Impact of Agricultural Intensification on the Water Resources in a Semi-Arid Catchment in India

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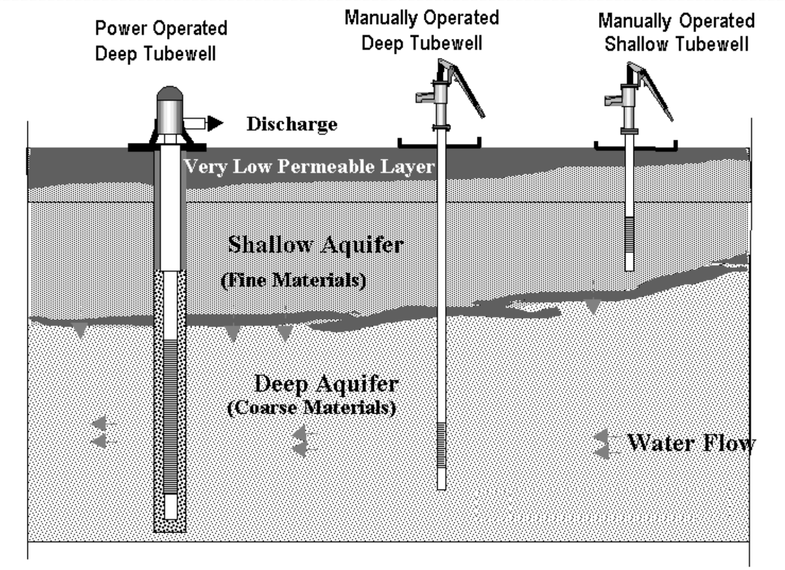
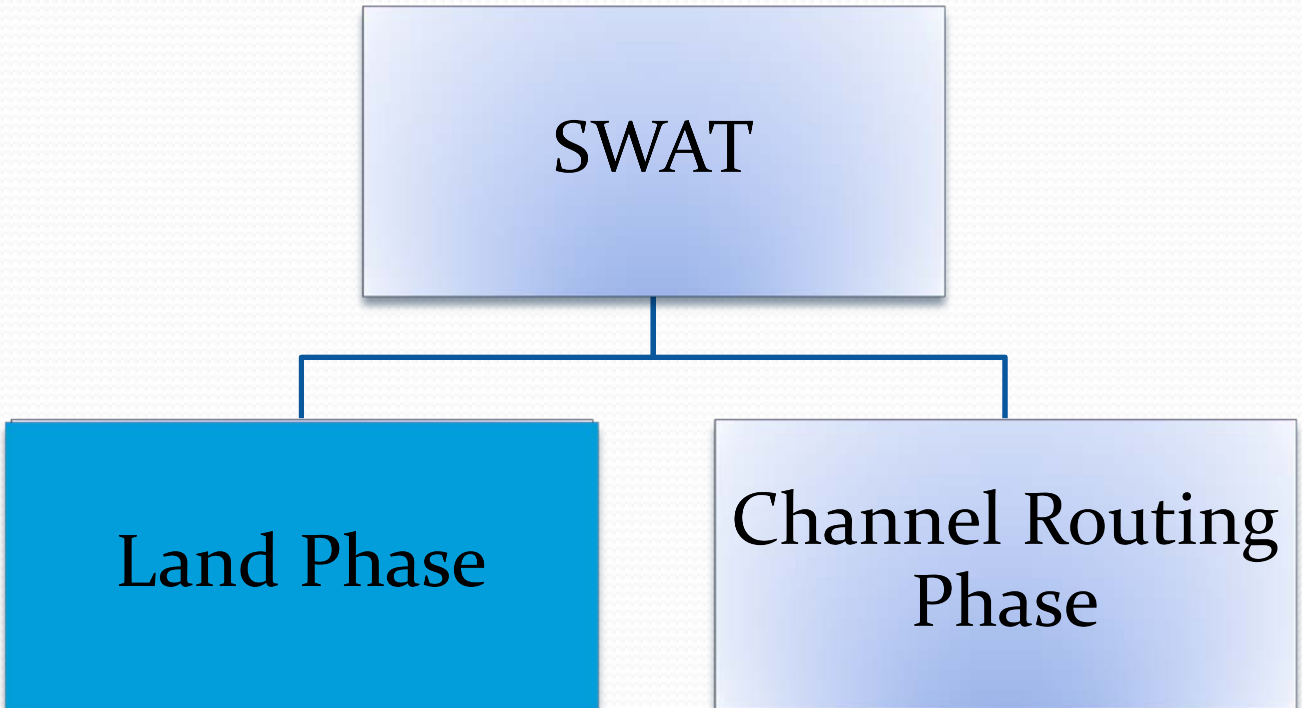
Agriculture Intensification Vs Water Resource depletion



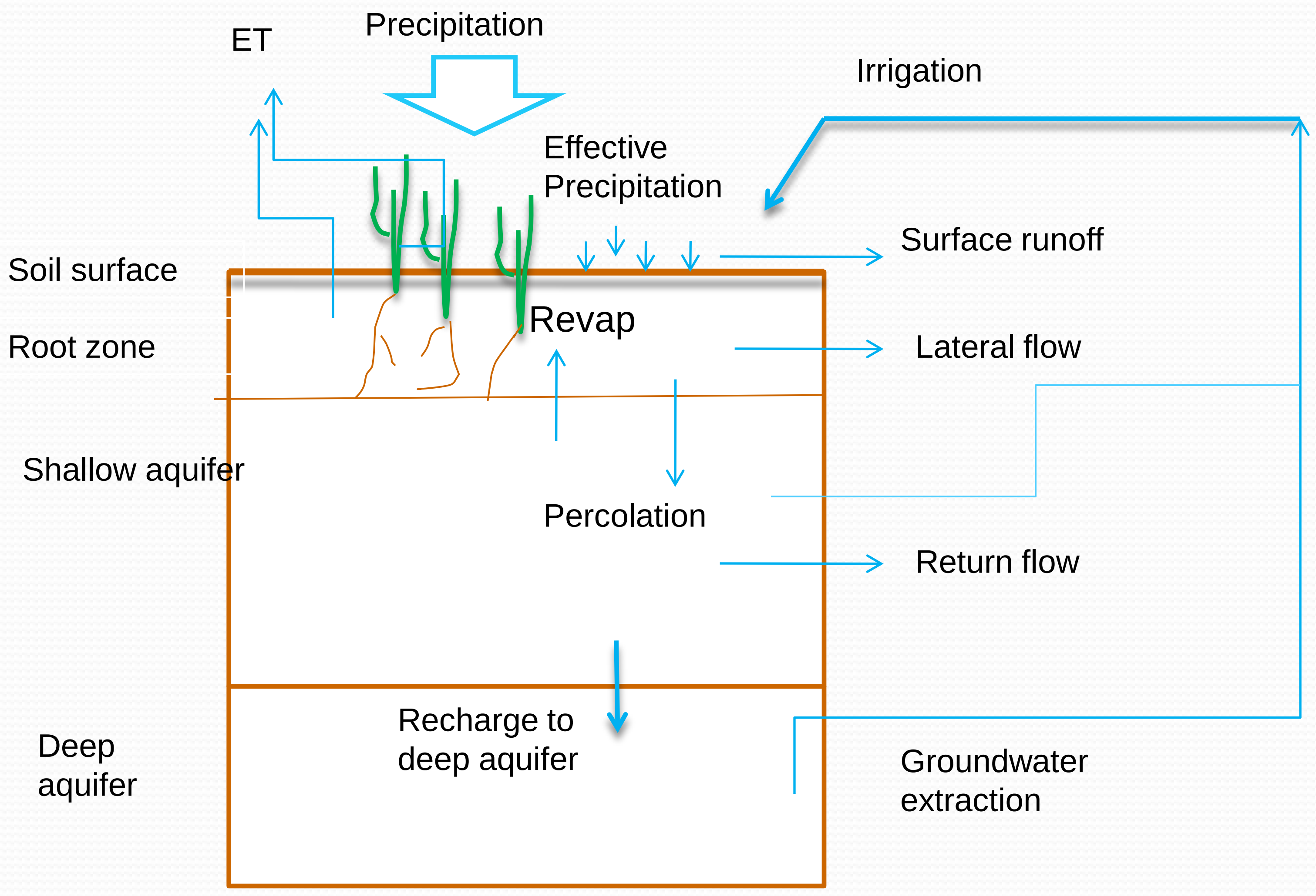
Why This Study?

- An Integrated model capable of simulating surface and subsurface hydrologic processes is required
- SWAT
  - Simple and robust model available in the public domain
  - Conceptual model that is highly efficient in simulating stream flow and sediment transport
  - GIS integrated versions makes the incorporation of spatial data simpler
- Objective
  - Apply ArcSWAT to study the groundwater scenario
  - Study the impact of excessive groundwater extraction for irrigation

SWAT Model Description



ArcSWAT Model Land Phase Components



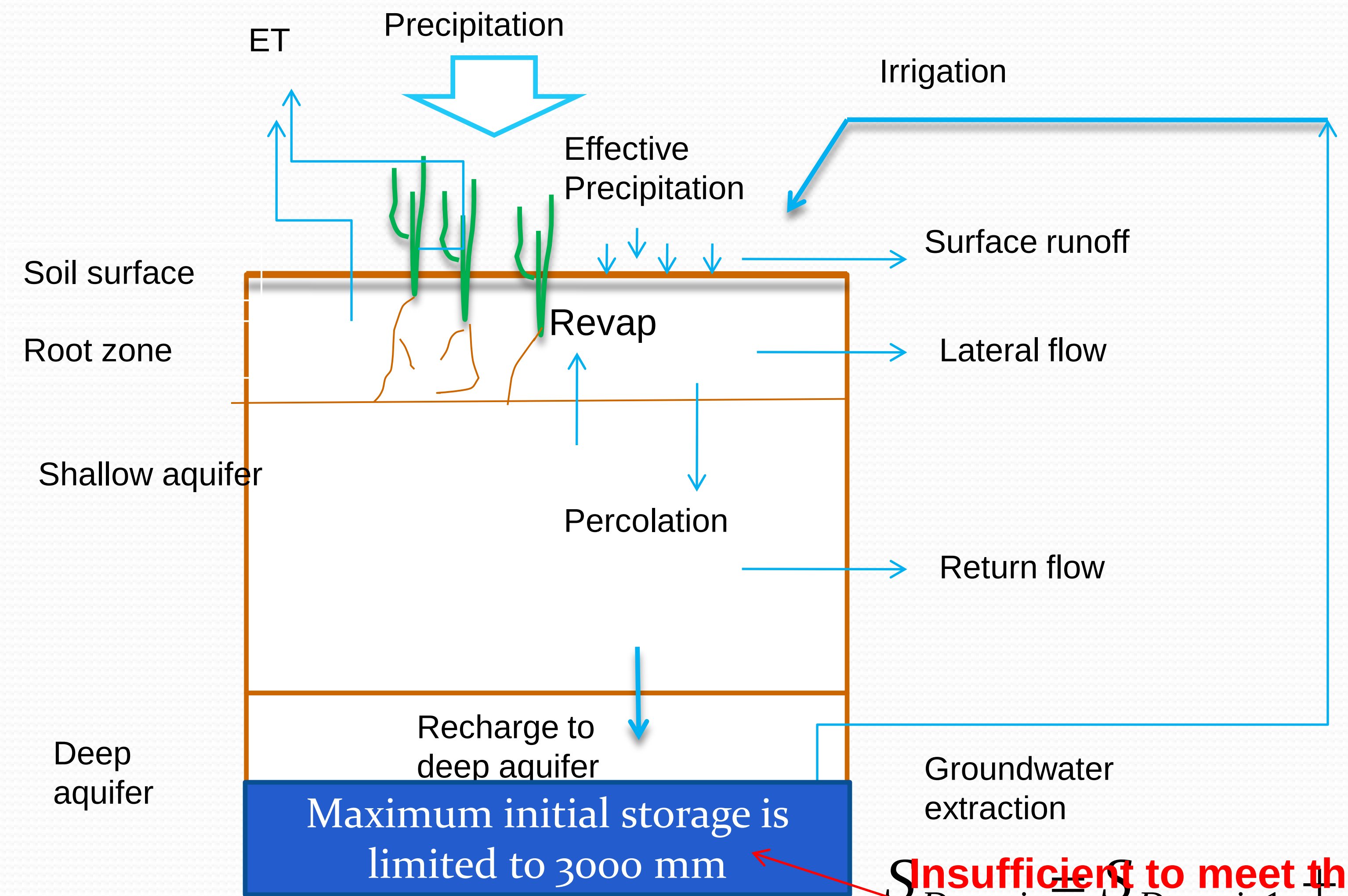
Review of SWAT

- Reasonably accurate results for the stream flow simulation (Ficklin et al., 2009; Ghaffari et al., 2010; Dessu and Melesse, 2012)
- Groundwater component
  - Compatible with the surface components, requiring only minimum readily available inputs from the field (Arnold et al., 1993)
  - Two control volumes: Shallow and Deep aquifer
  - Major drawback : Lumped model is used for the groundwater component (Sophocleous et al., 1999).
- SWAT + MODFLOW
  - Distributed modelling of the groundwater component taking recharge information from SWAT (Sophocleous et al., 1999, Kim et al.,2008).
  - Not available for ArcSWAT

Methodology

- ArcSWAT (v.2009) was selected
- Groundwater processes considered in ArcSWAT was assumed to be satisfactory for the analysis
- Identified some problems when ArcSWAT is applied to simulate large scale groundwater extraction from deep aquifer

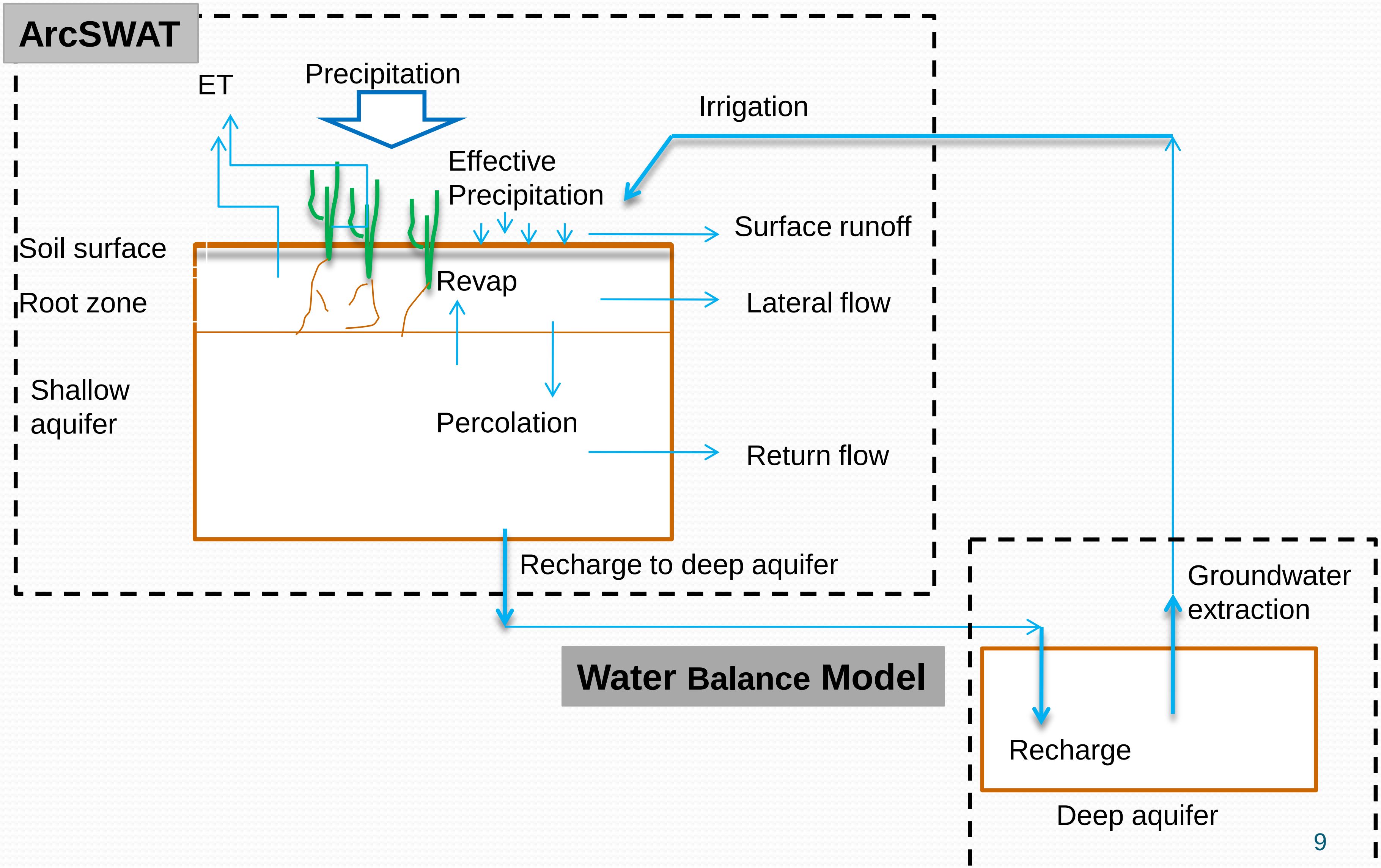
ArcSWAT Model Components



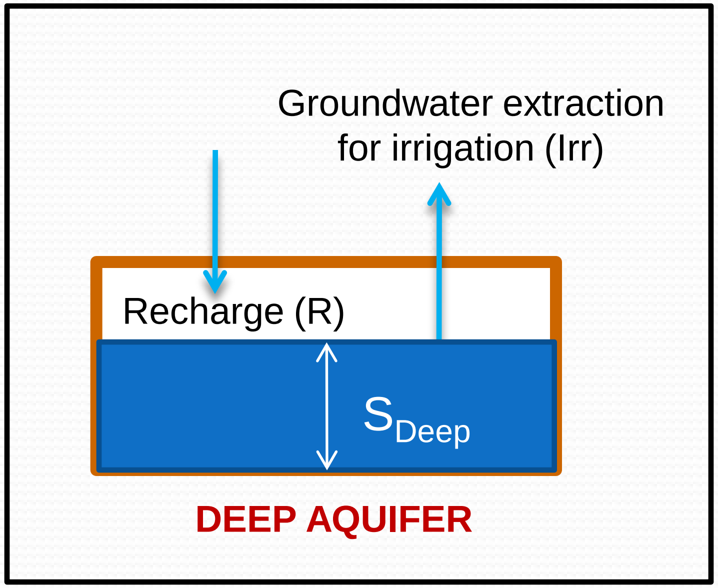
$$S_{Deep,i} = S_{Deep,i-1} + R_i - Irr_i$$

Insufficient to meet the high irrigation demand

ArcSWAT with Additional Water Balance Component



Deep Aquifer Water Balance Model



- *R* and *Irr* : from ArcSWAT (at HRU level)
- Irrigation source: Source outside the basin

- Change in deep aquifer water table depth

$$\nabla WT = \frac{\sum R_i . A_i - \sum Irr_i . A_i . \varepsilon_i}{s . \sum A_i}$$

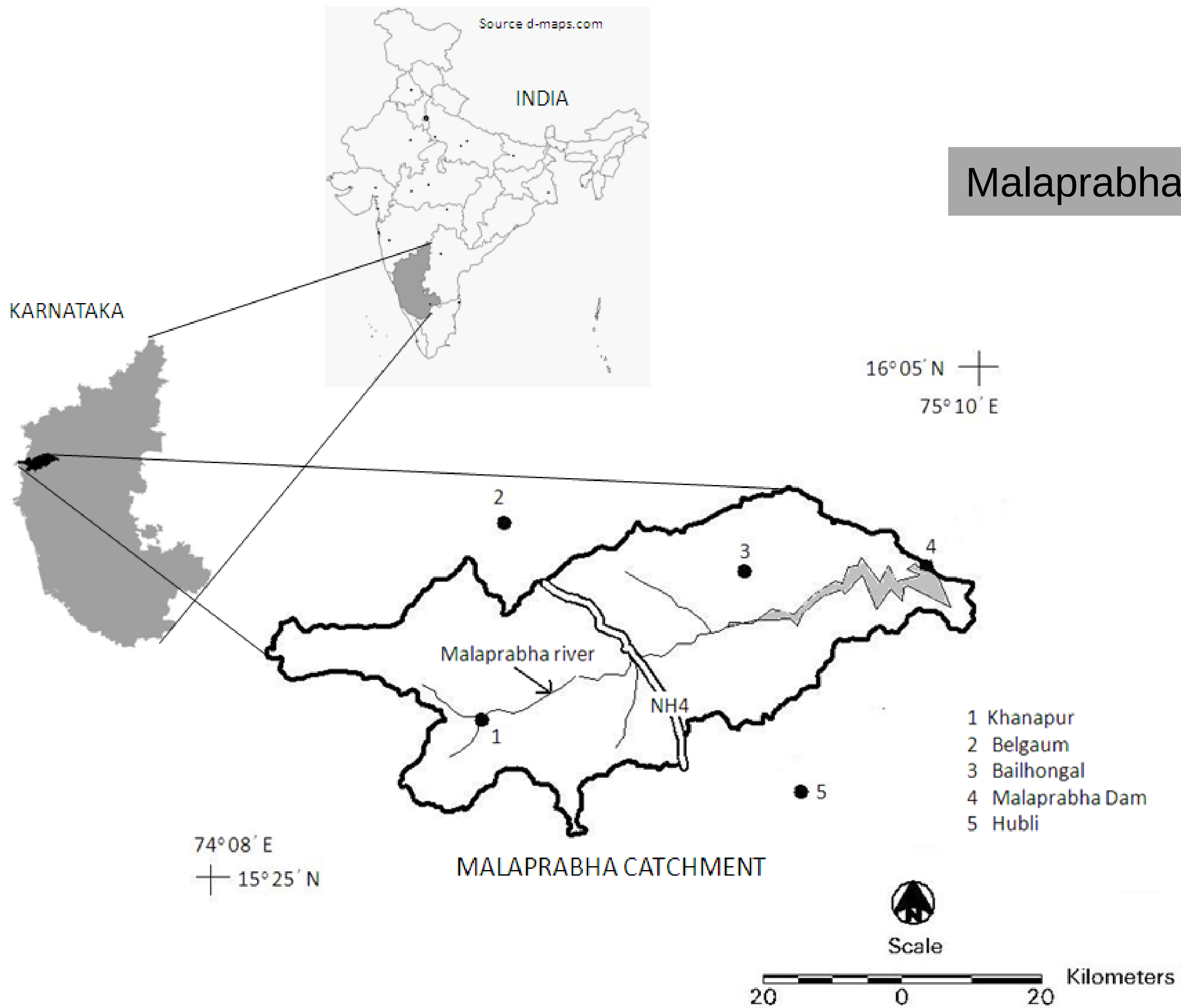
ε_i = *I*rrigation efficiency

A_i = Area of the i^{th} HRU in the sub-basin

s = Aquifer specific yield in the sub-basin

Study Area

Malaprabha Catchment in India



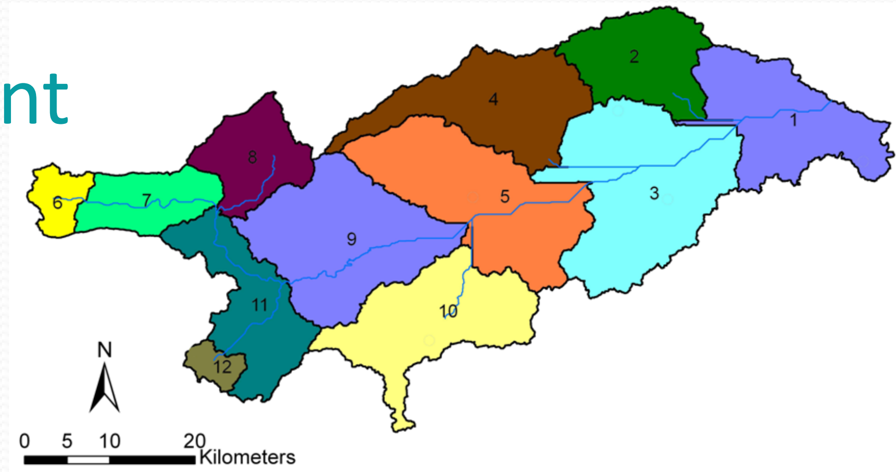
Study Area Description

- Climatology: Tropical humid to semi-arid
- Agricultural watershed
- Major crops: paddy, sugarcane, oil seeds, cereals and pulses, mostly irrigated
  - DES statistics shows that the net irrigated area and groundwater irrigated area have almost doubled in the last three decades.
- Geology: Greywacke/Argillite, pink granite, basalt
- Agriculture intensification multiplied the irrigation demand
- Large scale groundwater extraction for irrigation
- Drastic groundwater table depletion

Database for the Model

- DEM : ASTER DEM of 30m resolution
- Soil map : NBSS & LUP (Nagpur)
- Land use/ Land cover map: Landsat-7 ETM+
- Rainfall : Multi-site rainfall data from DES, Bangalore
- Weather data : DES, Bangalore
- Stream flow : WRDO, Bangalore
- Groundwater table fluctuation

Model Setup for the Catchment



- Raster DEM→ Drainage network →

  12 Subbasins
- LU/LC + Soil + Slope → HRUs
- Crop management practices were manually defined
- Irrigation is enabled when plant stress reaches 0.95
- Irrigation source : Source outside the basin
- SCS-CN method → Surface runoff
- Hargraves method → Potential evapotranspiration
- Specific yield = 3% (following CGWB)
- Irrigation efficiency = 0.4 for flood irrigation (Narayanamoorthy, 2006)

Model Sensitivity Analysis for the Basin

- LH-OAT method in ArcSWAT is used for sensitivity analysis
  - Each parameter is divided into sub-ranges
  - Each sub-range is sampled only once
  - Output shows the influence of the parameter changed
- 14 parameters related to flow and groundwater
- Sensitive parameters are
  - RCHRG_DP (Deep aquifer percolation coefficient)
  - EPCO (Plant uptake compensation factor)
  - CN2 (Curve number)

Model Calibration for the Basin

- Sensitive parameters were **manually** calibrated for **stream flow** as well as the **groundwater table fluctuation**

Rank	Parameter	Calibrated value	Range for good simulations
1	RCHRG_DP	0.01-0.8	0 – 0.8216
2	EPCO	1	0 – 0.888
3	CN2	CN2-20 to CN2+5	CN2-20 to CN2+24*
4	ALPHA_BF	0.01	0.01-0.9
5	SOL_K	2.19-4.86	-23.6 to 22.5 (%)*
6	GW_delay	31	0 – 46.34
7	CH_K2	5.0	0 - 4.75
8	CH_N2	0.03	0 – 0.029
9	GWQMN	Default value	0 – 979.2
10	SOL_AWC	0-3 times the observed values	-24.9 to 24.3(%)*
11	GW_revap	0.2-0.5	0 – 0.495
12	SURLAG	4	0.056 – 9.98
13	REVAPMN	Default values	0 – 99.43
14	ESCO	0.1	0 – 0.9951

* Parameter changes are with respect to the calibrated values

Model Calibration and Validation for Streamflow

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(o_i - m_i)^2}$$

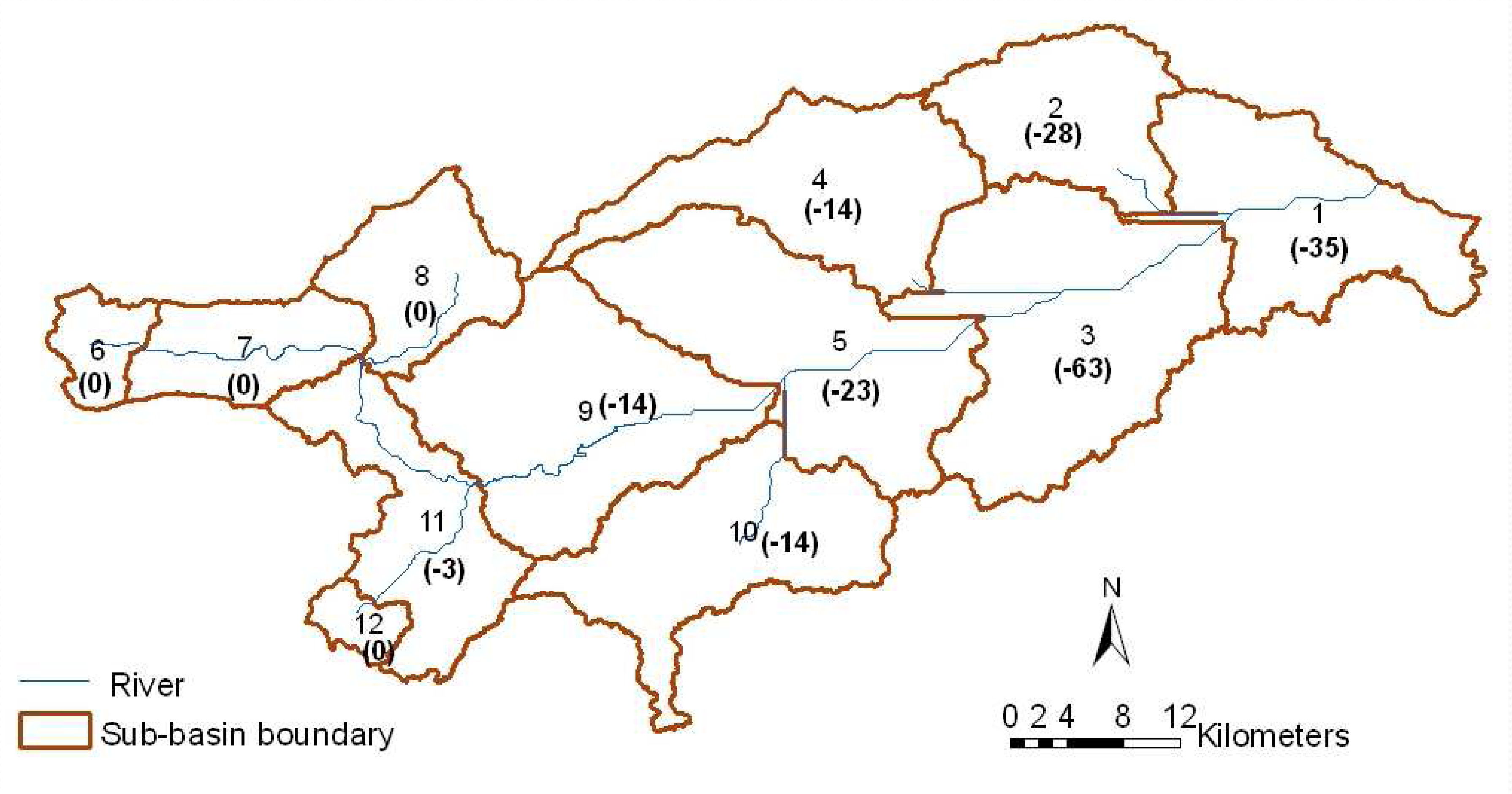
$$NMSE = \frac{\frac{1}{N}\sum_{i=1}^{N}(o_i - m_i)^2}{\sigma_{obs}^{\;2}}$$

$$NSE = \frac{\frac{1}{N}\sum_{i=1}^{N}(o_i - m_i)^2}{\frac{1}{N}\sum_{i=1}^{N}\left(o_i - \overline{o}\right)^2}$$

Statistical index	Calibration period (1992-1999)	Validation period (2000-2003)
Correl. Coeff.	0.963	0.961
RMSE	41.34 (M.cu.m)	18.10 (M.cu.m)
NMSE	0.074	0.075
NSE	0.925	0.923

o_i = Observed data
m_i = Model output
N = Total number of observations
σ_{obs} = Standard deviation of the observed data

GWT Depletion in the Basin During the Calibration Period



Summary & Conclusions

- ArcSWAT was used to study the impact of excessive water extraction on the groundwater resources
- ArcSWAT is clubbed with a water balance model to overcome the limitation on the maximum initial storage in the deep aquifer
- The model was applied to the Malaprabha catchment in India
- The model was found to be giving very good estimate of the stream flow.
- The groundwater table simulation shows drastic groundwater table depletion due to the excessive groundwater extraction in the semi-arid parts of the catchment
- The model is helpful to get a general picture of the groundwater scenario in the area.

Thank you for your attention

Acknowledgement
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