Green Water Credits Morocco: Inception Phase

Water Use and Demand in the Sebou Basin, Morocco – A Cost-Benefit Analysis using the Water and Evaluation and Planning Tool (WEAP)

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Key Points

- Water resources in Morocco are stressed and various initiatives have been developed to mitigate water shortage. Many of these initiatives focus on the so-called *blue water* component, ignoring an important aspect of the total water resource: *green water* .

- A critical analysis was carried out to explore the suitability of different tools and it was found that SWAT excelled in analysing the impact of upstream soil and water conservation measures on changes in rainfed productivity, erosion and streamflow.

- The Water Evaluation and Planning System (WEAP) tool then complements SWAT by using SWAT-generated results in a supply-demand evaluation leading towards a benefit-cost analysis. WEAP is a computer tool for integrated water resources planning. It provides a comprehensive, flexible and user-friendly framework for policy analysis

- The WEAP model was set-up for the Sebou basin in Morocco based on five sub-catchments to evaluate the impact of three *green water* management measures on water demand and supply and a benefit-cost analysis.

- Given the current stage of the project, the inception phase, the developed model should be considered more as explorative, rather than actually mimicking reality. Input was obtained from various global and local datasets, and results from the SWAT analysis.

- Three *green water* management measures were defined, and the impact of these measures was explored through the WEAP model. These scenarios were:
    - *Stone Lines*: small structures of stones placed along the contour across the slope.
    - *Bench Terraces*: embankments constructed along the contour.
    - *Contour Tillage*: a combination of contour ploughing and contour cultivation.

- The assumption was that these measures would be implemented on 25% of the rainfed fields in the basin. It is clear that all scenarios have a positive effect on reducing water shortage increasing reservoir storage and improving hydropower generation.

- Revenues for the five main sectors (rainfed agriculture, irrigation, domestic, industry and hydropower) can be up to US$ 43 million every year if these *green water* management measures are implemented.

- Benefits of green water credits in rainfed areas can be mainly attributed to the reduced loss in fertile soil through erosion, while additional benefits occur as more *blue water* becomes available and less siltation of the reservoirs takes place.

Abbreviations and Acronyms

GWC	Green Water Credits
SWAT	Soil and Water Assessment Tool
SWC	Soil and Water Conservation
WEAP	Water Evaluation And Planning System
WOCAT	World Overview of Conservation Approaches and Technologies

1. Introduction

1.1 Relevance

Water resources in Morocco are stressed and various initiatives have been developed to mitigate water shortage. Many of these initiatives focus on the so-called *blue water* component, ignoring an important aspect of the total water resource: *green water* (see Box: Green Water Credits).

The concept of Green Water Credits (GWC) has been introduced to the Sebou basin in Morocco, based on initial experience with the Tana basin in Kenya. An important component of GWC is to explore the potential impact of various *green water* management measures. Such an explorative study has been undertaken using a combination of two modelling tools: SWAT and WEAP (seen next section). Results of the SWAT analysis, including a detailed description of the basin - and issues in the basin - has been described elsewhere (Hunink et al., 2011; Terink *et al.* 2011).

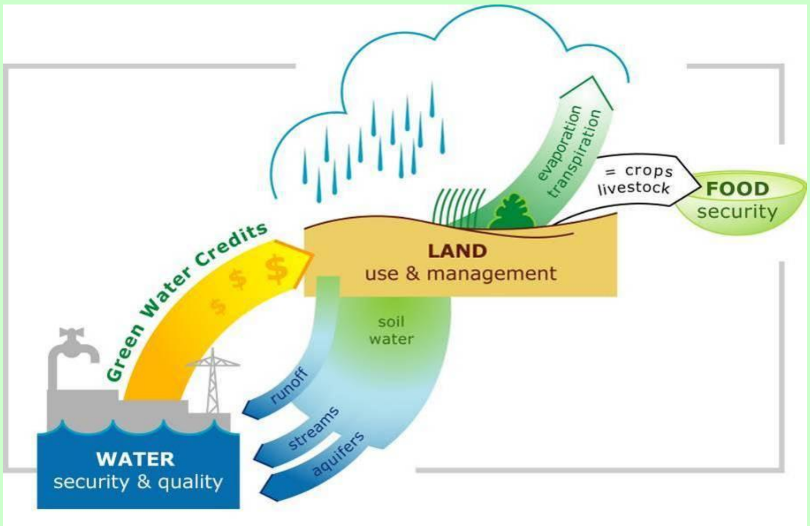
This report focuses on a benefit–cost analysis, based on demand-supply modelling using the WEAP tool.

Green Water Credits

The concept of *green water* and *blue water*, and the GWC mechanism

Green water is water held in the soil as moisture. *Green water* flow refers to its return as vapour to the atmosphere by plants through transpiration or from the soil surface through evaporation. It is the largest fresh water resource, but can only be used *in situ*: where it has fallen as precipitation. *Green water* is managed by farmers, foresters, and pasture or rangeland users.

Blue water is all liquid water. It includes surface runoff, groundwater, streamflow and ponded water that can be used elsewhere - for domestic and stock supplies, irrigation, industrial and urban use - and which supports aquatic and wetland ecosystems. *Blue water* flow and resources, in quantity and quality, are closely determined by the management practices of upstream land users.



Green water management addresses sustainable water resource utilisation in a catchment, or a river basin, at source. It links water that falls onto rainfed land and is used there, to the water resources of rivers, lakes and groundwater: it aims to optimise the partitioning between *green* and *blue water* to generate benefits both for upstream land users and downstream consumers. *Green water management* is targeted at increasing productive transpiration, reducing soil surface evaporation, controlling runoff, reducing flood risk, encouraging infiltration and groundwater recharge.

Green Water Credits (GWC) is a financial mechanism that supports upstream farmers to invest in improved *green water* management practices – and those farmers will benefit directly. However to support these investments, a GWC fund needs to be created by downstream private and public water-use beneficiaries. Initially however, public funds may be required to bridge the gap between investments by upstream land users and the realisation of the benefits by those downstream.

The concept of green water and blue water was originally proposed by Malin Falkenmark as a tool to help in the understanding of different water flows and resources - and the partitioning between the two (see Falkenmark M 1995 Land-water linkages. FAO Land and Water Bulletin 15-16, FAO, Rome).

1.2 Modelling Tools

One reason for the application of water resources models is a better understanding of processes. Models can provide output over an unlimited time-scale, at an unlimited spatial resolution, and for difficult-to-observe sub-processes (e.g. Droogers and Bastiaanssen 2002). These three aspects are a weak point in field experiments, but are simultaneously the most crucial components within the concept of sustainable water resources management.

The most important aspect of applying models, however, is in their ability to explore different scenarios. These scenarios can capture aspects that cannot directly be influenced, such as population growth and climate change (Droogers and Aerts 2005). These are often referred to as “projections”. On the other hand are the “management scenarios” or interventions where water managers and policy makers can make decisions that will have a direct impact. Examples are changes in reservoir operation rules, water allocation between sectors, investment in infrastructure such as water treatment or desalinisation plants, and agricultural/irrigation practices. In other words, models enable a change in focus from a *reactive* towards a *pro-active* approach. (Figure 1).

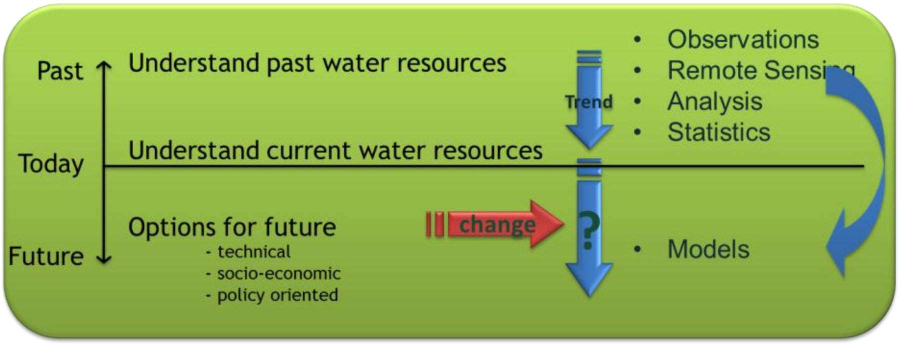


Figure 1: The concept of using simulation models in scenario analysis

A huge number of water resources models exist, and applications are growing rapidly. The number of pages on the internet including “water resources models” is over 75,000 (Google, July 2011); Figure 2. A critical question for hydrological model studies is therefore related to the selection of the most appropriate model. One of the most important issues to consider is the spatial scale to be incorporated in the study, and how much physical detail to include. Figure 3 illustrates the negative correlation between the physical detail of the model applied and spatial scale of application. The figure indicates also the position of commonly used models in this continuum.

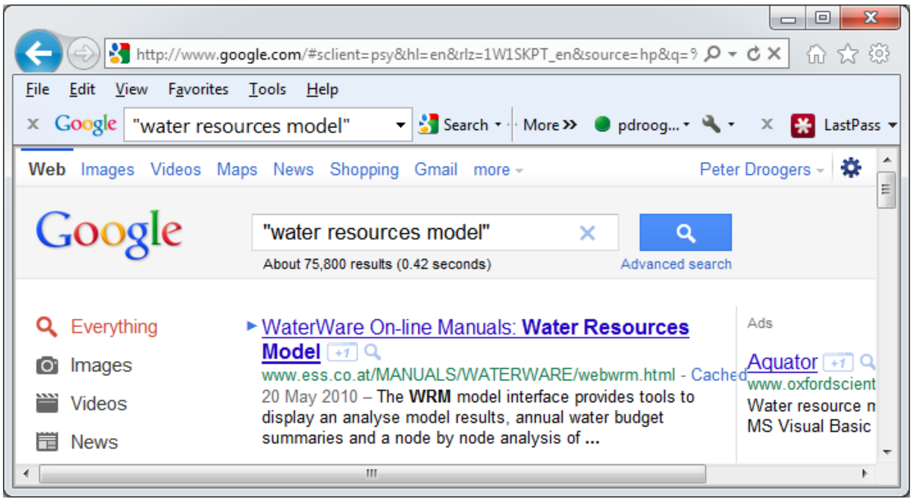
For the application of models under Green Water Credits a critical analysis was carried out to explore the suitability of different tools (Droogers *et al.* 2006). It was found that SWAT excelled in analysing the impact of upstream Soil and Water Conservation on changes in rainfed productivity, erosion and streamflow. The WEAP tool then complements SWAT by using SWAT-generated results in a supply-demand evaluation leading towards a benefit-cost analysis. A summary of the main differences and application of SWAT and WEAP in GWC is shown in

Table 1.

Table 1: Summary of SWAT and WEAP in GWC application

SWAT *(Soil and Water Assessment Tool)*	WEAP *(Water Evaluation And Planning system)*
• Supply analysis • Physical Based • Impact of soil and water conservation measures • Detailed farm management analysis • Public domain • User-friendly interface	• Demand analysis • Conceptual based • Benefit–Cost analysis • Detailed upstream-downstream interactions • Public domain • Very user-friendly interface

For the purpose of this Benefit-Cost analysis, the WEAP system is recommended as the most appropriate tool. WEAP follows an integrated approach to water development, that places water supply projects in the context of multi-sectoral, prioritised demands, and water quality and ecosystem preservation and protection. WEAP incorporates these values into a practical tool for water resources planning and policy analysis. WEAP places demand-site issues such as water use patterns, equipment performance, re-use strategies, costs, and water allocation schemes on an equal footing with the supply-site aspects of streamflow, groundwater resources, reservoirs, and water transfers. WEAP is also distinguished by its integrated approach to simulating both the natural (e.g. rainfall, evapotranspirative demands, runoff, baseflow) and engineered components (e.g. reservoirs, groundwater pumping) of water systems, allowing the planner to have access to a more comprehensive view of the broad range of factors that must be considered in managing water resources for the present as well as for future use. WEAP is an effective tool for examining alternative water development and management options.



"water resources model"

About 75,800 results (0.42 seconds)

WaterWare On-line Manuals: **Water Resources Model**

www.ess.co.at/MANUALS/WATERWARE/webwrm.html - Cached

20 May 2010 – The **WRM** model interface provides tools to display an analyse model results, annual water budget summaries and a node by node analysis of ...

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Figure 2: Number of pages returned with “water resources model” (July 2011)

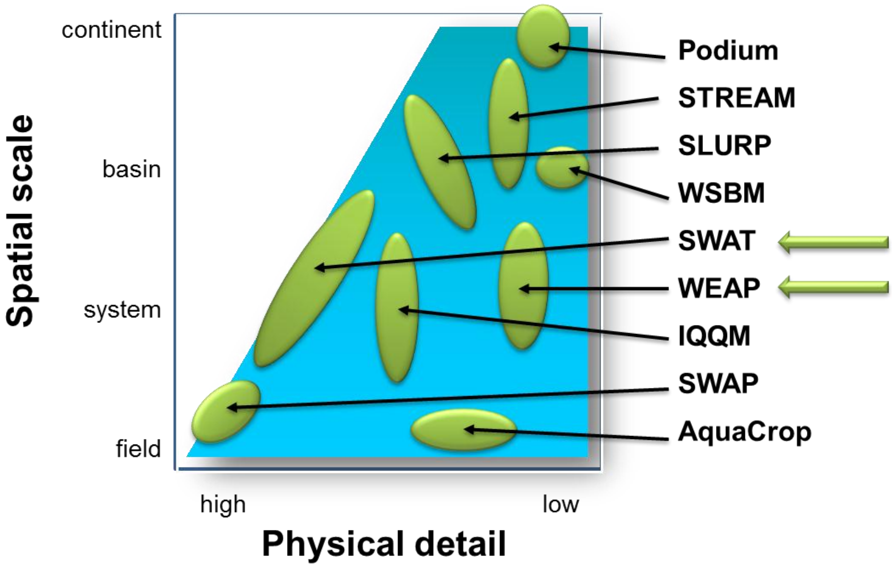


Figure 3.:Spatial and physical detail of water resources models

1.3 WEAP model

1.3.1 Background

The Water Evaluation and Planning System, most commonly known by its abbreviation of WEAP, is a computer tool for integrated water resources planning. It provides a comprehensive, flexible and user-friendly framework for policy analysis (SEI 2011).

Many regions face formidable freshwater management challenges. Allocation of limited water resources, environmental quality, and policies for sustainable water use are issues of increasing concern. Conventional supply-oriented simulation models are not always adequate. Over the last decade, an integrated approach to water development has emerged. This places water supply projects in the context of demand-side issues, water quality and ecosystem preservation. WEAP aims to incorporate these values into a practical tool for water resources planning.

WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation: it is effectively a desktop laboratory for examining alternative water development and management strategies (SEI 2011).

1.3.2 WEAP approach

WEAP operates on the basic principles of a water balance. The analysis represents the system in terms of its various supply sources (e.g. rainfall, rivers, creeks, groundwater, and reservoirs); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The data structure and level of detail can readily be customised to meet the requirements of a particular analysis, and to reflect the limits imposed by available data.

Operating on these basic principles, WEAP is applicable to many scales; municipal and agricultural systems, single catchments or complex transboundary river systems. WEAP not only incorporates water allocation, but also water quality and ecosystem preservation modules. This makes the model suitable for simulating many of the fresh water problems that exist in the world today.

WEAP applications generally involve several steps. The study definition determines the time frame, spatial boundary, system components and configuration of the problem. The “Current Accounts”, which can be viewed as a calibration step in the development of an application, provide a snapshot of the actual water demand, pollution loads, resources and supplies for the system. Key assumptions may be built into the current accounts to represent policies, costs and factors that affect demand, pollution, supply and hydrology. “Scenarios” build on the current accounts and allow exploration of the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

WEAP calculates a water and pollution mass balance for every node and link in the system. Water is dispatched to meet instream and consumptive requirements, subject to demand priorities, supply preferences, mass balance and other constraints. Point loads of pollution into receiving bodies of water are computed, and instream concentrations of polluting elements are calculated.

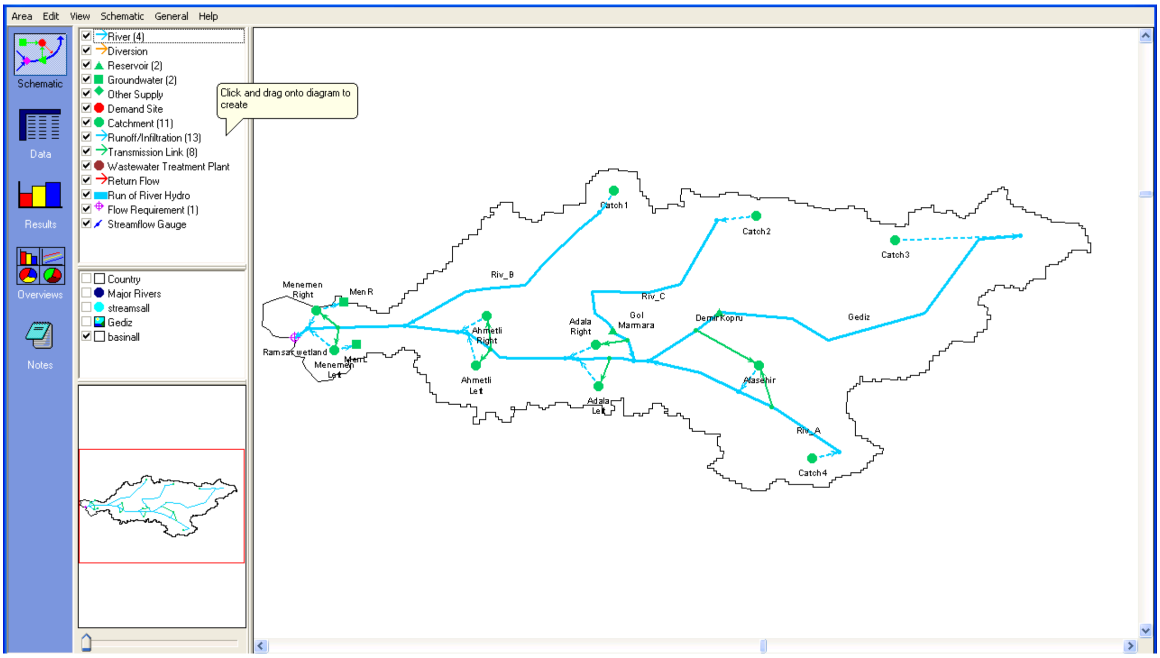
WEAP operates on a monthly time basis, from the first month of the current account’s year through to the last month of the last year in the scenario. Each month is independent of the previous, except for reservoir and aquifer storage. Thus, all of the water entering the system in a month (e.g. headflow, groundwater recharge, or runoff) is either stored in an aquifer or reservoir, or leaves the system by the end of the month (e.g. outflow from river, demand-site consumption, reservoir or river reach evaporation, transmission and return flow link losses). Because the time scale is relatively long (monthly), all flows are assumed to occur instantaneously. Thus, a demand-site can withdraw water from the river, consume some, return the rest to a wastewater treatment plant that treats it and subsequently returns it to the river. This return flow is available for use in the same month to downstream demands.

Each month the calculations (algorithms) follow this order (SEI 2011):

1. Annual demand and monthly supply requirements for each demand-site and flow requirement.
2. Runoff and infiltration from catchments; irrigation.
3. Inflows and outflows of water for every node and link in the system. This includes calculating withdrawals from supply sources to meet demand, and dispatching reservoirs. This step is solved by a linear programme (LP), which attempts to optimise coverage of demand-site and instream flow requirements, subject to demand priorities, supply preferences, mass balance and other constraints.
4. Pollution generation by demand-site, flows and treatment of pollutants, and loadings on receiving bodies, concentrations in rivers.
5. Hydropower generation.
6. Capital and operating costs and revenues.

1.3.3 Programme structure

WEAP comprises five main views: (i) schematic, (ii) data, (iii) results, (iv) overviews, and (v) notes. These views are listed as graphical icons on the “view bar”, located on the left of the screen: click an icon in the view bar to select one of the views. For the “results and overviews” view, WEAP will calculate scenarios before the view is displayed - if any changes have been made to the system or the scenarios.



Click and drag onto diagram to create

Figure 4: Example of the WEAP schematic view

1.3.3.1 *Schematic view*

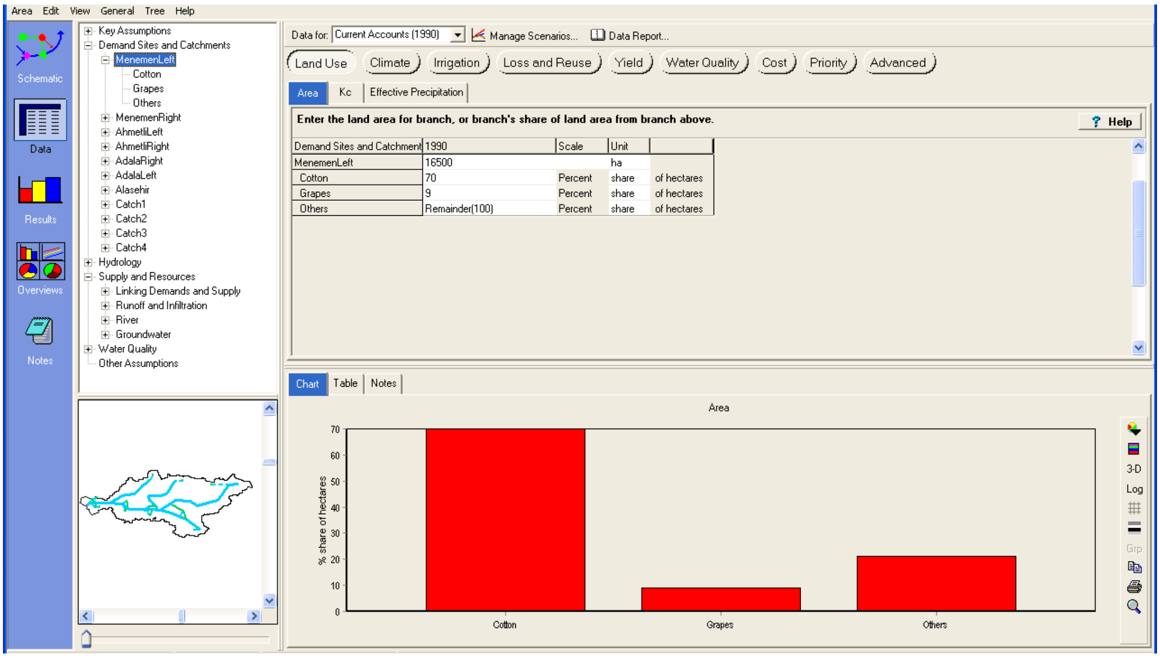
In the Schematic view the basic structure of the model is created (Figure 4). Objects from the item menu are dragged and dropped into the system. First the river is created and the demand-sites and supply-sites are positioned appropriately in the system. Pictorial files can be added as a background layer. The river, demand-sites and supply-sites are linked to each other by transmission links, runoff/infiltration links or return flow links.

1.3.3.2 *Data view*

Adding data to the model is done in the “data view”. The data view is structured as a data tree with branches. The main branches are named “key assumptions”, “demand-sites”, “hydrology”, “supply and resources” and “water quality”.

The objects created in the schematic view are shown in the branches. Further sub-divisions of a demand-site can be created by the analyst. The example in Figure 5 shows 0a sub-division of the demand-sites into land use classes.

The data view allows creation of variables and relationships, entering assumptions and projections using mathematical expressions, and dynamically linking to input files (SEI 2005).



Data for: Current Accounts (1990)

Enter the land area for branch, or branch's share of land area from branch above.

Demand Sites and Catchment	1990	Scale	Unit	
MenemenLeft	16500		ha	
Cotton	70	Percent	share	of hectares
Grapes	9	Percent	share	of hectares
Others	Remainder(100)	Percent	share	of hectares

Figure 5. Example of the WEAP Data view.

1.3.3.3 Result view

Clicking the results view will trigger WEAP to run its monthly simulation and report projections of all aspects of the system, including demand-site requirements and coverage, streamflow, instream flow requirement satisfaction, reservoir and groundwater storage, hydropower generation, evaporation, transmission losses, wastewater treatment, pollution loads, and costs.

The results view is a general purpose reporting tool for reviewing the results of scenario calculations in either chart or table form, or displayed schematically (Figure 6). Monthly or yearly results can be displayed for any time period within the study horizon. The reports are available either as graphs, tables or maps and can be saved as text, graphic or spreadsheet files. Each report can be customised by changing any of the following: the list of nodes displayed (e.g. demand-sites), scenarios, time period, graph type, unit, gridlines, colour, or background image. Customised reports can be saved as a "favourite" for later retrieval. Up to 25 "favourites" can be displayed side-by-side by grouping them into an "overview". Using favourites and overviews, the user can simply assemble a customised set of reports that highlight the key results of the analysis (Figure 7).

In addition to its role as WEAP's main reporting tool, the results view is also important as the main location where intermediate results can be analysed to ensure that data, assumptions and models are valid and consistent.

The reports are grouped into five main categories:

- Demand
- Supply and Resources
- Catchments
- Water Quality
- Financial

Details about output generated by WEAP can be found in Table 2. This table indicates also the processes that are included in WEAP, and to which level of detail output can be obtained.

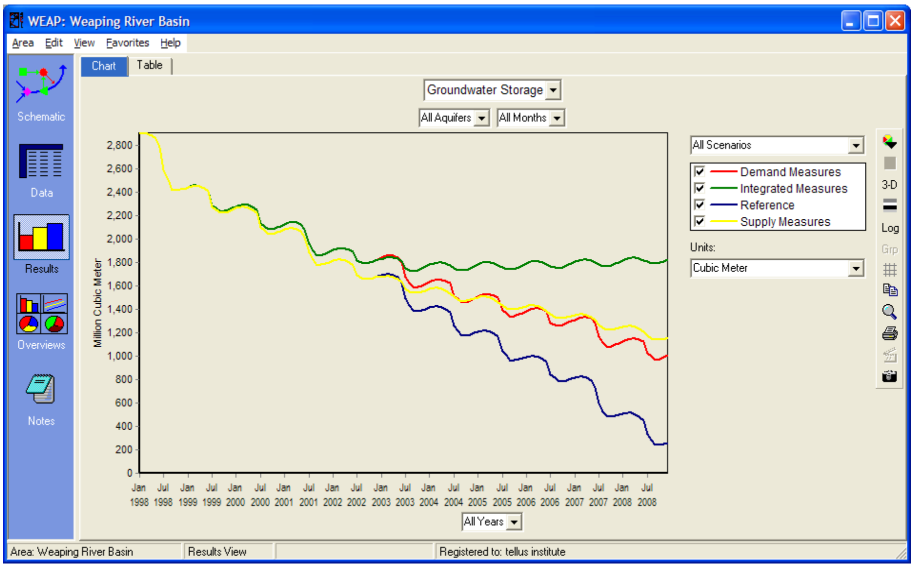


Figure 6: Example of the WEAP Results view

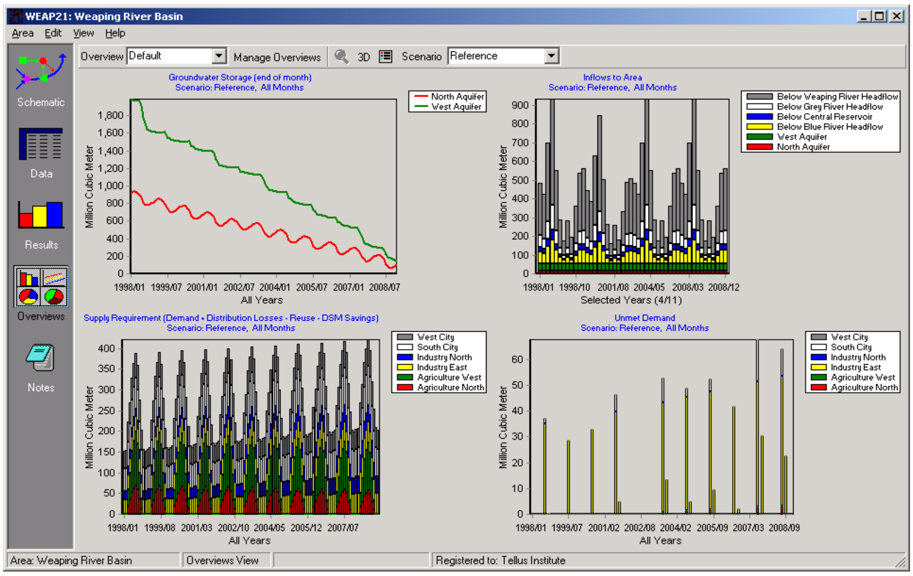


Figure 7: Example of the WEAP Overviews view

Table 2: WEAP output organised into five groups.

Demand Results

- Water Demand
- Supply Requirement
- Supply Delivered
- Unmet Demand
- Coverage
- Demand-Site Inflow and Outflow
- Instream Flow Requirement
- Instream Flow Requirement Delivered
- Unmet Instream Flow Requirement
- Instream Flow Requirement Coverage

Supply and Resources Results

- Inflows to Area
- Outflows to Area
- River
  - Streamflow
  - Streamflow Relative to Gauge (absolute)
  - Streamflow Relative to Gauge (%)

    - Stage
    - Velocity
    - Reach Length
- Groundwater
    - Storage
    - Inflows and Outflows
    - Overflow
    - Height Above River
    - Outflow to River
- Reservoir
    - Storage Volume
    - Storage Elevation
    - Inflows and Outflows
    - Hydropower
- Transmission Link
    - Flow
    - Inflows and Outflows
- Other Supply
    - Inflows and Outflows
- Return Link
    - Flow
    - Inflows and Outflows

Catchment Results

- FAO method results
    - Runoff from Precipitation
    - Observed Precipitation
    - Infiltration/Runoff Flow
    - ET Potential
    - ET Actual (including irrigation)
    - ET Shortfall
    - Total Yield
    - Total Market Value
- Soil Moisture Method Results
    - Land Class Inflows and Outflows
    - Observed Precipitation
    - Snow Accumulation
    - Infiltration/Runoff Flow
    - Effective Monthly Precipitation for ET (including snowmelt)
    - Area
    - Temperature
    - Net Solar Radiation
    - Reference Monthly PET
    - ET Potential
    - ET Actual (including irrigation)
    - Relative Soil Moisture 1 (%)
    - Relative Soil Moisture 2 (%)
    - Flow to River No Irrigation
    - Flow to River Full Irrigation
    - Flow to GW No Irrigation
    - Flow to GW Full Irrigation
    - Irrigation Return Flow Fraction to Surface Water
    - Irrigation Return Flow Fraction to Groundwater

Water Quality Results

- Pollution Generation
- Pollution Loads
- Pollution Inflow to Treatment Plants
- Wastewater Treatment Plant Inflows and Outflows
- Surface Water Quality

Financial Results

- Net Cost Report
- Net Present Value Report
- Average Cost of Water Report

2 Model Set-up

2.1 Overview

The WEAP model was set-up for the Sebou basin to evaluate the impact of three *green water* management measures on water demand and supply and a benefit-cost analysis. Given the current stage of the project, the inception phase, the developed model should be considered more as explorative, rather than actually mimicking reality. Input was obtained from various global and local datasets, and results from the SWAT analysis. Details are described in the associated SWAT report (Terink *et al.* 2011).

2.2 Set-up

2.2.1 Overall

The WEAP model was set-up for the Sebou basin in Morocco based on five sub-catchments (Figure 8). For each of these sub-catchments the following information was included:

- Water availability
- Irrigated areas and water requirements
- Domestic and industrial water requirements
- Reservoirs

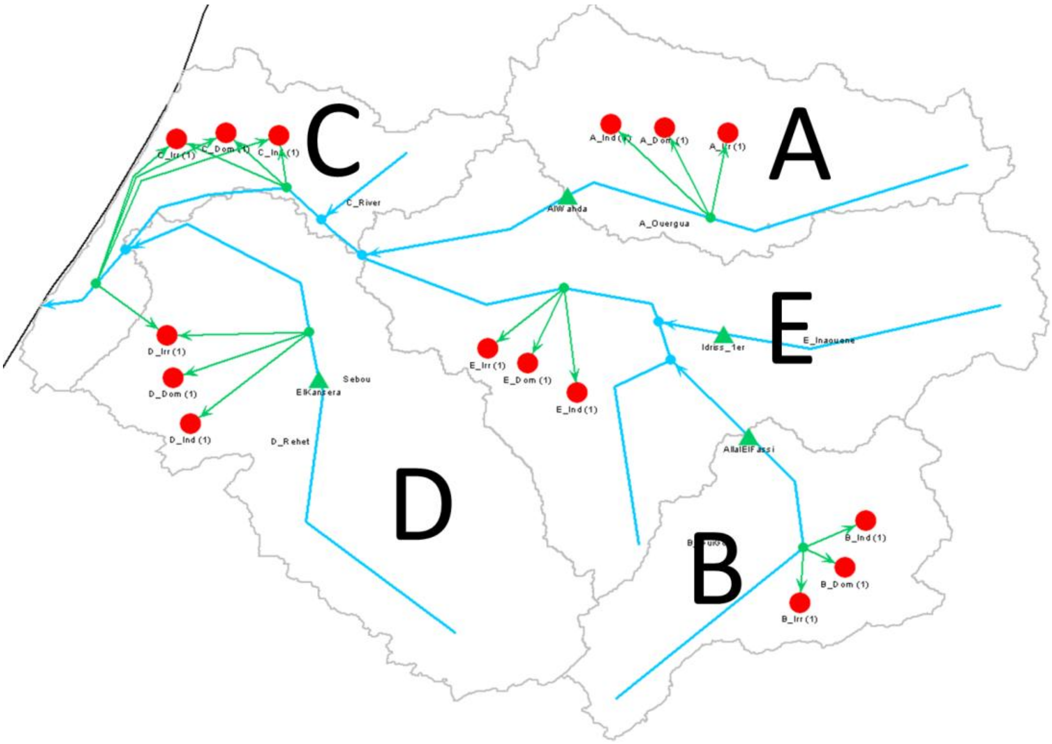


Figure 8. Overview of five sub-catchments (A-E) included in the model analysis.

2.2.2 Water Yield

The total amount of water available for further application is referred to as the “water yield”. The water yield is the sum of water from the surface runoff, the lateral flow (drainage), and groundwater flow. This water yield is the same as the *blue water* and can be used for hydropower, irrigation, domestic and industrial allocation and/or environment flow requirements. The water yield is derived from the SWAT analysis (Terink *et al.* 2011). The amount of water yield depends on various interlinked factors such as the size of the sub-catchment, weather conditions, soil-land characteristics and complex hydrological processes.Irrigated areas
Three main irrigated crops with their growing seasons were defined in the SWAT study:

- Broad beans: 01 Dec - 01 Apr
- Olives; 01 Jan - 15 Oct
- Winter wheat: 15 Oct - 15 May

It is known that also other irrigation takes place in the region especially for smaller scale applications. It was estimated, based on local information, that, on average, 400 mm of irrigation was applied, and this amount was assumed to be distributed over the months as:
Jan 0%, Feb 2.5%, Mar 2.5%, Apr 20%, May 30%, Jun 15%, Jul 5%, Aug 5%, Sep 5%, Oct 10%, Nov 5%, Dec 0%

It was assumed that canal losses represented 20% of the water delivered.

2.2.3 Domestic and industrial water requirements

In the absence of disaggregated data, it was assumed that population distribution and industrial water requirements were proportionally distributed relative to the size of the five sub-catchments. If and when more detailed data become available, these can be directly incorporated within the model.

For domestic water extraction an amount of 150 litres per person per day was assumed (~ 55 m^3 per year per person). For industrial extractions the WEAP approach of “production units” was used. It was assumed that 1000 production units exist in the basin, and that each production unit extracts 1000 m^3 per day.

Losses for domestic and industrial water extraction were set at 10%.

2.2.4 Reservoirs

Only the major reservoirs were included in the generalised WEAP model:

- Allal El Fassi
- Idriss 1er
- El Kansera
- Al Wahda

These reservoirs were selected since they represent the largest in terms of storage capacity and/or hydropower generation.

2.2.5 Economics

To undertake a benefit-cost analysis the following assumptions have been included in the model:

- Value of agricultural production in rainfed systems is based on the concept of water productivity. Each m^3 of water used for transpiration in rainfed farming has a value assumed to average US$ 0.05 m^{-3}.
- Value of irrigation water is set at a fixed value of US$ 0.15 m^{-3}.
- Revenues from domestic and industrial water supply is set at US$ 0.30 m^{-3}.
- Revenues from electricity were set at US$ 50,000 /GWH.

These figures were taken as averages based on existing country data - and in accordance with other GWC studies. Obviously, if more accurate numbers become available, these can be readily included in the analysis.

2.3 *Green water* management measures

A total of three *green water* management measures were defined, and the impact of these measures was explored through the WEAP model. These scenarios are:

> *Stone Lines*: small structures of stones, where the stones are placed along the contour across the slope. The distance between the lines is a function of the slope and availability of stone.
>
> *Bench Terraces*: embankments constructed along the contour using stone and/or soil as construction material. Bench terraces are established by excavating soil to form a level terrace “bed” and using this material to form the embankments between beds. Stone (where available) is used to face the “riser” of each embankment.
>
> *Contour Tillage*: a combination of contour ploughing and contour cultivation.

A more detailed description can be found in the SWAT report (Terink *et al.* 2011) and in the WOCAT database (WOCAT 2011).

Results of the SWAT analysis of these three *green water* management measures were included in the WEAP model. The major output that is used as input for WEAP includes changes in:

- Rainfed crop transpiration
- Streamflow
- Inflow to reservoirs
- Erosion and sedimentation

Based on this WEAP calculates:

- Rainfed agricultural production value
- Irrigated agricultural production value
- Domestic water value
- Industrial water value
- Hydropower value

3 Results

Results of the analysis using the WEAP approach will be discussed in three sections:

- Baseline: representing the situation during the 10 year period from 2001 to 2010
- Future projection: representing the situation around the year 2025 if no adaptation measures were taken.
- *Green water* management measures: exploring the future with three *green water* management measures implemented.

All results are presented for a period of 10 years to ensure that year-to-year variation is included. As indicated earlier, in this phase of the project (the inception phase) most emphasis has been put on an initial estimate of potential impacts (Droogers et al., 2008). Further refinement and calibration/validation of data and results is required.

3.1 Baseline

Some outputs of the analysis will be presented here to demonstrate the capabilities of the model.

Figure 9 shows the water demand, the un-met demand for the five sub-catchments and all water extractions (irrigation, industry and domestic). Demand and unmet demand varies substantially over the months and years.

Figure 10 shows the amount of water available from runoff, drainage and base flow for the sub-catchments. This amount is referred to as “water yield” in WEAP, or as *blue water* in GWC terminology. Note that these “headflows” differ from the rainfall as all complex hydrological processes, such as evapotranspiration and delays, are included by using the results from the SWAT model.

Figure 11 displays the volume of the reservoirs in the study area. It is clear that at the beginning of this century and again around 2008, water levels were at critically low levels.

Figure 12 shows the amount of hydropower generated by the reservoirs. Allal El Fassi and Al Whada generate the majority of hydropower in the basin.

This baseline attempts to mimic the real situation as realistically as possible. However, since this work was done in a relative short time frame available during the implementation phase of GWC, improvements are possible. The main objective is to demonstrate the use of the tool and to get a first estimate of a better understanding of processes in the basin.

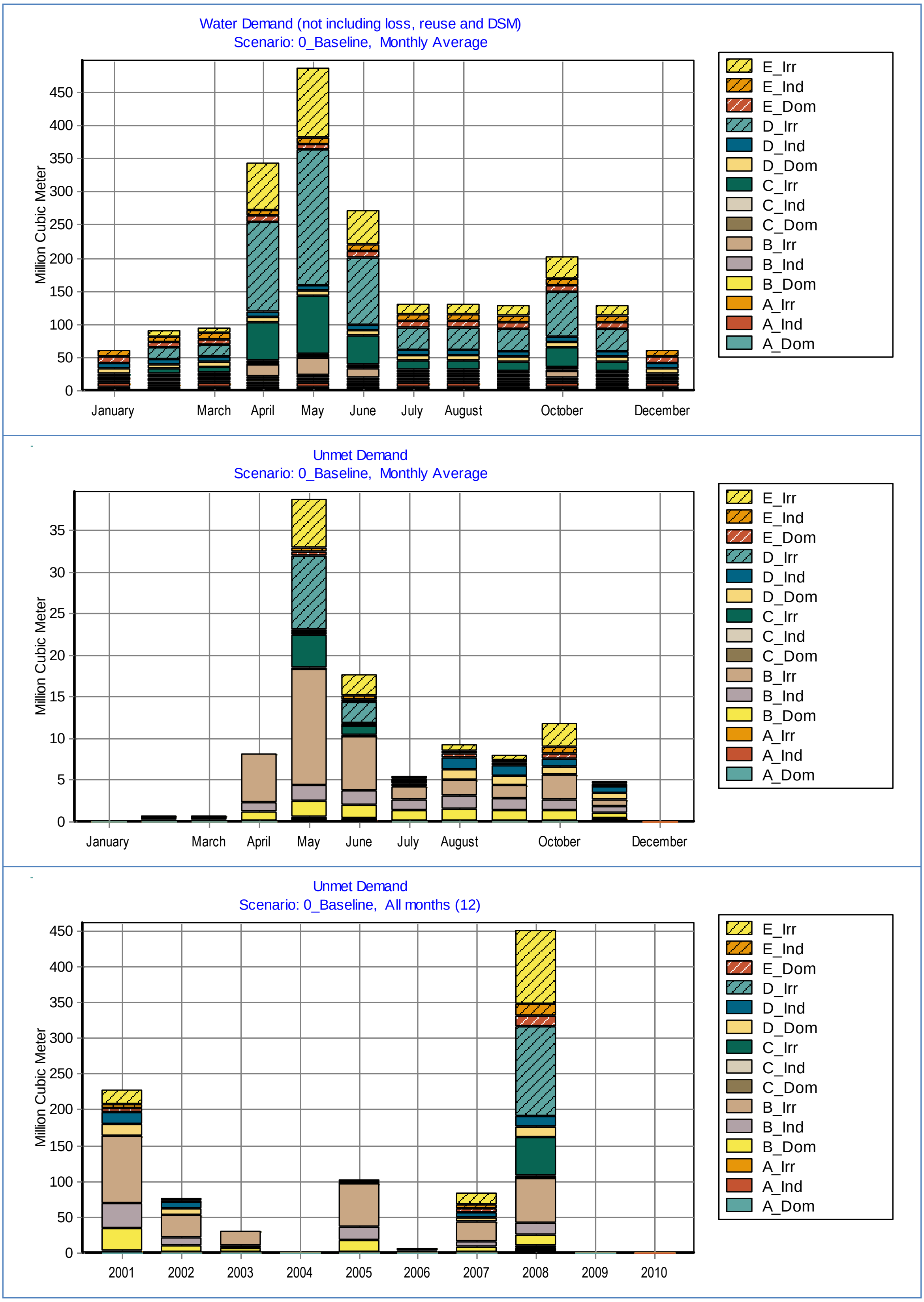


Figure 9: Water demand average monthly (top), unmet demand average monthly (middle) and annual unmet demand (bottom) for the baseline

Irr = Irrigation; Ind = Industry; Dom = Domestic; A-E refer to the five sub-catchments.

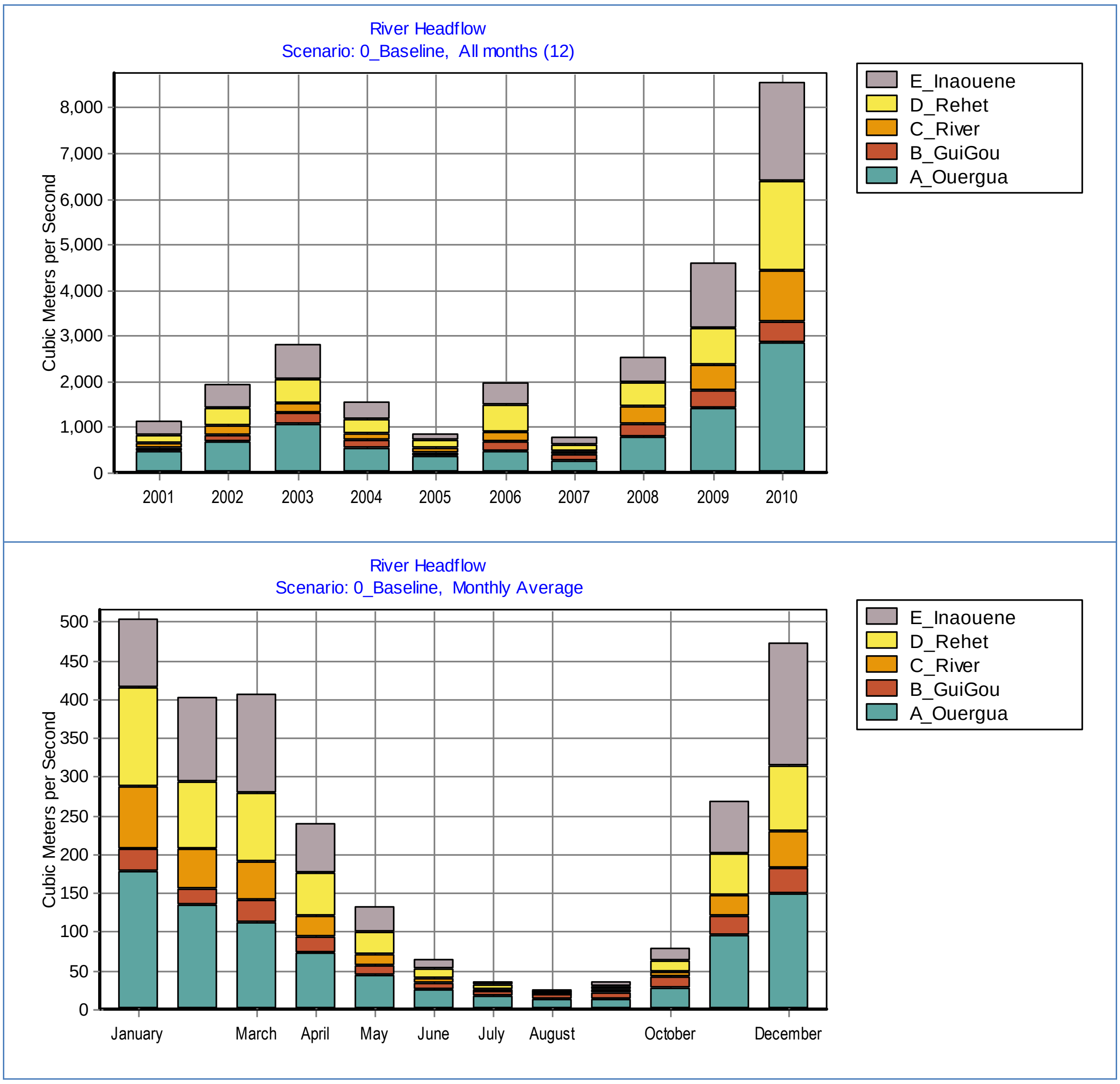


Figure 10: Water Yield (runoff) for the 10 years (top) and average per month (bottom) for the baseline

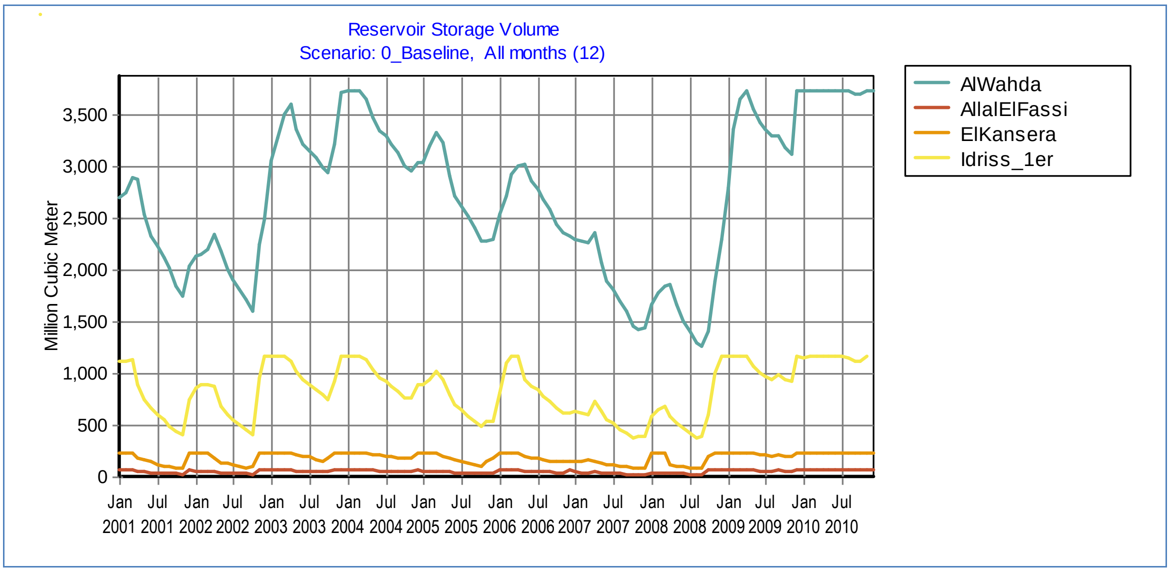


Figure 11: Reservoir storage volume for the baseline situation

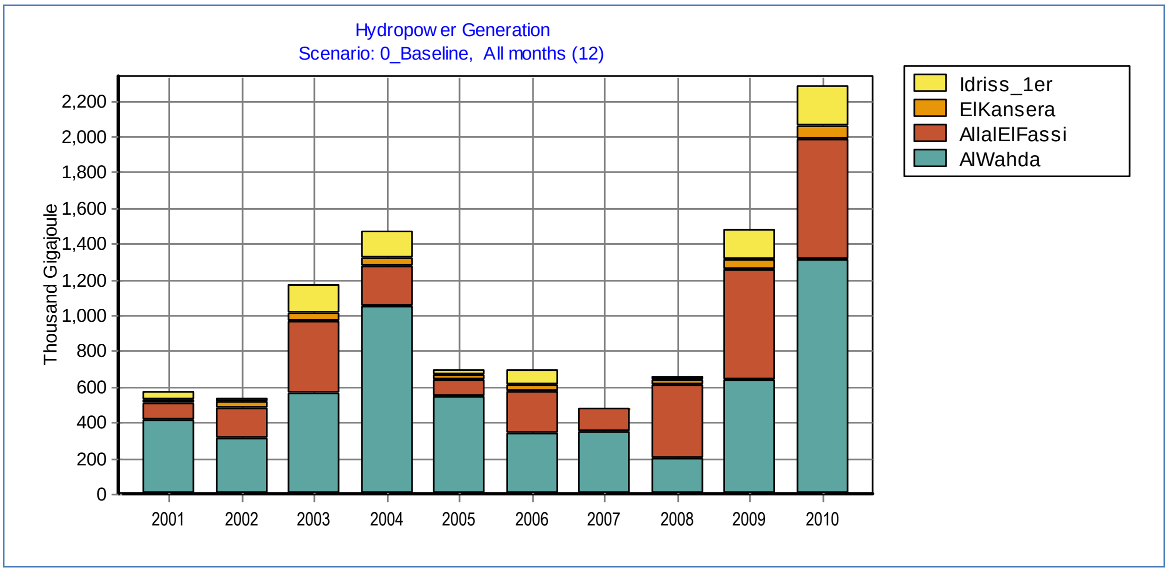


Figure 12: Hydropower generation for the baseline

3.2 Future Projection

It is clear the Sebou basin will experience major changes in the future. Climate will alter, population will change and economic growth will have influence on water demand. It is beyond the scope of the current study to calculate all these potential individual changes – but it was assumed that these will, cumulatively, have a negative impact on water availability, reducing availability of water to 80% of the current situation. This was introduced into WEAP by reducing all the monthly headflows by 20%.

The impact of these changes is summarised in Figure 13 which compares the baseline scenario with future projections, using similar conditions assuming that green water management would have been implemented. Water shortage (unmet demand) will increase substantially, especially during dry years, and dry months when water shortage can be more than double. At the same time, reservoir levels will reduce by more than 20% and will not be able to store sufficient water to cover dry spells. Reservoir capacity appears to be sufficient, but total water resources are apparently the limiting factor. Moreover, hydropower generation will be reduced by hundreds of Gigawatt-Hours every year (Figure 13).

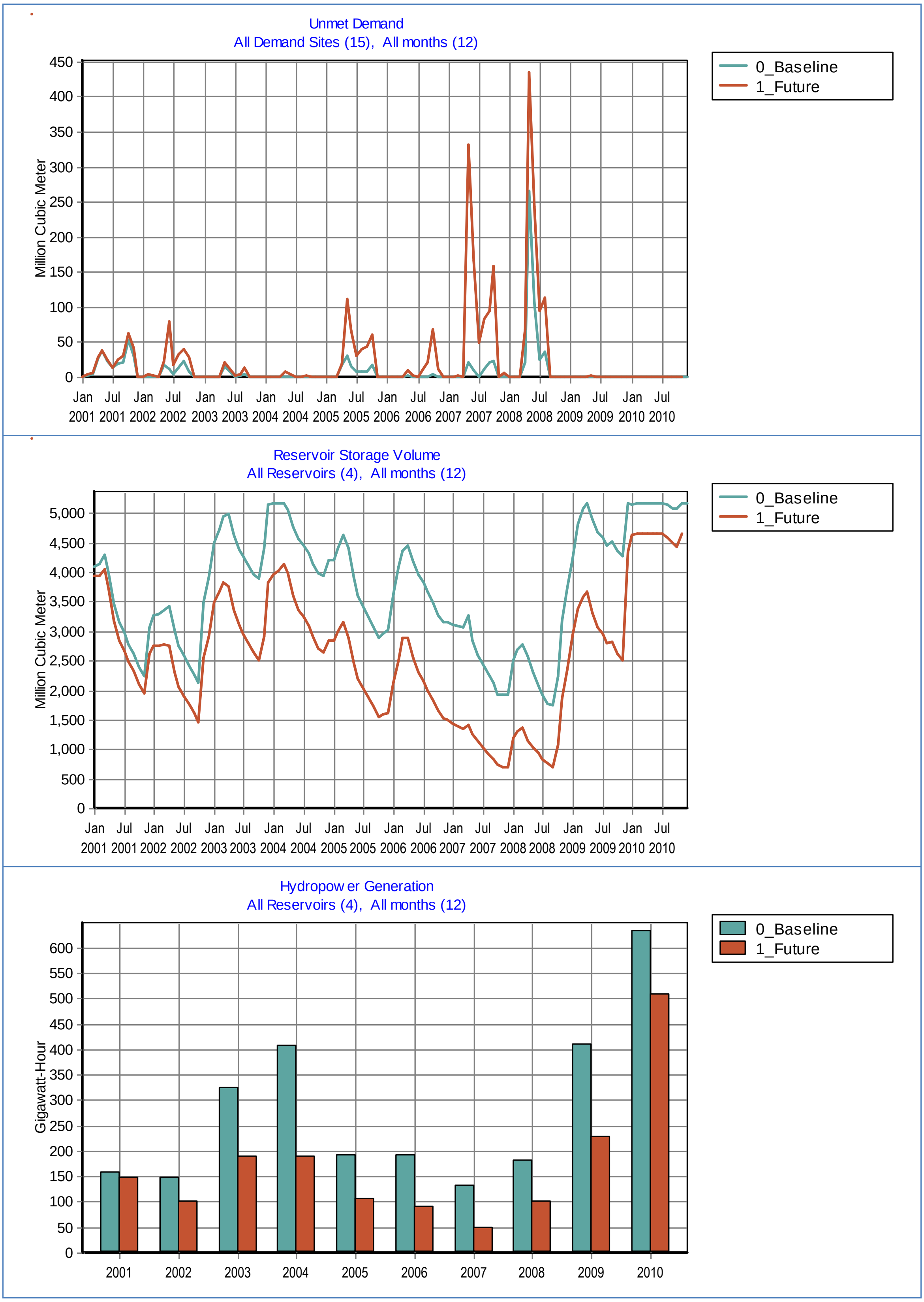


Figure 13: Comparing the baseline scenario with future projections. Monthly unmet demand (top), monthly volume of the four reservoirs (middle) and annual hydropower generation (bottom). Note that "Future" reflects the current situation under the condition that green water management would have been implemented.

3.3 *Green water* management measures

Water related problems as indicated in the previous two sections require innovative solutions. Therefore, the impact of implementation of the three *green water* management measures (A_StoneLine, B_BenchTerraces, C_CountourTillage) described under 2.3 was evaluated using WEAP.

The assumption was that these measures would be implemented on 25% of the rainfed fields in the basin. It is clear that all scenarios have a positive effect on reducing water shortage (Figure 14), increasing reservoir storage (Figure 15) and improving hydropower generation (Figure 16).

Revenues, expressed in million US$, for the five main sectors (rainfed agriculture, irrigation, domestic, industry and hydropower) are shown in Table 3. It can be seen that increases in revenues can be up to US$ 43 million every year if these *green water* management measures are implemented. Benefits of green water management in rainfed areas can be mainly attributed to the reduced loss in fertile soil through erosion, while additional benefits occur as more *blue water* becomes available and less siltation of the reservoirs takes place.

A first estimate of costs of implementation of the *green water* management measures has been made as well. These initial estimates are based on a combination of a publication by Shiferaw and Holden (2001), earlier GWC work and expert estimates. More work however needs to be done on these costs. The assumptions of these cost estimates are that construction costs will be depreciated in 10 years, and that for most scenarios, annual maintenance costs have to be made.

The final benefit-cost analysis can be seen in Table 4. This benefit-cost analysis is based on the assumption that implementation will take place on 25% of the area.

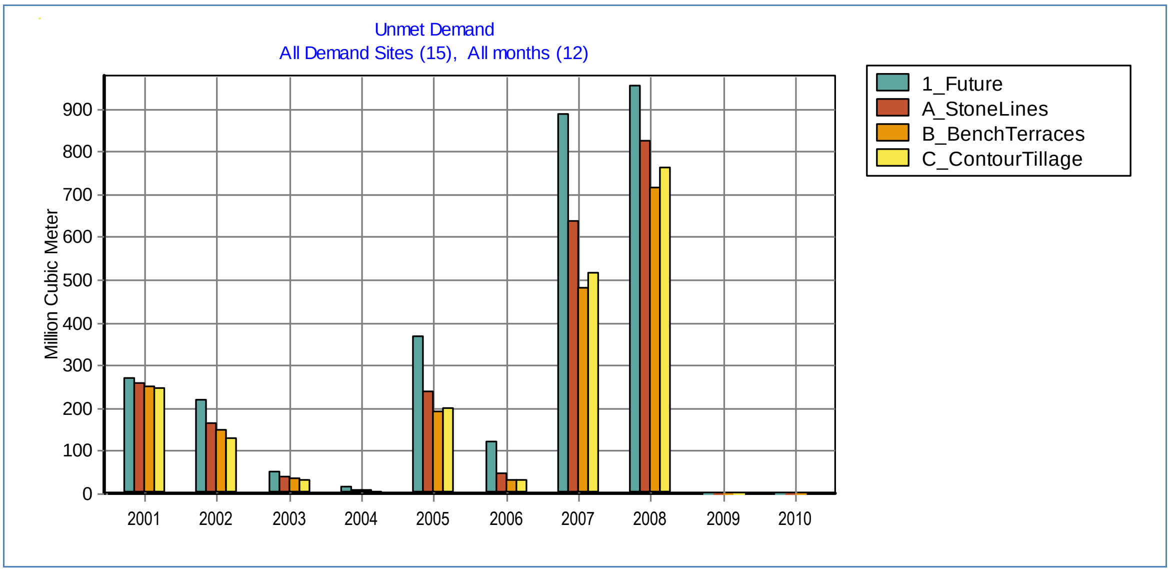


Figure 14: Water shortage (unmet demand) for the future and the three *green water* management scenarios

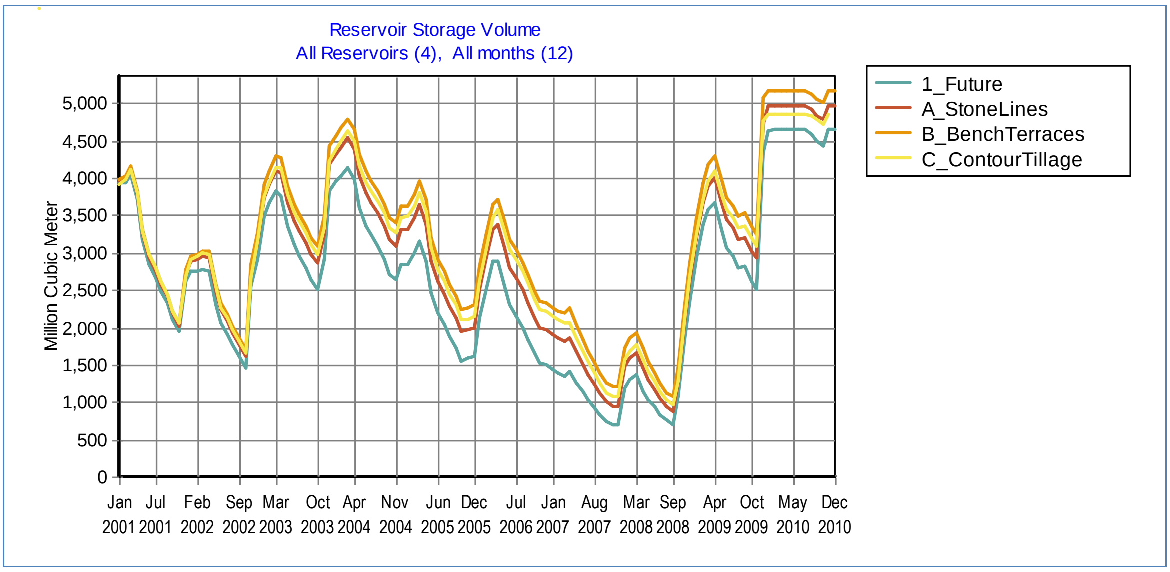


Figure 15: Reservoir storage for the future and the three *green water* management scenarios

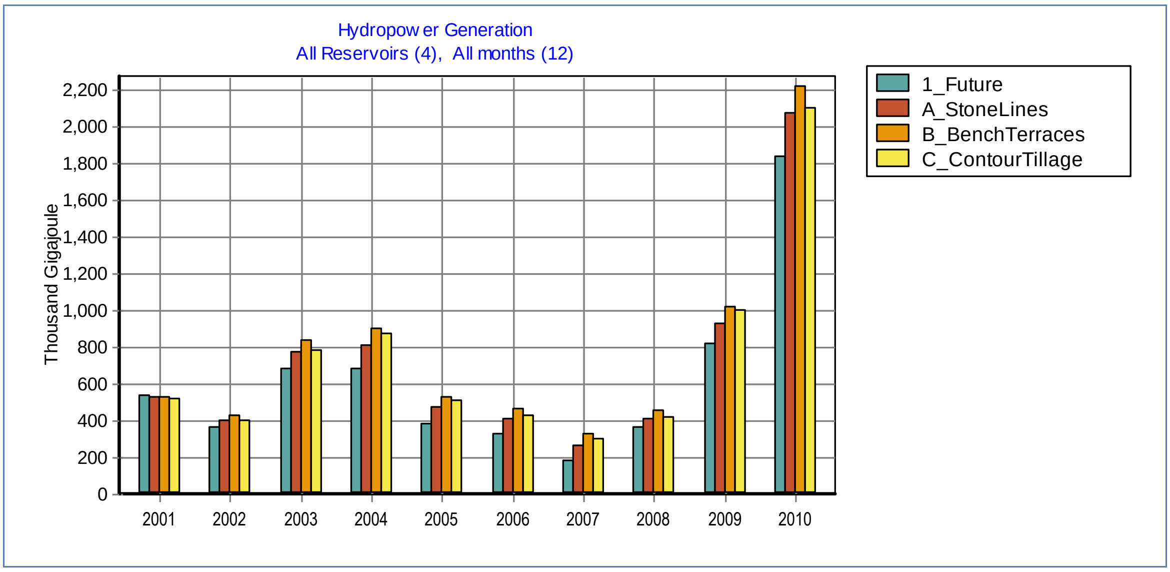


Figure 16: Hydropower generation for the future and the three *green water* management scenarios

Table 3: Total benefits from water services under the various scenarios. All values are average per year over the period 2001-2010

	Rainfed Agr.		Irrigated Agr.		Domestic & Industry		Hydropower		**TOTAL**
Scenario	mm/y	mUS$	MCM/y	mUS$	MCM/y	mUS$	GWH	mUS$	**mUS$ / y**
0_Baseline	420	93.6	1,714.9	257.2	737.8	221.3	278	13.9	**586**
1_Future	336	74.9	1,576.2	236.4	684.6	205.4	172	8.6	**525**
A_StoneLines	418	93.0	1,623.9	243.6	704.0	211.2	196	9.8	**558**
B_BenchTerraces	432	96.2	1,649.0	247.3	714.3	214.3	214	10.7	**569**
C_ContourTillage	408	90.9	1,644.9	246.7	713.1	213.9	203	10.1	**562**

Table 4: Benefit-cost analysis of the three *green water* management measures. All values averages per year

	Benefits	**Costs**				**B/C**
Scenario	mUS$ / y	ha	Construction US$/ha	Maintanance US$/ha /y	Total mUS$ / y	mUS$ / y
A_StoneLines	32.4	111,400	100	40	5.6	26.8
B_BenchTerraces	43.3	111,400	200	50	7.8	35.5
C_ContourTillage	36.4	111,400	0	0	0.0	36.4

4 Conclusions

The concept of Green Water Credits addresses the sustainable management of the water resources in a river basin at source. It links the rainwater that falls and is used (*green*) on rainfed land (or evaporates from the soil surface) to the (*blue*) water resources of rivers, lakes and groundwater. The importance of proper management of soil water on the provision of the *blue water* resources is often overlooked. One of the reasons for this is the difficulty in quantifying the potential impact of these measures. By using the SWAT model in combination with WEAP the potential benefits can be assessed.

The WEAP system as developed during this Proof of Concept phase needs additional validation and calibration. The overall purpose of the study is to demonstrate the use of the tools and to provide a first estimate of the potential impact of the *green water* management measures. Results should therefore be interpreted with caution. The assumption regarding the three *green water* management measures explored during this study is that implementation will take place on about 25% of the rainfed area.

The most effective measures, in terms of benefits only are implementation of bench terraces, followed by carrying out contour tillage, and then constructing stone lines. However, bench terraces are much more expensive than the other two measures, and contour tillage is the most preferable in terms of benefit-cost ratio.

More detailed analysis should reveal what the most effective *green water* management measure is a particular area (crop, soil, slope, etc.). However, these first analyses indicate clearly that there is scope to introduce Green Water Credits in the Sebou basin.

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