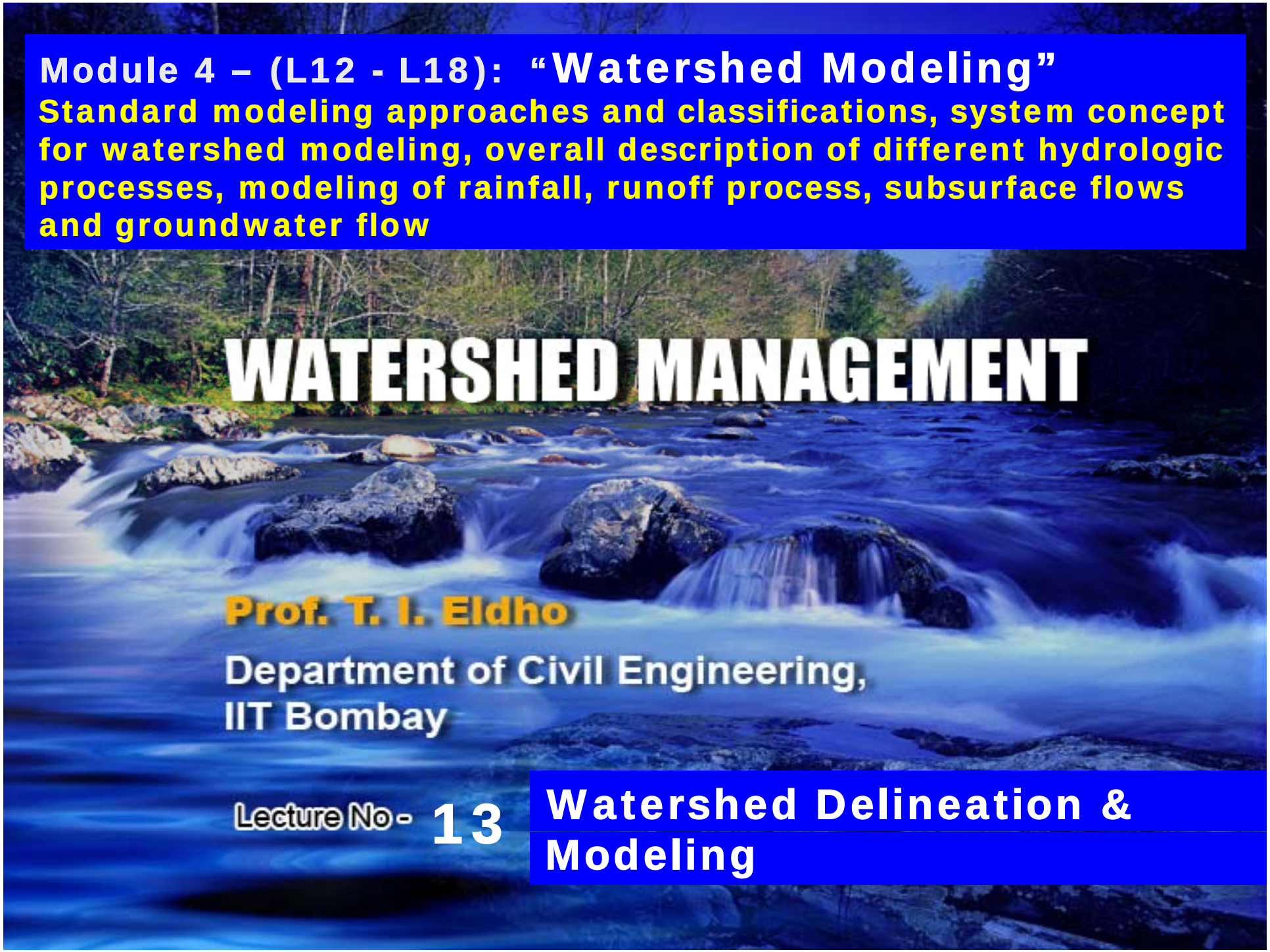
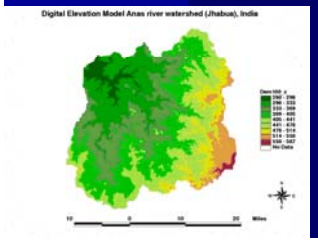

Module 4 – (L12 - L18): "Watershed Modeling"
Standard modeling approaches and classifications, system concept for watershed modeling, overall description of different hydrologic processes, modeling of rainfall, runoff process, subsurface flows and groundwater flow
WATERSHED MANAGEMENT
Prof. T. I. Eldho
Department of Civil Engineering,
IIT Bombay
Lecture No - 13
Watershed Delineation & Modeling

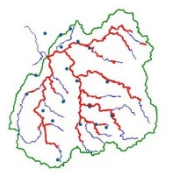
WATERSHED MANAGEMENT

# L13– Watershed Delineation & Modeling

- **Topics Covered**
- Watershed delineation, Watershed Modeling, Mathematical Modeling
- Keywords: Watershed delineation, Mathematical modeling

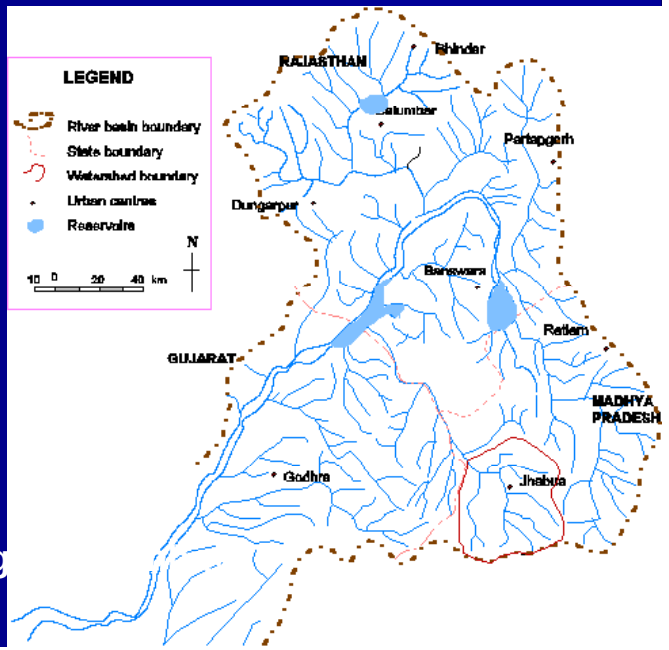



Prof. T I Eldho, Department of Civil Engineering, IIT Bombay



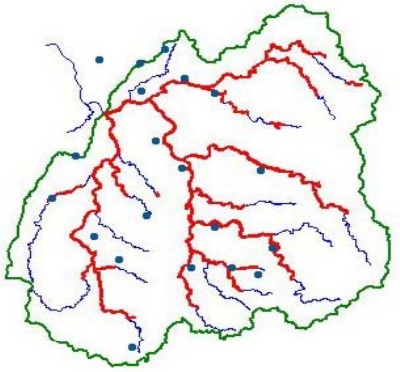
# Watershed Delineation

- Watershed - land area that drains water to the outlet during a rainstorm.
- Boundary of a watershed- consists of the line drawn across the contours joining the highest elevations surrounding the basin.
- A common task in hydrology is to delineate a watershed from a topographic map.



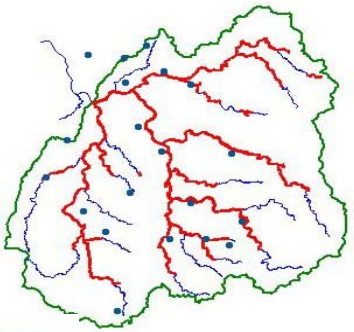


Prof. T I Eldho, Department of Civil Engineering



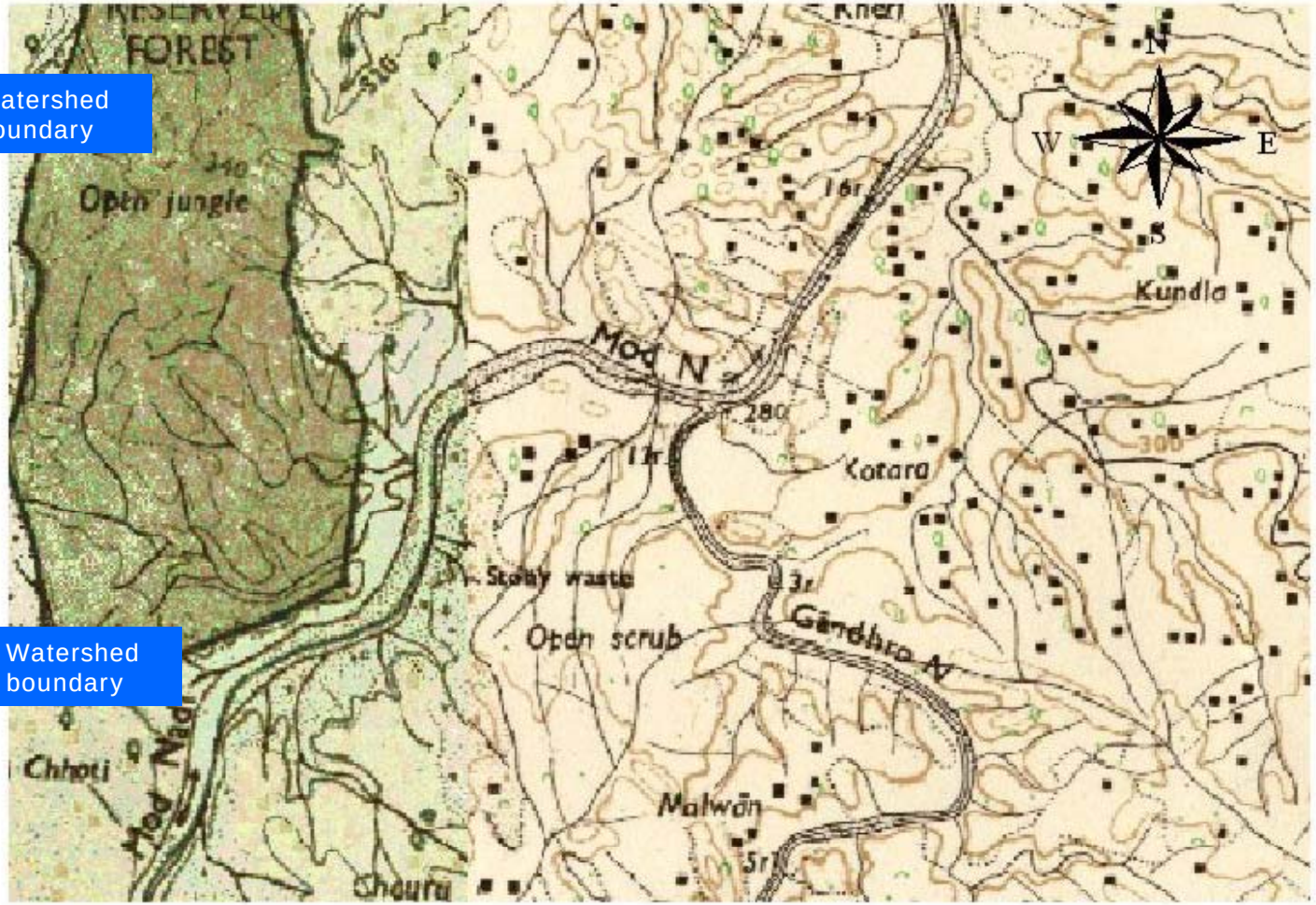
# Watershed Delineation

- Topographic Maps: fundamental source of data for delineating and studying watersheds
- Scale varies
- These maps - wealth of information -topographic contour lines, locations of cities, buildings, roads, road types, railroads, pipelines, water bodies, forested land, stream networks, and stream gauging stations and benchmarks.
- For watershed delineation - topographic maps best starting point.
- More detailed analysis - a detailed topographic survey of the area of interest.
- Topographic maps - available at all state / federal geological survey offices



# Watershed Delineation...

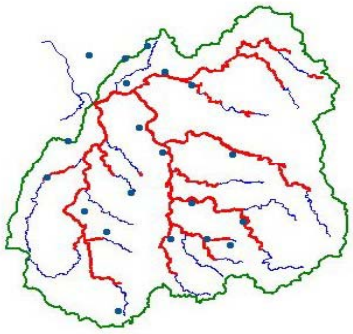
Watershed boundary



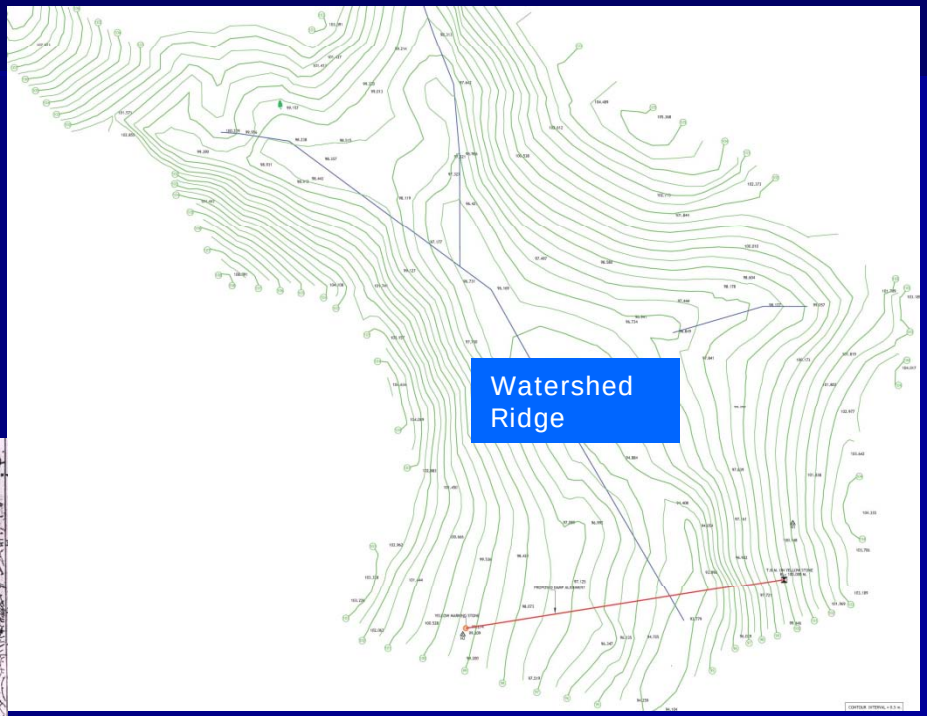

Watershed boundary

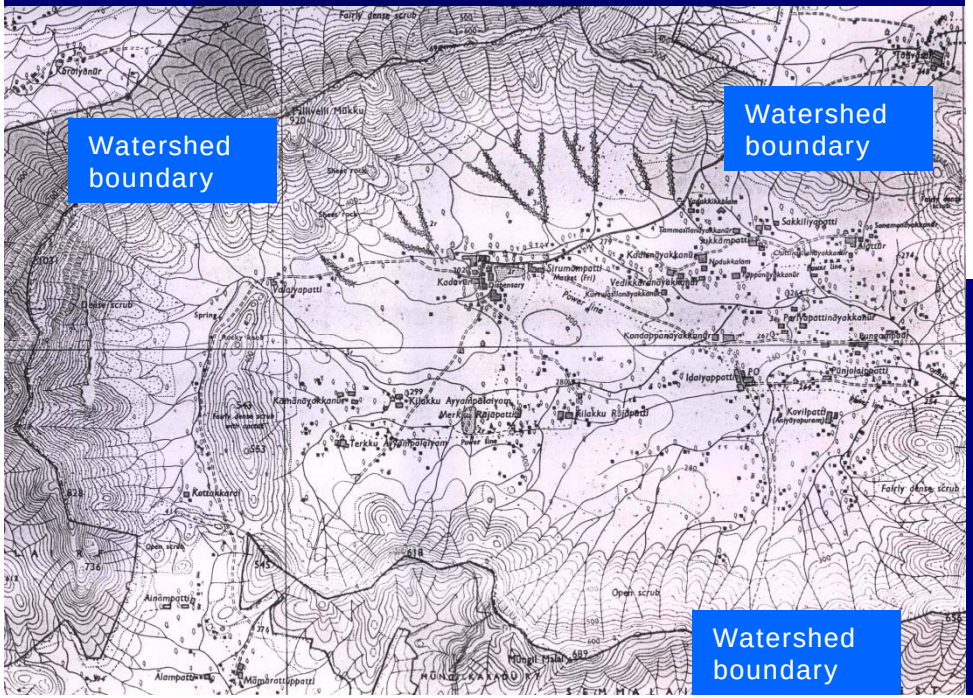
# Watershed Delineation

- To trace the boundary, - start at the outlet & then draw a line away on the left bank, maintaining it always at right angles to the contour lines. (The line should not cross the drainage paths)
- Continue the line until it is above the headwaters of the stream network. Return to the outlet and repeat the procedure with a line away from the right bank.
- Two lines should join to produce the full watershed boundary.
- Use of GIS (Geographic Information System) popular and has facilitated much of the work of hydrologists.
- The use of DEMs (Digital Elevation Models) in particular has made watershed delineation a smooth procedure.



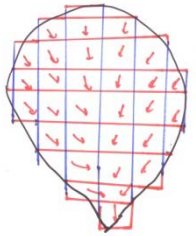
# Watershed Delineation



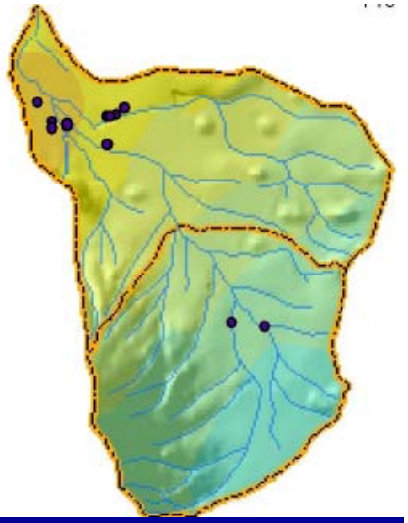



# Watershed Delineation

- Delineation Steps
- There are two basic steps to follow in watershed delineation.
- Step 1: Choose the point of the watershed outlet. This is generally our point of interest for designing a structure or monitoring location.
- Step 2: Delineate the watershed boundary by drawing perpendicular lines across the elevation contour lines for land that drains to the point of interest.
- Note - A watershed boundary always runs perpendicular to the contour lines.
- “Arrows” that point upstream are valleys.
- “Arrows” that point downstream are hills.

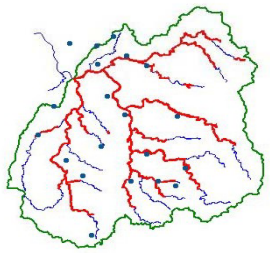


# Watershed Delineation



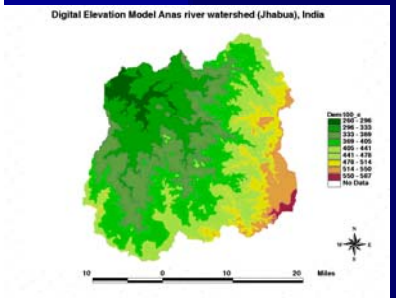
**Delineation of watersheds**

- Boundary defined by all points that shed water to the outlet
- Identify ridge lines from topo-sheet
- Water will travel perpendicular to the elevation contours which is the direction that maximize slope
- Watershed boundary is delineated by drawing lines perpendicular to the elevation contour lines for land that drains to outlet



# Watershed Delineation by Digital Elevation Models

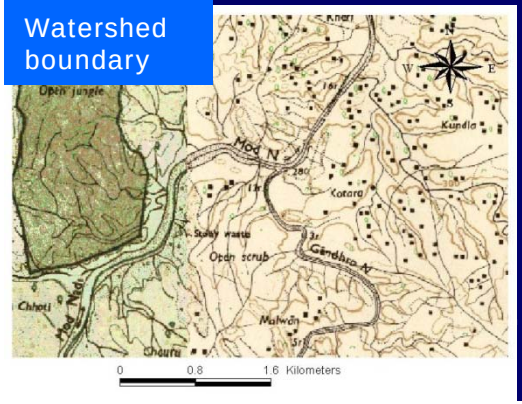
- Using computers, geographic data can now be stored electronically.
- Digital Elevation Models (DEM's) store topographic data in the form of grid cells.
- Typically, these grid cells have a resolution of 30 meters or less and elevation intervals of 1 meter.
- Using a DEM within a Geographical Information System (GIS), we can perform digital terrain analysis (DTA) such as calculating slopes, flow lengths, and delineate watershed boundaries and stream networks.



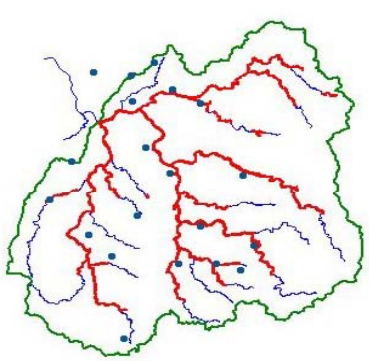
# Watershed Delineation using GIS

- Any GIS package can be used – eg. ArcGIS, GRAM++
- Here use of ArcGIS 9.3 is explained
- The major tools used are ArcMap and ArcCatalog
- ArcMap is used for performing the operations on the data
- ArcCatalog is used for maintaining the data and files
- The input required are topo sheets
- The scanned topo sheets are geo-registered in ERDAS IMAGINE

Watershed boundary

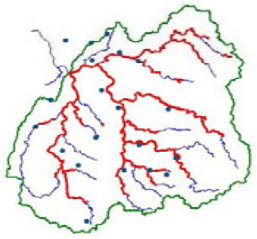


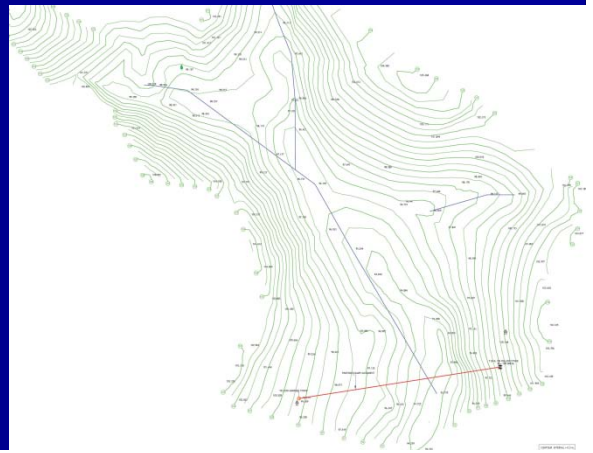

T I Eldho, Department of Civil Engineering, IIT Bombay



# Watershed Delineation using GIS

- ArcMap contains the ArcTool box, which has all the tools required for modifying, reading, determining and viewing maps
- Shape files (.shp) are the files that can be created in ArcCatalog and edited in ArcMap
- The map we provide acts as a background for creating the shape files
- For watershed delineation, the contours are to be digitized from the scanned toposheet





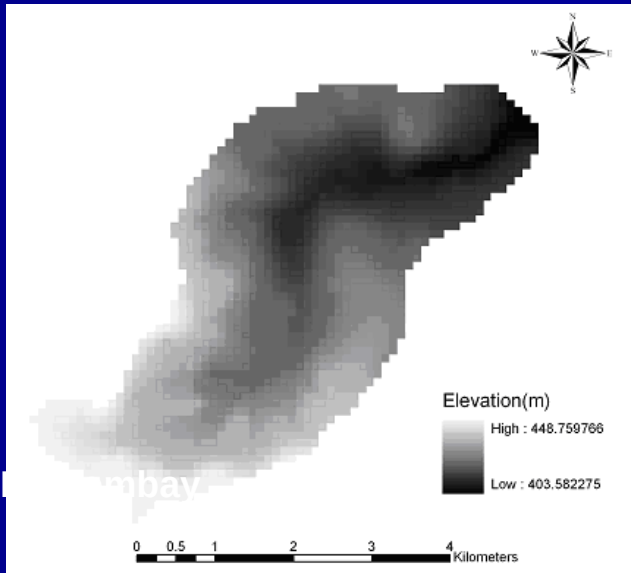
**Prof. T I Eldho, Department of Civil Engineering, IIT**

# Watershed Delineation using GIS

- Major steps involved in delineating a watershed using ARC GIS are:
  - Geo-registering the scanned topo sheets
  - Creating shapefiles
  - Contour digitization
  - Preparation of DEM
  - Filling of DEM
  - Flow Direction Raster generation
  - Flow Accumulation Raster

Determining Pour Points

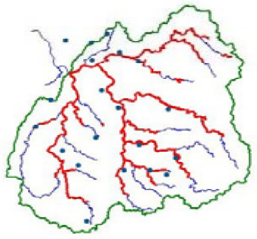
Watershed Delineation


**Prof. T I Eldho, Department of Civil Engineering,**

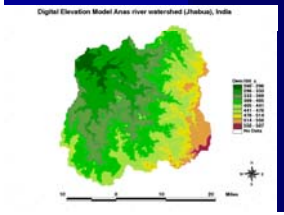
# Creation of Shapefile

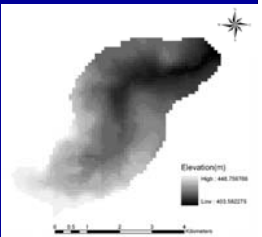
- Initially a shape file is to be created in ArcCatalog
- For contours, the polyline shape files are used
- The coordinate system of the shape file must be determined
- An existing coordinate system can be used or a coordinate system being used in another file can be imported
- Open the attribute table of this shape file and add a new attribute elevation (any name can be given)
- **Contour Digitization**
- This shape file must now be added to the ArcMap as a layer
- Open the editor tool bar and click on start editing
- If there are multiple shape files in the ArcMap at the same time, specify the target file in the box provided
- Select the Create new feature tool (pencil tool) and start sketching along the contours
- After a contour is completed, specify its elevation in the attribute table



# Preparation of DEM

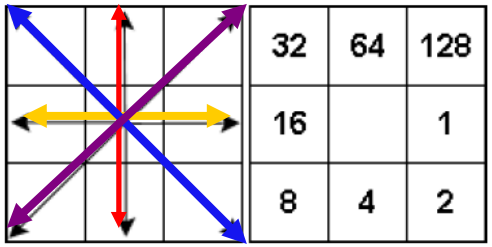
- In the Arc Tool box, open the spatial analyst extension
- Open interpolation tools
- Open the topo to raster option
- In the topo to raster window, specify the input file as the shapefile created
- Change the type as contour and field to elevation
- Run the topo to raster to get the DEM
- Filling the DEM
- After getting the DEM, there is need to fill the depressions if any in the DEM to get avoid false routings
- Open the hydrology tool box in the spatial analyst extension
- Open the fill tool and give the DEM as the input file
- It fills the sinks in the surface raster and removes small imperfections in the data



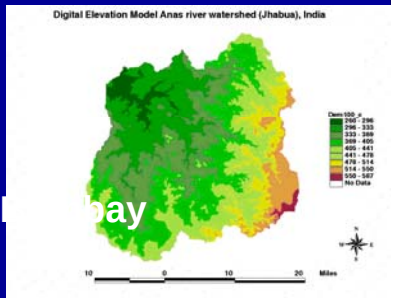


# Preparing Flow Direction map

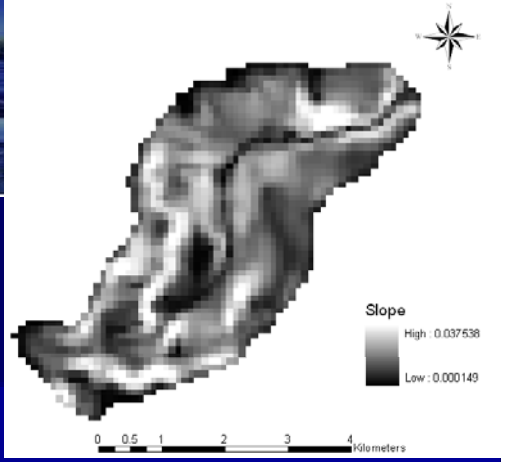
- The filled DEM is used to prepare the Flow Direction map
- Flow direction tool is available in the hydrology tool box in spatial analyst extension
- It creates the raster with flow direction to the steepest neighboring cell down the slope
- It is used to determine the direction of flow of water in the given topography
- Direction of flow must be known for each cell, because it is direction of flow that determines the ultimate destination of water flowing across the surface.



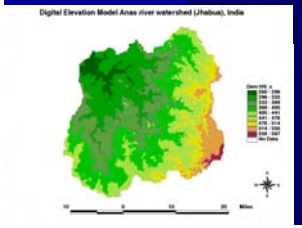


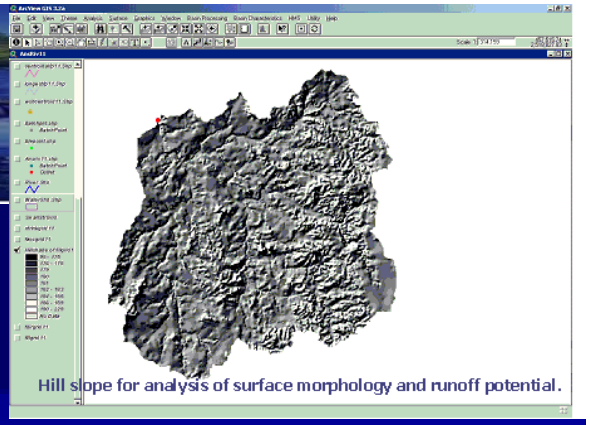
# Flow Accumulation



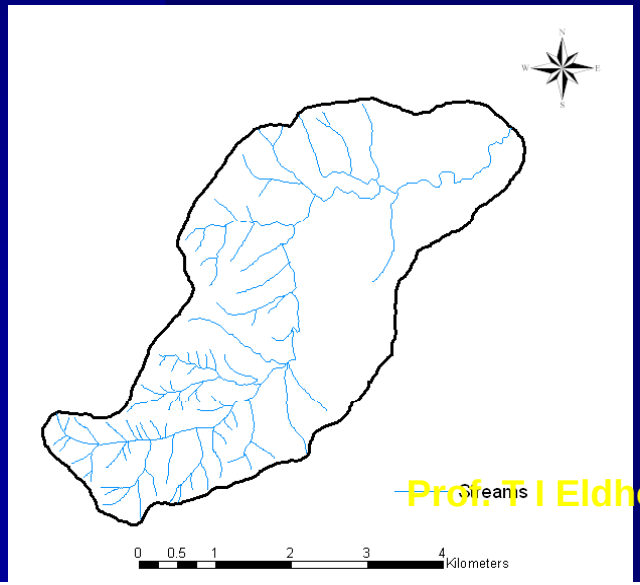

- It is done using hydrology tool box
- It shows the drainage path based on the flow direction raster
- It shows the accumulation of flow in each cell
- The maximum accumulated path gives the drainage path
- **Pour Points**
- After getting the flow accumulation raster, pour points are required to determine watershed pertaining to the flow path
- We create a point shape file for determining the pour points
- These pour points are determined in the path using flow accumulation raster
- Care should be taken that the pour point lies in the line of flow accumulation

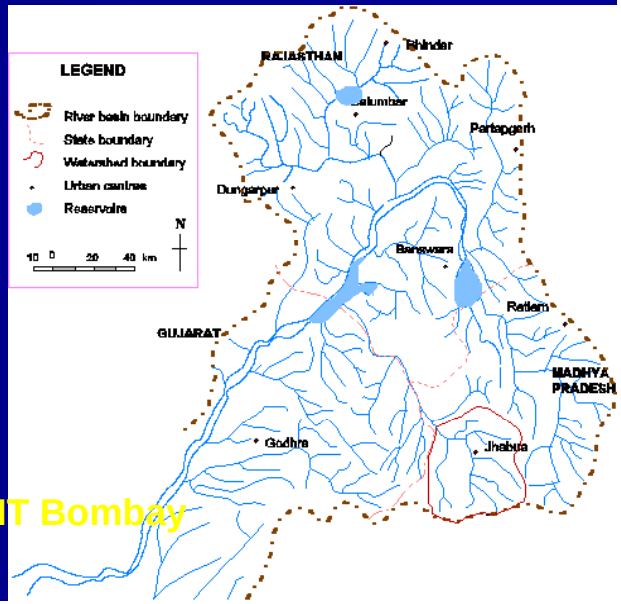


# Watershed Delineation




- Using the watershed tool in hydrology tool box, a watershed is delineated
- The input required are the flow direction raster and the pour point shape file
- If there are multiple watersheds in a topo sheet, the watersheds corresponding to the drainage paths also can be determined



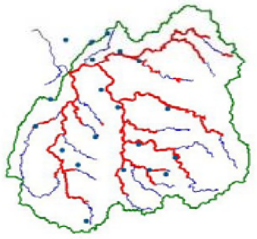



# WATERSHED MANAGEMENT

## Watershed Coding

- To provide uniformity and fixing identity to each watershed
- Done in districts, combination of letters and digits or by using name of stream. **Steps:**
  - Find the name of river/stream, draining the watershed. e.g. Periyar
  - Take first letter of main river .e.g. “P” of Periyar
  - Find name of sub-catchment. e.g. Kalady of Periyar
  - Use first letter of sub-catchment “K” ; Combine PK
  - Use digits for watershed delineated within sub-catchment e.g. PK1, PK2 etc.
  - Finally code sub-watershed by adding another digit after a hypen e.g. PK1-1, PK1-2
- Coding downstream to upstream

Also ‘L’ for Left of stream “R” –right of stream



# Watershed Coding (Ref: Watershed Planning & Management, R. Singh2000)

| Hydrologic unit | Size (100 Thousand-Ha) | Nomenclature | Base map scale |
|---|---|---|---|
| **Macro-Delineation** | | | |
| Region | 270 – 1130 | Number(1-9) | 1:10m |
| Basin | 10 – 50 | Alphabets (A-H) | 1:4m |
| Catchments | 10 – 50 | Number(1-9) | 1:1m |
| Sub-catchments | 10 – 50 | Alphabets | 1:25,000 |
| Watersheds | 0.5 - 2 | Number(1-9) | 1:25,000 |
| **Micro-delineation** | | | |
| Sub-watersheds | 0.1-0.5 | Alphabets | 1:50,000 |
| Milli watersheds | 0.01-0.1 | Alphabets | 1:10,000 |
| Mini-watersheds | 0-0.001 | Number | 1:4000 |

# Watershed Modeling – System Approach

- **Mo**tivation - need to solve various problems of watershed with large number of complex variables.
- A tool is needed for providing the required information prior to making the decision.
- **Typical examples**

  - To assess runoff in a watershed for given rainfall conditions.
  - To estimate the groundwater available in a watershed
  - To assess groundwater pollution problem in a watershed area
  - Sometimes, models are used to provide Information required by regulations



Soil erosion in a watershed

# Watershed Management & Modeling

- Two questions then arise:
- What is a "Management problem"?
- Why do we need models to solve a management problem?
- In a management problem, decisions have to be made concerning

  - Planning and operation of a considered (managed) system in order to achieve certain goals, without violating technical and non-technical constraints that are imposed on the managed system.

- Example

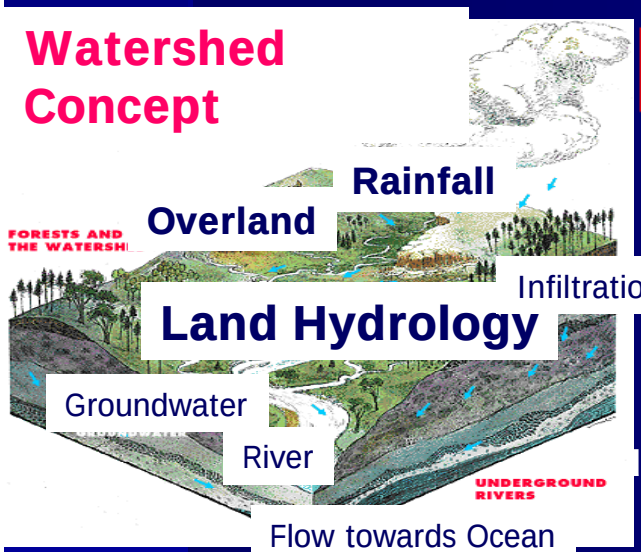
  The case of construction of a check dam at the outlet of a watershed.

  Decisions to undertake are

  - Where the check dam to be constructed?
  - What is the size/ height?
  - How much storage possible?

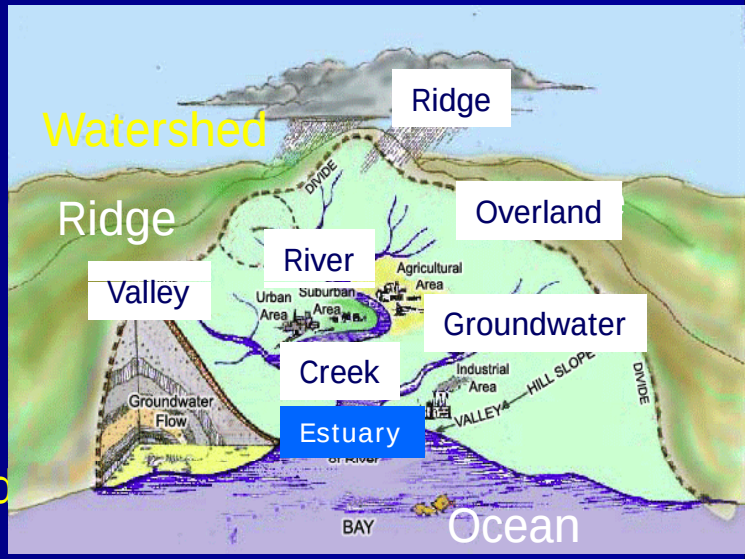
# Watershed Modeling

- A model may be defined as a selected simplified version of a real system, which approximately simulates the latter's excitation-response relations that are of interest .
- Key words in the above definition:
- SELECTED, SIMPLIFIED, APPROXIMATELY,
- & EXCITATION--RESPONSE RELATIONS.




# Watershed Modeling…

- Predicting the behavior of a considered system in response to excitations that stem from the implementation of management decisions.
- Obtaining a better understanding of the considered system from the geological, hydrological, and chemical points of view.
- Providing information required to comply with regulations.
- Providing information for the design of observation networks, by predicting the system's future behavior.
- Providing information for the design of field experiments.



# Modeling Procedure

- **Steps in general modeling process**
  - **Step 1: Identification of the information required for management decisions.**
    - For example for groundwater flow modeling, the information required include:
      - water levels at selected points
      - spring discharge
      - boundary discharge or recharge
      - concentration at specified points
      - quantity and quality of water pumped
      - geological parameters
      - hydrology parameters etc.

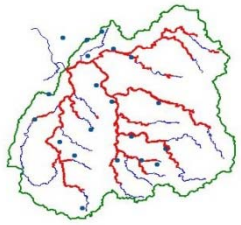
# Modeling Procedure…

- **Step 2: Development of a conceptual model**
  - To simplify the complex real system for our understanding of nature and its behavior some simplifying assumptions are introduced are with respect to
    - The geometry of investigation domain
    - Effect of heterogeneity at different scales
    - Nature of solid and fluid phases involved
    - Flow regimes of fluids
    - The various physical, chemical and biological processes


# Modeling Procedure...

- The selection of the appropriate conceptual model for a particular case depends on three main factors:

- The objective (s) of the investigations, i.e. what kind of information is the model expected to provide for the purpose of making management decisions.
- The available resources (including expertise, skilled personnel, field data, and computers) required for constructing and solving the model. This includes the ability to understand and describe processes that take place and the data required for validating the model and determining the numerical values of its coefficients.
- The legal and regulatory framework which pertains to the considered case.






# Modeling Procedure...

- **Step 3: Development of a mathematical model**

  In this step conceptual model is expressed in the form of mathematical model which consist of

  - A definition of the *geometry* of the surfaces.
  - *Equations* that express the *balances.*
  - *Flux equations* that relate the fluxes.
  - *Constitutive equations.*
  - *Sources and sinks*.
  - *Initial conditions.*
  - *Boundary conditions.*

# Modeling Procedure...

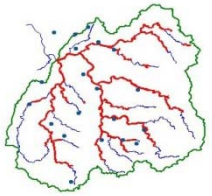
- **Step 4: Model Development**
- **Step 5: Model validation / verification**
- **Step 6: Model calibration and parameter estimation**
  - **Various techniques exist for determining the 'best', or 'optimal', values of various coefficients.**

**- Basic trial-and-error approach.**

**- Sophisticated optimization methods**

**- *Priori* estimates of values to be expected for the coefficients, as well as information about lower & upper bound**

**- When conditions as described above do not exist, they can be created as a *field* or *laboratory experiment* for determining the sought coefficients.**



# Modeling Procedure...

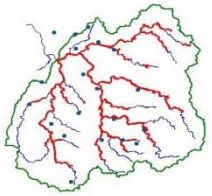
- Step 7: Model applications

  Once we have calibrated the model for a considered problem, the model is ready for use. Computer runs can be carried out employing appropriate data to obtain the required results.

- Step 8: Analysis of model uncertainty and stochastic modeling

- Uncertainty about many elements associated with the model
  - Is the selected conceptual model appropriate?
  - - Are the values of various coefficients used are correct?
  - Are the selected boundaries & conditions appropriate?

- These considerations pave the way for the development of stochastic models.



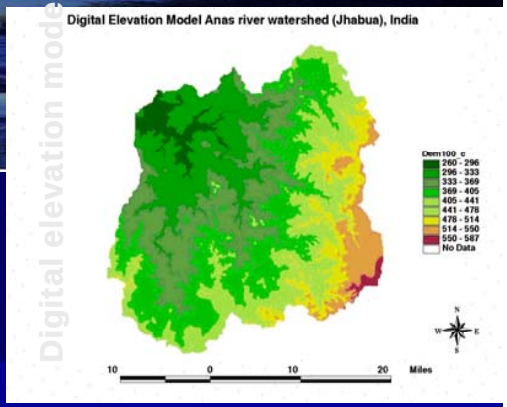
# Modeling Procedure...

- **Step 9: Summary, conclusions and reporting**

The summary and conclusions should include:

- Information that the model was expected to provide
- Additional information concerning the accuracy of the information
- Uncertainty involved, suggested follow-up work, or other activities.
- The report on the modeling activities may be part of a larger report on solving the considered problem, say as an appendix, or a report that stands on its own.

# Modeling Procedure…




- **Preprocessing and Post-processing**
- While using models for watershed modeling, the computer model generally consists of:
  - Preprocessing
  - Processing
  - Post-processing.
- Model limitations:
  - Limitations – conceptual or application related
  - Conceptual limitations – relate to representation of actual process or system with a model
  - Application limitations – data limitations, model familiarity

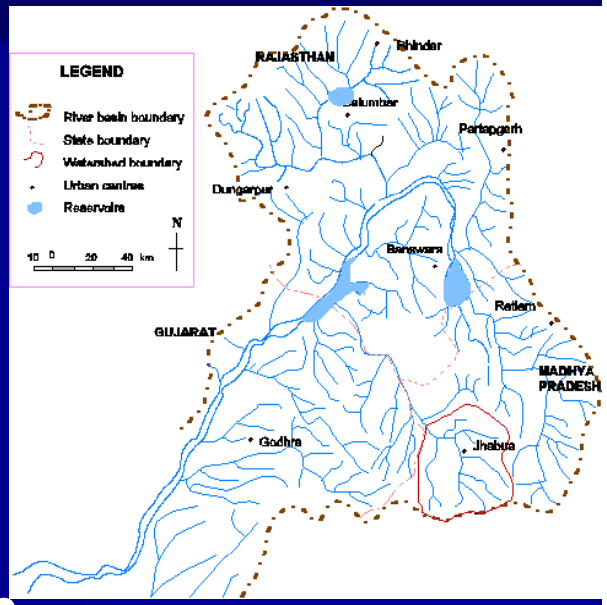
# Structure of Watershed Model

## Watershed modeling steps

1. Formulation
2. Calibration / verification
3. Application

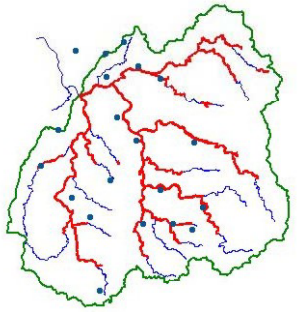
## Watershed model constitutes

1. Input function
2. Output function
3. Transform function



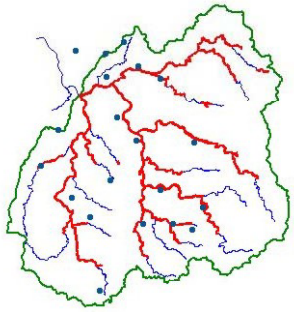

# References


- Raj Vir Singh (2000), Watershed Planning and Management, Yash Publishing House
- J.V.S Murthy (1991), Watershed Management, New Age international Publications
- http://www.nh.nrcs.usda.gov/technical/Publications/Topowatershed.pdf
- http://www.nh.nrcs.usda.gov/technical/WS_delineation.html
- *www.esri.com/software/**arcgis**/**arcgisonline**/index.html*
  http://el.erdc.usace.army.mil/emrrp/emris/emrishelp2/delineating_watersheds_spatial_topics.htm
- *www.arcgis.com/*



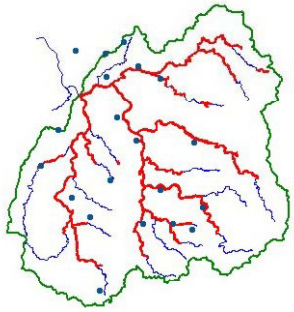
# Tutorials - Question!.?.

- Using ArcGIS software, delineate a watershed based on the toposheet.
- Obtain topo sheet for the selected watershed
- Use the steps mentioned for delineation.
- Obtain the DEM and delineate the watershed.
- *Refer for details: www.**arcgis**.com/*



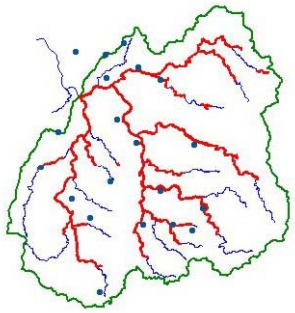
# Self Evaluation - Questions!.

- Illustrate the manual watershed delineation step by step.
- Why mathematical modeling is important for watershed management?.
- Illustrate preprocessing, processing & post processing in watershed modeling



# Assignment- Questions?.

- Describe the step by step for watershed delineation using ArcGIS
- Why Coding of Watershed is required?
- Illustrate the step by step procedure for watershed modeling.



# Unsolved Problem!.

- Identify your watershed and delineate the watershed area using manual procedure using toposheet.
- Obtain the toposheet for your area.
- Get the contour details.
- Using the steps mentioned, delineate your watershed area.

# WATERSHED MANAGEMENT

# THANK YOU

**Dr. T. I. Eldho**
**Professor,**
**Department of Civil Engineering,**
**Indian Institute of Technology Bombay,**
**Mumbai, India, 400 076.**
**Email: eldho@iitb.ac.in**
**Phone: (022) – 25767339; Fax: 25767302**
**http://www.civil.iitb.ac.in**