Remote Sensing and GIS Applications for Water Resources Assessment

Prof. D. Nagesh Kumar

Dept. of Civil Engg.

Indian Institute of Science

Bangalore – 560 012

URL: http://www.civil.iisc.ernet.in/~nagesh

Outline

- **Introduction**

- **Remote Sensing (RS), GIS & DEM for Hydrology**
  - RS for land use/ land cover
  - GIS for watershed delineation
  - DEM for drainage pattern estimation using SRTM data

- **AV SWAT Model**
  - Inputs for AV SWAT Model
  - Streamflow Projections

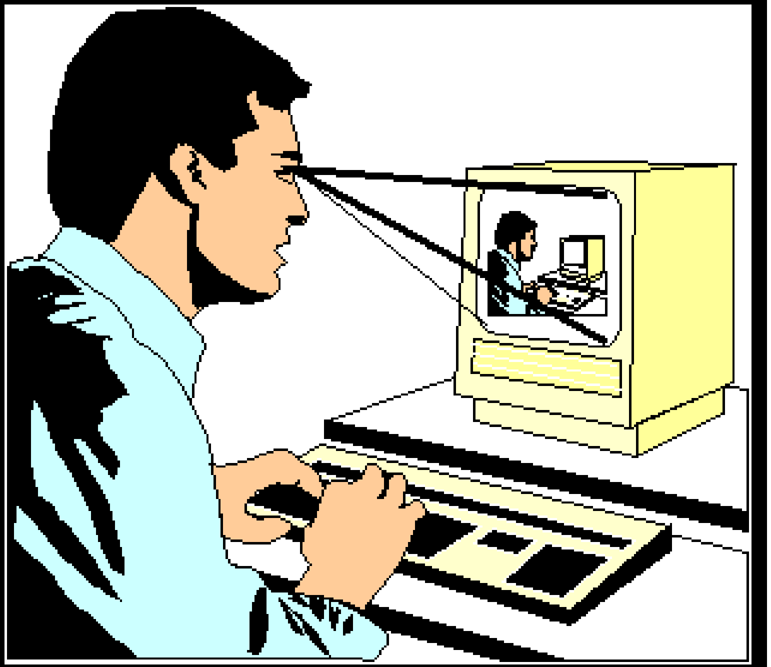
- **AV SWAT Model Application to Malaprabha Basin**

- **Conclusions**

Remote Sensing Introduction

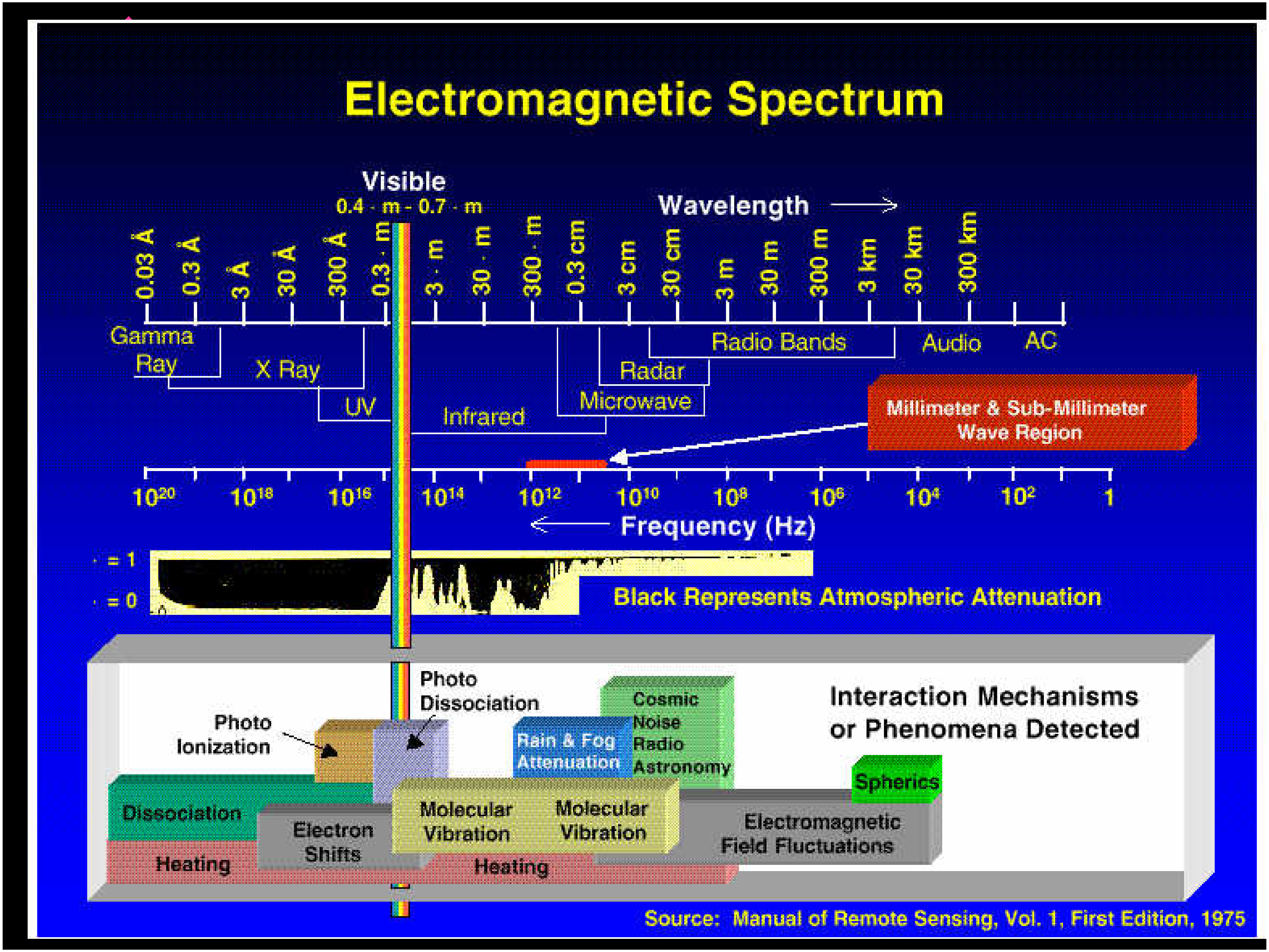
Remote Sensing

Remote Sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in physical contact with the object, area or phenomenon under investigation.



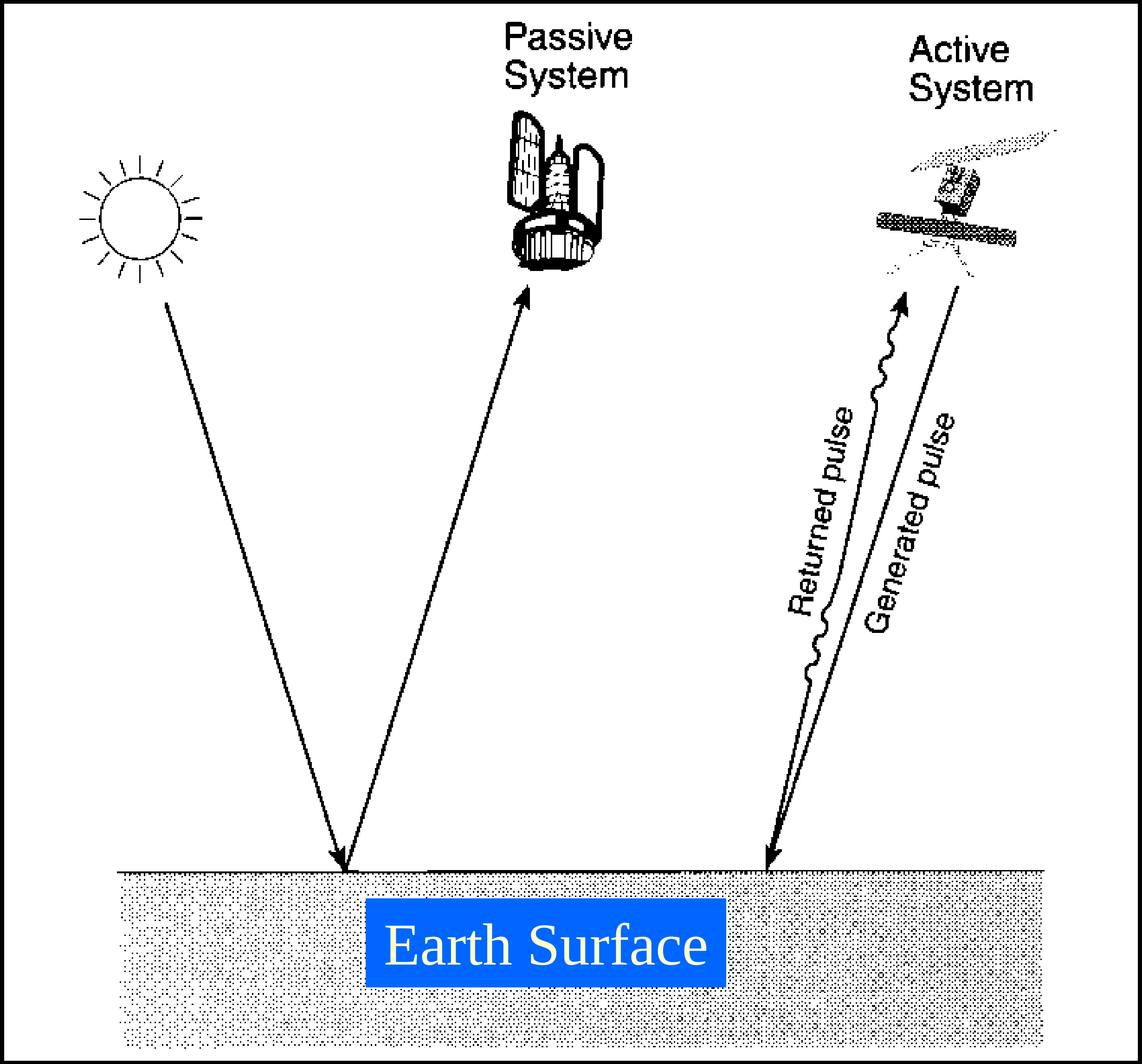
Examples

1. Eyes are living examples (EMR distribution)
2. Sonar (like bats): Acoustic wave distribution
3. Gravity Meter: Gravity force distribution



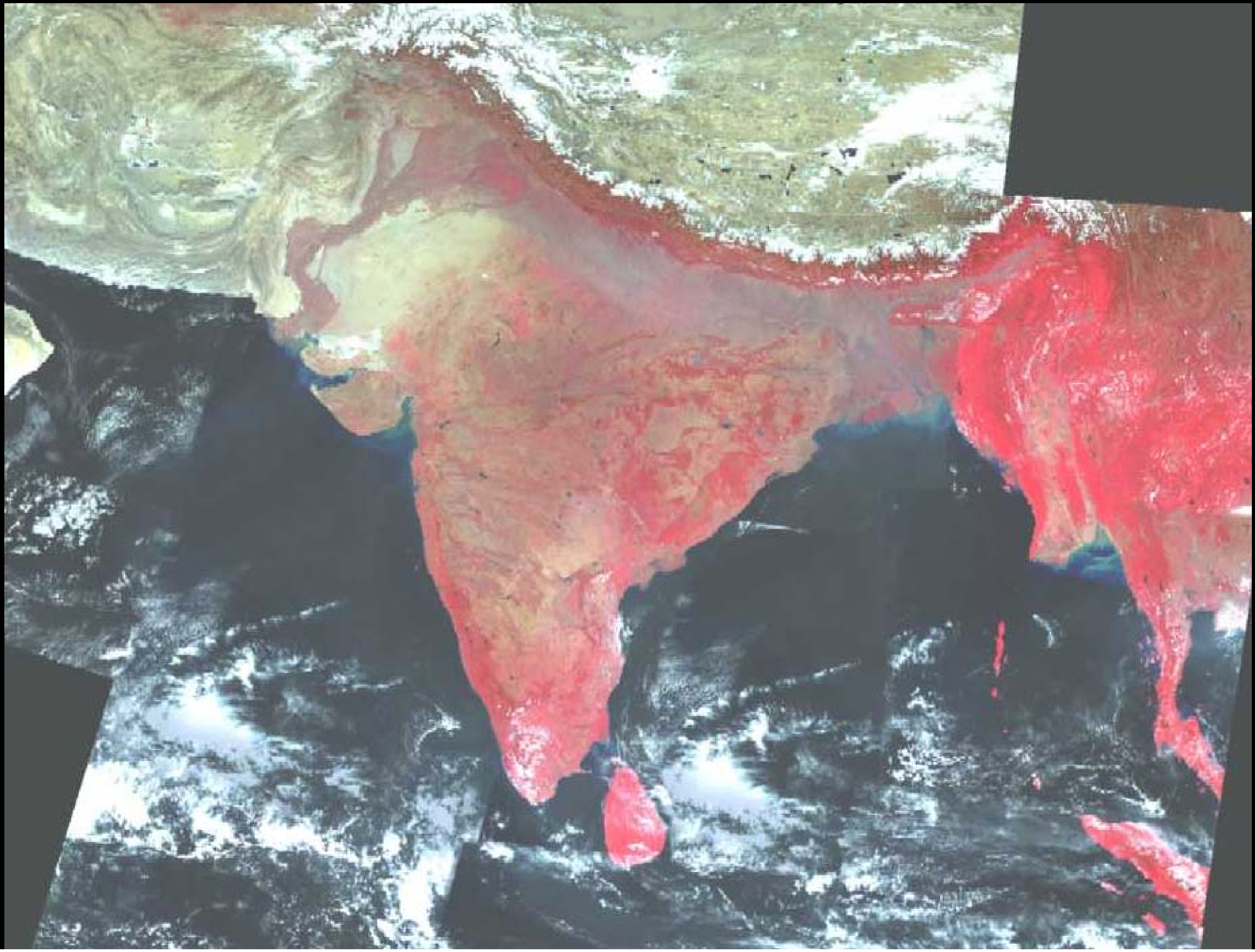
Electromagnetic Spectrum
Visible
0.4 · m - 0.7 · m
Wavelength
0.03 Å
0.3 Å
3 Å
30 Å
300 Å
0.3 · m
3 · m
30 · m
300 · m
0.3 cm
3 cm
30 cm
3 m
30 m
300 m
3 km
30 km
300 km
Gamma Ray
X Ray
UV
Infrared
Microwave
Radar
Radio Bands
Audio
AC
Millimeter & Sub-Millimeter Wave Region
10^20
10^18
10^16
10^14
10^12
10^10
10^8
10^6
10^4
10^2
1
Frequency (Hz)
· = 1
· = 0
Black Represents Atmospheric Attenuation
Photo Ionization
Photo Dissociation
Rain & Fog Attenuation
Cosmic Noise
Radio Astronomy
Interaction Mechanisms or Phenomena Detected
Spherics
Dissociation
Electron Shifts
Molecular Vibration
Molecular Vibration
Electromagnetic Field Fluctuations
Heating
Heating
Source: Manual of Remote Sensing, Vol. 1, First Edition, 1975

Passive and Active Remote Sensing



Synoptic Coverage

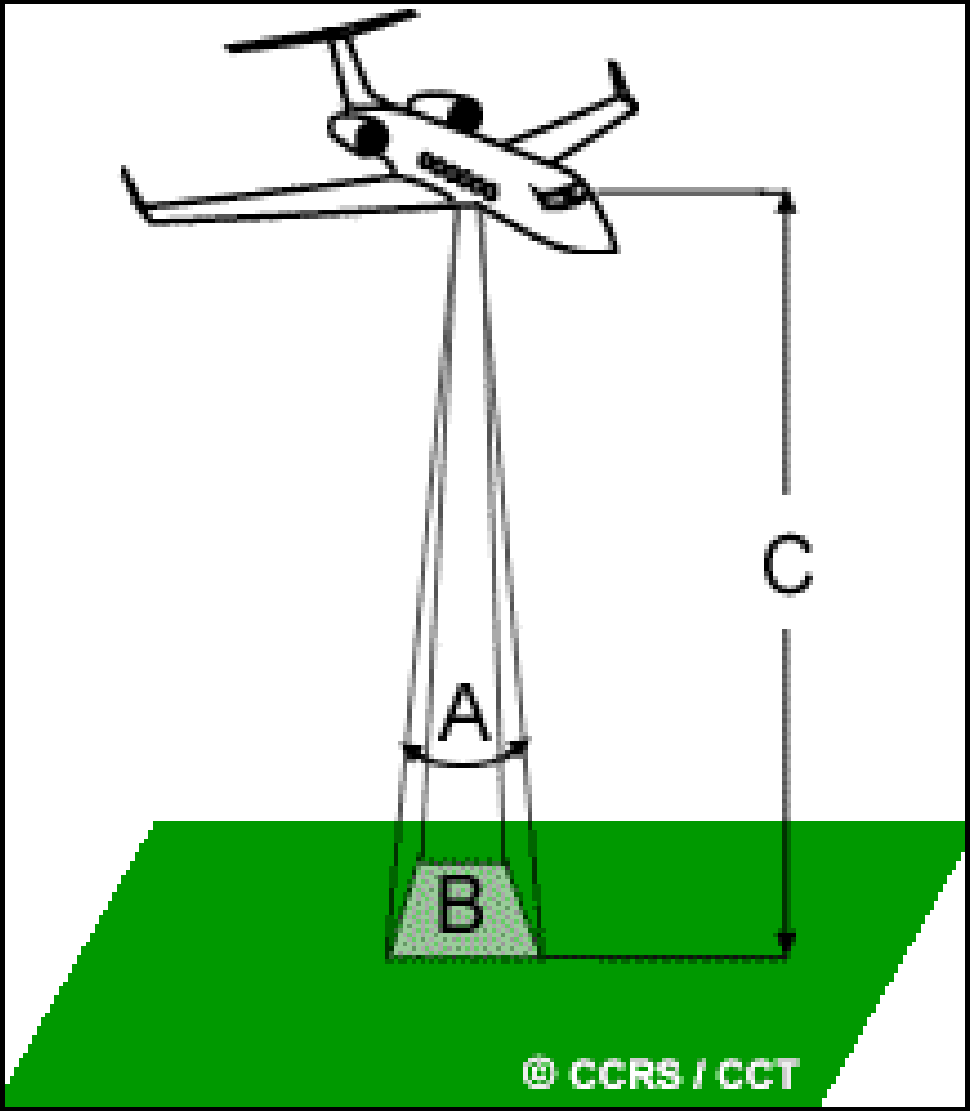
Mosaic from IRS P4 – Oceansat - OCM



Characteristics of RS

- Spatial Resolution
- Spectral Resolution
- Radiometric Resolution
- Temporal Resolution

Spatial Resolution



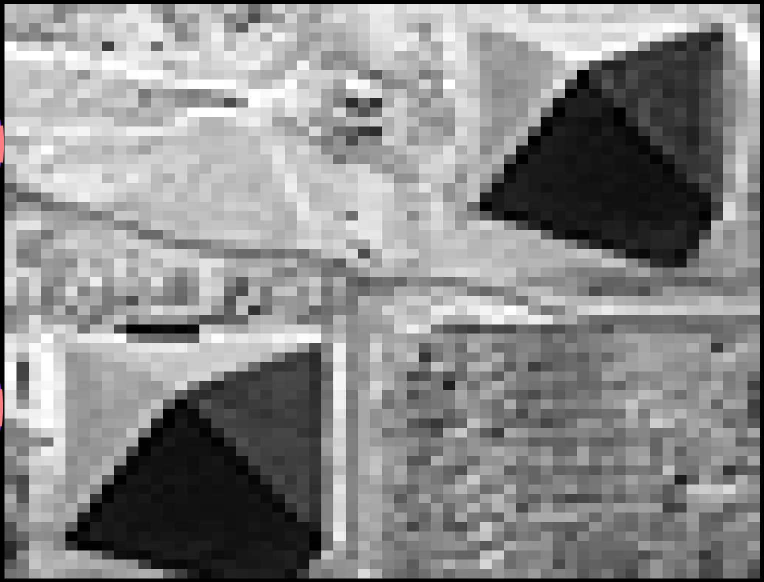
Spatial Resolution

Coarse Spatial Resolution

Fine Spatial Resolution

Spectral Resolution

Pan Image (Course)



Landsat TM RGB=543 (Fine)

Spectral Resolution (Contd..)

TM Band 1
0.45–0.52 um
(blue)

TM Band 2
0.52–0.60 um
(green)

TM Band 3
0.63–0.69 um
(red)

TM Band 4
0.76–0.90 um
(near–infrared)

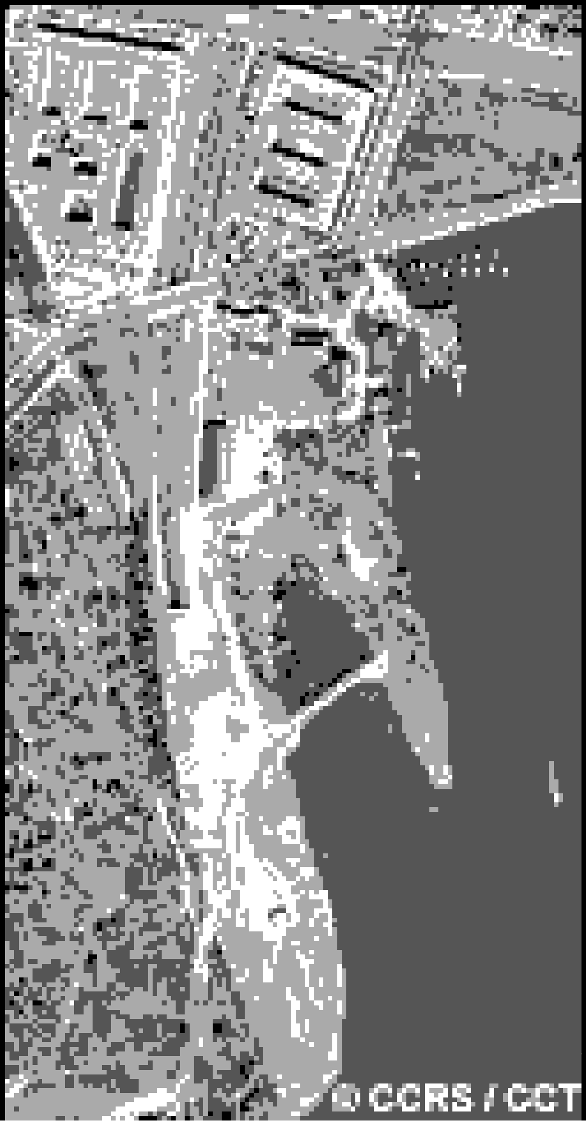
TM Band 5
1.55–1.75 um
(mid–infrared)

TM Band 6
10.4–12.5 um
(thermal–infrared)

TM Band 7
2.08–2.35 um
(mid–infrared)

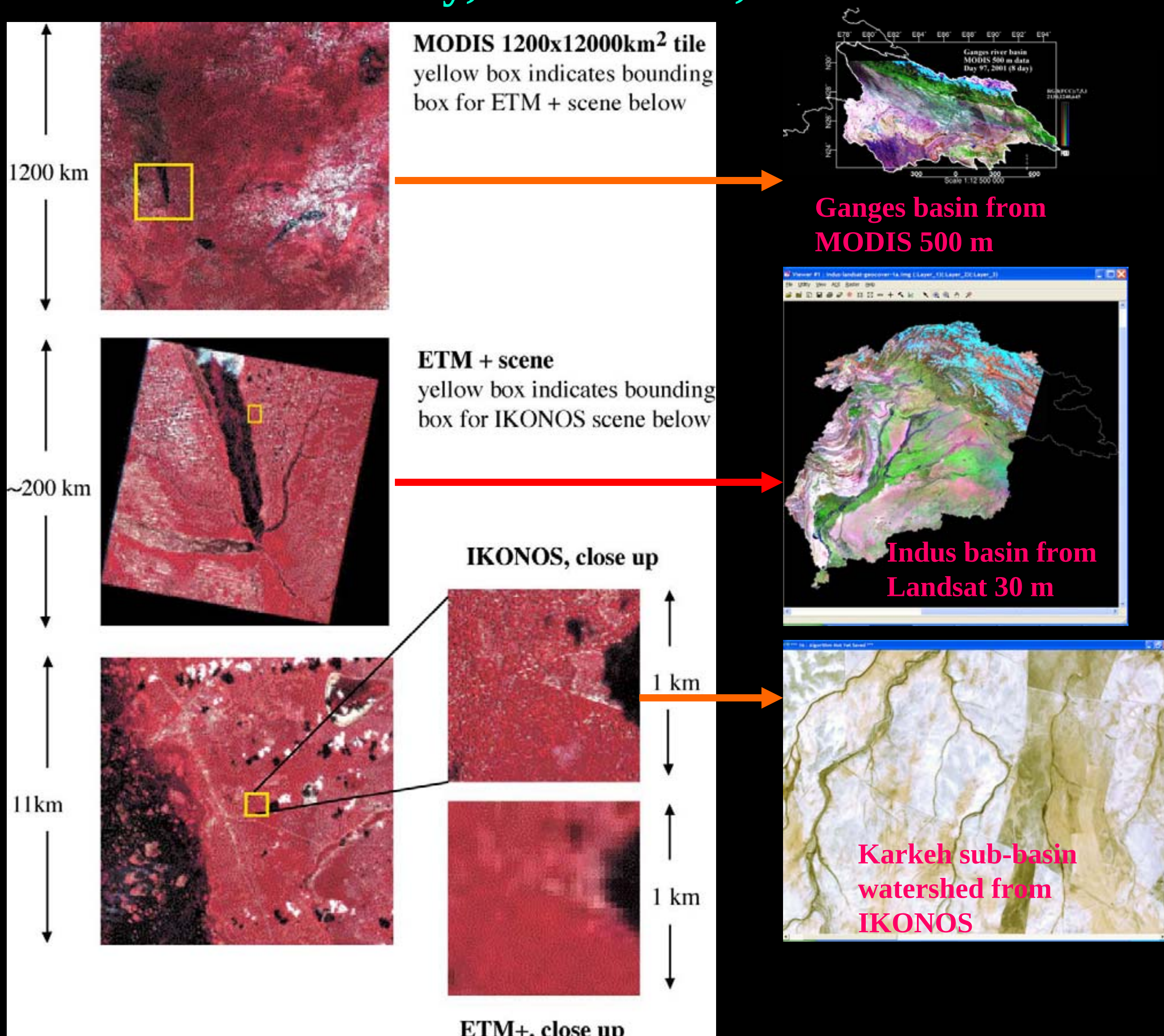
Radiometric Resolution

2 Bit Data (Coarse)



8 Bit Data (Fine)

Data in a wide range of Pixel Resolutions (or scales), Radiometry, Bandwidths, and time-scales



False color composite image (red = 850 nm, green = 650 nm, blue = 555 nm) of MODIS, ETM+ and IKONOS imagery (Left image Courtesy: Morisette, 2002).

Importance of Temporal Resolution

- Change in Land Use/ Land Cover
- Temporal Variation
- Monitoring of a Dynamic Event
  - Cyclone
  - Flood
  - Valcono
  - Earthquake

Monitoring Floods

Non Flood Year (1988), TM 321

Flood Year (1993), TM 321

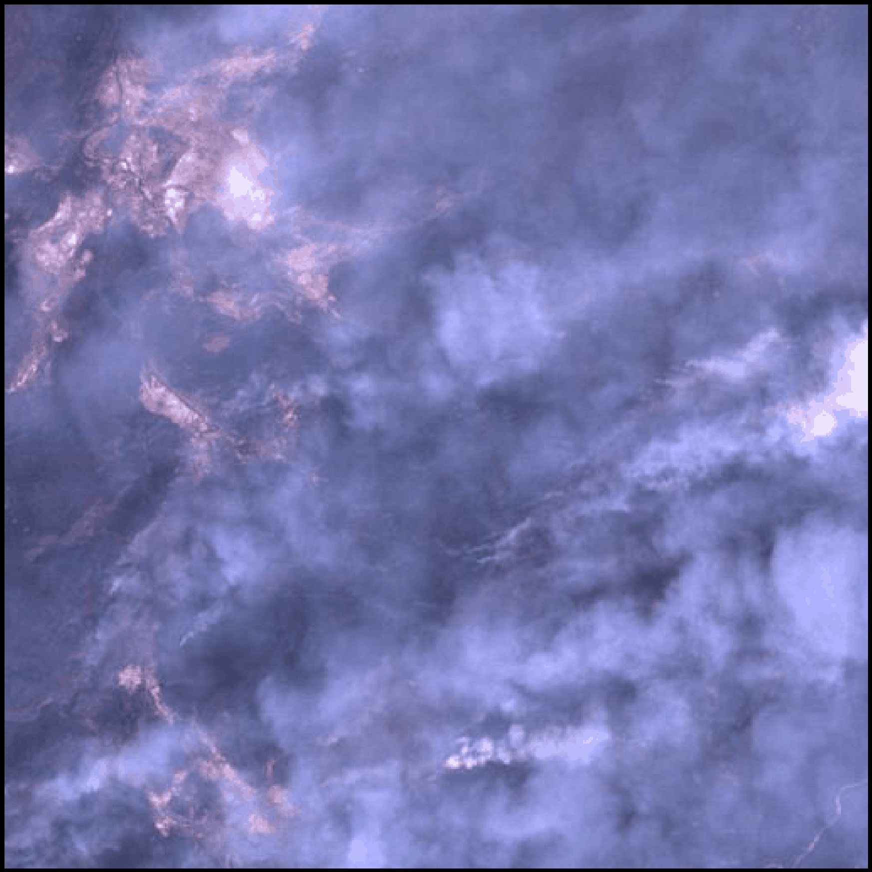
Monitoring Floods (contd..)

Non Flood Year (1988), TM 432

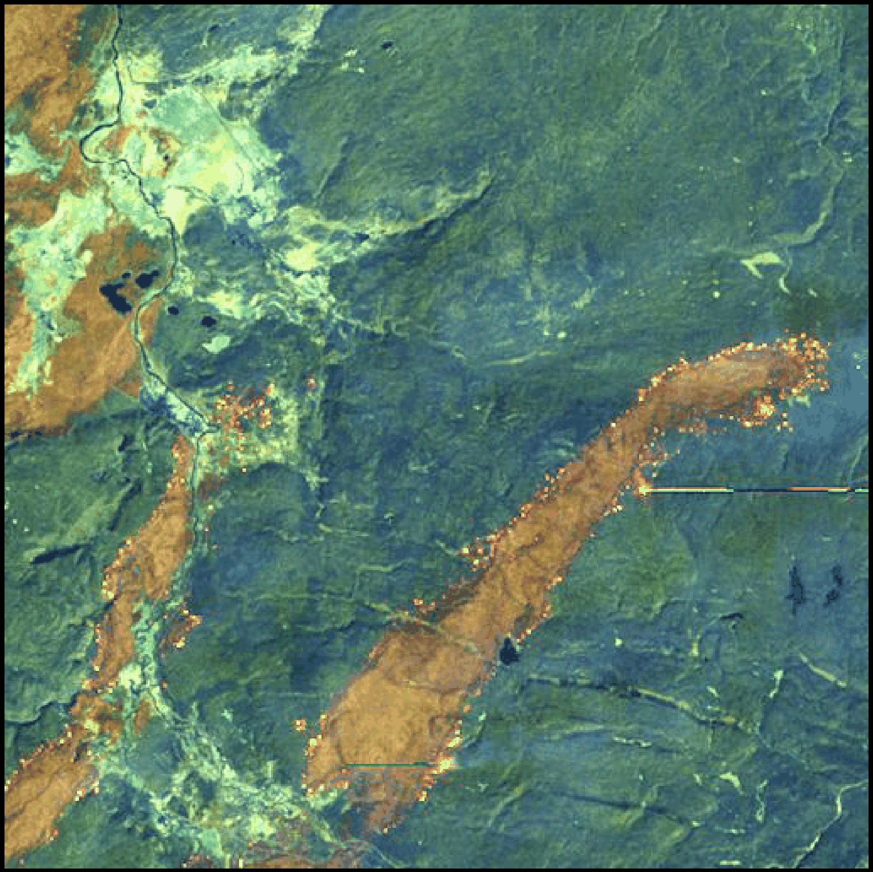
Flood Year (1993), TM 432

Forest Fire (Yellowstone NP)

Yellowstone NP, TCC (TM 321)

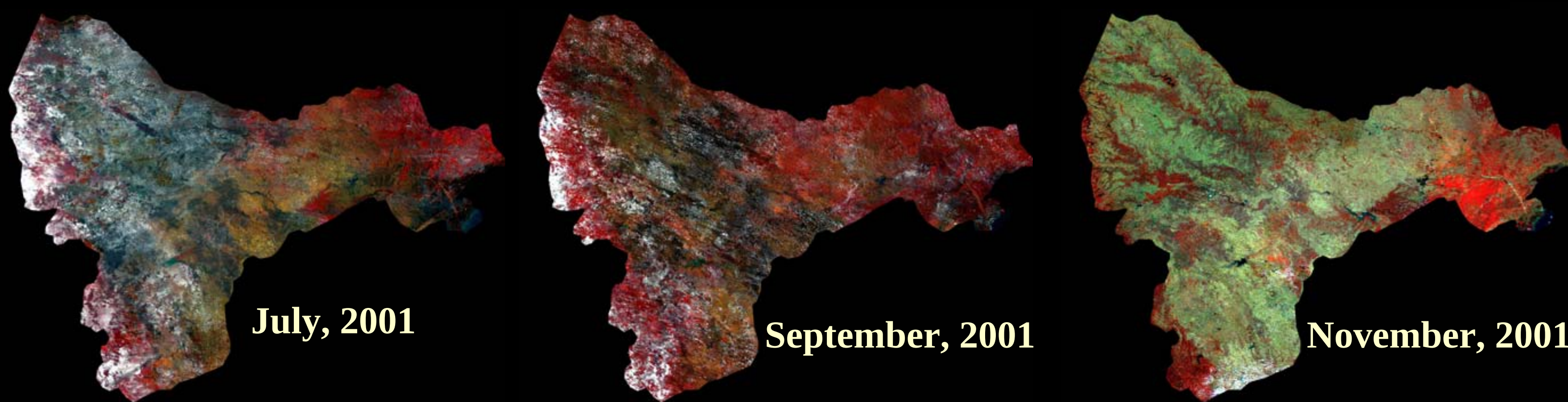


Yellowstone NP, FCC (TM 754)



Continuous Streams of MODIS Data Products

Similar data for entire World every 8-16 days, 250-1000 m, 36 bands



Krishna river basin, India

FCC (RGB): 2,1,6 (NIR, red, MIR1)

Source: IWMI, Colombo

Remote Sensing in Environmental Studies

Introduction

- Simple qualitative observations/ assessments are made
  - A visual observation of a photo that water from industrial effluent into a stream has a different color than the stream water, suggesting a site for collection of a sample
- Information on geometric form, dimensions, patterns, geographic location and distribution are derived for features such as land cover categories that influence runoff, water quality, evapotranspiration and soil moisture

Introduction

- Development of correlation between the remotely sensed observations and the corresponding point measurements on the ground for estimation of a environmental parameter
  - Examples include the estimation of rainfall, sediment load, non point source pollution etc.

Water Quality & Hydrologic Models

Introduction

- Models vary in many ways
  - Time step, scale, whether the model simulates single events or on a continuous basis, and how different components are computed
  - For example, for NPS (Non Point Source) modeling, the only feasible option is to incorporate a continuous approach. Loadings from a watershed area need to be represented over time, not just for a single event or single point

Components

- Rainfall Estimation
- Rainfall-runoff modeling
  - SCS CN Method
- Routing of the runoff
  - St. Venant's equation
- Sediment yield
  - USLE
- Chemical transport
  - Nitrogen and Phosphorus

Watershed Water Quality Models

- STORM
  - Storage, Treatment, Overflow Runoff Model
- SWMM
  - Storm Water Management Model
- DR3M-QUAL
  - Distributed Routing, Rainfall, Runoff Model – Quality
- CREAMS/GLEAMS
  - Chemical, Runoff, and Erosion from Agricultural Management Systems/ Groundwater Loading Effects of Agricultural Management Systems model
- EPIC
  - Erosion/Productivity Impact Calculator

Watershed Water Quality Models

- SWRRB
  - Simulator for Water Resources in Rural Basins
- PRZM
  - Pesticide Root Zone Management model
- AGNPS
  - Agricultural Non-Point Source pollution model
- SWAT
  - Soil and Water Assessment Tool

- Primary inputs for all these models can be obtained from remote sensing and GIS (Geographic Information System)

Rainfall Estimation

- Delineating the boundaries of areas likely to get rain
- Assessing basin rainfall totals over time
- Assessing extreme events of rainfall
- Assessing the climatology of rainfall distributions
- Forecasting of rainfall especially in regions with sparse data
- TRMM Data

Rainfall Estimation

- Most commonly used Wavelengths for rainfall studies are
  - Visible (VIS) : 0.5 – 0.7 μm
  - Infrared (IR) : 3.5 – 4.2 μm and 10.5 – 12.5 μm
  - Microwave (MW) : 0.81 to 1.55 cm
- NOAA, GOES, GMS, Meteosat, INSAT

Rainfall-Runoff Studies

- RS data is used either as a hydrologic model input or for the determination of model parameters
- Need to develop structures of hydrological models, which are amenable to the spatial and temporal resolution provided by RS data
- SCS CN depends on the hydrological soil group and land use description
  - RS provides these inputs

Watershed Planning and Management

- Physiographic measurements from RS
  - Watershed area, size and shape, topography, drainage pattern and landforms
  - Wavelengths: 0.6-0.7 μm & 0.8-1.1 μm
- Stereoscopic attributes for basin topography
- Information on drainage network/ pattern
  - Lithology and structure of the basin
  - Stream orders, stream length, stream frequency, bifurcation ratio, stream sinuosity, drainage density and linear aspects of channel systems

Watershed Planning and Management

- Watershed degradation of soil and land resources
- SRS for mapping of soil degradation involving salinity/alkalinity, water logging, erosion, desertification, shifting cultivation, excessive permeability, wet lands etc
- Growth of desertification, flood damage area and encroachment of ravines on agricultural lands

Erosion Features from RS

- Erosion potential associated with changes in vegetation and litter
- Changes in soil type and soil color
- Occurrence of dendritic soil patterns
- Occurrence of sand dunes
- Definition between bare soil or rock and
- Vegetal cover

Soil Salinity

- Causes for soil salinity problems
  - Rising water tables due to recharge from irrigation canals and watered fields
  - Naturally poor groundwater quality
  - Rock weathering
- Salinity effects in irrigated areas
  - stunted crop growth, poor and patchy germination, crop stress, death of crop, encroachment of halophytic species, bare soils with efflorescence and salt crust development

Reservoir Sedimentation

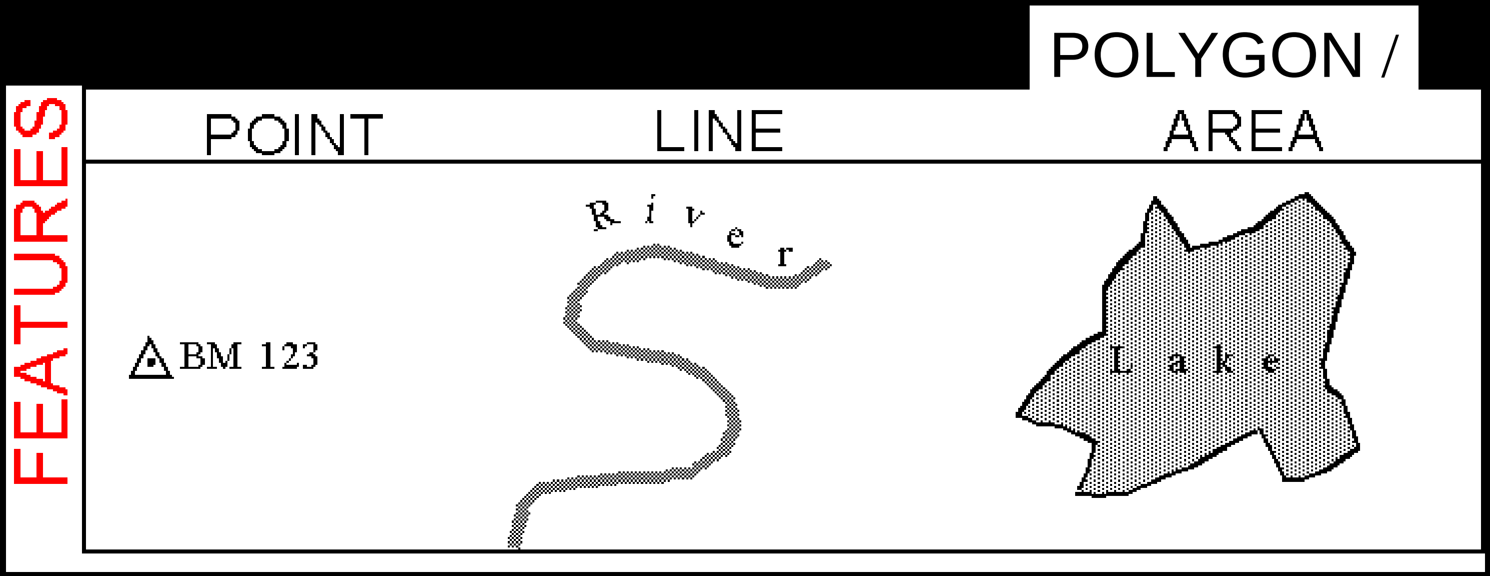
- Suspended sediment causes the most serious pollution of water bodies
- Reservoir Sedimentation not only reduces the reservoir storage and its life but also restricts the use of water for the intended multiple purposes
- RS data is an important source in monitoring sedimentation of lakes and reservoirs through repetitive coverage

Geographic Information System

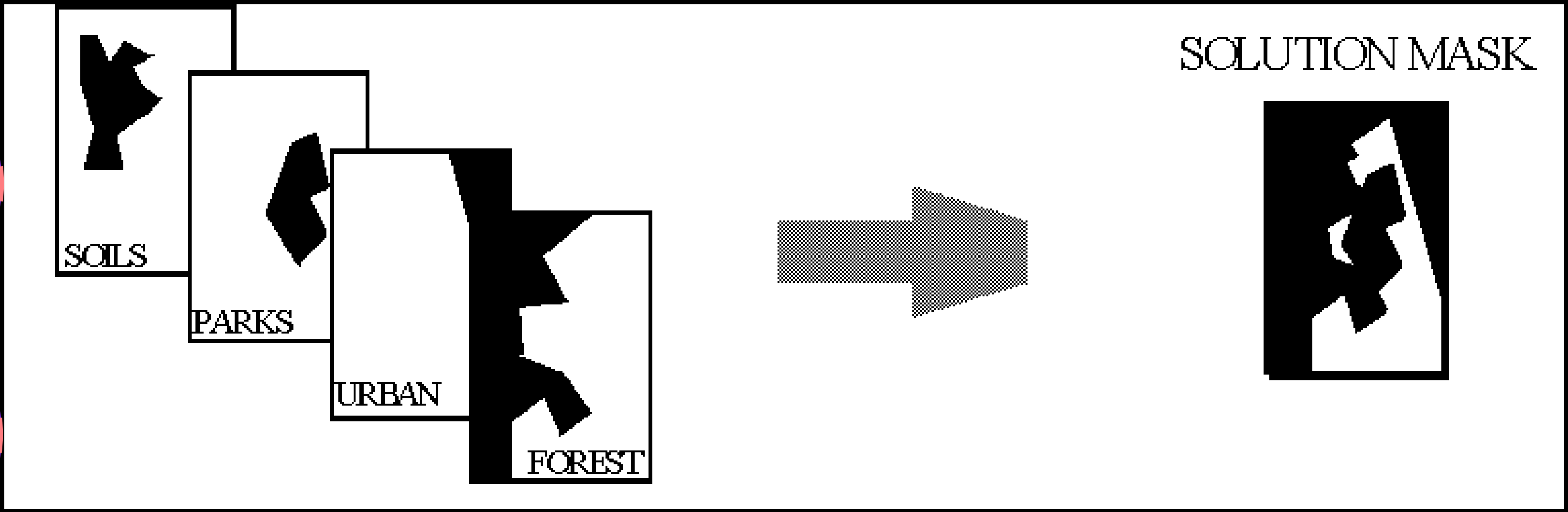
Geographic Information System

- GIS technology provides tools for effective and efficient storage and manipulation of remotely sensed information and other spatial and non-spatial information
- strength of GIS comes from its ability to analyze data representing a particular point, line, or polygon
  - Points - Point elevation, precipitation data from a rain gauge etc
  - Lines - Canal networks, roads and rivers
  - Polygons - Water bodies, Soil type and cropped areas

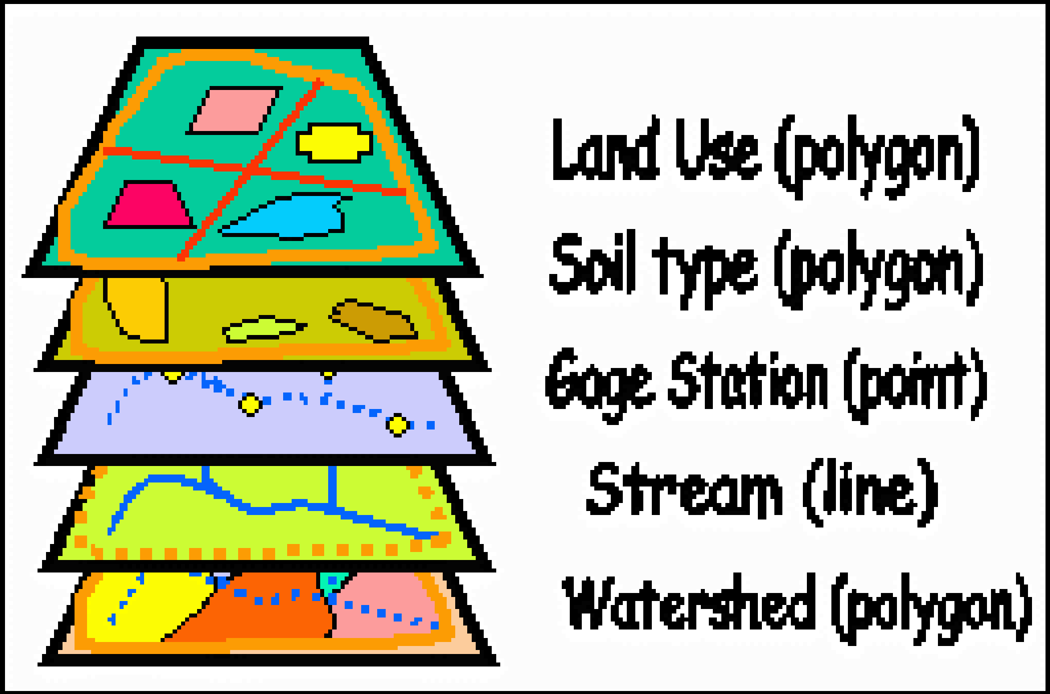
The Feature Model



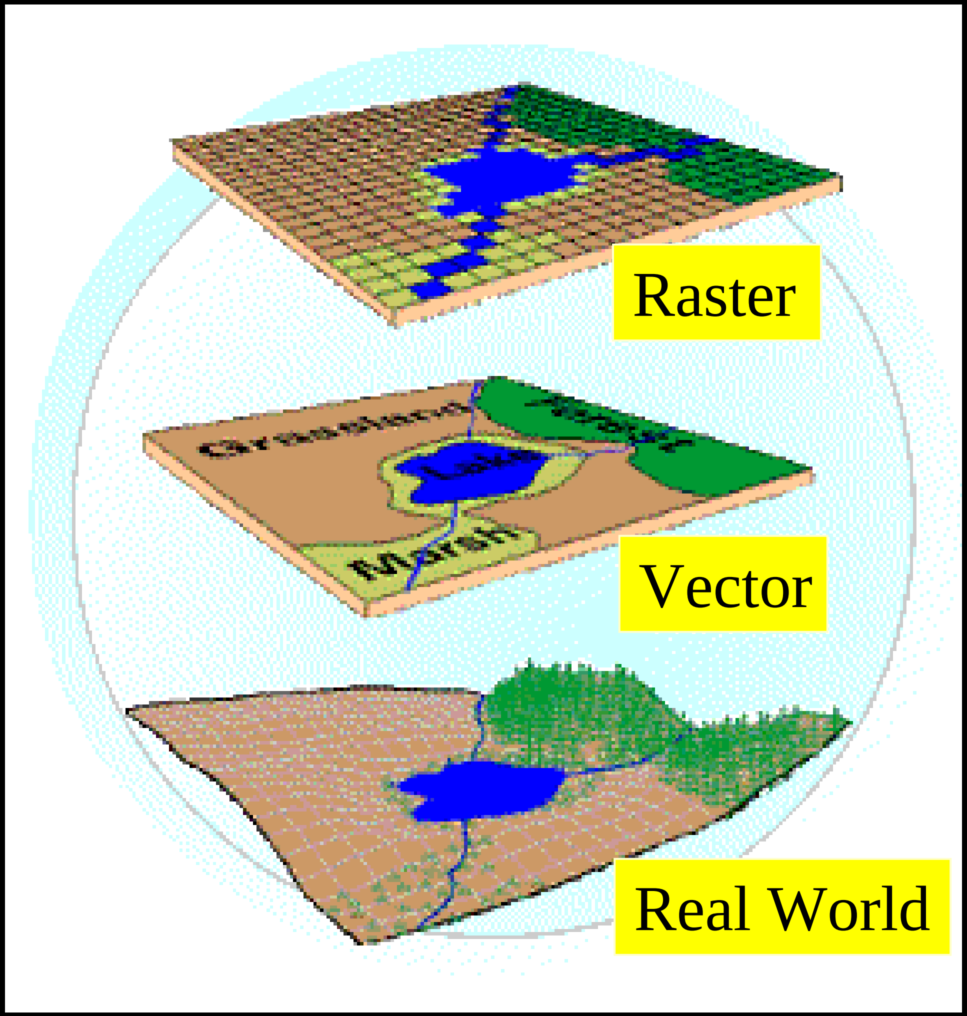
Map Overlay



Geospatial Database: a set of compatible data layers or themes



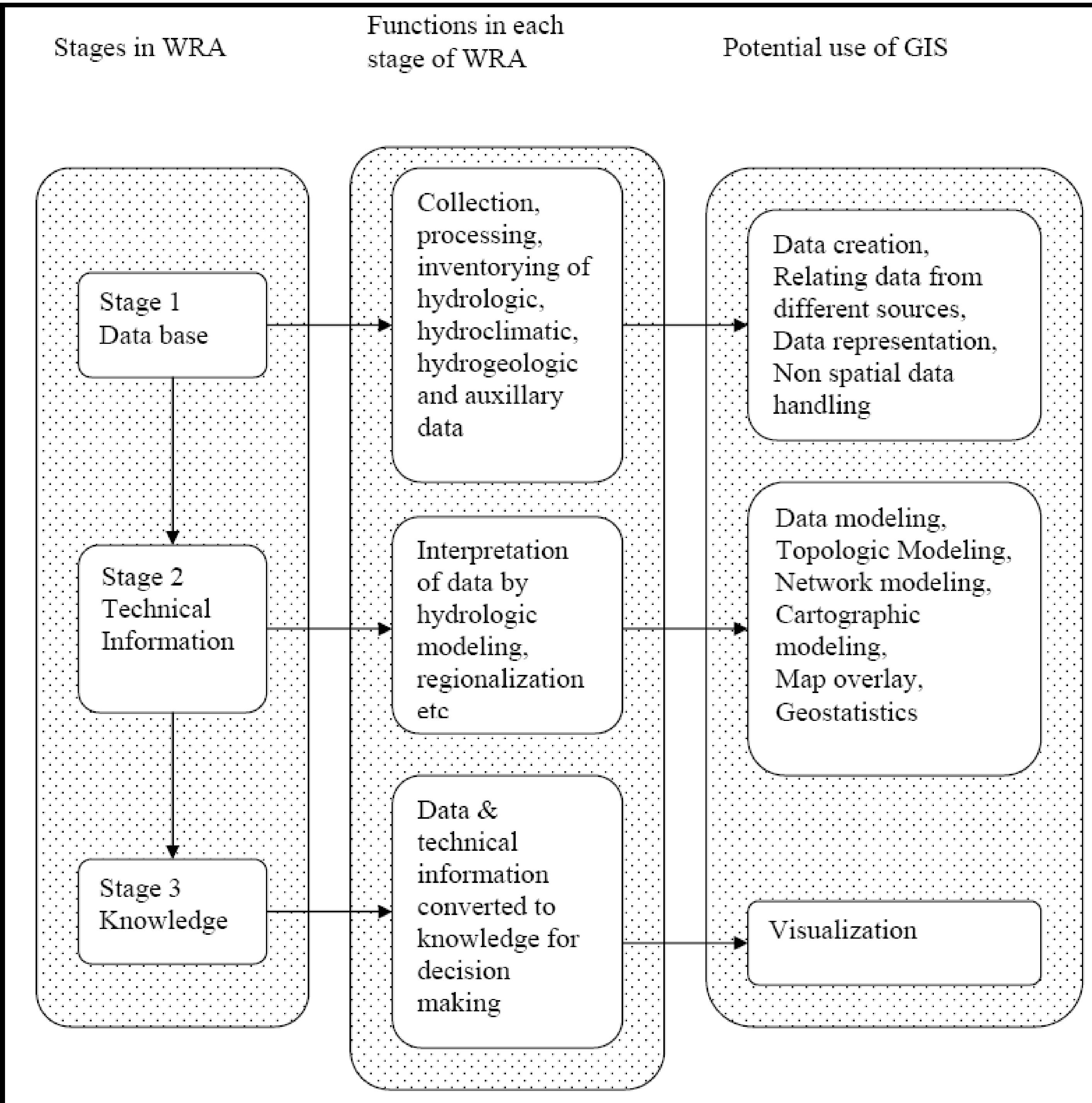
Raster-Vector Data Model



GIS Analyses

- Proximity analyses & neighborhood operations
  - Identifying objects within a certain neighborhood fulfilling specific criteria
- Determine the relationships between data sets within such a neighborhood
- Temporal operations and analyses
- Generation of new information by combining several data layers and attributes
  - Splitting or aggregating etc

Use of GIS in various components of Water Resources Assessment



AGricultural Non-Point Source (AGNPS) Pollution Model

- AGNPS (Young et al., 1989)
  - Distributed parameter model
  - Event-based model
- Soil erosion and nutrient transport/loadings from agricultural watersheds for real or hypothetical storms
- Watershed is subdivided into a grid of square elements
  - Each element, typically about 100 m square, requires 22 parameters
- Due to the grid based (square elements) approach AGNPS is readily adoptable to GIS

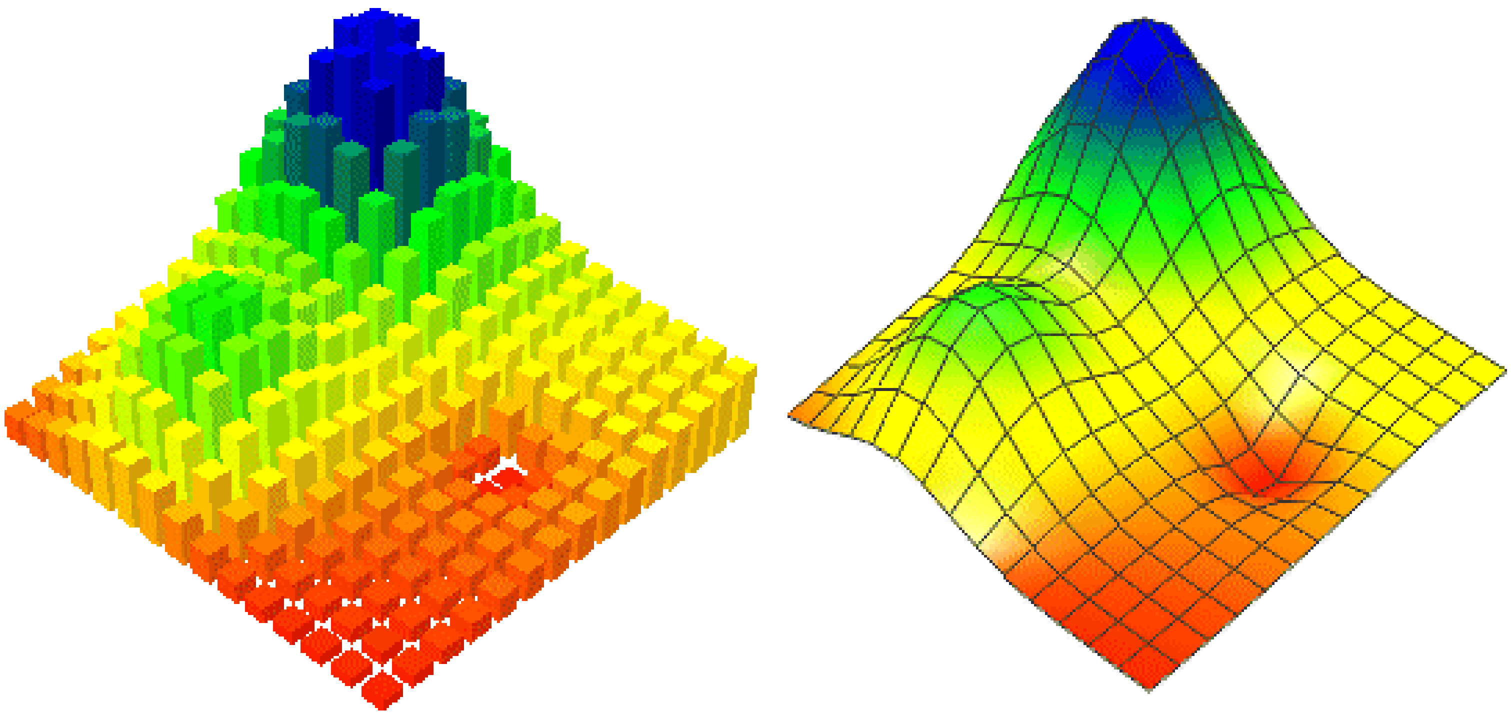
AGNPS - GIS Layers

- Soils
- Elevation
- Land use
- Management practice
- Fertilizer or nutrient inputs
- Type of machinery used for land preparation
- Channel slope
- Slope length factor

Digital Elevation Models

Any numeric or digital representation of the elevation of the land surface

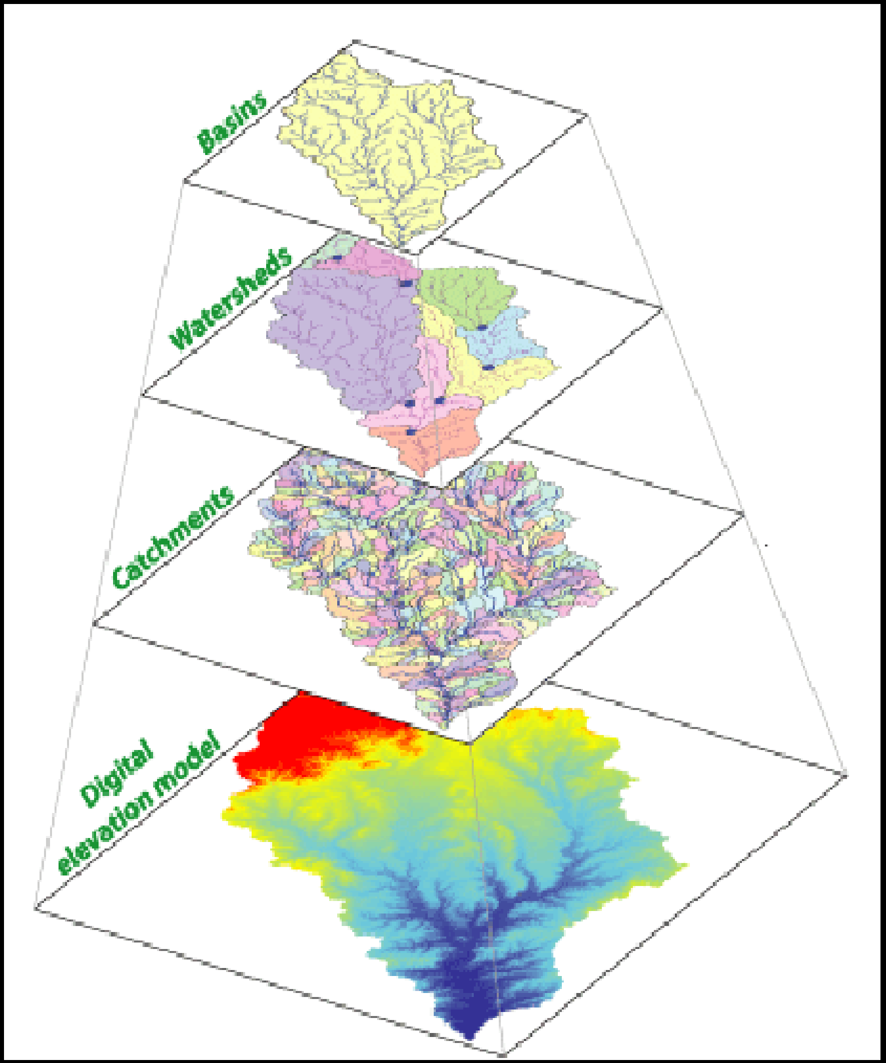
Which One's the DEM?



(a) Discrete Elevation Samples (b) Implicit (Linear) Continuous Surface

Terrain Attributes from DEM

- Flow direction
  Flow pathways
  Flow accumulation
  Stream network
- Catchment area
  Upstream contributing area for each grid cell
- Slope/ Aspect



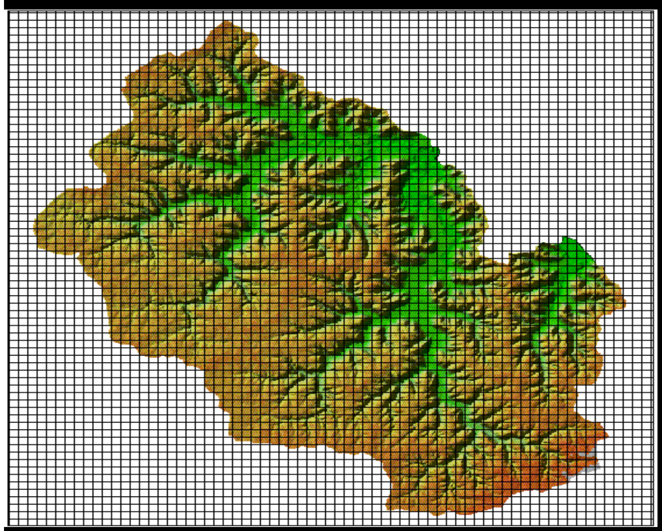
Indices calculated

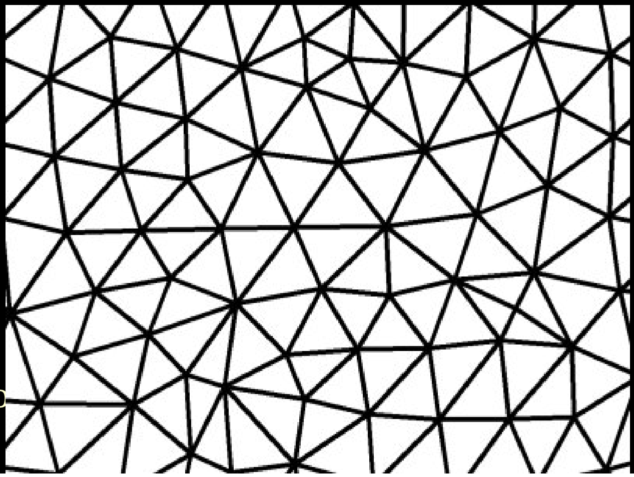
- Wetness indices
- Topographic indices

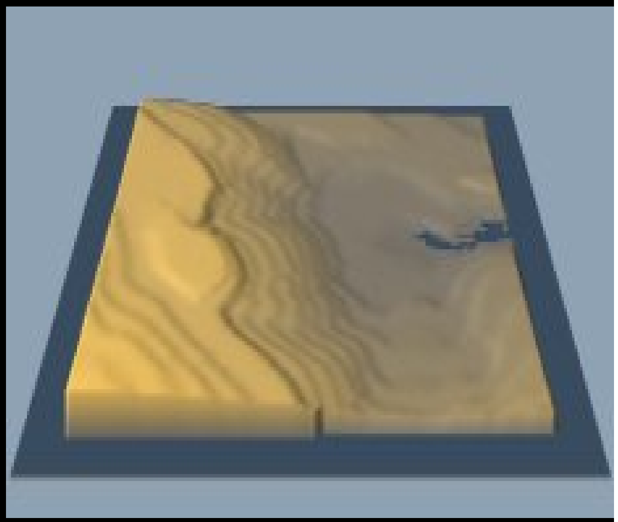
DEM - Types

Mainly three Types of DEM

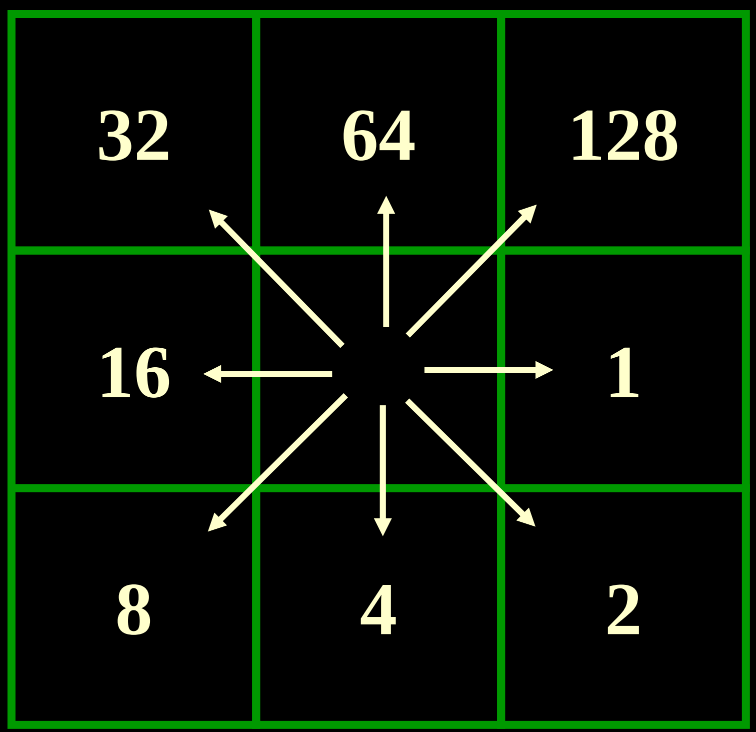
- Grid (regular square grid)
- TIN (Triangular Irregular Networks)
- Contour







Eight Direction Pour Point Model



Direction of Steepest Descent

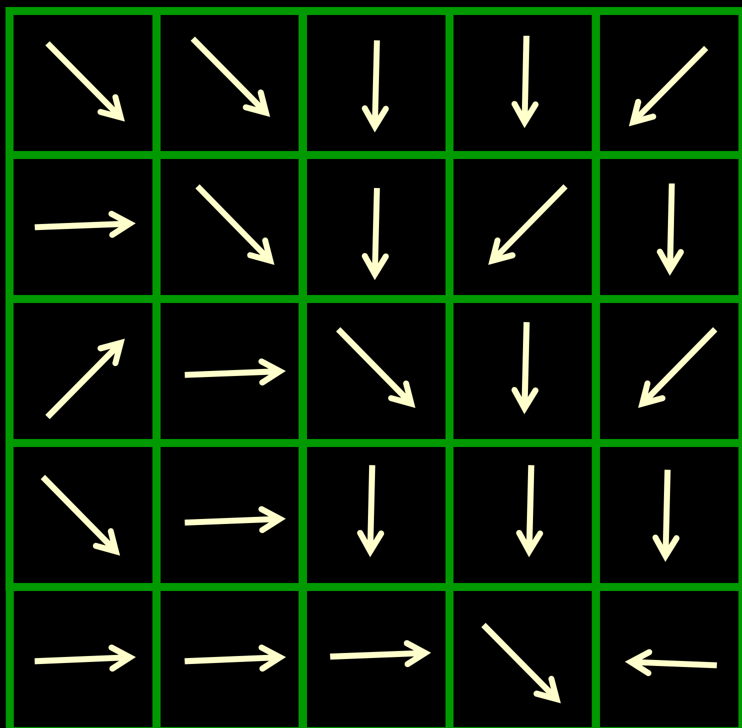
67	**56**	**49**
53	**44**	**37**
58	**55**	**22**

67	**56**	**49**
53	**44**	**37**
58	**55**	**22**

Slope:
$$\frac{67-44}{\sqrt{2}} = 16.26$$

$$\frac{67-53}{1} = 14$$

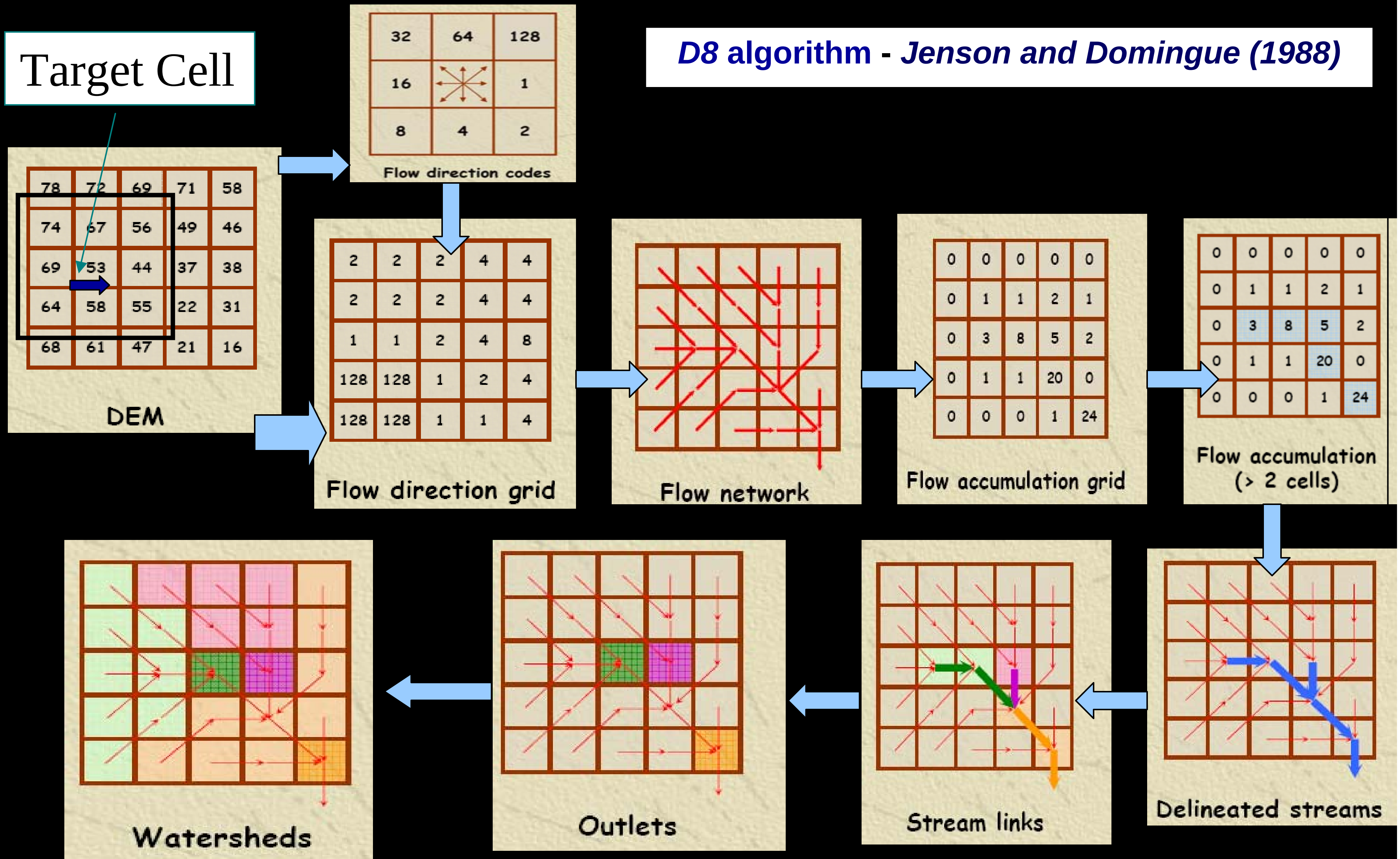
Flow Direction Grid



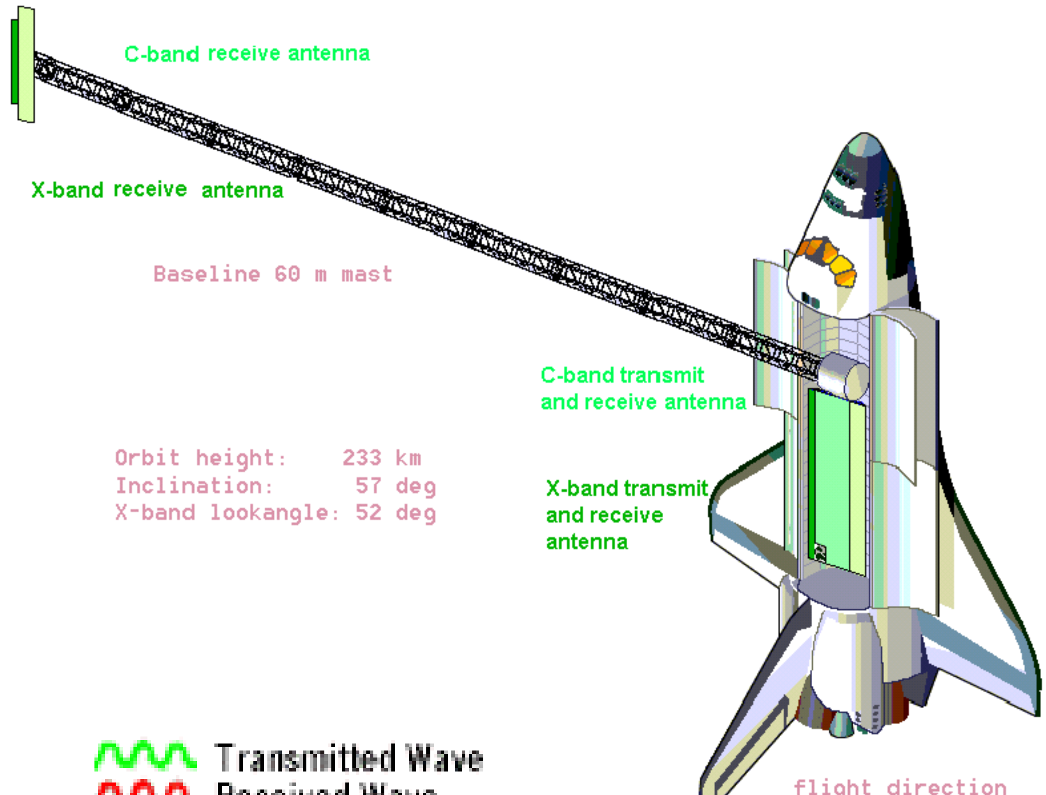
2	2	4	4	8
1	2	4	8	4
128	1	2	4	8
2	1	4	4	4
1	1	1	2	16

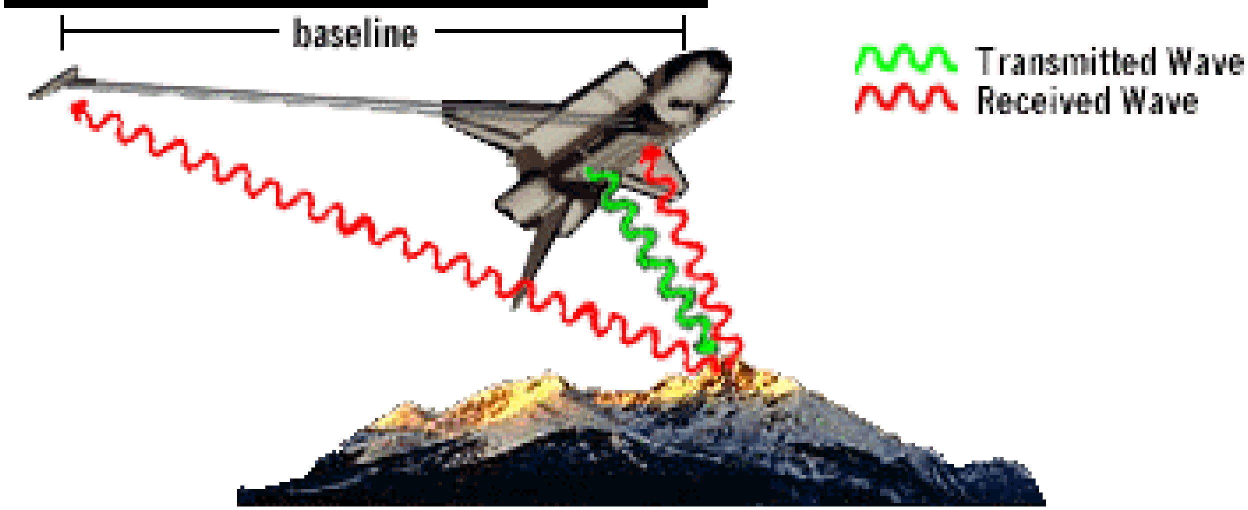
Steps in extracting catchment area from DEM

D8 algorithm - *Jenson and Domingue (1988)*



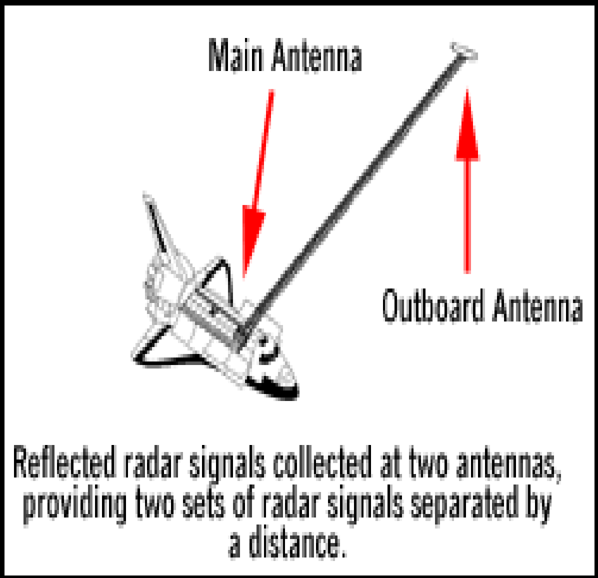
Shuttle Radar Topography Mission (SRTM)

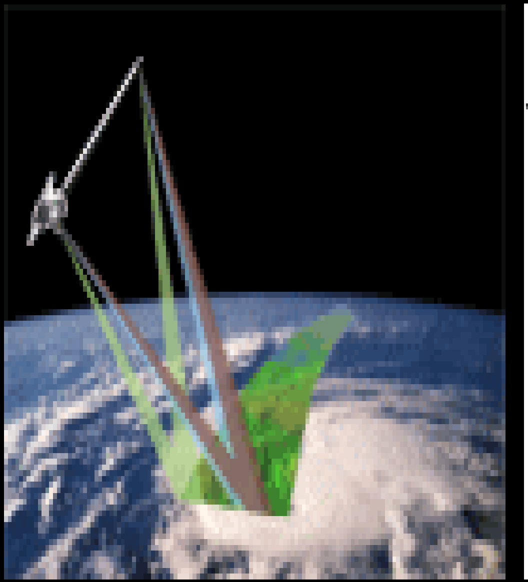


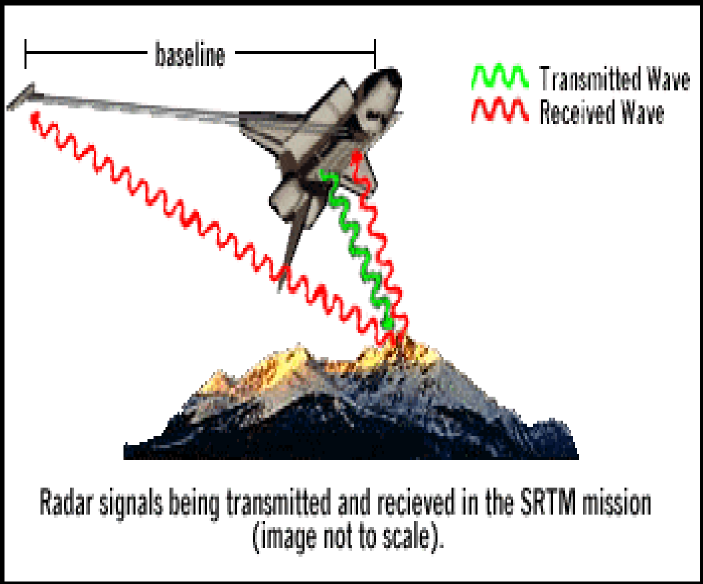


Radar signals being transmitted and recieved in the SRTM mission (image not to scale).

Shuttle Radar Topographic Mission (SRTM)

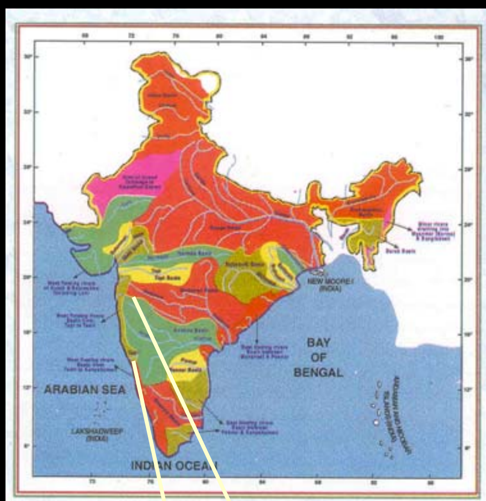


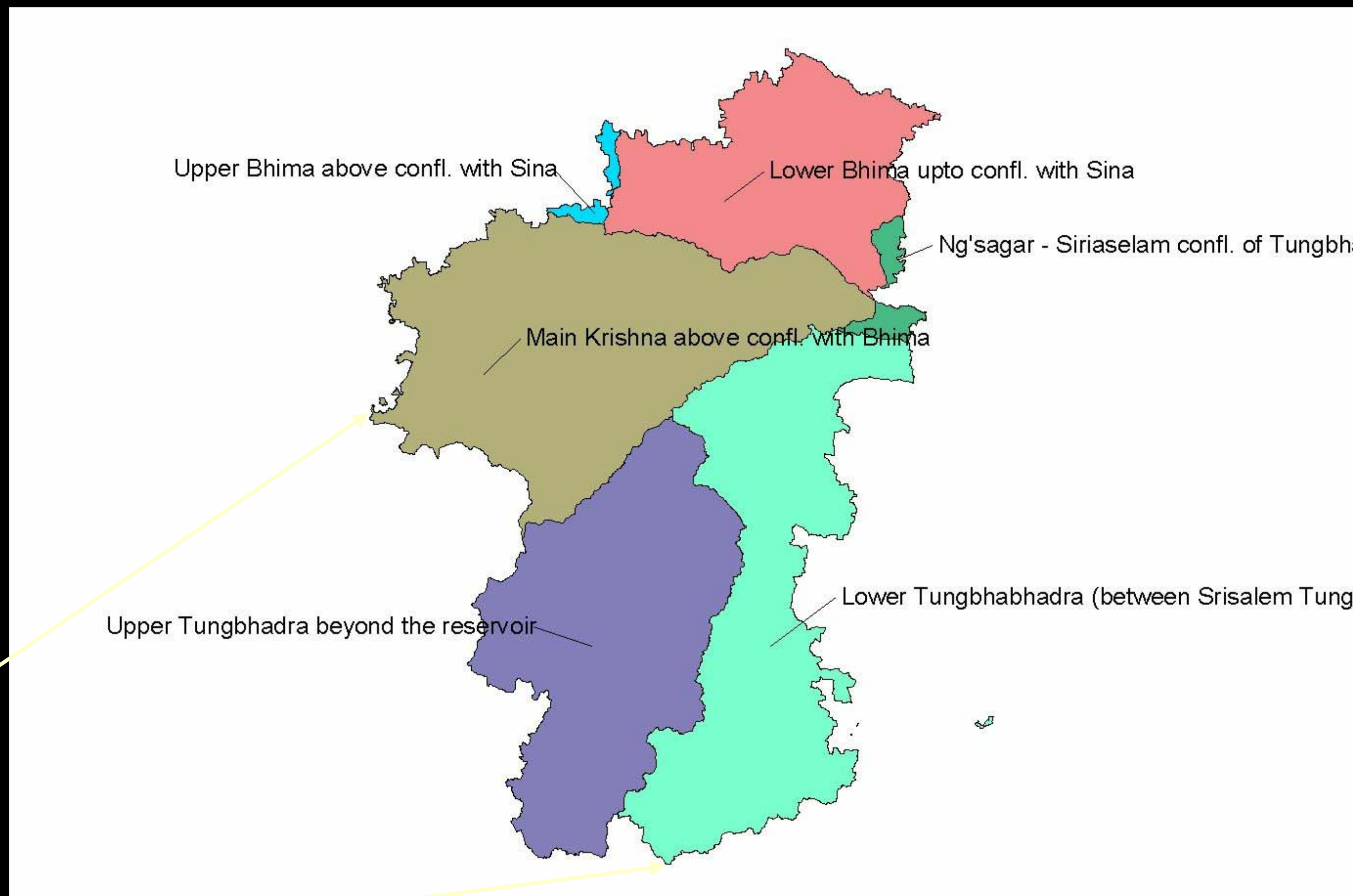




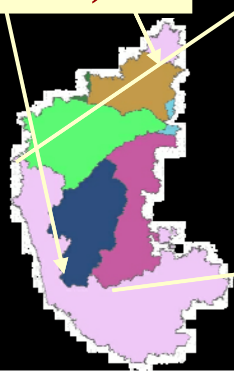
- A joint international project: National Geospatial-Intelligence Agency (NGA) and National Aeronautics and Space Administration (NASA)
- SRTM consisted of a radar system that flew onboard the Space Shuttle Endeavor during an 11-day mission in February, 2000
- The original data has a resolution of 1' (aproximately 30 m). The free online data has a resolution of about 90 m (3')
- It was developed through the use of “radar interferometry” technique

Krishna Basin (Karnataka) – Sub basins

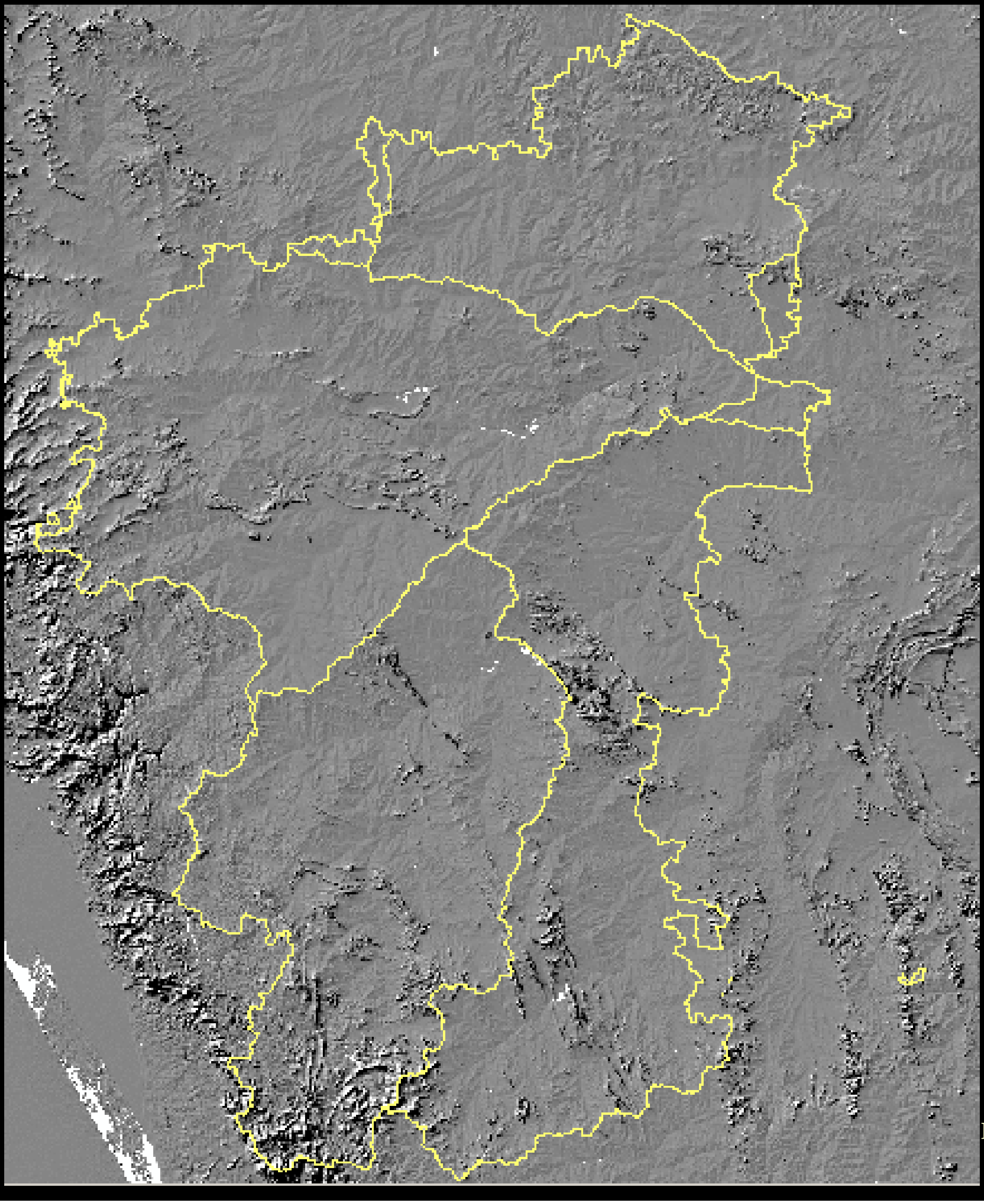




Krishna Basin (Karnataka)



SRTM DEM 100 meter – Hillshade



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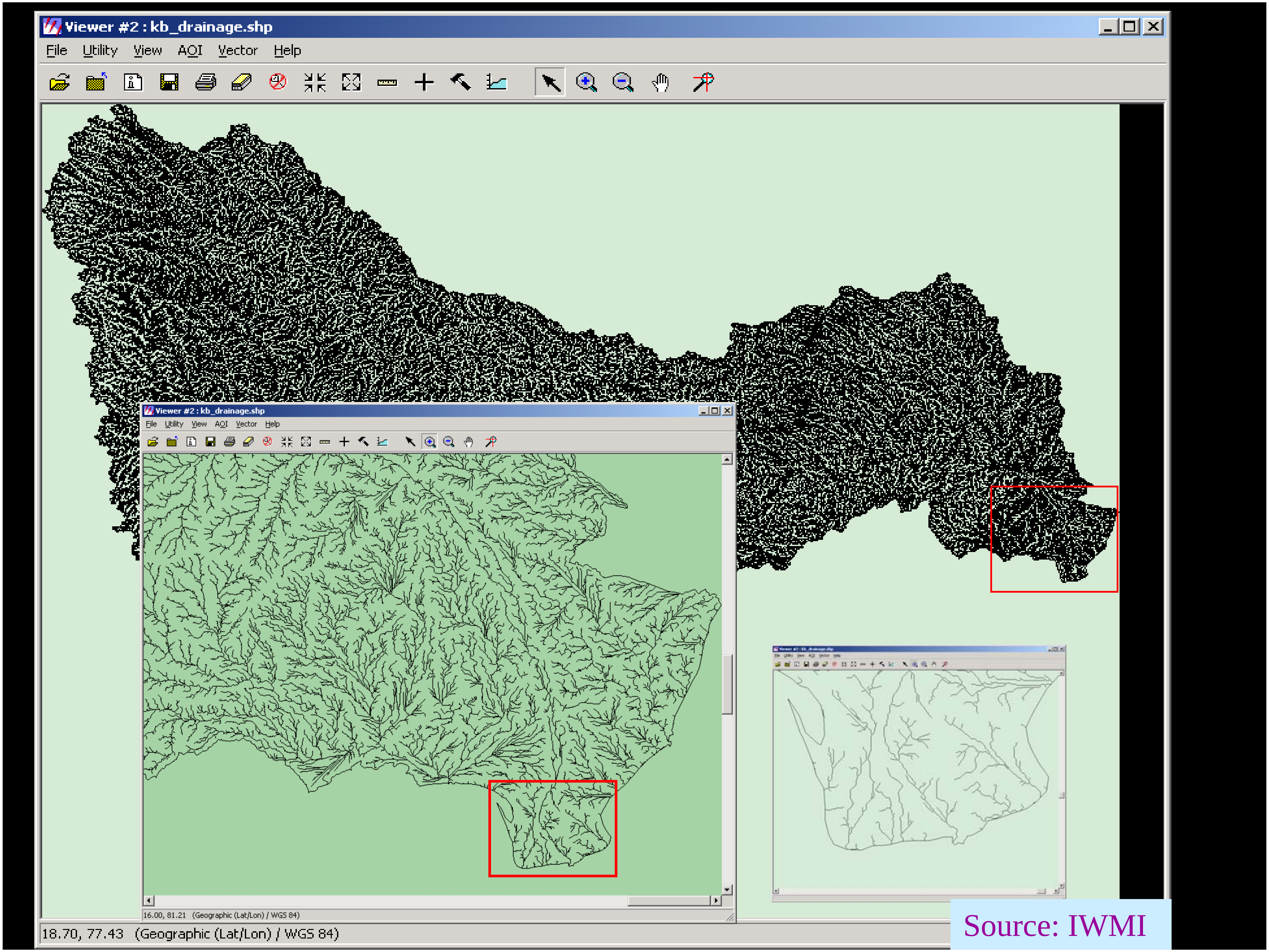
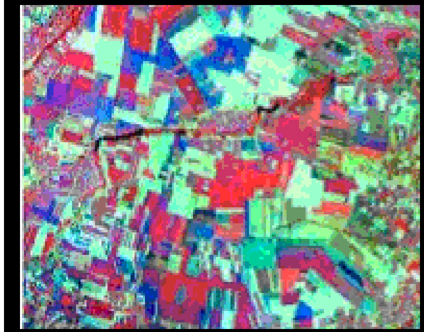
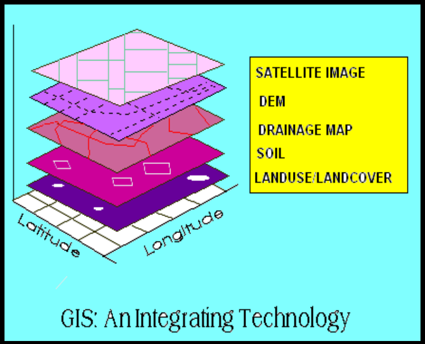
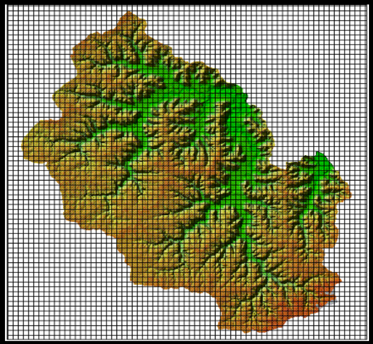

Viewer #2 : kb_drainage.shp
File Utility View AOI Vector Help
Viewer #2 : kb_drainage.shp
File Utility View AOI Vector Help
16.00, 81.21 (Geographic (Lat/Lon) / WGS 84)
18.70, 77.43 (Geographic (Lat/Lon) / WGS 84)
Source: IWMI

Integration of RS, GIS, DEM and Hydrological Models







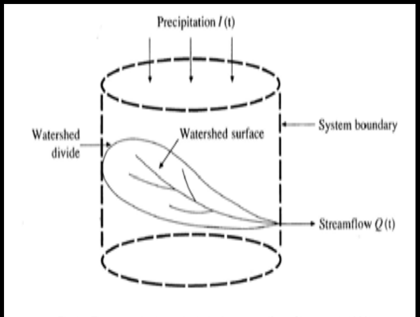


Fig.1.1 The watershed as a hydrologic system (from Chow et al, 1988)

RS **GIS** **DEM** **Hydrological Model**

Integration of RS, GIS, DEM and Hydrological Models

- Hydrological model is a good tool for understanding and managing phenomena related to hydrological processes

- RS provides essential inputs for hydrologic models

- GIS provides a Platform for Simulation of Hydrological Model.

- RS, GIS & DEM combined with mathematical models provide a convenient platform for handling, compiling, and presenting large amounts of spatial data essential to river basin management and the use of GIS makes the models accessible to a broad range of users.

AV-SWAT Model

Soil and Water Assessment Tool (SWAT)

- SWAT is a river basin, or watershed scale model (Neitsch et al., 2002)
- Physically based & Continuous time model
- To predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time.
- Due to its easy adaptability to situations with limited data availability, it has become very popular even to study the climate change impact on a river basin scale

SWAT - benefits

- Watersheds with very limited data (e.g. stream gauge data) can be modelled.

- Relative impact of alternative input data (e.g. changes in management practices, climate, vegetation, etc.) on water quality or other variables of interest can be quantified

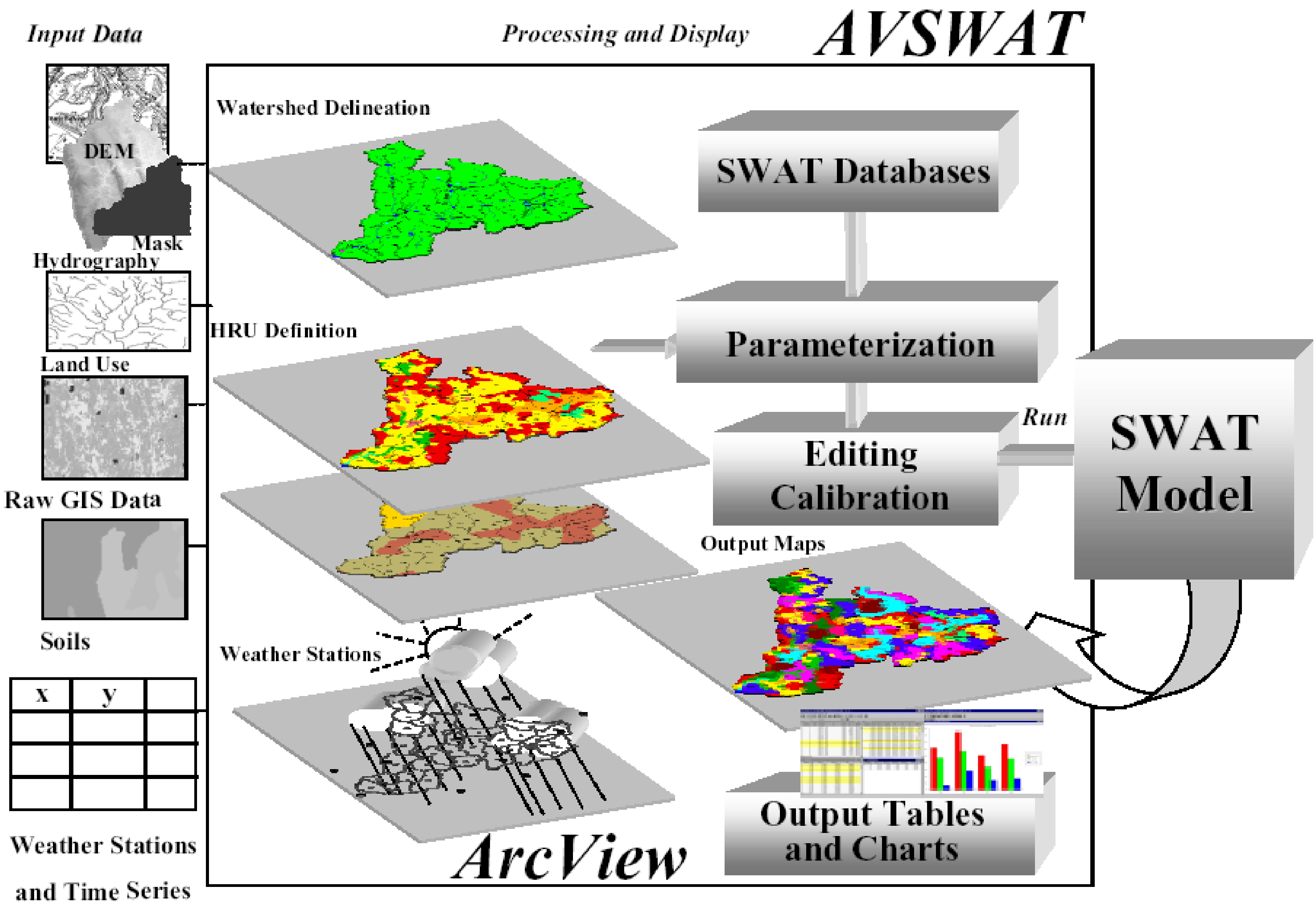
- Uses readily available inputs. While SWAT can be used to study more specialized processes such as bacteria transport, the minimum data required to make a run are commonly available from government agencies.

ArcView SWAT (AV SWAT)

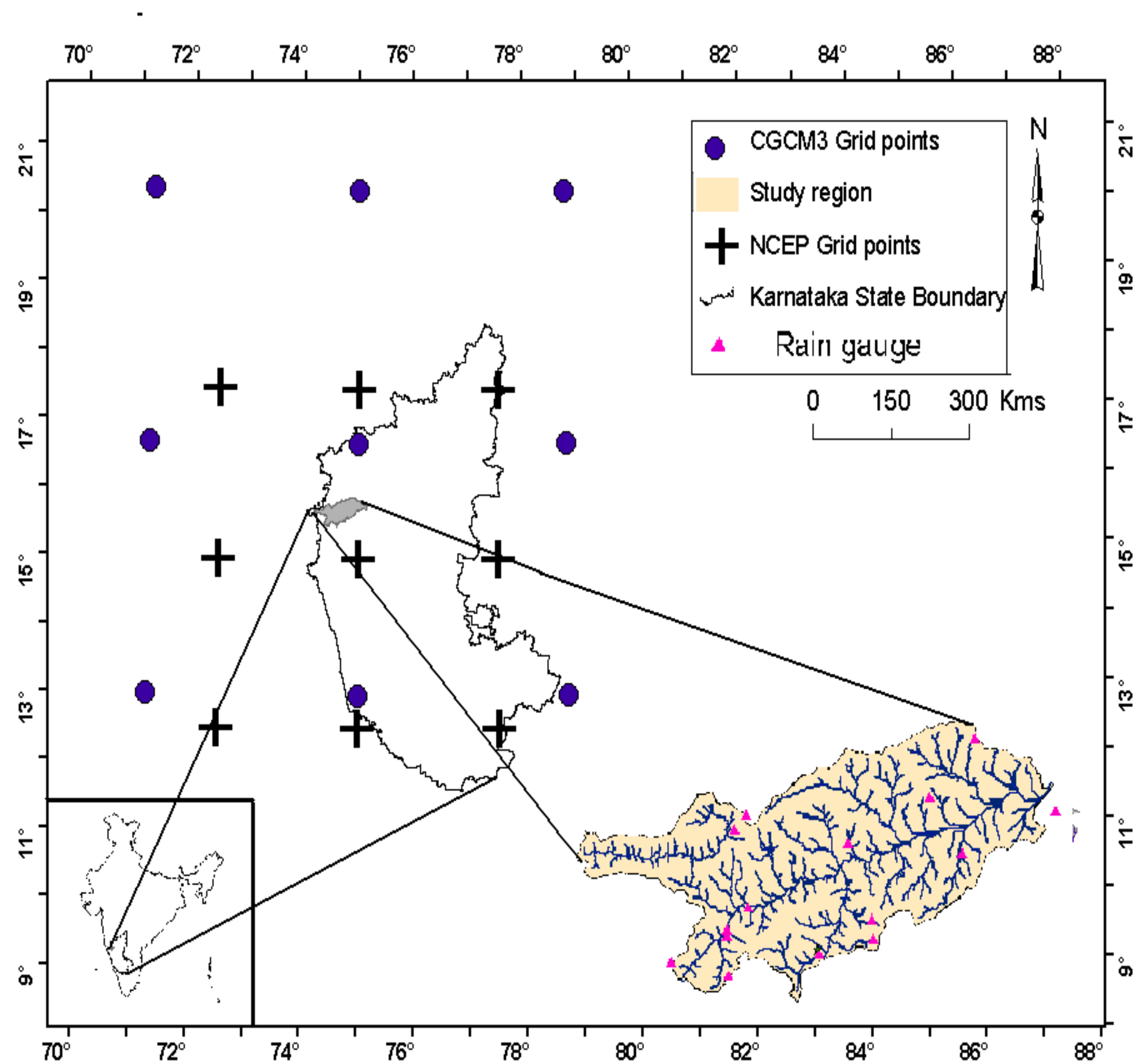
- For modeling purposes, a watershed is partitioned
  - into a number of sub-basins
  - which are further subdivided into Hydrological Response Units (HRUs)
    - HRUs are the aggregated land areas within the sub-basin that comprise of unique land cover, soil and management combinations

AV SWAT is organized in a sequence of several linked tools grouped into eight modules:

(1) Watershed delineation
(2) Definition of Hydrological Response Unit (HRU)
(3) Definition of the weather stations
(4) AVSWAT databases ex. Soil attributes
(5) Input parameterization, editing and scenario management
(6) Model execution
(7) Read and map-chart results and
(8) Calibration tool


Input Data
Processing and Display
AVSWAT
DEM
Mask
Hydrography
Land Use
Raw GIS Data
Soils
x
y
Weather Stations
and Time Series
Watershed Delineation
HRU Definition
Weather Stations
ArcView
SWAT Databases
Parameterization
Editing
Calibration
Run
SWAT
Model
Output Maps
Output Tables
and Charts

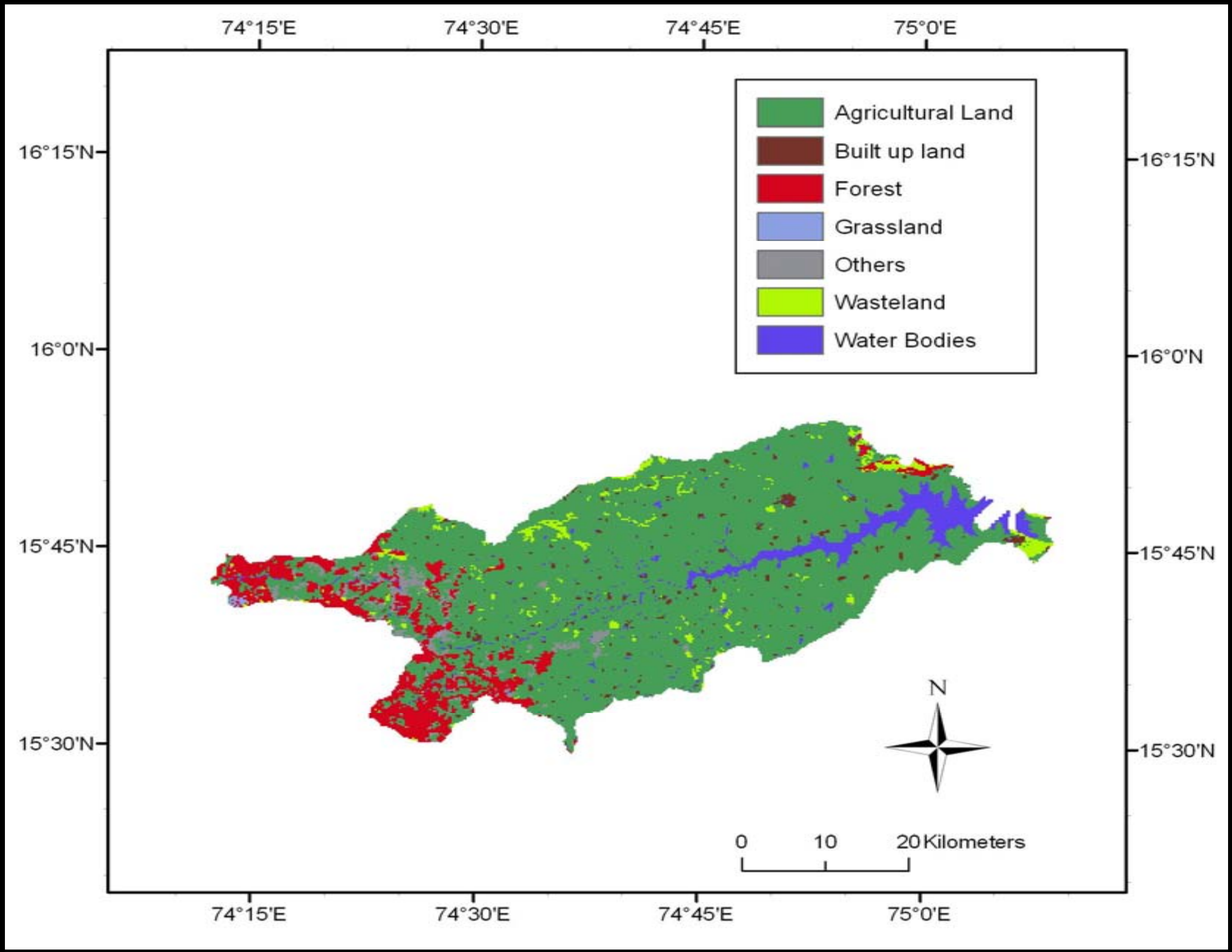
Malaprabha Basin



Map showing grid points and rain gauge locations in Malaprabha reservoir catchment

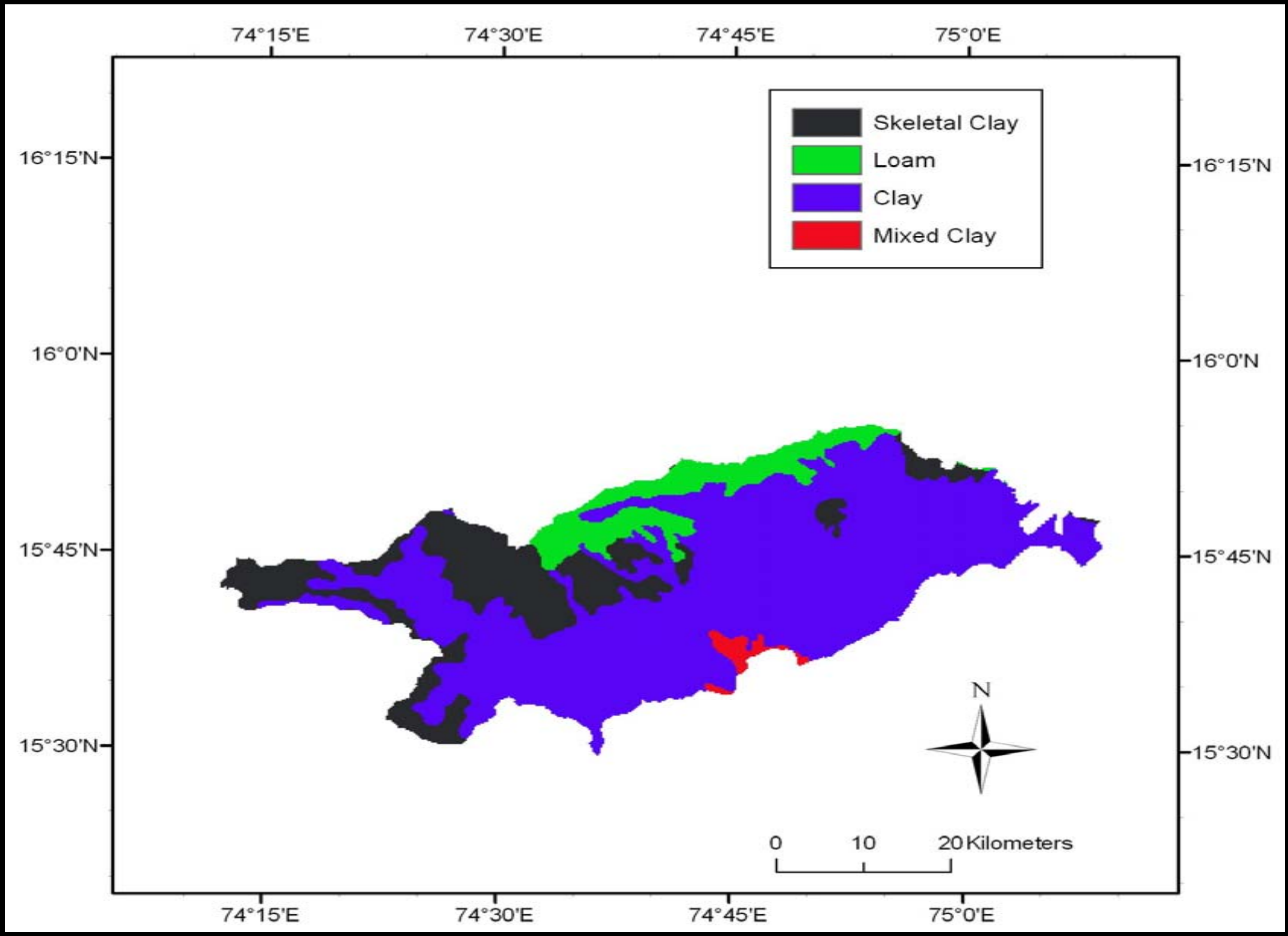
- Part of Krishna Basin in Karnataka
- The climate of the study region is dry, except in monsoon months
- Avg. annual rainfall:1051mm
- Catchment Area:2564 sq km
- Hydro-meteorological variables used (1978-2000)
  - Runoff
  - Precipitation
  - Maximum Temperature
  - Minimum Temperature
  - Wind Speed
  - Relative Humidity
  - Solar Radiation

Land use/ land cover theme of the Malaprabha reservoir catchment derived from RS

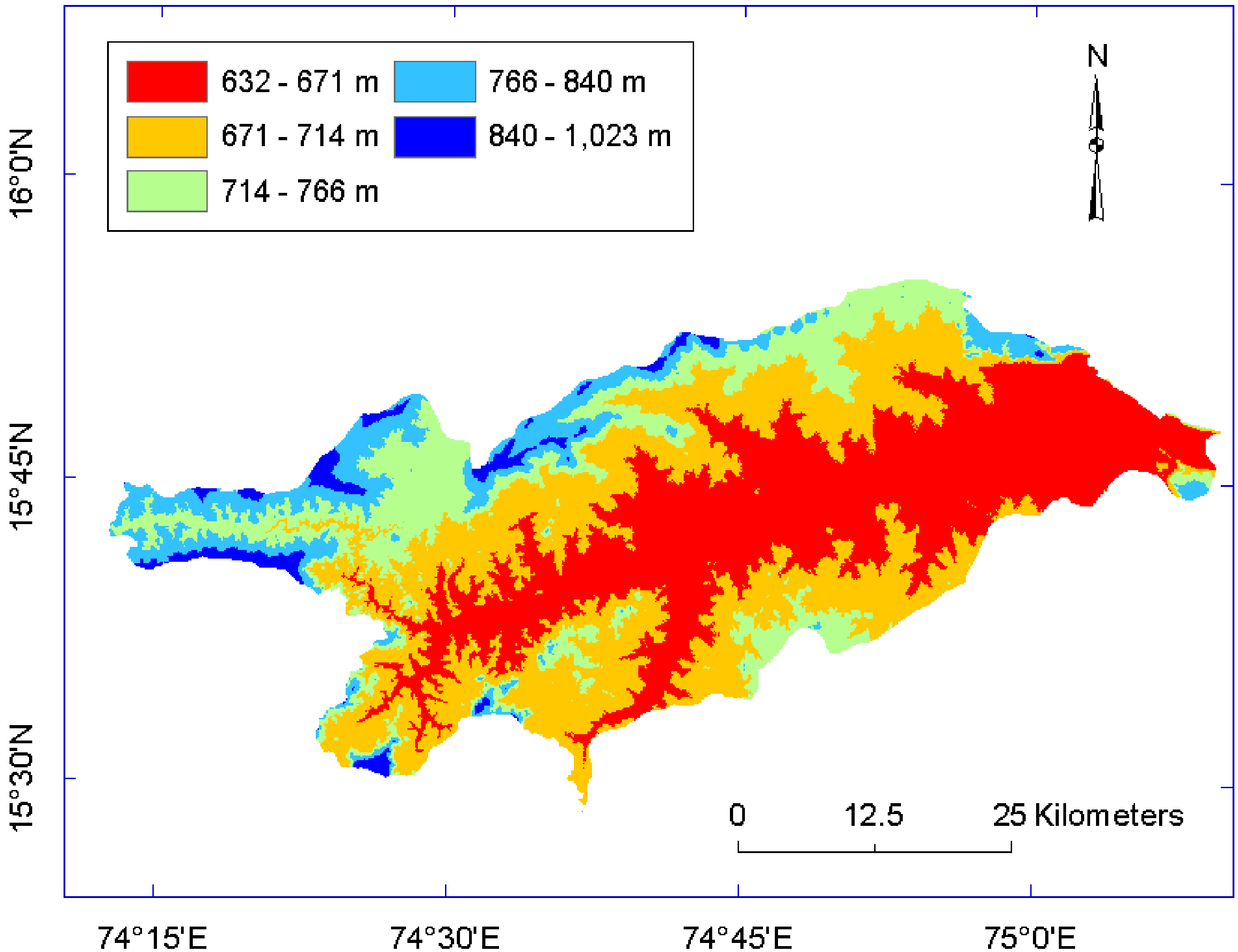


Derived from IRS LISS III data merged with PAN data

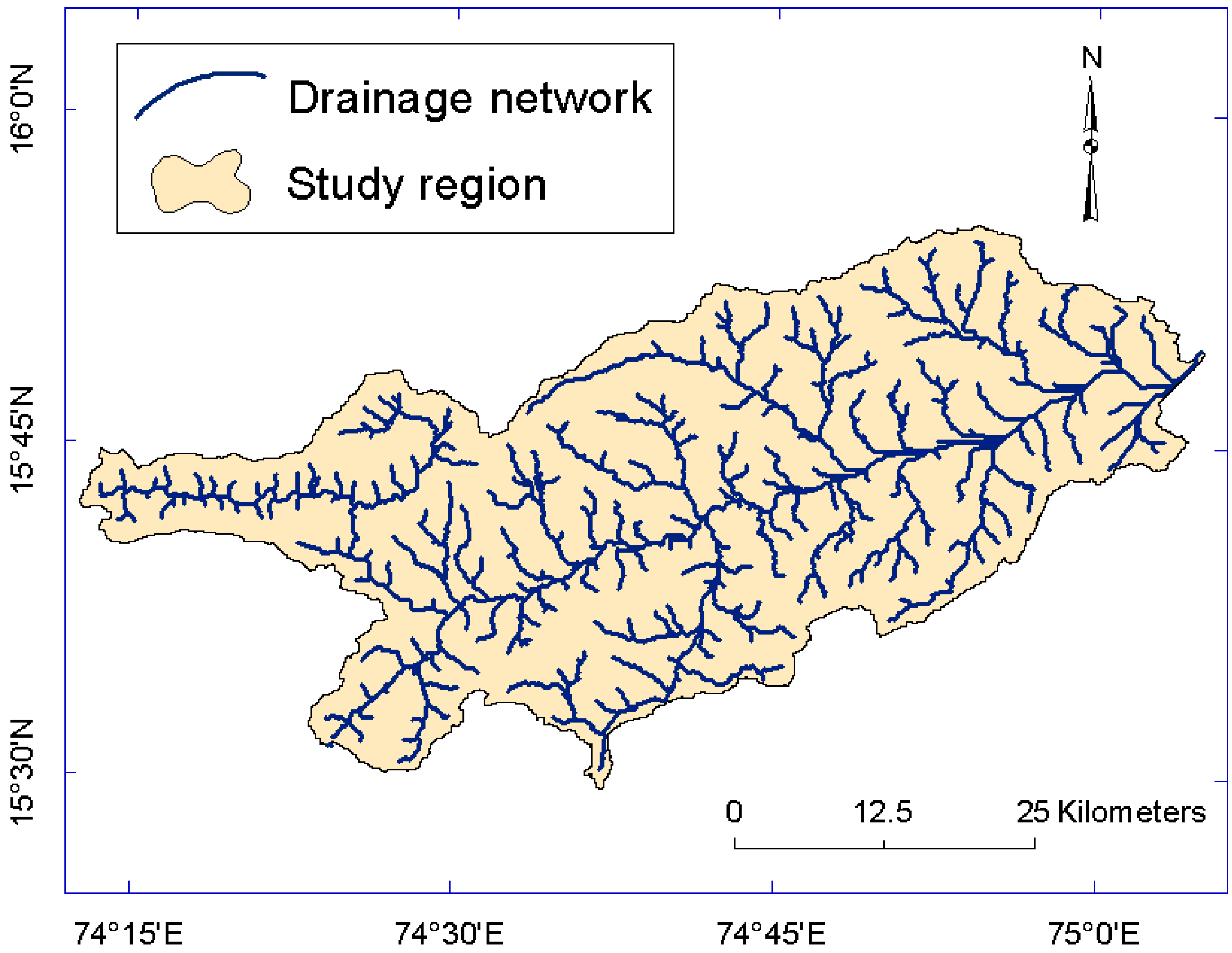
Major soil groups in the Malaprabha reservoir catchment derived from RS



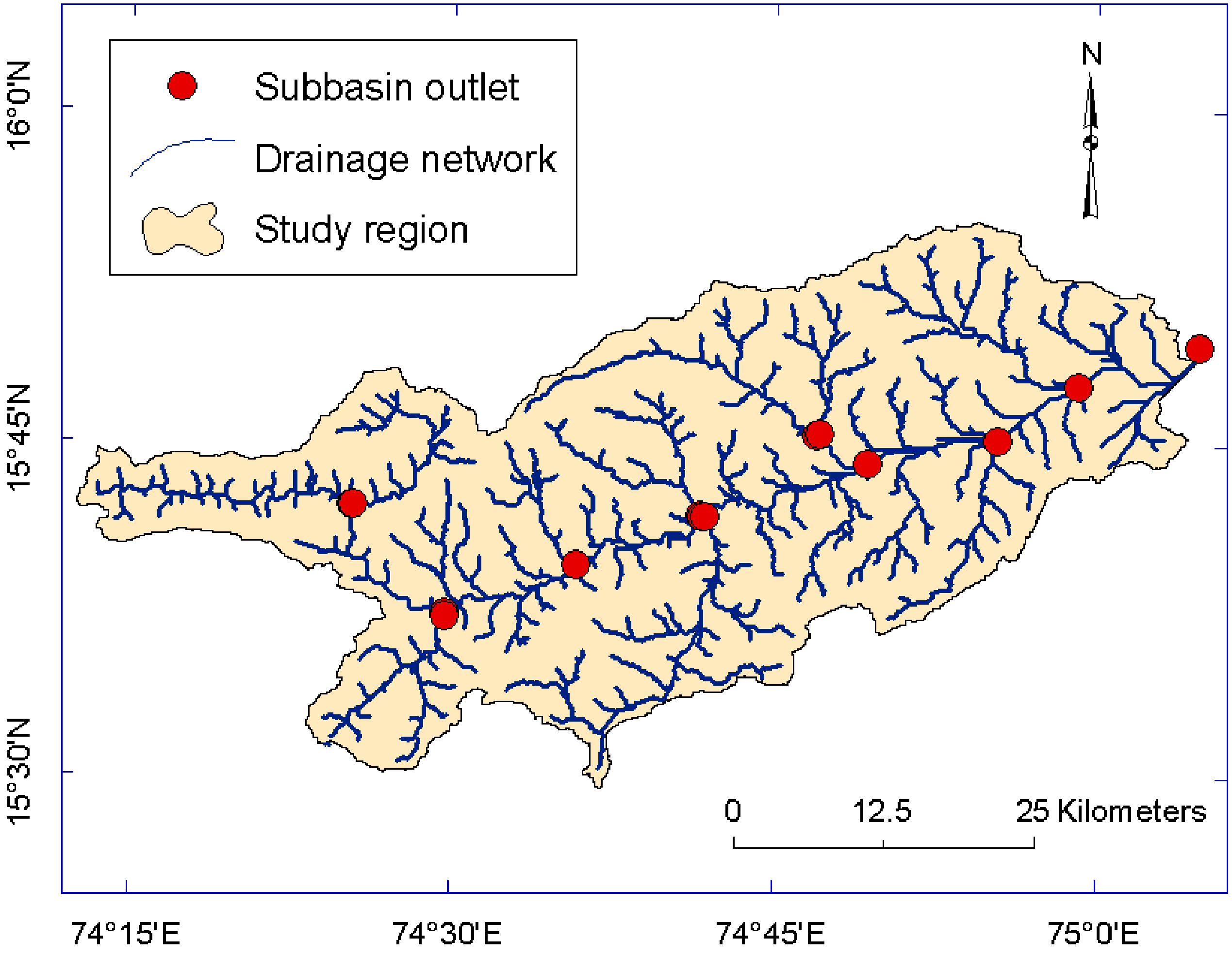
DEM of the catchment of Malaprabha reservoir Obtained from SRTM data



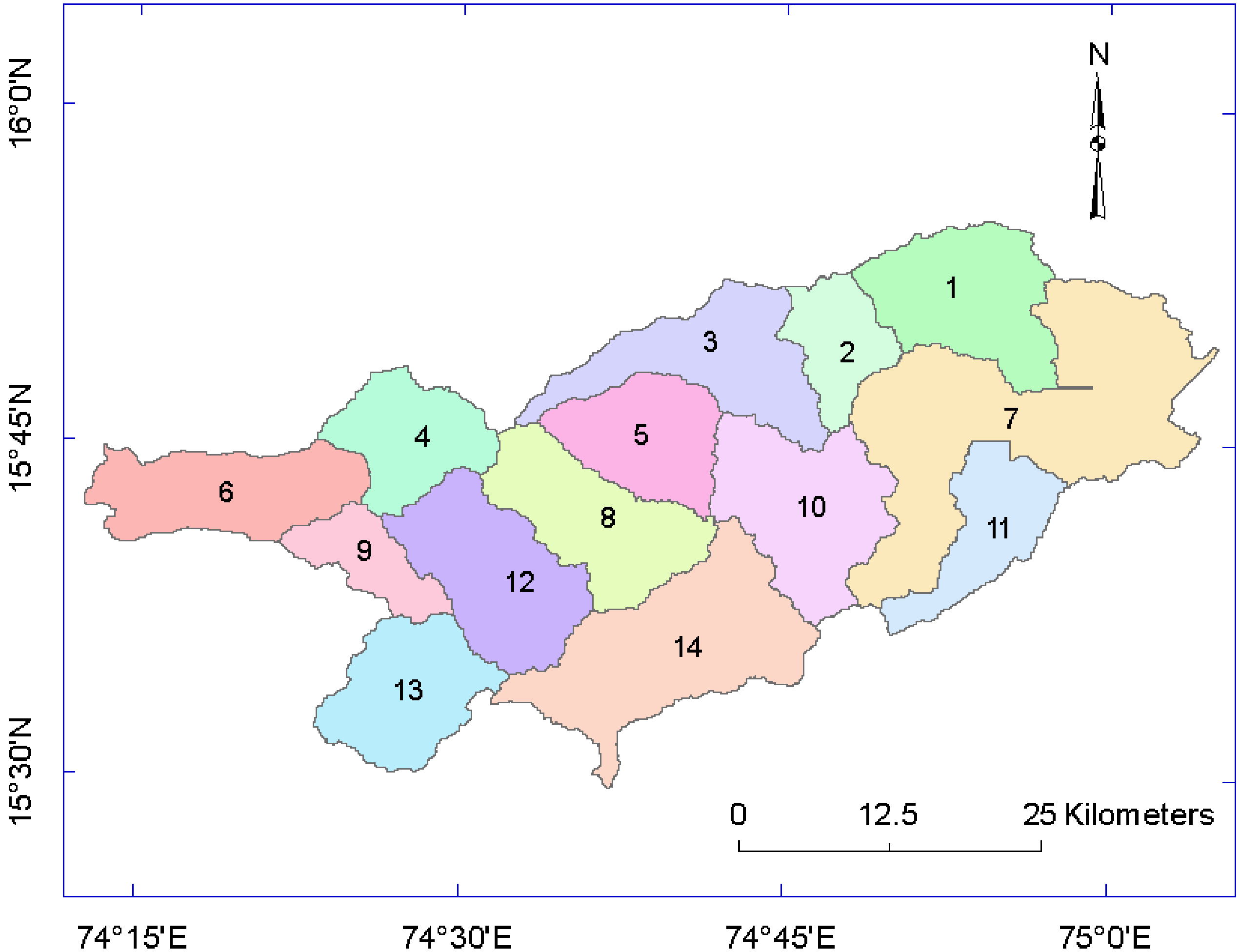
Stream network in the catchment of Malaprabha reservoir obtained from AVSWAT model using DEM



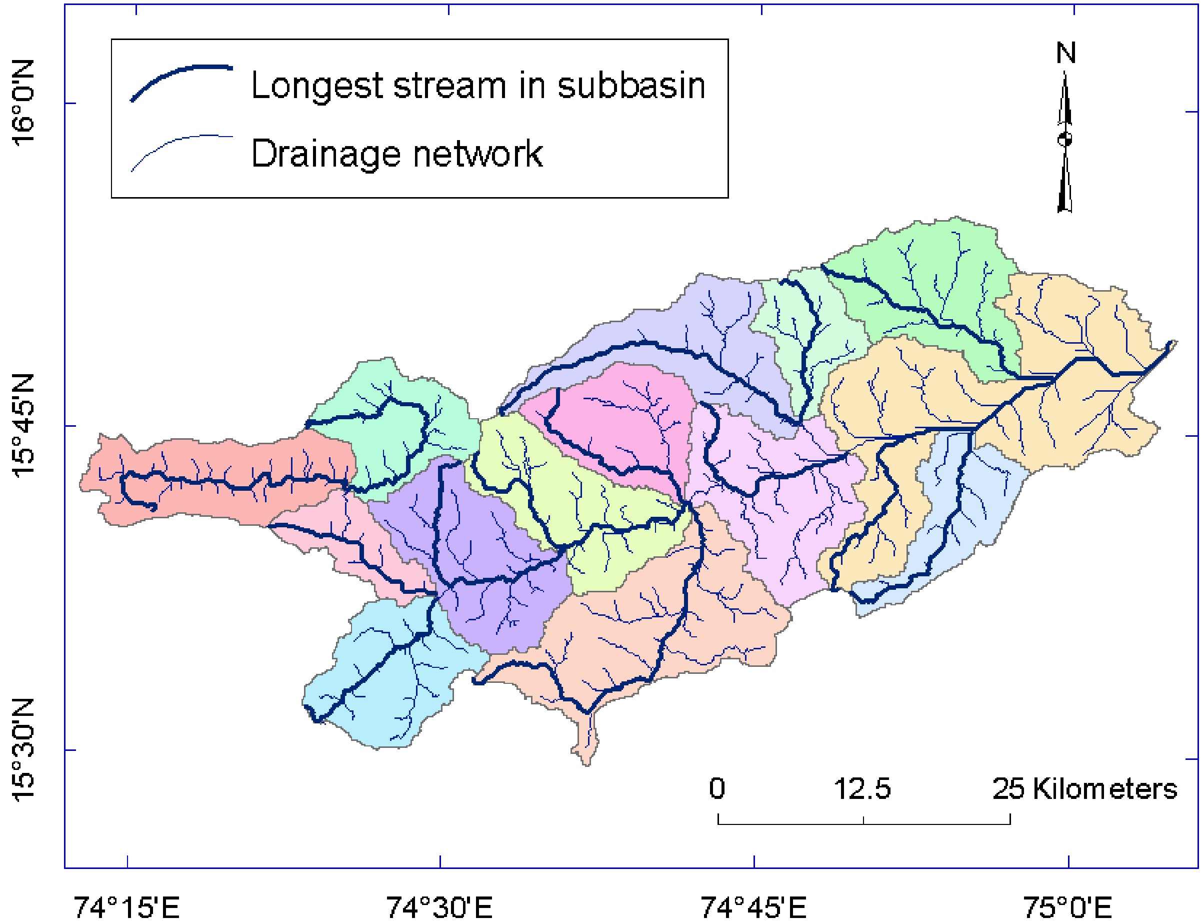
Drainage sub-basin outlets that are fixed in the catchment of Malaprabha



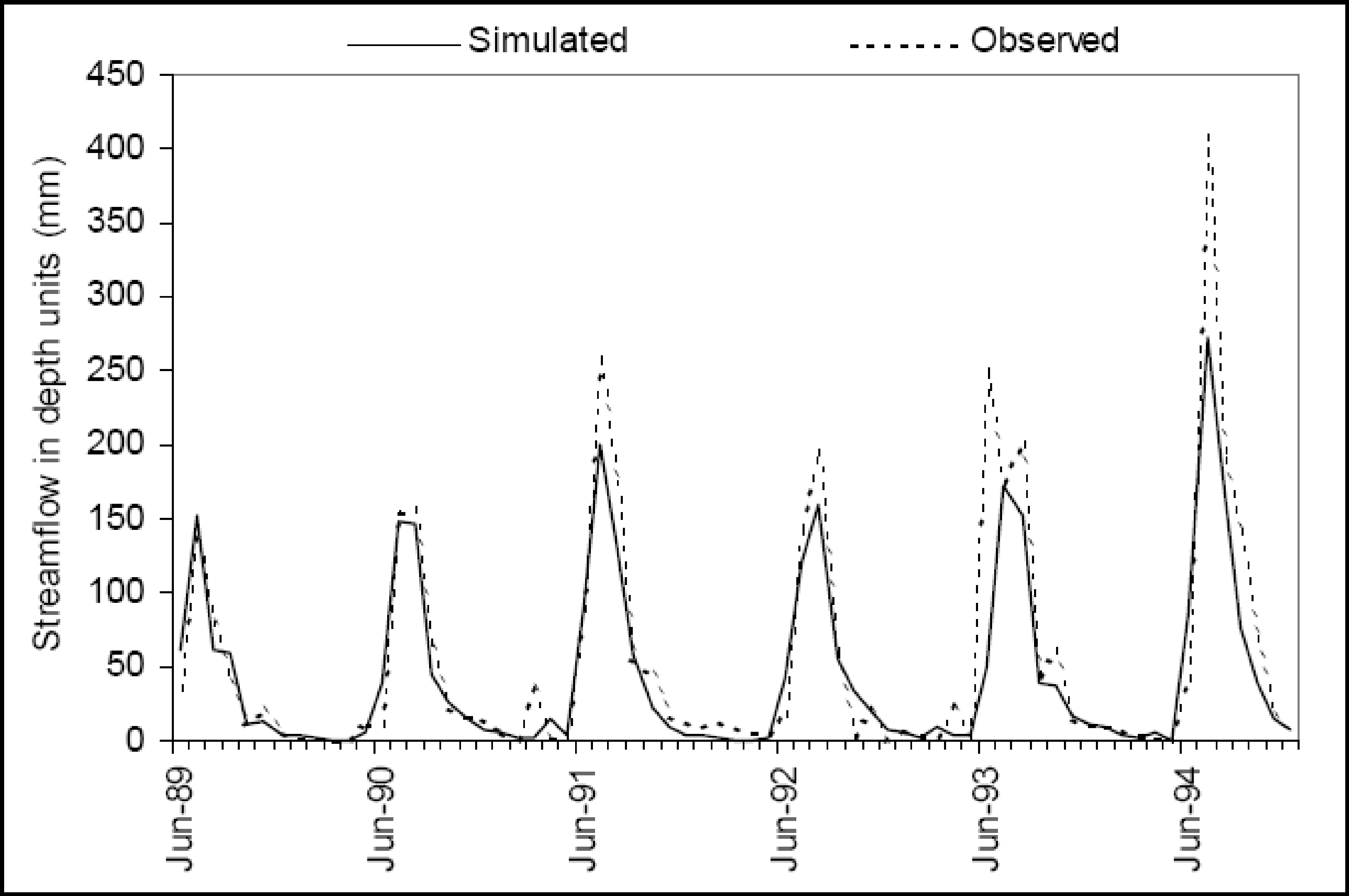
Sub-basins formed by AVSWAT for the outlets fixed in the catchment of Malaprabha reservoir



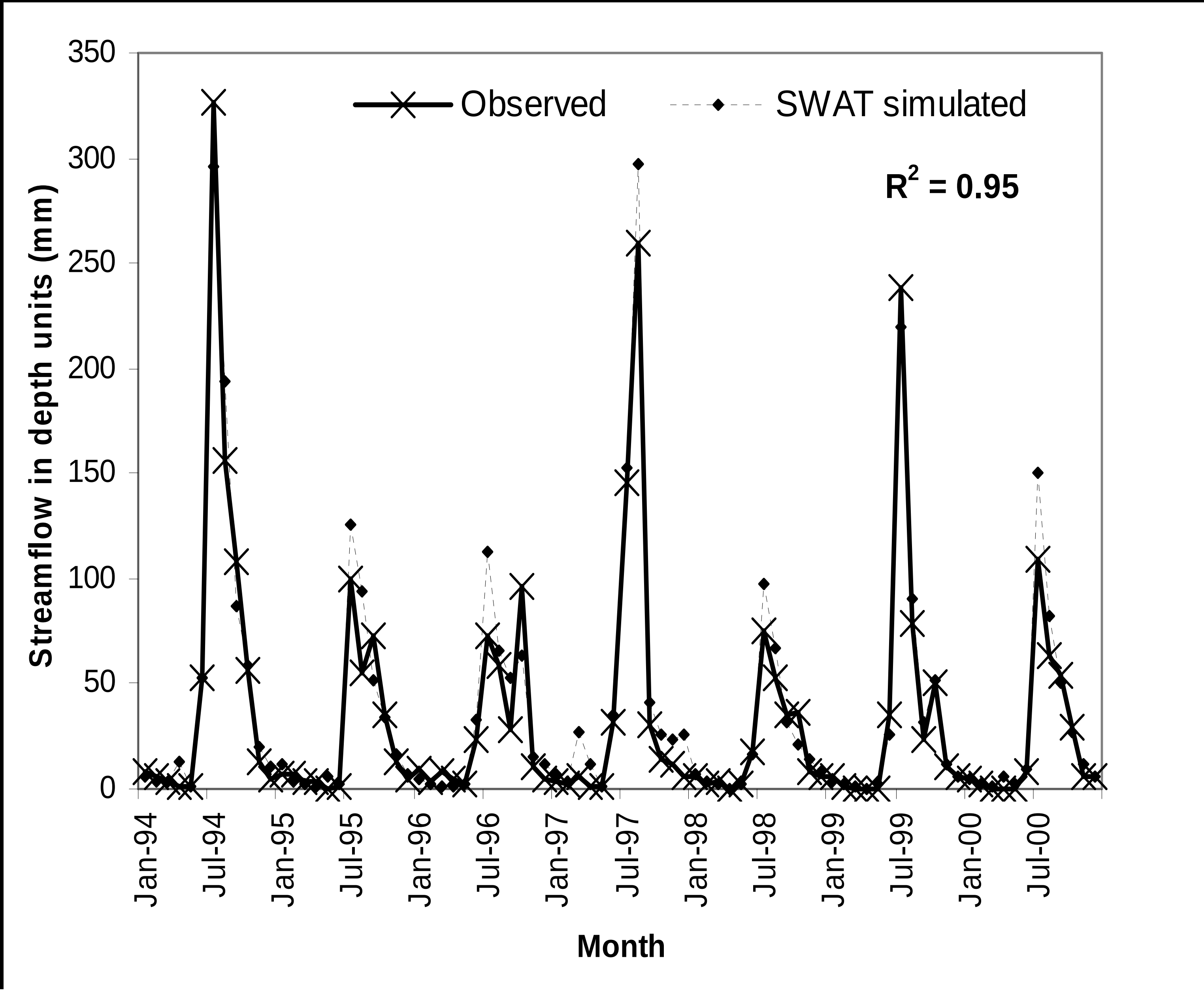
Longest stream in each sub-basin obtained from AVSWAT model



Model Performance
during the Calibration Period (1989-1994)



Model Performance
during the Validation Period (1994 –2000)



Conclusions

- Strong potential for use of RS, GIS and DEM for water resources planning and management
- Proper image processing of remotely sensed data, DEM and spatio-temporal analyses with GIS would be very effective for Water Resources Assessment & Management

Scope for Future Research

- Use of
  - Microwave Remote Sensing data
  - Hyperspectral data
  - Synergy of multispectral multi-date data

- Image processing techniques to delineate different vegetation species (ex. Sugar cane, Cotton etc.)

- Challenges in DEM
  - Limitations in detecting stream network

- Impact of Climate Change on Water Resources

- DSS Floated on GIS

Thank you