MODELING WASTEWATER MANAGEMENT OPTIONS WITH A WATER EVALUATION AND PLANNING TOOL (WEAP) FOR WADI NAR WATERSHED, WEST BANK, PALESTINE

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ABSTRACT

Water supply is a critical issue in the Middle East, particularly in the West Bank and Gaza Strip (Palestine). Water resources are scarce due to the arid climate and the population growth while water resources management and development is complicated by the ongoing Israeli occupation. There is a critical lack of sanitation in the West Bank. Only 45% of the Palestinian population is connected to a sewer network; the majority of households dispose of domestic sewage into unlined cesspits. There is currently only one operational wastewater treatment plant (WWTP) in the West Bank, so most of the sewage is directly discharged to the environment without treatment. Reuse of treated wastewater has great potential to alleviate this problem and improve crop yield. This paper presents a case study in the Wadi Nar Watershed (WNW) in the West Bank. The Water Evaluation and Planning Tool (WEAP) was used for mapping the management options related to wastewater reuse in WNW. Results show that WEAP is a sound management tool that can visualize the impact of key factors on the treated wastewater quantities and corresponding total area of wastewater reuse.

INTRODUCTION

The Middle East region including West Bank suffers from a chronic shortage in water resources accessibility. One of the most potential and promising alternative solutions is to reuse the treated wastewater for irrigation in agriculture. Wastewater management challenges are increasingly common. In water scarce regions, treated wastewater becomes a valuable alternative water resource for agricultural use. The identification and evaluation of different wastewater management options requires the integration of manifold issues to meet the needs of all stakeholders involved in the decision making process. This paper aims at documenting the development of a Water Evaluation and Planning (WEAP) tool for mapping the management options related to wastewater reuse in Wadi Nar Watershed (WNW), West Bank, Palestine. WNW is a watershed that extends from the eastern hills of Jerusalem and drains into the Dead Sea as shown in Figure 1.

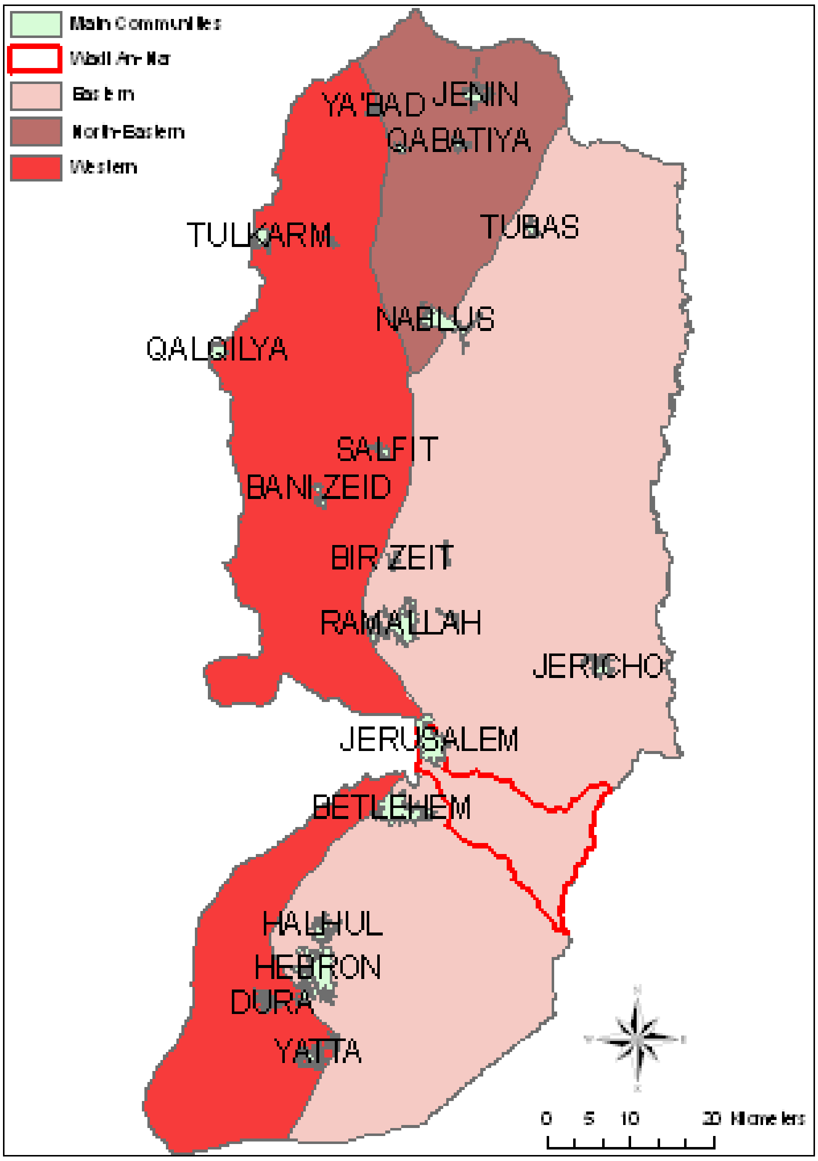

Figure 1. Location of WNW in the West Bank

The watershed lies entirely within the eastern groundwater basin of the Mountain Aquifer and is contained within Jerusalem and Bethlehem governorates. Figure 2 depicts a multitude of general properties of the watershed. Apparently, WNW is of great heterogeneities in terms of ground surface elevation, head contours of groundwater, evapotranspiration, rainfall distribution, subsurface formations, and aridity. For a detailed elaboration of these issues, see Mutlak et al. (2006) and HWE (2007a).

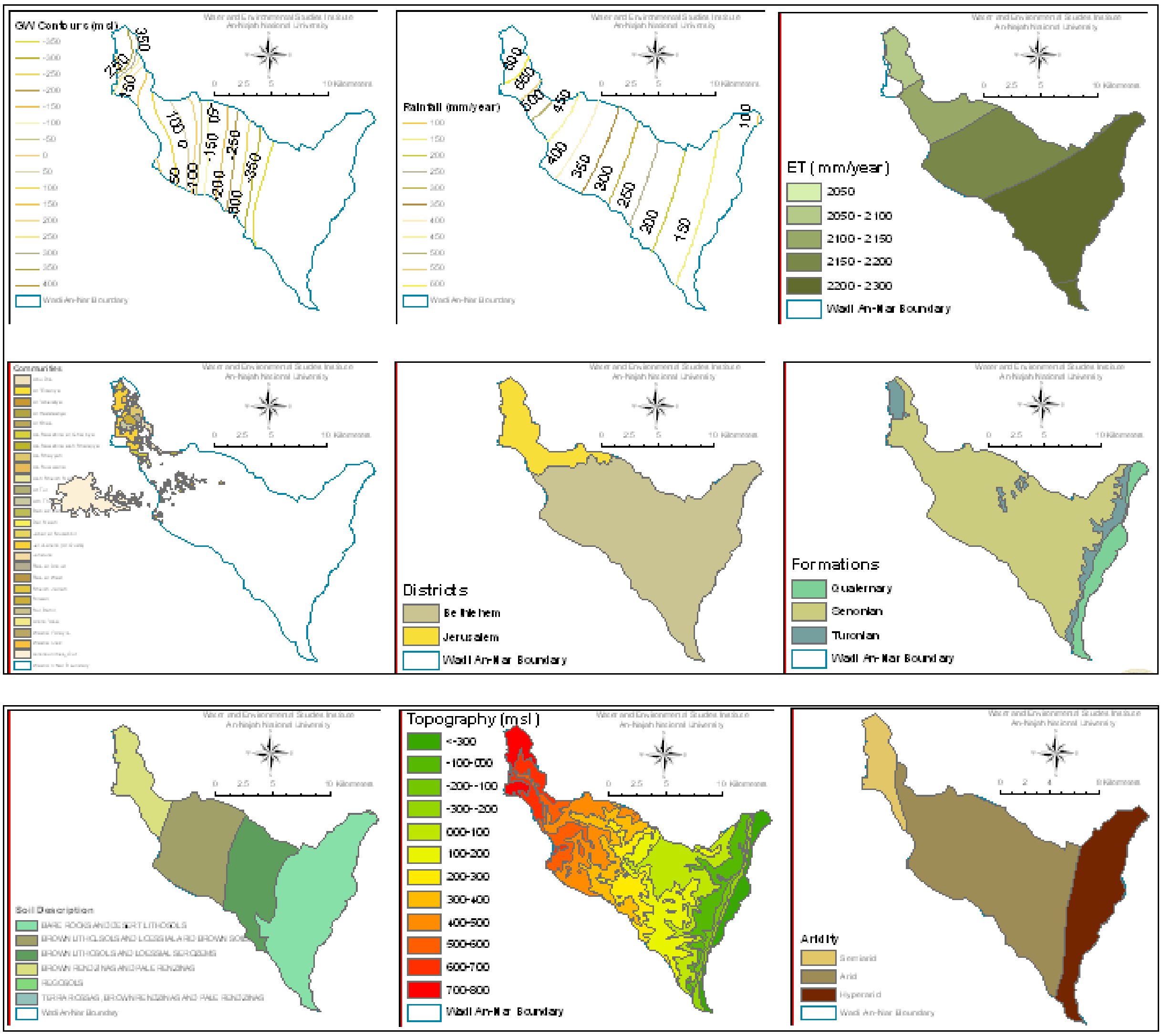

Figure 2. General properties of Wadi Nar catchment

PROBLEM IDENTIFICATION

WNW witnesses the disposal of untreated wastewater into the main wadi course. Wastewater originates from the major Palestinian cities and local communities in the area, including East-Jerusalem that are inhabited by a total of approximately 135,000 residents.

The on-going practice of the disposal of untreated wastewater into the Wadi course forms a health hazard, does not comply with the environmental requirements, and may potentially contaminate the underlying aquifer. Management options proposed for WNW would imply the reuse of the generated wastewater by installing wastewater treatment plants in the area. Based on the work of HWE (2007a) and Klawitter et al. (2007), Figure 3 shows the expected population size of the study area by year 2035, the corresponding water consumption, wastewater generation, and the area of land needed to implement an economically-sound wastewater reuse scheme.

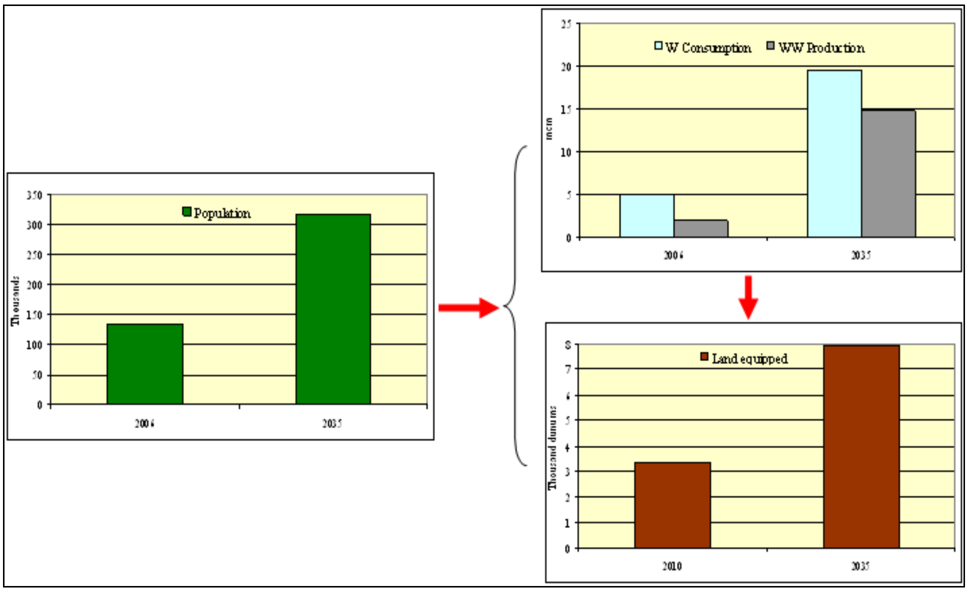

Figure 3. Current and expected future population, water consumption and wastewater production, and proposed land to be equipped for potential wastewater reuse in the study area

SCOPE AND OBJECTIVES

This paper aims at documenting the development of a Water Evaluation and Planning (WEAP) tool for mapping the management options related to wastewater treatment and reuse in WNW. Scope of work includes the following:

- To map the recent wastewater collection situation;
- To visualize and describe different wastewater management scenarios taking into account increasing wastewater quantity caused by population growth and increasing central water supply;
- To build up the WEAP model allowing for the simulation and analysis of various treated wastewater use scenarios in relation to the availability of land fit for irrigation in WNW.

The WEAP model developed for WNW takes into account the following management options (Klawitter et al., 2007):

Option I: Reuse of wastewater from all Palestinian communities including East Jerusalem. This option connotes the construction of a centralized treatment plant for wastewater generated from all the Palestinian communities (including East Jerusalem) linked to WNW.

Option II: Under the second option, there are two alternatives:

- (IIa) reuse of wastewater from all Palestinian communities excluding East Jerusalem. This implies the construction of one separate treatment plant for the wastewater from all the Palestinian communities (excluding East Jerusalem) linked to WNW;

- (IIb) Reuse of wastewater from all Palestinian communities in East Jerusalem through a separate wastewater treatment plant for the wastewater originated from these communities.

Therewith, WEAP visualizes the following planning output spatially and temporarily (among others):

- Amount of water consumed by each community in the study area based on the activity level (population size and per capita water consumption on daily basis);
- Amount of wastewater generated from each community in the study area;
- Amount of wastewater treated by each proposed wastewater treatment plant; and
- Total agricultural area that can be irrigated adequately.

METHODOLOGY AND IMPLEMENTATION

In order to achieve the research objectives, we implemented the methodology depicted in Figure 4 and outlined in the subsequent sections.

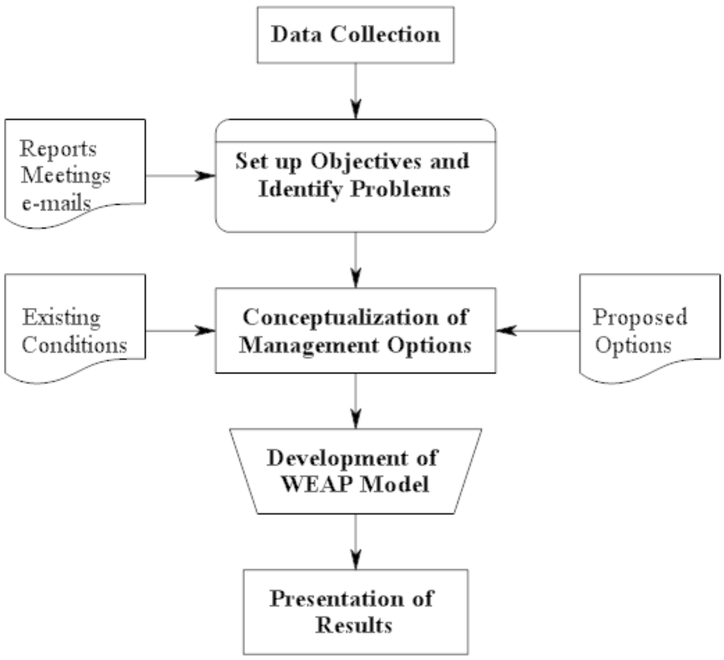

Figure 4. A pictorial representation of the methodology

We started by gathering the available relevant information mainly from the discussion papers developed within the overall study. In addition, information was obtained through meetings and workshops. This important step facilitated the conceptualization of the WEAP model. In addition, this is a guarantee that the data used and the options mapped are in full concordant with the other team members. After collecting relevant data, work objectives were developed and existing problems were comprehended such that the objectives address these problems.

Conceptualization was a crucial step since it precedes the development of the WEAP model. The conceptualization rotated around the design of the management options that were agreed upon earlier. We relied largely on the study of Abu-Madi (2006) in mapping the management options and in creating the WEAP model. After determining the options and the designation of the related input parameters, WEAP models that address the different options were developed and tested accordingly. WEAP results were verified for the different options by comparing them with the results presented by Abu Madi (2006). The outcomes from running the WEAP models developed to map the above-mentioned options are presented and analyzed in the following sections.

CONCEPTUALIZATION OF MANAGEMENT OPTIONS

Existing conditions – status quo

This scenario considers the existing conditions. Conceptually, Figure 5 depicts this scenario. Almost 2 million cubic meters (mcm) of raw wastewater are recently being dumped in the Wadi untreated.

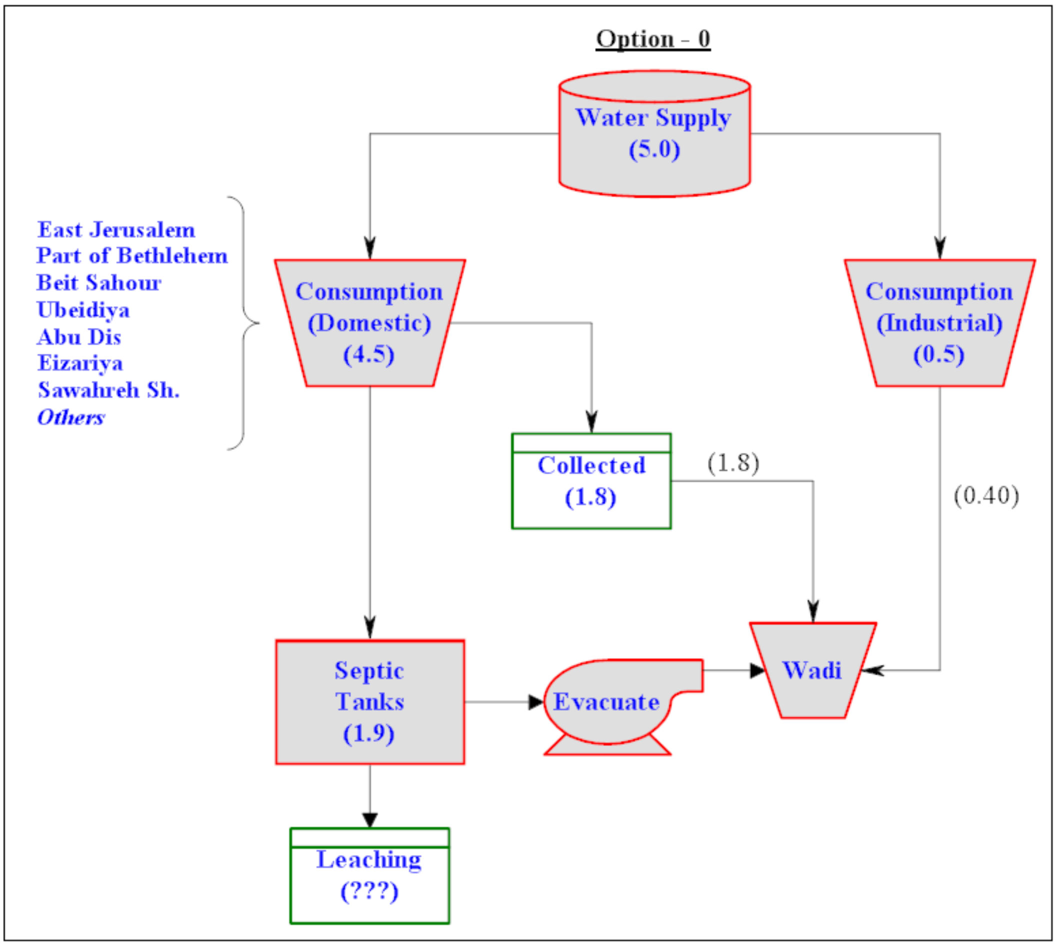

Figure 5. Conceptual representation of the status-quo scenario

Option I: Reuse of wastewater from all Palestinian communities including East Jerusalem

This option connotes the construction of a centralized treatment plant for the wastewater generated from all the Palestinian communities (including East Jerusalem) linked to WNW. Figure 6 depicts the conceptual representation of this option. The location of the WWTP is next to Ubeidiya located within WNW.

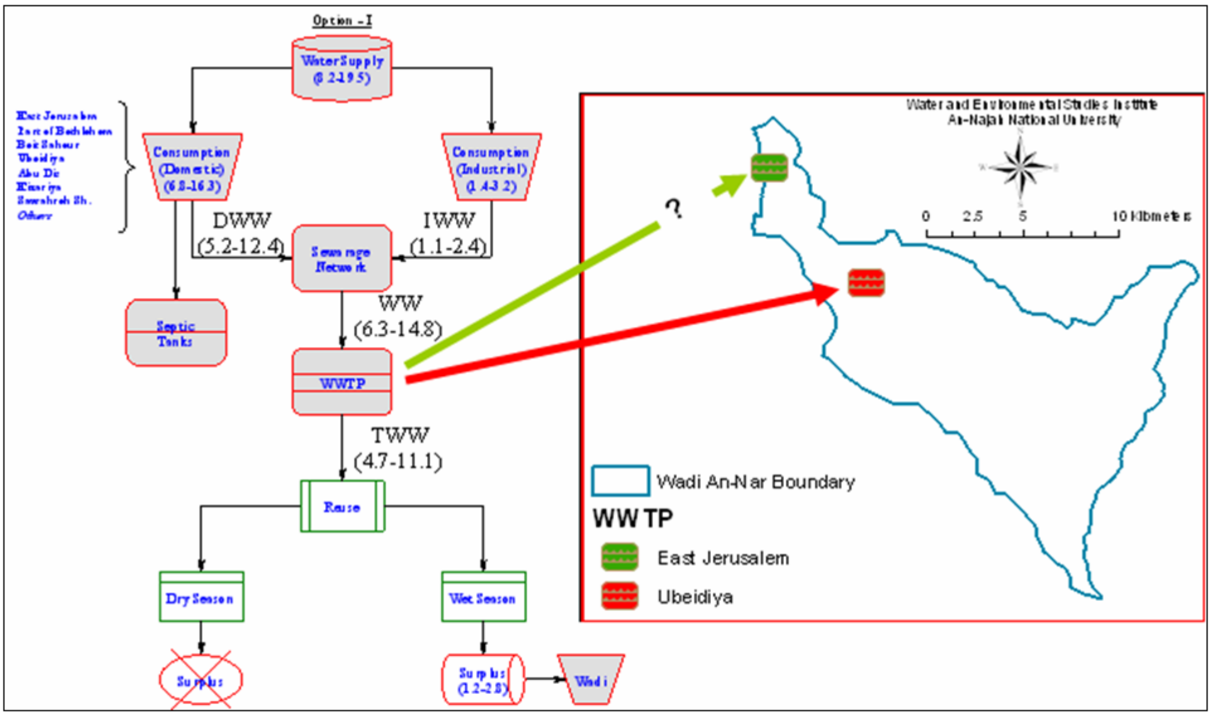

Figure 6. Conceptual representation of the first management option (Option – I)

Option IIa: Reuse of wastewater from all Palestinian communities excluding East Jerusalem

This implies the construction of one separate treatment plant for the wastewater from all Palestinian communities (excluding East Jerusalem) linked to WNW. Figure 7 depicts the conceptual representation of this option.

Option IIb: Reuse of wastewater from all Palestinian communities in East Jerusalem through a separate wastewater treatment plant for the wastewater originated from these communities

This implies the construction of one separate treatment plant for the wastewater generated from the Palestinian communities in East Jerusalem. Figure 8 depicts the conceptual representation of this option.

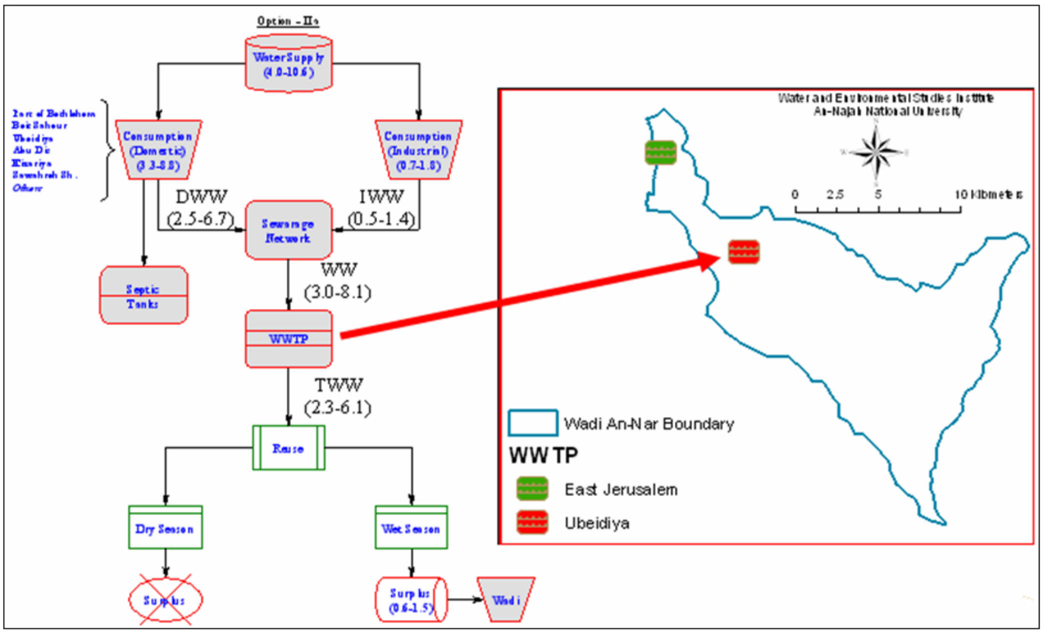

Figure 7. Conceptual representation of the Option – IIa

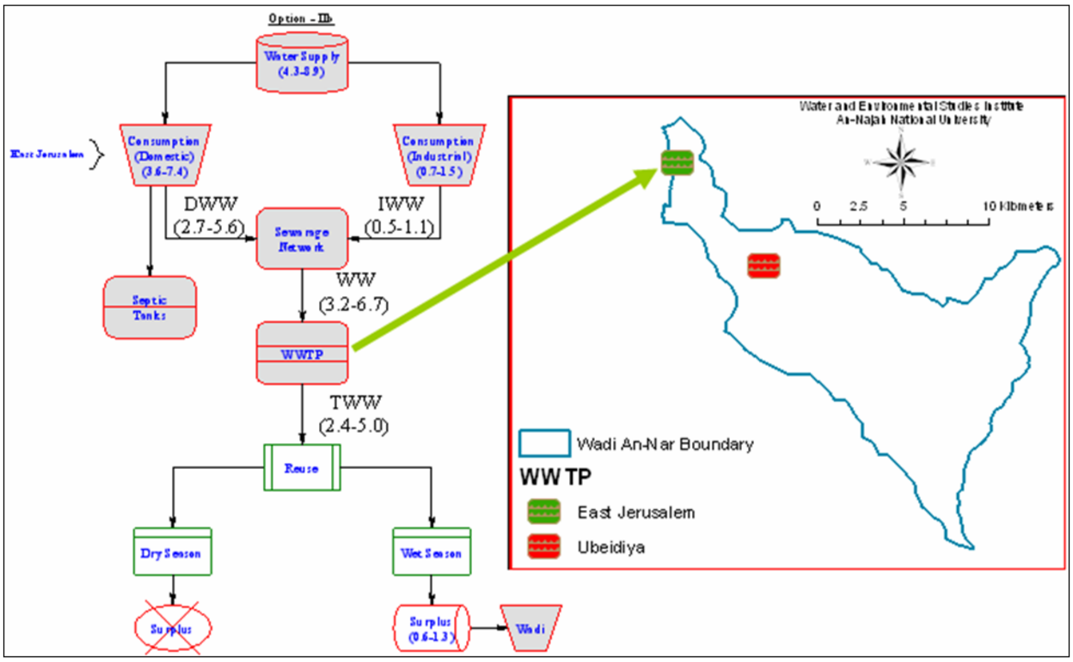

Figure 8. Conceptual representation of the Option – IIb

DEVELOPMENT OF WEAP MODELS

General description of WEAP

WEAP stands for Water Evaluation And Planning System (see Figure 9).

Figure 9. The opening window of WEAP

WEAP is developed by the Stockholm Environment Institute (SEI) based in Boston, MA, US. WEAP Can be downloaded from www.weap21.org. WEAP is a tool for integrated water resources planning and provides a comprehensive, flexible and user friendly framework for policy analysis and impact assessment. WEAP is comprehensive, straightforward, easy to use, and attempts to assist rather than substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, storage, pollution generation, treatment and discharge, etc. As a policy analysis tool, WEAP evaluates a full range of water development and management options. WEAP operates on the basic principle of water balance where it places the demands (water use patterns, equipment efficiencies, reuse, prices and allocation) on an equal footing with the supply (streamflow, groundwater, reservoirs and water transfers). WEAP is applicable to municipal and agricultural systems and single catchments or complex transboundary water systems. Additional information about WEAP is available at www.weap21.org.

WEAP development

WEAP development in general connotes several steps. In the definition, we set up the time frame which is in this case the year 2006 for the current accounts. These accounts simulate the existing situation of the water demand, population, and resources of the system, the spatial boundary, system components and configuration of the problem.

Alternative sets of future assumptions are based on policies, technological development and other factors that affect demand, pollution, and supply and hydrology. Scenarios are constructed based on several assumptions. Finally, the scenarios are evaluated with regard to water sufficiency and other considerations. The scenarios can address a broad range of *What if* questions such as: what if population growth and economic development patterns change? WEAP calculates a water mass balance for every node and link in the system on a monthly time step. In our work, the time extends from the year 2006 to the year of 2035. A total of 10 demand nodes in the current account and 11 demand nodes in the scenarios were considered. Demand nodes and water consumption rates are summarized in Table 1. The percentages of population connected to the sewage networks are summarized in Table 2.

Table 1. Demand nodes and water consumption rates (l/c/d) in the communities under study

Community	2006	2010	2015	2020	2025	2030	2035
Part of Bethlehem	62	90	90	140	140	140	140
Beit Sahour	62	90	90	140	140	140	140
Ubediya	62	90	90	140	140	140	140
Abu Dis	147	140	140	140	140	140	140
Al Ezariya	141	140	140	140	140	140	140
Sawahreh Sharqeyeh	62	90	90	140	140	140	140
East Jerusalem	90	140	140	140	140	140	140
Others[1]	62	90	90	140	140	140	140

[1] Several small communities within WNW

Table 2. Percentage of population connected to sewerage network for the communities under study

Comunity	2006	2010 - 2035
East-Bethlehem	95%	95%
Beit Sahour	95%	95%
Ubediya	0%	95%
Abu Dis	10%	95%
Al Ezariya	3%	95%
Sawahreh Sharqeyeh	0%	95%
East Jerusalem	80%	95%
Others	5%	95%

It was assumed that the industrial sector consumes 10% of the domestic water consumption until the year 2010 and 20% of the domestic water consumption afterward. In the development of the WEAP model, it was assumed that water resources are adequate and suffice all the demands from the communities of WNW throughout the simulation period. In addition, a population growth rate of 3% was considered up to the year of 2035.

WEAP model components and assumptions

During the course of WEAP development, the following assumptions were made:

- Demand sites and water consumption rates are as summarized in Table 1;
- The annual activity level is assumed based on a population growth rate of 3%;
- The return flow links connect the demand sites and the disposal nodes or the WWTP;
- The transmission links connect the demand sites with the supply node with a maximum flow rate sufficient to cover the site demand;
- As the demand sites are not fully connected to the wastewater networks, septic-tank nodes where assumed in the system to account for the amount of wastewater that is not collected by the sewerage system. We assumed that 50% of the septic tanks are generally evacuated and that either the evacuated wastewater was disposed off in the Wadi or diverted to the wastewater treatment plant (WWTP);
- We considered that 20% of the water consumed is lost and that 80% of this water returns to the system as wastewater (represented in WEAP as return flow). Thereafter, the return flow is then routed based on the percent of connection to the wastewater network;
- In the proposed future options two options where adopted; the first option is to collect all the wastewater from the West Bank and East Jerusalem communities and to be treated in Wadi Nar WWTP while the second option is to collect the wastewater from West Bank communities and East Jerusalem communities and to treat the wastewater separately. That is, there will be two WWTPs; one in East Jerusalem and the second in Al-Ubeidiya;
- Agricultural area that can be irrigated with the treated wastewater is based on a water consumption rate of 700 CM/dunum in the dry season and 350 CM/dunum in the wet season. This agricultural area increases over time, incrementally.

RESULTS AND ANALYSIS

In the following sections, results from WEAP model were obtained for the different options. The essence of these options relies on the fact that the communities will be almost connected to the sewerage collection network. These options differ from each other when considering the existence of a wastewater treatment plant. Another key factor embedded in these options is that the growth rate leads to an increased population and indeed results in an increase in the generated wastewater in the area due to the increase in water consumption.

Existing conditions

To map the existing situation in terms of wastewater generation, collection, population, and future growth, the model was developed accordingly taking into account the assumptions made earlier. Figure 10 illustrates the schematic of the WEAP model for mapping the existing situation of wastewater. WEAP was executed and results are summarized in Figure 11. Results cover the period up to the year 2035. Key results cover the calculated water consumption and the generated wastewater quantities (named return flow as in Figure 12).

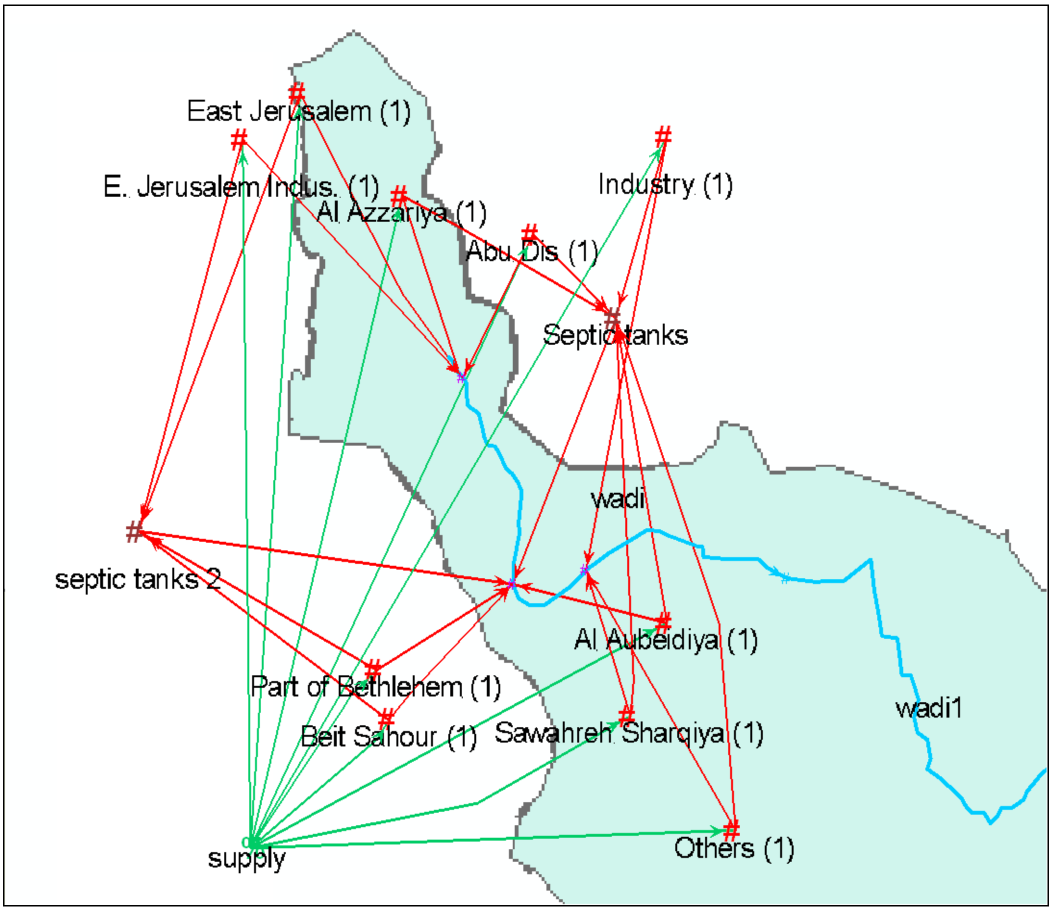

Figure 10. Schematic of WEAP model for the existing conditions

	2006	2010	2015	2020	2025	2030	2035	**Sum**
Abu Dis	649.5	731.1	847.6	982.6	1,139.1	1,320.5	1,530.8	7,201.3
Al Aubeidiya	193.5	316.1	366.4	660.8	766.0	888.0	1,029.5	4,220.3
Al Azzariya	895.0	1,007.4	1,167.8	1,353.8	1,569.4	1,819.4	2,109.2	9,922.0
Beit Sahour	347.8	568.2	841.7	1,187.9	1,377.1	1,596.5	1,850.7	7,770.0
E. Jerusalem Indus.	203.0	710.9	824.1	955.4	1,107.5	1,283.9	1,488.4	6,573.1
East Jerusalem	2,030.1	3,554.3	4,120.4	4,776.7	5,537.5	6,419.5	7,442.0	33,880.7
Industry	252.9	661.7	767.1	889.2	1,030.9	1,195.1	1,385.4	6,182.4
Others	124.5	203.4	235.7	425.1	492.8	571.3	662.3	2,715.1
Part of Bethlehem	203.7	332.8	544.6	695.6	806.4	934.9	1,083.8	4,601.8
Sawahreh Sharqiya	117.4	191.9	222.4	401.1	465.0	539.0	624.9	2,561.6
Sum	5,017.5	8,277.7	9,937.9	12,328.3	14,291.8	16,568.1	19,207.0	85,628.3

Figure 11. Water demand (consumption) in thousand cubic meters for the study area for different years

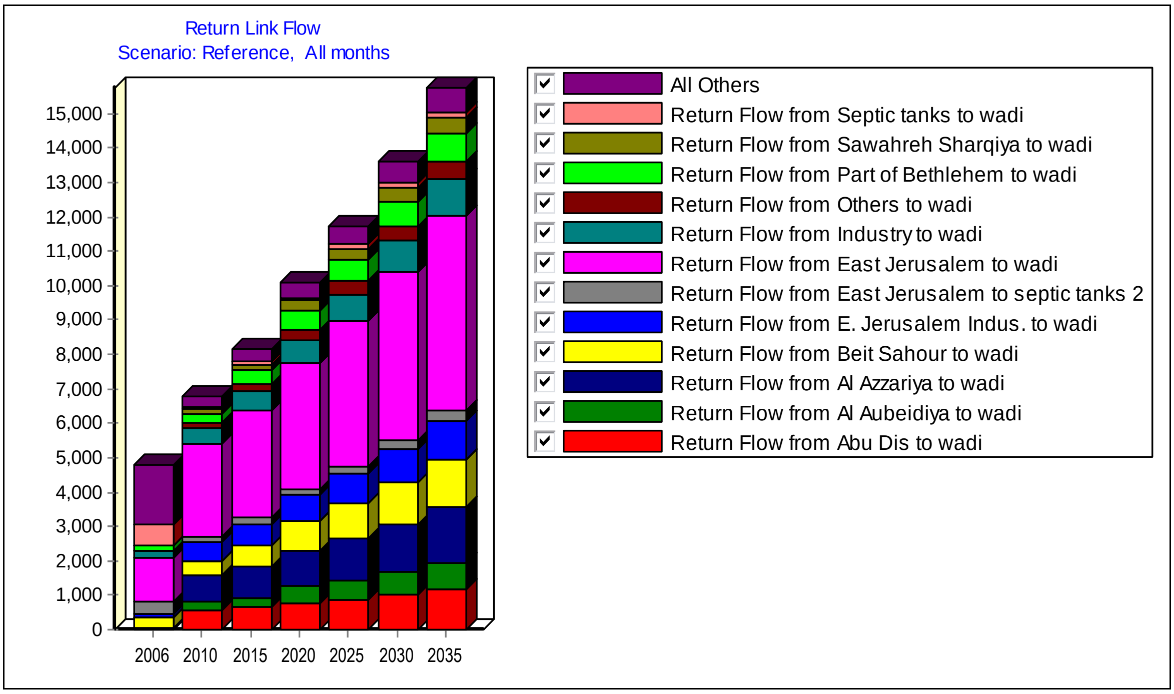

Figure 12. Return flow from the different communities (and components) in Wadi Nar catchment

Option I

As mentioned earlier, Option I considers the construction of a central WWTP that receives wastewater from all the communities in the WNW. It is proposed that this option and Option II are to be implemented in the year 2015. The following figure (Figure 13) illustrates the schematic of the WEAP model for mapping Option I. As can be seen from this figure, there is one WWTP placed in Al-Ubeidiya. Since this option entails the construction of the WWTP, Figure 14 illustrates the inflows and outflows of the proposed WWTP of WNW. The amount of treated wastewater that can be used for irrigation purposes in agricultural area varies between 4.7 MCM in 2010 to 11.2 MCM in 2035.

Since the total area that can be irrigated with wastewater depends largely on the amount of wastewater being generated and later treated, this implies that the area itself varies with time as can be shown in Figure 15. It is worthwhile to mention that this estimation of land use availability for the use of treated wastewater relies on the assumption of a consumption rate of 700 CM/dunum in the dry season and 350 CM/ dunum in the wet season.

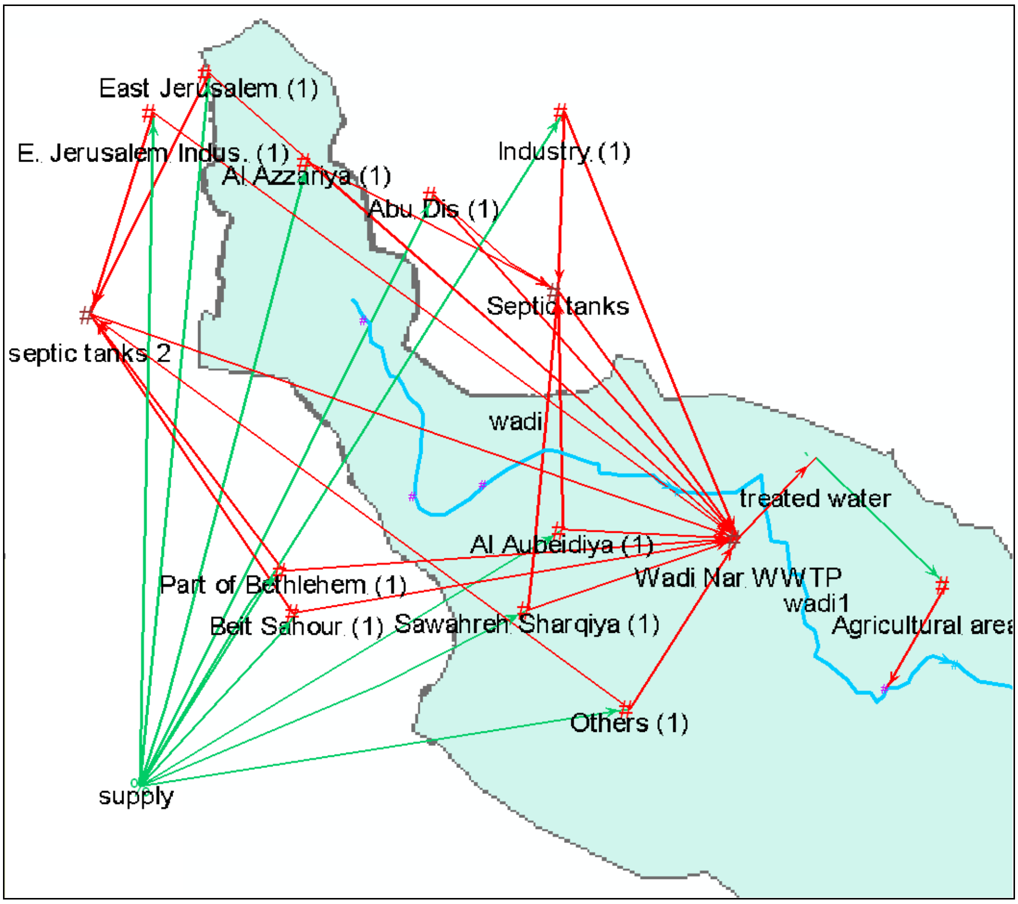

Figure 13. Schematic of WEAP model for option I

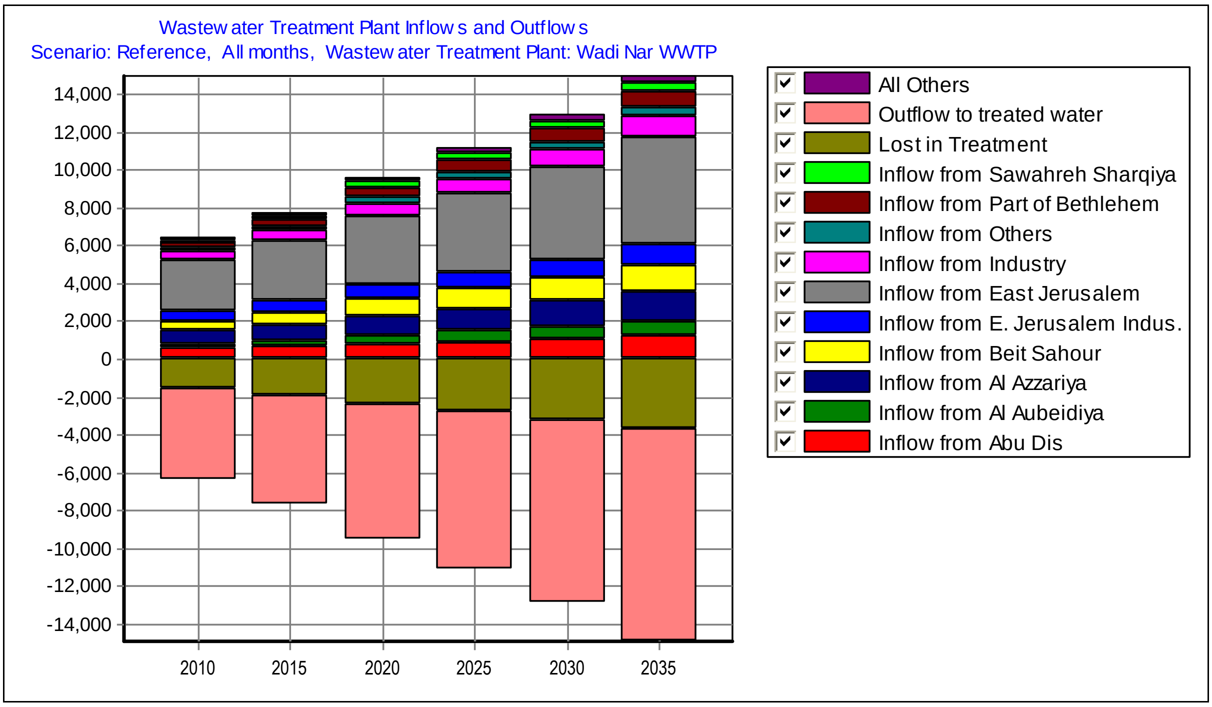

Figure 14. The time distribution of the inflows and outflows of the proposed WTTP of WNW corresponding to Option I

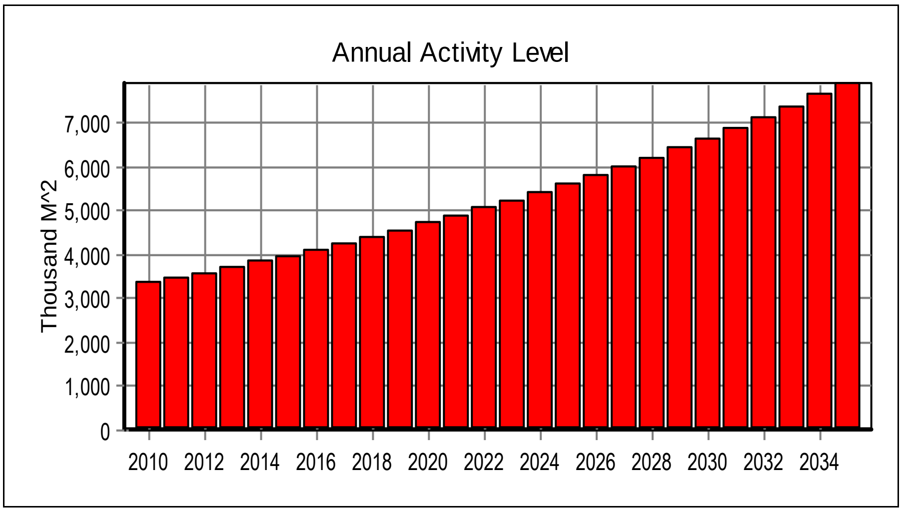

Figure 15. The temporal distribution of the total agricultural area that can be irrigated with treated wastewater corresponding to option I in the units of thousands of squared meters

Option II

Option II implies the treatment of wastewater of the West Bank communities and East Jerusalem communities each one separately. The following figure (Figure 16) illustrates the schematic of the WEAP model for mapping option II. As can be seen from this figure, there are two WWTPs placed in East Jerusalem and Al-Aubeidiya.

Figures 17 and 18 depict the inflows and outflows to the two proposed WWTPs from the different communities within the study area. Figure 19 shows the temporal distribution of the wastewater quantities that are expected to be used in irrigation as obtained from the two proposed WWTPs. Figure 20 and Figure 21 depict the agricultural area that can be irrigated using the treated wastewater from the two proposed WWTPs.

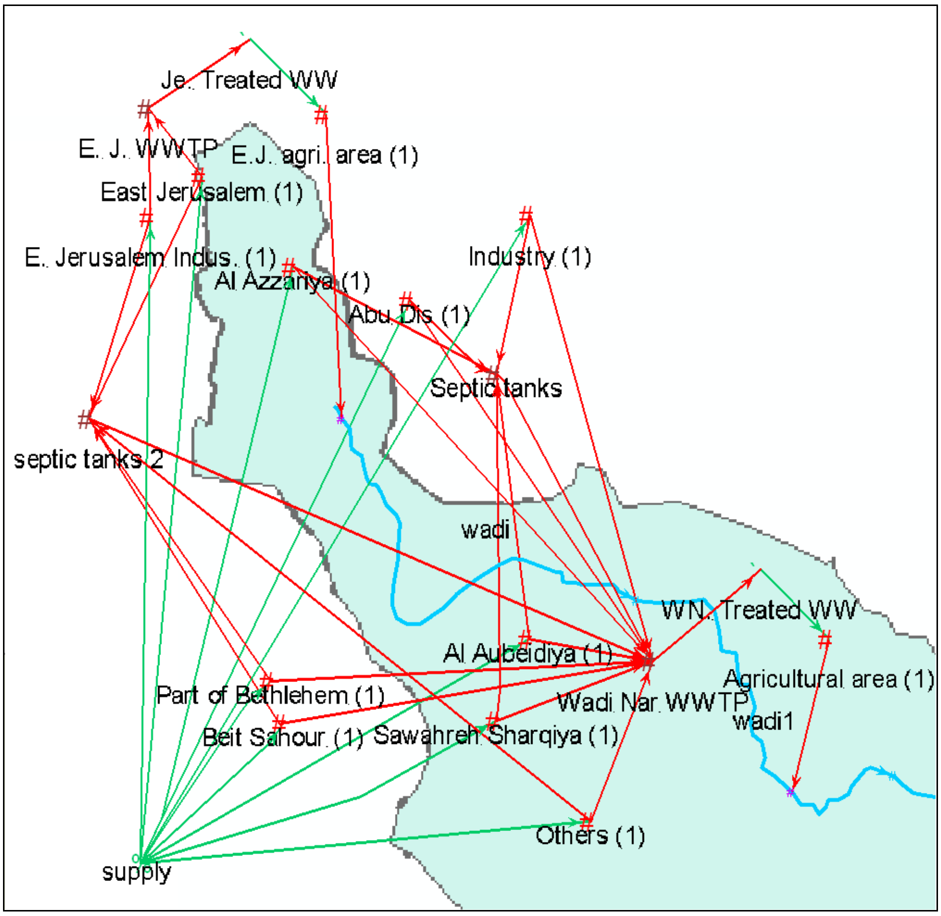

Figure 16. Schematic of WEAP model for option II

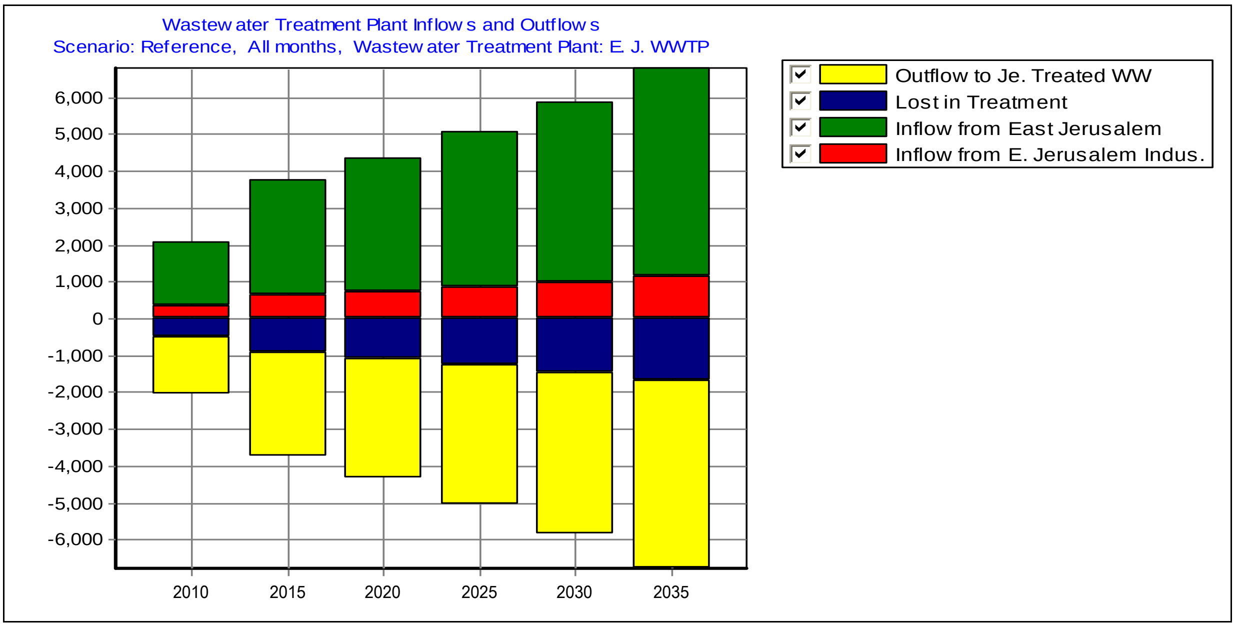

Figure 17. The time distribution of the inflows and outflows of the proposed WTTP of East Jerusalem corresponding to Option II

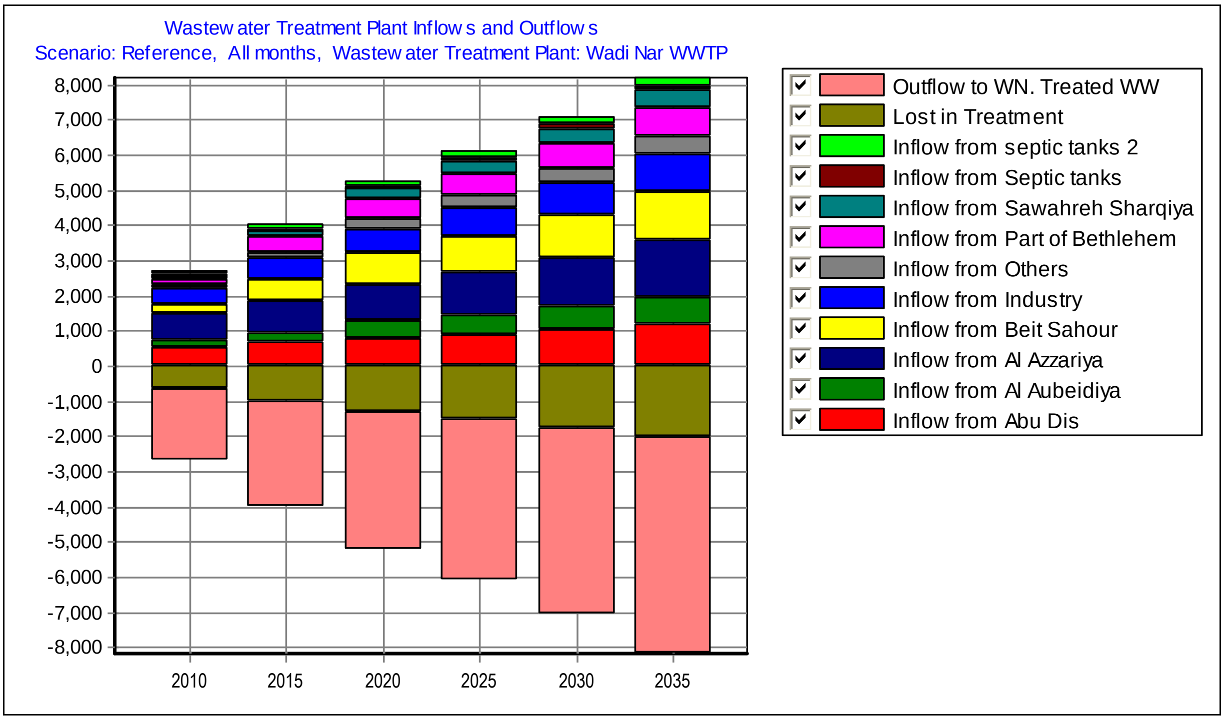

Figure 18. The time distribution of the inflows and outflows of the proposed WTTP of East Jerusalem corresponding to Option II

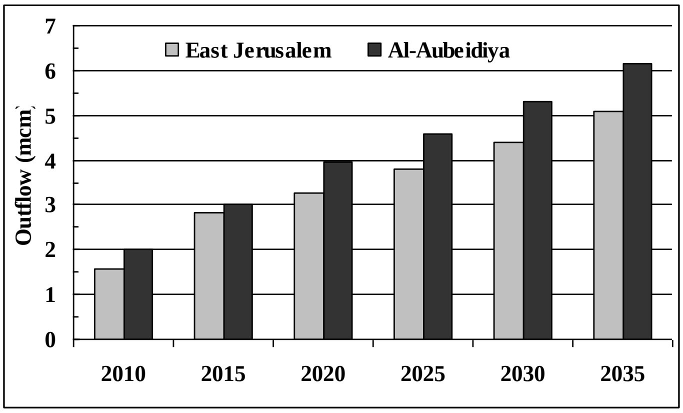

Figure 19. The time variability of the quantities of treated wastewater that can be readily used in irrigation as obtained from the two proposed WWTPs

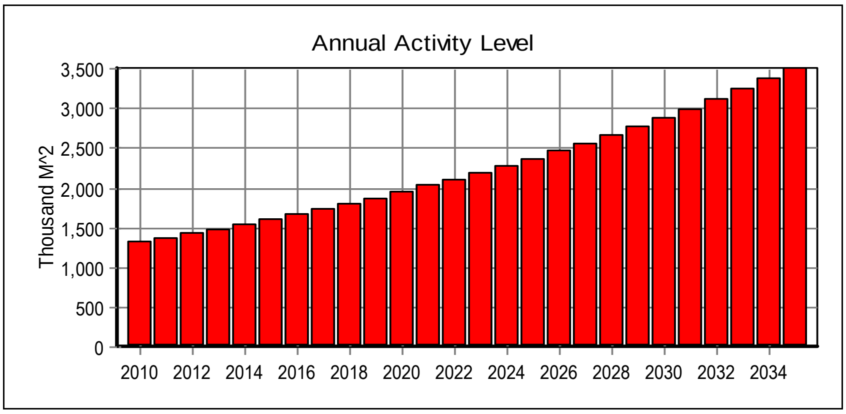

Figure 20. The total area that can be irrigated using the treated wastewater from the WWTP of East Jerusalem

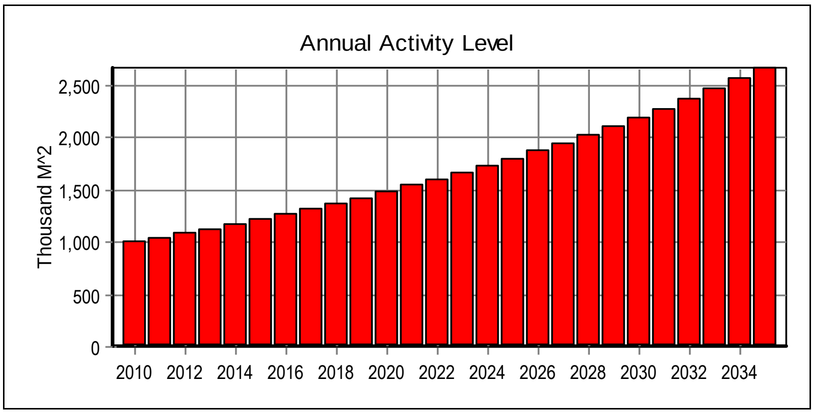

Figure 21. The total area that can be irrigated using the treated wastewater from the WWTP of Al-Aubeidiya

Scenario assessment using WEAP

As was furnished earlier in this paper, all scenarios assume a water consumption rate of 140 l/c/d starting from the outset in year 2010 and also assume that all communities are connected to the sewerage network at a percentage of 95%. However, such a scenario may not occur. If this is the case, then the expected benefits that may take place will not be attained due to the decline in the amount of wastewater being generated. This implies in turn that there will be a reduction in the total area that can be irrigated using the treated wastewater.

In this section, we attempt to utilize the developed WEAP model in finding out the implications of not fulfilling the above-mentioned assumptions. In other words, WEAP will be utilized in addressing *what if* questions. By doing this, we aim to demonstrate WEAP applicability and flexibility and to show the overall sensitivity of WEAP outcome to changes in key inputs. Such an example definitely suites the desire of decision makers in processing emerged scenarios and predicting the corresponding output. As such, we ran a scenario in which only 60% of the population that is currently without a collected network are connected to a sewerage system.

This very scenario reflects potential influence of the current political situation in Palestine and the possible impedance of connecting these communities to the sewerage system. To determine the per capita daily consumption of water, it was assumed that water consumption increases by 1 litre per capita per year. Figure 22 depicts the amounts of wastewater that are expected to be generated from the two WWTPs. These quantities can be used in irrigation. The agricultural area that can be irrigated from the WWTP located in Al-Aubeidiya is 3,493 donums in the year 2035 while the wastewater treated in the WWTP of East Jerusalem can irrigate a total area of 2,978 dunums.

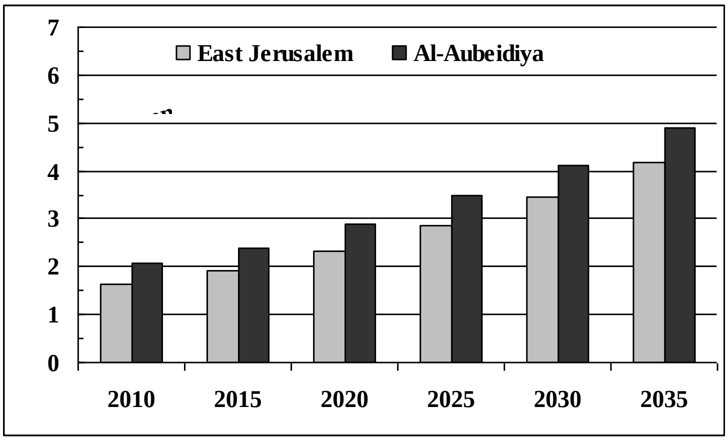

Figure 22. The time variability of the quantities of treated wastewater that can be readily used in irrigation. These quantities are obtained from the two proposed WWTPs under the assumption that only 60% of the population are connected to a sewerage network in million cubic meters

Cost estimate

WEAP can provide a cost estimate. In our model if we use an activated sludge WWT method and for option I, the following figure illustrates cost of one cubic meter of treated wastewater from year 2010 to the year 2035. It costs \$1.32 /m^3 in the year of 2010 to \$0.56 /m^3 in the year 2035 as shown in Figure 23.

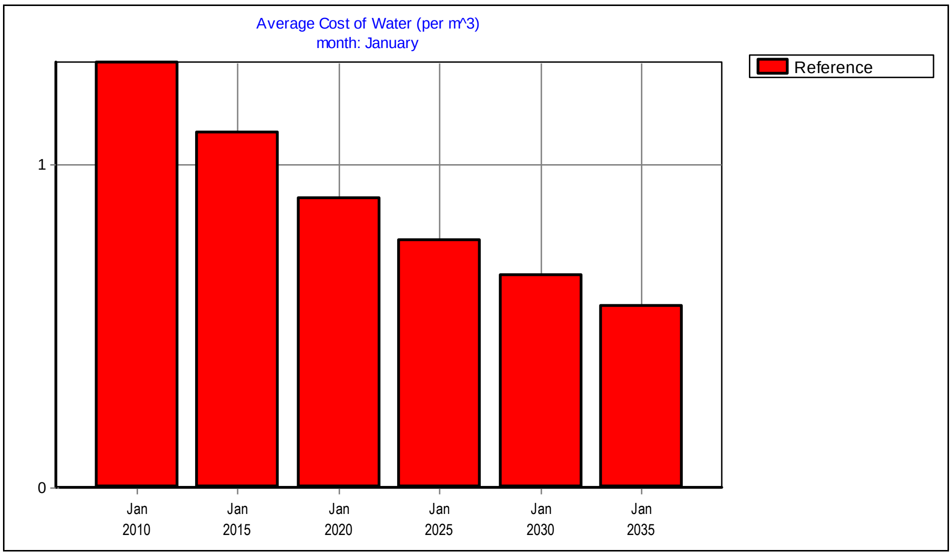

Figure 23. The time variability of the cost of one cubic meter of treated wastewater from year 2010 to the year 2035 under option I

CONCLUSIONS

The following are the main conclusions:

1. WEAP is a sound management tool that can visualize the impact of key factors on the final outcome in terms of the treated wastewater quantities and corresponding total area that can be irrigated accordingly;
2. Results show that the outcome depends largely on the population size (growth rate) and the percentage of connection to sewerage systems. This is an indication of the high sensitivity of the WEAP output to variations in the input parameters. Needless to mention that the uncertainty in the values of these parameters would drastically lead to unrealistic estimates of anticipated benefits. In other words, there are two major concerns:
    a. We do not expect that the per capita water consumption will go up to 140 l/d starting from 2010
    b. We do not expect that the communities (within the study area) that are currently unconnected to the sewerage system to be connected at 95% level
3. There is variability in time and space in terms of the area that can be irrigated using the treated wastewater. In other words, with increasing the population size more wastewater will be available for reuse;
4. It is recommended that the data used in the development of the WEAP model to be updated on regular basis to insure that the data is genuine and to verify the impacts of the data on the overall planning strategies; and
5. One of the issues that need to be considered in a rational way is the availability of freshwater resources that can furnish the designated water consumption rates. In addition, this applies to the percentage of connection to the sewerage systems since it is quite defying to arrive at 95% of connection within the specified time span.

ACKNOWLEDGEMENTS

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