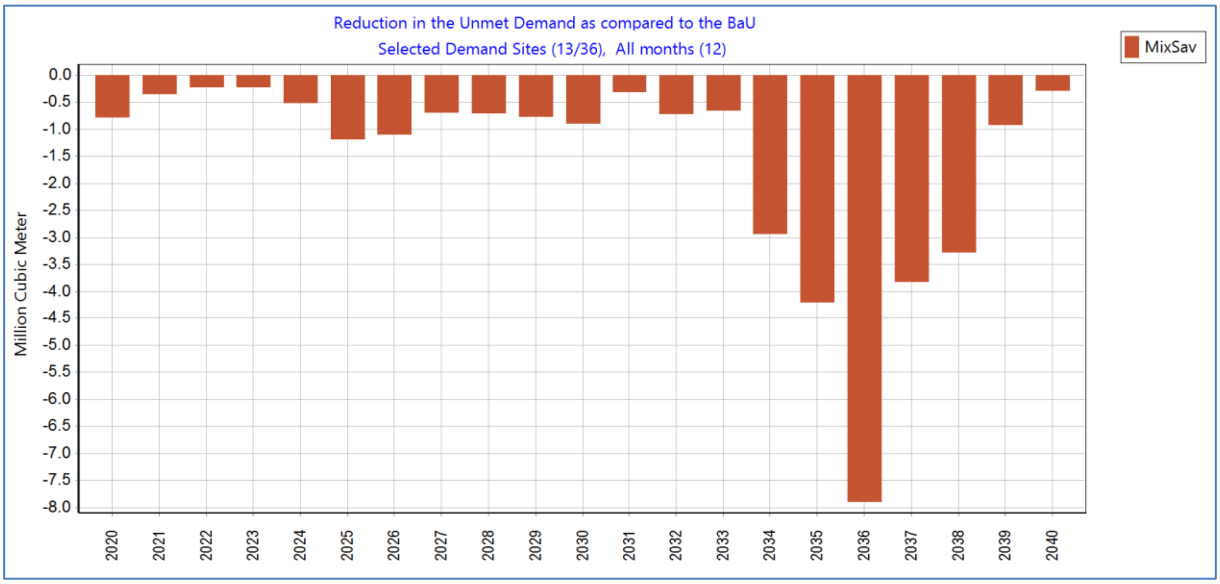



**Figure 5-9: Comparison of the unmet demand under the MixSav scenario in relation to the BaU scenario (top: MixSav as compared to the BaU, bottom: net reduction of the unmet demand as compared to the BaU)**

## 5.6 RESULTS: URBSUP2 & AGRSUP2 SCENARIOS

The proposed detention ponds of 100-150 m2 capacity, 1 km2 drainage area, and a total of around 20 ponds per sub-catchment/demand site, is 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 UrbSup2 and AgrSup2 scenarios is that they 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, these scenarios have not been deemed suitable for simulation, although recommended as a practice for individual use in the agricultural sector mainly.

## 5.7 RESULTS: MOEW SCENARIO

The implementation of the different demand management measures as simulated in the UrbSav, UrbSup, AgrSav, MixSav can meaningfully contribute to the reduction of unmet demand, yet they cannot fully eliminate the problem as there still remains a portion of demand which cannot be covered by the existing water supply sources, especially under the future conditions. It is thus understood that the problem cannot be eliminated by applying demand management measures alone, and some increase in water supply is also necessary. The results of the implementation of the Boqaata Dam are presented in Figure 5-10 below. It has been assumed in the model that the Boqaata Dam will be operational in 2025. A storage capacity of 6 Mm3 has been assumed, and an expected supply of 5-10

Mm3 per year. The model results indicate that the Boqaata Dam can deliver a water supply of about 7.5-10.5 Mm3/year (depending on the climatic conditions of the year).

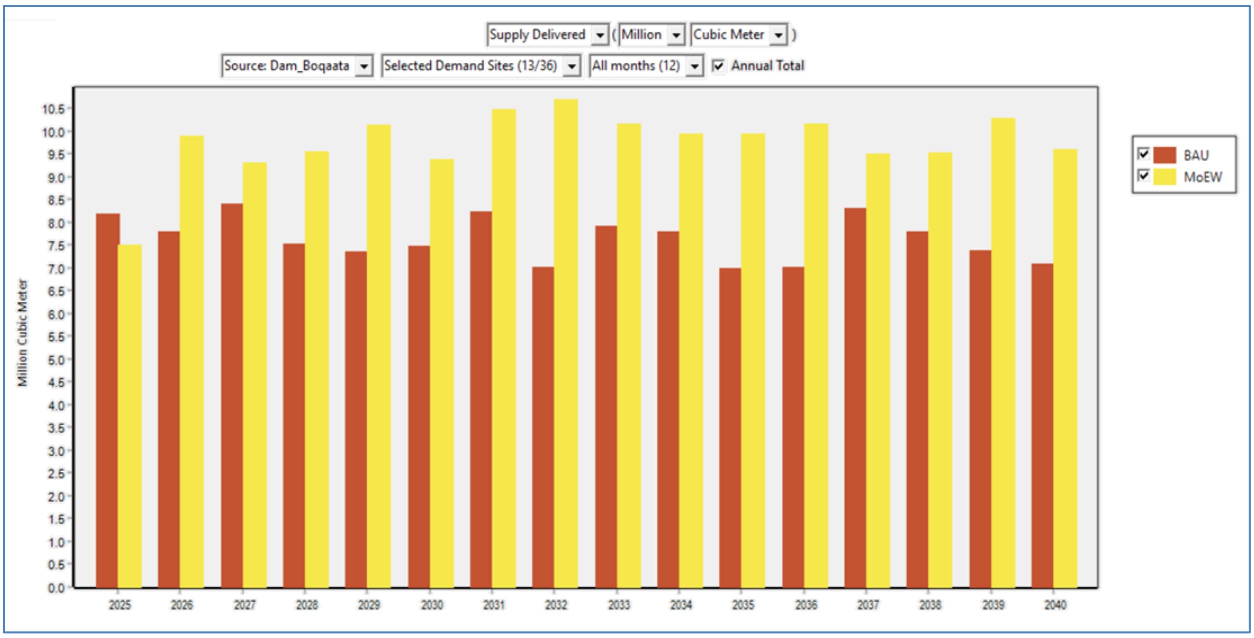



**Figure 5-10: Expected increase in the annual water supply (as estimated by the WEAP model) in the Nahr El-Kelb basin for the period 2025-2040, with the operation of the Boqaata Dam (scenario MoEW) as compared to the to the BaU scenario**

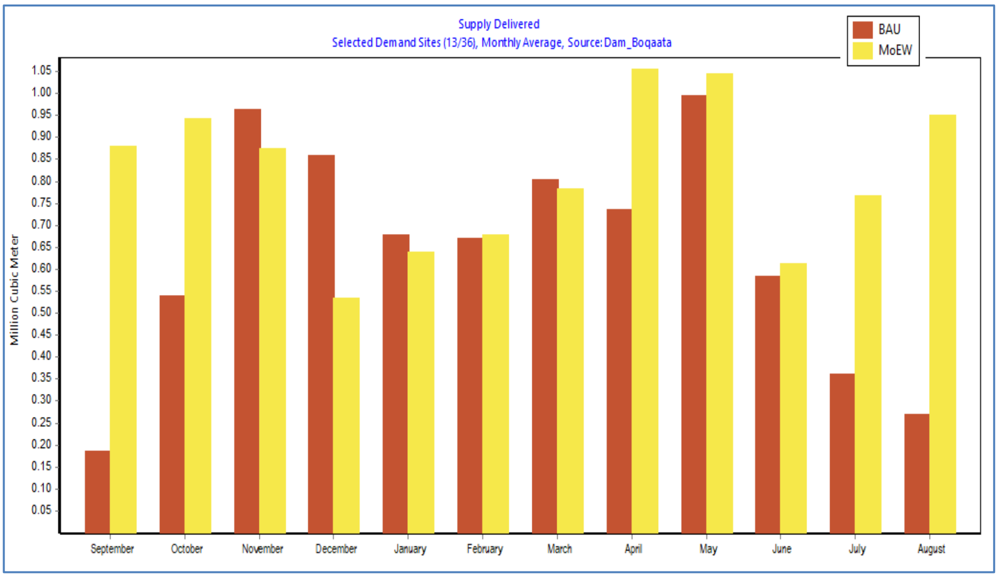



**Figure 5-11: Expected increase in the monthly average water supply (as estimated by the WEAP model) in the Nahr El-Kelb basin for the period 2025-2040, with the operation of the Boqaata Dam (scenario MoEW) as compared to the to the BaU scenario**

# 6. CONCLUSIONS AND POLICY RECOMMENDATIONS

Unmet demand (i.e. imbalance between water demand and water supply delivered) occurs in the Nah El-Kelb river basin every year. The annual average total unmet demand for the reference period 2000-2018 has been 3.67 Mm3/year with the highest observed at 5.99 Mm3 in 2010. These numbers are projected to increase in the future 2020-2040 period, with the annual average reaching 5.69 Mm3/year (i.e. a 62% increase) and a maximum observed value of 15.68 mio me in 2036.

In the urban sector the average unmet demand for the reference period 2000-2018 was 1.07 Mm3/year, with a maximum of 1.98 Mm3 observed in 2008. This numbers increase in the future, as the average agricultural unmet demand is expected to reach 2.51 Mm3/year (i.e. 135% increase) and with a pick of 6.1 Mm3 observed in 2036. The highest unmet demands occur in July-September. In the agricultural sector, the average unmet demand for the reference period 2000-2018 was 2.6 Mm3/year, with a maximum of 4.5 Mm3 observed in 2010. This numbers increase in the future, as the average agricultural unmet demand is expected to be 3.45 Mm3/year (i.e. 33% increase) and with a pick of 9.5 Mm3 observed in 2036. The highest unmet demands occur in July-September.

Overall, unmet demand is increasing in the Nahr-El Kelb river basin after the year 2020 since demand projections have been incorporated. The irrigated land is assumed to stay the same, while population is assumed to increase at a rate of 2.6% per year. This population increase results in an increase in the projected demands for the years 2020-2040 and consequently in the unmet demand. It is thus important to implement demand management measures (either water saving or increase supply measures) to mitigate this problem. The different scenarios that have been simulated in WEAP demonstrated a good potential to reduce unmet demand, at various rates and costs, depending on the measures embedded in each scenario. A comparison of all scenarios across them and against the BaU is presented in Figure 6-1 below. The scenario with the lowest unit cost (i.e. € spent per m3 of unmet demand reduction in AEC) is the AgrSav (0.08 €/m3 AEC), followed by the MixSav (0.29 €/m3 AEC) and the UrbSav (0.49 €/m3 AEC). All these three scenarios can introduce savings with less than 0.5 €/m3 AEC, while the UrbSup scenario requires a respective AEC of more than 2€/m3 (Table 6-1).

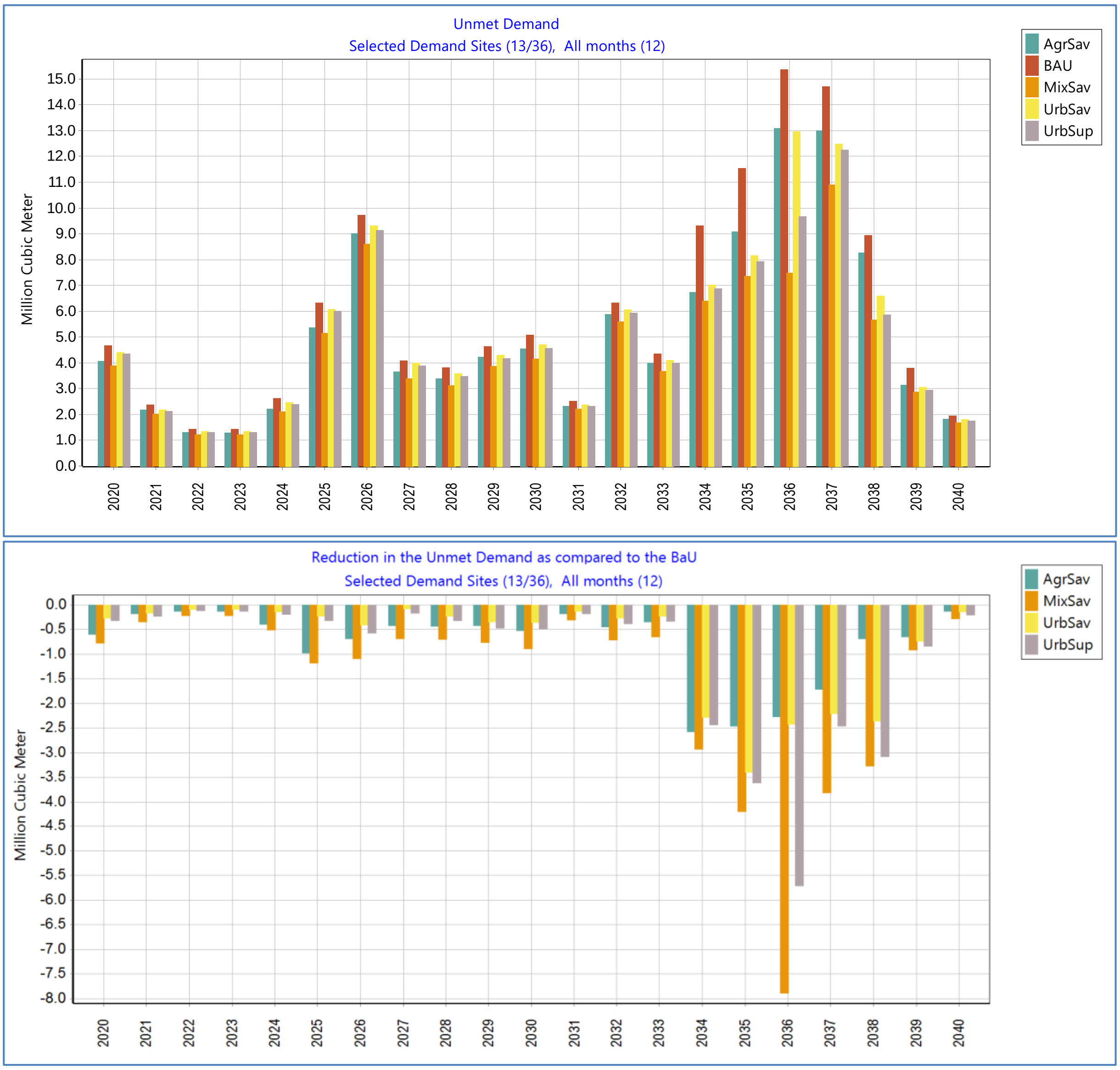



**Figure 6-1: Expected reductions in the annual unmet demand (as estimated by the WEAP model) in all the demand sites (lump sum) in the Nahr El-Kelb basin for the period 2000-2040, when applying the different demand management scenarios (UrbSav, UrbSup, AgrSav, MixSav) as compared to the BaU scenario (top: all scenarios as compared to the BaU, bottom: net reduction of the unmet demand as compared to the BaU for each scenario)**

**Table 6-1: Reduction in unmet demand after implementation of the different scenario as compared to the BaU scenario**

| Solution | Total reduction in unmet demand* (Mm3) in the basin for 2020-2040 | Mean annual reduction in unmet demand* (Mm3/year) | Maximum annual reduction in unmet demand* (Mm3/year) | Minimum annual water reduction in unmet demand* (Mm3/year) | Total AEC (mio €) for the basin | Unit AEC of unmet demand reduction/ saving (€/m3) |
|---|---|---|---|---|---|---|
| 0 (BaU) | 0 | 0 | 0 | 0 | 0 | 0 |
| UrbSav** | 16.62 | 0.89 | 3.39 | 0.08 | 8.12 | 0.49 |
| UrbSup** | 22.59 | 1.08 | 5.71 | 0.12 | 48.24 | 2.14 |

| | | | | | | |
|---|---|---|---|---|---|---|
| AgrSav | 16.37 | 0.78 | 2.57 | 0.13 | 1.26 | 0.08 |
| MixSav*** | 32.37 | 1.57 | 7.89 | 0.22 | 9.38 | 0.29 |

* based on the WEAP model outputs

**The UrbSav and UrbSup scenarios here refer to the Solutions No.20 and No. 20m respectively which are the ones that deliver the maximum savings among the different options.

*** MixSav includes: UrbSav Solution No. 20 and AgrSav (reduce losses to 15.5% & increase application efficiency to 84%)

The implementation of the different demand management measures as simulated in the UrbSav, UrbSup, AgrSav, MixSav can meaningfully contribute to the reduction of unmet demand, yet they cannot fully eliminate the problem as there still remains a portion of demand which cannot be covered by the existing water supply sources, especially under the future conditions. For example, the total annual unmet demand in the urban sector in the year 2018 reached 0.96 Mm3. Under the future population projection and climate variability simulation this unmet demand can reach 2.4 Mm3/year in 2030 and even 6.1 Mm3/year in 2036 if we experience some dry years. The simulated demand management measures of scenarios UrbSav, UrbSup, AgrSav, MixSav can reduce this unmet demand by 0.8-1.5 Mm3/year on average (depending on the scenario) and with a max potential reduction of 2.6-7.9 Mm3/year (during some years). It is thus understood that the problem cannot be eliminated by applying demand management measures alone, and some increase in water supply is also necessary. The implementation of the Boqaata Dam has been simulated under the MoEW scenario, and it has been calculated by the model that the Boqaata Dam can deliver a water supply of about 7.5-10.5 MCM/year (depending on the climatic conditions of the year).

The findings of the current study have been discussed with the relevant stakeholders in a participatory Workshop held on March 14th 2019 in Beirut. The discussions and exchanges led to the definition of the following policy targets, to be subsequently presented in a Policy Document, as well as some additional goals

**Policy Target for the Nahr El-Kelb River Basin**

- Introduce **domestic water saving of 15%**
- Increase **irrigation efficiency by 10-12%** (mixed field application and conveyance efficiencies)
- Promote **rainwater harvesting** at altitudes of **700m and below**
- Explore the **potential of detention ponds for irrigation**/ capturing also snowmelt in the higher areas (either at individual or collective scale)
- Investigate the **construction on rainwater harvesting lakes of 200-500 m3** for irrigation
- **Wastewater reuse to supply at least 10 Mm3/yr** for irrigation to cover current demands. If we want to "free-up" potable water, then a larger amount should be provided through wastewater reuse

**Additional Goals for the Nahr El-Kelb River Basin**

- Obtain data from the smaller wastewater treatment plans (Masterplan for small WWTPs)
- Execute wastewater treatment plan and wastewater network

- Draft a River Basin Management Plan
- Draft a Masterplan for irrigation
- Update the Masterplan for potable water, including drinking water protection zones
- Implement water metering
- Develop a Registry of all groundwater wells (incl. illegal)
- Decrease pollution (so minimize industrial lu)
- Promote the rational land use planning in the new Masterplan for land use (conflict between urban and agri. areas), limit the expansion of urban areas
- Improve Governance: law 77/2018 - application decrees, establishment of River Basin Organization (RBO)

Finally, some general remarks can be draw in relation to the objectives of this pilot study and the methodological approach implemented. The objectives on this pilot study in the Nahr El-Kelb river basin were concurrent with the challenges faced in Lebanon in the field of water resources management. The overall methodological approach has proven to be:

- generic, flexible, easily adaptable to various area-specific contexts, sectoral structures, and technical arrangements
- modular and expandable: its engineering components (tools) can be implemented as stand-alone, or as part of an integral system
- parsimonious in terms of data needs: input data to the various tools are relatively easy to acquire (e.g. precipitation, water demand, costs, yields, etc.)
- replication potential: can be applied in other river basin in Lebanons
- supports the design of medium to longer-term mitigation options, helping thus to remove structural barriers
- links science to decision-making, enables the definition of sectoral policy targets, and supports the development of river basin management plans providing a robust DSS

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