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Comparison of Various Models for Water Resources Planning & Analysis, and Flood Forecasting

River Basin Planning Models

A number of river basin models like MIKE HYDRO Basin (DHI), RIBASIM (Deltares), Source (eWater), WEAP (SEI), and ReSyP (NIH) have been compared. These models support water allocation and planning from a local catchment to international basins, use node and branch network to illustrate flow and use of water, simulate surface and groundwater sources, evaluate demand from multiple sectors, and link with water quality analyses with varying degree of details. All models can be used to assess a wide variety of planning issues of water allocation at the basin-wide.

WEAP has been used extensively for optimization problems having over 18,000 licenses with applications in India. For applications requiring optimizing allocation, infrastructure, conservation measures or policy, this is the preferred package. Source, RIBASIM, and MIKE HYDRO Basin are simulation routines with wide breadth of capabilities desirable in India. RIBASIM incorporates demand calculators into demand nodes for rapidly evaluating population growth, crop changes, and increased industrialization, and can be used in Delft FEWS to create customized output. MIKE HYDRO Basin offers similar functionality minus the economics and demand calculators. Source has more powerful tracking and accounting for water usage in basins, as well as a 1-D built-in groundwater model.

In view of their widespread use, functionality, ease of use, cost, and support, RIBASIM and WEAP models deserve a first choice in selecting an RBM. This can be followed by SOURCE model, which is in free domain and has similar capabilities and additional integration for groundwater simulation. Mike HYDRO Basin has also comparable strengths but needs stronger justification for use (say, availability of expertise and experience in using the model) in view of its capabilities and cost. If reservoir planning and operation is the sole focus for RBM, NIH ReSyP could be a good alternative as it is in free domain and supports output tables familiar to reservoir working tables in India.

Hydrological Models

Hydrological models are used to describe major components of the hydrological cycle, such as precipitation, evapo-transpiration, runoff, and recharge. Such models can be used to assess the impact of climate change, land use practices, and groundwater recharge/pumping within a watershed or basin. As water resource issues and available data vary, software package are available that offer several different approaches for numerically simulating water movement ranging from simple, lumped conceptual models to advanced, distributed, and physically-based solutions. In general, as modeling complexity increases so does the data required and the computational power.

Some of the widely used models, such as GSFLOW, GSSHA (WMS), MIKE SHE, SWAT have been compared in the base document. In addition, nine free-domain, commonly used, well documented and continuously updated hydrologic models (AnnAGNPS, GSSHA, HYPE, Hec-HMS, MIKE-SHE, PRMS, SWAT, WetSpa, and WinSRM) have been reviewed by Dhami and Panday (2013). These publications can be referred for details of these models. All applications can be used to assess land use change at scales ranging from watershed to basin.

SWAT has numerous applications in India to model water availability, sediment runoff, and water quality (point source and non-point source). Even with lumped nature of HRUs as its limitation, this model has been most widely used for evaluating impact of land use and climate changes on stream flow, water quality, and sediment runoff. AnnAGNPS is similar to SWAT model but has limited spatial scale. For both the models, input data requirement can be managed from freely available public sources. Both models have their own weather generator model. The worldwide application of SWAT reveals that it is a promising model for continuous simulation and to integrate multiple environmental processes.

Hec-HMS is promising model for providing multiple options to simulate hydrologic processes. WinSRM is robust and efficient model for simulating snow dominated watersheds. For continental or multi-basin simulation, HYPE is better option. Modular design, fully distributed and physically-based WetSpa model is available to simulate several hydrological processes with minimum data requirement. PRMS can be applied either as a lumped or distributed parameter type model. It is suitable for coupling with other models but it may subject to computational instability problem due to its governing equations requiring numerical approximation for their solutions.

If impacts from land use and management strategies on groundwater are of primary interest, GSFLOW, GSSHA (WMS), and MIKE SHE are more appropriate. MIKE SHE and GSSHA (WMS) incorporate the most sophisticated GUI for pre and post-processing, running simulations, and viewing results. MIKE SHE and GSSHA require extensive input data, are computationally intensive and may suffer from numerical instability for large watersheds. If cost is a consideration, GSSHA (WMS) is the more desirable package.

Models for Flood Planning

Flooding in India is a major issue every year, forcing the evacuation of many communities, as well as damaging crops, infrastructure, and property. Flood management involves both, planning and real-time warning. Flood planning requires models to be able to simulate rainfall-runoff process, route floodwaters, and compute water levels through the river network. Results from the flooding analysis are used to develop inundation maps for different flooding frequencies; develop emergency management plans; establish regulatory guidelines for development (e.g. flooding zones); develop operational strategies of dams and other control structures; and inform policy makers, stakeholders, and general public of the risk of flooding. The hydrological model for flood planning must be able to simulate the propagation of floodwaters and map the results illustrating the extent of flooding.

Some of the widely used models for flood management that are included in the base document are Delft3D Suite, HEC-RAS, MIKE-11, MIKE Flood, and SOBEK. All packages support flood planning and mapping. There are a number of HEC-RAS applications in India for flood modeling and dam break analysis in Tapi, Mahanadi, and Godavari River systems. Delft3D has been used in 2-D coastal applications of Andhra Pradesh and Tamil Nadu. MIKE FLOOD has been applied for dam break analysis for the Ukai Dam and mitigation planning for the downstream Kakrapara weir. MIKE 11 has been extensively used for Yamuna basin flood simulation and MIKE HYDRO River has been used for evaluating flood risk and determining the safe guard level at Himavat Thermal Power Plant. SOBEK was used in Burhi-Gandak and Brahmani-Baitarani basins to examine integrated flood management under climate change.

For systems with simple hydraulics and limited data, HEC-RAS, SOBEK, and MIKE-11 are more applicable. Further, in view of widespread use, user-friendly GUI interface, non-proprietary status, and large user community, HEC-RAS is a preferred tool for assessing flood planning in simple systems.

For more complicated systems and where floodplain topography is known, Delft3D Flexible Mesh, SOBEK, and MIKE FLOOD are applicable. In view of the cost considerations and applications in Indian conditions, Delft 3D Suite deserves a first choice. MIKE FLOOD and SOBEK provide an efficient computational solution, but have licensing fee issues. Budget, user familiarity, and support may be considered when choosing between these packages. Once released, HEC-RAS 5.0 will handle complicated systems and be available as a non-proprietary, freely downloadable option to MIKE FLOOD and SOBEK.

Models for Real-time Flood Warning

Real-time flood warning systems require the automation of retrieving hydro-meteorologic data, incorporation of data into hydrologic and hydraulic models, determination of magnitude and timing of flooding, and transmission of a warning to water resources managers, and interested stakeholders. These systems also assist water resource managers to quickly test alternative scenarios for managing flooding events.

Several RTFWS developed to support flood warning systems include Delft FEWS, HEC-RTS, and MIKE 11 Real-Time Enterprise Package (MIKE 11 RT). Delft FEWS (Deltares) provides an open shell system that incorporates a wide range of general data handling utilities and provides an open interface to any external forecasting model. HEC-RTS (USACE) is public domain comprehensive data acquisition and hydrologic modeling system used for short-term decision making regarding water control operations in real-time to support water control management. MIKE 11 RT is a subset of DHI software that has been combined into a RTFWS. In India, MIKE 11 RT has been widely used for applications in real-time stream flow forecasting and reservoir operation system for Krishna and Bhima basins in Maharashtra, Bagmati-Adhwara basin in Bihar, and Brahmaputra basin in Assam. Delft FEWS has been widely used in the world as operational flood forecasting tool. In India, it is currently being used to coordinate the Ganga Rejuvenation Project. HEC-RTS has been extensively used in US for operational water management. It has been successfully implemented for operational management of Bhakra-Nangal and Beas

Reservoirs in Satluj and Beas basins in India which can serve as a role model for the country.

MIKE 11 RT uses MIKE-11 and NAM models that have been widely used in India. However, primary limitation of MIKE 11 RT is its license fee. If budgetary constraints are a significant factor, Delft FEWS and HEC-RTS are good alternatives. Delft FEWS allows for a wide variety of simulation models to be used. HEC-RTS employs a full suite of public domain software, including HEC-HMS and HEC-RAS, which are used to successfully manage water resources in India.

Water quality and sediment transport models

All hydrodynamic models mentioned above for flood planning have the capability to simulate water quality. Transport of a limited set of water quality constituents [such as dissolved nitrogen (NO3-N, NO2-N, NH4-N, and Org-N); dissolved phosphorus (PO4-P and Org-P); algae; dissolved oxygen (DO); and carbonaceous biological oxygen demand (CBOD)] is available in HEC-RAS. Delft 3D uses D-Water Quality module that simulates many water quality variables and their related water quality processes. This module is highly flexible due to the many standard options as well as user-defined options, and has a library of 900 processes and substances, including eutrophication, adsorption, desorption, nutrients, bacteria, oxygen, phytoplankton, heavy metals and micro-pollutants. In MIKE FLOOD, water quality is calculated through ECO Lab, an open-ended ecological and water quality modeling framework that allows for user-defined equations and permits the user to simulate transport of chemicals, ecological processes, agent-based modeling, or other hydraulic influenced processes.

All packages have functionality to compute sediment transport. HEC-RAS, MIKE HYDRO River, and SOBEK offer sediment routing with the choice of multiple sediment transport equations. DELT3D Suite and MIKE FLOOD can model sediment transport in 2-D. An additional package, MIKE 21C (DHI), is one of the most well-established tools for simulating development of the river bed and channel plan form, caused by changes in the hydraulic regime. MIKE 21C, is specifically tailored for morphology applications and simulates processes like bank erosion, scouring and shoaling brought about by activities such as construction and dredging, seasonal fluctuations in flow, and more.

For standard analyses, all packages simulate water quality as a module in the software. For constituents not included in the HEC-RAS simulations, either D-Water Quality Module (Delft3D) or ECO Lab provide greater options. Choice of water quality model should be made with regard to hydraulic model selected.

MIKE 11 ST, SOBEK, and HEC-RAS have multiple sediment transport equations and can simulate mobile boundaries to account for aggradation and erosion along a bed and in simulating sediment loading to reservoirs from a watershed. Of these, HEC-RAS is the top choice due to price consideration. However, MIKE 21C is a robust software for modeling sediment in riverine settings where bed and banks are mobile, and the user’s purpose is to determine stresses and potential erosion.

Groundwater flow models

Groundwater models are physically-based distributed models that represent groundwater movement using 2-D or 3-D gridded finite difference and finite volume solutions based on Darcy's equations. Data requirements for such models include aquifer thickness, hydro-geological parameters (e.g. hydraulic conductivity, transmissivity), boundary conditions (e.g. constant flow, fixed head, non-flow), groundwater recharge, and pumping rates. Typical outputs from such models include groundwater heads, drawdown, flow magnitude and direction, and water budgets throughout the modeling domain. If water quality simulation is required, capabilities include the fate and transport of chemicals and multi-density flow (for cases such as saline intrusion). Six generally used models include GMS, Groundwater Vistas, MODFLOW, iMOD, and MIKE SHE, and Visual MODFLOW.

GMS (Aquveo) is a groundwater modelling system, based on MODFLOW code, which provides tools for every phase of a groundwater simulation including site characterization, model development, post-processing, calibration, and visualization. Groundwater Vistas (Rockware) provides Windows modelling environment for MODFLOW family of models that allows for the quantification of uncertainty. iMOD (Deltares) is an open source, easy to use Graphical User Interface + an accelerated Deltares - version of MODFLOW with fast, flexible and consistent sub-domain modeling techniques. It facilitates very large, high resolution MODFLOW groundwater modeling, geo-editing of the subsurface, and interaction with SEAWAT (for density-dependent groundwater flow) and MT3D (groundwater quality). MODFLOW (USGS) is 3-D finite-difference groundwater model with modular structure that provides a robust framework for integration to additional simulation capabilities that build on and enhance its original scope. The family of MODFLOW-related programs now includes capabilities to simulate coupled groundwater/surface-water systems, solute transport, variable-density flow (including saltwater), aquifer-system compaction and land subsidence, parameter estimation, and groundwater management. Visual MODFLOW (Waterloo Hydrogeologic Software) simplifies model development by providing a workflow driven GUI to guide construction and use of groundwater flow and contaminant transport model. It comes with pre-pre-processing and post-processing tools. MIKE SHE's structure includes dynamically linked modules to compute saturated zone flow, evapo-transpiration, overland flow, river and lake flow, unsaturated zone flow, and anthropogenic use (e.g. irrigation, ground water pumping, irrigation drains) to allow for the examination of the full hydrologic cycle.

MODFLOW, iMOD, and MIKE SHE offer means to compute groundwater quality (some such issues in India include salinity in irrigation, fate and transport of chemical spills, and prediction of saline intrusion along coastal zones). Transport packages associated with MODFLOW include MT3DMS, MT3D99, SEAWAT, RT3D, and PHT3D. GMS, Visual MODFLOW, and Groundwater Vistas support the use of many of these packages. All packages are supported with sophisticated GUI interfaces for inputting data and viewing results. USGS has developed ModelMuse to support MODFLOW, an interface that provides the basics in editing and viewing function. ModelMuse and iMOD are open source software packages for use in developing groundwater models. GMS, Visual MODFLOW, MIKE SHE, and Groundwater Vistas require licenses.

All packages simulate groundwater quantity and quality using similar algorithms and offer support for users of their software packages. The difference mainly lies in the GUI interface and price of the software. iMOD, with the pre-processing and post-processing, strong visualization abilities, strong support, and open source availability, is the strongest candidate for groundwater modeling. GMS provides a platform to support the modular nature of MODFLOW while Visual MODFLOW provides GUI that guides groundwater model development through a straightforward workflow. While MIKE SHE simulates groundwater, its fixed grid system and licensing fee limits adoption for strictly groundwater simulations, though it is robust in situations where it is important to simulate interaction between surface - ground water.

Conjunctive use models

Conjunctive management is groundwater management that accounts for the dynamic interaction with surface and land use activities such as irrigation. In India, typical applications include command areas, exchange in wetlands/field drains, and influence of tanks and check dams on local infiltration to increase groundwater levels. Three packages support conjunctive management directly: MIKE SHE, MODFLOW-OWHM, and WMS (WMS) which dynamically link surface water, unsaturated zone, and groundwater activities.

MIKE SHE is the dominant package for these applications due to its worldwide application. MIKE SHE dynamically couples each component of the hydrologic cycle, making it an excellent tool for conjunctive management. MIKE SHE and FEFLOW (not evaluated here) have been used in the Saph Pani- Enhancement of Natural Water Systems and Treatment Methods for the Safe and Sustainable Water Supply in India Project. One pilot study used this model to examine the efficacies of a water retaining structure, such as check dams/ponds near Chennai, to arrest or reduce the salinity ingress on groundwater system. A second study was carried out to examine the impact of irrigation infrastructure on groundwater regime as well as the impact of wastewater on the groundwater quality for the Musi Wetland. DHI created a MIKE SHE application to demonstrate the management and impact of small tanks on surface and groundwater availability in the Vaippar Basin, Tamil Nadu.

The USGS software package used for conjunctive use studies is MODFLOW-OWHM: an integrated hydrologic flow model for the analysis of human and natural water movement within a supply-and-demand framework. MODFLOW-OWHM dynamically simulates hydrologic process packages for evapo-transpiration, surface water routing, rivers, lakes and reservoirs, wells, recharge, irrigation, drain and return flow, unsaturated zone, and seawater intrusion. The package has been applied in the western US for the conjunctive management of river and reservoir diversion as well as groundwater use for irrigation, most notably applied to the Central Valley in California.

GSSHA (WMS) is a physically based, distributed-parameter, structured grid, WRM model that simulates the hydrologic response of a watershed subject to a given hydro-meteorological input. The software fully couples 2-D overland flow, 1-D stream flow, 1-D infiltration, and 2-D groundwater to simulate flow between the groundwater, vadoze zone, streams, and overland flow. The user interface for GSSHA is Aquaveo's WMS, which provides pre-processing and post-processing tools that make the workflow of model construction, simulation, and viewing straightforward.

MIKE SHE and GSSHA (WMS) have better GUI interfaces and have more capabilities stemming from their more complex operations of surface water control structures. However, their limitations are the cost per license, which provides a barrier to their widespread adoption, and their inability to change the mesh density near areas of concern (e.g. groundwater pumping wells, tanks and check dams for groundwater recharge). Otherwise, GSSHA (WMS) is significantly less expensive than MIKE SHE. MIKE SHE and GSSHA (WMS) are preferred if budgets are not limited, technical staff have limited experience with modeling, or if complicated control of surface water is required. If technical staff are familiar with creating, calibrating, and using MODFLOW packages, the MODFLOW-OWHM is good solution.

The comparison of various model considered is tabulated in Table-1, 2 & 3 annexed herewith.

Table-1 Comparison of different software/ models available

SN	Software/Model/Company	Applications	Limitations	License /cost
1.	MIKE HYDRO Basin (DHI)	Rainfall Runoff, Water Allocation, River Flow Routing, Reservoir Operation, Irrigation & Water quality	Predefined scenario viewing, water demand calculator not available, economic module is not available.	2.9 lakhs for basic pkg
2.	RIBASIM (Deltares)	Rainfall Runoff, Water Allocation, River Flow Routing, Reservoir Operation, Irrigation & Water quality	Predefined scenario viewing.	1.88 lakhs for basic pkg
3.	Source (eWater)	Rainfall Runoff, Water Allocation, River Flow Routing, General Hydrology, Reservoir Operation, Irrigation, Ground Water, conjunctive use & Water quality	Scenario option is not available, water demand calculator not available	Free for GoI
4.	WEAP (SEI)	Rainfall Runoff, Water Allocation, River Flow Routing, Reservoir Operation, Irrigation & Water quality	Option of monthly time step only available.	Free for GoI
5.	ReSyP (NIH)	Reservoir operation		Free
6.	GSSHA(WMS)- USACE	Rainfall Runoff, Water Allocation, River Flow Routing, General Hydrology, Reservoir Operation, Irrigation, Flood Mapping, Ground Water, conjunctive use & Water quality	Predefined scenario viewing	3.7 lakhs
7.	GSFLOW (USGS)	Rainfall Runoff, River Flow Routing, General Hydrology, Ground Water & Water quality	Predefined scenario viewing ,Technical support not available	Free
8.	MODFLOW (USGS)	Ground Water , conjunctive use & Water quality	Less suitable for aquifer with river boundaries, variation of results w.r.t. horizontal and vertical discretization	Free
9.	iMod (Deltares)	Ground Water & Water quality		Free
10.	MIKE 11 (DHI)	Rainfall Runoff, Water Allocation, River Flow Routing, Reservoir Operation, Flood Mapping, Flood Warning , Water quality& sediment transport	2-D computation and mesh is not available.	INR 6.0 lakh+
11	MIKE FLOOD (DHI)	Rainfall Runoff, River Flow Routing, Reservoir Operation, Flood Mapping, Water quality & sediment transport	-	INR 6.8 lakh+

12.	HEC-RAS, HEC-HMS (USGS)	Rainfall Runoff, River Flow Routing, Flood Mapping, Flood Warning , Water quality & sediment transport	HEC-HMS - Not suitable for urban catchments HEC-RAS – Not considers 2D modeling. HEC-RAS: 3D viewing, 2D computation and mesh, multicore processing is not available.	Free
13	MIKE SHE-MIKE11(DHI)	Rainfall Runoff, Water Allocation, River Flow Routing, General Hydrology, Reservoir Operation, Irrigation, Flood Mapping, Ground Water , conjunctive use & Water quality	Predefined scenario viewing	INR 5.5 lakh+
14.	SOBEK (Deltares)	Rainfall Runoff, Water Allocation, River Flow Routing, Reservoir Operation, Flood Mapping, Flood warning, Water quality & sediment transport		INR 2.3 lakh+
15.	Delft3D Suite (Deltares)	Rainfall Runoff, River Flow Routing, Reservoir Operation, Flood Mapping, Water quality & sediment transport	Flood Impact calculator is not available	Compiled - INR 2.4 lakh+ , Uncompiled - free
16.	GMS (Aquaveo)	Ground Water	-	INR 1.0 lakh+
17.	Groundwater Vistas (RockWare)	Ground Water & Water quality	-	INR 1.0 lakh+
18.	SWAT (USDA)	Rainfall Runoff, River Flow Routing, General Hydrology, Irrigation, Ground Water, conjunctive use, Water quality & sediment transport	Gridded data set cannot be used as input. Empirical snowmelt model, Predefined scenario viewing	Free
19.	MODFLOW-OWHM (USGS)	Water Allocation, River Flow Routing, General Hydrology, Irrigation, Ground Water, conjunctive use & Water quality	Technical support is not available.	Free
20.	Visual MODFLOW (Waterloo Hydrogeologic)	Ground Water & Water quality	-	INR 1.0 lakh+
21.	Delft FEWS(Deltares)	For managing forecasting processes and/or handling time series data	-	Free for demonstration and research purpose
22	HEC-RTS softwares	➢ ***HEC-MetVue***:- Processes observed	-	Free

		meteorological data for input to HMS. Inputs are either point or gridded estimates of meteorological data such as precipitation and temperature. Outputs are observed meteorological time series formatted for compatibility with HEC HMS (Hydrologic Modeling System). ➢ ***HEC-MFP (Meteorologic Forecast Processor)**:-* Processes meteorological forecasts for input to HEC-HMS. Inputs are forecasted meteorological data such as precipitation and temperature. You can enter these forecasts manually or obtain them from external sources such as ECMWF,GFS,IMD. Outputs are forecasted meteorological time series formatted for compatibility with HEC-HMS. ➢ ***HEC-HMS:-*** Hydrologic Modeling System. Simulates watershed response to precipitation. Inputs may include observed or forecasted precipitation, temperature, snowpack, and other environmental conditions. Outputs include flows throughout the watershed, including inflows to reservoirs and local flows below the reservoirs. ➢ ***HEC-ResSim:-*** Reservoir System Simulation program. Simulates behavior of reservoirs and linking channels, following user-specified operations for reservoir release decision making. Inputs include flows into reservoirs and unregulated flows downstream of reservoirs (from HEC-HMS). Outputs include reservoir releases, downstream regulated flows, and reservoir storage conditions. ➢ ***HEC-RAS:-*** River Analysis System. Simulates behavior of channels and adjacent floodplains. Simulation of channels is in one dimension, and simulation of adjacent floodplains is in one or two dimensions. The output from HEC-RAS permits determination of water surface elevations corresponding to flows computed by HEC-HMS or		

		HEC-ResSim. Inputs include flows, and outputs include water surface elevations, depth grids, and inundation maps. ➢ ***HEC-FIA:-*** Flood Impact Analysis. Estimates the consequences of flow or water surface elevations in the system. Inputs include computed or observed flows or water surface elevations throughout the flood plain. Outputs include economic, life loss, or other measures of impact, or optionally, information on actions to be taken in response to flows or water surface elevations that will be experienced. *A HEC-RTS forecast is a simulation of watershed processes and consequences of flooding based on input data and information and hydrologic, reservoir operation, hydraulic, and impact analysis models configured in HEC-RTS. Forecast results include flow and stage in the channel from watershed runoff, reservoir release schedules, floodplain inundation maps, floodplain consequence reports, and reports listing actions for emergency responders to take. These results inform water management decision making.*		
23	HEC-WAT	The Watershed Analysis Tool (HEC-WAT) software is a tool that streamlines the analytical and reporting processes of software commonly used by the multi-disciplinary teams in water resources studies. The WAT accomplishes this through a common graphical user interface in the PC environment. The WAT is able to integrate various pieces of software knowing little about the individual software's code. The WAT provides a framework to coordinate the study, while the individual pieces of software provide the analytical computations. To meet the needs of performing water resources studies in a integrated, collaborative, systems based	-	Free

		approach, HEC has developed the Watershed Analysis Tool (HEC-WAT). Will be a tool for reconnaissance and feasibility studies; incorporates social and environmental consequences. Improves the capability to facilitate, convene, advise, and work collaboratively across a study team and with stakeholders. Provides an effective way to communicate risk within the study team and to external partners and the public HEC-WAT Framework Coordinate a watershed study, while the individual pieces of software provide the analytical computations. Load GIS-based files including ARC shape files, digital elevation models, etc. Develop a spatially correct representation of the study watershed. Develop and organize system alternatives. Import existing models or develop new models. Match models to system alternatives. Edit model data. Run the modeling software and manage data transfer between models. View results and compare results between system alternatives HEC-WAT Model Integration Integrate models and tools used during the analytical process: ❖ Hydrology - HEC-HMS, GeoHMS. ❖ Reservoir Operations - HEC-ResSim. ❖ Hydraulics - HEC-RAS, GeoRAS. ❖ Economics - HEC-FIA. ❖ Environmental - HEC-EFM. ❖ Statistical - HEC-SSP. ❖ Other software - GSSHA, FLO-2D, ADH, River-Ware Share data across models. Involve modelers early in the study process and encourage a team approach.		
24	MODSIM 8.5	MODSIM 8.5 is a generic river basin management	-	Free

		decision support system for analysis of long term planning, medium term management, and short term operations on desktop computers operating under MS Windows. MODSIM is free from expensive licenses for proprietary software since all components are developed from native code or shareware under the MS .NET Framework. MODSIM includes a powerful, interactive graphical user interface for creating, locating and connecting river basin network components, as well as spreadsheet-style data editing in an object-oriented spatial data base management system. Flexible data import and export tools are included for interaction with external data base management systems. One of the greatest advantages of the MS .NET Framework is the ability to customize MODSIM for any specialized operating rules, input data, output reports, and access to external modules such as water quality models running concurrently with MODSIM, all without having to modify the original source code. The basic solver in MODSIM is a state-of-the-art network flow optimization algorithm up to two orders of magnitude faster than solvers in other river basin modeling packages and capable of simulating complex, large-scale networks. An iterative solution procedure allows consideration of non-network and conditional constraints. GEO-MODSIM, a full implementation of MODSIM operating as a custom extension in ArcGIS (ESRI, Inc.), allows automatic generation of MODSIM networks from geometric networks and processing of spatial database information in a GIS.		

Table-2 Specifications of main river basin modeling software

Detail	MIKE BASIN Hydro	RIBASIM	Source	WEAP
Allocation Algorithm	Simulation, Optimization	Simulation	Simulation	Optimization
Time Step	User defined. Typical daily to monthly	Month, half month, decade, week, day.	User defined. Typical daily to monthly	Monthly
Rainfall-Runoff	Lumped: • NAM • Unit Hydrograph Method	Lumped: • Sacramento Model Distributed: • Wflow	Lumped: • Sacramento Model • GR4J • SimHYD • SMARG • AWBM	Lumped: • Simplified FAO • MABIA • PGM • SMM
Demand Calculator	None	Demand Calculator Dynamically Linked	None	Demand Calculator Dynamically Linked
Irrigation	Algorithm based on FAO56	• Fixed affirmation demand, • Variable irrigation demand, • DelftAGRI module	Demand Computed on Soil Deficiency	Algorithm based on FAO56
Groundwater	• Conceptual Reservoir (Individual)	• Conceptual Reservoir (Linked) • Links to MODFLOW	• Conceptual Reservoir • 1-D Groundwater Model, • Links to MODFLOW	• Conceptual Reservoir (Individual) • Links to MODFLOW
Water Quality	ECO Lab Module	DELWAQ/WLM Module	• Built-in fully mixed • Built-in particle tracking method	• Built-in • QUAL2k • User plugin
Sediment	Built-in (reservoir sedimentation)	RibSERES (reservoir sedimentation)	Dynamic SedNet	• None

Table 3 Specifications of main DHM

Hydrologic Process	GSFLOW	GSSHA (WMS)	MIKE SHE – MIKE 11	SWAT
Evapo-transpiration	Canopy interception, plant transpiration, soil evaporation (HRU*)	• Priestley-Taylor Method (G) • Penman-Monteith with seasonal canopy resistance (G)	Plant transpiration, soil evaporation (HRU*, G)	Canopy interception, plant transpiration, soil evaporation (HRU*)
Overland Flow	3-layer soil model: preferential flow reservoir layer (HRU*)	2-D lateral diffusive wave (G) (options: Explicit, Alternating Direction Explicit, Alternating Direction Explicit with Prediction-Correction	2-D Finite Difference (G)	• SCS runoff (HRU*) • Green-Ampt infiltration equation (HRU*)
Rivers/Lake Network	• steady-flow and kinematic-wave approaches (1-D), • Diffusive wave approaches (1-D), • Continuity based lake simulation (1-D)	• 1-D longitudinal (options: Explicit, Up-gradient, Diffusive wave) • Lakes: Level pool routing (1-D) • Wetlands: Mixed Darcian and Manning's Flow (1-D)	• Kinematic Wave (1-D), • Steady-state (1-D), • Fully dynamic, 1-D Saint Venant equations (1-D)	• Time of Concentration (HRU*) • kinematic-wave approaches (1-D)
Unsaturated Zone (UZ)/ Infiltration	3-layer soil model: capillary reservoir layer, gravity reservoir (HRU*)	• Green & Ampt (G) (options: basic, multi-layered, with redistribution), • 1-D vertical Richards' equation (G)	• 2 layer water balance, (G) • Gravity equation, (G) • Richard's equation (G)	3-layer soil model: capillary reservoir layer, gravity reservoir (HRU*)
Saturated Zone (SZ)	3-D Finite Difference (G)	• 2-D lateral Finite Difference (G)	• Linear Reservoir (SD) • 3-D Finite Difference (G)	• Linear Reservoir (SD)
Anthropogenic	Change HRU* parameters for land use, vegetation, nutrient application	• Land use change (G) • Irrigation through precipitation (HRU*, G) • Structure operations (1-D)	• Land use change (G) • Irrigation (SD, G) • Structure operations (1-D)	Change HRU* parameters for land use, vegetation, nutrient application
Water Quality (WQ)/Sediment (ST)	Unknown	• WQ: Unknown • ST: Loading: Modified Universal Soil Loss Equation (HRU*). Routing: River/lakes using ST module.	• WQ: River/lakes, UZ, SZ water quality using ECO Lab. External program computes loading (HRU*) • ST: Loading: Modified Universal Soil Loss Equation (HRU*). Routing: River/lakes using ST module in MIKE 11. (1-D)	• WQ: Extensive computations of chemical processes associated with the storm runoff and return flows (HRU*). • ST: Modified Universal Soil Loss Equation (HRU*)