



Hydrological Modelling with SWAT

Lecture 1

- Hydrological modelling and the SWAT model

Lecture 2

- Model performance evaluation and calibration

Assignment

- A model set-up and analysis for a study catchment
- Evaluation: Poster 70% + Presentation 30%
- Timeline
 - Before 18th Dec to submit a protocol
 - In January to submit poster and to present

Aim of the course

- Understand the concept of hydrological modelling and the SWAT model
- Understand the calibration and the statistical evaluation of the model performance
- Apply the SWAT by setting-up a model for a study catchment, evaluate the model's reliability and perform scenario analysis.

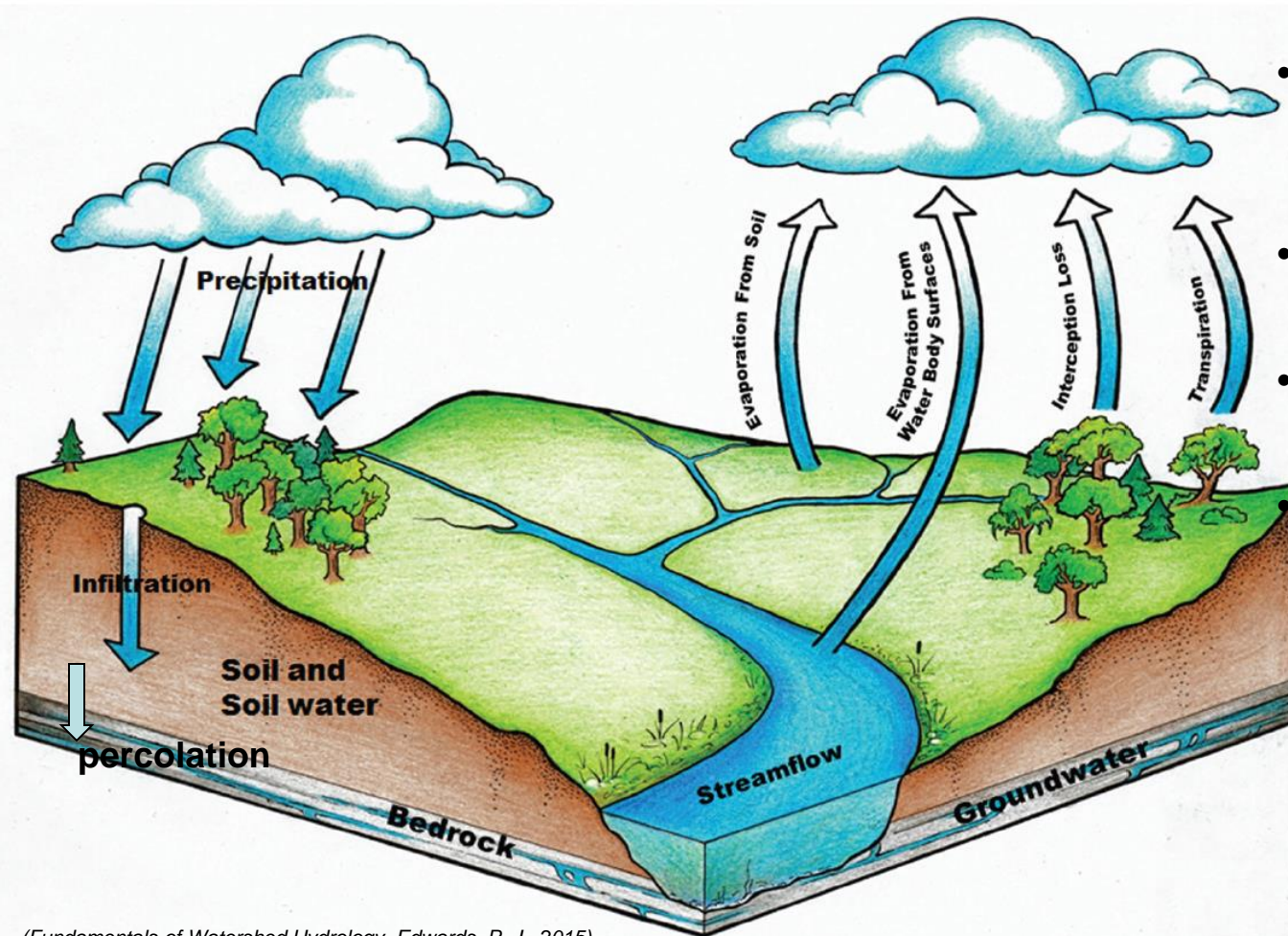
1. Hydrological modelling
2. SWAT model - The theory
3. SWAT model application - A case study
4. Overview of input data and data sources
5. Set-up a SWAT model demonstration
6. QSWAT installation

Part 1 – Hydrological modelling

- Hydrological process
- Hydrological modelling
- GIS with hydrological modelling

Part 1

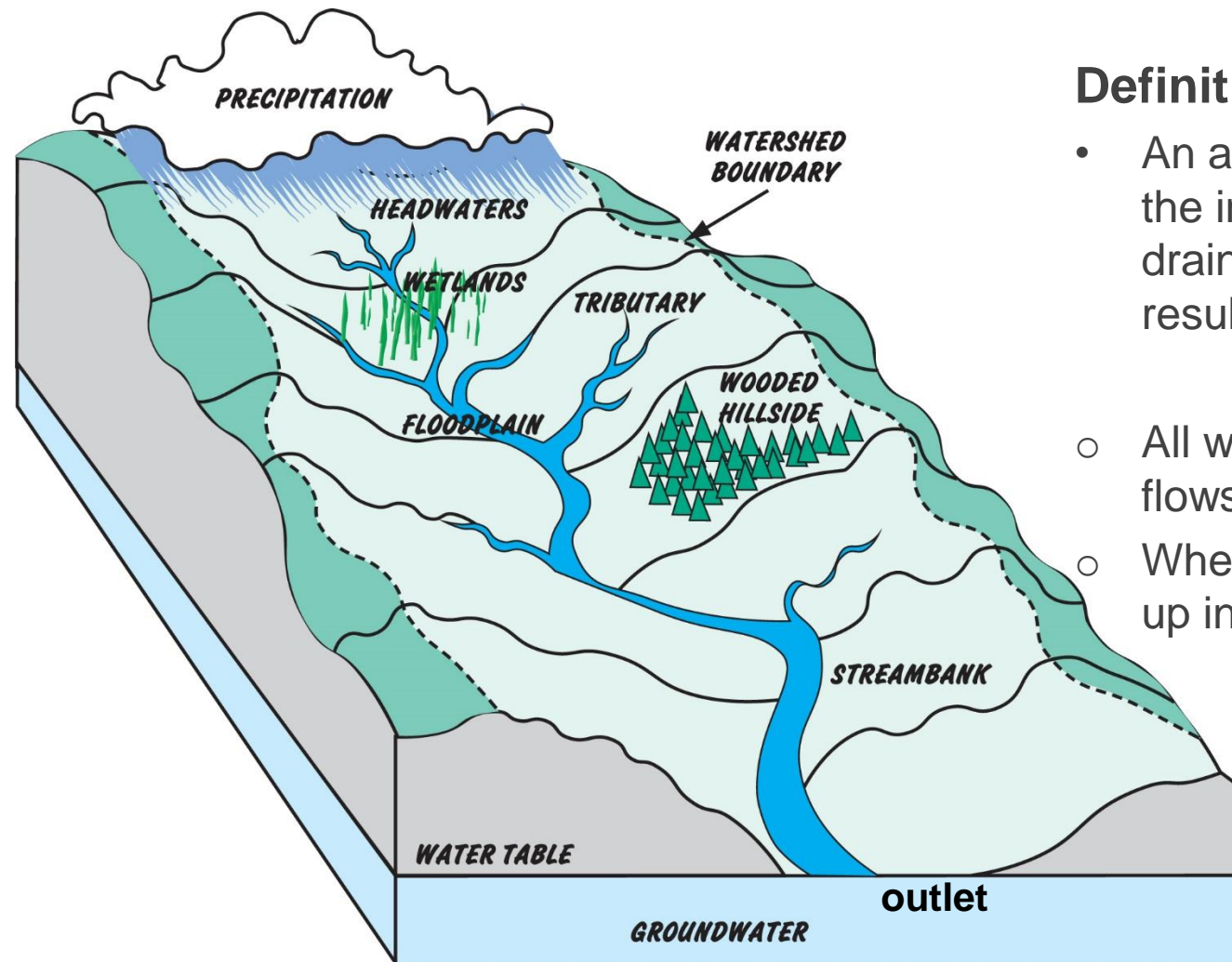
The hydrological cycle



- Where does the water on the earth come from?
- How is the water moving around?
- How is the water back to the atmosphere?
- What moves together with the water?

Part 1

Watershed – the spatial unit of hydrology



Definition

- An area of land in which all of the incoming precipitation drains to the same place as a result of its topography.
 - All water falling on the surface flows downhill.
 - Wherever rainfalls, it will end up in the same place
-
- Basin/Catchment

Part 1

Watershed – Water balance equation

$$P - Q - E = \Delta S$$

- The flux transferring or storing in the hydrological cycle
 - Flux: a rate of flow of some quantity

P	Q	E	ΔS
<input type="checkbox"/> Precipitation	<input type="checkbox"/> Runoff	<input type="checkbox"/> Evapotranspiration	<input type="checkbox"/> Storage change
<input type="checkbox"/> Rainfall	<input type="checkbox"/> Surface runoff	<input type="checkbox"/> Plants	<input type="checkbox"/> Soil moisture
<input type="checkbox"/> Snowfall	<input type="checkbox"/> Lateral flow	<input type="checkbox"/> Open waterbody	<input type="checkbox"/> Plant interception
<input type="checkbox"/> Hail,...	<input type="checkbox"/> Groundwater flow	<input type="checkbox"/> Soil surface	<input type="checkbox"/> Groundwater
			<input type="checkbox"/> Waterbody

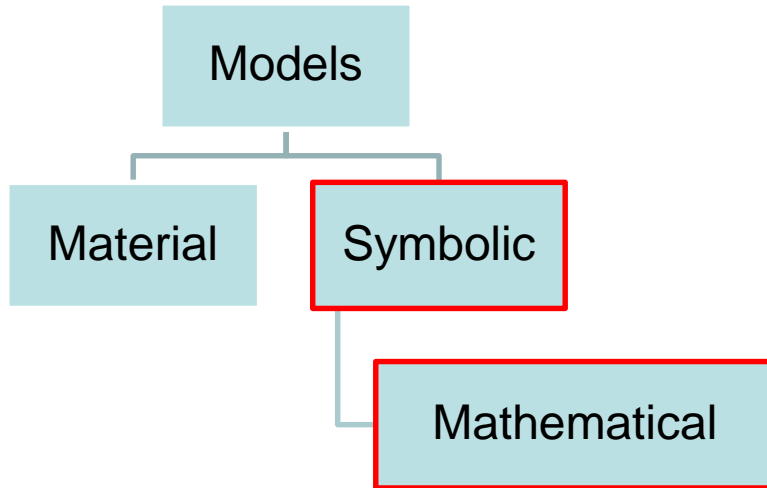
Unit: e.g. mm/day

Time span: subdaily, daily, monthly, annually

- **Hydrological modelling**
 - Model components
 - Model category

Part 1

Hydrological modelling



(Defined by Singh and Chow, 1988)

To use symbolic expression in logical terms of an idealised, relatively simple situation sharing the structural properties of the original system.

Equations to describe the system

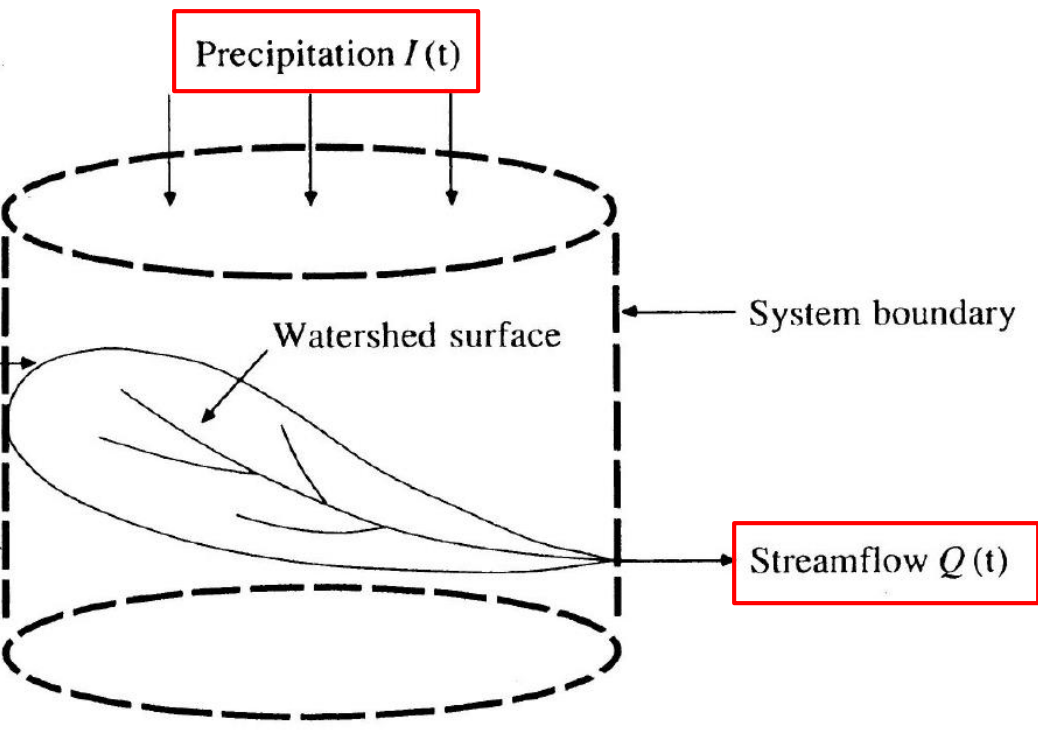
- An approximation of the actual complex system

Aim:

- A better understanding of the hydrologic phenomena operating in a catchment and of how changes in the catchment may affect these phenomena.
- The generation of hydrological data for facility design or for use in forecasting

Part 1

Hydrological modelling – Model components



(chow et al, 1988)

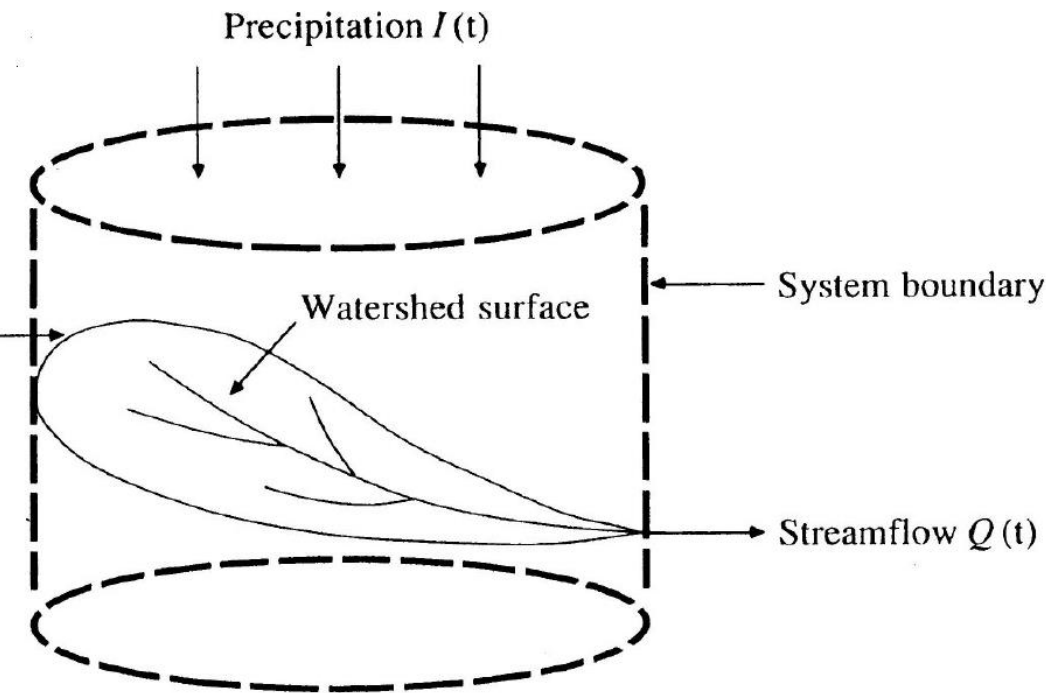
Input variable

Hydrological system

Output variable

Part 1

Hydrological modelling – Model components



(chow et al, 1988)

- **A variable**

A characteristic of a system which maybe measured, and might vary with time

- **A hydrological system**

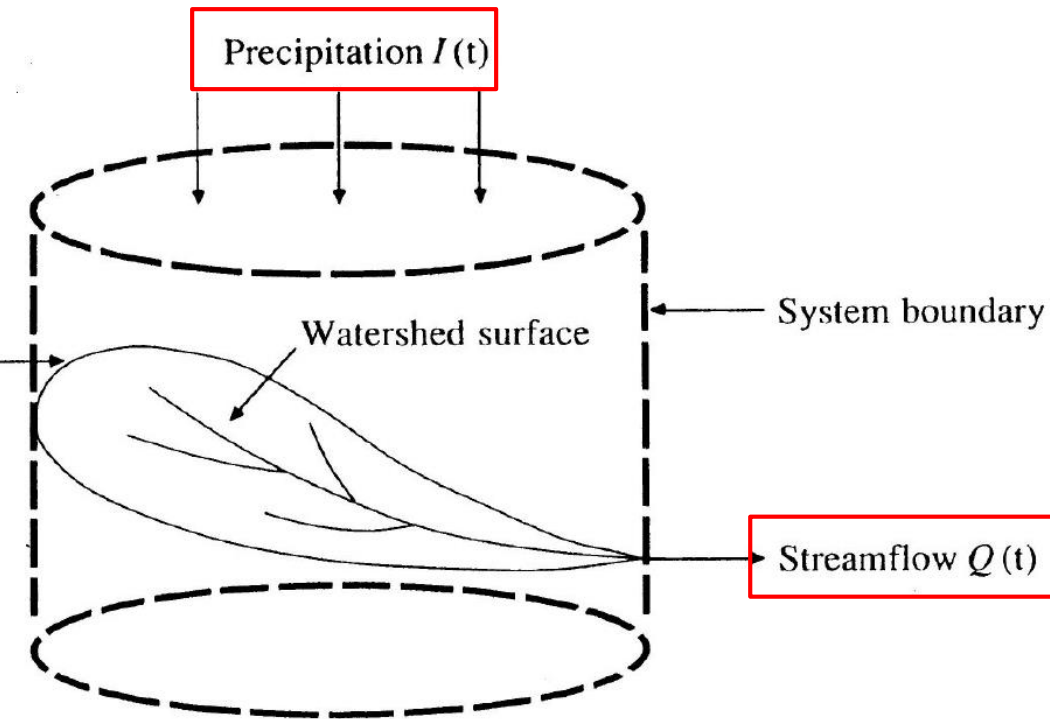
A set of physical, chemical, and/or biological processes acting upon input variables, to convert them into an output variable (Dooge, 1973)

- **A parameter**

A quantity to characterise the system

Part 1

Hydrological modelling – Model components



(chow et al, 1988)

- measured or simulated, but independent from the hydrologic system
- Simulated and relied on the input and the hydrological system

- How can the model to describe it properly?

Part 1

Hydrological modelling – Model category

By assumptions:

Theoretical

- A logical structure similar to the real-world system
- Mass, energy, momentum conservation
- e.g. diffusive wave equation for overland flow

Empirical

- Mathematical description between two or more parameters
- No need to have physical significance
- e.g. SCS curve number assumption

$$I_a \approx 0.2S$$

Represent different levels of approximation of reality.

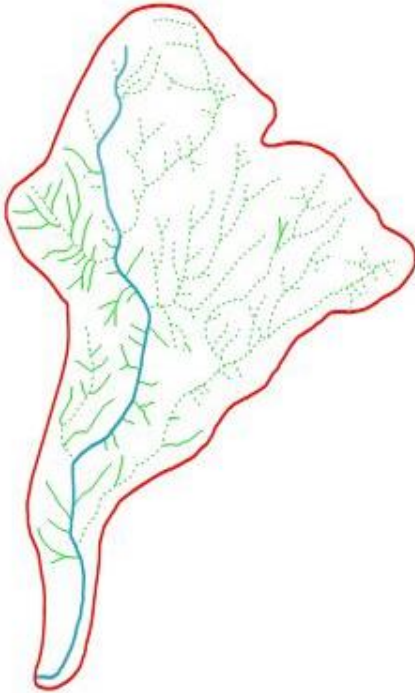
- Objective; complexity of the problem; degree of accuracy required

Part 1

Hydrological modelling – Model category

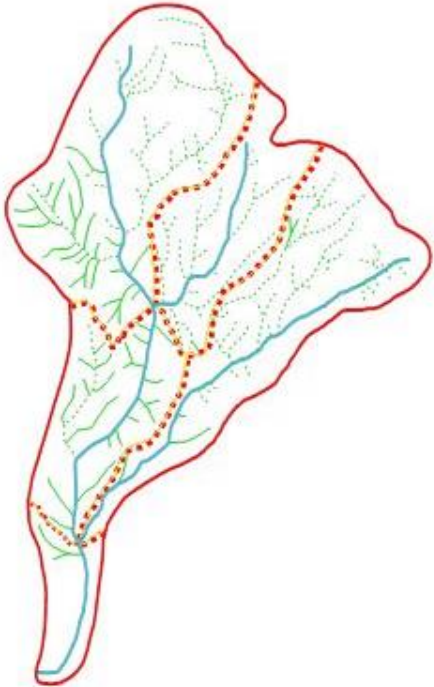
By spatial delineation:

Lumped



Homogeneous spatially

Semi-distributed



Homogeneous spatially

Distributed



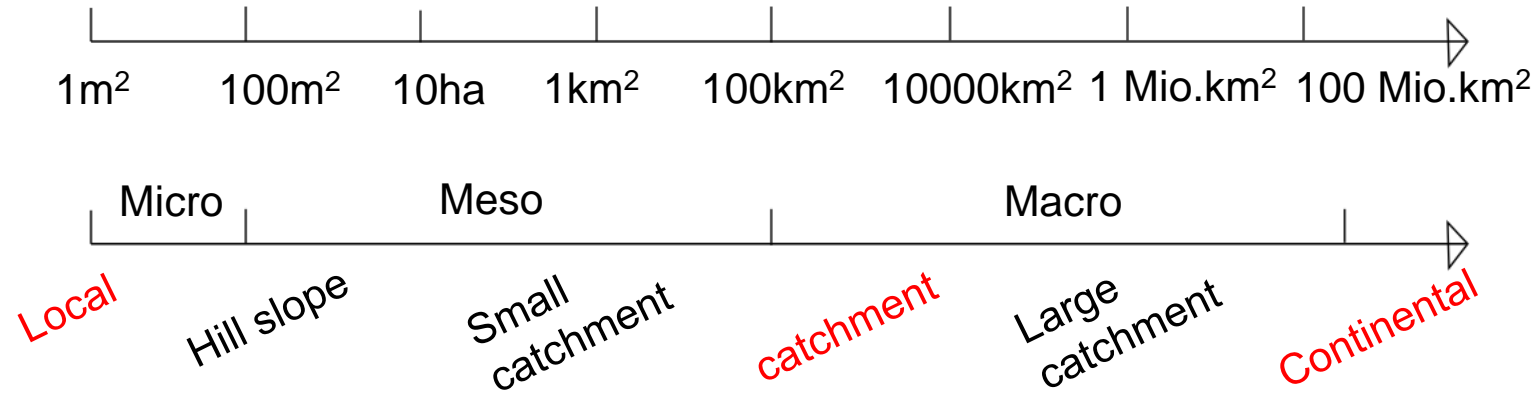
Homogeneous in the grid

Part 1

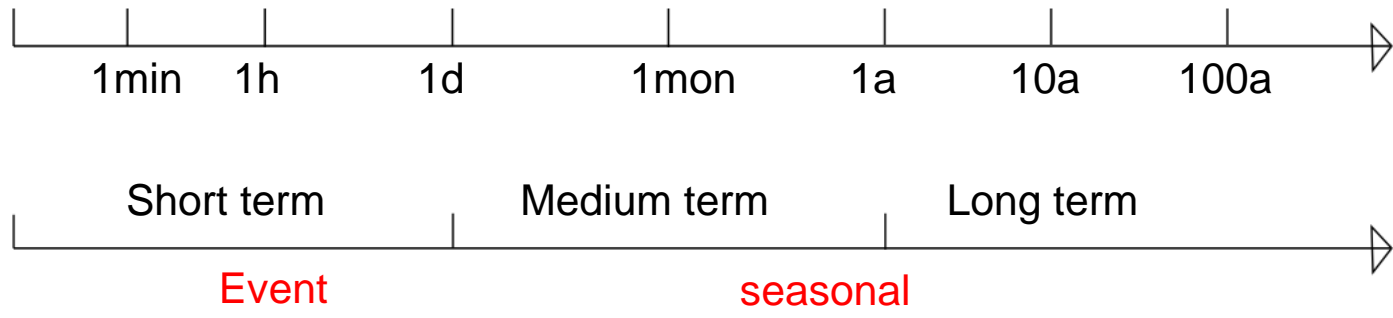
Hydrological modelling – Model category

By scale:

Spatial scale



Time scale



(Adapted from: Bronster, A.; Coupled models for the hydrological cycle, 2005)

- **ArcGIS with hydrological model**

- Geo-data processing

DEM, landuse, spatial distribution of climate data

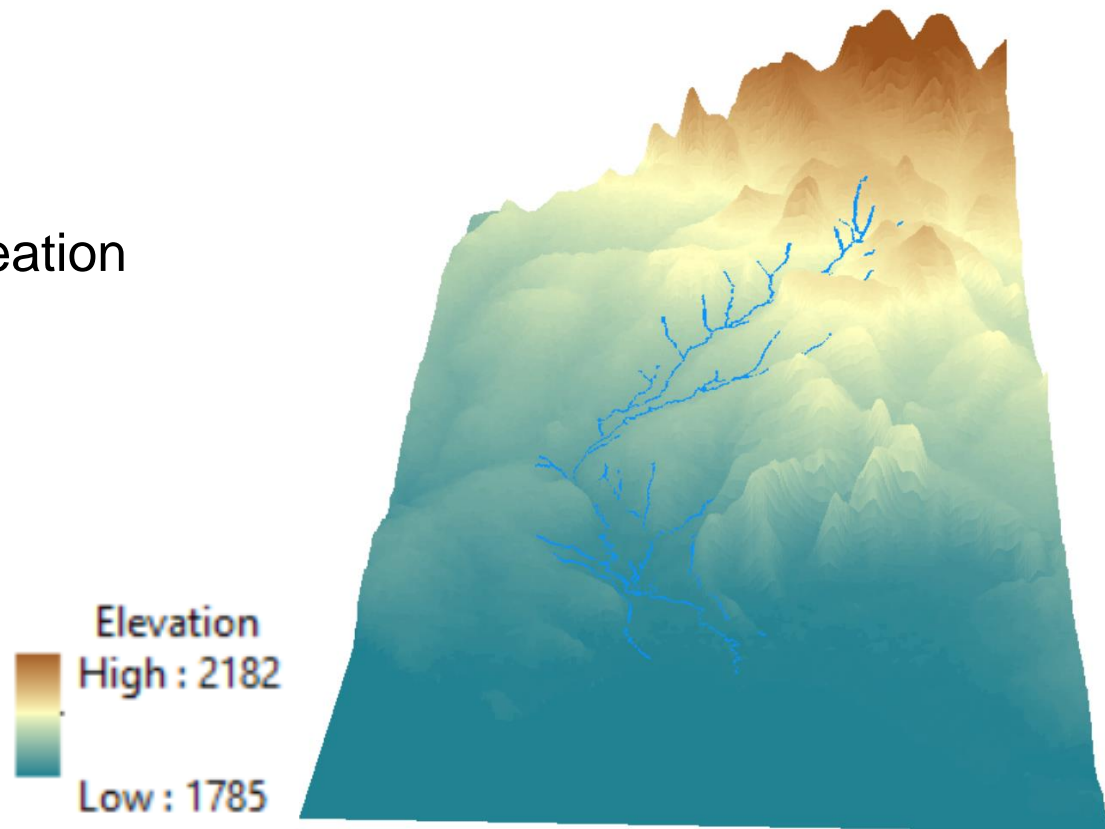
- QGIS/ArcGIS as a Geographical user interface (GUI)

GUI: It allows the use of icons or other visual indicators to interact with electronic devices, rather than using only text via the command line.

Part 1

ArcGIS with hydrological model

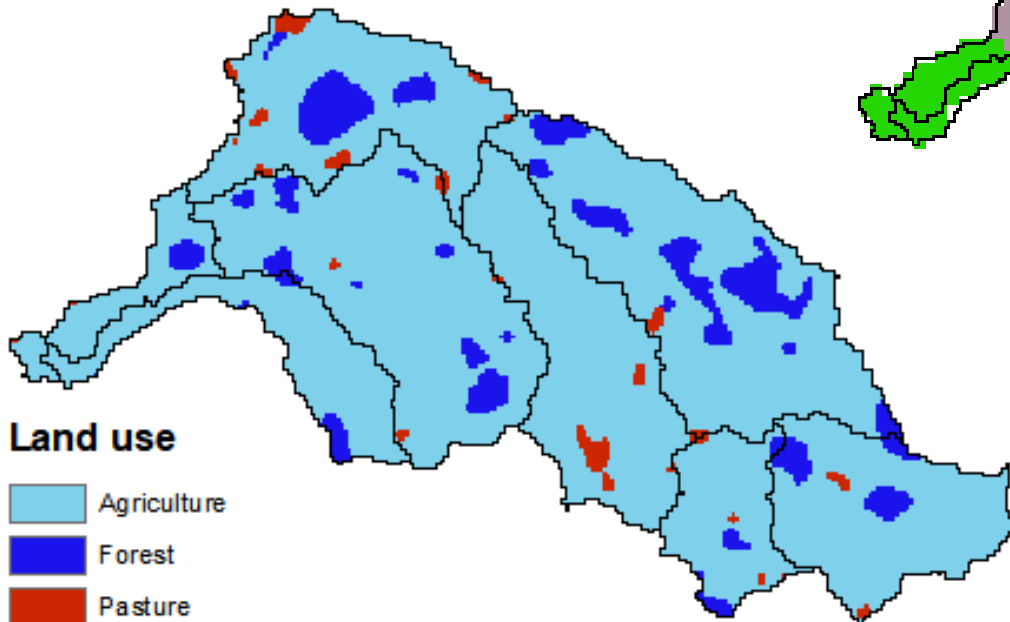
- DEM analysis – Hydrology
 - Slope
 - Flow direction
 - Watershed Delineation



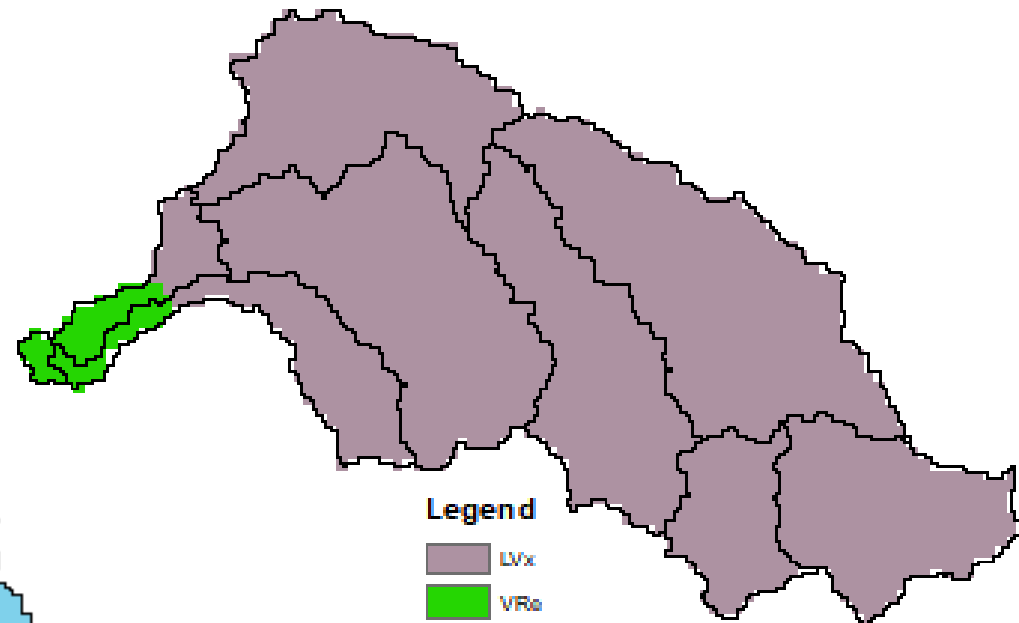
Part 1

ArcGIS with hydrological model

- Land use



- Soil type



Part 2 – Approaches used by SWAT

- SWAT introduction
- Approaches to simulate the hydrological processes
- SWAT application: a case study

Part 2

SWAT model introduction



SWAT – Soil and Water Assessment Tool, is a river basin, or watershed scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service.

SWAT was developed 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.

8 components: climate, hydrology, nutrients/pesticides, erosion, land use/plant, management practices, channel processes, water bodies.

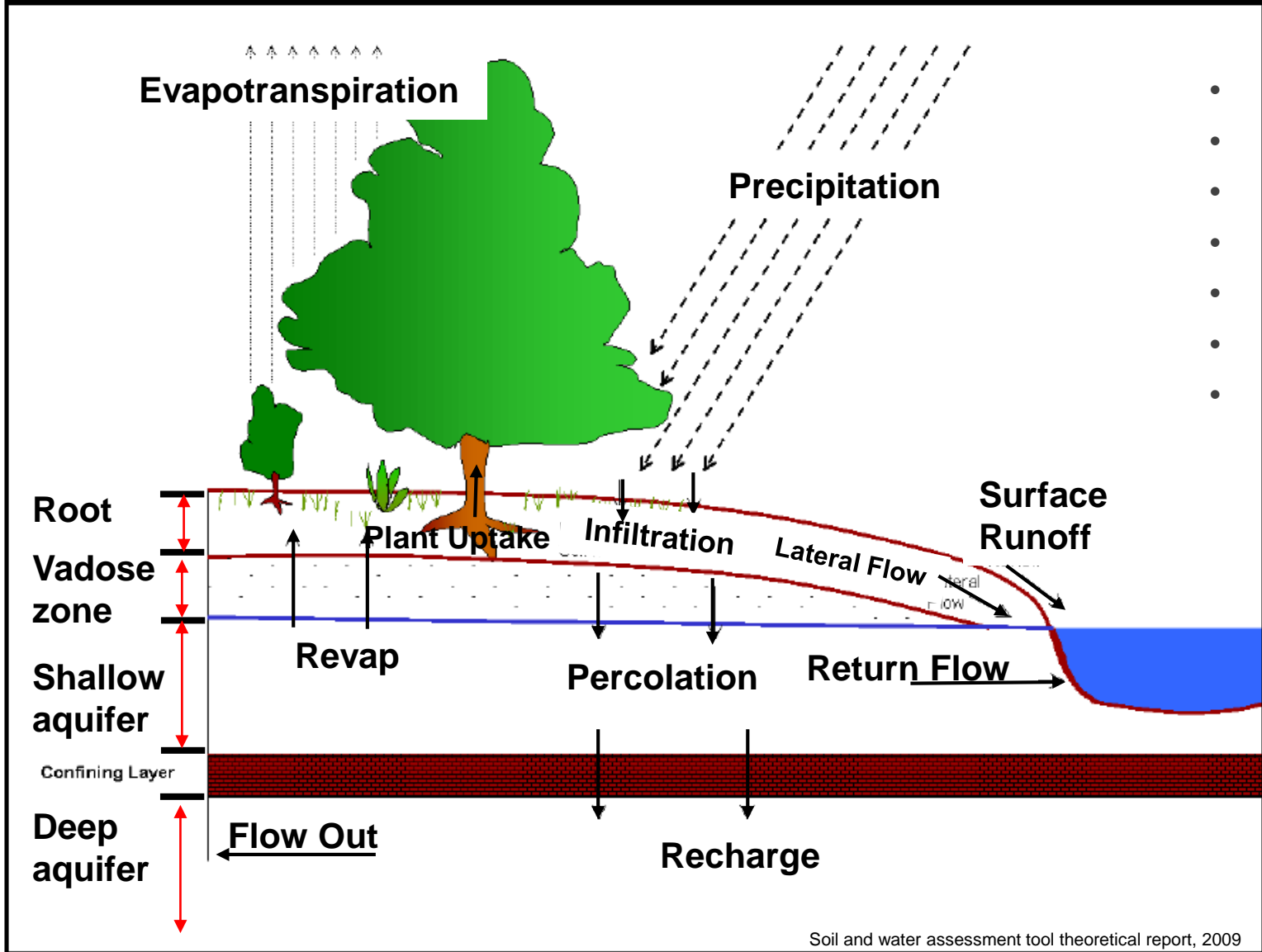
Part 2

SWAT model features

- **Physically based**
 - specific information about the catchment
 - Suitable for large catchments/basins, even continents
- **Semi-distributed**
 - HRU: hydrologic response unit (overlay of specific landuse, soil and slope)
 - Not lumped, not fully-distributed
 - Computationally efficient
- **Long term impacts**
 - Long-term effect (10~30 years)
 - Temporal scale: daily/monthly/annually
 - Not suitable for single event storm simulation
- **Readily available datasets**

Part 2

Hydrology component



- Water balance
- Surface runoff
- Infiltration
- Evapotranspiration
- Soil water
- Groundwater
- Channel process

Part 2

Water balance

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

SW_t – final soil water content

SW_0 – initial soil water content

R_{day} – precipitation

Q_{surf} – surface runoff

E_a – evapotranspiration

w_{seep} – the amount of percolation flow exiting the soil profile bottom

Q_{gw} – groundwater flow enters the channel (return flow)

Unit – mm H₂O

t – is the time span to apply the equation

Part 2

Surface runoff

Method: SCS curve number

$$\begin{cases} Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \\ S = 25.4 \left(\frac{1000}{CN} - 10 \right) \\ I_a \approx 0.2 S \end{cases} \quad \longrightarrow \quad CN \rightarrow Q_{surf}$$

- I_a is the initial abstraction and S is the potential storage
- CN is the curve number (CN↑ potential of runoff↑), a function of the soil's permeability, landuse and antecedent soil water condition.
- Empirical equation, CN is subjective



(www.progressivereform.org)



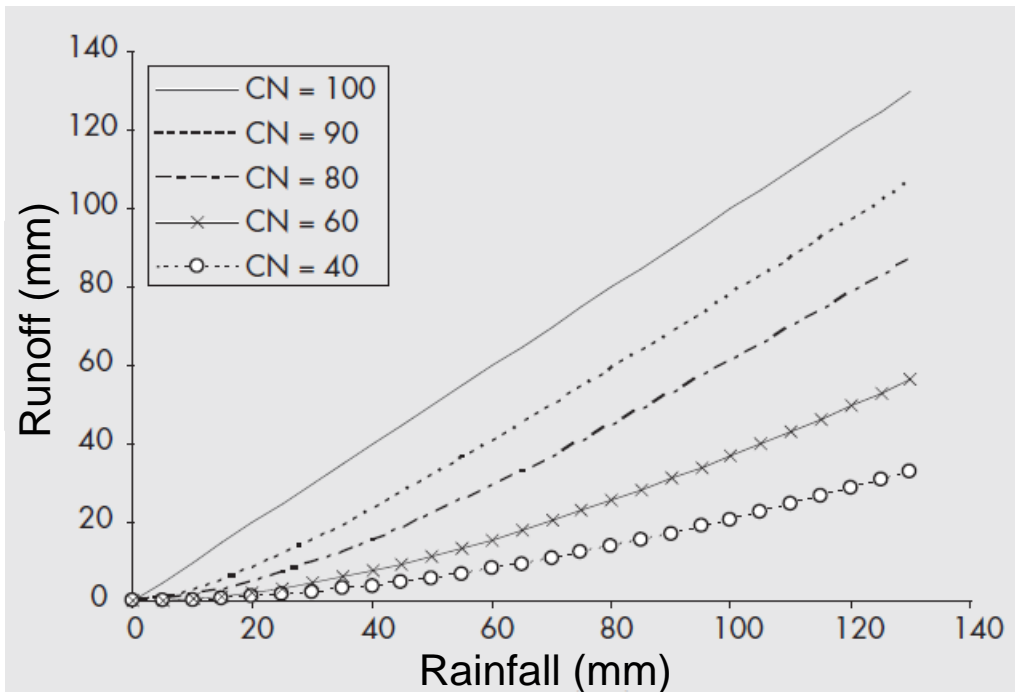
(upload.wikimedia.org)

Part 2

Hydrological analysis – Rainfall and runoff

$$\left\{ \begin{array}{l} I_a \approx 0.2 S \\ S = \frac{25400}{CN} - 254 \end{array} \right. \longrightarrow Q_{surf} = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

CN is the curve number (0 ~ 100)



(Tim Davie, Fundamentals of Hydrology, 2002)

- Soil infiltration rate
(soil hydrologic groups: A, B, C, D; by U.S. NRCS)
- Land use
- Antecedent soil moisture condition
(dry, average moisture, wet)
- Slope

CN

Urban Areas

Cover description	Average percent impervious area ^{2/}	Curve numbers for hydrologic soil group			
		A	B	C	D
<i>Fully developed urban areas (vegetation established)</i>					
Open space (lawns, parks, golf courses, cemeteries, etc.) ^{3/} :					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) ^{4/}		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
<i>Developing urban areas</i>					
Newly graded areas					
(pervious areas only, no vegetation) ^{5/}		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

Part 2

Evapotranspiration

- Potential Evapotranspiration:

- Penmen-Monteith
- Hargreaves equation

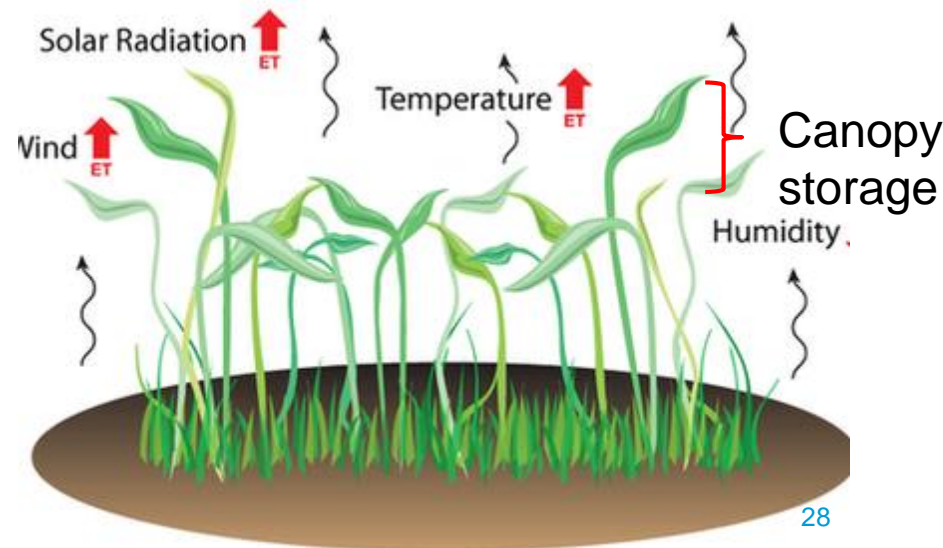
- Actual Evapotranspiration:

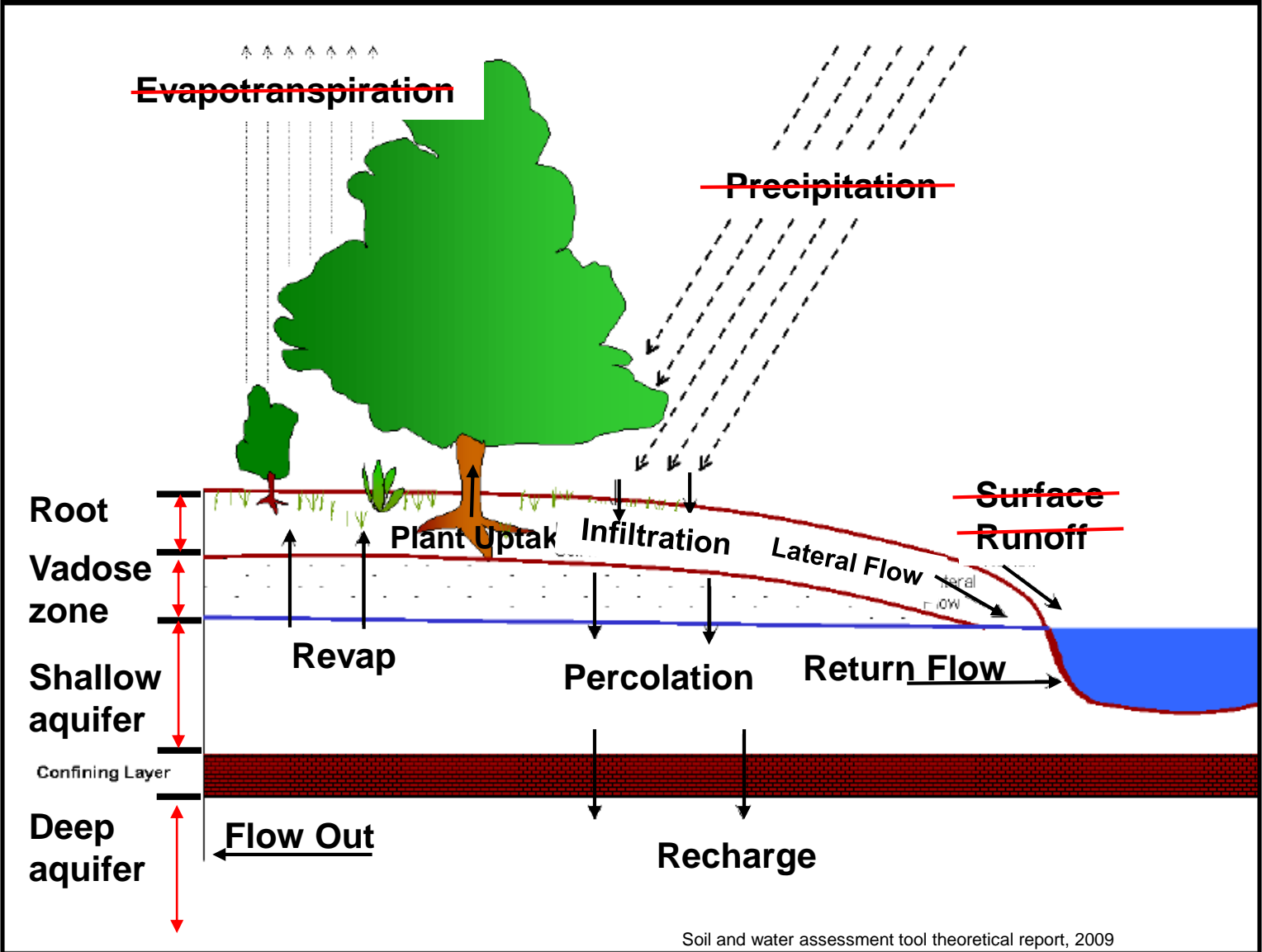
- Evaporation
 - Canopy interception
 - Soil (depth, biomass, residue)
- Transpiration
 - Leaf Area Index (LAI)
 - Potential E

Penmann-Monteith equation:

$$PET = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 \delta_e}{\Delta + \gamma(1 + 0.34u_2)}$$

- PET* – potential evapotranspiration
- R_n* – net radiation at the crop surface ← Solar radiation
- G* – soil heat flux density
- γ* – psychrometric constant
- u₂* – wind speed at 2m height
- δ_e* – saturation vapour pressure deficit ← Relative humidity
- T* – mean daily air temperature at 2m height





Soil and water assessment tool theoretical report, 2009

Infiltration rate

- Green & Ampt infiltration method
- Assumptions
 - Soil profile homogenous
 - Antecedent moisture is uniformly distributed in the profile
 - Soil above the wetting front is completely saturated
 - There is a sharp break in moisture content at the wetting front

$$f_{inf,t} = K_e \cdot \left(1 + \frac{\Psi_{wf} \cdot \Delta\theta_v}{F_{inf,t}} \right)$$

Soil properties:

- Saturated hydraulic conductivity
- Bulk density
- Porosity
- Clay and sand content

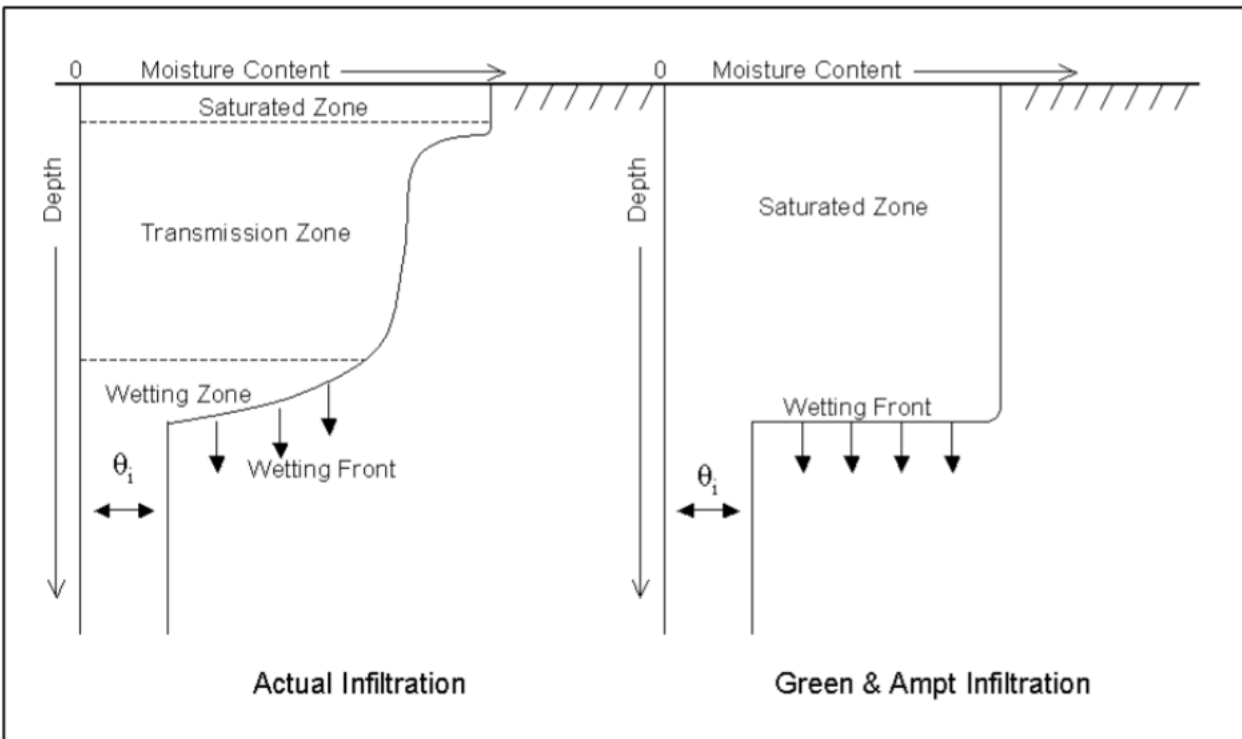
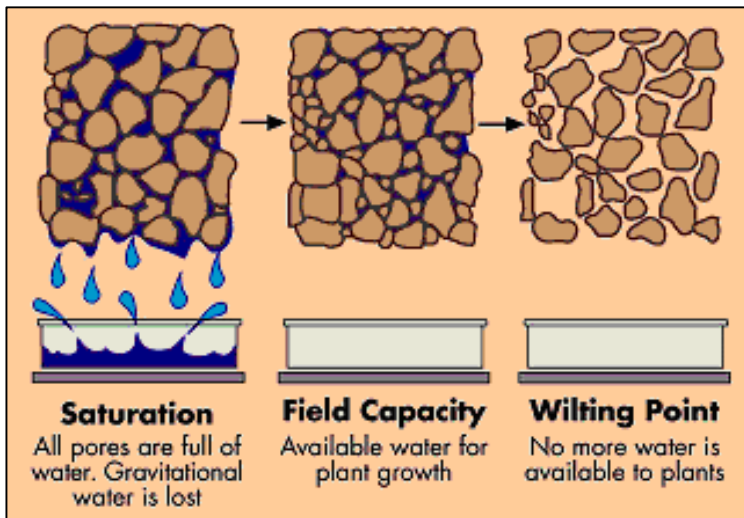


Figure 2:1-2: Comparison of moisture content distribution modeled by Green & Ampt and a typical observed distribution.

Part 2

Soil water

- Majority of the soil water is uptaken by plants
- Saturation, field capacity (FC), wilting point (WP), plant available water capacity (AWC)



$$FC = WP + AWC ;$$

- WP – proportional to bulk density and clay content
- AWC – crop individual parameter

- Percolation assumptions: when the water content $>$ FC, percolation starts

Storage routing methodology

- $W_{perc,ly} = SW_{ly,excess} \left(1 - \exp \left[-\Delta t / TT_{perc} \right] \right)$
- $TT_{perc} = \frac{SAT - FC}{K_{sat}}$

Part 2

Groundwater

- Water balance

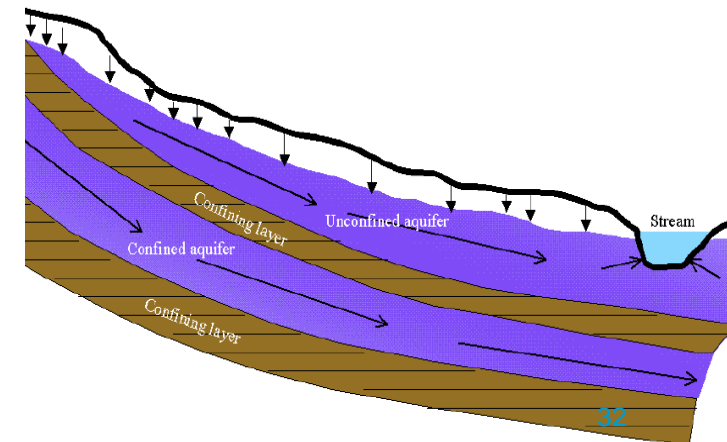
$$aq_{sh,i} = aq_{sh,i-1} + w_{rchrg,sh} - Q_{gw} - w_{revap} - w_{pump,sh}$$

- Recharge: $w_{rchrg,sh}$

- ❑ Function of water existing at the bottom of the soil profile and drainage time
- ❑ Partition between shallow and deep aquifer

Table 2:4-1: SWAT input variables used in shallow aquifer calculations.

Variable name	Definition	File Name
GW_DELAY	δ_{gw} : Delay time for aquifer recharge (days)	.gw
GWQMN	$aq_{shthr,g}$: Threshold water level in shallow aquifer for base flow (mm H ₂ O)	.gw
ALPHA_BF	α_{gw} : Baseflow recession constant	.gw
REVAPMN	$aq_{shthr,rvp}$: Threshold water level in shallow aquifer for revap (mm H ₂ O)	.gw
GW_REVAP	β_{rev} : Revap coefficient	.gw
RCHRG_DP	β_{deep} : Aquifer percolation coefficient	.gw
GW_SPYLD	μ : Specific yield of the shallow aquifer (m/m)	.gw



Part 2

Channel process

- Assumption
 - Channel: trapezoid, side slope: 0.5
- Steady state
 - Flow rate and velocity: Manning's equation
 - Water depth, Width of channel, length of the channel, n
 - Flow storage routing: kinetic wave model
 - $V_{stored} = Prism\ storage + Wedge\ storage$
- Balance:
 - Transmission loss
 - Evaporation
 - Diversion
 - Bank storage

$$q_{ch} = \frac{A_{ch} \cdot R_{ch}^{2/3} \cdot s l p_{ch}^{1/2}}{n}$$

$$v_c = \frac{R_{ch}^{2/3} \cdot s l p_{ch}^{1/2}}{n}$$

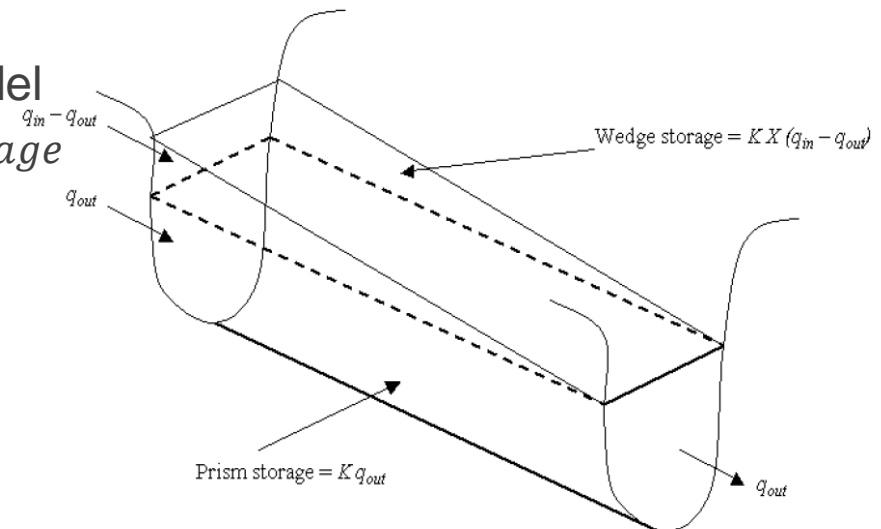


Figure 7:1-3: Prism and wedge storages in a reach segment (After Chow et al., 1988)

Part 2

Other components in SWAT

Climate	Meteological data	Simulation period, as driving force
	Historical meteological data	Weather generator, to generate missing data
Nutrient/Pesticide	Nitrogen Phosphorous Pesticide	Plant uptake, in-soil process, erosion, in-stream process
Erosion	Over land, instream, water body sediment	MUSLE approach
Water bodies	Reservoir Pond/wetland	Water balance
Land use/Plant growth	Growth cycle of plants based on heat unit theory	
Management strategies	Plant growth cycle, time of fertilizer/pesticide, removal of plant biomass	

Part 2

Nitrogen module in SWAT

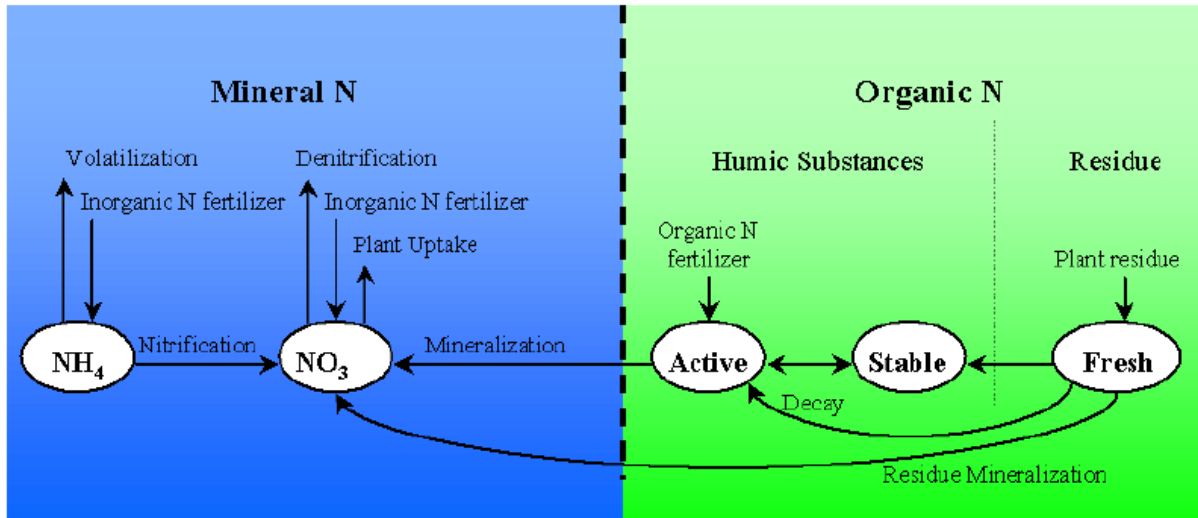


Figure 0.6: Partitioning of Nitrogen in SWAT (From: Soil and water assessment tool theoretical report, 2009)

- Both in-land and in-stream dynamic
 - Transformation + plant uptake
- Transport processes
 - Nitrate → runoff + infiltration
 - Organic N → erosion
- Catchment nitrogen input
 - Point sources: effluent from sewers
 - Non-point sources: waste from rural area, fertilizer, feedlots, atmospheric deposition and etc.

Phosphorus and sedimentation module in SWAT

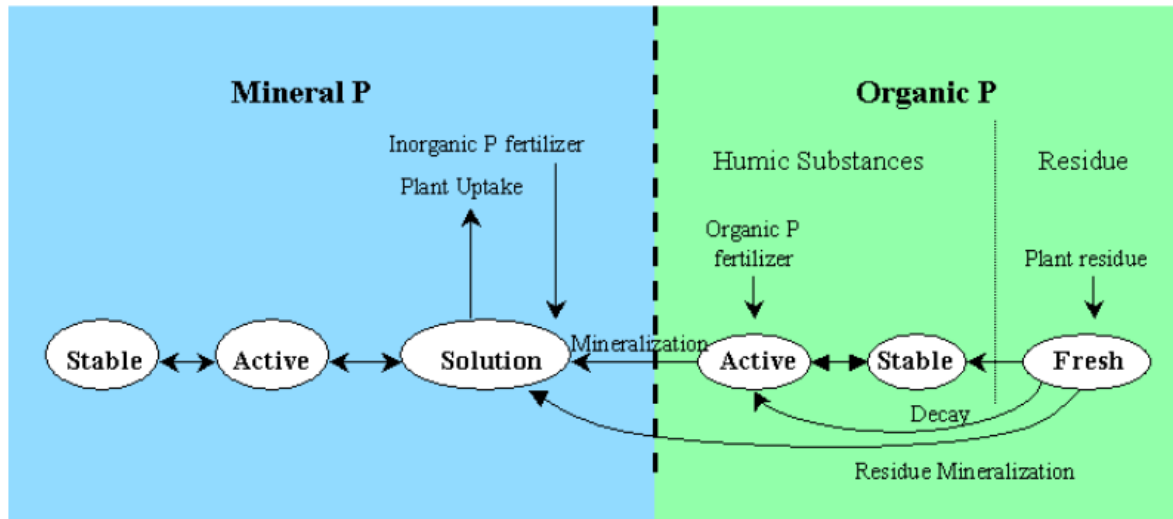


Figure 0.7: Partitioning of Phosphorus in SWAT

- Plant uptaken and erosion
- Low mobility of solution P

Erosion

MUSLE: modified universal soil loss equation

$$sed = 11.8 \cdot (Q_{surf} \cdot q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG$$

- Runoff rate; soil erodibility factor; etc.

Part 2

Plant growth module in SWAT

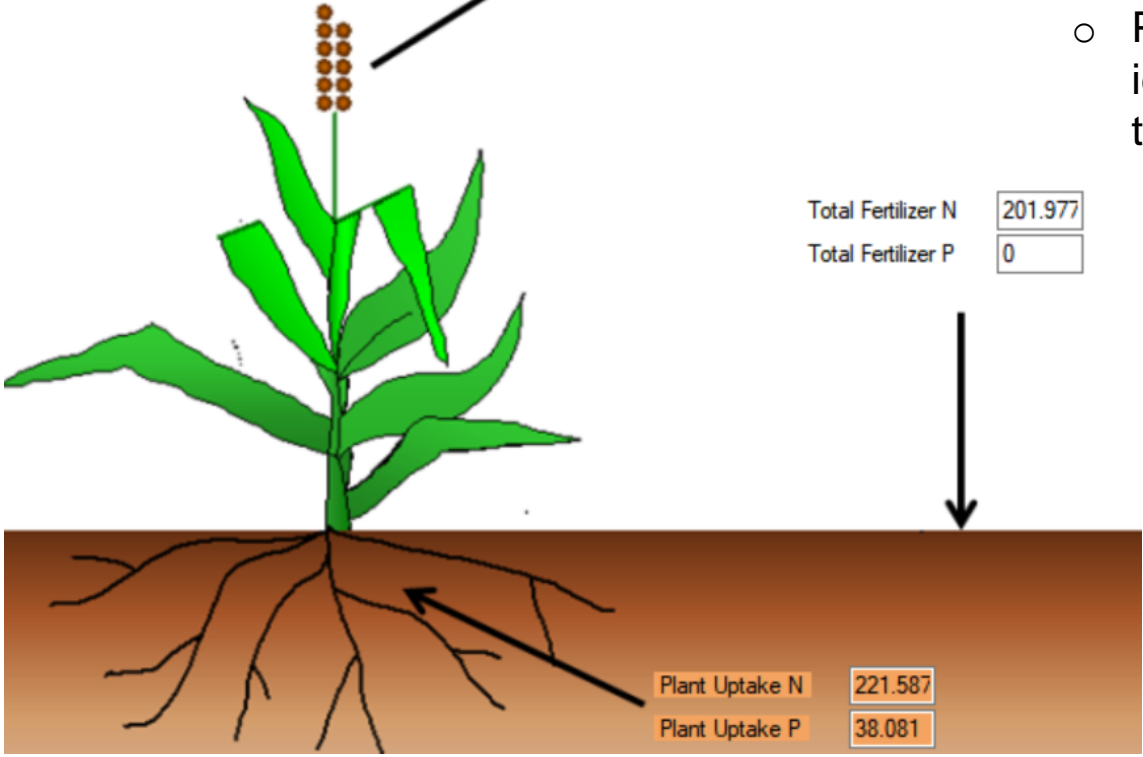
Average Biomass (Mg/ha)
Average Yield (Mg/ha)

All Units kg/ha

N Removed in Yield
P Removed in Yield

- Heat Unit approach
 - Heat accumulated if temperature above a threshold
 - Plants specific parameters to identify the respective heat needed to go mature

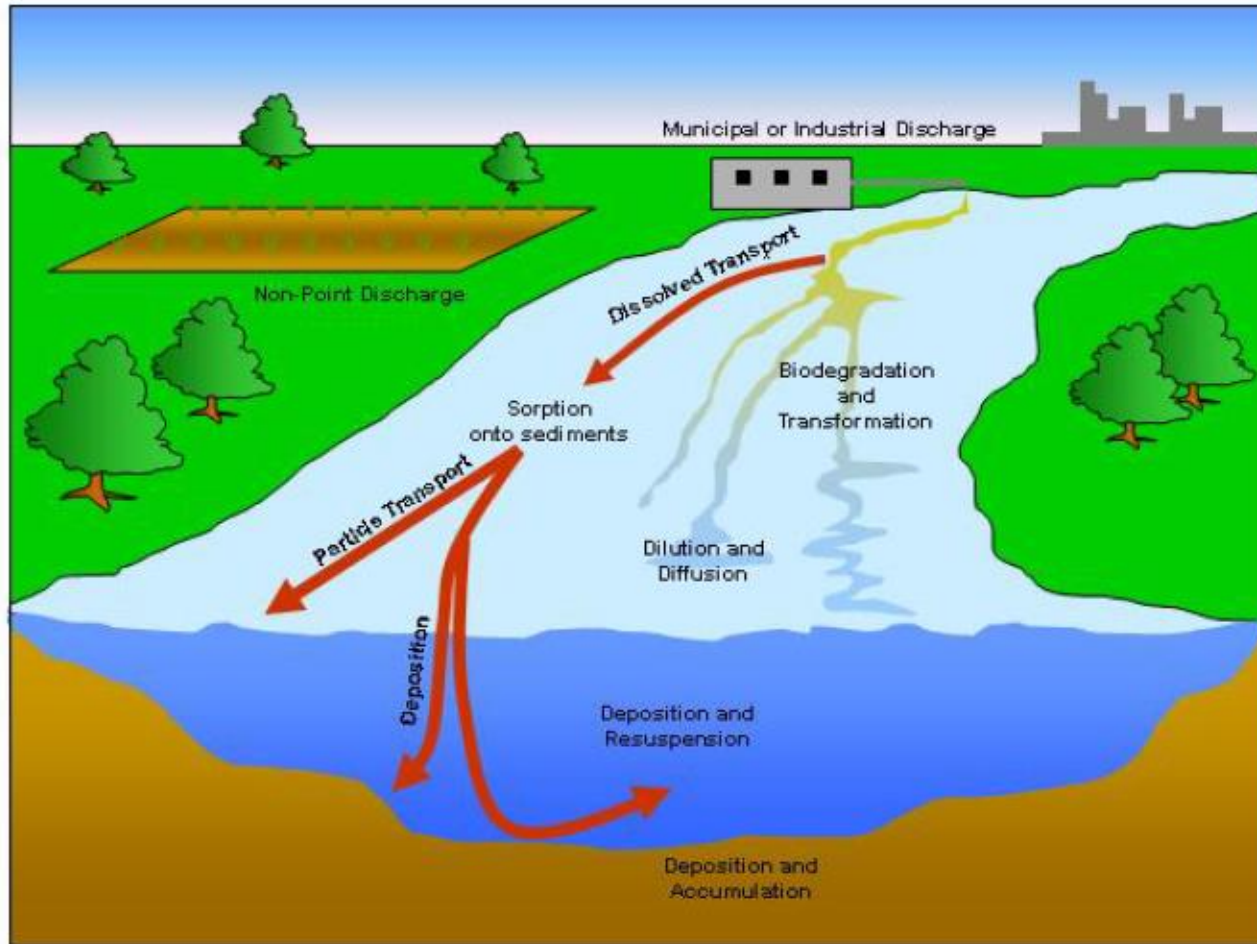
Total Fertilizer N
Total Fertilizer P



Plant Uptake N
Plant Uptake P

Part 2

In-stream module in SWAT



- Load from point and non-point source aggregated at each outlets
- QUALE2 model
 - Algae growth rate
 - Hydrolysis rate
 - Settling
- Computational unit
 - channel (upstream to downstream)

Figure 0.9: In-stream processes modeled by SWAT

Part 3 – A case study

- Catchment overview
- Problem identification
- Model results analysis

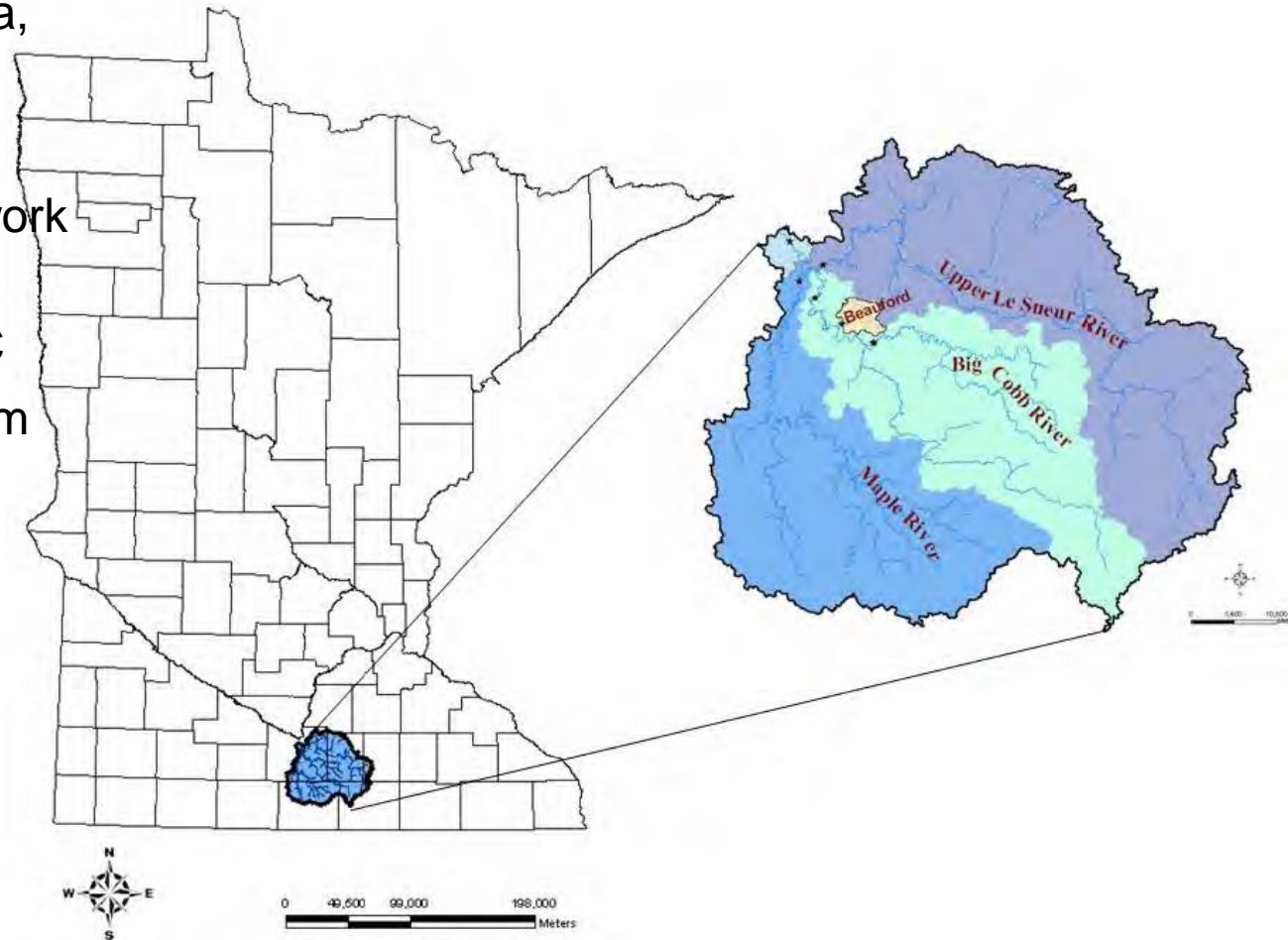
Part 3

Case study – Le Sueur River Watershed (LRW)

Brandenburgische
Technische Universität
Cottbus - Senftenberg

- South central Minnesota, 2850 km²
- Precipitation: 800mm
- 41% of the stream network is perennial
- T: min -11°C, max 22°C
- Elevation: 223m to 418m
- Land use: 70% corn/soybean, 2 year rotation

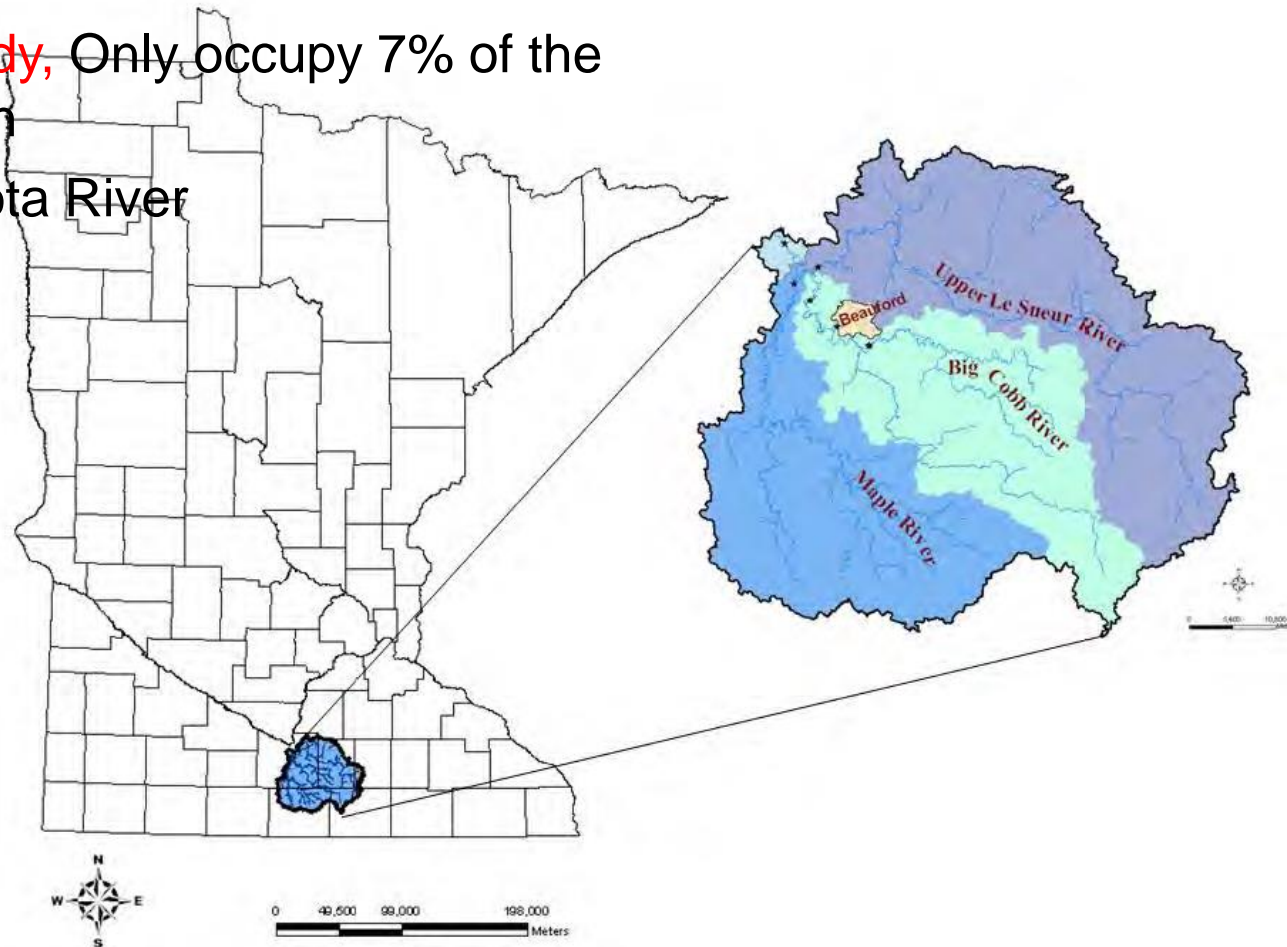
- Population: 56100
- Livestock: 1.1 million



Part 3

Problem identification

- An impaired water body, Only occupy 7% of the Minnesota River Basin
- Contribute to Minnesota River
 - Sediment: 53%
 - NO₃-N: 20%
 - P: 31%
 - Pesticide



Mitigate the contaminant loads!!!

Part 3

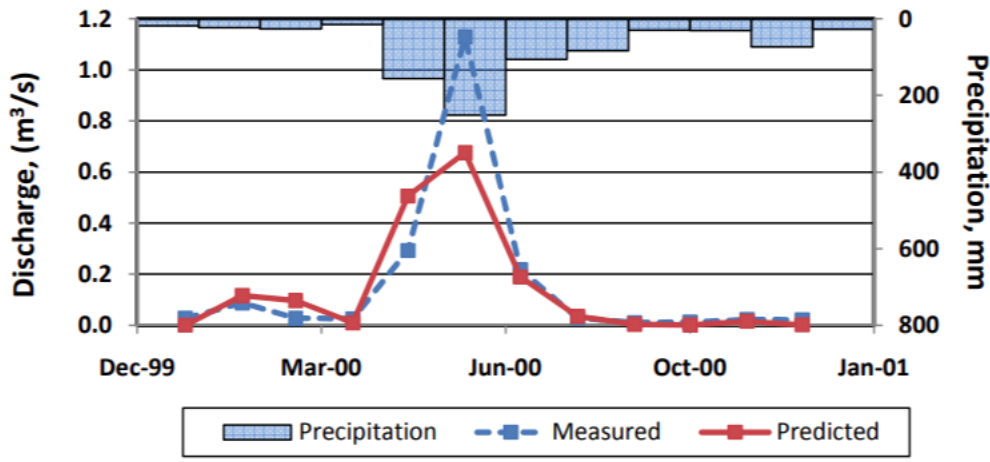
Objectives

- To accurately and efficiently **quantify** sediment, nutrient and pesticide losses from the watershed
- To identify and prioritize **critical sub-watersheds** and to evaluate the relative importance of managing them
- To evaluate the **effectiveness** of alternative best management practices(**BMPs**) at reducing pollutant loads from the Le Sueur River watershed.

Quantify the problem and identify critical location,
find solutions and evaluate solutions

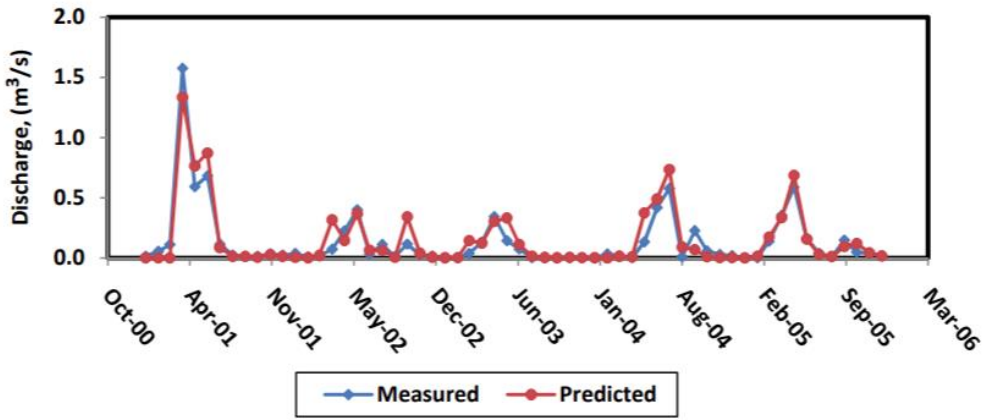
Part 3

Le Sueur River Watershed – Discharge simulation



Calibration

Figure 2-14: Calibration of monthly stream flow

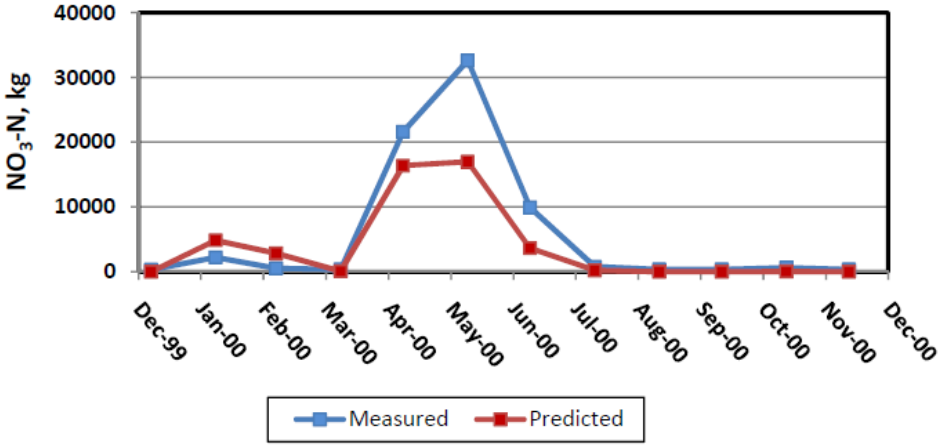


Validation

Figure 2-15: Validation of monthly flow in the Beauford sub-watershed

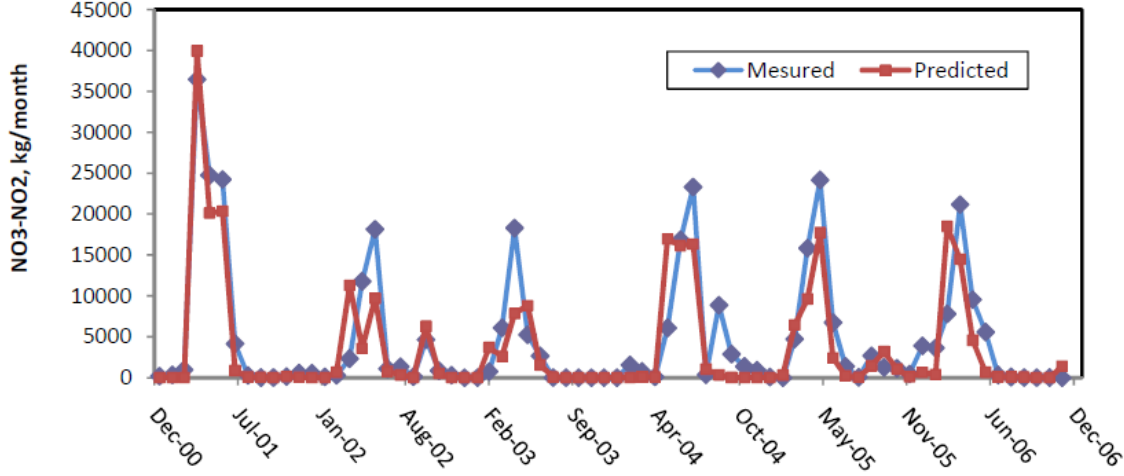
Part 3

Le Sueur River Watershed – Nitrogen simulation



Calibration

Figure 5-3: Nitrate-Nitrogen calibration in the Beauford Sub-watershed.

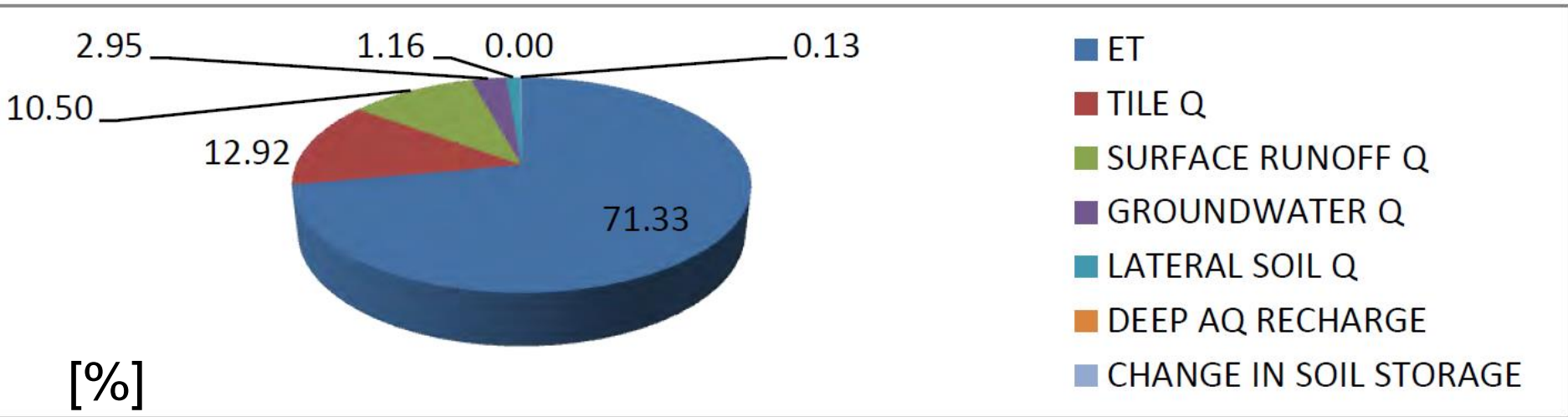


Validation

Figure 5-4: Average Monthly Nitrogen Loss Validation in the Beauford Sub-watershed

Part 3

Le Sueur River Watershed – Annual water budget



ET occupies > 70%;
Water yield in the River = Surface Q + Groundwater Q + Lateral Q + Tile Q

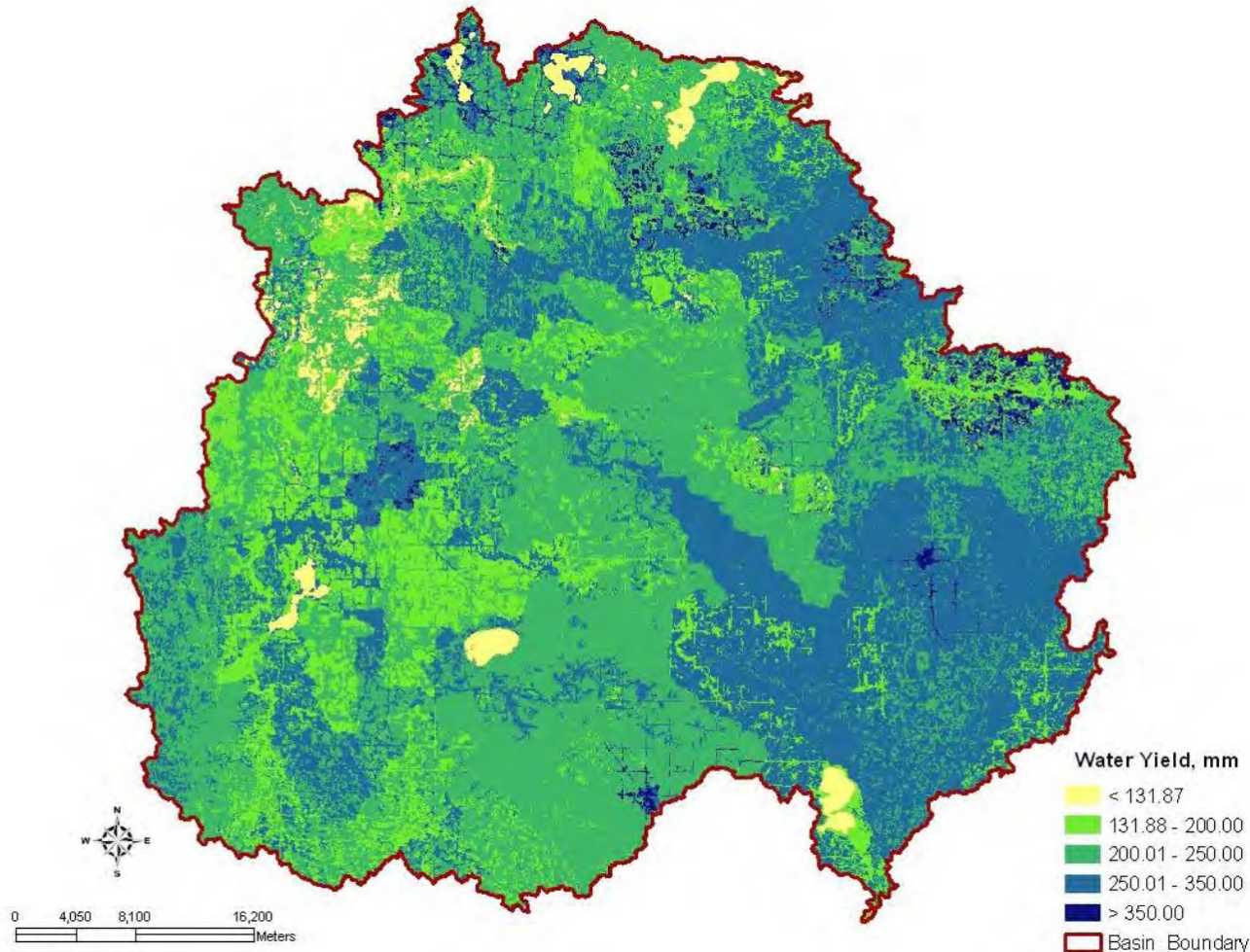


Tile flow

https://articles.extension.org/sites/default/files/w/a/a3/Tile_drainage_Ohio.jpg

Part 3

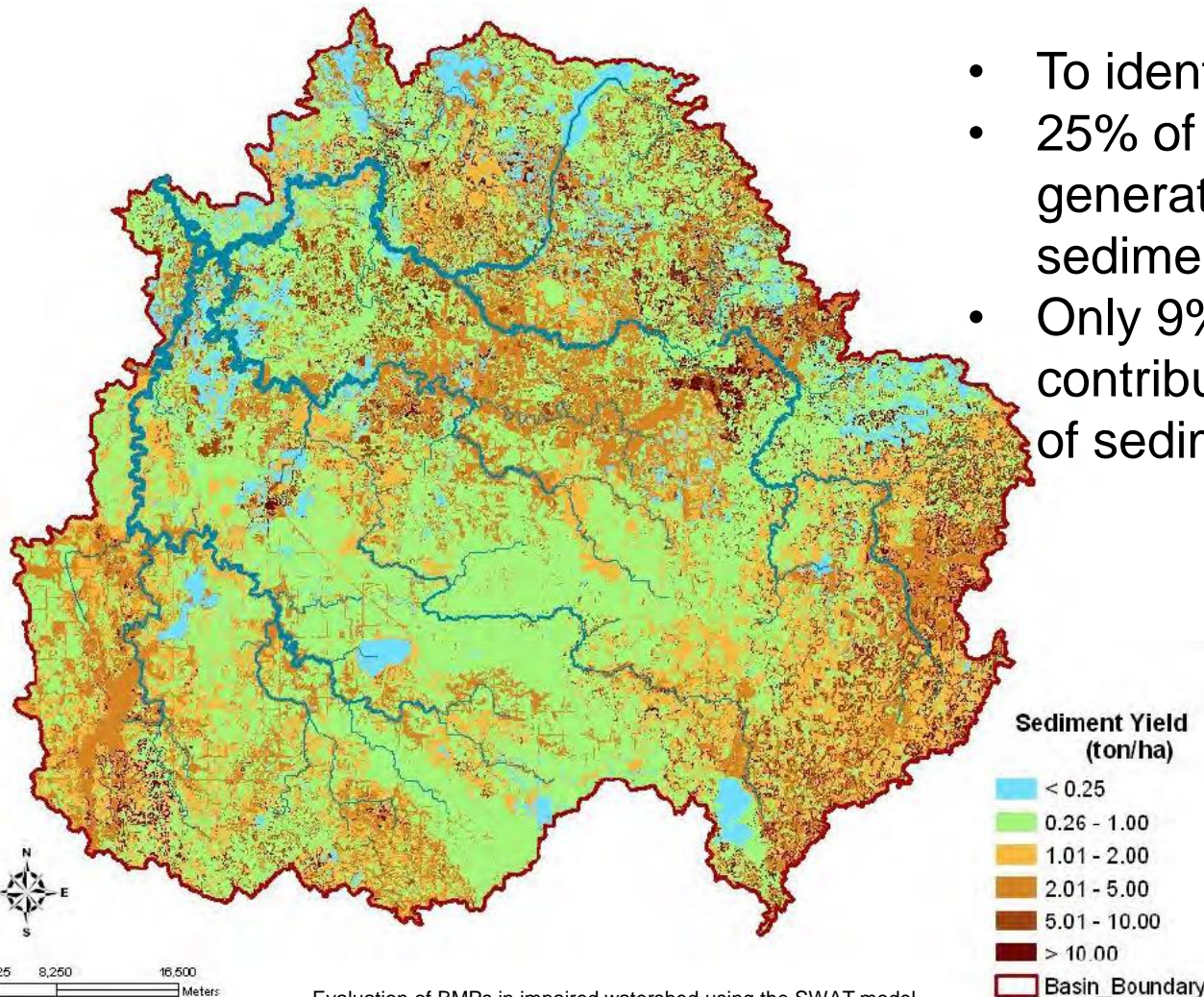
Le Sueur River Watershed – Spatial variation of water yield



The contribution of
water in river from
each watershed

Part 3

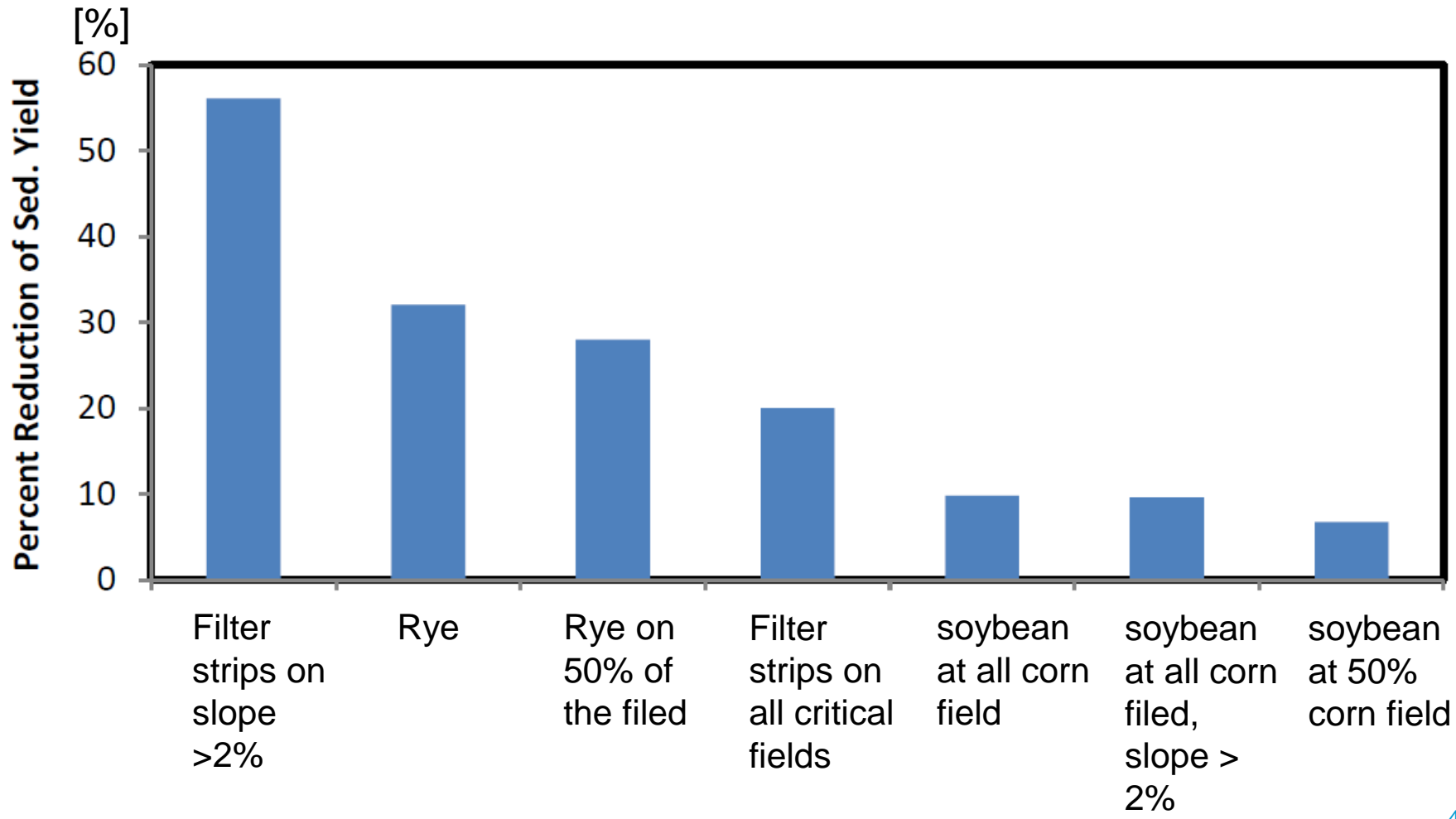
Le Sueur River Watershed – spatial distribution of sediment yield



- To identify critical areas
- 25% of the total area generates 50% of the sediment losses
- Only 9% of the region contributes more than 5t/a of sediment

Part 3

Le Sueur River Watershed – sediment BMPs



Part 3

Le Sueur River Watershed – sediment BMPs

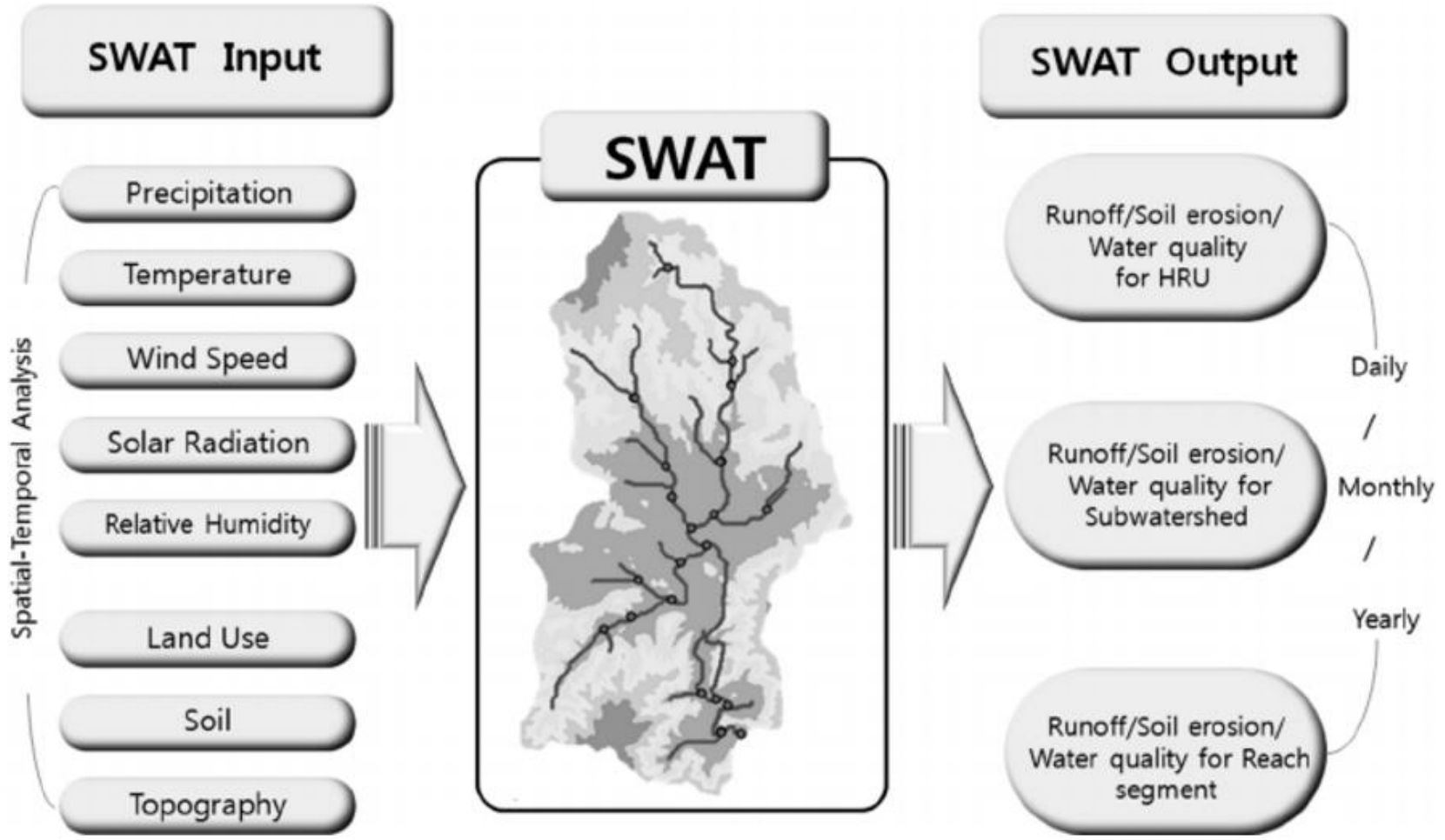
- Problem identification
- Input data collection and analysis
- Model set-up, calibration and validation
- Model application to management strategies

Part 4 – Overview of input data and data sources

- Input data
- Data sources

Part 4

Input and output data overview



https://www.researchgate.net/figure/259527294_fig2_Fig-2-Overview-of-the-swat-model-model-inputoutput-parameters

Part 4

SWAT model input data overview

Category		Sources
Raster data	Digital Elevation Model	<ol style="list-style-type: none"> 1. http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp 2. http://earthexplorer.usgs.gov/
	Land use	<ol style="list-style-type: none"> 1. http://due.esrin.esa.int/page_globcover.php 2. http://www.globallandcover.com/GLC30Download/index.aspx 3. https://landcover.usgs.gov/landcoverdata.php
	Soil map	http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/HWSD_Data.html?sb=4
Time series	Climate data	<ol style="list-style-type: none"> 1. https://www.ncdc.noaa.gov/cdo-web/ 2. https://globalweather.tamu.edu/
	Streamflow for calibration	<ol style="list-style-type: none"> 1. http://www.bafg.de/GRDC/EN/Home/homepage_node.html 2. https://waterdata.usgs.gov/nwis/rt

Part 4

SWAT model input data – DEM

1. CGIAR “Consortium for Geospatial Information”

SRTM (Shuttle Radar Topography Mission), NASA, 2000

<http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp>

Product Specifications

Projection	Geographic
Horizontal Datum	WGS84
Vertical Datum	EGM96 (Earth Gravitational Model 1996) ellipsoid
Vertical Units	Meters
Spatial Resolution	90m at the equator; vertical errors < 16m

Robit Watershed: N 11°27'26" ~ 11°47'49"; E 37°22'55" ~ 37°30'50"

Part 4

SWAT model input data – DEM

1. Earth Explorer by U.S. Geological Survey

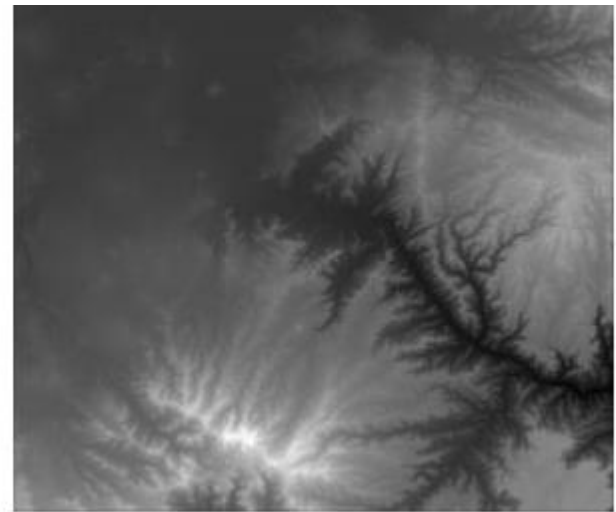
<http://earthexplorer.usgs.gov/>

2. Select Your Data Set(s)
 Check the boxes for the data set(s) you want to search. When done selecting data set(s), click the *Additional Criteria* or *Results* buttons below. Click the plus sign next to the category name to show a list of data sets.

Use Data Set Prefilter [\(What's This?\)](#)

Data Set Search:

- Aerial Imagery
- AVHRR
- CEOS Legacy
- Commercial Satellites
- Declassified Data
- Digital Elevation
 - ASTER GLOBAL DEM
 - CoNED TBDEM
 - EDNA
 - GMTED2010
 - GTOPO30
 - GTOPO30 HYDRO 1K
 - IFSAR Alaska
 - LIDAR
- SRTM
- Digital Line Graphs
- Digital Maps
- EO-1
- Global Fiducials



Standard Browse

Data Set Attribute	Attribute Value
<u>Entity ID</u>	SRTM1N11E037V3
<u>Acquisition Date</u>	11-FEB-00
<u>Publication Date</u>	23-SEP-14
<u>Resolution</u>	1-ARC
<u>Date Updated</u>	

Part 4

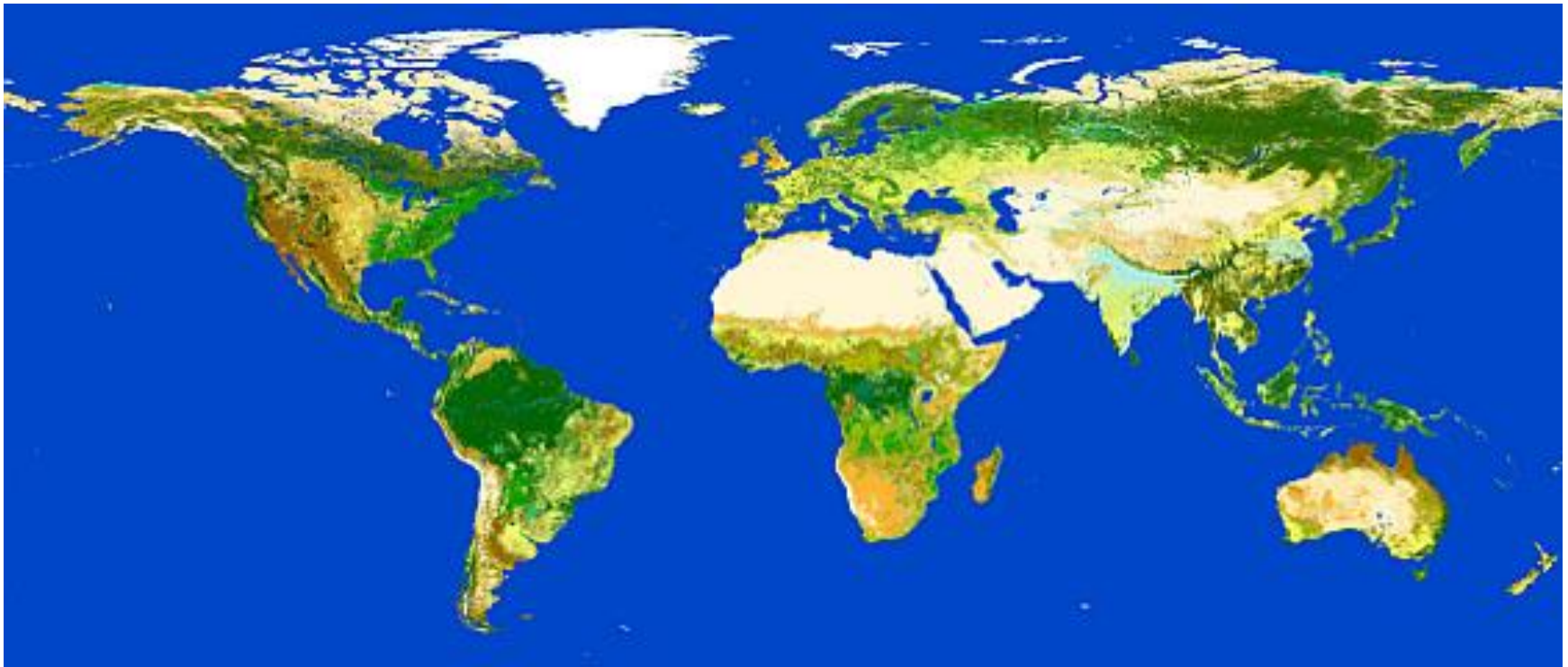
SWAT model input data – land use

1. GlobalCover ESA – European Space Association

http://due.esrin.esa.int/page_globcover.php

Dec. 2004 – Jun. 2006 and Jan. 2009 – Dec. 2009

Spatial resolution: 300m , 23 land use classes



Part 4

SWAT model input data – land use

2. GLOBELAND30 – National Geomatics Center of China

<http://www.globallandcover.com/GLC30Download/index.aspx>

2000 or 2010, 10 land use classes

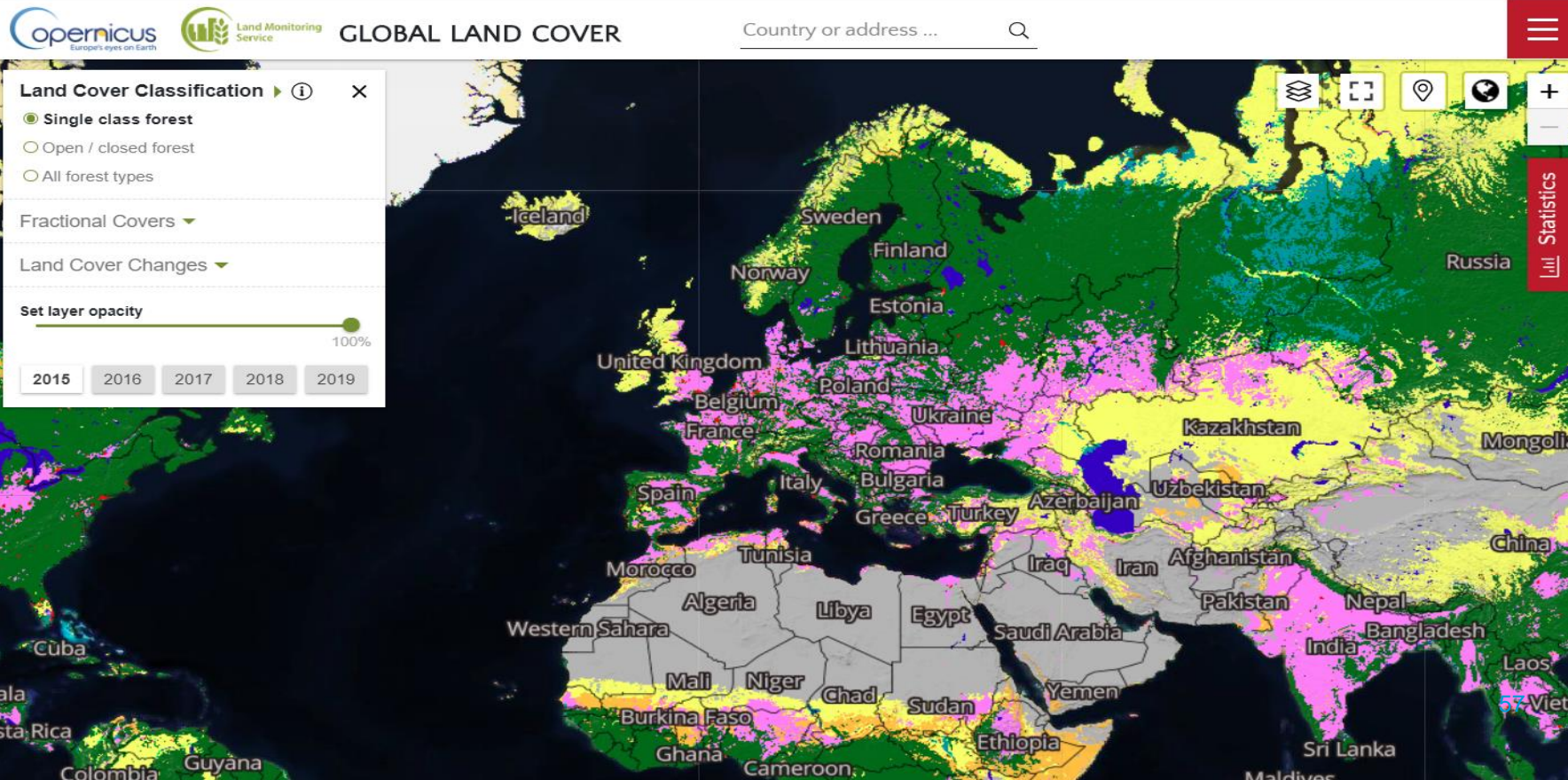
The screenshot displays the GLOBELAND30 web application interface. At the top, there is a navigation bar with links for Home, Papers, 3D, Download, Geo-tagging, Geo-Statistics, GLC-Seek, GLCVal, Knowledge Map, and About. A search bar and a LOGIN button are also present. The main content area features a world map with a color-coded land cover overlay. On the left side, there is a legend titled "Land Cover Types" and "Water bodies". The legend includes icons and labels for various land cover classes: Water bodies, Wetland, Artificial Surfaces, Tundra, Permanent snow and ice, Grass lands, Barren lands, Cultivated land, Shrub lands, and Forests. Below the legend, there is a "NEXT" button and a "Description" section. The map itself shows a global view with a red crosshair indicating the current location. The bottom right corner of the map displays the coordinates: Longitude: -60.21710, Latitude: -18.15672.

Part 4

SWAT model input data – land use

3. Copernicus Global Land Service – <https://land.copernicus.eu/global/products/lc>

2015 – 2019, 100m



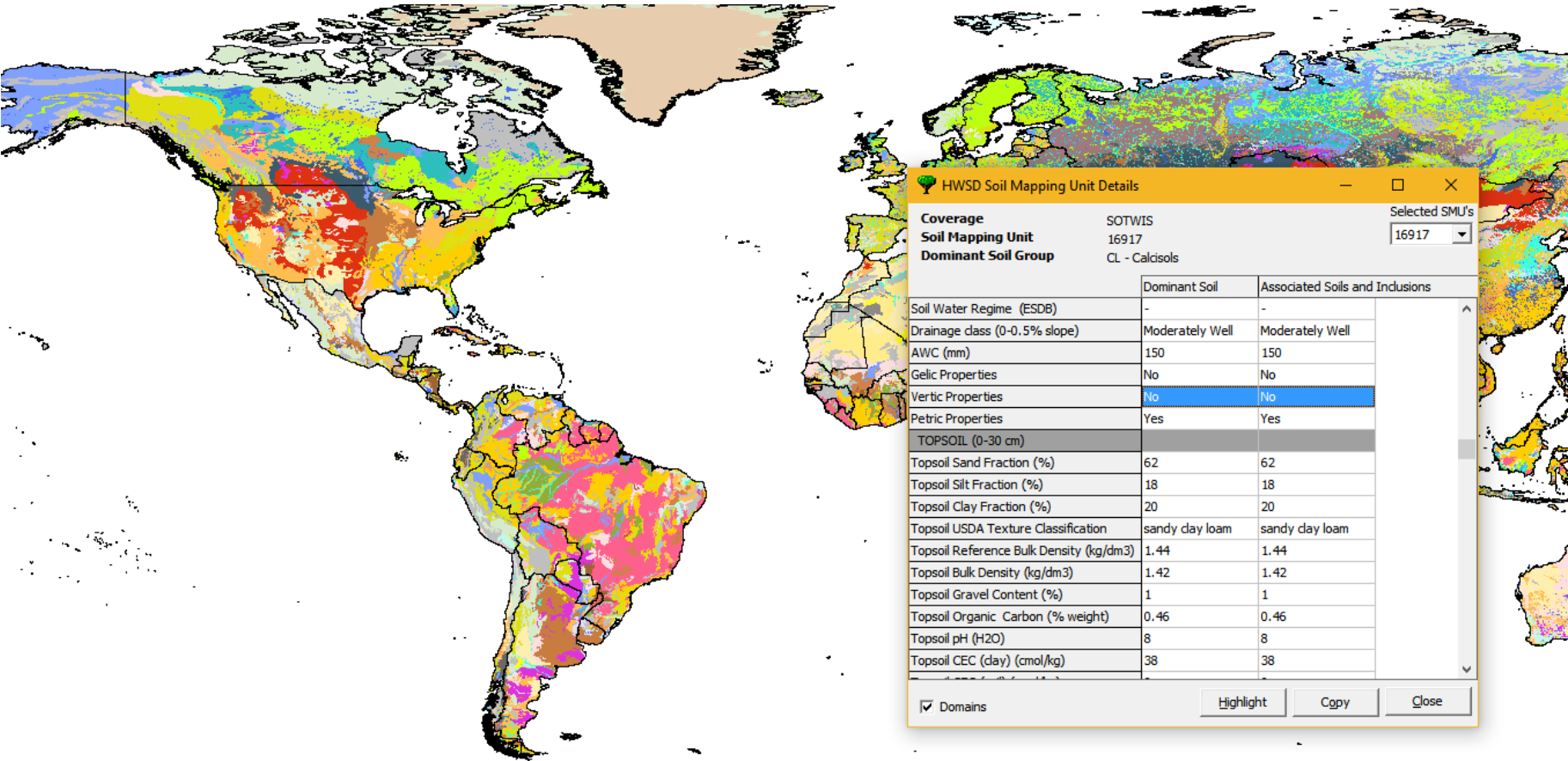
Part 4

SWAT model input data – soil type

Harmonized World Soil Database

http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/HWSD_Data.html?sb=4

Spatial resolution: 1000m



Part 4

SWAT model input data – climate

1. U.S. National Centers for Environmental Information

<https://www.ncdc.noaa.gov/cdo-web/>

Land-based stations

The screenshot shows the NOAA website interface. At the top, the NOAA logo and name are displayed. Below the navigation bar, a search bar contains the text "Ethiopia" and a "SEARCH" button. To the right of the search bar is a map of the world with Ethiopia highlighted in red. Below the search bar, there is a summary for Ethiopia: "Ethiopia", "View Full Details", "Location ID: FIPS:ET", and "Period of Record: 1951-01-01 to 2017-06-11". There is also an "ADD TO CART" button. At the bottom left, it says "1 - 1 of 1".

LOCATION DETAILS	
Name	Ethiopia
ID	FIPS:ET
Type	Country
Included Stations	18 (See station list below)

PERIOD OF RECORD	
Start¹	1951-01-01
End¹	2017-06-11
Coverage²	100%

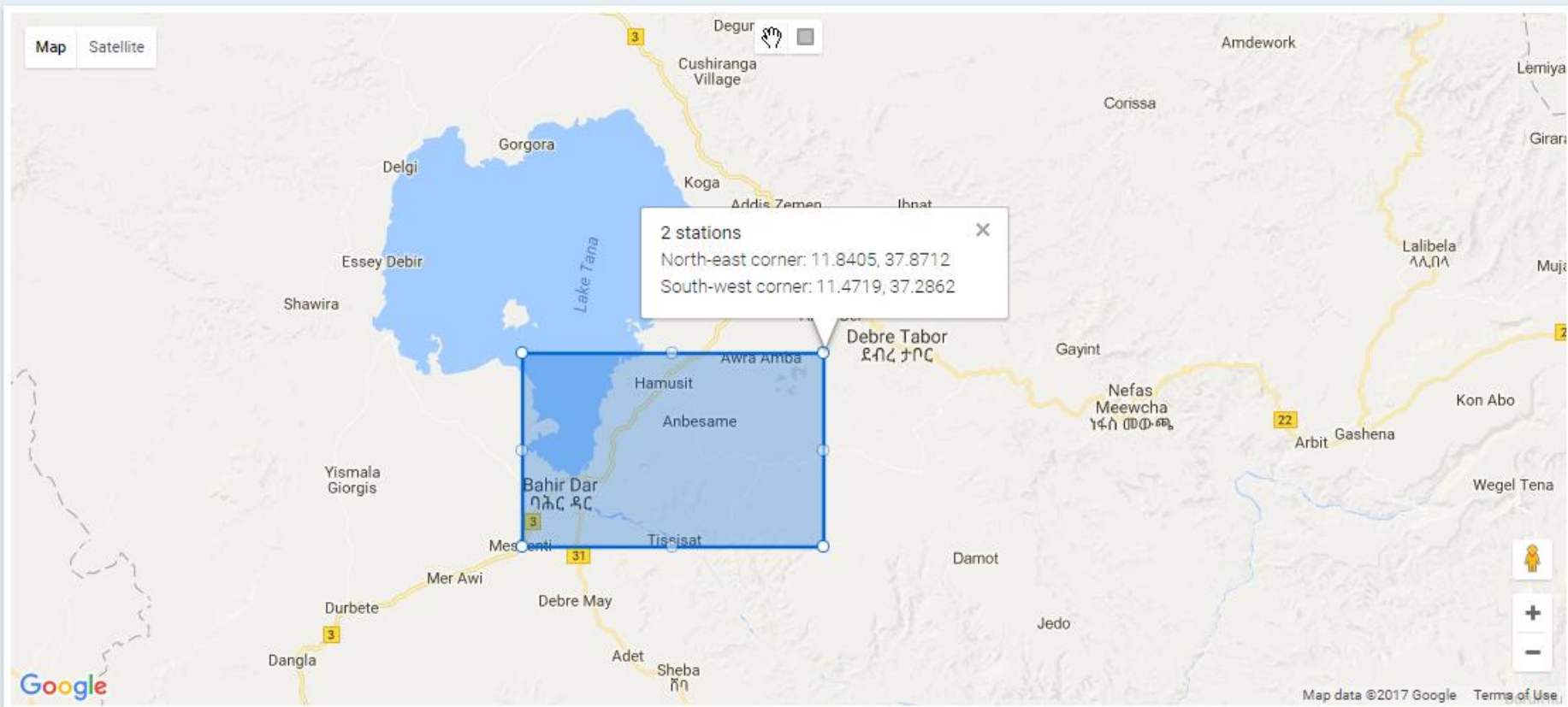
Part 4

SWAT model input data – climate

2. Climate Forecast System Reanalysis

<https://globalweather.tamu.edu/>

From 1979-01-01 to 2014-07-31, time series of daily data in SWAT file format



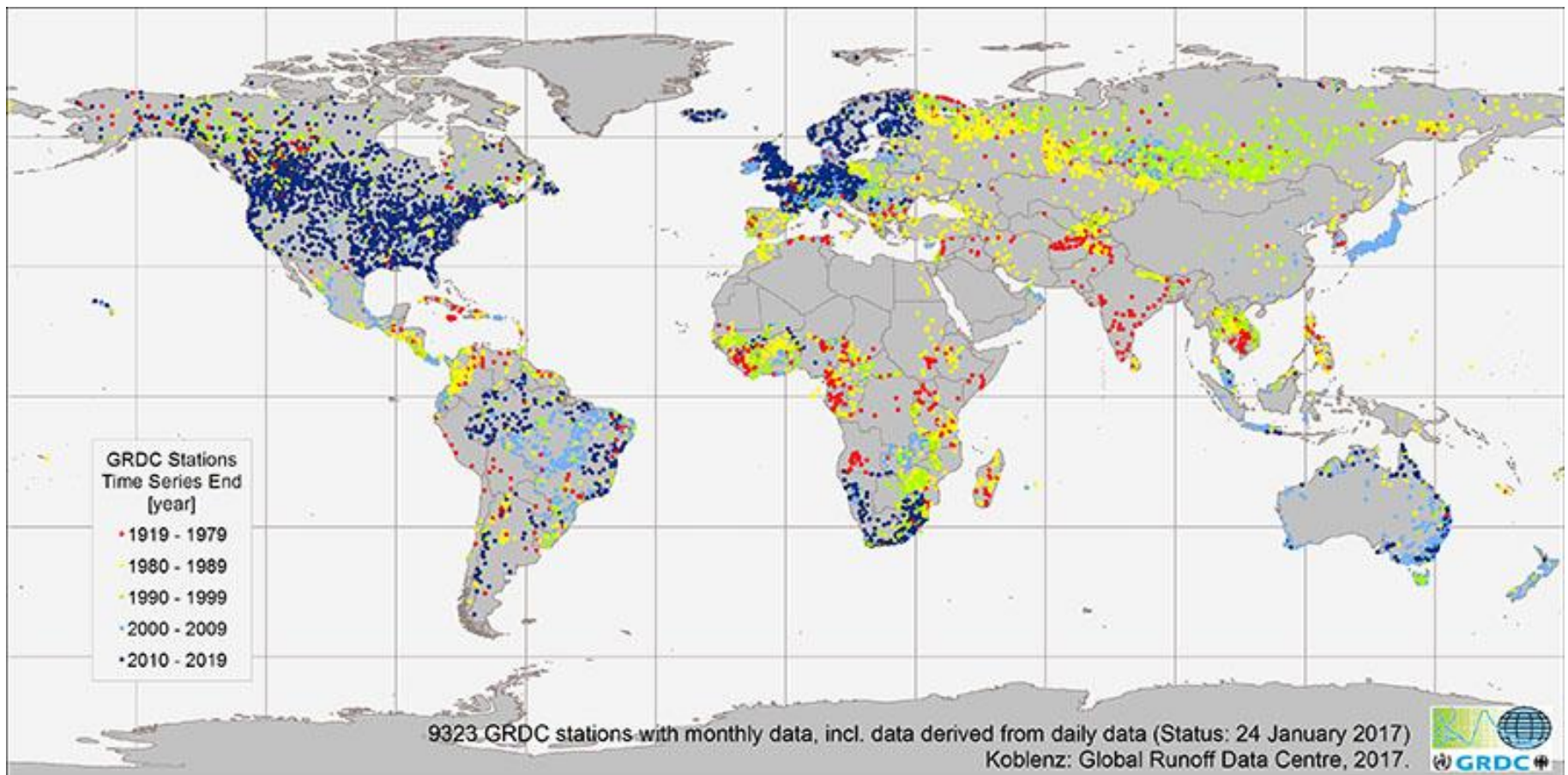
Part 4

SWAT model input data – streamflow

1. Global runoff data center

http://www.bafg.de/GRDC/EN/Home/homepage_node.html

9,200 stations in 160 countries



Part 4

SWAT model input data – streamflow

2. U.S. Geological Survey

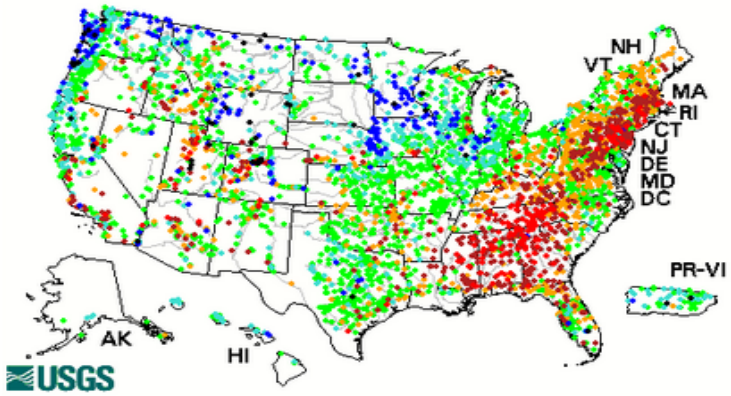
Only U.S. <https://waterdata.usgs.gov/nwis/rt>

USGS Current Water Data for the Nation

--- Predefined displays ---
Introduction [v] go

Daily Streamflow Conditions

Friday, November 25, 2016 11:30ET



- Explanation**
- High
 - > 90th percentile
 - 76th - 90th percentile
 - 25th - 75th percentile
 - 10th - 24th percentile
 - < 10th percentile
 - Low
 - Not ranked

The colored dots on this map depict streamflow conditions as a percentile, which is computed from the period of record for the current day of the year. Only stations with at least 30 years of record are used. The **gray circles** indicate other stations that were not ranked in percentiles either because they have fewer than 30 years of record or because they report parameters other than streamflow. Some stations, for example, measure stage only.

Part 5 – Set- up a SWAT model demonstration

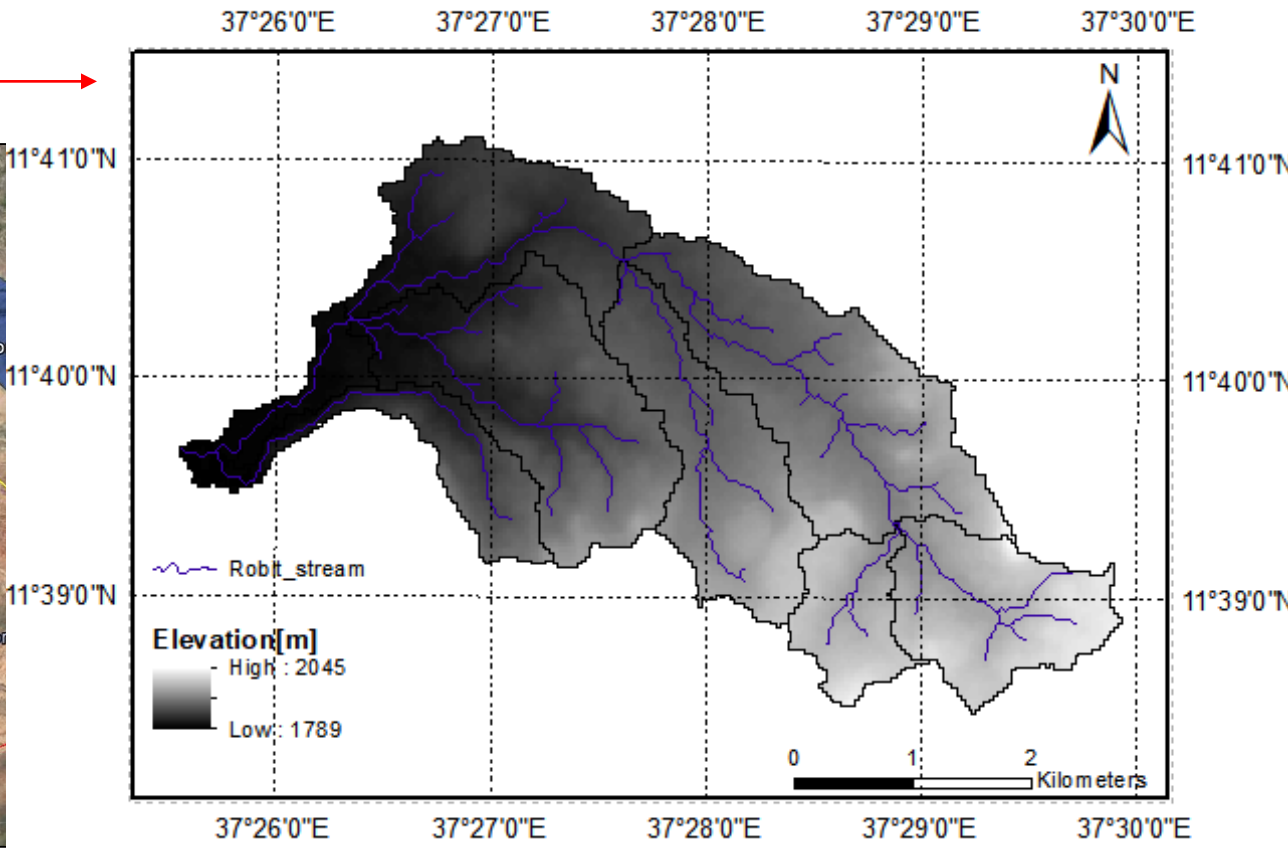
- Robit Watershed in Ethiopia as an example
- Model set-up procedure
- Data structure of the model

Part 5

Input data overview – Robit watershed



Digital Elevation Model

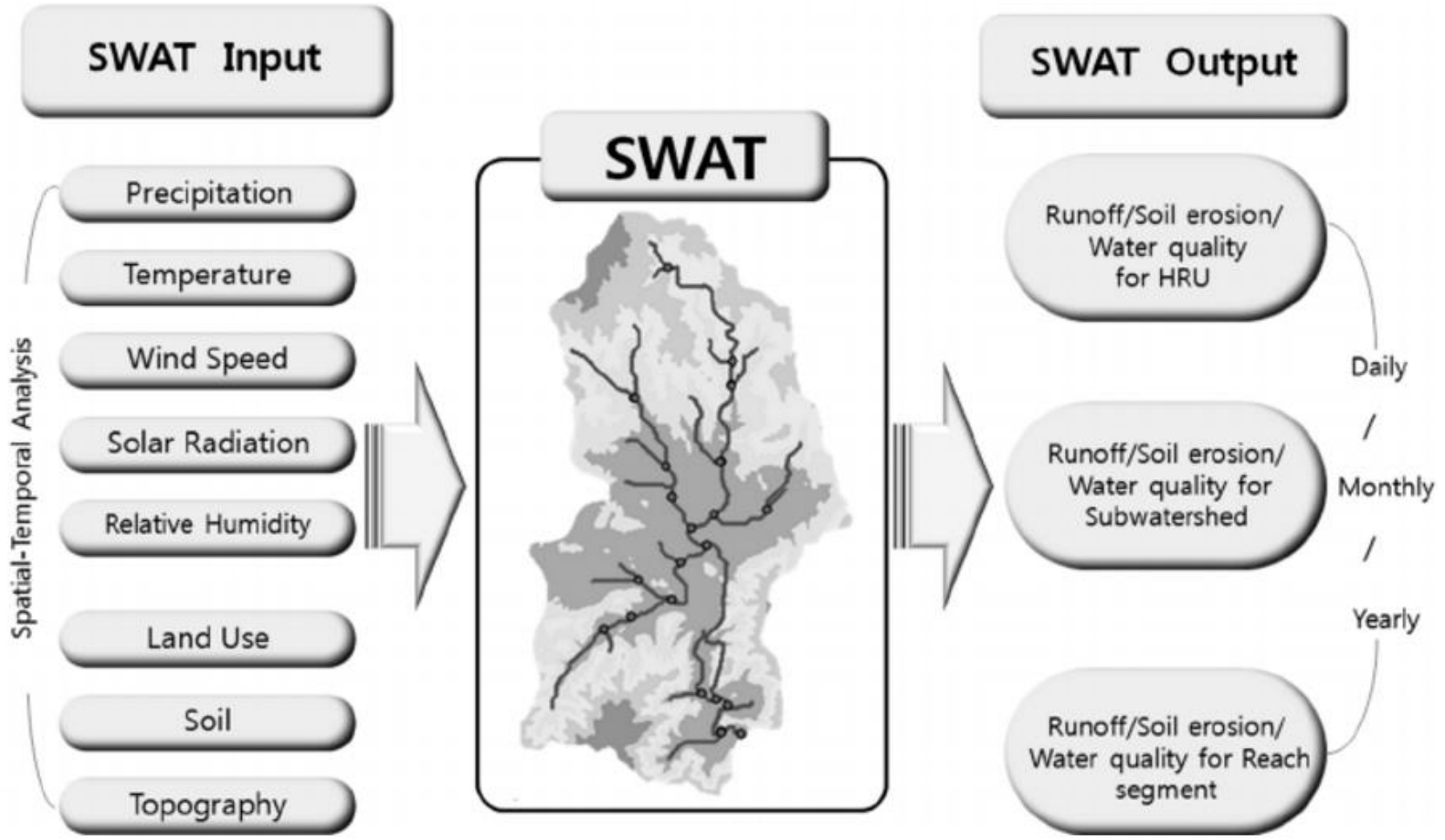


(Satellite image from google earth)

Area: 16.75 km²

Part 5

Input and output data overview



https://www.researchgate.net/figure/259527294_fig2_Fig-2-Overview-of-the-swat-model-model-inputoutput-parameters

Part 5

Input data overview

Example Data Set: Robit Watershed, Lake Tana Basin

Path: C:\user's home directory\.qgis2\python\plugins\Qswat

	Remark
ClimateRobit	Climate input, with measuring sites and time series
DEM	
Landuse	
MainOutlet	Location of the outlet
Observed	Observed discharge at basin outlet (m3/s)
RobitStreams	Stream .shp
Soil	
MainOutlet.zip	Landuse look up table, with corresponding SWAT Landuse Code
Robit_landuses.csv	
Robit_soils.csv	Soil look up table, with corresponding data to link the usersoil.xlsx
usersoil.xlsx	Soil database created by the user
WGEN_Robit.xlsx	Weather statistics for weather generator

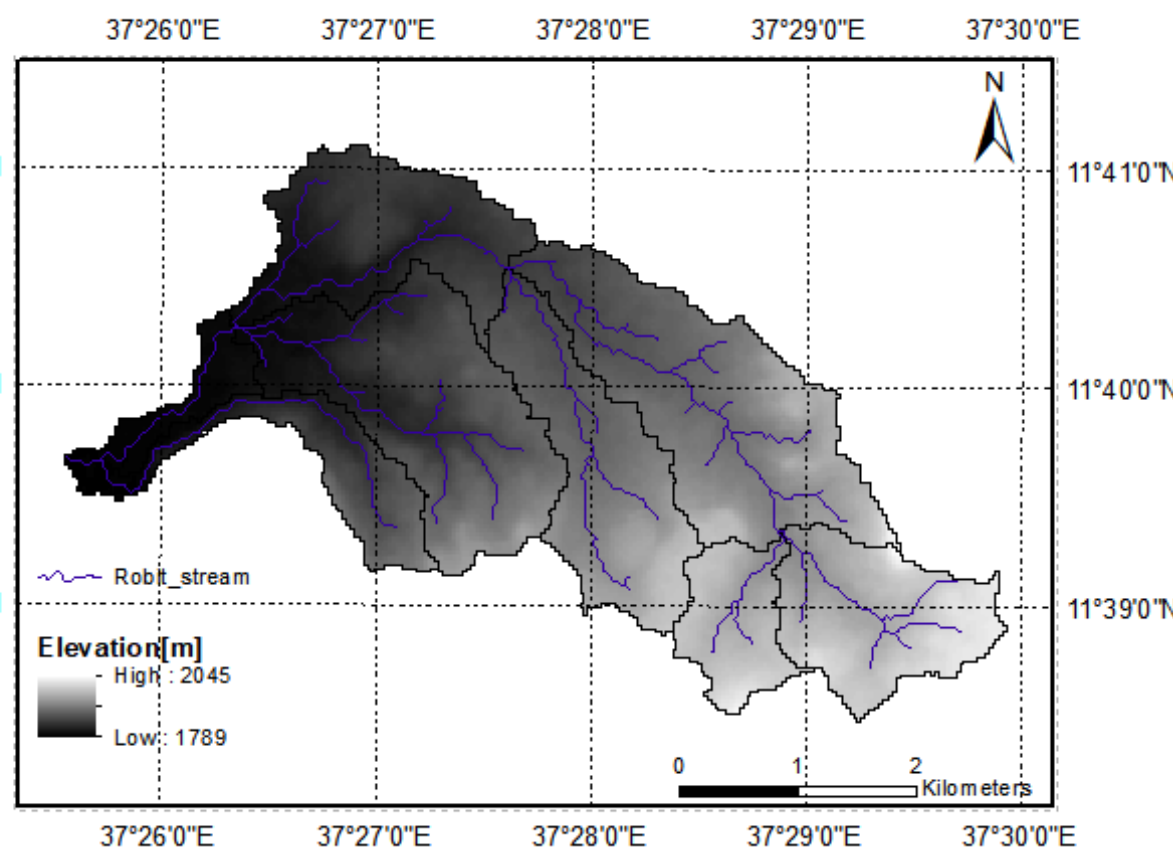
Part 5

Input data overview – Robit watershed



(Satellite image from google earth)

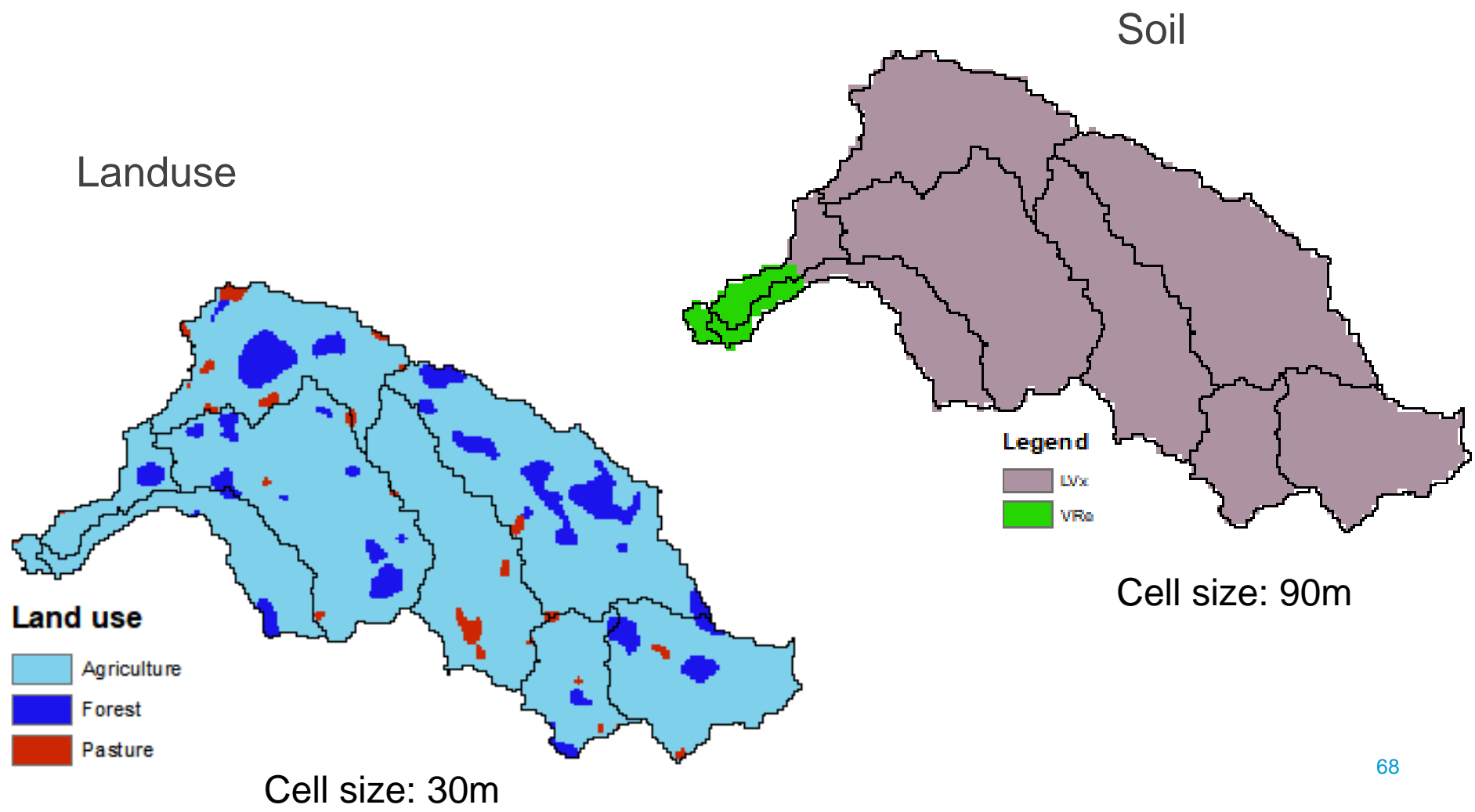
Digital Elevation Model



Area: 16.75 km²

Part 5

Input data overview – Robit watershed



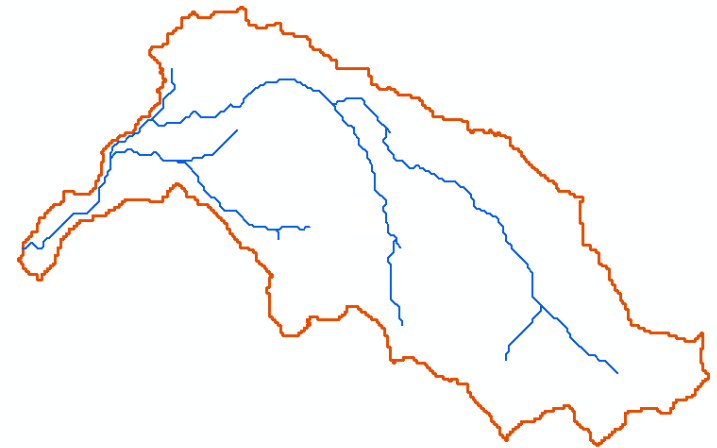
Part 5

Input data overview – Robit watershed

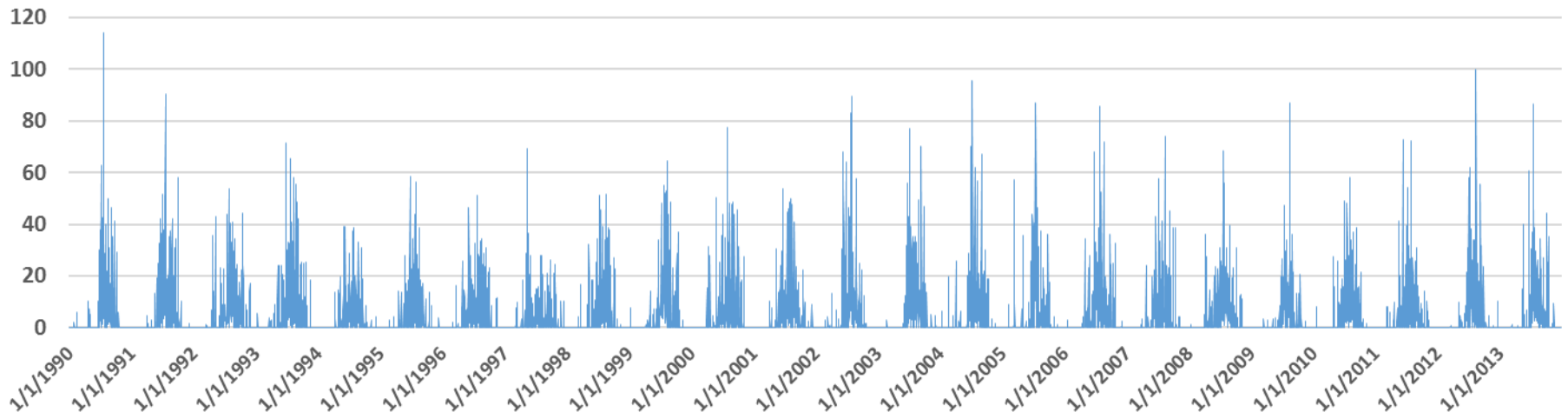
Daily weather data: (1990 - 2013)

- Precipitation
- Temperature
- Wind speed
- Solar Radiation
- Relative humidity

PET



Daily precipitation from 1990 to 2013 in mm

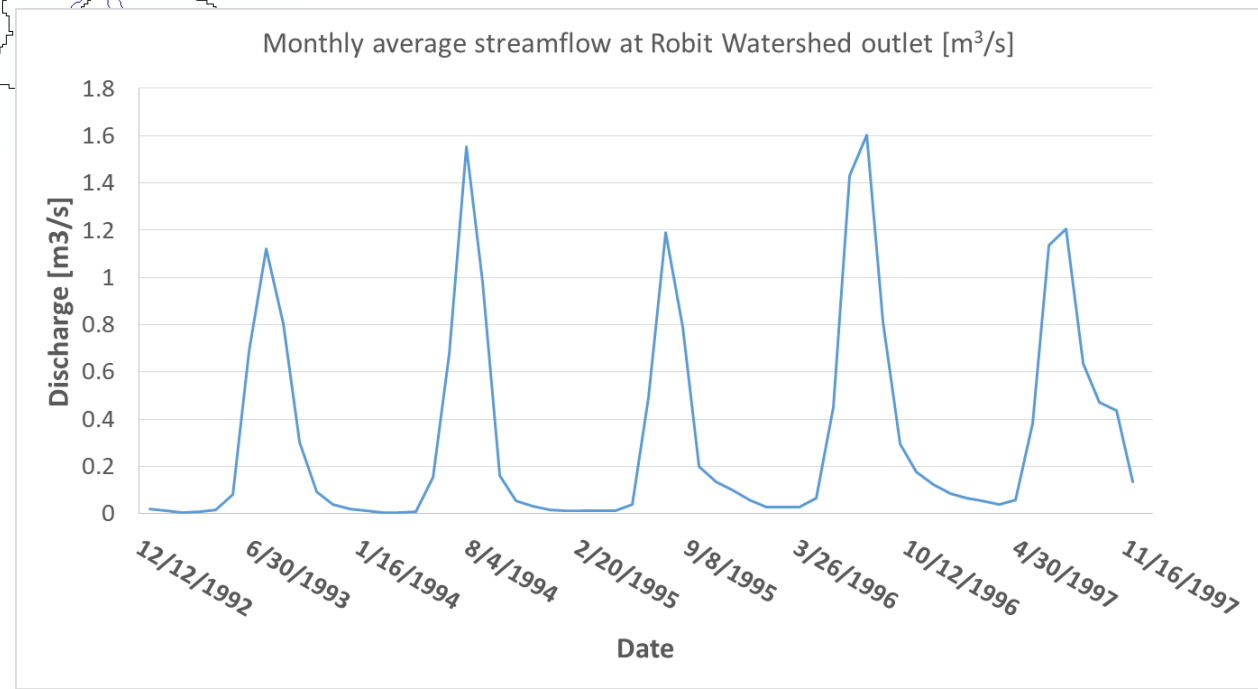
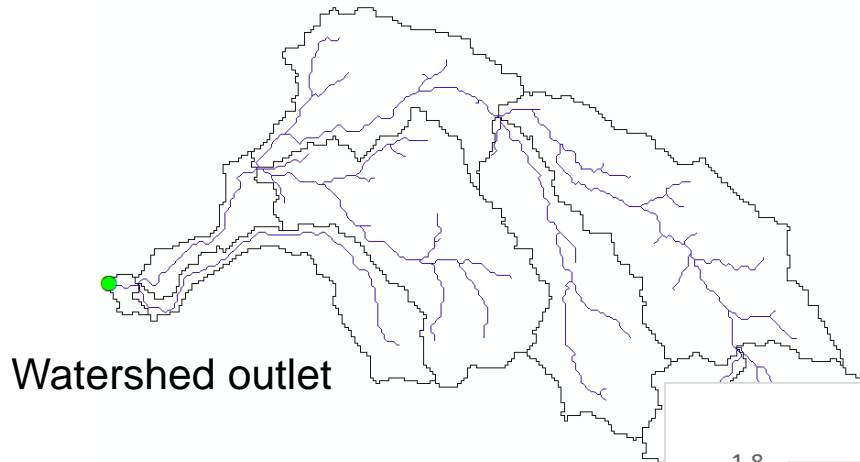


Part 5

Input data overview – Robit watershed

River network and measured streamflow discharge

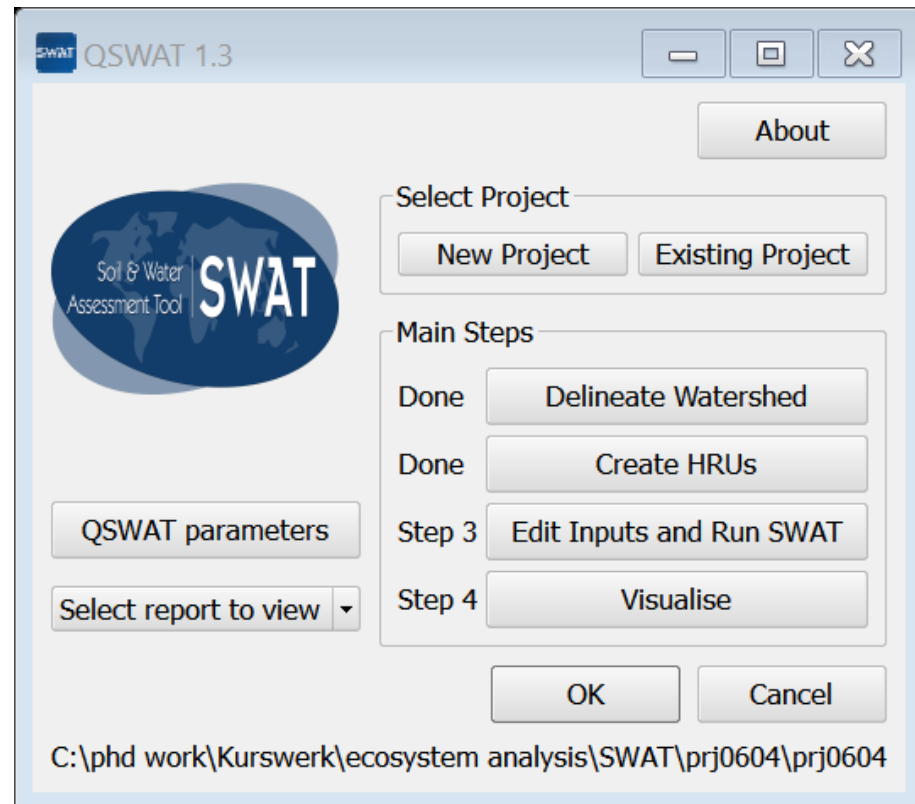
- Jan. 1993 to Dec. 1997
- Monthly average discharge in m^3/s



Part 5

SWAT model procedure

1. Watershed delineation
2. HRU analysis
3. Write Input tables





Part 5


SWAT model data structure


Database


- Reference database: QSWATRef2012.mdb
- Project database: prj1.mdb


 Scenarios


 Source


 Watershed


 fert.dat


 pest.dat


 plant.dat

 prj1.mdb

 QSWATRef2012.mdb

 septwq.dat

 till.dat

 urban.dat

Part 5

SWAT model procedure

1. Watershed delineation (DEM)

- Insert the DEM, outlet, stream network
- Define the shape of the basin/watershed
- Delineate the basin in order to obtain the subbasins

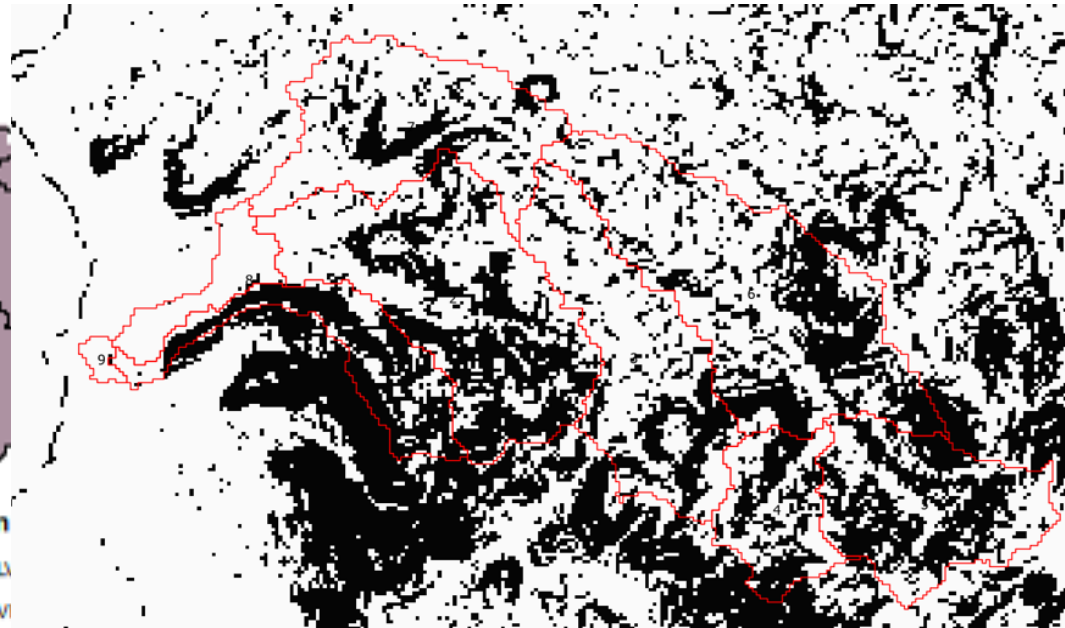
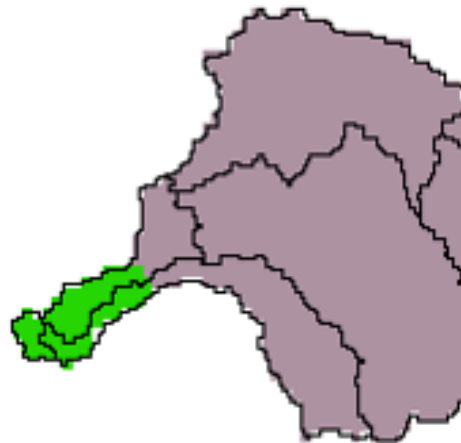
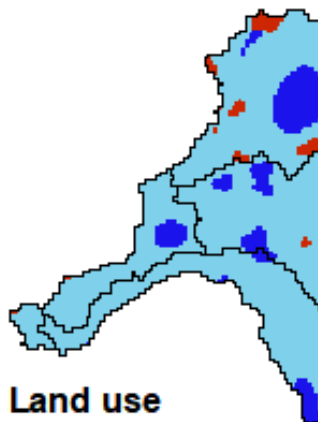


Part 5

SWAT model procedure

2. HRU analysis (landuse, soil type, slope)

- Add land use, soil type data and link the attributes to SWAT database
- Choose the combination of landuse, soil type and slope range in order to obtain the suitable HRUs

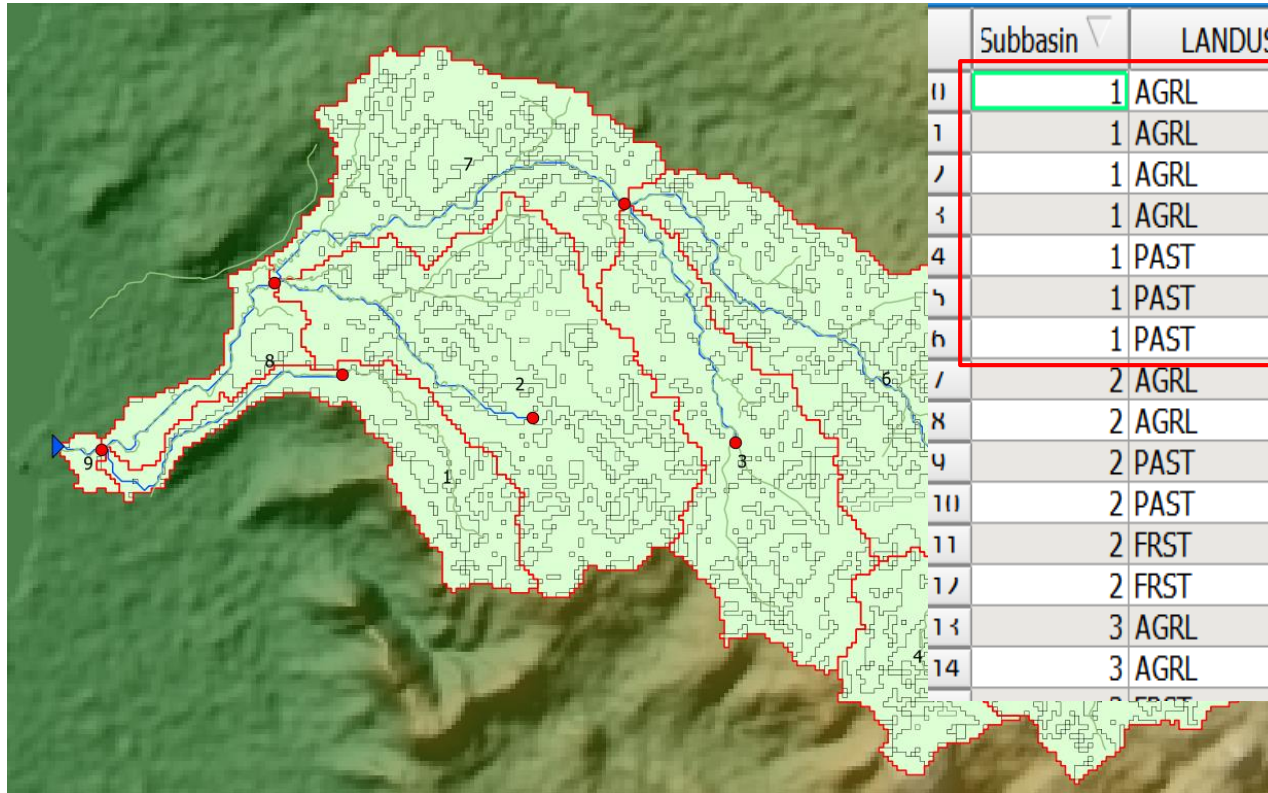


Part 5

SWAT model procedure

HRU: Hydrological Response Unit

- Computational unit
- combination of land use, soil and slope within one subbasin
- HRUs is spatially defined and has no interactions with each other



	Subbasin ▾	LANDUSE	SOIL	SLOPE_BAND	AREA (ha)	%SUBBASIN
11	1	AGRL	VRe	0-10.0	12	9.42562
1	1	AGRL	VRe	10.0-9999	7	6.03829
7	1	AGRL	LVx	0-10.0	29	24.0795
3	1	AGRL	LVx	10.0-9999	66	54.2709
4	1	PAST	VRe	0-10.0	0	0.07363
6	1	PAST	LVx	0-10.0	2	1.47275
8	1	PAST	LVx	10.0-9999	6	4.63917
7	2	AGRL	LVx	0-10.0	172	50.0915
8	2	AGRL	LVx	10.0-9999	143	41.6950
4	2	PAST	LVx	0-10.0	15	4.34213
10	2	PAST	LVx	10.0-9999	11	3.21736
11	2	FRST	LVx	0-10.0	1	0.26157
17	2	FRST	LVx	10.0-9999	1	0.39236
13	3	AGRL	LVx	0-10.0	166	68.6733
14	3	AGRL	LVx	10.0-9999	68	27.8706

Part 5

SWAT model procedure

2. HRU analysis

The number of HRUs (too many?? Too long computational time??)

- Dominant HRU: only the largest HRU will be considered
- HRU threshold: select the threshold of landuse, soil and slope(e.g. 10%,...)
- ...

- HRU threshold

Landuse → soil → slope

e.g. subbasin 1: landuse 20%, soil 15%

Single/Multiple HRUs

Dominant landuse, soil, slope

Dominant HRU

Filter by landuse, soil, slope

Filter by area

Target number of HRUs

	Landuse	A			B		C	
1	%	40			10		50	
	Soil type	a	b	c	a	b	b	c
2	%	10	30	60	20	80	20	80

- Land use A: $0.4/(1-0.1) = 0.44$
- In Land use A: soil type "a" will be eliminated
- In Land use A: soil type "b": $0.3/(1-0.1) = 0.33$

Part 5

SWAT model procedure

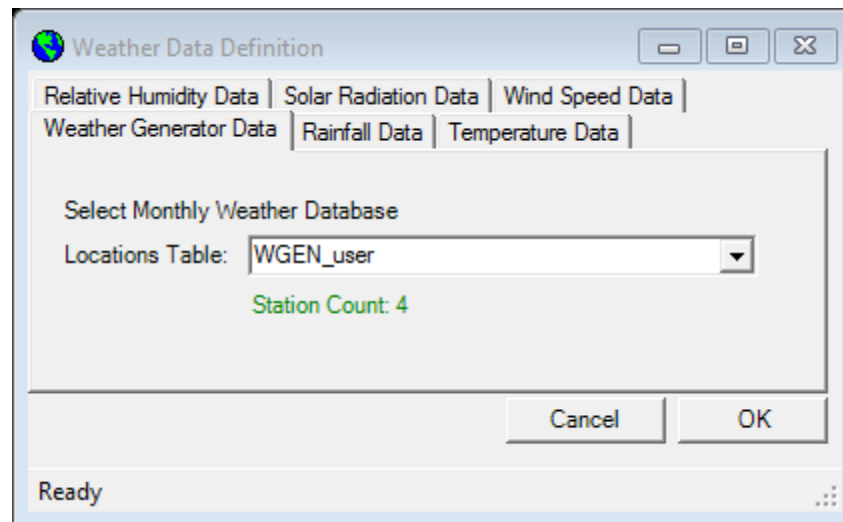
- DEM → Watershed delineation!
- Landuse and soil type, slope → HRU analysis
- Climate!

Part 5

SWAT model procedure

3. Write Input tables (weather data, management strategy,...)

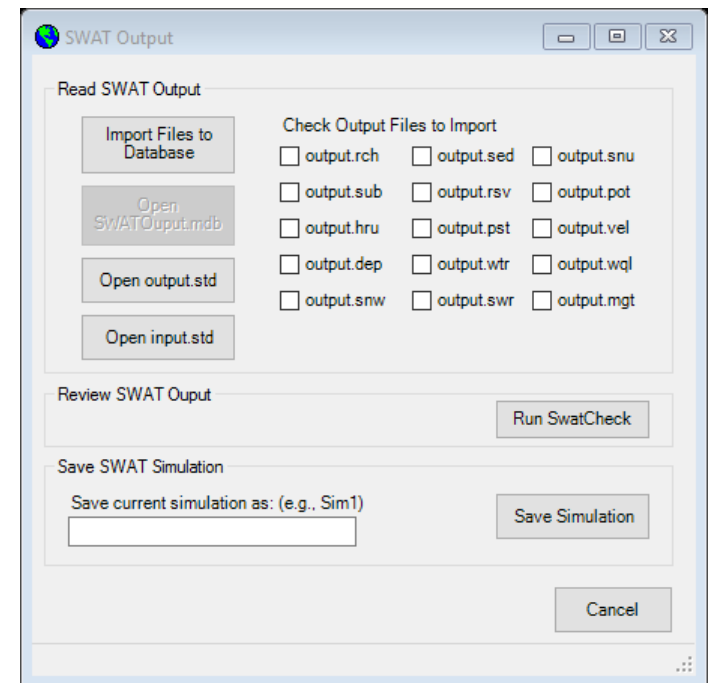
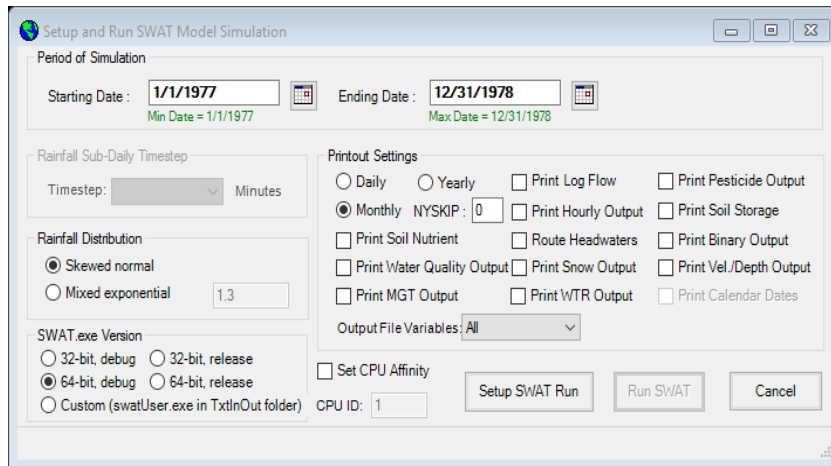
- Weather data as the driving force of the model
- Other input data are also considered if obtained
 - Point source input at each subbasin if applicable
 - Agricultural operations: fertilization (date, time, quantity)
 - Irrigation, water consumption,...



Part 5

SWAT simulation

- Skip 3~5 years as warm up period

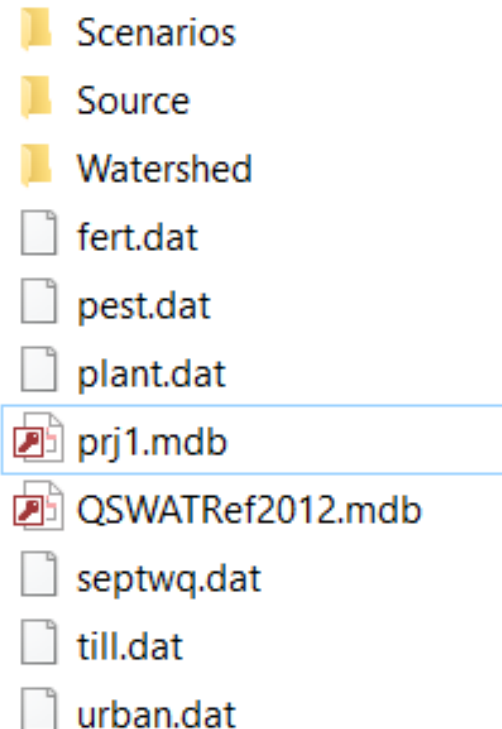


Import output to Database

Part 5

SWAT model project structure

- Scenarios
 - All the saved simulations with input and output data
- Source
 - Store DEM, landuse and soil
- Watershed
 - Store the generated subbasin, HRU information in .txt



Part 6. QSWAT installation

<https://swat.tamu.edu/software/qswat/>

QGIS3 + SWAT Editor + QSWAT

- Windows Operation System
- Better to have no other QGIS version installed

QSWAT3 Requirements

Microsoft Windows (any version, as far as we are aware)

Text editor and a tool to unzip archived files

SWAT Editor - requirements include:

- Microsoft Windows
- Microsoft .Net Framework 3.5
- [Adobe Acrobat Reader](#) version 7 or higher

Other Documents

[Download global datasets](#)

[Preparing global DEM data for QSWAT](#) 

Installation

Install QGIS3 by going to the [QGIS download page](#) and selecting under Long term release repository (most stable) the QGIS Standalone Installer Version 3.10 (32 bit or 64 bit: see Release Notes above for which to choose). This gives you an executable file which you run to install QGIS3. Use the default folder C:\Program Files\QGIS 3.10 (or C:\Program Files (x86)\QGIS 3.10) as the installation folder. Note that it is essential that you select QGIS3 rather than the earlier QGIS2, because they use different versions of the Python language, and it is also essential that you select a 32 bit or 64 bit version according to the Release Notes, and the corresponding QSWAT3 or QSWAT3_64. We recommend that you select the long term release version of QGIS (currently 3.10) because that is the one we test QSWAT3 against.

Install [SWAT Editor 2012](#) in its standard place C:\SWAT\SWATEditor.

- Refer to Appendix I of the QSWAT Manual for help updating a database.
- Refer to the [SWATEditor_Documentation.pdf](#) in C:\SWAT\SWATEditor\SWATEditorHelp for help getting started.

Task for next two weeks

- Install QSWAT: QGIS3+SWAT Editor +QSWAT
- Set-up the hydrological model for Robit Watershed (voluntary)
 - Reference: [step_by_step_installation_model_set_up.pdf](#)

- Tim Davie (2008): Fundamentals of Hydrology, Second Edition;
- Chong-yu Xu (2002): Textbook of Hydrologic Models; www.soil.tu-bs.de/lehre/Master.Unsicherheiten/2012/Lit/Hydrology_textbook.pdf
- Axel Bronstert (2005): Coupled models for the hydrological cycle. Integrating atmosphere, biosphere and pedosphere
- swat.tamu.edu
- SWAT2009 Theoretical Documentation <http://swat.tamu.edu/documentation/>
- SWAT2009 Input/Output File Documentation <http://swat.tamu.edu/documentation/>
- Folle, Solomon Muleta (2010). Swat modeling of sediment, nutrients and pesticides in the Le-Sueur River watershed, south-central Minnesota
<https://conservancy.umn.edu/handle/11299/59212>