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Remote Sensing, GIS & DEM for Hydrological Modeling (AV-SWAT)

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Outline

- Geographic Information System (GIS)
- **Digital Elevation Model (DEM)**
- **Integration of RS, GIS, DEM and Hydrological Models**
- Remote Sensing in Watershed & Water Quality Models
- **Case Study: AV SWAT for Malaprabha**
- Conclusions

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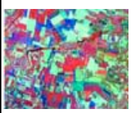
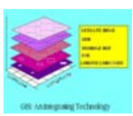
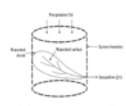
Integration of RS, GIS, DEM and Hydrological Models


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.
- GIS technology is often linked to information and knowledge management systems and is readily available to most governmental entities, a high degree of transparency in decision making for stakeholders can be achieved.

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Role of Remote Sensing in Watershed & Water Quality Models

Introduction

- Models vary in many ways
  - Time step, scale, whether the model simulates single event 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.

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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
  - Digital Elevation Model (DEM) and
  - Geographic Information System (GIS)

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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

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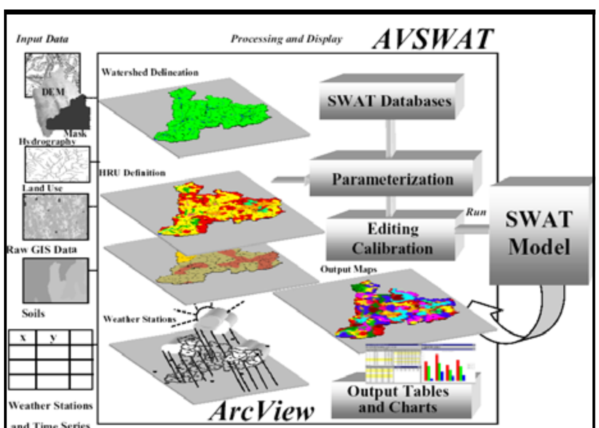
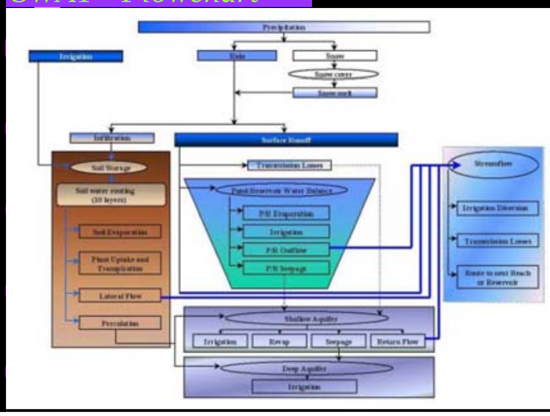


Figure 1.1

SWAT - Flowchart



SWAT - Advantages

- Watersheds with little monitoring data (e.g. no stream gauge data) can be modeled
- 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
- Computationally efficient. Simulation of very large basins for a variety of management strategies can be performed without excessive investment of time or money.
- Enables users to study long-term impacts. Many of the problems currently addressed by users
  - Involve the gradual buildup of pollutants
  - Impact on downstream water bodies

SWAT - Inputs for estimating surface runoff & routing

- Weather Related Parameters
  - Mean monthly weather data for weather generator
    - Max Temperature
    - Min temperature
    - Daily Solar radiation reaching the earth surface
    - Moist Soil albedo
    - Relative humidity
    - Wind velocity
    - Latitude of the sub basin – for earth sun calculations
    - PET values
  - Daily or hourly precipitation
- Soil Properties
  - Detailed spatial soil map
  - Bulk density
  - Percentage sand, silt & clay
  - Available water holding capacity
  - Depth of individual soil layer in the horizon
  - Plant uptake compensation factor
  - Soil cover index

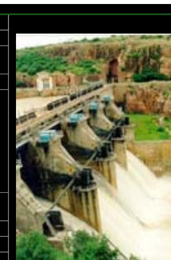
SWAT – Inputs – contd..

- Topography
  - DEM
  - Drainage network
- Vegetation
  - Detailed landuse-landcover map
  - Leaf area index
  - Plant uptake compensation factor
  - Water stress that triggers irrigation
  - land management practices
- Irrigation
  - Timing of irrigation (month/day)
  - Irrigation amount (depth of irrigation in each HRU)
- Channel Characteristics
  - Top width of channel at full bank
  - depth of channel at full bank
  - Slope of the channel
  - Length of channel
  - Manning n for the channel
  - Muskingum X
  - Weighing coefficient – 1. Fraction of storage time const for fullbank
  - Weighing coefficient – 2. Fraction of storage time const for fullbank
  - Effective hydraulic conductivity of channel
  - Revap coefficient
  - Fraction of transmission losses portioned to deep aquifer
  - Bank flow recession const. Or Const of proportionality
  - Fraction of overland flow

Description of the Study Region

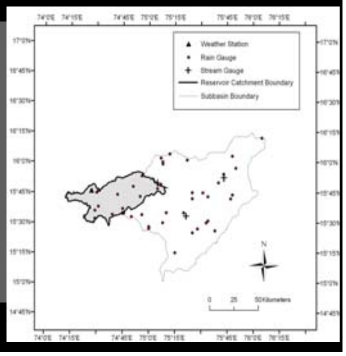
- The study region is the catchment of Malaprabha River, upstream of Malaprabha reservoir.
- It has an area of 2093.46 km^2 situated between latitude 15°30' N to 15°56' N and longitude 74°12' E to 75°8' E.
- It lies in the extreme western part of the Krishna river basin and includes parts of Belgaum, Bagalkot and Dharwad districts of North Karnataka.
- The Malaprabha irrigation project has a masonry dam of height 145.53m and length 40.23 m.
- The reservoir has a gross storage capacity of 37.73 TMC (~1070 Mm^3) and live storage capacity of 29.32 TMC (~ 830 Mm^3)
- Area envisaged to be irrigated by RBC is 2,02,708 ha and that by LBC is 41,364 ha (PIR, 1986).
- The sub-basin has a wide variety of soils such as medium black soil, deep black soil, mixed red and black soils, red sandy soil and red loamy soil (NIH, 1989), which can be broadly classified into three textures, namely clay, skeletal clay and loam. Further, among all the soils in the sub-basin, black soil is predominant.

1. Name of Project	Malaprabha	
2. River Basin	Krishna	
3. Name of Stream/ sub-basin	Malaprabha	
4. Location		
a. Nearby village/town b. Taluk c. District d. latitude e. Longitude	Navilutheertha Saundatti Belgaum 15^0 - 49' - 0'' N 75^0 - 6' - 0" E	
5. Catchment area (Sq.Km)	2093	
6. Yield (Tmc)	42.57	
7. Storage (Tmc)		
a. Gross b.Live c.Dead`	37.73 29.32 3.39	
8. Planned Utilisation (Tmc)		
a. Withdrawals by canals b. Reservoir losses c. Water supply d. Gross utilisation		43.39 4.84 0.42 48.65
9. Irrigable Area		218191 Ha
10. Submersion		
a. Area (ha) b. Village affected (Nos.) c. Population affected (Nos.)		13578 43 41000

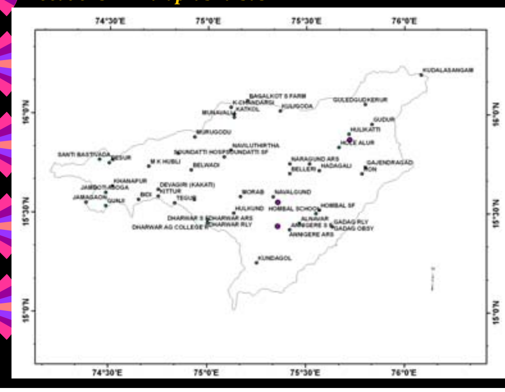


Data used for the Study

- Daily rainfall records at 16 gauging stations in the catchment of Malaprabha dam are considered.
- Rainfall data, from May 1979 to November 2003, is procured from the Directorate of Economics and Statistics (DES), Bangalore.
- Meteorological parameters such as daily maximum, minimum, and mean temperatures, wind velocity and relative humidity, for the period June 1991 to December 2003, observed at Santebastwadi station are obtained from WRDO, Bangalore.
- Runoff data (inflows into Malaprabha reservoir) is collected from WRDO.



Rain gauge & CWC Stream gauge Locations in Malaprabha basin



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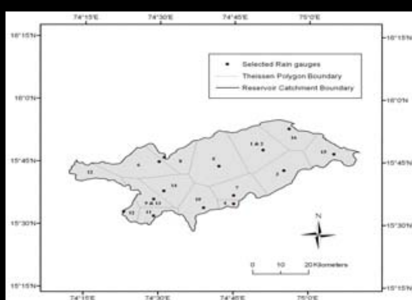
Thiessen polygons for the catchment of Malaprabha reservoir to compute representative rainfall



Number shown in each polygon refers to the serial number of the corresponding rain gauge shown in previous table

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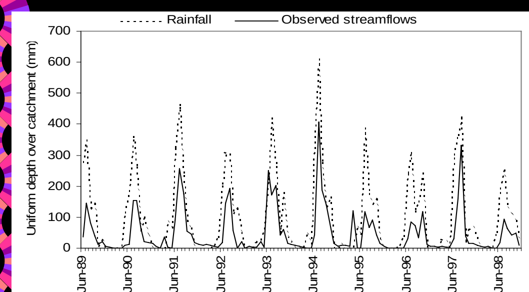
Temporal distribution of average rainfall over the catchment of Malaprabha reservoir and resulting streamflows at the reservoir site



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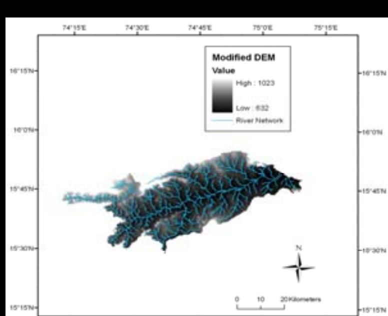
SRTM DEM data pre-processed using ArcView interface of SWAT model, to obtain stream network in the catchment of the Malaprabha reservoir



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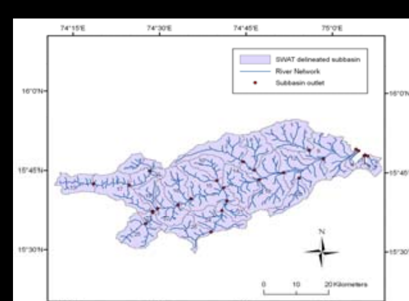
Stream network was reviewed and drainage basin outlets are specified through screen interactive option of the SWAT model to form 26 drainage sub-basins



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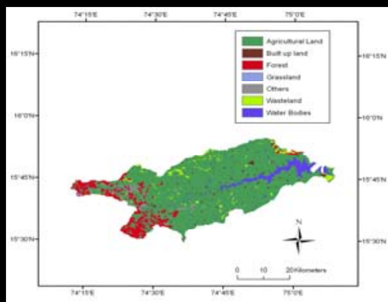
Land use/land cover theme

of the Malaprabha reservoir catchment



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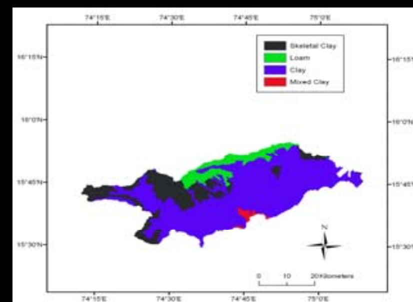
Major soil groups

in the Malaprabha reservoir catchment



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Area (in ha) under different land use/land cover and soil textures in the Malaprabha catchment within the 26 drainage sub-basins

	LAND USE/ LAND COVER						SOIL			
	PAST	WATR	URBN	Forest	AGRL	Total	Clay	Loam	Skeletal clay	Total
Malaprabha catchment	6450.64 (3.08)	11809.19 (5.64)	4025.66 (1.92)	25646.60 (12.25)	161414.37 (77.10)	209346.45 (100.00)	147392.75 (70.41)	19351.29 (9.24)	42602.42 (20.35)	209346.45 (100.00)
Subbasin-1	340.64 (0.16)	89.73 (0.04)	22.43 (0.01)	4229.76 (2.02)	2064.61 (0.99)	6747.18 (3.22)	1029.40 (0.49)	0.00 (0.00)	5717.78 (2.73)	6747.18 (3.22)
Subbasin-2	45.50 (0.02)	9.10 (0.00)	29.78 (0.01)	1048.21 (0.50)	3708.87 (1.77)	4841.47 (2.31)	1452.77 (0.69)	0.00 (0.00)	3388.70 (1.62)	4841.47 (2.31)
Subbasin-3	380.04 (0.18)	0.83 (0.00)	93.36 (0.04)	430.44 (0.21)	4520.84 (2.16)	5425.50 (2.59)	1107.90 (0.53)	0.00 (0.00)	4317.60 (2.06)	5425.50 (2.59)
Subbasin-4	360.31 (0.17)	248.75 (0.12)	99.17 (0.05)	6410.36 (3.06)	5713.71 (2.73)	12832.28 (6.13)	8949.05 (4.27)	0.00 (0.00)	3883.24 (1.85)	12832.28 (6.13)
Subbasin-5	3.29 (0.00)	35.42 (0.02)	18.94 (0.01)	1489.18 (0.71)	1174.54 (0.56)	2721.38 (1.30)	6311.49 (1.22)	0.00 (0.00)	413.17 (0.08)	6724.66 (1.30)
Subbasin-6	60.20 (0.03)	74.22 (0.04)	92.37 (0.04)	6374.92 (3.05)	2709.13 (1.29)	9310.84 (4.45)	4563.88 (2.18)	0.00 (0.00)	4746.96 (2.27)	9310.84 (4.45)
Subbasin-7	34.56 (0.02)	34.56 (0.02)	83.94 (0.04)	1024.52 (0.49)	3378.86 (1.61)	4556.44 (2.18)	2705.72 (1.29)	0.00 (0.00)	1850.72 (0.88)	4556.44 (2.18)
Subbasin-8	117.67 (0.06)	100.39 (0.05)	200.78 (0.10)	1664.68 (0.80)	6279.39 (3.00)	8362.92 (3.99)	7292.35 (3.48)	0.00 (0.00)	1070.57 (0.51)	8362.92 (3.99)
Subbasin-9	185.76 (0.09)	123.29 (0.06)	129.87 (0.06)	281.10 (0.13)	8491.43 (4.06)	9211.45 (4.40)	1731.82 (0.83)	854.81 (0.41)	6624.81 (3.16)	9211.45 (4.40)
Subbasin-10	362.65 (0.17)	57.56 (0.03)	79.77 (0.04)	0.00 (0.00)	5368.27 (2.56)	5868.25 (2.80)	1800.94 (0.86)	3148.76 (1.50)	918.56 (0.44)	5868.25 (2.80)
Subbasin-11	39.67 (0.02)	95.05 (0.05)	185.14 (0.09)	983.58 (0.47)	5736.98 (2.74)	7040.42 (3.36)	17397.24 (3.36)	0.00 (0.00)	0.00 (0.00)	17397.24 (3.36)
Subbasin-12	554.51 (0.26)	498.56 (0.24)	357.06 (0.17)	438.50 (0.21)	14448.42 (6.90)	16297.05 (7.78)	9383.00 (4.48)	1544.23 (0.74)	5369.82 (2.57)	16297.05 (7.78)

PAST refers to pasture or range land; WATR denotes water bodies; URBN represents urban area; AGRL stands for agricultural land. Numbers in brackets indicate the percentage of catchment area

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Area (in ha) under different land use/land cover and soil textures in the Malaprabha catchment within the 26 drainage sub-basins – Contd.

	LAND USE/ LAND COVER						SOIL			
	PAST	WATR	URBN	Forest	AGRL	Total	Clay	Loam	Skeletal clay	Total
Subbasin-13	1101.69 (0.53)	65.59 (0.03)	215.85 (0.10)	0.00 (0.00)	11583.05 (5.53)	12966.18 (6.19)	5742.54 (2.74)	7207.86 (3.44)	15.77 (0.01)	12966.18 (6.19)
Subbasin-14	80.72 (0.04)	74.95 (0.04)	203.45 (0.10)	0.00 (0.00)	8660.11 (4.14)	9019.23 (4.31)	6832.38 (3.26)	2186.86 (1.04)	0.00 (0.00)	9019.23 (4.31)
Subbasin-15	125.78 (0.06)	726.74 0.35)	263.89 (0.13)	12.33 (0.01)	8835.95 (4.22)	9964.69 (4.76)	8946.93 (4.27)	228.54 (0.11)	789.22 (0.38)	9964.69 (4.76)
Subbasin-16	307.27 (0.15)	1150.21 (0.55)	313.02 (0.15)	18.07 (0.01)	15936.94 (7.61)	17725.51 (8.47)	17491.36 (8.36)	0.00 (0.00)	234.15 (0.11)	17725.51 (8.47)
Subbasin-17	469.66 (0.22)	191.50 (0.09)	262.48 (0.13)	215.43 (0.10)	12622.24 (6.03)	13761.32 (6.57)	9206.68 (4.40)	4078.37 (1.95)	476.26 (0.23)	13761.32 (6.57)
Subbasin-18	76.42 (0.04)	132.30 (0.06)	100.25 (0.05)	20.54 (0.01)	5683.30 (2.71)	6012.82 (2.87)	6012.82 (2.87)	0.00 (0.00)	0.00 (0.00)	6012.82 (2.87)
Subbasin-19	29.57 (0.01)	2251.52 (1.08)	561.03 (0.27)	0.00 (0.00)	10937.26 (5.22)	13779.39 (6.58)	12745.21 (6.09)	0.00 (0.00)	1034.17 (0.49)	13779.39 (6.58)
Subbasin-20	680.96 (0.33)	4217.19 (2.01)	190.57 (0.09)	700.67 (0.33)	9292.77 (4.44)	15082.16 (7.20)	13097.60 (6.26)	101.86 (0.05)	1882.70 (0.90)	15082.16 (7.20)
Subbasin-21	0.00 (0.00)	546.09 (0.26)	11.53 (0.01)	0.00 (0.00)	650.69 (0.31)	1208.31 (0.58)	1208.31 (0.58)	0.00 (0.00)	0.00 (0.00)	1208.31 (0.58)
Subbasin-22	108.69 (0.05)	88.10 (0.04)	237.13 (0.11)	0.00 (0.00)	256.90 (0.12)	690.82 (0.33)	690.82 (0.33)	0.00 (0.00)	0.00 (0.00)	690.82 (0.33)
Subbasin-23	0.00 (0.00)	232.46 (0.11)	0.00 (0.00)	0.00 (0.00)	391.00 (0.19)	623.46 (0.30)	623.46 (0.30)	0.00 (0.00)	0.00 (0.00)	623.46 (0.30)
Subbasin-24	706.42 (0.34)	515.03 (0.25)	38.61 (0.02)	18.89 (0.01)	814.03 (0.39)	2092.99 (1.00)	1978.81 (0.95)	0.00 (0.00)	114.18 (0.05)	2092.99 (1.00)
Subbasin-25	179.89 (0.09)	64.07 (0.03)	66.54 (0.03)	76.39 (0.04)	3914.08 (1.87)	4300.98 (2.05)	4300.98 (2.05)	0.00 (0.00)	0.00 (0.00)	4300.98 (2.05)
Subbasin-26	98.74 (0.05)	185.97 (0.09)	168.69 (0.08)	209.01 (0.10)	8241.01 (3.94)	8903.41 (4.25)	8903.41 (4.25)	0.00 (0.00)	0.00 (0.00)	8903.41 (4.25)

PAST refers to pasture or range land; WATR denotes water bodies; URBN represents urban area; AGRL stands for agricultural land. Numbers in brackets indicate the percentage of catchment area

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Curve numbers used in the SWAT model

for different land use/ land cover types

Land use	Soil type	Curve number
Agricultural land	Loam	86
	Skeletal clay	90
	Clay	93
Forest	Loam	40
	Skeletal clay	58
	Clay	61
Grass land	Loam	61
	Skeletal clay	74
	Clay	80
Water bodies	Loam	98
	Skeletal clay	98
	Clay	98

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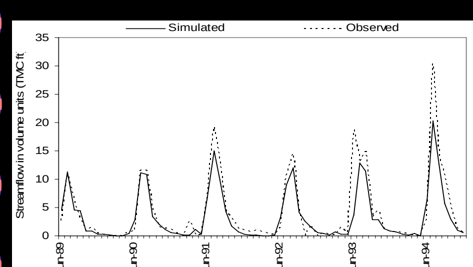
Observed and simulated monthly streamflows at Malaprabha reservoir (Jun 1989-Dec 1994)



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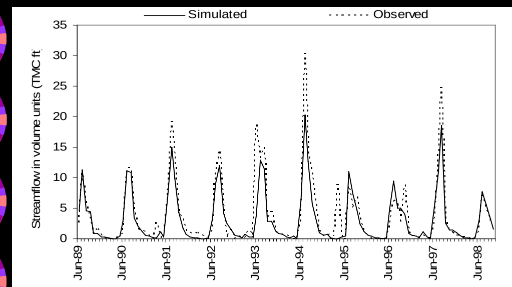
Average rainfall received by the catchment and average observed and simulated streamflows at the reservoir site for the period Jun 1989- Nov 1998

Month	Rainfall (mm)	Streamflow in depth units	
		Observed (mm)	SWAT simulated (mm)
January	1.39	5.93	6.10
February	0.00	4.45	2.07
March	5.82	7.69	3.60
April	23.78	17.05	3.43
May	50.47	2.36	2.51
June	236.25	52.48	54.62
July	381.56	173.65	158.95
August	230.29	152.94	130.66
September	100.57	60.45	53.93
October	118.16	43.14	29.61
November	26.17	15.81	14.16
December	6.18	7.65	8.05
Annual	1243.94	595.63	498.63

Observed and simulated monthly streamflows at Malaprabha reservoir (Jun 1989 - Nov 1998)

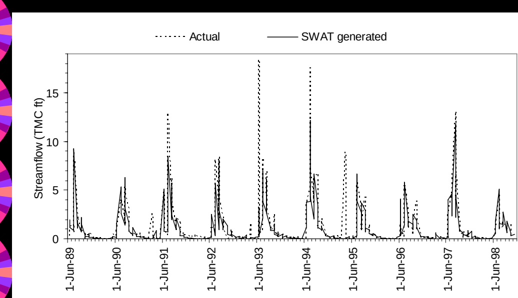


Typical Output from AVSWAT model for the catchment of Malaprabha reservoir

Year	Month	Rainfall (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERC (mm)	ET (mm)	WYLD (mm)
1979	5	25.22	7.55	0.00	0.03	1.01	3.24	0.82
1979	6	247.61	130.83	0.00	1.89	36.10	18.56	47.19
1979	7	211.66	113.84	0.03	27.74	73.01	22.81	75.69
1979	8	472.16	340.95	0.05	63.98	116.38	14.94	261.90
1979	9	229.40	142.99	0.06	74.06	68.79	16.20	94.79
1979	10	47.70	21.63	0.07	68.55	15.70	13.82	20.64
1979	11	80.45	43.75	0.06	44.67	32.97	4.66	25.42
1979	12	0.00	0.02	0.06	33.02	0.95	6.51	11.92
1980	1	0.00	0.00	0.06	13.55	0.00	4.45	12.11
1980	2	0.00	0.00	0.05	3.85	0.00	4.61	3.90
1980	3	0.00	0.00	0.05	1.47	0.00	6.08	1.52
1980	4	45.43	18.93	0.04	0.81	2.96	14.01	6.19
1980	5	27.81	15.63	0.04	2.26	3.00	10.12	1.95
1980	6	334.89	200.26	0.05	9.30	84.08	19.09	74.60
1980	7	414.58	279.50	0.08	59.15	125.89	19.31	181.46
1980	8	370.26	221.78	0.10	92.22	124.27	17.00	202.40
1980	9	140.04	80.14	0.11	93.83	48.35	15.03	76.07
1980	10	28.60	17.06	0.12	75.17	16.11	8.73	21.17
1980	11	43.04	21.11	0.10	42.19	13.88	6.75	18.24
1980	12	3.15	1.45	0.10	21.52	0.36	4.32	8.30

SURQ, LATQ and GWQ represent surface runoff, lateral flow and groundwater contributions to streamflow during the month; PERC denotes the amount of water percolating out of root zone; ET is actual evapotranspiration for the month; WYLD denotes simulated water yield

Observed and simulated ten-daily streamflows at Malaprabha reservoir (Jun 1989 - Nov 1998)



Concluding Remarks

- Strong potential for use of remote sensing, GIS & 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 better understanding and management of water resources.

Thank you