Module 9

5 Lectures

Hydrologic Simulation Models

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Objectives of this module is to investigate on various hydrologic simulation models and the steps in watershed modeling along with applications and limitations of major hydrologic models

Topics to be covered

- Hydrologic simulation models
- Steps in watershed modeling
- Major hydrologic models
  - HSPF(SWM)
  - HEC
  - MIKE

Module 9

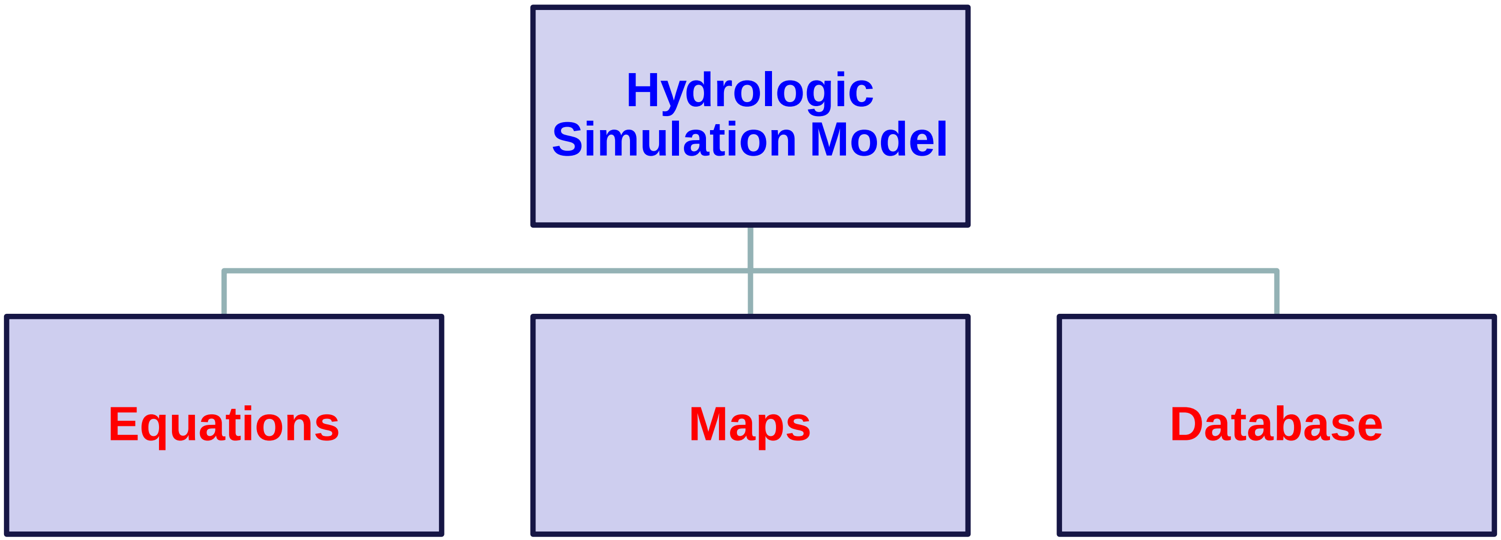
Lecture 1: Introduction to hydrologic simulation modelling

Watershed Classification

Watershed (ha)	Classification
50,000-2,00,000	Watershed
10,000-50,000	Sub-watershed
1,000-10,000	Milli- watershed
100-1,000	Micro-watershed
10-100	Mini-watershed

(Bedient et al., 2008)

Hydrologic Simulation Model



A hydrologic simulation model is composed of three basic elements, which are:

(1) **Equations** that govern the hydrologic processes,

(2) **Maps** that define the study area and

(3) **Database** tables that numerically describe the study area and model parameters.

Hydrologic Simulation Model **Contd…**

❖ A **hydrological simulation model** can also be defined here as a mathematical model aimed at synthesizing a (continuous) record of some hydrological variable Y, for a period T, from available concurrent records of other variables X, Z, ...

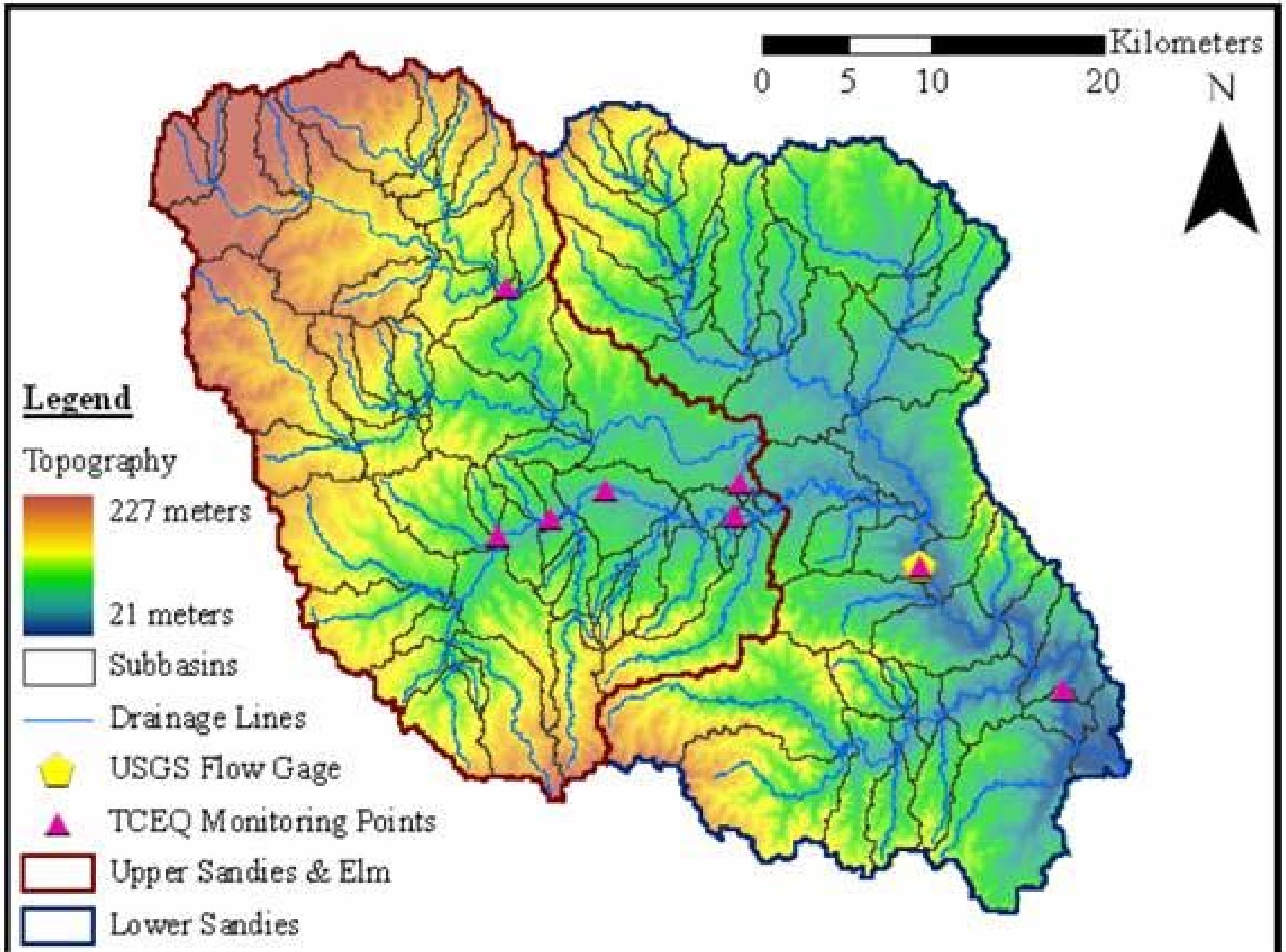
❖ In contrast, a **hydrological forecasting model** is aimed at synthesizing a record of a variable Y (or estimating some of its states) in an interval ΔT, from available records of the same variable Y and/or other variables X, Z, ... , in an immediately preceding period T.

Hydrologic Simulation Model **Contd…**

❖ A hydrological simulation model can operate in a **"forecasting mode"** if estimates of the records of the independent variables (predictors) X, Z, ..., for the forecast interval ΔT are available through an independent forecast. Then the simulation model, by simulating a record of the dependent variable, $[Y]_{\Delta T}$ will in fact produce its forecast.

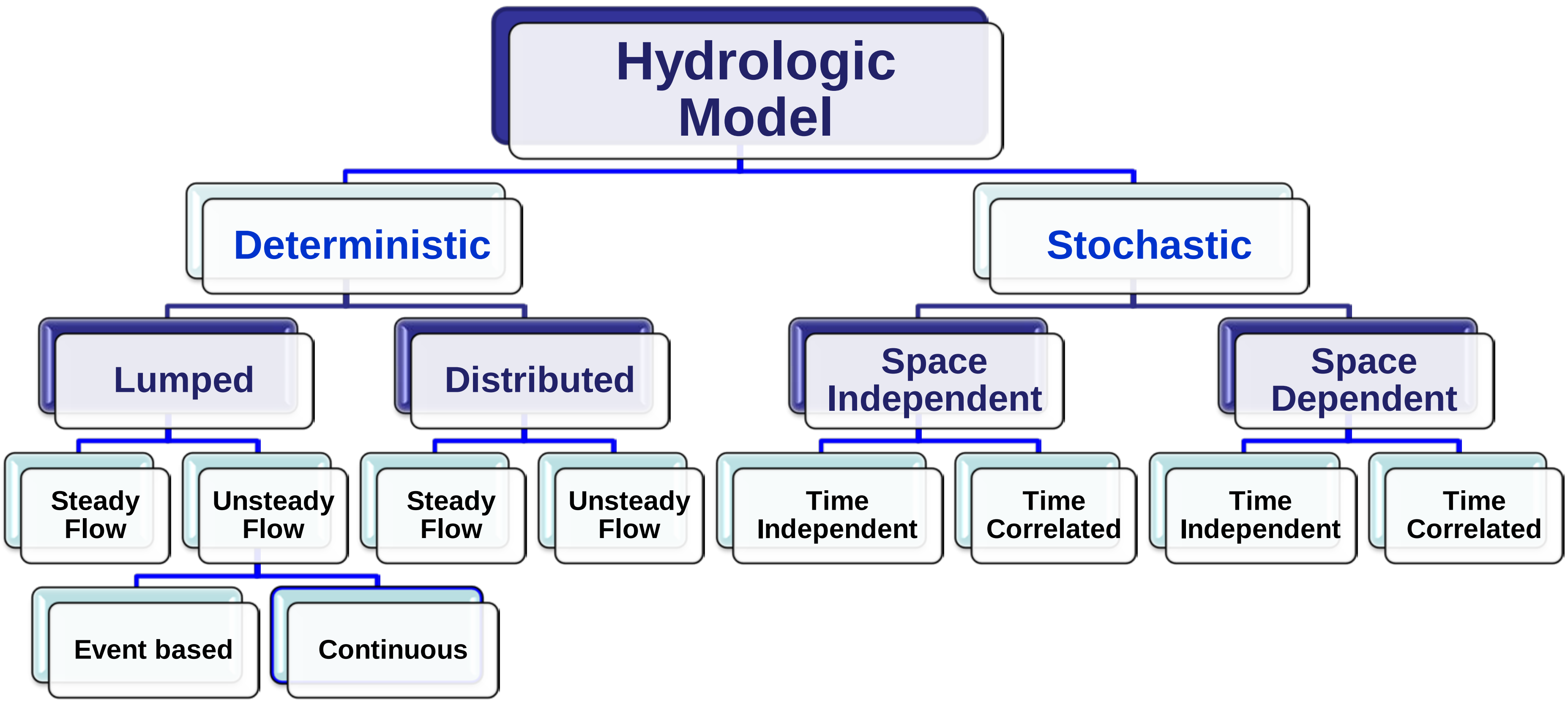
In short, a hydrological simulation model works in a forecasting mode whenever it uses forecasted rather than observed records of the independent variables.

A Typical Watershed Delineation Model



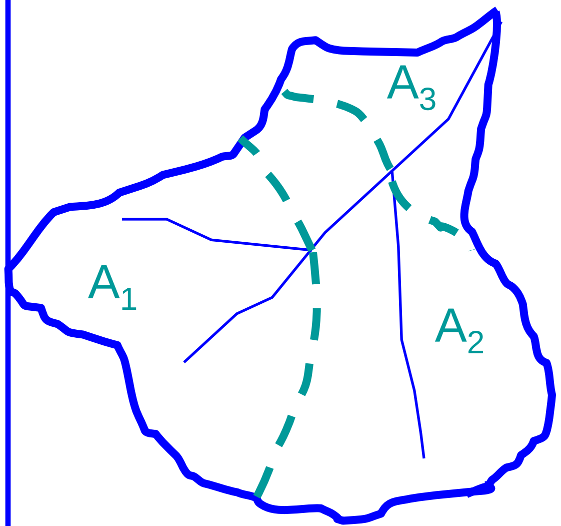
http://www.crwr.utexas.edu/gis/gishydro06/WaterQuality/GIStoHSPF/GIStoHSPF.htm

Classification of Hydrologic Models

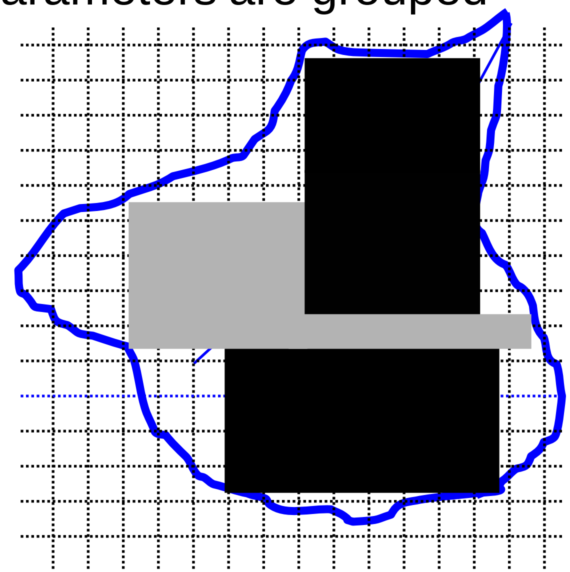


Spatial Scaling of Models

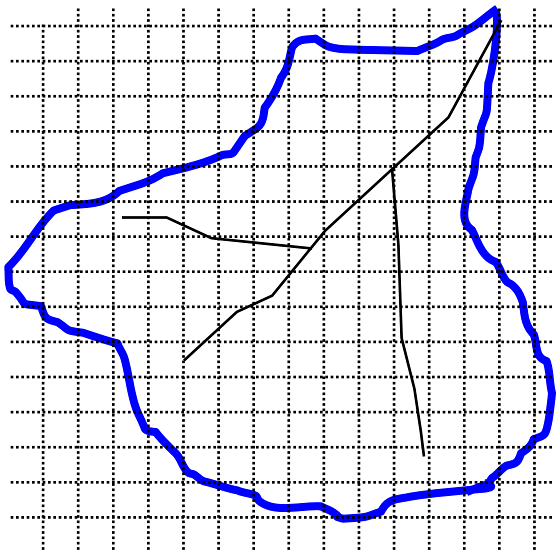
Lumped
Parameters assigned to each sub-basin



Semi-Distributed
Parameters assigned to each grid cell, but cells with same parameters are grouped



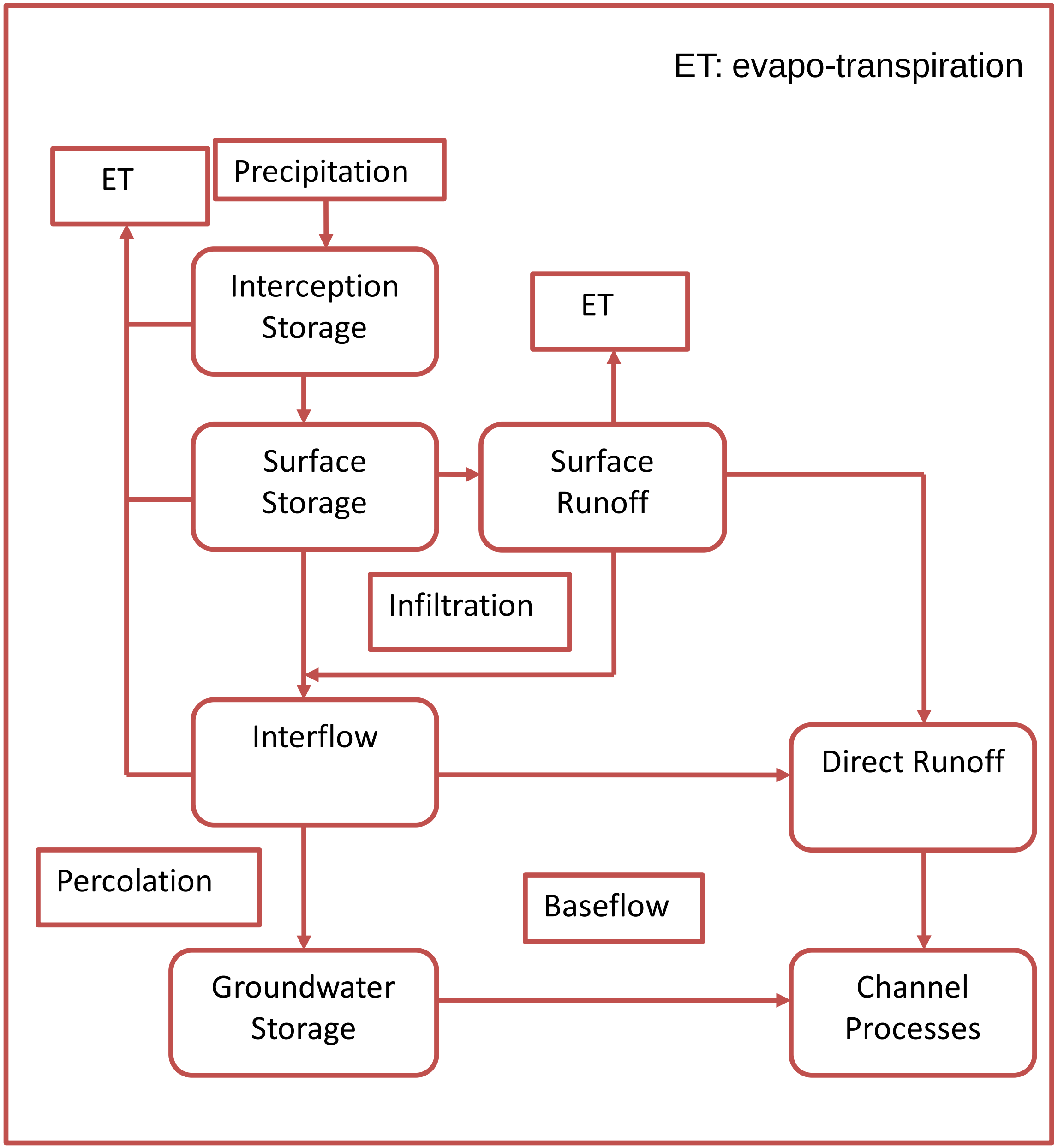
Fully-Distributed
Parameters assigned to each grid cell



Parameters of Watershed

1. Size
2. Shape
3. Physiography
4. Climate
5. Drainage
6. Land use
7. Vegetation
8. Geology and Soils
9. Hydrology
10. Hydrogeology
11. Socioeconomics

Flowchart of simple watershed model (McCuen, 1989)



Strengths of Watershed Models

❖**Diversity of the current generation of models**

There exists a multitude of watershed models, and their diversity is so large that one can easily find more than one watershed model for addressing any practical problem.

❖**Comprehensive Nature**

Many of the models can be applied to a range of problems.

❖**Reasonable modeling of physical phenomena**

In many cases models mimic reasonably well the physics of the underlying hydrologic processes in space and time.

Strengths of Watershed Models

❖ **Distributed in Space and Time**

Many models are distributed in space and time.

❖ **Multi-disciplinary nature**

Several of the models attempt to integrate with hydrology :

a) Ecosystems and ecology,
b) Environmental components,
c) Biosystems,
d) Geochemistry,
e) Atmospheric sciences and
f) Coastal processes

➔ This reflects the increasing role of watershed models in tackling environmental and ecosystems problems.

Deficiencies of Watershed Models

The most ubiquitous deficiencies of the models are:

- Lack of user-friendliness,
- Large data requirements,
- Lack of quantitative measures of their reliability,
- Lack of clear statement of their limitations, and
- Lack of clear guidance as to the conditions for their applicability.

Also, some of the models cannot be embedded with social, political, and environmental systems.

Although watershed models have become increasingly more sophisticated, there is a long way to go before they become "household" tools.

Hydrologic Models

Model Type	Example of Model
Lumped parameter	Snyder or Clark UH
Distributed	Kinematic wave
Event	HEC-1, HEC-HMS, SWMM, SCS TR-20
Continuous	Stanford Model, SWMM, HSPF, STORM
Physically based	HEC-1, HEC-HMS, SWMM, HSPF
Stochastic	Synthetic streamflows
Numerical	Kinematic or dynamic wave models
Analytical	Rational Method, Nash IUH

Hydrologic Models

Contd…

Models	Application Areas
HEC-HMS	Design of drainage systems, quantifying the effect of land use change on flooding
National Weather Service (NWS)	Flood forecasting.
Modular Modeling System (MMS)	Water resources planning and management works
University of British Columbia (UBC) & WATFLOOD	Hydrologic simulation
Runoff-Routing model (RORB) & WBN	Flood forecasting, drainage design, and evaluating the effect of land use change
TOPMODEL & SHE	Hydrologic analysis
HBV	Flow forecasting

A List of
Popular Hydrologic Models

Popular Hydrologic Models

Model name/acronym	Author(s)(year)	Remarks
Stanford watershed Model (SWM)/Hydrologic Simulation Package-Fortran IV (HSPF)	Crawford and Linsley (1966), Bicknell et al. (1993)	Continuous, dynamic event or steady-state simulator of hydrologic and hydraulic and water quality processes
Catchment Model (CM)	Dawdy and O’Donnell (1965)	Lumped, event-based runoff model
Tennessee Valley Authority (TVA) Model	Tenn. Valley Authority (1972)	Lumped, event-based runoff model
U.S. Department of Agriculture Hydrograph Laboratory (USDAHL) Model	Holtan and Lopez (1971), Holtan et al. (1974)	Event-based, process-oriented, lumped hydrograph model
U.S. Geological Survey (USGS) Model	Dawdy et al. (1970, 1978)	Process-oriented, continuous/event-based runoff model

Popular Hydrologic Models **Contd…**

Model name/acronym	Author(s)(year)	Remarks
Utah State University (USU) Model	Andrews et al. (1978)	Process-oriented, event /continuous streamflow model
Purdue Model	Huggins and Monke (1970)	Process-oriented, physically based, event runoff model
Antecedent Precipitation Index (API)Model	Sittner et al. (1969)	Lumped, river flow forecast model
Hydrologic Engineering Center—Hydrologic Modeling System (HEC-HMS)	Feldman (1981), HEC (1981, 2000)	Physically-based, semi-distributed, event-based, runoff model
Streamflow Synthesis and Reservoir regulation (SSARR) Model	Rockwood (1982) U.S. Army Corps of Engineers (1987), Speers (1995)	Lumped, continuous streamflow simulation model

Popular Hydrologic Models Contd…

Model name/acronym	Author(s)(year)	Remarks
National Weather service-River Forecast System (NWS-RFS)	Burnash et al. (1973a,b), Burnash (1975)	Lumped, continuous river forecast system
University of British Columbia (UBC) Model	Quick and Pipes (1977), Quick (1995)	Process-oriented, lumped parameter, continuous simulation model
Tank Model	Sugawara et al. (1974) , Sugawara (1995)	Process-oriented, semi-distributed or lumped continuous simulation model
Runoff Routing Model (RORB)	Laurenson (1964), Laurenson and Mein (1993, 1995)	Lumped, event-based runoff simulation model
Agricultural Runoff Model (ARM)	Donigian et al. (1977)	Process-oriented, lumped runoff simulation model

Model name/acronym	Author(s)(year)	Remarks
Storm Water Management Model (SWMM)	Metcalf and Eddy et al. (1971), Huber and Dickinson (1988), Huber (1995)	Continuous, dynamic event or steady-state simulator of hydrologic and hydraulic and water quality processes
Areal Non-point Source Watershed Environment Response Simulation (ANSWERS)	Beasley et al. (1977), Bouraoui et al. (2002)	Event-based or continuous, lumped parameter runoff and sediment yield simulation model
National Hydrology Research Institute (NHRI)Model	Vandenberg (1989)	Physically based, lumped parameter, continuous hydrologic simulation model
Technical Report-20 (TR-20) Model	Soil Conservation Service (1965)	Event-based, process-oriented, lumped hydrograph model
U.S. Geological Survey (USGS) Model	Dawdy et al. (1970, 1978)	Lumped parameter, event based runoff simulation model

Model name/acronym	Author(s)(year)	Remarks
Physically Based Runoff Production Model (TOPMODEL)	Beven and Kirkby (1976, 1979), Beven (1995)	Physically based, distributed, continuous hydrologic simulation model
Generalized River Modeling Package—Systeme Hydroloque Europeen (MIKE-SHE)	Refsgaard and Storm (1995)	Physically based, distributed, continuous hydrologic and hydraulic simulation model
ARNO(Arno River)Model	Todini (1988a,b, 1996)	Semidistributed, continuous rainfall-runoff simulation model
Waterloo Flood System (WATFLOOD)	Kouwen et al. (1993), Kouwen (2000)	Process-oriented, semidistributed continuous flow simulation model
Topgraphic Kinematic Approximation and Integration (TOPIKAPI)Model	Todini (1995)	Distributed, physically based, continuous rainfall-runoff simulation model

Model name/acronym	Author(s)(year)	Remarks
Soil-Vegetation-Atmosphere Transfer (SVAT) Model	Ma et al. (1999), Ma and Cheng (1998)	Macroscale, lumped parameter, streamflow simulation system
Systeme Hydrologique Europeen Transport (SHETRAN)	Ewen et al. (2000)	Physically based, distributed, water quantity and quality simulation model
Daily Conceptual Rainfall-Runoff Model (HYDROLOG)-Monash Model	Potter and McMahon (1976), Chiew and McMahon (1994)	Lumped, conceptual rainfall-runoff model
Soil Water Assessment Tool (SWAT)	Arnold et al. (1998)	Distributed, conceptual, continuous simulation model
Distributed Hydrological Model (HYDROTEL)	Fortin et al. (2001a,b)	Physically based, distributed, continuous hydrologic simulation model