Module 6 – (L22 – L26): "Use of Modern Techniques in Watershed Management"

Applications of Geographical Information System and Remote Sensing in Watershed Management, Role of Decision Support System in Watershed Management

WATERSHED MANAGEMENT

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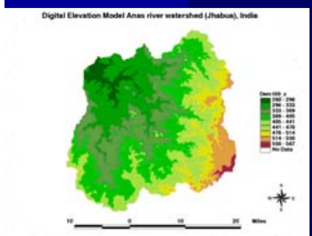
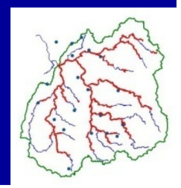
Lecture No - 25

Integrated Watershed Modeling Using Numerical Methods, GIS & Remote Sensing

L25– Integrated Watershed Modeling Using Numerical Methods, GIS & Remote Sensing

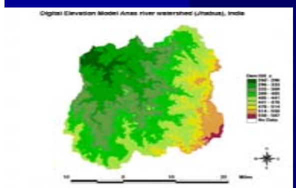
- **Topics Covered**
- Integrated watershed modeling; Numerical methods; Finite element method; Computer modeling; Geographical Information System; Remote sensing; Applications in Watershed Management.
- Keywords: Integrated watershed modeling, numerical modeling; GIS; Remote sensing.



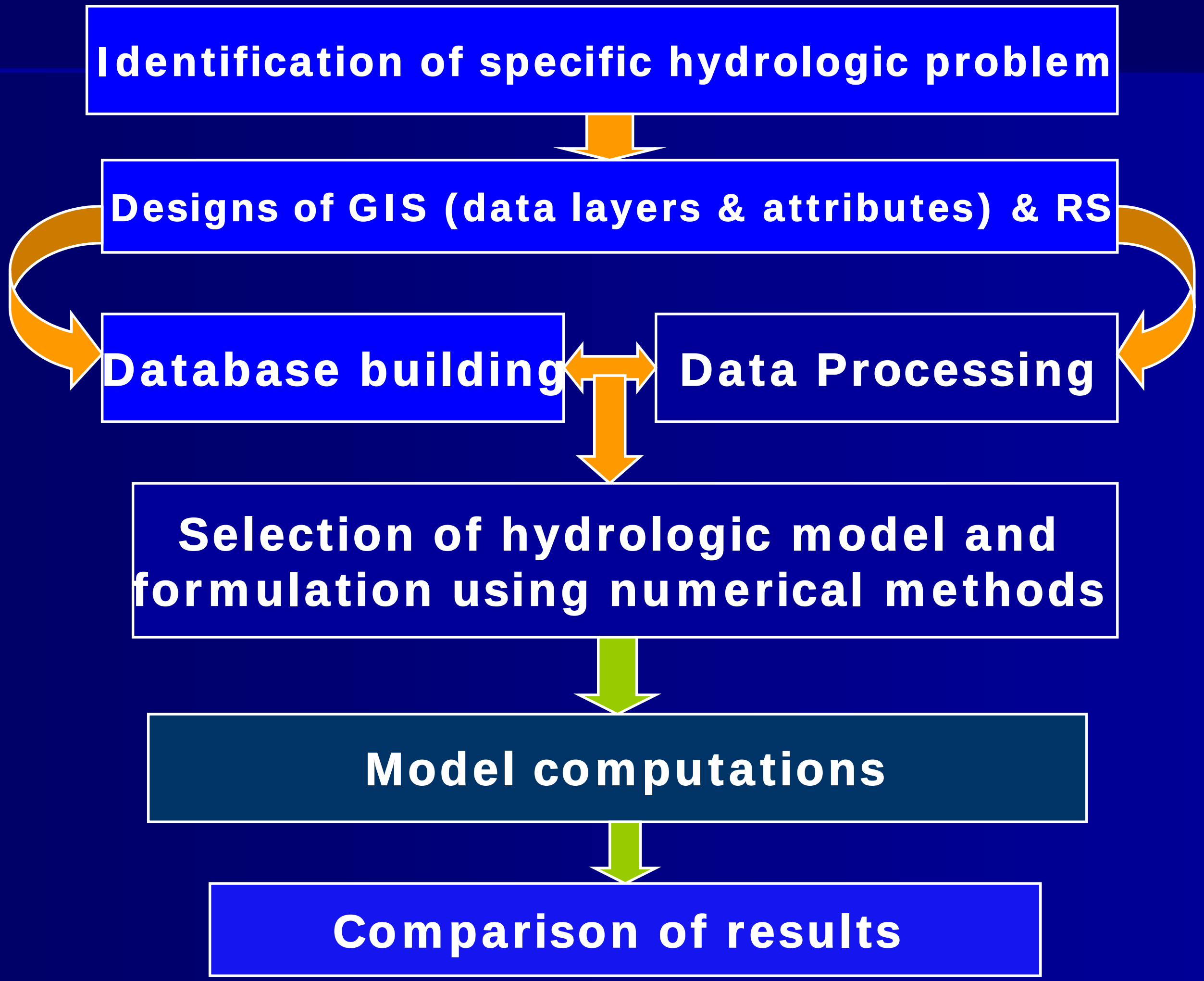


Necessity of Integrated Catchment/ Watershed Based Modeling

- Water resources management- catchment/ watershed based
- Watershed / catchment based- Watershed modeling- Planning & management
- Catchment/ Rainfall – runoff
- Modeling based on physical laws – Importance, necessity
- An integrated catchment/ watershed model.
- Hydrological Processes- Infiltration, Runoff, evaporation etc.
- Digital revolution
- Recent advances in watershed modeling -Use of numerical modeling, remote sensing and GIS.

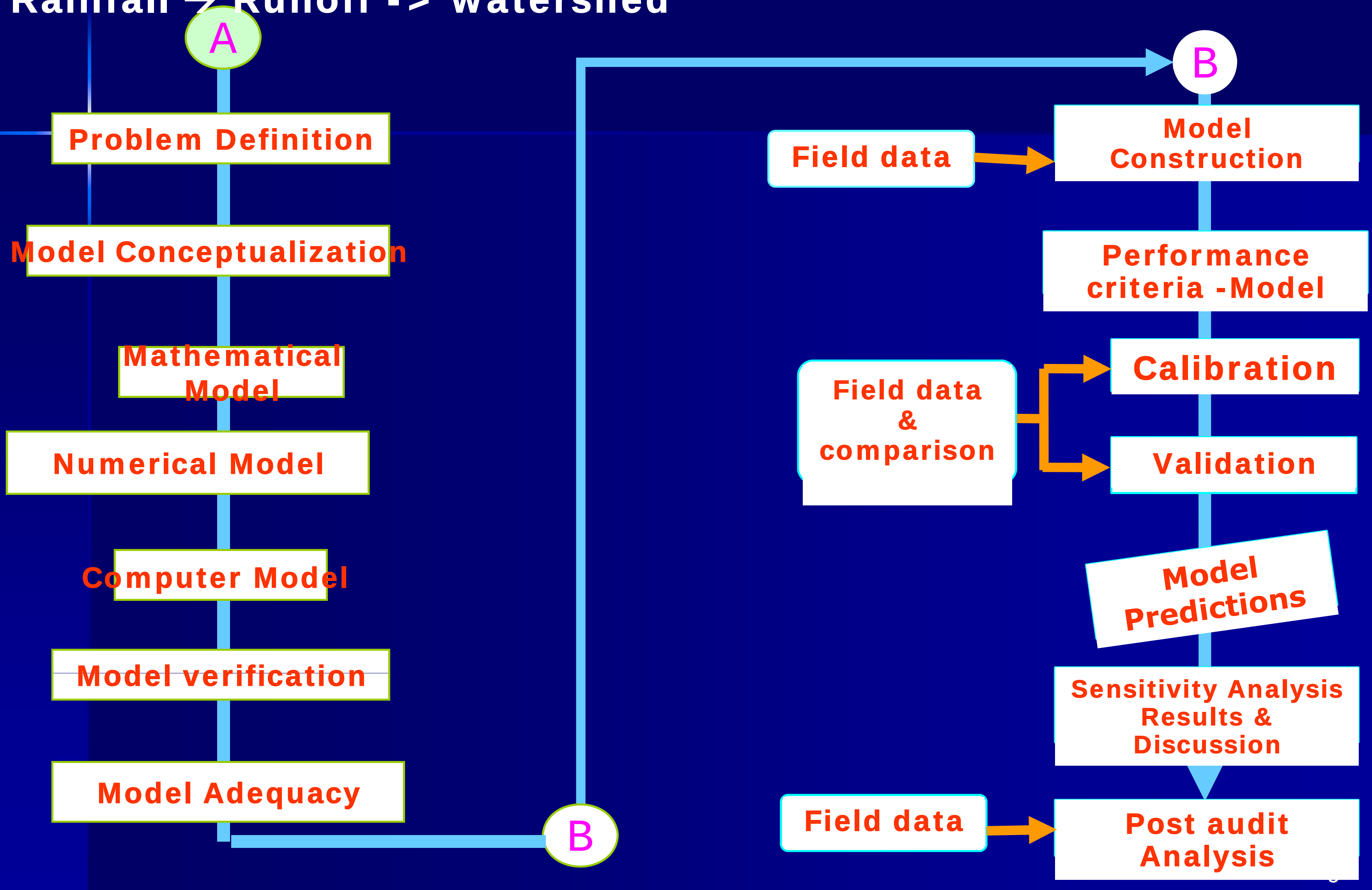


Integrated Watershed Modeling Approach



Hydrologic/ Hydraulic Modeling

Rainfall → Runoff -> watershed



Physically Based Distributed Models

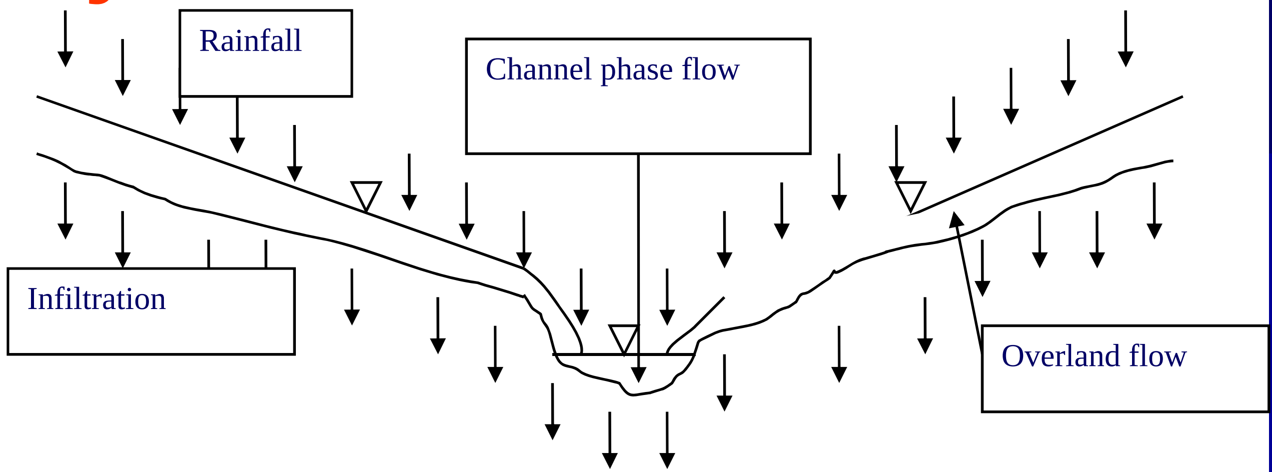


Fig. Flow in a watershed – Typical flow pattern

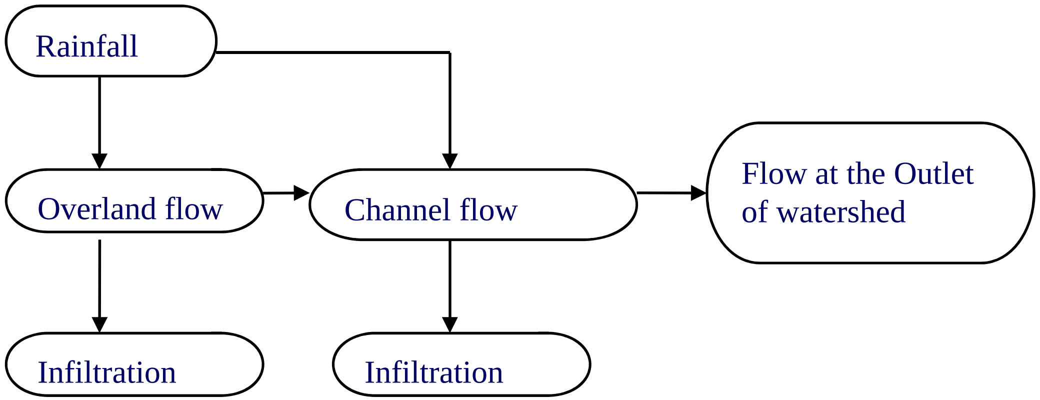


Fig. General concept of flow modeling

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Remote Sensing, GIS & Numerical Methods

- **Remote sensing**

  The remote sensing data are capable of solving the problem of scarcity of data.

- Spatial variation
- Temporal variation

- **Remote sensing process**

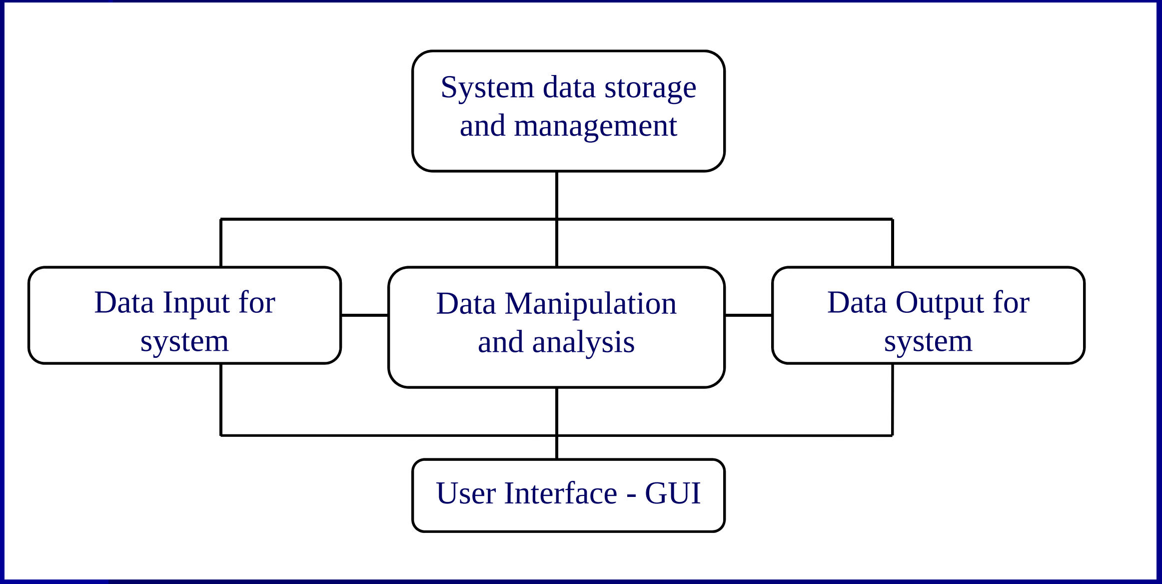
  1. Data acquisition
  2. Data analysis

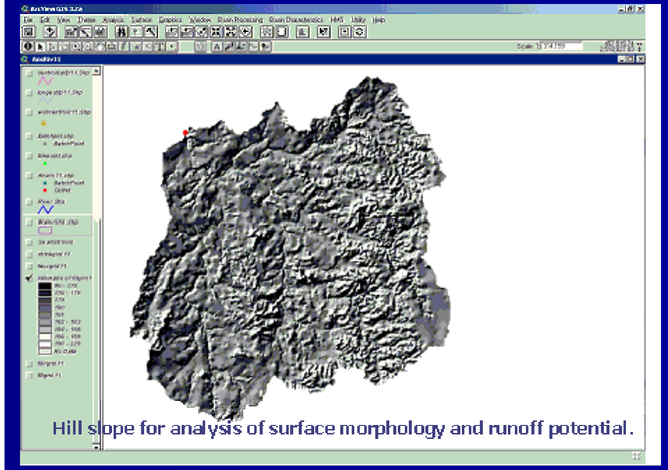
- Remote sensing - Capability of observing several hydrological variables - Over large areas on repetitive basis

Geographic Information Systems (GIS)

- **Components of GIS**

1. Data input data
2. Storage and management
3. Data manipulation and analysis
4. Data output





Numerical Methods – Computer Models

- Conceptual modeling
- Mathematical modeling
- Mathematical problems - solved by arithmetical operations.
- Digital revolution- the role of numerical methods
- Computer models – various models
- Numerical methods
  - (a) finite difference method
  - (b) finite element method
  - (c) finite volume method
  - (d) boundary element method

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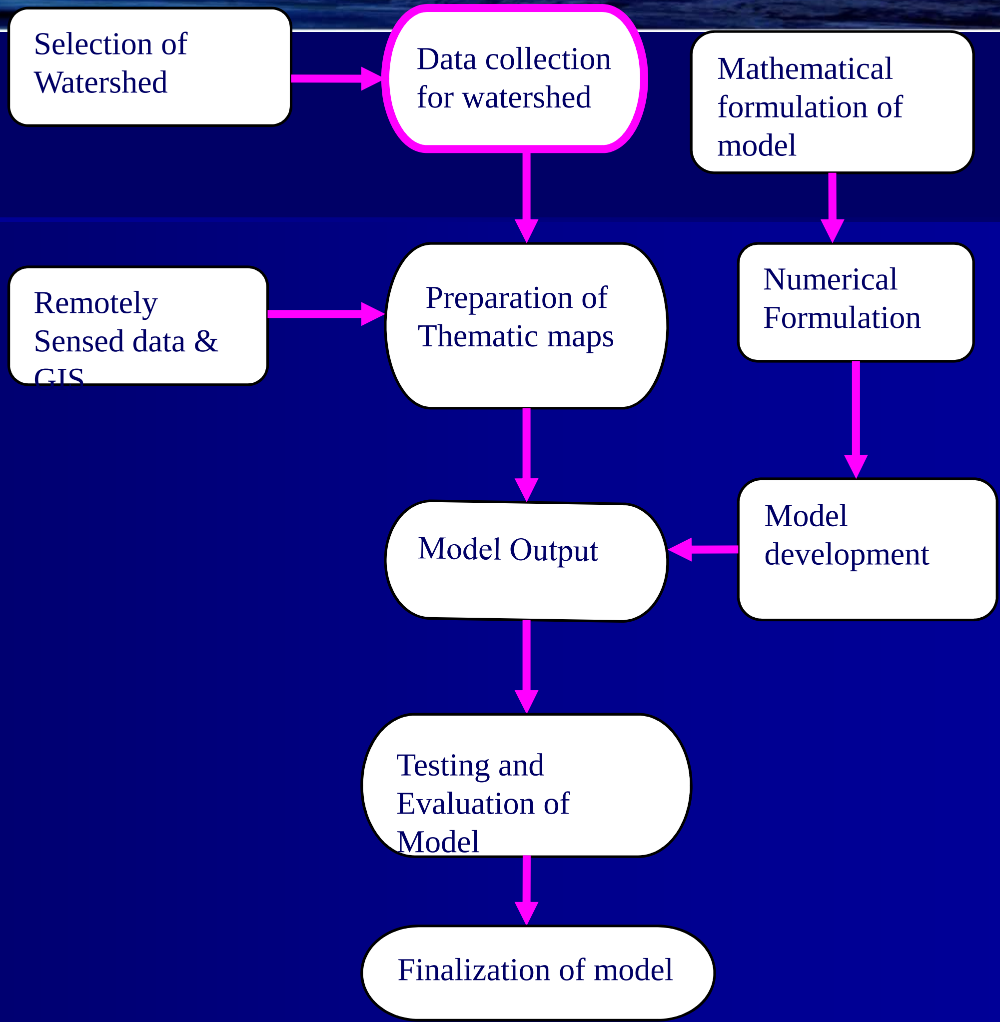
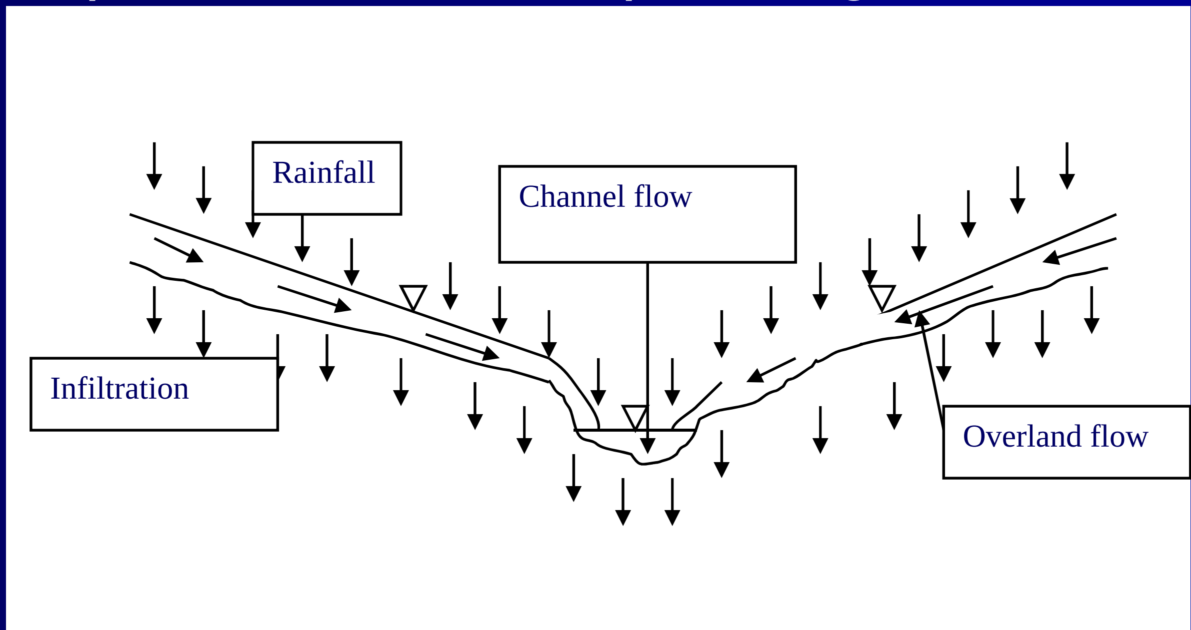
WATERSHED MANAGEMENT



Integrated Use of Numerical Method, GIS & Remote sensing

Watershed Based Runoff modeling

- Infiltration – Various models
- Overland flow - One dimensional/ 2D
- Channel flow - One dimensional
- Component models coupled to get the runoff



Flow in a watershed – Typical flow pattern

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Infiltration

Eg. Philip Infiltration Model: To calculate infiltration rate and subsequent excess rainfall

The rate of infiltration is given by

$$f = \frac{1}{2} s_i \, t^{-1/2} + K$$

f potential infiltration rate

s_i infiltration sorptivity

K hydraulic conductivity

Infiltration sorptivity

$$s_i = 2(1 - s_{ini}) \left[\frac{5 \eta K_s \Psi \Phi(d, s_{ini})}{3 \lambda \pi} \right]^{1/2}$$

K_s saturated hydraulic conductivity

s_{ini} initial (uniform) soil saturation degree

Ψ saturated matrix potential of the soil

$\Phi(d, s_{ini})$ dimensionless surface sorption diffusivity of the soil

λ pore size distribution index

d diffusivity index ($d = (1 + 2\lambda)/\lambda$)

η Effective porosity of the soil

Physically based Model

- Governing equations for surface runoff

1. Overland flow (Two dimensional)

a. Continuity equation

$$\frac{\partial h}{\partial t} + \frac{\partial \bar{u} h}{\partial x} + \frac{\partial \bar{v} h}{\partial y} = r - i \qquad (1)$$

b. Momentum equation

$$\frac{\partial \bar{u}}{\partial t} + \bar{u}\frac{\partial \bar{u}}{\partial x} + \bar{v}\frac{\partial \bar{u}}{\partial y} + g\frac{\partial h}{\partial x} - g\left(S_{ox} - S_{fx}\right) + (r - i)\frac{\bar{u}}{h} = 0 \qquad (2)$$

Physically based Model..

$$\frac{\partial \bar{v}}{\partial t} + \bar{u}\frac{\partial \bar{v}}{\partial x} + \bar{v}\frac{\partial \bar{v}}{\partial y} + g\frac{\partial h}{\partial y} - g\left(S_{oy} - S_{fy}\right) + (r - i)\frac{\bar{v}}{h} = 0 \quad (3)$$

$$S_{fx} = \bar{u}\left(\bar{u}^2 + \bar{v}^2\right)^{1/2}\frac{n^2}{h^{4/3}} \qquad S_{fy} = \bar{v}\left(\bar{u}^2 + \bar{v}^2\right)^{1/2}\frac{n^2}{h^{4/3}} \quad (4) \quad (5)$$

2.Channel flow (One dimensional)

a. Continuity equation

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q = 0 \quad (6)$$

Physically based Model...

b. Momentum equation

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) = gA\left(S - S_f\right) - gA\frac{\partial y}{\partial x} \qquad (7)$$

- Governing equation for ground water flow (Two dimensional)

$$\frac{\partial}{\partial x}\left[K_x h \frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_y h \frac{\partial h}{\partial y}\right] + I(x, y, t) - S\frac{\partial h}{\partial t} = 0 \qquad (8)$$

- **Governing equations for overland flow (Diffusion Wave/ Kinematic Wave Models)**

1. Continuity equation

$$\frac{\partial q}{\partial x} + \frac{\partial h}{\partial t} = r_e$$

q flow per unit width

h depth of flow

r_e excess rainfall intensity

2. Momentum equation

$$\frac{\partial h}{\partial x} = S_o - S_f$$

$S_o = S_f$ (kinematic)

S_o slope of overland flow plane

S_f friction slope of flow plane

- **Finite element formulation - Galerkin's criterion is used**

$$[C]\{h\}^{t+\Delta t} = [C]\{h\}^{t} - \Delta t[B]\left\{(1-\omega)q^{t} + \omega q^{t+\Delta t}\right\} + \Delta t\{f\}\left((1-\omega)(r_e)^{t} + \omega(r_e)^{t+\Delta t}\right)$$

ω is the factor that determines the type of finite difference scheme involved (0.5)

For diffusion wave modeling

$$S_{f_i} = S_{o_i} - \frac{h_k - h_i}{L}$$

L length of element i and k represent successive nodes in flow direction

Governing equations for channel flow

The equation of continuity

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q = 0$$

Q is discharge in the channel,

A is area of flow in the channel,

Momentum equation

$$\frac{\partial h}{\partial x} = S - S_{f_c}$$

$S_o = S_f$ (kinematic)

S is bed slope of channel

S_{f_c} is friction slope of channel

Manning's equation

$$Q = \frac{1}{n} R^{(2/3)} S_{f_c}^{(1/2)} A$$

R is hydraulic radius (A/P),

P is wetted perimeter

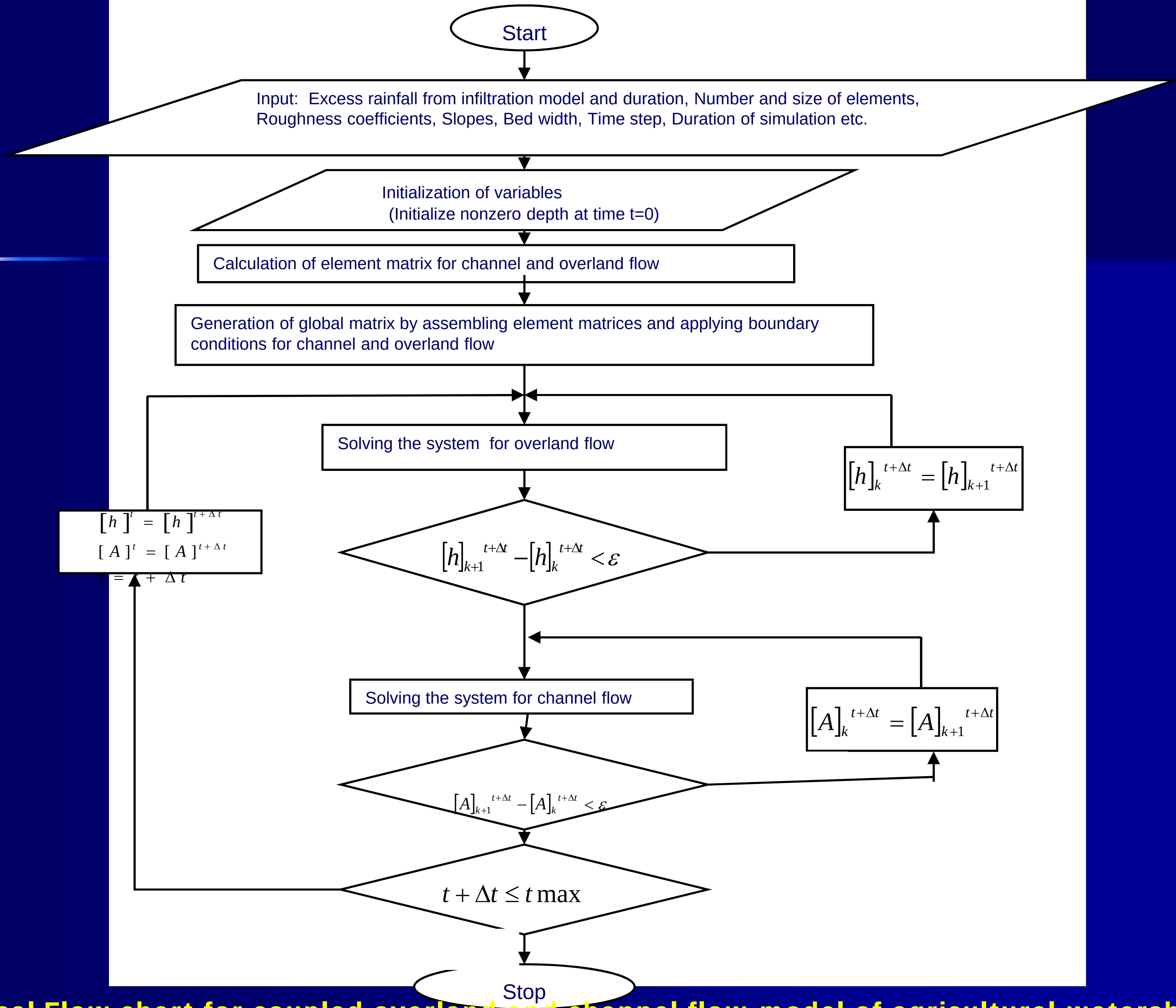
n is channel flow Manning's roughness coefficient

Finite element formulation

$$[C]\{A\}^{t+\Delta t} = [C]\{A\}^{t} - \Delta t[B]\{(1-\theta)Q^{t} + \theta Q^{t+\Delta t}\} + \Delta t\{f\}((1-\theta)q^{t} + \theta q^{t+\Delta t})$$

For diffusion wave modeling

$$(S_{f_c})_i = S_i - \frac{h_k - h_i}{L}$$



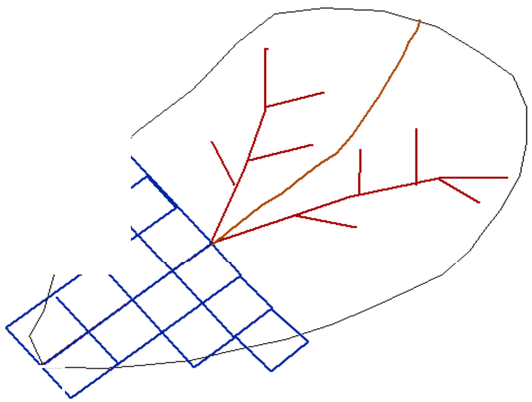
Typical Flow chart for coupled overland and channel flow model of agricultural watershed
(Reddy et al. (2007))

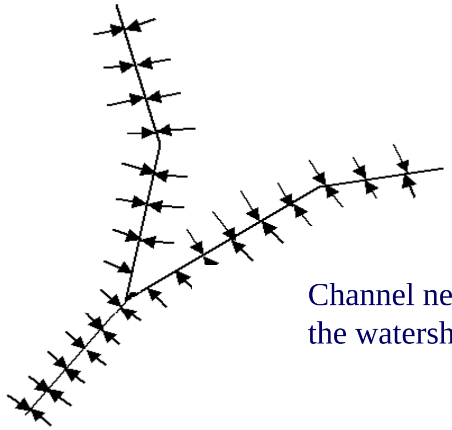
Modeling Procedure

- Data collection for the selected watershed.
- Mathematical modeling.
- Numerical formulation for the mathematical model.
- Preparation of thematic maps of the watershed by using
- Remote sensing imageries and GIS.
- Development of software for the formulated model.
- Testing and evaluation of the model for different rainfall events
- Finalization of model.

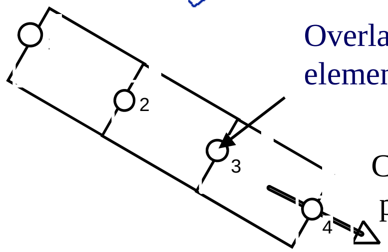
Modeling Procedure…

Discretization as rectangular strips





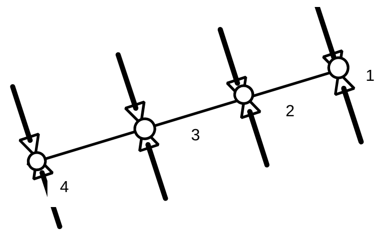
Channel network in the watershed



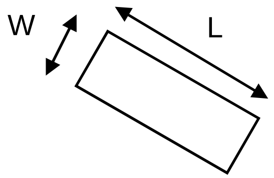
Overland flow element node

Channel meeting point

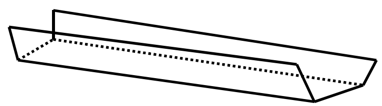
Overland flow strip



Single discretized channel with overland flow adding at channel nodes



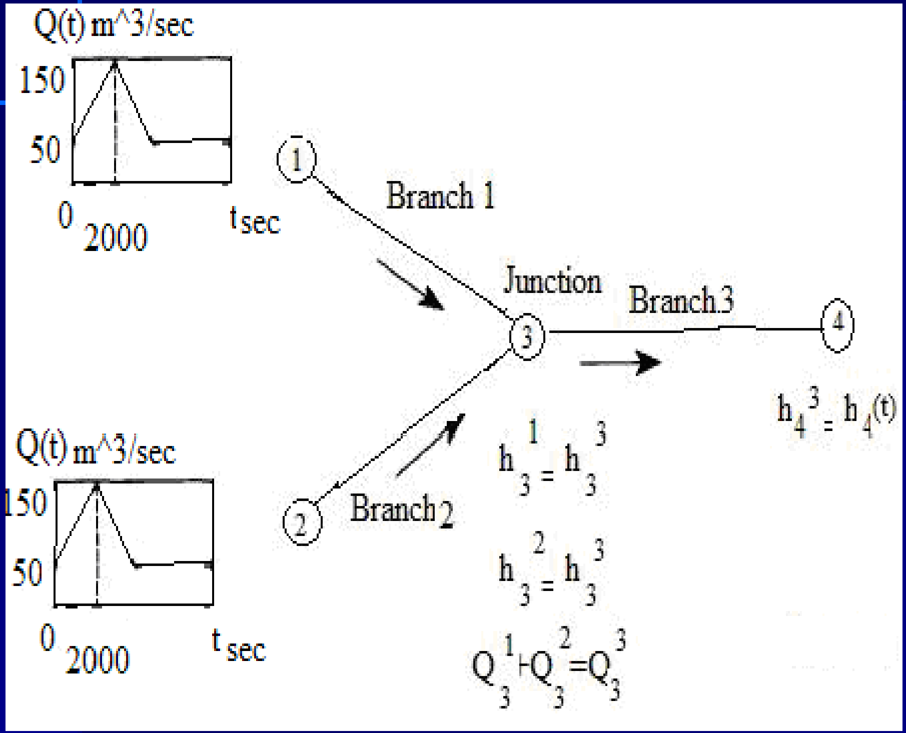
Overland flow element

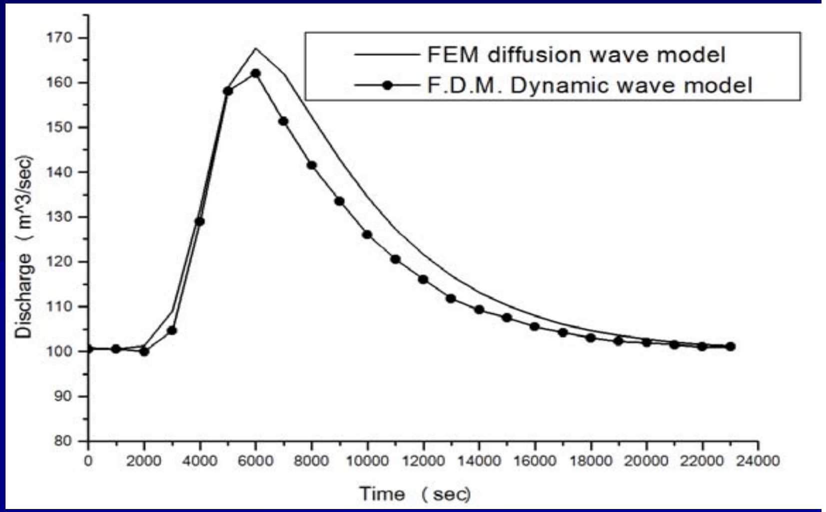


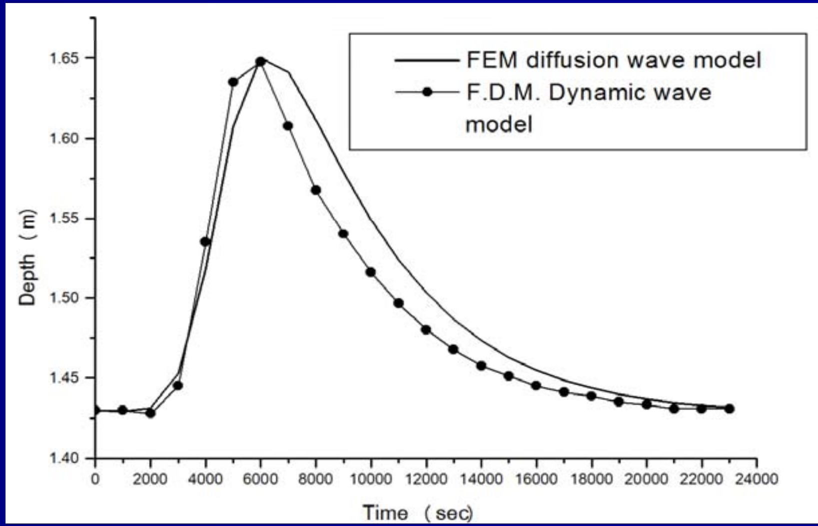
Channel flow element

Example of Channel flow model: Diffusion wave model **(Aral et al. 1998).**

Example







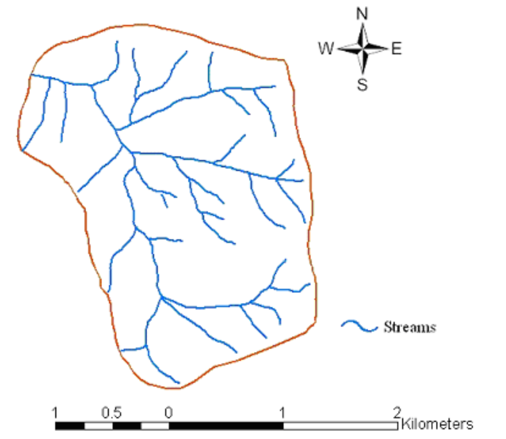
Length of each branch = 5,000 m; channel width is 50 m for two upstream channels & 100 m for d/s channel. Bed slope is 0.0002. Roughness coefficient is 0.025.

15 elements with element length 1000 m & time step 200 sec is used. Results for 23000 sec. Discharge & depth variation at 4000 m in branch 3 are shown

Case Study: Khadakhol Watershed

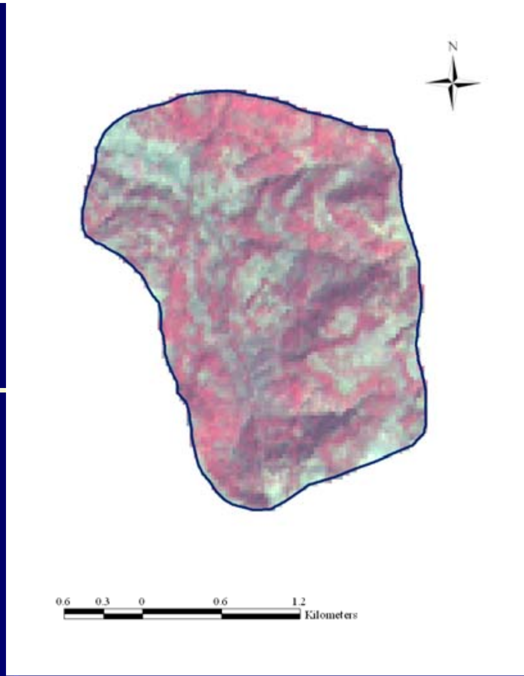
(Venkata Reddy, 2007)

- Location- Nashik district, Maharashtra, India
  East Longitudes of 73° 17' and 73° 20'
  North Latitudes of 20° 07' and 20° 09'.
- Area- 5.89 km^2
- Major soil class – Silty loam
- Remotely sensed data- IRS 1D LISS III image Jan.13,1998
- Thematic maps - Drainage, Slope and LU/LC, DEM

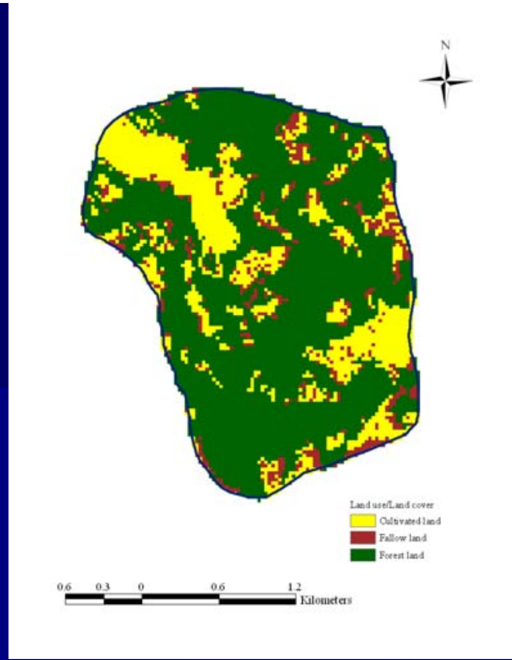


Case Study: Rainfall –Runoff Modeling

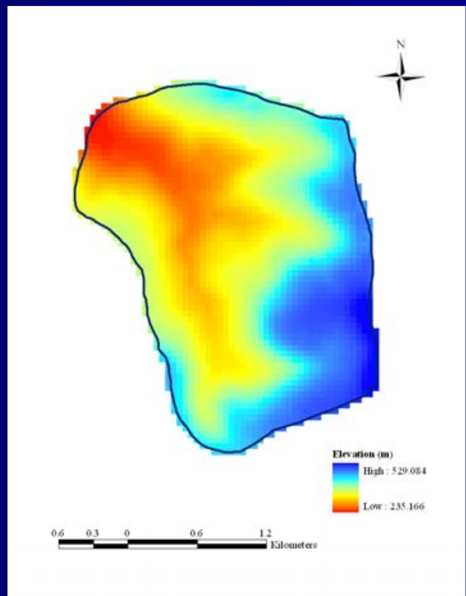
- **Database preparation**
- *Drainage map:* Initially scanned topographical maps of the area in 1:25000 scale are registered in ERDAS IMAGINE software. Watershed boundary and the drainage maps are digitized in ArcMap.
- *Slope map:* Contours with 10 m interval of the watershed are digitized in ArcMap from topographical maps and Digital Elevation Model (DEM) with 100 m cell size has been generated using TOPOGRID option of ArcInfo software.
- *LU/LC map:* Remotely sensed data of IRS 1D LISS III path 105 and row 55 of January 13, 1998 has been used to extract LU/ LC of the watershed. LU/LC map is derived from remotely sensed data of watershed by supervised classification using ERDAS IMAGINE software



False Colour Composite

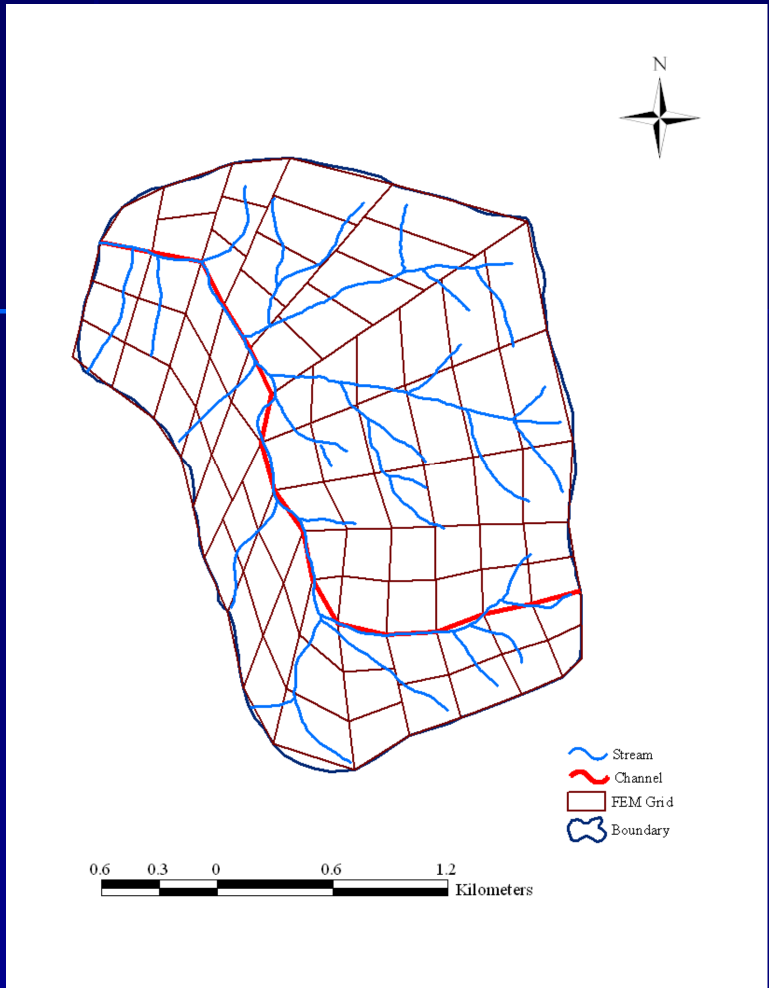


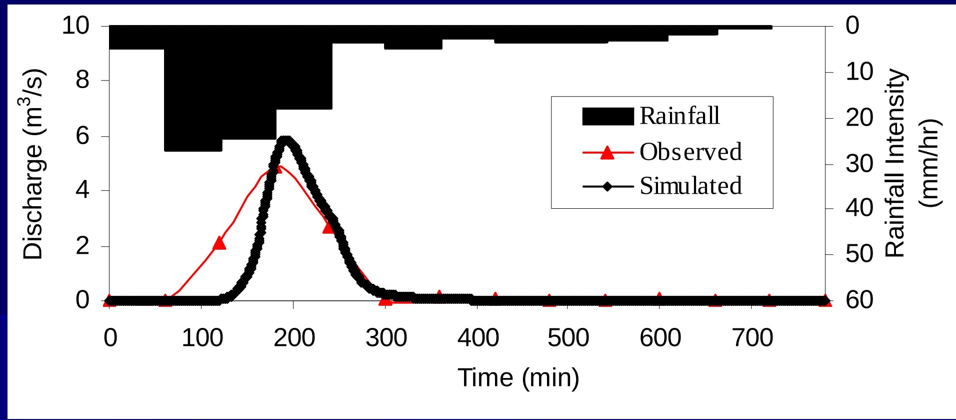
Land Use/Land Cover map



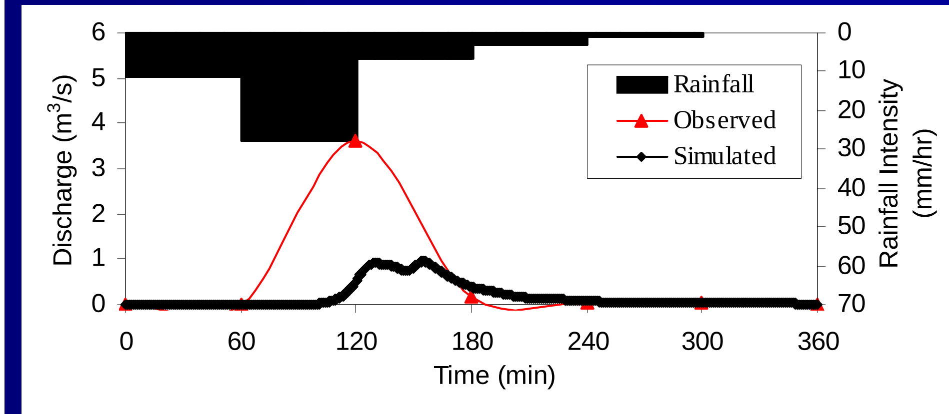
Khadakohol Watershed

Digital Elevation Model map





August 23, 1997



August 22, 1997

Finite element grid map

Observed and Simulated hydrographs

Khadakohol Watershed

Integrated Modeling – Concluding Remarks

- The digital revolution.
- Recent advances -remote sensing and GIS technologies.
- Use of remote sensing and GIS in watershed modeling.
- Use of Distributed / Lumped models
- Hydrologic/ Hydraulic Modeling – By Numerical methods
- Integrated models – Remote Sensing, GIS & Hydrologic Models

References

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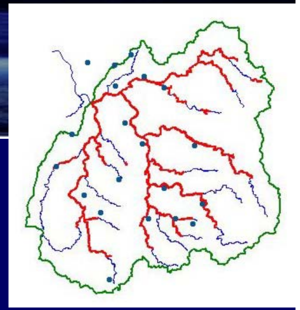
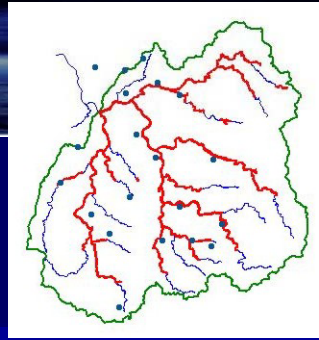
- Cunderlik, J. M. (2003). "Hydrologic model selection for the CFCAS project: Assessment of Water Resources Risk and Vulnerability to changing Climatic Conditions – Project Report 1", Department of Civil and Environmental engineering, University of Western Ontario



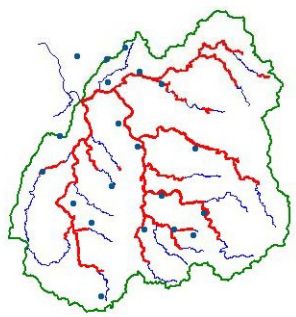
Tutorials - Question!.?.

- Critically study the necessity of integrated approach of watershed modeling using numerical methods, GIS and remote sensing. Study various case studies available in literature (details can be obtained from Internet).
- Study the role of integrated watershed modeling in Integrated Water Resources Management.



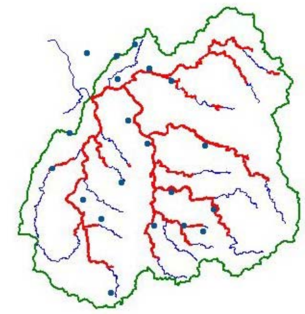
Self Evaluation - Questions!.

- Describe the necessity of Integrated Watershed based modeling.
- Explain the step by step methodology in use of numerical models, GIS and remote sensing for watershed based modeling
- Differentiate between dynamic wave/ diffusion wave/ kinematic wave based physical modeling for rainfall-runoff modeling of watersheds.



Assignment- Questions?.

- Illustrate how GIS & remote sensing can help in effective watershed modeling in combination with numerical modeling.
- For physically event based rainfall runoff modeling, illustrate various hydrologic processes to be considered in the modeling.
- In integrated approach of watershed modeling, describe the modeling procedure.



Unsolved Problem!.

- For your watershed area, study the scope of integrated modeling for rainfall-runoff using numerical models, GIS and remote sensing. Remote sensing for the watershed area may be obtained from ASTER (http://asterweb.jpl.nasa.gov/)/ SRTM (http://srtm.usgs.gov/index.php) / BHUVAN/ IRS (http://bhuvan.nrsc.gov.in/bhuvan_links.html)

- Hydrological model may be obtained from HEC-RAS, HEC-HMS software: *www.**hec**.usace.army.mil/software/**hec-hms***
- For the average/ maximum/ minimum rainfall pattern in the watershed area, asses the runoff for the watershed.

▪ THANK YOU

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