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Application of WEAP to Assess Future Water Demands: The State of Art

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Abstract

Integrated water resources management is considered as the primary approach in addressing sustainable water resources. Decision Support Systems (DSS) can provide effective tools for water allocation, supply and demand analysis. The present paper describes the review of the river basin simulation modeling using Water Evaluation and Planning (WEAP) DSS tool for allocating water resources among various users. The step by step modeling procedure along with calculation algorithm at each stage for assessing future water demands using WEAP is studied in this paper. The model has been used to assess future water demands in many basins such as Limpopo Basin, Samuel (2006), Olifant basin, Roberto (2007), Blue Nile, Matthew (2009) and Niger River, Zakari (2011). The process involves studying model structure, setting general parameters, entering data for components of river basin system viz. supply component (river), demand site (agriculture, domestic, industrial etc.) and delivery systems. Model performance can be evaluated statically by comparing the observed and simulated values thereby accomplishing calibration of model. If variation in values is acceptable then the model's prediction is valid and reliable and hence can be used to assess future water demands. Then Scenarios need to be formulated and evaluated. Based on the results obtained best suitable action may be chosen for assessing future water demands for basin.

Keyword- Decision Support System; Future water demands; Integrated water resources management; Water Evaluation and Planning

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I. INTRODUCTION

River Basin Models are widely used to simulate water resource system behavior based on a set of rules governing water allocations and infrastructure operation. They represent not only the natural and physical processes, but also the artificial "hardware" (physical projects) and "software" (management policies) systems as well using node-link network. They utilize optimization and simulation techniques and helps decision-maker to reduce the time and improve the consistency and quality of those decisions. River basin models include the interactions between water allocation, agricultural productivity, nonagricultural water demand, and resource degradation to estimate the social and economic net benefits from water allocation and use. For every reservoir, water balances are calculated as:

$$S_j^t - S_j^{t-1} = Q_{in,j}^t - Q_{out,j}^t - L_j^t \qquad (1)$$

Where, S_j^t=Volume of water in reservoir j at time t (million m^3);$Q_{out,j}^t$ =Release from reservoir j in period t (million m^3);$Q_{in,j}^t$=Inflow to reservoir j in period t (million m^3); L_j^t=Loss from reservoir j over time t (million m^3) from seepage or evaporation.

To solve the river basin model and obtain values for flow and storage in all links and nodes of the basin network, some solution criterion must be established to provide regulation of the water resources of the basin river under various imposed conditions (scenarios).

Many programs like SOBEK, RIBASIM (River Basin Simulation Model), HYMOS, MIKE-BASIN, MODSIM, WBalMO (Water Balance Model) and WEAP (Water Evaluation and Planning) are available for River basin modeling. These programs are designed to simulate water development and management policies in river basins. They are generic in that they are designed to be applicable to a wide variety of specific river basin water resource system configurations, institutional conditions, and management issues. For present study, WEAP has been chosen.

Water Evaluation and Planning System (WEAP) developed by the Stockholm Environment Institute's Boston Center (Tellus Institute) is a water balance software program that was designed to assist water management decision makers in evaluating water policies and developing sustainable water resource management plans. WEAP operates on basic principles of water balance accounting and links water supplies from rivers, reservoirs, and aquifers with water demands, in an integrated system. Designed to be menu-driven and user-friendly, WEAP is a policy-oriented software model that uses water balance accounting to simulate user-constructed scenarios. WEAP can simulate issues including sectoral demand analyses, water conservation, water rights, allocation priorities, groundwater withdrawal and recharge, streamflow simulation, reservoir operations, hydropower generation, pollution tracking (fully mixed, limited decay), and project cost/benefit analyses. Groundwater supplies can be included in the

WEAP model by specifying a storage capacity, a maximum withdrawal rate, and the rate of recharge. Minimum monthly instream flows can be specified. WEAP is relatively straightforward and user-friendly for testing the effects of different water management scenarios. The results are easy to view for comparisons of different scenarios. Changing input data to model newly proposed scenarios can be readily accomplished.

A growing number of water professionals are finding WEAP to be a useful addition to their toolbox. This model has been applied to other basins in the world with satisfactory results. It has been applied in Limpopo Basin to model the response of small multi-purpose reservoirs to hydrology for improved rural livelihoods in Mzingwane catchment (Samuel 2006). It has also been used to simulate current and future water demands the Olifant basin in South Africa (Roberto 2007), Blue Nile (Matthew 2009) and Niger River (Zakari 2011).

II. Methodology

Below are the steps for using WEAP model to assess future water demands for a Basin:

A. WEAP Model Structure

WEAP Resources, Installation, and Sample River Basins is explained below:

1) Go to the WEAP home page (http://www.weap21.org/) and overview the resources available for you. These resources include a demonstration, user guide, tutorials, and user forums.
2) Download and install WEAP (skip Step 2 if you are working on a computer where the program is already installed).
   a) On the left side of the WEAP home page under Using WEAP, click Download, join the WEAP forum, login with your newly assigned password, and follow the directions from there. Also, read the box “Download WEAP” (below) and start downloading.
   b) The free version of WEAP you downloaded is an evaluation version and therefore has limited use. Opening the program will prompt you to register the program. To register, enter the User Name and Registration Code (provided by your professor or obtained from download). After registering, enter your initials and click “End user information” in the window provided.
3) Open the program and explore the Weaping River Basin sample model.
   a) In the Schematic mode (click top icon at left), explore the system spatial configuration. How many reservoirs, aquifers, and demand sites are in the sample model?
   b) In the Data mode (click second icon at left), explore the types of data entered. The data is organized into a tree of Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Water Quality and Other Assumptions. How are demands disaggregated and entered for the South City and Agricultural North demand sites? Is this disaggregation the same for other sites? Note this disaggregation is different from demand data in the Weber River Basin case study.
   c) In the Results mode, explore the numerous available results for one or multiple model runs (scenarios); four scenarios are defined in the model (Demand Measures, Integrated Measures, Reference, and Supply Measures). In the Chart view, use the drop-down menu to select results to view. What menu option would you select to view shortages at a demand site (i.e., the difference between the actual delivery and the delivery target)?
   d) Click the Scenario icon to view, define, and compare results from the various scenarios created.

B. Data Required

This includes collecting data for river basin components: sources of water supply (groundwater and surface water), a delivery system (river, canal and piping network), water users (agricultural, municipal, and industrial), and a drainage collection system (surface and subsurface). Data for water supply component includes Basin Map, River data (eg. streamflow), Reservoir data, Climate data (rainfall, evaporation, Temperature etc.). Demand data includes data for demand sites like agricultural site (Delta, Duty), Domestic demand site (Total population, per capita water use rate, growth rate of population) etc.

C. Evaluation of WEAP Model

1) Area Setup

4) Using the “Area, Create Area” menu option a new, blank area can be created. A window will appear in which, click on the “Initially Blank” option. In the next screen, select the geographic area for our project from the world map that appears.

2) Setting General Parameters

5) Using the “General” menu, set Years and Time step (Accounts Year, Last Year of Scenarios, Time Steps per year, Time Step Boundary, water year start) and Units.

3) Model Schematic

6) The Schematic mode has three tool boxes arranged in a column just to the right of the Schematic, Data, Results, etc. icons at the far left. The top box provides tools to add elements to the model. The middle box shows GIS files which can be layered onto the schematic. And the lower box shows a wide- angle zoom of the schematic.

7) First, add shape files to help place reservoirs, demand sites and other elements on the schematic. From the Schematic menu, select Add Vector Layer. Navigate to the Shape Files folder and select the file. In the subsequent MapLayer window, click OK.
8) Now, add the elements (Reservoir, demand site, transmission link, return flow link etc.) into schematic.
   a) To add a Reservoir, click the Reservoir label in the box, drag it, and drop it at the desired location.
   b) To add a Demand Site, go to the top box and follow steps given below:
   1) Click the Demand Site label in the box, drag it, and drop it at the desired location.
   2) After dropping, a General Info window will open. Enter a Name and Optional Label.
   3) Give Demand Priority to various demand sites. Demand priority determines the order in which scarce water is allocated and delivered to demand sites. Higher priority (lower numbered) sites receive their full demands before lower priority (higher numbered) sites receive any water.
   4) Keep all other options to default values and click OK.
   c) Repeat Step 8a for other Demand Sites that need to be added to the schematic.
   d) Add a Transmission Link by dragging the transmission link tool, clicking on the starting point, and dragging to an ending point at a desired Demand Site. Keep all other options to default values. You can also add a Return Flow from a Demand Site back to the river using a similar procedure.
   e) Add any other model elements you may need.
9) 9. After adding all the missing elements, save work using “Area”, “Save…” menu or press Ctrl+S.

4) Data Entry

10) Now enter data for the model elements you added in Step 8 by selecting the Data icon. While entering data, make sure to press “Enter” after each data entry. You will need to enter data for river, reservoirs, demand sites, transmission links, and return flows.
11) Reservoir Data: For modeling reservoirs, enter data for the same. First, on the Data For dropdown list, make sure to select Current Accounts. Then right click on Reservoir, and select Edit Data=>Storage Capacity. A data window will open. Enter the Physical, Operation, and Priority data for the reservoir by clicking the various buttons.
    a) Physical Data: On the Storage Capacity and Initial Storage tabs, enter data using the appropriate units. On the Volume Elevation Curve tab, use the two column table provided to enter (or paste in) data for the Volume-Elevation Curve. On the Net Evaporation tab, you can choose Monthly Time-Series Wizard too to enter the monthly values provided. Leave Loss to Groundwater at the default setting of zero, if not required.
    b) Operation Data defines the reservoir zones (pools) and releases from them. Enter storage volumes that correspond to the Top of Conservation, Top of Buffer, and Top of Inactive pools. Enter the Buffer Coefficient as a number between 0 and 1 to indicate the fraction of water in the buffer pool available for release each month (should the storage level drop into the buffer pool).
    c) Enter hydropower, water quality, or cost data for reservoirs.
12) Demand Sites. A demand site's (DS) demand for water is calculated as the sum of the demands for all the demand site's bottom-level branches (Br). A bottom-level branch is one that has no branches below it.

$$\text{Annual Activity Level DS} = \sum_{\text{Br}}(\text{Total activity Level}_{\text{Br}}\ \text{X Water Use Rate}_{\text{Br}}) \qquad (2)$$

The total activity level for a bottom-level branch is the product of the activity levels in all branches from the bottom branch back up to the demand site branch (where Br is the bottom-level branch, Br' is the parent of Br, Br" is the grandparent of Br, etc.).

$$\text{Total Activity Level}_{\text{Br}} = \text{Activity Level Br x Activity Level Br}'\text{x Activity Level Br}''\text{x} \qquad (3)$$

The monthly demand represents the amount of water needed each month by the demand site for its use, while the supply requirement is the actual amount needed from the supply sources. The supply requirement takes the demand and adjusts it to account for internal reuse, demand side management strategies for reducing demand, and internal losses. These three adjustment fractions are entered as data--see Demand\Loss and Reuse and Demand\Demand Side Management.

$$\text{Monthly Supply Requirement}_{\text{DS,m}} = (\text{Monthly Demand}_{\text{DS,m}}\text{x}(1 - \text{Reuse rate}_{\text{DS}})\text{x}(1 - \text{DSM Savings}_{\text{DS}}))/(1 - \text{Loss rate}_{\text{DS}}) \qquad (4)$$

For entering data, right click on a Demand Site you created in Step 8a. Select Edit Data=>Method. A data window will open.

a) Select the Advanced button at the far right. In the Method table, click the Demand Site name, select Specify Monthly Demand, and press enter.
b) The demand for a month (m) equals that month's fraction (specified as data under Demand\Monthly Variation) of the adjusted annual demand.

$$\text{Monthly Demand}_{\text{DS,m}} = \text{Monthly Variation Fraction}_{\text{DS,m}}\text{x}(\text{adjusted Annual Demand}_{\text{DS}}) \qquad (5)$$

Select the Water Use button. Enter data for Annual Activity Level (cultivated area for Agricultural demand site, population data for urban demand site etc.), Annual water use rate, Monthly variation and consumption.

The amount supplied to a demand site (DS) is the sum of the inflows from its transmission links. (The inflow to the demand site from a supply source (Src) is defined as the outflow from the transmission link connecting them, i.e., net of any leakage along the transmission link).

$$\text{Demand Site Inflow}_{\text{DS}} = \sum_{\text{Src}} \text{TransLink Outflow}_{\text{Src,DS}} \quad (6)$$

Every demand site has a monthly supply requirement for water, as computed in Demand Calculations. The inflow to the demand site equals this requirement, unless there are water shortages due to hydrological, physical, contractual or other constraints.

$$\text{Demand Site Inflow}_{\text{DS}} \leq \text{Supply requirement}_{\text{DS}} \quad (7)$$

Some fraction of the water received by a demand site will be unavailable for use elsewhere in the system (i.e., because the water is consumed--lost to evaporation, embodied in products, or otherwise unaccounted for--it disappears from the system.) This consumption fraction is entered as data.

$$\text{Consumption}_{\text{DS}} = \text{Demand Site Inflow}_{\text{DS}} \text{x Demand site consumption}_{\text{DS}} \quad (8)$$

Of the inflow that is not consumed, the remainder flows out of the demand site, either to another demand site for reuse, to a wastewater treatment plant for treatment, or to surface or groundwater. Any demand sites directly reusing this outflow will take what they need. The remainder is sent to the various return flow destinations.

$$\text{Demand site Return outflow}_{\text{DS1}} = \sum \text{TransLinkOutflow}_{\text{DS1,Ds2}} \quad (9)$$

$$\text{Demand site Return Flow}_{\text{DS}} = \text{Demand Site Inflow}_{\text{DS}} - \text{Consumption}_{\text{DS}} - \text{Demand Site Reuse Outflow}_{\text{DS}} \quad (10)$$

c) Select the Loss and Reuse button. Enter Loss rate and reuse rate.
d) Repeat Steps 12a-c for other Demand Sites you added to the schematic.

13) Transmission Links. Right click on a Transmission Link and select Edit Data=>Maximum Flow Volume. Here you can leave all settings at their default values (i.e., unlimited capacity, first priority use, no losses, and no costs).

In a transmission link from a supply source (Src) to a demand site (DS), the amount delivered to the demand site (i.e., the outflow from the transmission link) equals the amount withdrawn from the source (i.e., the inflow to the transmission link) minus any losses along the link.

$$\text{TransLink Outflow}_{\text{Src,DS}} - \text{TransLink Inflow}_{\text{Src,DS}} - \text{TransLink Loss}_{\text{Src,DS}} \quad (11)$$

The losses in the transmission link are a fraction of its inflow, where the loss rates are entered as data.

$$\text{TransLink Loss}_{\text{Src,DS}} = \left(\text{TransLink loss from system}_{\text{Src,DS}} + \text{TransLink loss to Groundwater}_{\text{Src,DS}}\right)\text{xTransLink Inflow}_{\text{Src,DS}} \quad (12)$$

You may set constraints to model the physical, contractual or other limits on the flow from a source to a demand site, using one of two types of constraints. One type of constraint is a fixed upper bound (MaximumFlowVolume) on the amount of water flowing into the link. For example, this might represent a pipeline capacity, or a contractually limited allotment.

$$\text{Translink Inflow}_{\text{Src,DS}} \leq \text{Maximum Flow volume}_{\text{Src,DS}} \quad (13)$$

The other type of constraint allows you to set the maximum fraction (MaximumFlowPercent) of the demand site's supply requirement that can be satisfied from a particular source. Both of these constraints are entered as data (see Supply and Resources\Transmission Links\Linking Rules).

$$\text{Translink Outflow}_{\text{Src,DS}} \leq \text{Maximum Flow percent}_{\text{Src,DS}} \text{x Supply requirement}_{\text{DS}} \quad (14)$$

14) Return Flows. Right click on a Return Flow, and select Edit Data=>Return Flow Routing. Again, leave all settings at their default values (i.e., 100% return flow routing, zero loss from system, zero groundwater loss, zero gain from groundwater, and no costs). Return Flow Routing is the percent of total outflow from a demand site that is directed through a Return Flow Link.

Demand site return flow links transmit wastewater from demand sites (DS) to destinations (Dest), which may be either wastewater treatment plants or receiving bodies of water. The amount that flows into the link is a fraction of demand site return flow (outflow minus the flow to demand sites for reuse).

$$\text{DS Return Link Inflow}_{\text{DS,Dest}} = \text{DS Return flow Routing Fraction}_{\text{DS,Dest}} \text{x Demand Site Return flow}_{\text{DS}} \quad (15)$$

The amount that reaches the destination (i.e., the outflow from the link) equals the outflow from the demand site (i.e., the inflow to the link) minus any losses along the link.

$$\text{DS Return Link outflow}_{\text{DS,Dest}} = \text{DS Return Link Inflow}_{\text{DS,Dest}} - \text{DS Return Link loss}_{\text{DS,Dest}} \quad (16)$$

The losses along the link are a fraction of its inflow, where the loss rates, both from the system and to a named groundwater node, are entered as data (see Supply and Resources\Return Flows\Losses).

$$\text{DS Return Link Loss}_{\text{DS,Dest}} = (\text{DS Return Link Loss From system}_{\text{DS,Dest}} + \text{DS Return Link loss to Groundwater}_{\text{DS,Dest}})\text{xDS Return Inflow}_{\text{DS,Dest}} \quad (17)$$

D. Model Calibration and Validation

Calibration includes changing the model parameters to better simulate historic patterns. WEAP21 has no automatic calibration routine; therefore, calibration involves manually comparing the simulated and observed time series. If the resultant fit is acceptable then the model's prediction is valid and reliable.

III. RESULTS

15) With the system schematic represented and all pertinent data entered, you can now run the model and generate results.
16) Click the Results icon. When asked to recalculate results, select Yes.

17) There are numerous results to view and explore in WEAP. To view results for an element, right-click the element and select View Results and the result type. For example:
    a) What is the reliability of deliveries to the Demand Site(s) you created?
    b) Which demand site(s) experience shortage(s)?
    c) What is the lowest reservoir storage volume seen?
    d) A variety of tools are available at the right-hand-side of plots to reformat and export results, including exporting to Excel.

E. Evaluation of Future water Demands in the Basin

1) Scenario Explorer

18) Scenarios allow you to test the effects of new infrastructure, operations, demand forecasts, climate projections, or other changes to model inputs. Following are the examples of scenario analyses:
- 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?

19) In WEAP the typical scenario modeling effort consists of three steps. First, a "Current Accounts" year is chosen to serve as the base year of the model; Current Accounts has been what we have been adding data to in the previous step. A "Reference" scenario is established from the Current Accounts to simulate likely evolution of the system without intervention. Finally, "what-if" scenarios can be created to alter the "Reference Scenario" and evaluate the effects of changes in policies and/or technologies.
    a) First, create the scenario. Click the Data icon. On the top row of the data page, click the Manage Scenarios button. In the Manage Scenarios window select Current Accounts and click the Add button at the top left corner of the window. Finally, Name the new scenario. Click OK and close the windows to return to the Data page.
    b) Now change one or more inputs to reflect the new scenario. What input data did you change and at what locations?
20) To compare results among scenarios:
    a) Go to the Results mode. Select a result type from the dropdown menu located on the top middle of the screen. Choose a convenient unit for the volume.
    b) Choose a location, make sure that the All months option is selected, and unselect the Monthly Average box.
    c) In the dropdown menu to the right of the label Monthly Average, choose No Comparison (rather than a one-to-one comparison). From the far right drop down menu, choose All Scenarios. Make sure All Years is selected at the bottom of the window.

IV. CONCLUSION

Following conclusions can be drawn from the above study:
- Model tries to balance water at the model nodes during each period of a specified planning horizon.
- Satisfy, to the extent possible, the demands of water users in the basin during the planning horizon.
- Follow the operation regimes of the basin reservoirs according to their technical requirements and rules of their operation; and
- Satisfy, to the extent possible, requirements for environmental flows.

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