Technical Brief 2

Hydrologic Modelling of the Upper Malaprabha Catchment using ArcView SWAT

Technical briefs are short summaries of the models used in the project aimed at non-technical readers. The aim of the PES-India project is to assess feasibility criteria for schemes for payment for environmental services (PES), particularly watershed services(PWS). In order to test such feasibility criteria the project is carrying out a number of assessments on different issues regarding water availability and water requirements at various water user sectors in the Malaprabha river basin. This includes land-use scenario analysis using hydrological and allocation models, evaluation of water conservation measures by upstream land-users, and the legal and institutional feasibility of Payments for Watershed Services schemes.

In this technical brief we describe hydrological modelling of the upper Malaprabha catchment using SWAT. The modelling exercise is carried out to primarily estimate runoff from various land-use types, crop water consumption, and the spatial distribution of water resources within the basin.

Description of the catchment

Malaprabha catchment in Belgaum district, Karnataka, India is one of the deficit sub-basins in the Krishna River Basin. Location map of the Malaprabha catchment is shown in Fig. 1.

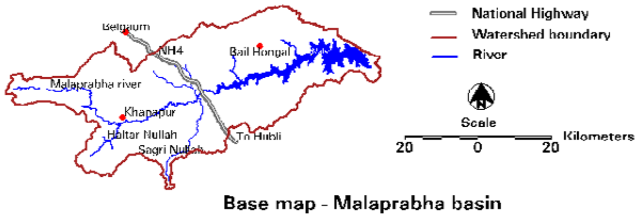


Fig. 1 Location map of the upper Malaprabha catchment

The catchment area is characterized by the heterogeneity in climate, soils, land-use and hydro-meteorological characteristics. Hydrologically the catchment area can be roughly divided into three zones as shown in Fig. 2.

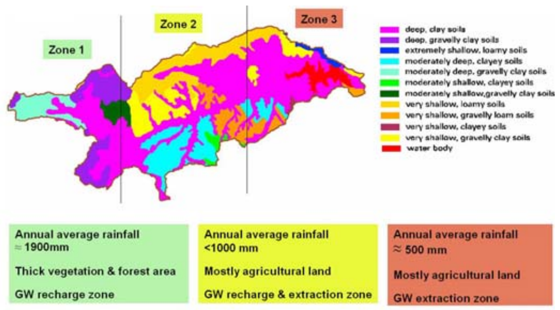


Fig. 2 Hydrological zones in Malaprabha catchment

Annual average rainfall in the area varies between 2000mm in zone 1 to 500 mm in zone 3. Due to the variation in rainfall distribution, soil type, land use conditions, slope, and geological characteristics of the catchment, nearly 80% of the monsoon stream flow and significant ground water recharge to the shallow and deep aquifers comes from upper catchment (zone-1). This part of the catchment has 38 % area under forests and grasslands and 47 % under agriculture-which is mostly rainfed. Since the 1990's due to rapid expansion of water intensive crops in the catchment, much of the stream flow generated from zone 1 is extracted by zone 2 and zone 3, mainly for irrigation. From the historical rainfall series it has been found that annual rainfall has fairly remained unchanged and that the primary cause of reduction in the dry season flows is rapidly changing land use, particularly agricultural intensification.

Modelling framework

Within the larger framework for feasibility analysis of PWS schemes, the hydrological modelling framework is developed to estimate various components of the water budget. Within the hydrological modelling framework, the catchment is initially divided into various sub-basins based on topography and stream network. Modelling aims at estimating the stream flow, evaporation and seepage losses, and irrigation demands at individual sub-basin level. In order to achieve water balance, the model essentially needs to consider water storage at different layers starting from the canopy storage to the ground water storage. In addition to this, various land use scenarios need to be built in the model to study the impact on water availability.

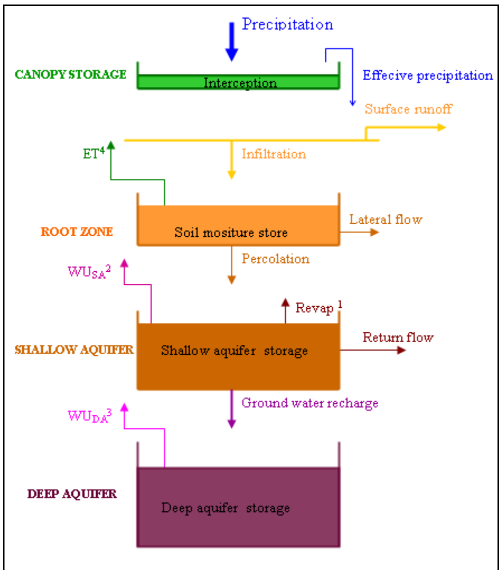
Hydrologic modelling using SWAT

Soil and Water Assessment Tool (SWAT), developed by J.G.Arnold (Arnold et al., 2000) is one of the most robust models available for watershed modelling. SWAT model was originally developed as a lumped model, based on the physical laws of water movement.

In the course of modelling the hydrologic processes in a watershed, SWAT considers water storage in four different layers viz., canopy storage, root zone storage, shallow aquifer storage and deep aquifer storage. Schematic representation of the model is presented in Fig. 3. It also considers surface runoff, infiltration, soil moisture redistribution, evapotranspiration, lateral sub-surface flow, storage in reservoirs and ponds, transmission losses in the stream and return flow.

Key features that make the model applicable for a wide range of studies are:

- Modelling based on physical processes associated with soil and water interaction
- Flexibility to incorporate crop characteristics, cropping stage and duration
- Flexibility on input data requirement
- Capability of modelling the changes in land use and management practices
- Computational efficiency
- Capability of long-term simulations
- Capability of modelling catchment areas varying between few hectares to thousands of sq.km.
- The model is freely available and can be easily downloaded from the internet.



[1]Revap = water that moves from the shallow aquifer to the soil and is lost by soil evaporation or plat root uptake
[2]WU_{SA} = water extraction from the shallow aquifer
[3]WU_{DA} = water extraction from the deep aquifer
[4]ET = Actual evapotranspiration

Fig. 3 Schematic representation of hydrologic processes in SWAT

GIS Interface for SWAT - AVSWAT

In order to facilitate the modelling using spatially distributed data viz., land use, soil and meteorological characteristics, SWAT is integrated with the Geographic Information System (GIS) ArcView developed by ESRI (Di Luzio et al., 2002). This GIS integrated SWAT (AVSWAT) provides a user friendly interface, facilitates the input of geographically referenced physical data and climate data at multiple stations within the catchment. Schematic representation of AVSWAT is shown in Fig. 4.

Important functional components in AVSWAT are: Watershed delineation; definition of Hydrologic Response Units (HRU); input parameterization, editing and scenario management; model execution; calibration tools.

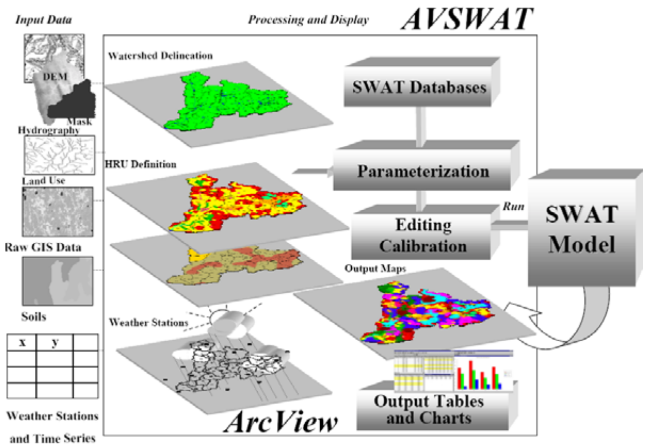


Fig 4. Schematic diagram of the integration of ArcView with SWAT (Di Luzio et al., 2002)

Hydrologic modelling using AVSWAT

AVSWAT will be applied in the Malaprabha catchment to estimate the water availability at different sub-catchments. Generation of input data, steps involved in the modelling and the output data format are explained in the following sections.

Model Data Requirements:

Input data required for SWAT include Digital Elevation Model (DEM) of the watershed, digital maps of soil and land use, hydro-meteorological data and the SWAT database presenting the hydrological characteristics of each soil and land use types.

Elevation data: Elevation data is obtained from the SRTM (Shuttle Radar Topography Mission). It is freely downloadable from SRTM website for the entire globe at 90m horizontal resolution.

Land use information: Digital land use map of the area will be generated from the IRS P6 LISS-III images using digital image processing techniques and ground truth information.

Soil map: Primary data for soils in the Malaprabha catchment is sourced from NBSS (National Bureau of Soil Survey and Land Use Planning). Model relevant parameters are derived from theoretical relationships between soil texture and soil-hydraulic properties. Important characteristics required by the model are soil type, texture, soil depth, available water content, bulk density, and soil hydraulic conductivity

Rainfall: Rainfall data from 18 raingauge stations spread across the basin are compiled from DES acquired data (Department of Economics and Statistics). The data is provided in the model on daily basis for the duration of the model run.

Climate data: Parameters relevant for the estimation of potential evapotranspiration is collected from various source including IMD (Indian Meteorological Department)

Stages in Modelling:

The modelling exercise will be carried out in four steps. In the first step, sub-basins are identified from the DEM through the topographic analysis. In the second step, SWAT model will be set up with the current land use scenario. The model estimates surface runoff, evaporation, percolation, lateral flow and return flow, each of which are presented at sub-basin level. The runoff estimated from each sub-basin is routed to the main channel or to the watershed outlet. Third step in the modelling is the model calibration to redefine appropriate parameters that are representative of the catchment. This is done after a series of tests done to assess the model's sensitivity to critical parameters.

Final step is model validation, which ascertains that the model parameterization is sound and representative for other time series. From this step onwards impacts of changes in the land use patterns can be modelled by changing relevant land-use parameters to obtain an objective function such as water availability at various points in the river eg., a scenario may decrease or increase the flow in the river. In other words, determines the severity of water scarcity at a point in the river where urban settlements may be dependent on the river flows to meet their domestic water requirements. Building scenarios and evaluating the impact on water availability forms the last step in the modelling.

Considering the current land use practices and current trends in irrigation demands, four different scenarios are proposed.

Scenario1: the current land use pattern is followed

Scenario 2: the current trend in the increasing irrigation water demand is followed

Scenario 3: By knowing the ideal demand at the downstream location, an ideal land use condition in the upper sub-basins is used to assure the required river flow.

Scenario 4: This will be designed with more realistic concern on feasible land use change.

Base Scenario is also tested in which artificial irrigation does not exist to arrive at the maximum possible watershed functions.

Output: The AVSWAT outputs are in the form of maps, tables and charts. The sub-catchments in the area obtained from the topographic analysis is the map outputs from the model (Fig. 5).

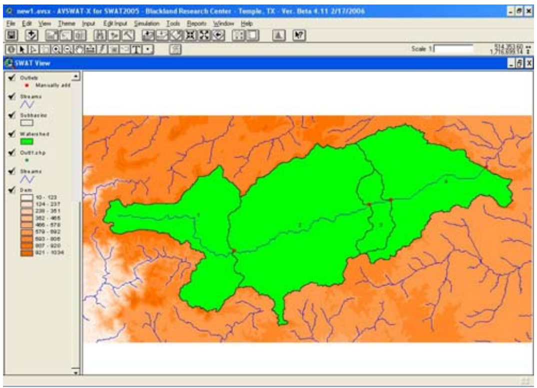


Fig. 5 Sub-basin delineation in AVSWAT

Stream flow, evapotranspiration, seepage and percolation losses are given in tables and chart format at each sub-catchment as well as at the catchment outlet.

Supported by the Royal Norwegian Embassy, India

Model Limitations

Following are some of the limitations using SWAT for hydrological modelling:

- Due to the heterogeneity of the catchment, a number of meteorological observation stations are required to present the spatial variation in the hydro-meteorological characteristics in the area. The lack of adequate number of observation stations affects the model output.
- In order to calibrate the model for the historic land use scenarios, the corresponding land use maps are needed. In order to get the real time picture of the land use pattern, this information can be extracted from the remote sensing satellite imageries by using digital image processing technique. However, acquisition of satellite imageries is expensive and also the expertise required for the image interpretation is another major limitation.
- Though SWAT is a free software tool, in order to represent the spatial variation in the catchment characteristics, GIS software ArcView is the pre-requisite to run the model.

References

Arnold, J. G., Williams, J. R., Srinivasan, R., and King, K. W. (2000). *Soil and Water Assessment Tool Manual*. USDA Agricultural Research Service, Texas.

DiLuzio, M., Srinivasan, R., Arnold, J. G., and Neitsch, S. L. (2002). "ArcView interface for SWAT2000, user's guide." *TWRI report TR-193,* Texas Water Resources Institute, Collage Station, Texas.

Further information:

reshmidevi@isec.ac.in