Using Water Evaluation and Planning System (WEAP) for Assessing Climate Change Impacts on Groundwater Resources
The situation of Water Resources in MENA region is characterized by scarcity, drought frequency and at the same time by increasing demands caused by rapid population growth and inefficient use of water especially by the agricultural sector.

The groundwater extractions often exceed the natural recharge volumes, resulting in a decline of the groundwater table and in a deterioration of the soil and water qualities (e.g. salinization).
Water authorities often derive their water supplies from several sources, which may include surface reservoirs, rivers, groundwater wells or combinations of these sources.

To identify the best combination of supply sources in the long term, or to determine the most effective way of managing existing systems, decision-makers need a lot of information to account for all of the hydrologic, hydraulic, water quality, and economic relationships within the system.

A Decision Support System (DSS) is needed to be used to develop water resources management plans, adaptable operating rules for water systems and regional policies.
Technical Cooperation Project:

“Management, Protection and Sustainable Use of Groundwater and Soil Resources in the Arab Region”

between

The Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD), Damascus, SYRIA

and

The Federal Institute for Geosciences and Natural Resources (BGR), Hannover, GERMANY

Funded by the German Federal Ministry for Economic Cooperation and Development www.bmz.de
A Decision Support System for Water Management (DSS)

- Aim of the Project?
  to develop and apply a :
    user-friendly
    efficient
    inexpensive
    easily sharable
    water planning and management tool
  and make it available in order to work together towards a more integrated water resources management in the Middle East and beyond
DSS Platform:

**WEAP as a DSS Platform**

- Provides a common framework and a transparent set of data that can be explored by all stakeholders and decision-makers
- Scenarios can be easily developed to explore options for the future
- Implications of various policies can be evaluated
Water Evaluation And Planning System

- Integrated watershed hydrology and water planning model
- GIS-based, graphical drag & drop interface.
- Physical simulation of water demands and supplies.
- Additional simulation modeling: user-created variables and modeling equations.
- Scenario management capabilities.
- Watershed hydrology, water quality and financial modules
- Developed by Boston Center of the Stockholm Environment Institute
Decision Support – Water Management
- Water Balance/ Abstraction Limits/ Safe Yield
- Current hydrological year planning
- Long term planning and scenario comparison

Model accuracy (modeled/measured)
- River gauges
- Observation wells
- Results by other modelling approaches
- General Monitoring data visualization
WEAP Schematic

Weap features
Drag and drop into the schematic

GIS features
Load vector (shp) or Raster layers as background into the schematic
RESERVOIR

SPRING OR RIVER

CATCHMENT (2)

GROUNDWATER

DEMAND SITE (1)

WW TREATMENT PLANT
Priority Allocation of Water Resources

- Demand Priorities
- Supply Preferences

Allocation Order

Using the demand priorities and supply preferences, WEAP determines the allocation order to follow when allocating the water. The allocation order represents the actual calculation order used by WEAP for allocating water.
Data View

Data is displayed numerically and graphically.

Annual level of activity driving demand, such as agricultural area, population using water for domestic purposes, or industrial output.

<table>
<thead>
<tr>
<th>Demand Site</th>
<th>1998</th>
<th>1999-2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture North</td>
<td>157.5</td>
<td>GrowthAsf{Key\Drivers\Built Environment Expansion,-0,0}    Thousand ha</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>50</td>
<td>Interp(2020,70) Percent share of hectares</td>
</tr>
</tbody>
</table>

Annual Activity Level
Results View

Results can be displayed in a wide range of formats and scales.
Overviews

Favorite charts can be selected to give quick overviews.
WEAP development through this cooperation project

1- MODFLOW

– Ground Water modeling

MODFLOW is a three-dimensional finite-difference groundwater modeling platform created by USGS.
**Linked DSS - Modeling Components** (calibrated alone beforehand)

**Modflow GW-Flow-Model**

Modflow 2000

Mathematical flow model to calculate:

**Groundwater:**
- level
- storage
- river interaction
- discharge at springs

**Resolution:**
- as raster (here 200x200m)

**Input:**
- 3D geometry of the aquifer
- permeabilities
- boundary conditions

**Licence:**
- free

**Weap – Model** (WEAP21)

Water Evaluation and Planning System
(www.weap21.org – Stockholm Environmental Institute)

Water management and planning model and remote control of MODFLOW to calculate:
- groundwater recharge
- irrigation demand
- detailed water balances for defined spatial planning units

**Resolution:**
- catchment/ landuse class/ MF raster

**Input:**
- climate data
- abstraction data (domestic)
- soil and crop data
- planning scenario setup

**Licence:**
- free to all Arab government and research institutions
Weap – Modflow interaction
(for each WEAP timestep)

**WEAP:**
Calculates GW recharge, abstraction rates, river stage for one timestep (based on parameters defined for the respective WEAP-scenario)

**Next time step**

**WEAP:**
Transcribes the result into a Modflow-conformal ascii-file (*.rch, *.wel, *.riv)

**WEAP:**
Runs mf2k.exe

**Modflow:**
Calculates cell-head, storage volumes, flows ...

**WEAP:**
Reads the Modflow result-files and updates the WEAP-internal parameters
Link MODFLOW Cells to WEAP Elements

- **MODFLOW**
  - modeling information is related to grid-cells with a specific row-column-layer address
  - grid has a defined geographic position

- **WEAP**
  - modeling information is related to abstract elements like "subcatchment" or "groundwater node"
  - Only numerical data is used for calculation but no geographic information

**Problem:**
As both models have to communicate with each other, each of the WEAP-items has to know, for which MODFLOW-cells it’s information is valid and vice versa.

**Solution:** A linkage acts as a “dictionary” between WEAP and MODFLOW

Linkage = the attribute table of a GIS-shapefile
WEAP development through this cooperation project

2- MABIA:

- Enhanced soil water balance model

  MABIA Method is a daily simulation of transpiration, evaporation, irrigation requirements and scheduling, crop growth and yields, and includes modules for estimating reference evapotranspiration and soil water capacity.

  The MABIA Method uses the ‘dual’ $K_c$ method, as described in FAO Irrigation and Drainage Paper No. 56.
WEAP development through this cooperation project

3- MODPATH:

- MODPATH is a groundwater particle tracking post-processing package that was developed to compute three-dimensional flow paths using output from steady-state or transient groundwater flow simulations by MODFLOW. Its purpose is to evaluate advective transport through a model.

- MODPATH tracks the trajectory of a set of particles from user-defined starting locations using the MODFLOW solution as the flow field. The particles can be tracked either forward or backward in time. Particle tracking solutions have a variety of applications, including the determination of zones of influence for injection and extraction wells.
GW-RECHARGE/IRRIGATION DEMAND AND SURFACE RUNOFF CALCULATIONS IN WEAP:

1) ENTER AS HARD DATA
2) FAO, IRRIGATION DEMAND ONLY
3) FAO RAINFALL-RUNOFF MODEL (ETref, Kc)
4) SOIL MOISTURE MODEL (soil, plant & climate parameters)
5) MABIA MODEL (soil, plant & climate parameters)

QUAL2K MODEL
MODFLOW MODEL
Scenario analysis

At the heart of WEAP is the concept of scenario analysis. Scenarios are self-consistent story-lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions.

Using WEAP, scenarios can be built and then compared to assess their water requirements, costs and environmental impacts.
• Scenarios in WEAP encompass any factor that can change over time, including those factors that may change because of particular policy interventions, and those that reflect different socio-economic assumptions.

• Sensitivity analyses may also be done by varying uncertain factors through their range of plausible values and comparing the results...
An important concept in using scenarios is the idea of scenario **inheritance**. Scenario inheritance allows you to create hierarchies of scenarios that inherit default expressions from their parent scenario.
Scenarios – What if....

• The scenarios can address a broad range of "what if" questions, such as:
  – What if population growth and economic development patterns change?
  – What if reservoir operating rules are altered?
  – What if groundwater is more fully exploited?
  – What if water conservation is introduced?
  – What if ecosystem requirements are tightened?
  – What if new sources of water pollution are added?
  – What if a water recycling program is implemented?
  – What if a more efficient irrigation technique is implemented?
  – What if the mix of agricultural crops changes?
  – What if climate change alters the hydrology?
PILOT STUDY I:
Zabadani Basin
SYRIA

PILOT STUDY II:
Berrechid Basin
MOROCCO

Hydraulic Basin Agency (ABH) of Bouregreg and Chaouia Basins, Benslimane
PILOT AREA I:

ZABADANI BASIN, SYRIA

- Area 165 km².

- Existing Water Conflict between multi-groundwater users (Drinking Water – Damascus/local, Agriculture, Tourism)

- The Climate of the Antilebanon Mountain Range, is a Mediterranean climate with precipitation occurring between October and May. For the reference year 2004/2005 the range of precipitation was between 400 and 1000 mm with an average of 714 mm/y.
Arab-German Cooperation Project (www.acsad-bgr.org): Management, Protection and Sustainable Use of Water and Soil
Arab-German Technical Cooperation
Management, Protection and Sustainable Use of Groundwater and Soil Resources
Decision Support System Zabudani Basin

Complexe Tectonics, Geology & Hydrogeology
Stakeholder Participation

The initial task has been to divide the basin into spatial subunits. Together with the members of the DSS steering committee the Zabadani basin was subdivided into 11 subcatchments, being crucial to the water management planning. Their outlines have been determined by aggregating the major drinking water well fields and if possible follow surface watersheds.
WEAP Model: 11 subcatchments/ 48 landuse classes

DW: 14 well fields
IR: evenly thru irrigated area

Annual Water Use Rate

RAWDA
HOSH_BEJET
MADAYA
ZABADANI
BLOUDAN
DAWSSA
EIN_HOUR

Million m$^3$

15.0
10.0
5.0
0.0
The studied area was divided to $124$ (rows) $\times 27$ (columns) $\times 3$ (layers) = 27528 cells.

The dimension of the cells is 200m by 200m.
groundwater head 3D-view
GW-MODEL RESULTS (MODFLOW 2000)

Groundwater level

Barada Spring discharge

Scenario: no change, All months, River: Barada Spring
Scenarios

Two sets of scenarios have been calculated by the DSS,

– a historic scenario (1998-2007) in order to check the calibration accuracy of the models and
A) **Historic scenario 1998 - 2007**

to evaluate the DSS accuracy (wet/dry years)

B) **Planning scenarios 2005 – 2017**

impacts of demand changes, climate change, boundary condition changes,…

1) 50_rain: 50% of the annual rain
2) 80_rain: 20% decrease of annual rainfall

3) DRA_2x_DAWSSA_3x_AGR_0.7: increase in drinking water abstraction/reduction in irrigation
4) no GW – inflow: no groundwater inflow from outside the basin.
Results A): groundwater head 2D-view, time series
• **Climate change scenario (80_rain):** Long-term climate change impacts have been assessed by Kunstmann *et al.* (2007) by downscaling the global B2 climate scenario model of ECHAM4 to a resolution of 18km x 18km in the eastern Mediterranean/Near East region. Preliminary calculation results have been derived for two thirty year (1961-1990 and 2070-2099) time periods.

• The graph indicates a decrease in precipitation and by averaging the yearly precipitations in the two time periods, **a decrease in precipitation of twenty percent can be calculated.**

• This decrease of twenty percent was applied to the planning scenario 2005-2017 in order to see on an even shorter time scale and more drastically the impact of possible decreases in precipitation. Further refinements of these climate models may give a better prediction basis.
Fig. 3.1.14. B2-ECHAM4 climate scenario impact on the Zabadani basin.
• **Drought cycle scenario (50_rain):** The historic precipitation measurements show that there is roughly every five to thirteen years a „drought“ year with less than half of the mean annual rainfall.

• From 1999 to 2001 there had been three „drought“ years in a row, causing severe impacts on the domestic and irrigation water supply. Therefore an additional planning scenario was created by reducing the average precipitation of the year 2004/2005 to 50% and calculating the impacts of consecutive drought years.
Fig. 3.1.15. Historic precipitation distribution recorded at the Damascus station.
Results B: groundwater level
Results B): groundwater storage
Impact on Barada Spring discharge

Yearly Discharge of Barada Spring applying respective scenarios

YEAR
DISCHARGE [Mm³/y]

80_RAIN
50_RAIN
DRA_2x_DAWSSA_3x_AGR_0.7
NO_GW_INFLOW
All documents, tutorials and tools are available for downloading...

THANK YOU!