APPLICABILITY OF WEAP AS WATER MANAGEMENT DECISION SUPPORT SYSTEM TOOL ON LOCALIZED AREA OF WATERSHED SCALES: TULKAREM DISTRICT IN PALESTINE AS CASE STUDY

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Water Resources Management; Simulation; Optimization
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ABSTRACT

The applicability of WEAP as a Decision Support Systems (DSS) tool for water resources management in a watershed or localized district was tested. The DSS for the management of water resources system under investigation consists of three components (1) stakeholders survey to determine key planning issues and questions needed for an operational DSS (2) data gathering, organizing, storage, manipulation/management capabilities; and visualization and (3) WEAP model that perform simulation and optimization of the water resources management through various scenarios and/or DSS questions. The DSS which involves taking account water quantity, water quality, cost, water management, water trading, and other. The developed DSS was tested on a case study of the Tulkarem district water resources system, in the Palestinian Territory. The Tulkarem district share 5% by area, 7 % by population, and 10% by irrigated land, and 11% by water use in agriculture of the West Bank. The results obtained demonstrate the feasibility of developing a DSS and its useful implementation for localized and or watershed water resource system. Also these results demonstrate that application of a WEAP model can support water management in the district.

Keywords: Decision support systems; Water resources management; Simulation; Optimization; Tulkarem; Palestine.

INTRODUCTION

Water resources management evaluation and planning on regional or a country level or basin scale is useful and necessary, however to optimize such evaluation and planning process focus should be given to watershed resources management. Economic growth and efficiency within the watershed or the area under investigation including agricultural production is very important in such evaluation and planning process.

The planning of water resource systems requires a multi-disciplinary approach that brings together an array of technical tools and expertise along with parties of varied interests and priorities. Often, the water management landscape is shaped and influenced by a set of linked physical, biological, and socio-economic factors: climate, topography, land use, surface water hydrology, groundwater hydrology, soils, water quality, ecosystems, demographics, institutional arrangements and infrastructure (Biswas 1981; Loucks 1995; Bouwer 2000; Zalewski 2002).

Olsen 2005 indicated that there is a lack of site-specific DSS that utilize local hydrological and socio-economic data for assessing regionally-based rural water supply schemes. Such a system and a user-friendly computer model would minimizes the need for gathering complex data, and incorporates non-technical factors into the computer algorithms, and greatly improve the process for managing rural water supply sources.

Potential conflicts arising from competing demands of complex water resource systems require a holistic approach to address the various components of water management. In this paper the Water Evaluation and Planning (WEAP) has been chosen to evaluate the Tulkarem district - Palestine water management options under alternative scenarios of the future.

There are a range of issues and challenges in Tulkarem district including among others,

- Refining the quantity and timing of pumping rates aiming towards actively managing water demands
- Shifting of water allocation (trade-offs and compromises) between various water sectors in the districts

For these reasons, this research attempts to give Tulkarem district water resources managers a tested water management tool to assist them in defining water supply and demand problems and options for various users, selecting and positioning appropriate best water management practices, and understanding the water quality problems including wastewater treatment and reuse. The end result should be an improved, sustainable and equitable water resources development plan and management policy, appropriate for the region and its people.

STUDY AREA

Palestine as presented in this paper consists of the West Bank including East Jerusalem and the Gaza Strip. The West Bank and the Gaza Strip are those parts of Historic Palestine which were occupied by the Israeli army during the 1967 war between Israel and Egypt, Syria, and Jordan. The land area of the West Bank is estimated at 5572 km^2 extending for about 155 km in length and about 60 km in width. The Gaza Strip, with an area of 367 km2 extending for approximately 41 kilometers in length and approximately 7 to 9 kilometers in width (Abdel Salam 1990, and Haddad 1998).

The Tulkarm district is located in the north western part of the West Bank. The district has an area of about 280 km2 and rises toward the east from 75m to 500m above sea level. It lies in the semi coastal agroecological region which is characterized by its high fertility soil.

It contains 42 localities of which 5 are classified as urban, 2 refugee camps and all others are rural areas. The results of local community survey indicated that there are 168,270 persons living in the district with a relatively high population density of about 601 persons/km^2 (PCBS, 2003).

METHODS

a. The WEAP Model

WEAP, water evaluation and planning system developed by the Stockholm Institute (SEI, 2001), is an adaptable water resource planning model that is scalable depending on the complexity of the system under investigation. WEAP is a water demand and supply accounting model (water balance accounting), which provides capabilities for comparing water supplies and demands as well as for forecasting demands. It has an accessible interface and transparent data structure that make it suited as a tool for deliberations between a diverse group of stakeholders.

WEAP is a generic computer package that suitable mainly for surface water planning. It develops a model schematization consisting of a network of nodes connected by links or branches. WEAP can simulate a water allocation policy. Water allocation priority rules are set within WEAP based on either first come first served, or specific use or user, and/or making allocation proportional to demand. Because it is generic, it is not capable of capturing every fine distinction or detail of a water resource system and as such is best applied to scenario screening and pre and feasibility levels of analysis rather than to detailed design and permitting tasks.

One of WEAP's advantages is that it places the demand side of the water balance equation on a par with the supply side, and addresses some of the critiques of water DSSs (Loucks 1995). WEAP main disadvantages include its reliance on the development of scenarios that can be quantified, without notifying how these scenarios should be developed and placing the actors deliberately outside the system's architecture.

WEAP outputs include various water demand parameters, Tables, Schemes, Charts, Estimates, and others.

b. The DSS

The DSS for the management of the Tulkarem district water resources system consists of two components (1) data gathering, organizing, storage, manipulation/management capabilities; and visualization and (2) WEAP model that perform simulation and optimization of the water resources management through various scenarios and/or DSS modules.

c. Database Structure and Input Data and Parameter Estimation

Water Supply and Demand: The main source of water is groundwater through wells belonging to local authorities, the amount of water supply does not satisfy human basic needs; moreover, about 45% of the water supplied is lost due to leakage in the distribution links. The people were obliged to use water with less quality such as rainfed cisterns and agricultural wells or to buy water from private water tankers.

The total amount of water supply delivered to the district is 5.776 MCM for municipal and industrial uses and 6.1 MCM for agricultural purposes. Domestic wells are contributing about 79% of total supply; while all other sources are contributing 21% percent (see Table 1 for details).

Even though the amount supplied in its best case is not more than 100 l-c-d which is far from WHO standards of 150 l/c-d, it represent one of the highest water supply rates in Palestine.

Water and Wastewater Infrastructure: Most of district population is served by water networks, about 81% of population has access to network through municipalities and only 8% don't have network and depend upon rainfed cisterns and private water tankers.

It was found that more than 48% of the water networks are older than 15 years and more than 50% of the water networks are in a bad physical condition or having high water losses levels (PHG). It was also found that 39 of the 42 localities (74 percent of total population) don't have wastewater collection networks and use percolation pits for wastewater disposal. Private tankers are used also to collect wastewater from filled percolation pits and subsequently they empty their content either in wadis, on agricultural lands, or open fields. This practice represents a potential to groundwater pollution.

There are two stabilization or collection ponds at the western outskirts of the city of Tulkarem. Only 50 % of the wastewater flows into the stabilization ponds and later flows to Wadi Al-Bud.

Climate, Hydrology, and Water Resources: The district is characterized by Mediterranean climate with hot, dry summers and wet, rather cold winters with short transitional seasons. Winter begins around mid-November and summer begins around the end of May. Rainfall occurs mainly during the winter months.

Maximum mean daily temperature is 26.2°C in August and minimum mean daily temperature is 11°C in January. Potential evaporation exceeds rainfall most of the year. It was estimated on the western slope 1369 mm/a.

It was estimated that runoff is only generated when precipitation is in excess of 50 mm in a single day or 65 mm in two consecutive days. (FORWARD, 1998; cited in CH2MHILL, 2003) There are four main wadis crossing the district toward the Mediterranean Sea: Massin, Zeimar, Abu Nar and Abraq. Runoff coefficient for the wadis was estimated to 0.34, 0.27, 0.23, and 0.3 of precipitation volume, and their annual discharge was estimated as 11.69, 8.7, 8.25, 8.15 MCM consequently. (CH2M HILL, January 2002). Examination of previous feasibility analysis Of West bank storm water development indicates that for wadis flowing to the Mediterranean Sea, only those with an estimated annual discharge greater than 10 MCM/yr at a relatively distinct discharge point were considered potentially feasible for storm water capture. Taking into consideration that 50 percent of the discharge is assumed to flow freely to Israel and the capture efficiency is 70 percent, the limit to storm water development from wadis is approximately 4 MCM/yr, but until now the water is lost through wadis (CH2MHILL, 2003).

It was assumed that only 20 percent of the built up area can feasibly be utilized as a collection surface and rainwater harvesting with storage efficiency of 50 percent, thus the maximum potential volume of water harvested is 10 percent, so for Tulkarm district is approximately 1.5 MCM. (CH2M HILL, 2003)

Annual recharge was estimated to about 211 mm (Abu Sadah et al 2005). Natural replenishment annual volume of rainfall was estimated at 173 MCM. The annual groundwater withdrawal or resource volume for the district is estimated at 19.9 MCM/yr. (Abu Sadah et al 2005). Annual water use rates and water demand planning assumptions used in the WEAP simulation runs are summarized in Table 1.

Table 1 Annual water use rates and water demand planning assumptions

Deamand Site	Annual Water Use Rate	Annual Activity Growth Rate	Demand Projection
Domestic	55 m^3/c-yr	2003-2010 3.5% 2010-2015 3% 2015-2020 2.5% 2020-2040 2%	2003-2010 55 m^3/C/y 2010-2015 75 m^3/C/y 2015-2020 90 m^3/C/y 2020-2040 100 m^3/C/y
<u>Agriculture</u> Trees Vegetables Field crops	950 m^3/dunum 601 m^3/dunum 550 m^3/dunum	0.5 %	Increase Effenciency 1425 901 825
<u>Livestock</u> Cattle Sheep	16.1 m^3/animal 3.00 m^3/animal	Assumed Constant	

d. Stakeholders Survey

Because of (1) scenario development is not a straightforward activity; it is partly an art that depends largely on the views of the stakeholders and (2) various stakeholders to the water resources system in Tulkarem district have potentially inconsistent interests and perspectives, it was recommended to involve district stakeholders not only in the planning and management of districts water resources but also in their problem solving and development. This involvement was made through a field survey to be conducted at the start of the study prior to the WEAP model simulation runs. The survey results should come out with the main water resources management decision support questions and issues to be run and found answers through the WEAP simulation runs.

The categories of stakeholders pertinent to Tulkarem district water resources, and representative of those likely to be involved in any comprehensive water management project and considered in the survey, are:

- The general public's level in urban and rural areas
- Farmers
- Technical/academic groups and individual experts.
- Local governmental departments including municipalities
- Local and international NGO's

Nine groups of questions were listed with a total 107 questions distributed as follows:.

1. Physical and Political Issues (4 questions)
2. Environmental Issues (8 questions)
3. Water Management Issues (24 questions)
4. Institutional Issues (15 questions)
5. Socio-Economic Issues (13 questions)
6. Agricultural Issues (15 questions)
7. Wastewater Reuse (7 questions)
8. Data Management and Modelling (13 questions)
9. Multiple Choice Issues (8 questions)

One hundred and seventy questionnaires were returned and properly completed out of three hundred distributed to stakeholders.

e. WEAP Model Application

The applicability and suitability of WEAP as water management DSS tool on Tulkarem district in Palestine is important to know and test. The applicability of WEAP as DSS in this case study is also aimed to be used to sustain the future planning, yield, reliability and risks, and associated costs of the Tulkarem district water resources system management taking in consideration various water resources constraints, competitive uses, and priorities.

As a result of the stakeholder field questionnaire on water management issues and the statistical - factor analysis - outcome two main factors were identified for better water management in Tulkarem district:

1. Agricultural aspects management
   a. I think that the government (PWA, ministry of agriculture or else) should introduce to farmers new agro technologies and on farm water and production management approaches
   b. I think that the government (PWA, ministry of agriculture or else) should appropriate some of the farms or farming practices and inappropriate others
   c. I think that existing land uses can be improved through better water and production (plant or animal) management practices

2. Physical and political Aspects and considerations
   - Israeli imposed and restricted water quotas has limited availability of water to Palestinian (including to farmers)
   - Palestinians will have to develop additional (conventional and non-conventional) water resources to meet their future water demands
   - Conflicts over water allocation between Palestinians and Israelis are limiting local economic development (including the expansion of agricultural land) and re-shaping political-economic landscapes of the district

The most important and weighted question from each of the other groups are listed bellow:

<u>Institutional Issues:</u> I think that the government (PWA, ministry of agriculture or else) should coordinate between itself, farmers –as one of the sector stakeholders – and the research/scientific, policy makers, and various decision makers.

<u>Wastewater Treatment and Reuse:</u> In case of the availability of treated wastewater I will increase my farm land and use the treated water in addition to available fresh water.

<u>Environmental Issues:</u> Negative impacts of uncontrolled disposal of agricultural waste as well as solid and liquid waste disposal are expected on groundwater quality.

<u>Water Management Issues:</u> I agree to reduce agricultural water demand to secure more fresh water for the domestic sector.

<u>Socio-Economic Issues:</u> I believe that economic growth in the district is directly connected to water availability constraints.

<u>Data Management and Modelling:</u> I trust the use of existing econometric models to dynamically determine crops maps from input variables including the Israeli fixed water quota.

f. WEAP Model Assumptions and Simulation Runs

As such, decisive issues used in testing WEAP as DSS for water management in Tulkarem district were determined from the outcome of the stakeholder field survey (see Figure 1). Accordingly, eight modules were identified in addition to the reference scenario.

Reference Scenario: Water demand projections were made for the year 2040. Estimates indicate that water demand is increasing from 18.366 MCM in base year 2003 to 53.379 MCM at the end of 2040. This increase is due to the improvement of living level and population growth.

Unmet demand was predicted by WEAP at 13.6 mcm in 2005 and increased to 46.6 in 2040 (see Figure 2). The reason of this unmet demand was due to demand increase while the water supply still unchanged due to the present Israeli constraints.

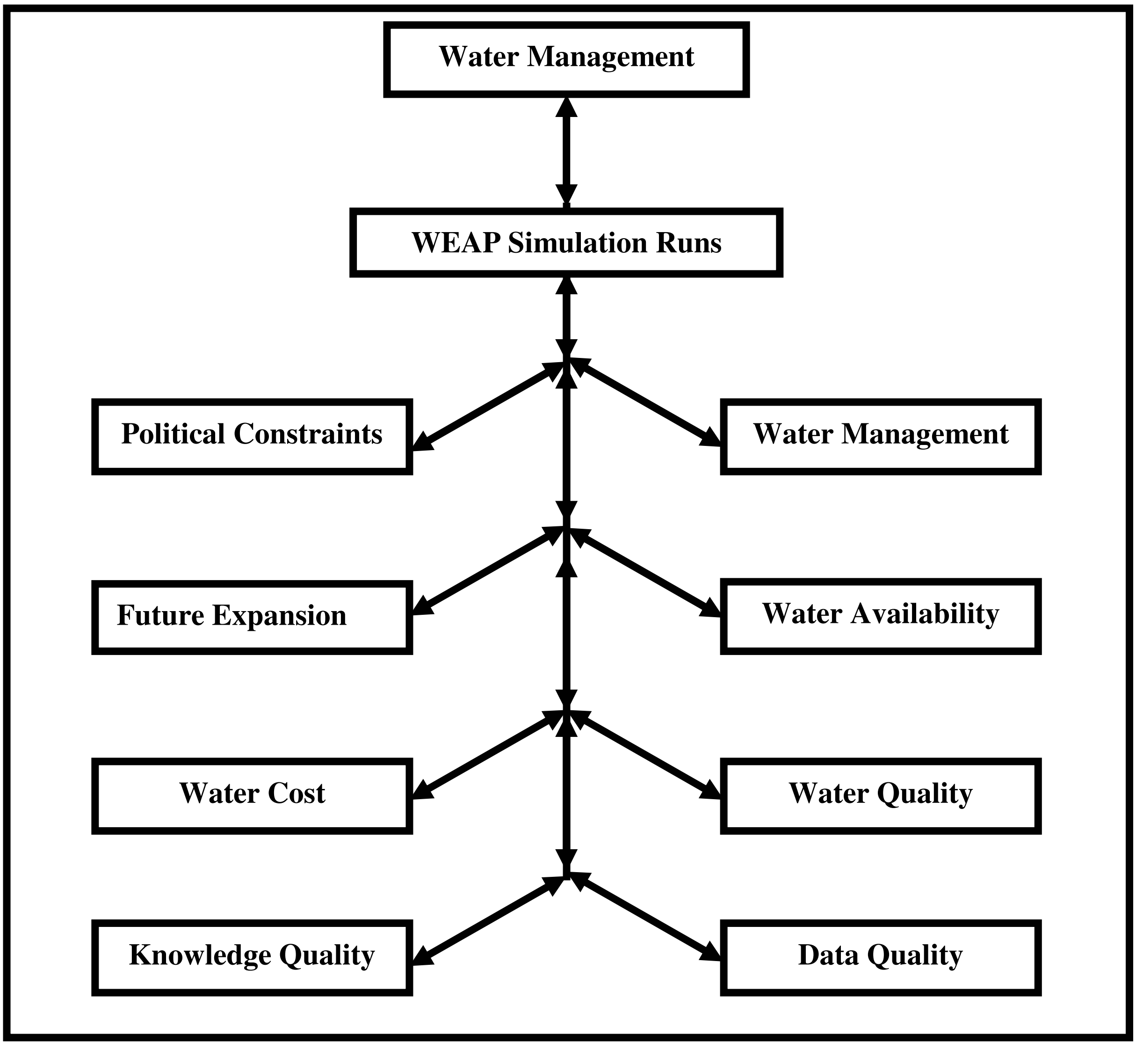
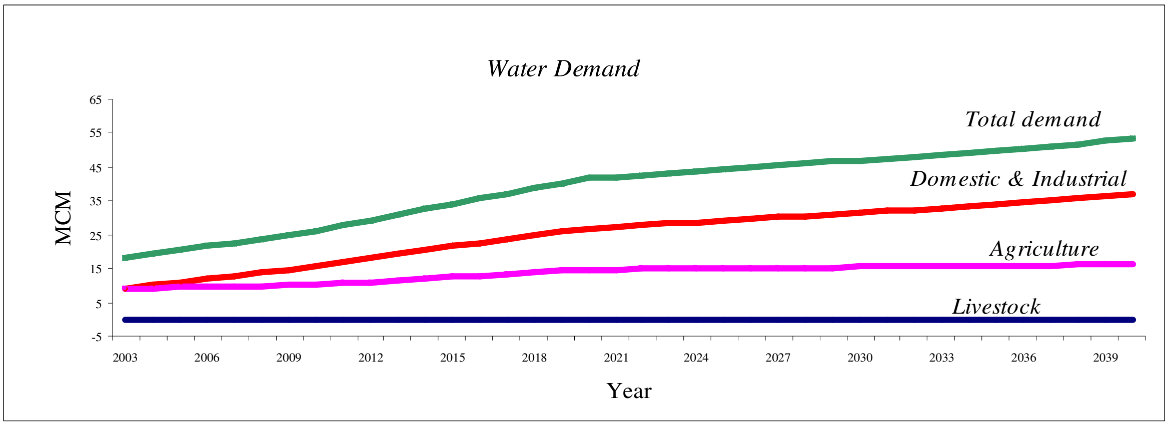


Figure 1 Decisive Issues Used in Testing WEAP as DSS for Water Management in Tulkarem District



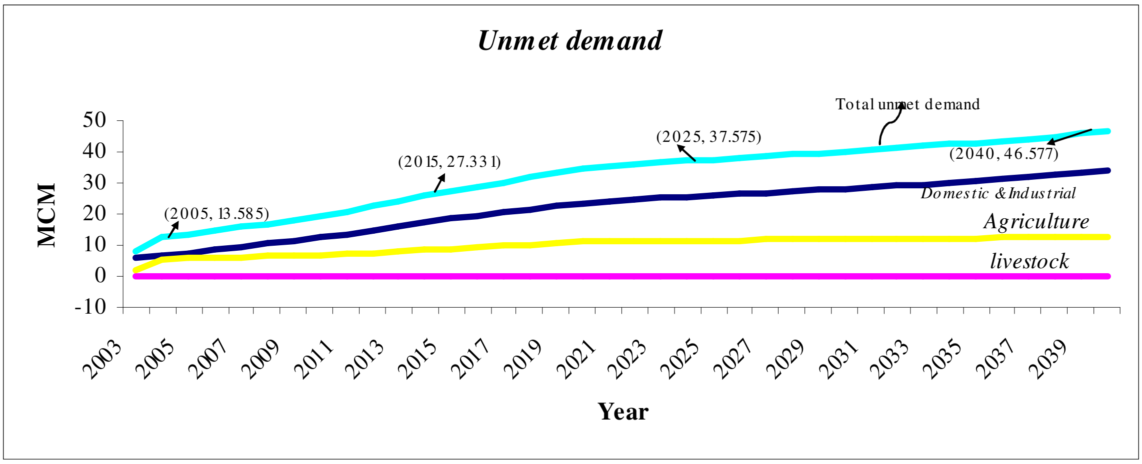


Figure 2 Model Predict Unmet and Water Demand Under Reference Scenario

<u>Module 1: Water Availability</u>

The Water Year Method defines climatic or hydrologic fluctuations in five categories ranging from very dry (0.41 of normal year) to very wet dry (1.59 of normal year). Rainfall data for the study area of 35 years (1968-2003) were used to estimate an average value and standard deviation.

As shown in Figure 3 and model predictions, groundwater storage was reduced by 60 mcm/yr or 51.7% at the end 2025 and annual recharge was reduced by 25% due to proposed climate change and compared to reference scenario.

Availability change scenario

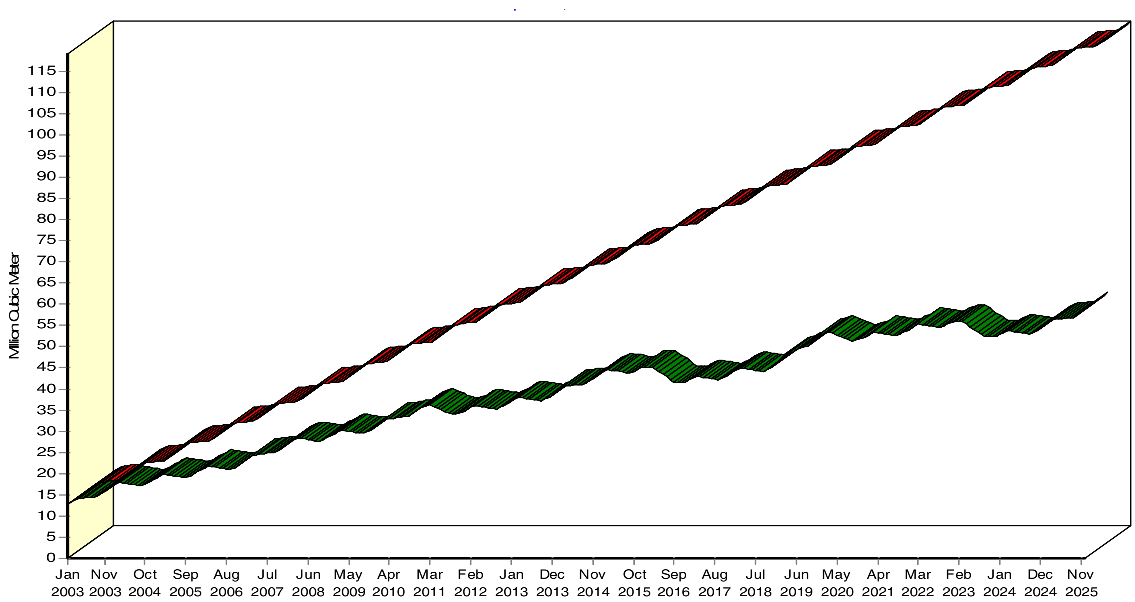


Figure 3 Ground water Storage under Water Availability Change

Module 2: Water Management

Water management aspects tested include: storm runoff water regulation, rain harvesting, water demand management practices, infrastructure improvements, and wastewater treatment and reuse. Other aspects such as privatization, farming practices change, institutional aspects, and others were not possible to consider due to either model limitations and/or data availability.

Storm Water Regulation: Wadis with runoff of more than 10 MCM were considered. Regulation efficiency of 70% and 75% were used for wadis towards the Mediteranean and the Jordan Valley, respectively. Potential storm water regulation in Tulkarm was estimated at 4 MCM/yr.

Rainfall harvesting: Potential rainwater harvesting potential volume was estimated at 1.5 MCM/yr (CH2MHILL 2003).

Wastewater Treatment and Reuse: Potential treated and reused wastewater for Tulkarm district was estimated at 4 MCM/yr assuming that 70% of domestic wastewater could be collected and treated.

Water Conservation and Infrastructure development: Applying conservation measures and improving water infrastructure was assumed to be reflected in unaccounted for water rates reduction from 30% in 2005 to 20% in 2015.

Demand Management Practices: Applying demand management practices were assumed to save about 20% of water demand. Introduction of new irrigation water technologies was assumed to save 25-35 % of irrigation water demand.

Model prediction for water management module (see Figure 4) indicates:

- No change in water demand predictions compared to reference scenario either under available resources development, or cost change, or water management changes.
- 26% reduction in supply predictions using water management changes compared to reference scenario.
- About 3% reduction in supply predictions using water cost changes compared to reference scenario.

Module 3: Water Cost

Improving water tariff system leads to personal demand management practices which can reduce water demand to about 5%, willingness to pay will increase water project cost recovery which will affect project sustainability.

Model prediction for water cost module indicate a 0.30 US$ reduction in water cost and 8% in unmet water demand by the year 2025.

Module 4: Water Trading

During extreme water shortages defined as the case of 10% aquifer depletion. In such cases, water supply priority will be given to satisfying the domestic uses by 100 l/c-d, and the remainder of available water will be directed to agriculture sector.

As shown in Figure 5, a reduction of 26% or 10 mcm/yr in the year 2025 in unmet water demand was predicted under water trading between uses compared with reference scenario (trading irrigation water for domestic). Model predictions also indicated that these reductions were associated with the same capital and operating costs and revenues for both scenarios the reference and the trading (little if any change).

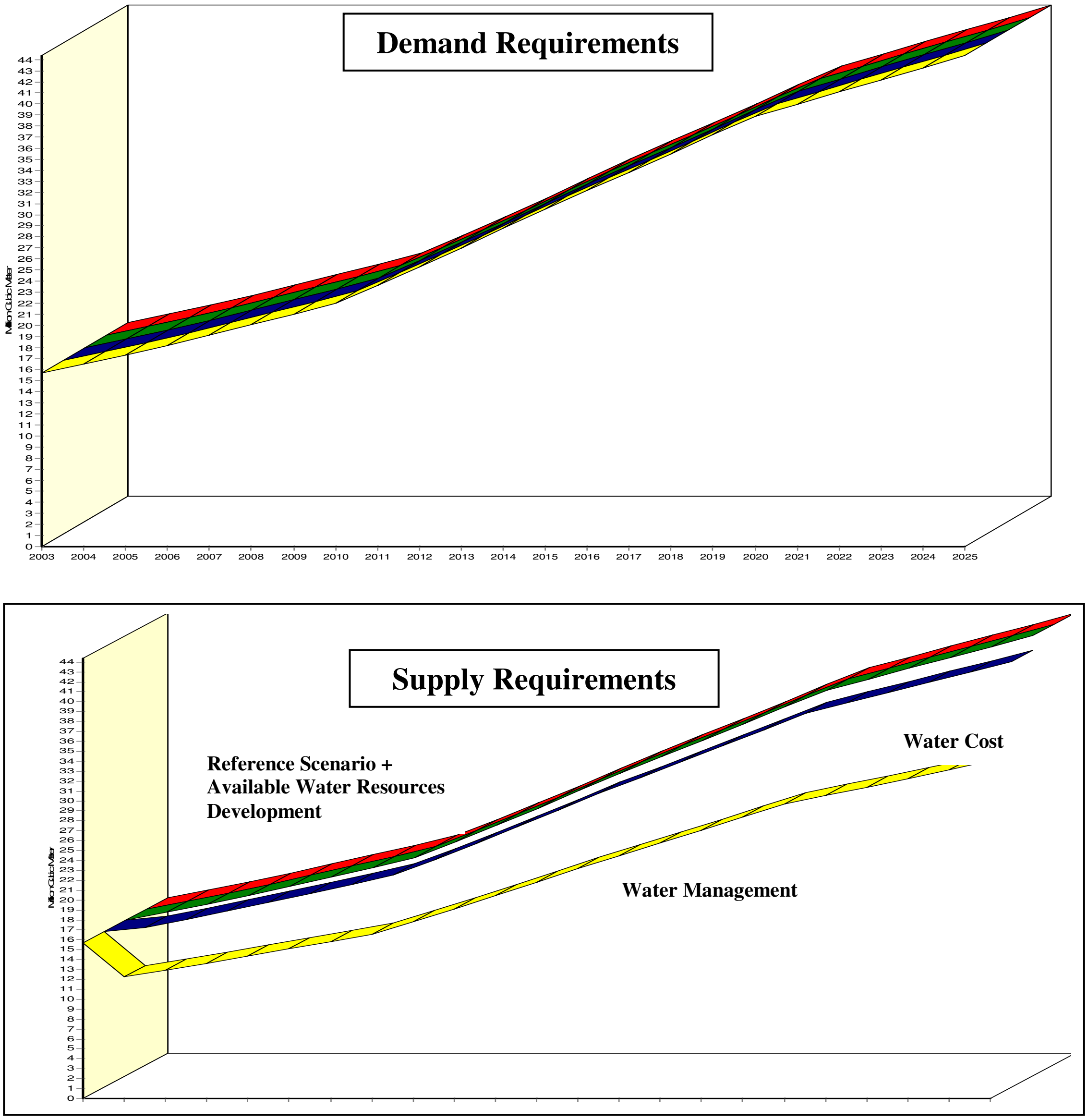


Figure 4 Predicted Water Supply and Demand under Water Management Scenario

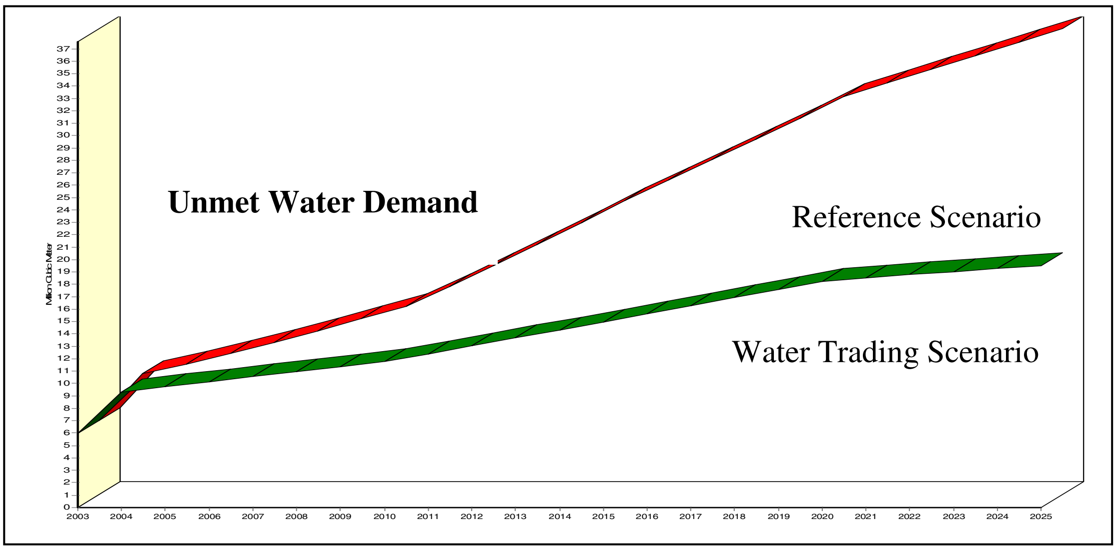


Figure 5 Predicted Unmet Water Demand under Water Trading Scenario

Module 5: Political/Legal Constraints

Under this scenario, different water right options ranging from Palestinians gaining full surface and groundwater rights to Palestinians gaining some surface and groundwater rights and to Palestinians continue living under current water allocations and constraints. Accordingly for Tulkarem district:

1. Full water rights case: Full fulfillment of future water demand for all purposes.
2. Compromise Solution: Tulkarem district will utilize 19.9 MCM/yr from the Western Aquifer
3. The current situation which is the reference scenario, but assuming that a national distribution grid is constructed and water is allocated equitably between Palestinians.

As water availability increase as described under points (1) and (2) above, model predicted that demand will be met, water management will improve slightly, and water cost either will be frozen (scenario (1)) or increase slightly (scenario (2)) during the design period up to 2025 and beyond. The scenario under point (3) is the same as the reference scenario and module 1 results.

Module 6: Water Quality

It was assumed that all communities with the district will have wastewater collection, treatment and reuse systems and plants. It was also assumed that collected and treated wastewater will be reused in agriculture. Accidental spills of hazardous wastes such as chemical or petrol spills could not be modeled in WEAP for GW.

Module 7: Data Quality

Risk of water data inaccuracy was not possible to consider due to model limitations and/or data availability

Module 8: Knowledge Quality

Consumer education and awareness level would affect his water use and practices, which could result in water demand reduction. In this case we will test farmer's awareness and knowledge through assuming an increase in education and awareness level that will result in an increase in irrigation efficiency of about 35%. No change in water demand was predicted under proposed knowledge change by the model. This result contradicts with known practices where the increase in consumer knowledge and/or awareness resulted in higher water conservation and demand reduction.

CONCLUSIONS

Water management and water trading scenarios were the two modules that resulted in water demand reduction in the future. A result that indicates the high need by water decision makers in Palestine to emphasize on water management and trading aspects to reduce future water demands.

Model prediction for water cost module indicates a reasonable reduction in water cost and in unmet water demand.

The model predicted that under increased water availability due to Palestinians attaining in part or in full their water rights, water demands will be met, water management will improve slightly, and water cost either will be frozen or increase slightly.

Predictions by WEAP of the water quality, data quality, and knowledge quality were either unsatisfactory or not possible to implement by the model.

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