River Basin Modeling of Tungabhadra & Vedavathi Sub-basin

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Benefits of model results for water management Engineers

River basin models are an important tool for improving basin water management. They:

- integrate data and knowledge of hydrological systems within a basin. All major components of basin water balance can be estimated and annual water accounts developed.

- can be used as a database for quality-controlled data sets relevant to hydrological processes. Data availability and transparency is improved, and water management rules must be explicitly expressed.

- provide a principal tool to aid communication between stakeholder groups within a basin. They contribute to the development of a shared understanding of how a basin water system works and how it can be changed by new management.

Some specific applications of river basin modeling are summarised below.

- Understanding effects of new projects on existing projects (e.g. Upper Bhadra Project)

- Assessing potential effects of water use efficiency measures (e.g. improved irrigation efficiency through use of drip irrigation or canal lining in areas where leakage is known to occur)

- Assessing the possible effects of climate change, population growth and other changes. Then testing new water management measures to mitigate any negative effects of these changes.

- Testing new operational rules for management of river basin water systems

- Testing new operational rules for management of irrigation command areas
Source River Basin Model

eWater Source is a definitive software package for modelling Integrated Water Resource Management (IWRM) at basin scale, providing:

- integrated water resource assessments including agricultural, urban water supply, rural water supply, industrial, hydropower and environmental requirements
- water balance studies from catchment to river basin scale
- water accounting and analysis of supply and demand
- inflow forecasting and multi-objective reservoir operations
- resource assessment, allocation policy development and planning
- trade-off analysis to balance sharing and equitable use of scarce water resources
- low flow and drought management
- water quality analysis based on catchment land use scenarios
- impacts of climate change and transboundary transfers
- bulk water systems optimisation and planning
- and operations including multiple supply options (reservoir / recycling / conjunctive groundwater – surface water use)

River Basin model application

ACIWRM selected the Tungabhadra (K8) and Vedavathi (K9) sub-basins of the Krishna basin (shown in Fig.1), for a pilot application of the Source river basin modeling platform. The Source model of K8 and K9 assesses the Sub-basin water balance components and is being used to understand effects of:

- water resource distribution
- water demand due to population increase
- sedimentation in the TB reservoir
- climate change scenarios
- various scenarios of the Upper Bhadra Project water use
- management of the Tungabhadra LBC
- integrated reservoir management.

Fig.1 Surface water features of the Tungabhadra and Vedavathi Sub-basins.
Rainfall Runoff models

A rainfall-runoff model typically uses inputs of rainfall and evaporation demand in a subcatchment and applies a conceptual model of land surface processes to characterise the generated runoff. Once calibrated, a rainfall-runoff model can be used to generate stream flow estimates from climate conditions. This is particularly useful for filling data gaps in stream flow time series and running climate change scenarios.

The Source river basin model includes a range of rainfall-runoff models within it as submodels. This allows a river basin modeller to choose the preferred rainfall-runoff model for the system being modeled and the study objectives. The rainfall-runoff models available are:

- AWBM
- GR4J
- IHACRES CMD
- Sacramento
- SimHyd and SimHyd with routing
- SMARG
- PERFECT GWlag.

Source also allows a modeller to use their own rainfall-runoff model entered as a function or installing by an externally-coded algorithm as a Source model plugin.

Calibration of a Rainfall-Runoff model for Tungabhadra Sub-basin

The Tunga river is a primary source of inflow to the Tungabhadra basin. This Tunga catchment is small but it receives a very high rainfall during the kharif season. As a part of the K8 & K9 river Sub-basin model, the GR4J rainfall-runoff model was calibrated at the Shivamogga gauge on the Tunga river.

The GR4J model is a rainfall runoff model that relates runoff (observed streamflow) to rainfall and evapotranspiration using daily data.

For rainfall-runoff modeling & calibration in K8 sub basin, the Digital Elevation Model (DEM) of K8 sub-basin (Fig.2) was loaded to Source in a Geographic Scenario and nodes were imported in shape-file format. The delineation of subcatchments within a river basin is part of the Source software functionality; it can use the locations of fixed water features (like dams and gauges) as nodes in this delineation process. Land use and land cover are also useful inputs (Fig.3).
Land use / land cover map used in Source as Functional Units (FUs) to represent the different land use areas within catchment / Sub-catchments.

Fig.3 Land use / Land cover in K8 & K9 Sub-basins.

Records of river flow at the Shivamogga gauge are used to calibrate a rainfall-runoff model for the Tunga River. Fig.4 provides an example of a sub-catchment delineation provided by Source. For calibration, 3 rain gauge stations in the contributing catchment area are used namely: Sringeri, Balehonnr & Thirthahalli. The average rainfall data of these 3 stations is calculated and populated into Source. The Fig.5a shows that there are many days of high rainfall during the Kharif season.

Pan-evaporation (Fig.5b) data of Kutrahalli station which is in the upstream of the Shivamogga gauge is used.

The results of the rainfall-runoff model calibration run are compared with observed data in Fig.6. The peak flow of modeled & observed data agrees well where as in low flow condition there is a slight variance. The Nash-Sutcliffe Efficiency (NSE) obtained for the calibration of the model is NSE=0.92 (Fig.7) this is a very good model fit (a perfect fit would have a value of NSE = 1.0).
Fig. 6 Rainfall-runoff calibration for Shivamogga stream gauge.

Fig. 7 Calibration results and GR4J Parameters for Rainfall-runoff at Shivamogga

**Reservoirs and other Storages**

Reservoirs and Storages in Source are configured by importing Level-Volume-Surface Area tables. Additional features include:

- Multiple outlets with priority setting
- Valves, Gates and Spillways
- Hydropower Generation
- Multi-purpose operations
- Evaporation from the water surface
- Seepage.

![Tungabhadra Reservoir](image)
3 major reservoirs and 15 other storages (barrages, large tanks etc) are included into the Tungabhadra (K8) and Vedhavathi (K9) model. Multiple outlets are configured as nodes for urban water supply, rural water supply, irrigation command area, environmental demand etc.

Water Users and Demands

‘Water User’ nodes in Source represent:

- irrigation and command area demands including: multiple crops with sowing dates for on-farm storages, check dams and return flows
- urban, rural - MVDWSS, industrial and domestic use demands are represented as time series, patterns and custom functions and plugins can also be used.
- environmental demand (extractive and non-extractive), including the capacity to specify complex flow and watering requirements.

Water Users in source model, data related to extract water via canal, pump, diversion weir or from groundwater can be represented same level. Demands can be modeled by a combination of surface water and groundwater with the ability to manage conjunctive extractions.

Setting up of a river basin planning model for the K8 and K9 Sub-basins

The Tungabhadra (K8) and Vedavathi (K9) Sub-basins are represented in the Source modeling platform using a node-link network. Here the nodes represent river features, water control structures and management rules and the links define the direction of water flow (Fig.8 and Fig.12 shows the detailed schematic source model and schematic model for upper part of the basin).
Fig. 8 Node-link network representing the Tungabhadra (K8) and Vedavathi (K9) Sub-basins. The Vedavathi Sub-basin is on the right of the figure represented by a smaller number of nodes.

**Outflow from the Bhadra reservoir is configured along the following links:**

- To the LBC command area
- To urban water supply
- To the Bhadra river downstream
- To Industrial water supply
- To the RBC command area and
- To the Upper Bhadra project transferring water from K8 to K9
Water inflows are a key input to the model. They can be specified in a number of different ways, for example using: a rainfall-runoff model (see Shivamogga example above), or measured flow at an upstream gauge, or back-calculated inflow to a reservoir.

The K8 & K9 river basin model represents irrigation command areas using a sub-model that estimates crop water requirements. This sub-model is based on FAO Irrigation and Drainage Report 56 and requires input data for each crop type including: crop canopy development, planting and harvest date, root depth, soil properties and sensitivity of the crop to a deficit in water supply.

When all the model inputs have been entered the model is run for a period, ideally for 20 or more years, usually using a daily timestep, we can also use a 10 daily timestep. Model outputs are compared with observed flow data - an example is shown in the below Fig.9

![Tungabhadra river flow](image)

**Fig. 9** shows good correspondence between observed and modelled inflow to the Tungabhadra reservoir.

Fig.10 shows the modelled annual crop water requirements for the cropping pattern of the Bhadra right bank canal (RBC). It also shows the water volumes released from the Bhadra reservoir into the RB canal. It appears that the water released is in excess of requirements, however there are a number of reasons why this might be the case:

- crop dates are taken from DPR which has not matched to present cropping date
- the canal conveyance efficiency may be less than 100%
- the estimated crop areas may not be correct
- additional water may be released to provide inflow volume to Shanti Sagar reservoir

Additional data for components of the water management regime can be used to develop an informed understanding of the likely causes of this result.
The Source model also estimates the effects of irrigation water supplied on crop water stress (Fig.11). When is a reduced irrigation volume going to cause plant water stress and ultimately affect crop yield?

Fig.11  Kharif Rice Paddy crop: Modelled effect of crop water stress on crop yield at harvest over a three year period. Crop water stress (orange line) ranges from 100%= no stress, to 0%=crop dies. The green area shows the crop yield relative to a well-watered healthy crop (100%) and this is an accumulated response to water stress over the lifetime of the crop.
Fig. 12  Detail of the node-link network in the K8 basin. The node-link network represents features like the Bhadra reservoir which is shown as a blue triangle. The Bhadra node itself contains the details of the reservoir (e.g. full supply storage volume), the dam (e.g. spillway parameters) and the outlets.

Model Scenarios

How will one project affect water availability at another project? Example of Upper Bhadra Project.

The Upper Bhadra Project (UBP) is anticipated that it will be in operation in couple of years. UBP will transfer up to 29.90 TMC of water each year from Tunga and Bhadra Reservoirs for irrigation in command areas, assistance to Vani Vilas Sagar Reservoir and number of tanks.

The K8 & K9 source model can be used to assess the effects of the proposed operation of the UBP. Using climate and inflow data from 2000 to 2015 the effects on Tungabhadra reservoir is evaluated for dry years, average years and wet years. Fig. 13 shows the effect of the UBP on the stored water volume in Bhadra reservoir through these years. Clearly, in the dry years there is a pronounced effect on the stored water volume in Bhadra, but otherwise the effect is small.
In Fig. 14 the effect of the UBP on Tungabhadra reservoir stored water volume is shown. Here the relative effect of the UBP is not as large as it was on the Bhadra reservoir.

Fig. 15 shows that in most years the effect of the UBP is to reduce the volume spilled from Tungabhadra reservoir. It is only in dry years (2002 and 2003) that with and without the UBP there is no downstream spill.
If the water utilised in the Upper Bhadra Project (UBP) was reduced in dry years, the effect on Tungabhadra command areas would be less severe. The model can be used to decide the conditions under which Upper Bhadra Project (UBP) utilisation should be reduced.

In wet years the effect of the Upper Bhadra project will be passed on to water users downstream of Tungabhadra. The result of the UBP full capacity utilisation is a reduction in spill water volume from Tungabhadra Reservoir by about 30 TMC which was recognised and accounted for in the master plan.

In dry years the effects of the UBP will be felt mainly in the K8 basin and not downstream (TB Reservoir does not spill in dry years with or without UBP). Bhadra reservoir will be affected most with 12 TMC extracted from the stored water volume in Bhadra – this will have implications for local Bhadra command areas.

In dry years (and the year after) the result of the UBP will be that Tungabhadra reservoir will have less water and the irrigation season will have to finish earlier (perhaps in January rather than in March). This could cause stress on Rabi crops in TB command areas.

**Modeling for Tungabhadra Left Bank Canal (TLBC)**

The Tungabhadra Left Bank Canal and command area (TLBC) is important to crop production in Karnataka and a comprehensive modernisation plan for the TLBC is currently being developed. To support development of this plan, a Source model of the TLBC is being used to estimate required water volumes for crops, and to model delivery of these water volumes to the areas where the crops are grown.

Fig. 16 shows the TLBC and command areas supplied by 88 distributary canals. Fig. 17 shows a part of the Source model representing the TLBC.
This modeling study is ongoing and additional data to represent canal and distributary conveyance efficiency and distributary flow capacities are being configured.

However, findings to date are as follows.

1. The water requirements of the current irrigated cropping pattern (dominated by paddy rice) are considerably higher than they would have been for the cropping pattern proposed when the system was first designed.

2. The distributary canal flow capacity (using capacity indicated in the original design) is insufficient to meet irrigated crop water needs of the areas that are currently sown.

The modernisation plan of the TLBC will address these issues and will seek to identify a sustainable cropping pattern and total area of irrigated cropping. A new water delivery system that is properly managed will make it possible to provide a reliable supply of sufficient water to these crops.
Water Governance

Source introduces the fourth dimension of water management, the opportunity to assign water to users from sources according to agreements.

Sharing and management methods include:

- resource assessment methods to allocate water between different competing uses and users within a jurisdiction or legal structure
- tracking of water based on state or country boundaries
- prioritisation of access according to policy decisions which can vary over time to represent policy adjustments (e.g. adaptive climate change approach)
- the ability to determine the effectiveness of water markets in order to tie development of policies to equitable outcomes.

Upcoming river basin modeling studies

The new skills in river basin modeling that are being developed at ACIWRM and Nigams will continue to be applied in current and future studies. These studies include the following:

- Modeling support for K8 & K9 river basin plan
- Setting up basin models for K2 (Middle Krishna), K3 (Ghataprabha), K4 (Malaprabha), and K6 (Lower Bhima)
- Setting up model for Cauvery basin within Karnataka
- Detailed irrigation command area modelling where required
- Testing future water management options in all of Karnataka’s river basins

Capacity building

Government of Karnataka has big focus on building the capacity of WRD engineers to this new skill set river basin modeling. 12 WRD engineers are trained at eWater, Canberra, Australia in using the Source followed by in-house support training.

3 workshops and hands on training on source modeling for 150 engineers from three zonal offices are held at KNNL Upper Tunga Project- Shivamogga, VJNL Upper Bhadra Project - Chitradurga, KNNL Irrigation Central Zone - Munirabad.
Source training at eWater, Canberra, Australia

KNNL Upper Tunga Project Zone, Shivamogga

VJNL Upper Bhadra Project Zone, Chitradurga

KNNL Irrigation Central Zone, Munirabad
River Basin Modeling of Tungabhadra & Vedavathi Sub-basin

A River Basin Plan for the Tungabhadra (K8) & Vedavathi (K9) Sub-basins in Karnataka is being prepared by ACIWRM and a detailed identification of the conditions and challenges effecting the basins water resource & demographic conditions were identified. To support the subsequent development of the river basin plan, a detailed Source river basin model is setup and modeling of hydrological conditions undertaken.

Source model makes an initial assessment of conditions in the Tungabhadra sub-basin as well as of some hypothetical scenarios for the basin in order to consider what might become the main hydrological drivers of development in the basin.

**Scenarios for river basin planning**

Scenarios here are defined as likely alternative futures of the Tungabhadra sub-basin that are relevant to future planning and management of the basin. They provide a high level insight into the future conditions in the basin and the possible significance of key factors. As there are unlimited number of conditions of land & water use characteristics in the basin only a few key scenarios are modeled.

The following various scenarios are modeled:

**Scenario 1A:** baseline or current situation under average conditions

**Scenario 1B:** under drought conditions as represented by the 2002 - 2003 years

**Scenario 2A:** selected future scenarios are projected to 2050 for land use & water availability conditions with attributes selected from the challenges identified in the river basin profile without climate change.

**Scenario 2B:** elected future scenarios are projected to 2050 for land use & water availability conditions with attributes selected from the challenges identified in the river basin profile with climate change.
Source Modeling to support River Basin Planning in Karnataka

The Advanced Centre for Integrated Water Resource Management (ACIWRM) of Government of Karnataka is developing river basin plans for all of Karnataka’s basins, starting with the Tungabhadra and Vedavathi basins (K8 and K9).

A river basin model is a tool for improving understanding of the hydrology of basins and quantifying the components of basin water balance. These models are used to assess effects on basin water resources of factors including increased water use, changes in climate, or changes in water management.

Applying models to basins in Karnataka will support the Nigams and Zones (water management engineers) in their improvement of water management to achieve fair and/or equitable distribution of water to all water users.
ACIWRM

The ACIWRM was established to become a Global Centre of Excellence by Government of Karnataka in February 2012. ACIWRM acts as a think tank to the government’s Water Resources Department (WRD). It is engaged in policy analysis, research, planning, capacity building and develop the knowledge base for gearing up the department up to its future vision 2030. The ACIWRM works with the various departments, civil society, the private sector, farmers and water user associations, and other organizations to produce integrated advice to the WRD for managing the state's water resources.

About Source Model

ACIWRM has selected eWater Source as the river basin model for Karnataka. Source is Australia’s national hydrological modelling platform. It is actively used to manage water resources and test new water management policies in the Murray-Darling Basin and in other basins of all Australian states. Source is also being used elsewhere in other countries of Asia, particularly in the Mekong Basin.

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