# THE BASICS OF HYDROLOGIC MODELS

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Deltares

Excerpts from slides prepared for Water, Peace and Security tailor-made capacity development activities in Iraq. Please attribute authors when using materials.

# Topics of the training on the modelling

- Survey of hydrologic models used
- Introduction to the models and their function in the Iraq application
- Discussion on model limitations

# Two types of models we will discuss

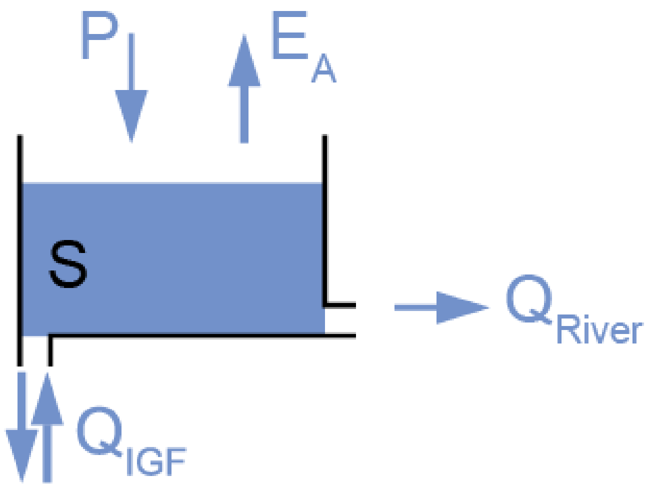
- Hydrological model – rainfall runoff model

- Water Resources model – water distribution and water allocation

## Hydrological models

- Large variety in existing hydrological models
  - Very simple (as below)
  - More complex (wflow_sbm)

- Despite their differences in how they represent processes, most models:
  - Are mass conservative and solve the water balance
  - Consist of:
    - **inputs** (e.g. precipitation, temperature)
    - **outputs** (e.g. streamflow)
    - **parameters** (e.g. root-zone storage)
    - **internal states** (e.g. snow, interception, groundwater)
    - **fluxes** (e.g. recharge to the groundwater)




$$\frac{\mathrm{d}S}{\mathrm{d}t} = P - E_A - Q_{\mathrm{river}} - Q_{\mathrm{IGF}}$$

# The modelling process

- **Data collection**: physical catchment characteristics, hydro-meteorological data, satellite data
- **Model set-up**: setting up the model from the understanding of the relevant hydrological processes
- **Calibration**: getting values for the parameters
- **Evaluation**: confronting the model output with observations

→ Typically an iterative process

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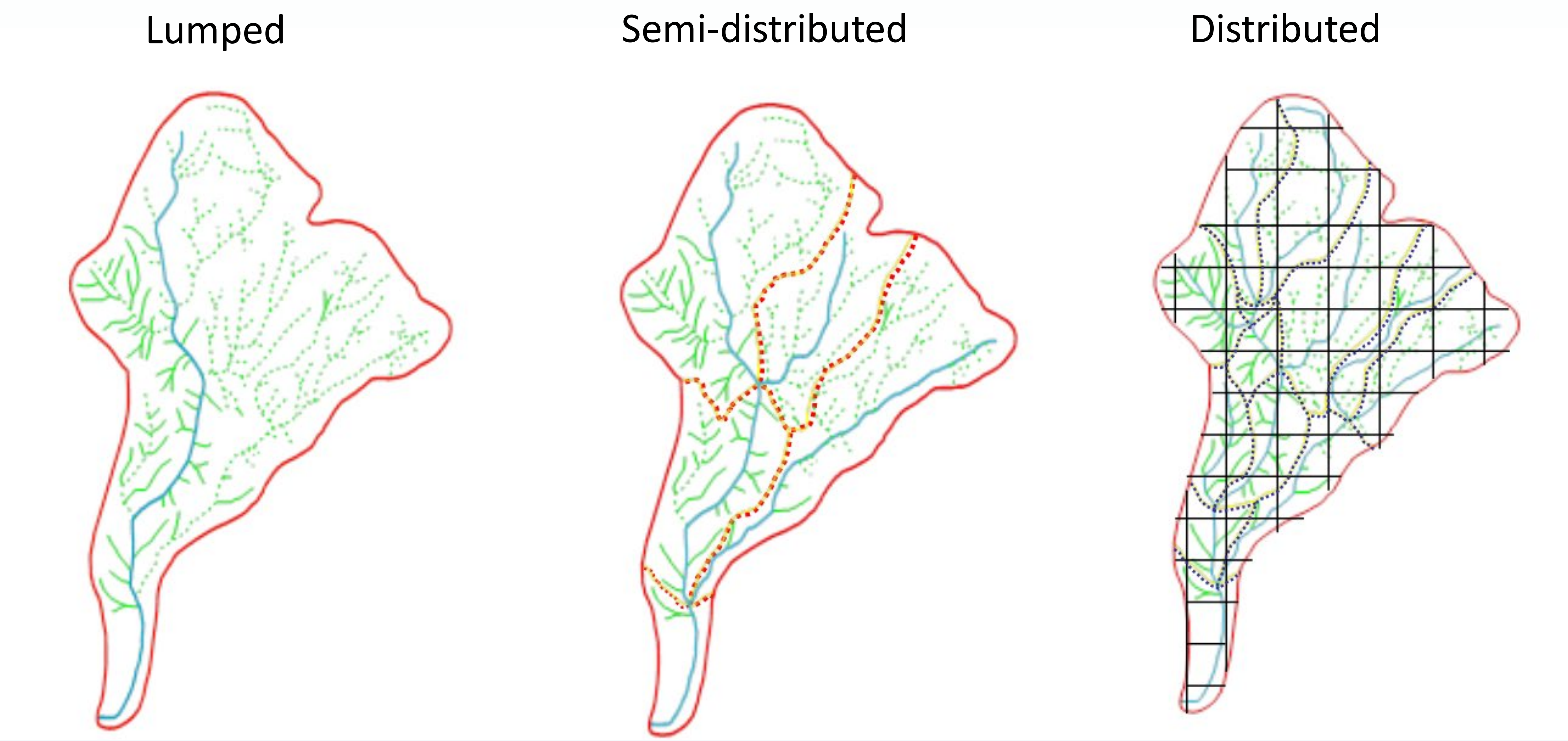
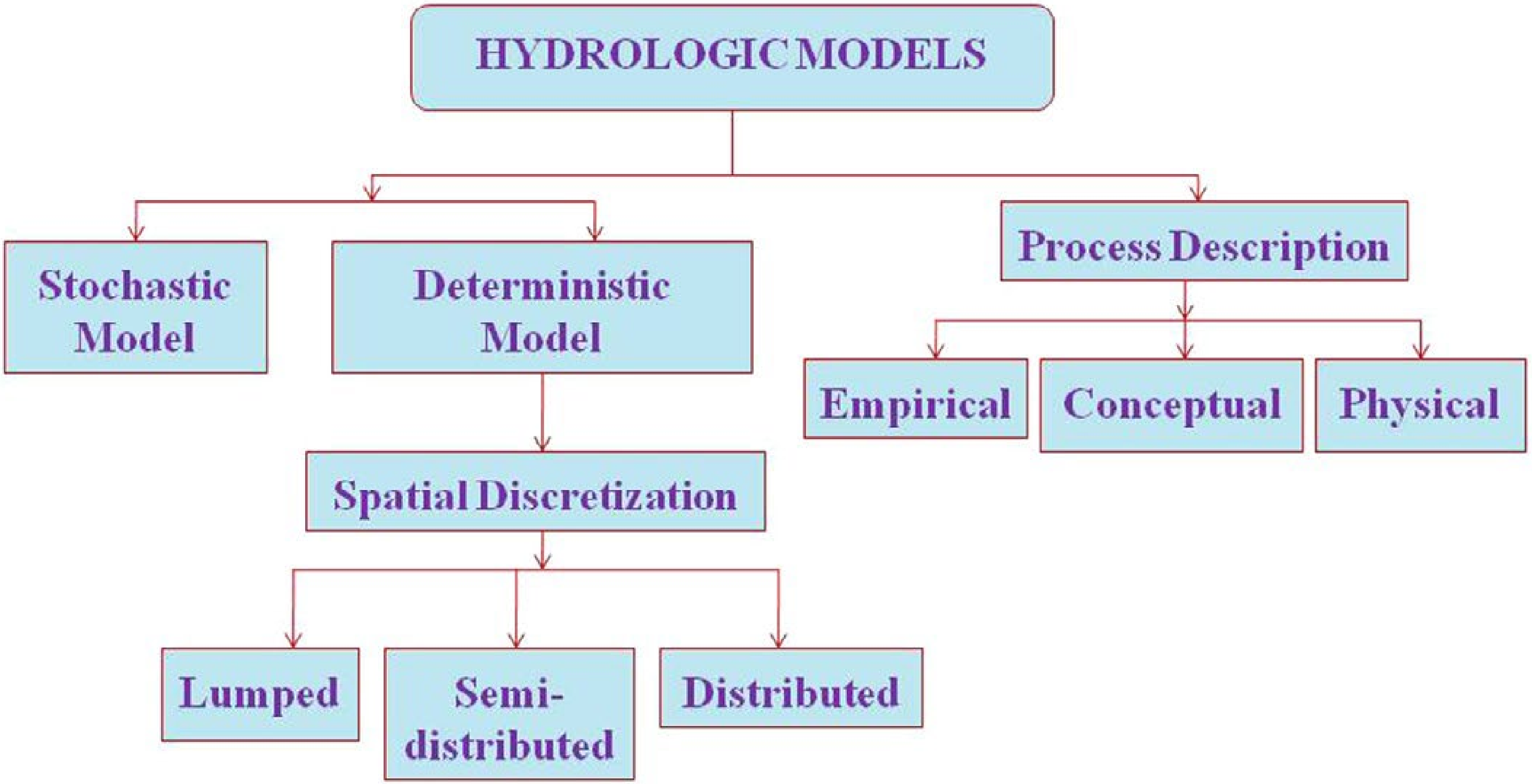
# Different types of hydrological models

- Models: simplifying the complex real world into models

- Different types of hydrological models:



# Many ways to categorize hydrological models



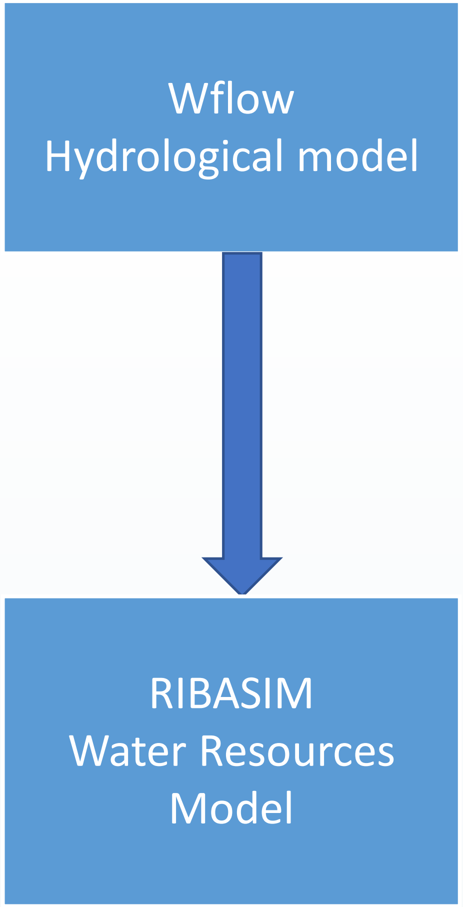
# Survey of hydrologic models used

- Mentimeter:
  - Which models are you familiar with?
  - Which models do you trust most to work with?

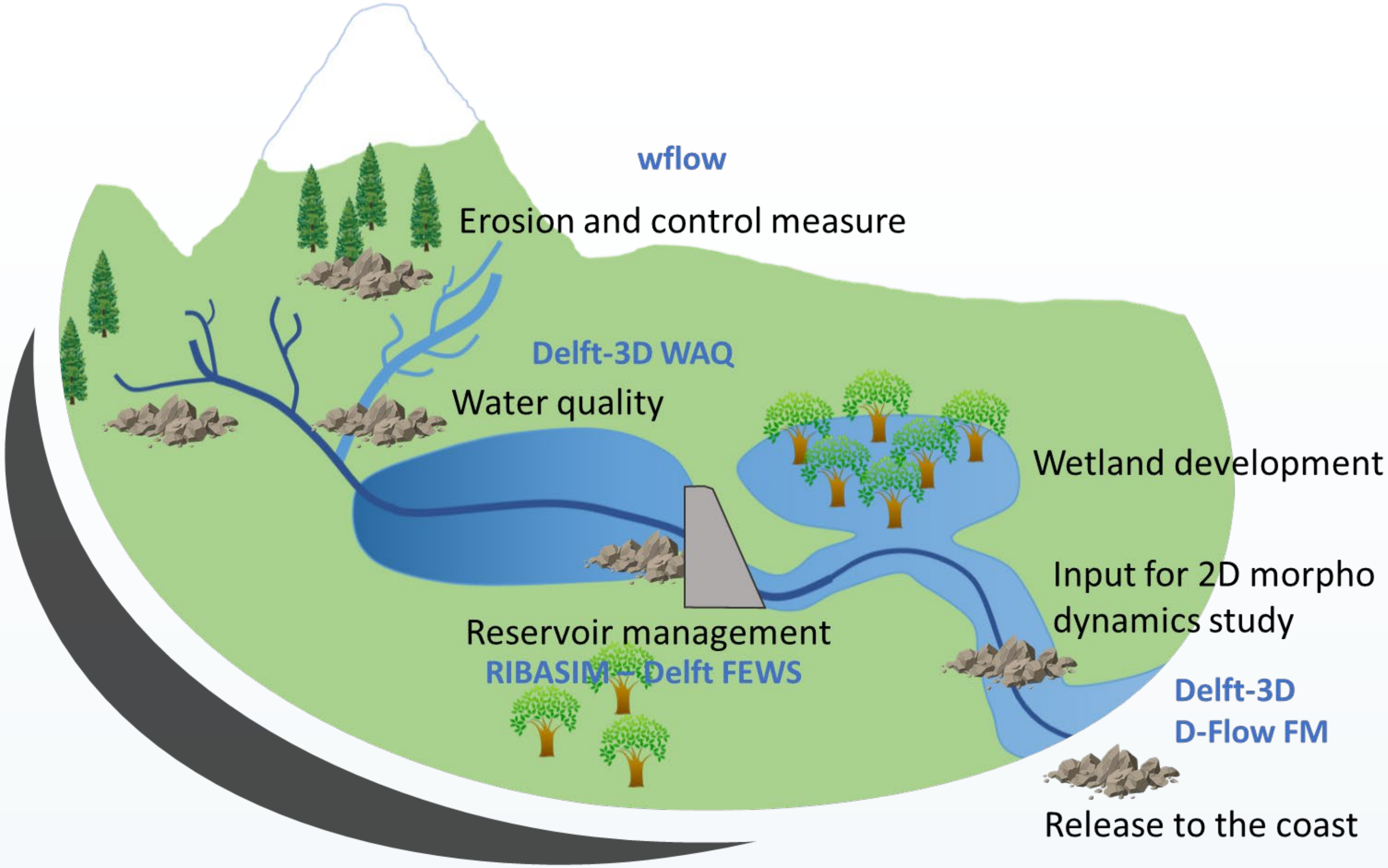
# Models used in the Iraq application

Two principal models used:

- Wflow – hydrological model / rainfall-runoff model
- RIBASIM – water resources model (“River Basin Simulation”)

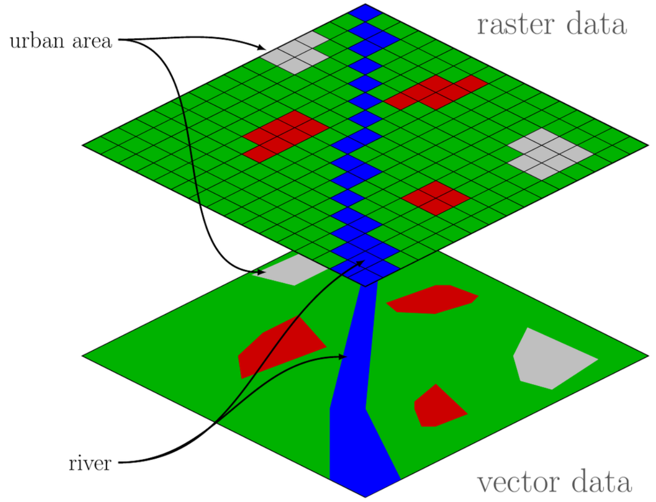


# Wflow – Hydrological model



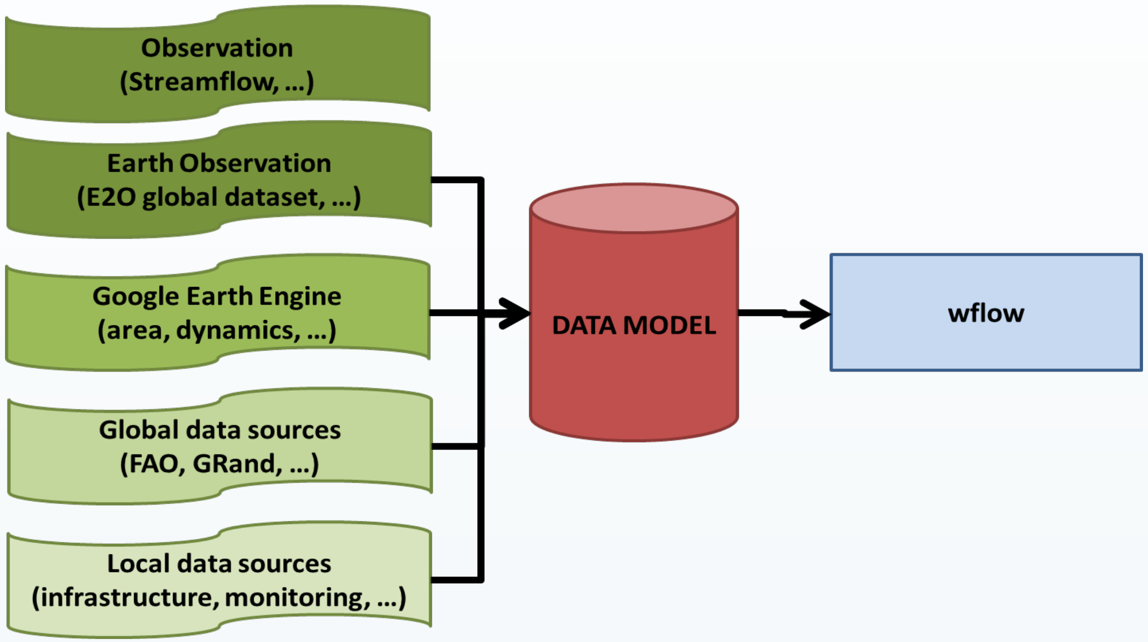
# About the Wflow framework

- The Deltares open-source hydrological modelling framework
- Used for catchment-scale rainfall-runoff modelling
- Fully distributed (grid-based)
- Different hydrological modelling concepts supported
- Open-source & free:
  - Source code (Julia: [https://github.com/Deltares/Wflow.jl](https://github.com/Deltares/Wflow.jl))
  - Pre-compiled versions availble for registered users (.exe)



# Distributed model

- Advantages of the gridded approach:
  - Stronger physical basis for simulations (linked to soil properties and land use / land cover)
  - Making optimal use of available spatial data (e.g. from satellites) → *HydroMT-Wflow*
  - Strong link to available meteorological forecasting products (e.g. ERA5, CHIRPS)

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# Strengths & weaknesses wflow model

Key strengths:

- Open source & free
- Easy to set up: directly links to available (gridded) datasets
  - Global parameterisation of the model, based on available global datasets
- Multiple hydrological concepts included
- Strongly linked to other packages (a.o. MODFLOW, Delft-FEWS, RIBASIM, D-Emission and Delwaq)

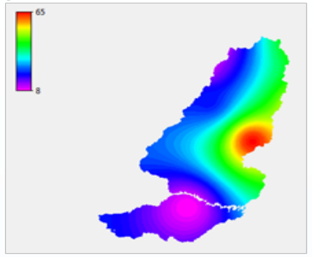
Weaknesses:

- Slow compared to semi-distributed or lumped models
- Size of data (in- and output) is sometimes very large
- Learning curve to work with NetCDF format (xarray python)

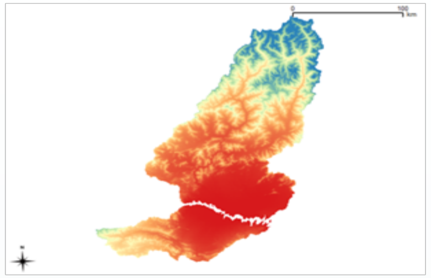
# Gridded input and output

## Gridded Inputs

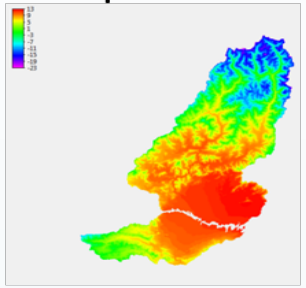
Precipitation



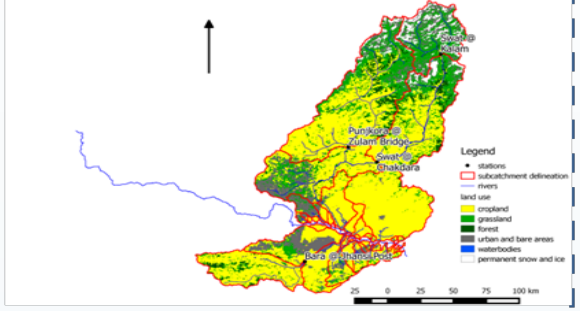
Digital elevation model



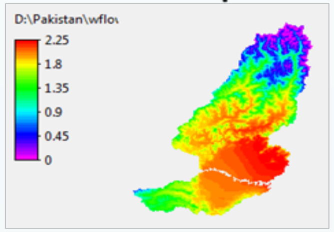
Mean temperature



Landuse map

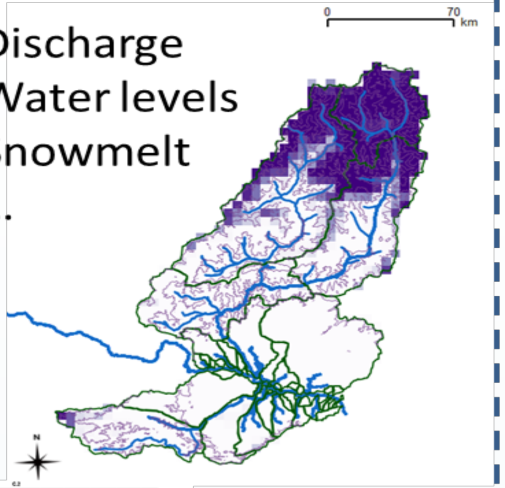


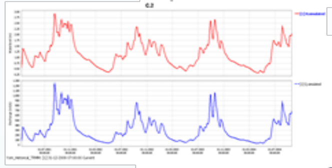

Reference evaporation

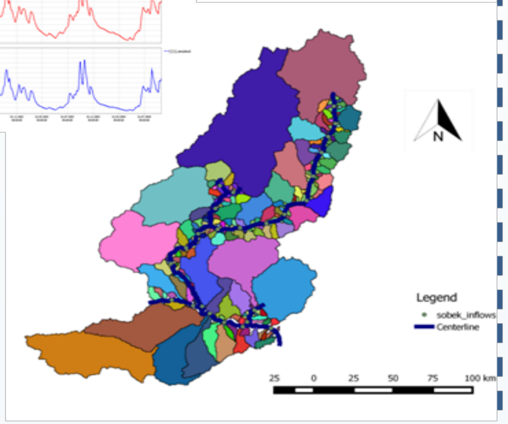



## Gridded Outputs

- Discharge
- Water levels
- Snowmelt
- ...

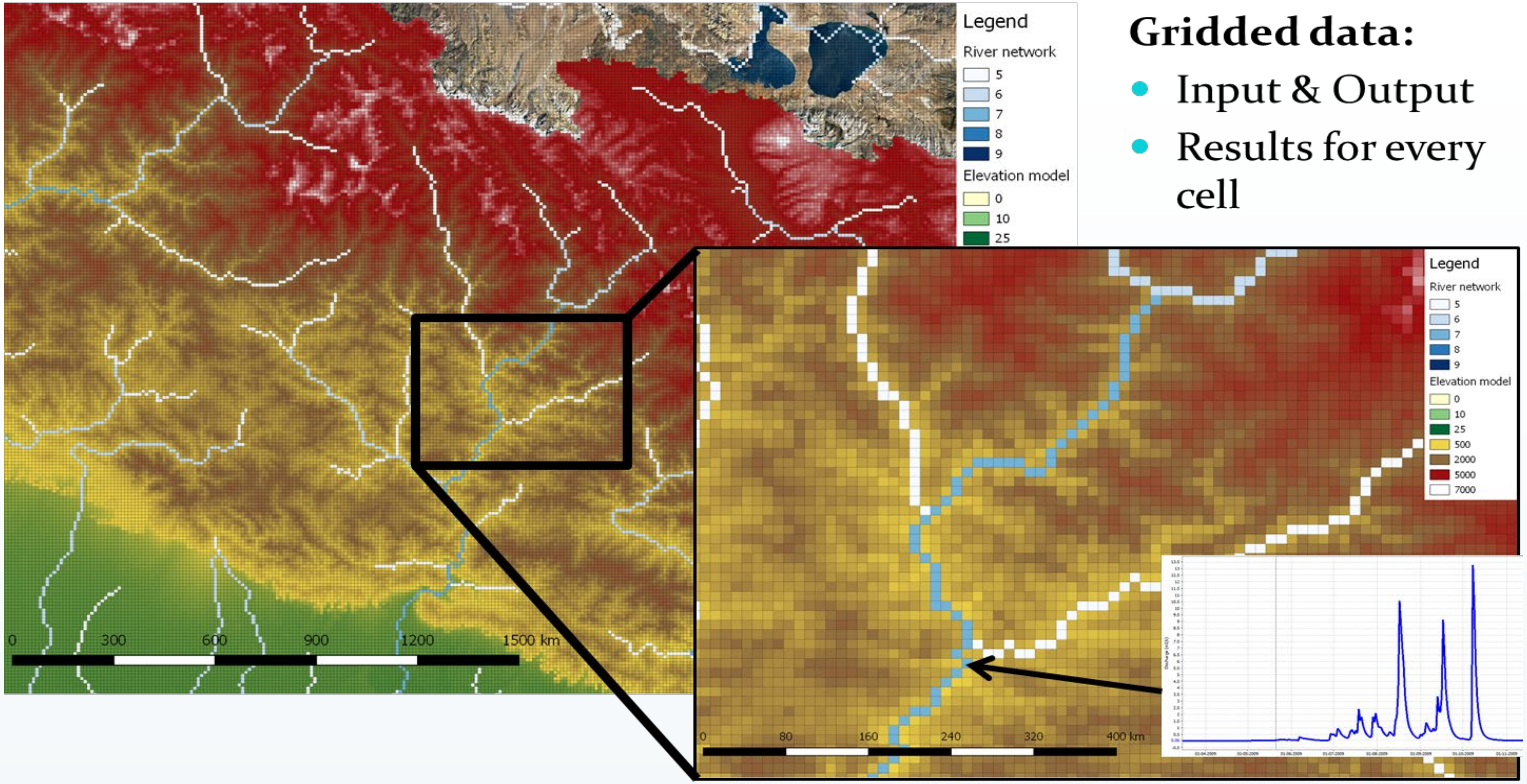




# Distributed model

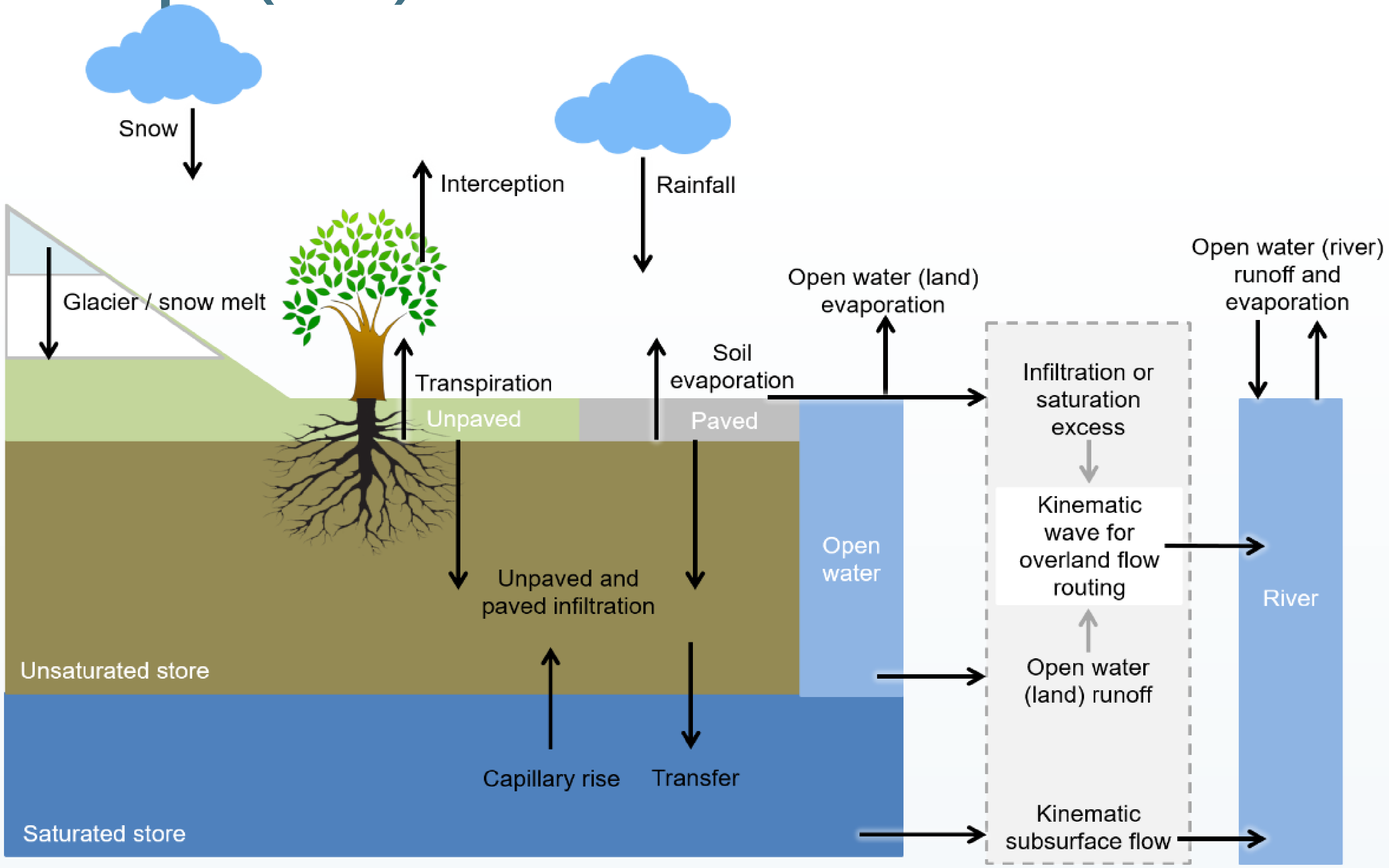
- Gridded output: results can be obtained for any point in the model




**Gridded data:**

- Input & Output
- Results for every cell

# Wflow concepts (SBM)

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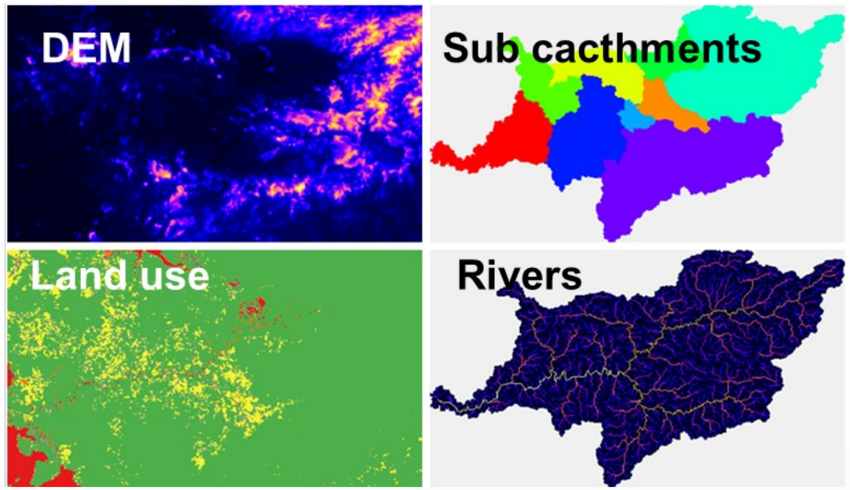
# Wflow SBM schematization: inputs

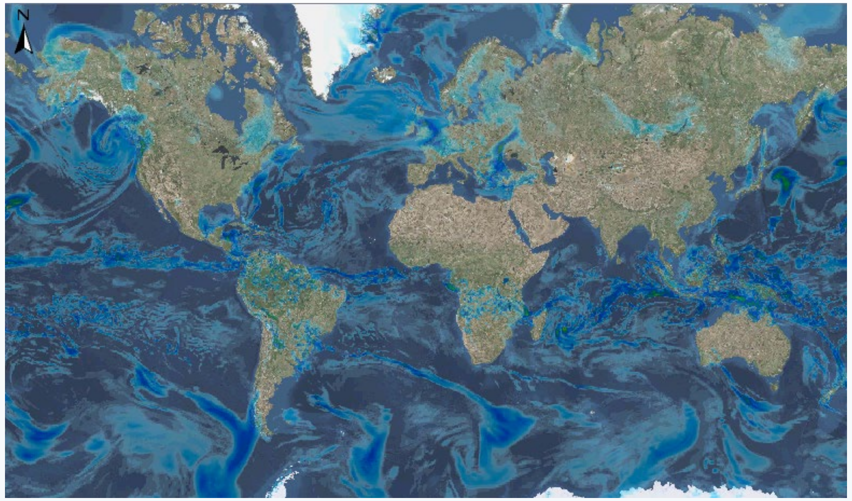
**Static input data**:

- Digital Elevation Model (DEM)
- Land use & soil map
- Rivers
- Catchments
- Local Drain Direction map (transport)

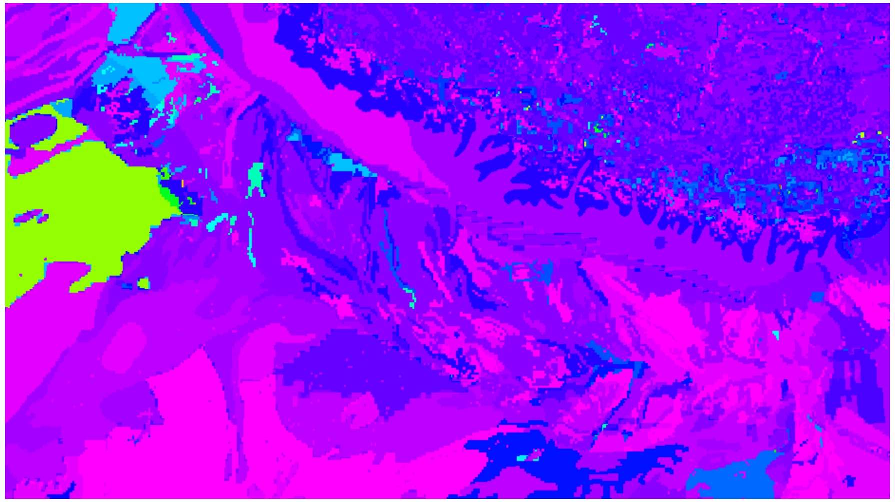



**Dynamic input data**:

- Precipitation
- Potential evapotranspiration
- Temperature

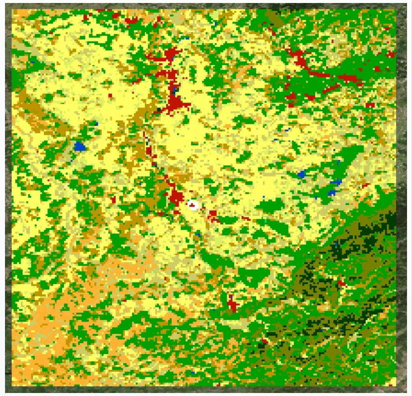


# Wflow SBM schematization: inputs



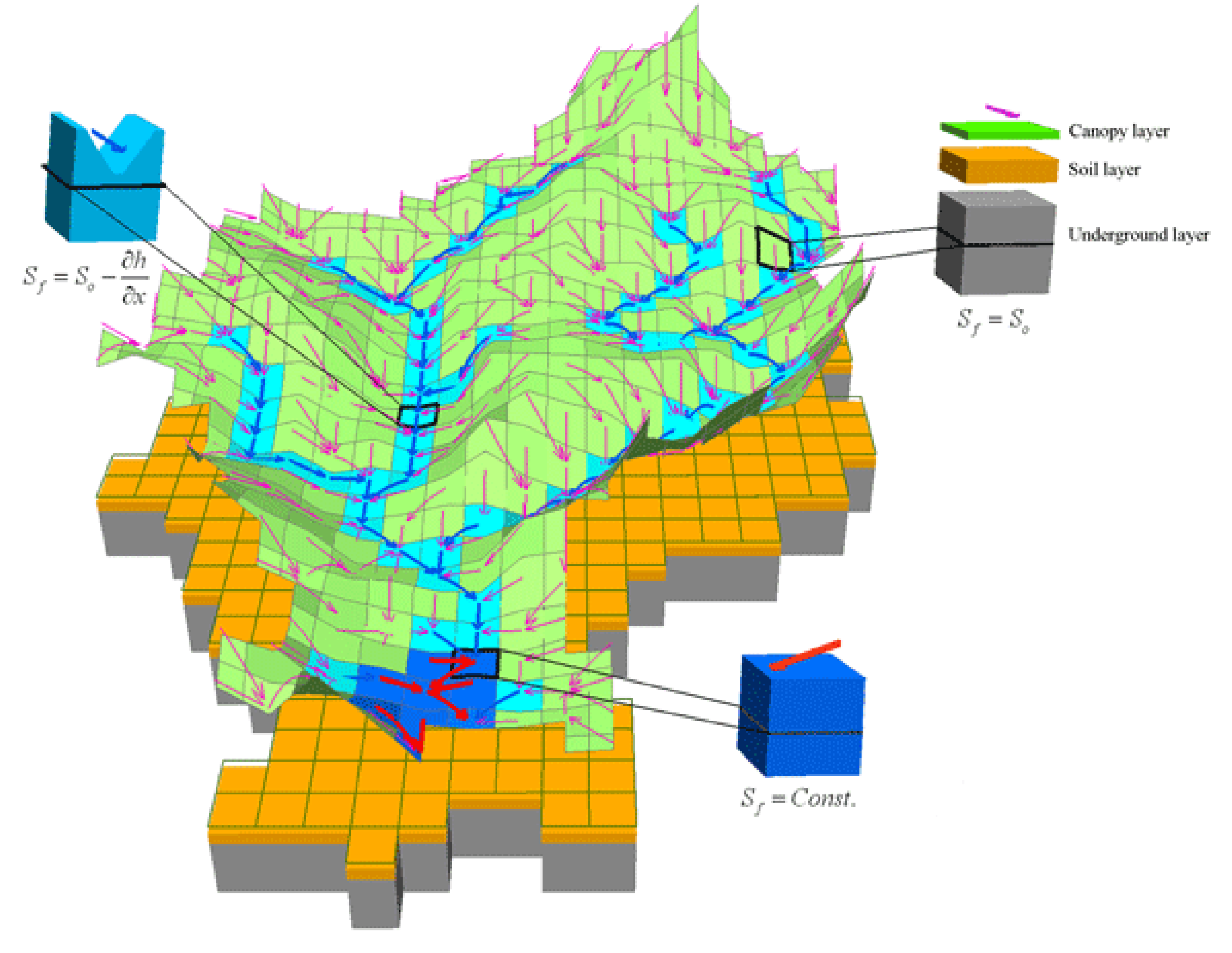
**Parameters**:

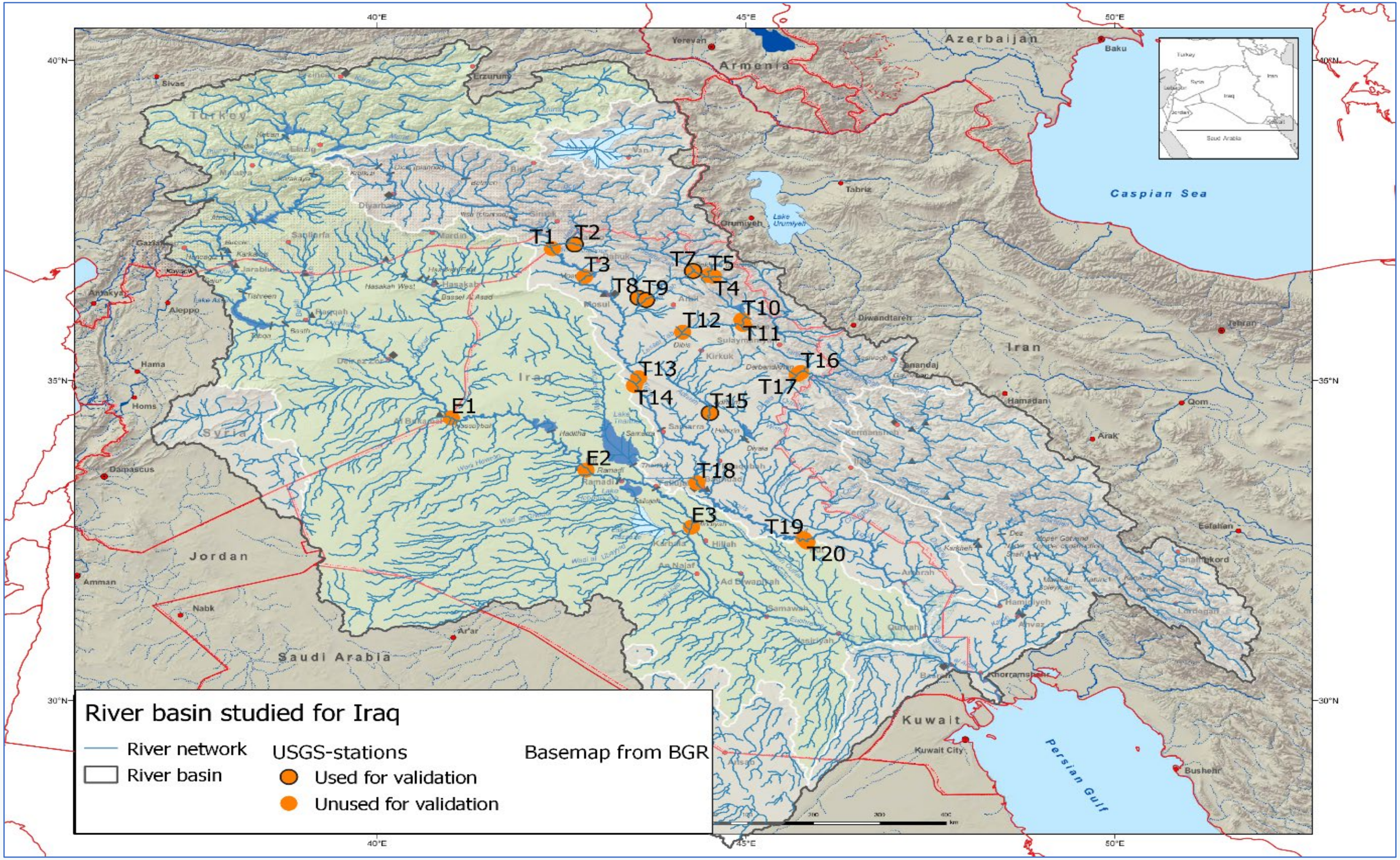
- Given as map files
- Can be derived from land use or soil properties



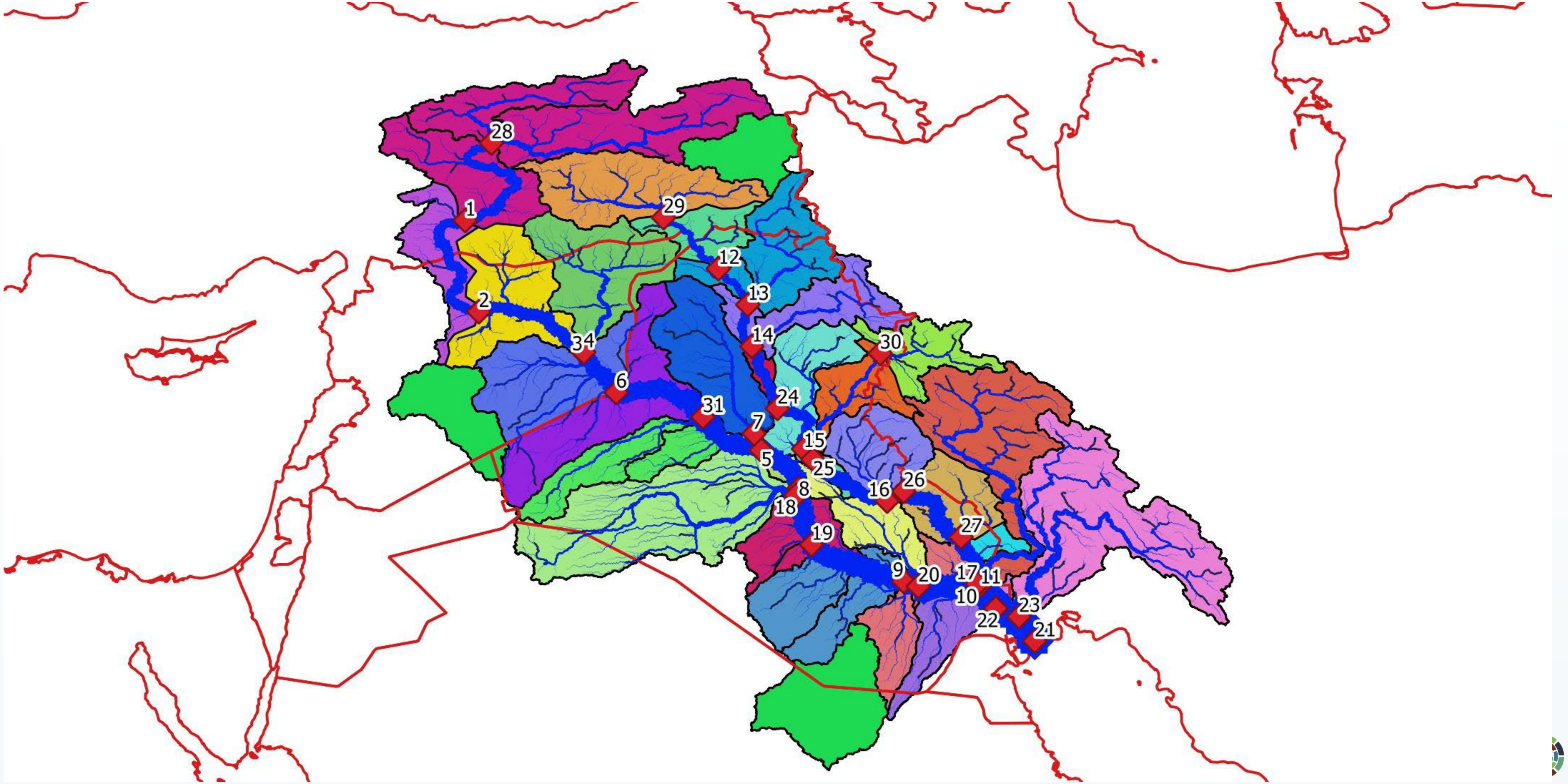
| globcover | description | Kext | N | PathFrac | RootingDepth | Sl | Swood | WaterFrac |
|---|---|---|---|---|---|---|---|---|
| 11 | Post-flooding or irrigated croplands (or aquatic) | 0.60 | 0.20 | 0.00 | 390.00 | 0.13 | 0.01 | 0.00 |
| 14 | Rainfed croplands | 0.60 | 0.20 | 0.00 | 390.00 | 0.13 | 0.00 | 0.00 |
| 20 | Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%) | 0.60 | 0.44 | 0.00 | 397.00 | 0.13 | 0.01 | 0.00 |
| 30 | Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%) | 0.60 | 0.56 | 0.00 | 400.00 | 0.13 | 0.01 | 0.00 |
| 40 | Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m) | 0.60 | 0.30 | 0.00 | 308.00 | 0.04 | 0.50 | 0.00 |
| 50 | Closed (>40%) broadleaved deciduous forest (>5m) | 0.80 | 0.80 | 0.00 | 430.00 | 0.04 | 0.50 | 0.00 |
| 60 | Open (15-40%) broadleaved deciduous forest/woodland (>5m) | 0.80 | 0.40 | 0.00 | 430.00 | 0.04 | 0.50 | 0.00 |
| 70 | Closed (>40%) needleleaved evergreen forest (>5m) | 0.80 | 0.10 | 0.00 | 382.00 | 0.05 | 0.50 | 0.00 |
| 90 | Open (15-40%) needleleaved deciduous or evergreen forest (>5m) | 0.80 | 0.40 | 0.00 | 382.00 | 0.05 | 0.50 | 0.00 |
| 100 | Mosaic forest or shrubland (50-70%) / grassland (20-50%) | 0.80 | 0.30 | 0.00 | 406.00 | 0.04 | 0.50 | 0.00 |
| 110 | Mosaic forest or shrubland (50-70%) / grassland (20-50%) | 0.60 | 0.46 | 0.00 | 286.00 | 0.07 | 0.20 | 0.00 |
| 120 | Mosaic grassland (50-70%) / forest or shrubland (20-50%) | 0.60 | 0.50 | 0.00 | 179.00 | 0.13 | 0.05 | 0.00 |
| 130 | Closed to open (>15%) (broadleaved or needleleaved evergreen or deciduous) shrubland (<5m) | 0.60 | 0.50 | 0.00 | 432.00 | 0.07 | 0.10 | 0.00 |
| 140 | Closed to open (>15%) herbaceous vegetation (grassland savannas or lichens/mosses) | 0.60 | 0.24 | 0.00 | 457.00 | 0.09 | 0.00 | 0.00 |
| 150 | Closed to open (>15%) herbaceous vegetation (grassland savannas or lichens/mosses) | 0.60 | 0.02 | 0.00 | 137.00 | 0.04 | 0.04 | 0.00 |
| 160 | Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water | 0.60 | 0.30 | 0.00 | 308.00 | 0.04 | 0.10 | 0.00 |
| 170 | Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water | 0.80 | 0.80 | 0.00 | 308.00 | 0.04 | 0.20 | 0.00 |
| 180 | Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh brackish or saline water | 0.60 | 0.15 | 0.00 | 107.00 | 0.13 | 0.01 | 0.00 |
| 190 | Artificial surfaces and associated areas (Urban areas >50%) | 0.60 | 0.01 | 0.75 | 179.00 | 0.04 | 0.01 | 0.00 |
| 200 | Bare areas | 0.60 | 0.01 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 |
| 210 | Water bodies | 0.70 | 0.08 | 0.00 | 0.00 | 0.04 | 0.00 | 1.00 |
| 220 | Permanent snow and ice | 0.60 | 0.01 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 |
| 230 | No Data | -999.00 | -999.00 | -999.00 | -999.00 | -999.00 | -999.00 | -999.00 |

# Spatial-distributed model simulation




River basin studied for Iraq
River network
River basin
USGS-stations
Used for validation
Unused for validation
Basemap from BGR
T1
T2
T3
T4
T5
T7
T8
T9
T10
T11
T12
T13
T14
T15
T16
T17
T18
T19
T20
E1
E2
E3
Turkey
Syria
Iraq
Iran
Jordan
Saudi Arabia
Kuwait
Armenia
Azerbaijan
Caspian Sea
Persian Gulf
Lake Urumiyeh
40°E
45°E
50°E
40°N
35°N
30°N

# Wflow division of sub-basins – Iraq



# RIBASIM – Water Resources Model

# RIBASIM – Water Resources Model

- is a **generic model package** for simulating the behavior of any river basins under various hydrological conditions.
- has been developed and fine-tuned since **1985** at Deltares in the course of many projects.
- is Deltares software and is **free available** for educational and research purpose.
- does **not require any software from other third parties**. QGIS, Python, other : not needed
- has been applied in **more than 30 countries** world-wide.

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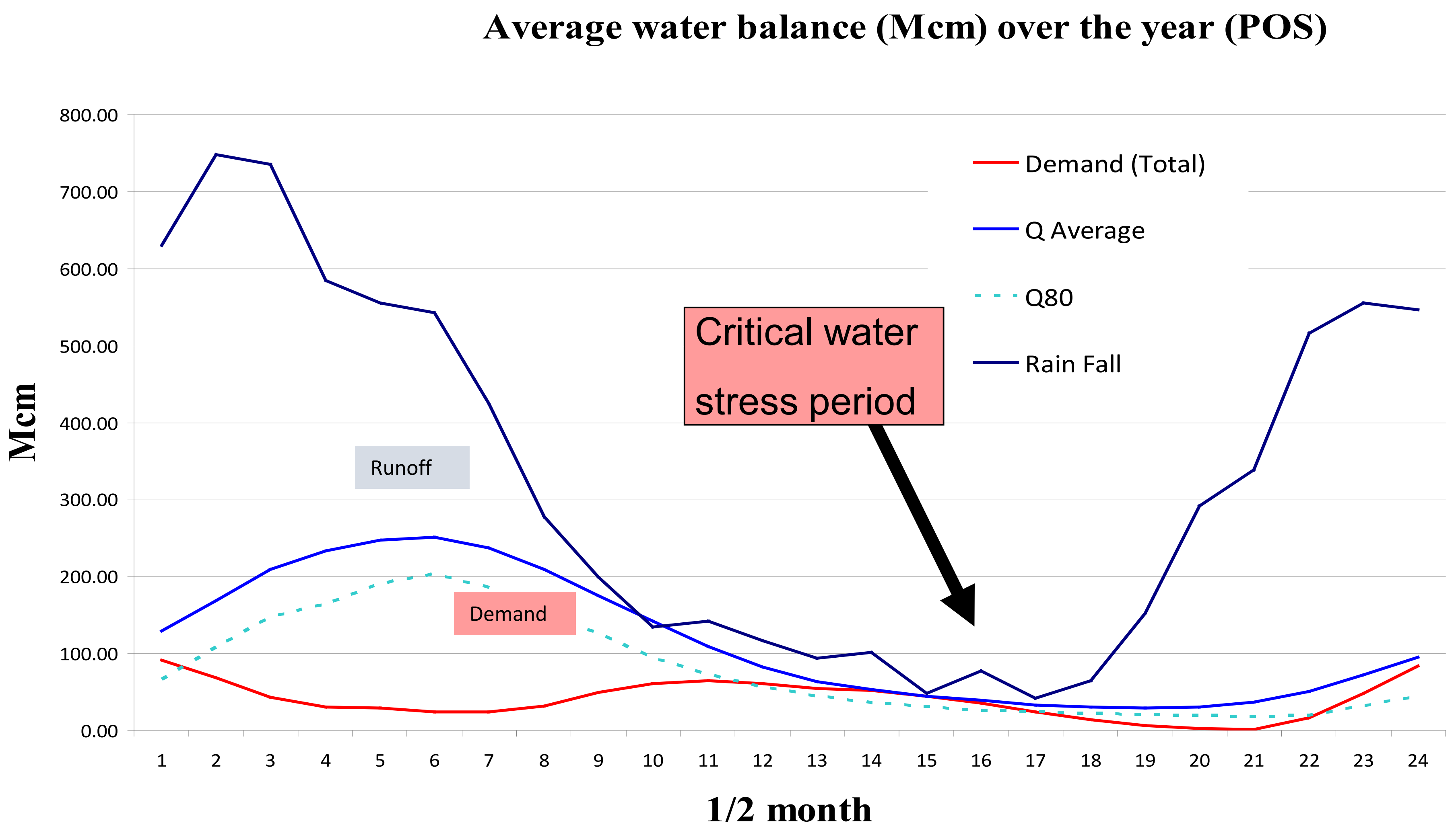
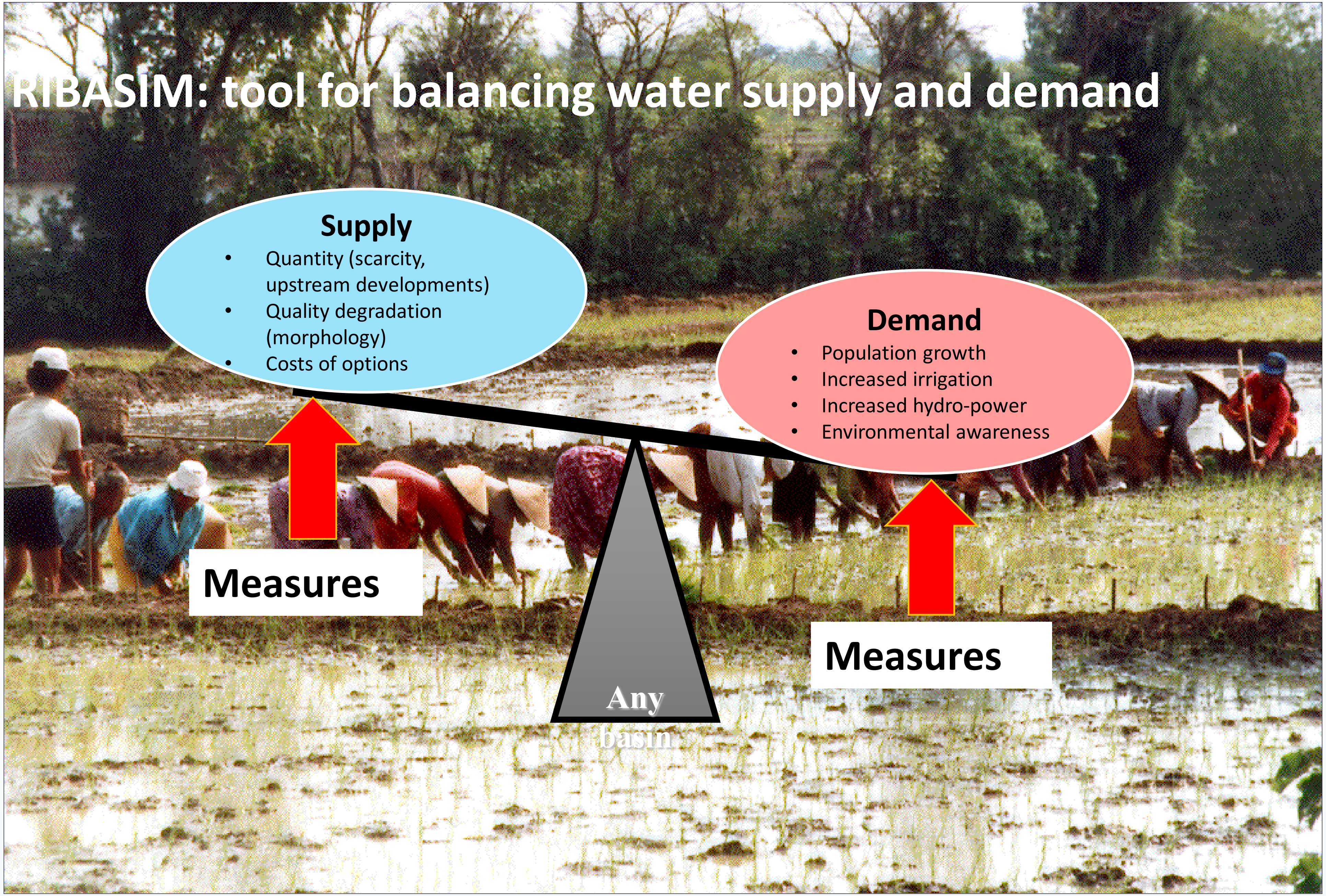
# RIBASIM is a ‘zero dimension model’ – water balances

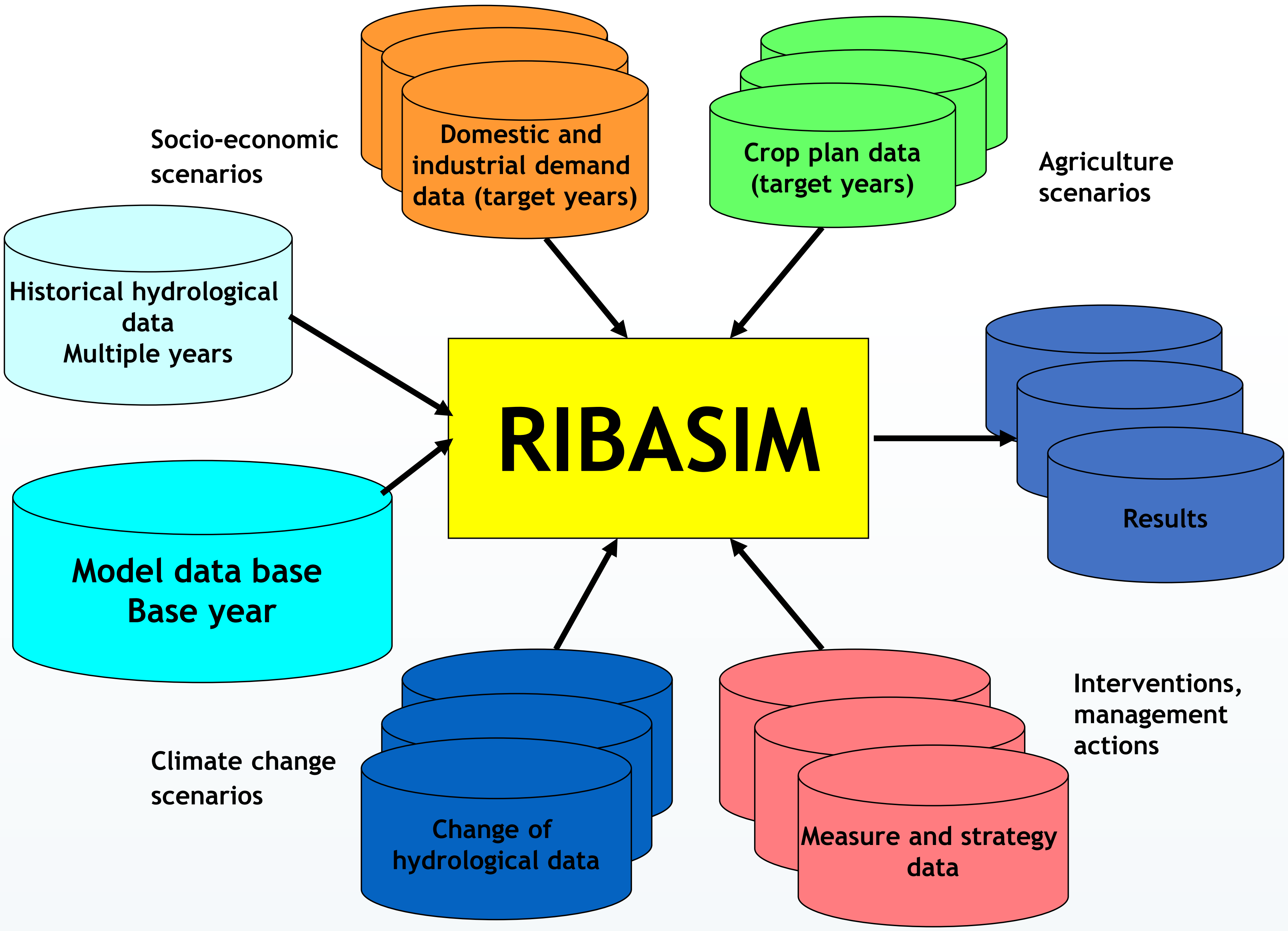
| Models | Dimension | Time scale | Problem area |
|---|---|---|---|
| RIBASIM | 0 D | days<br>weeks<br>decade<br>half-month<br>month | **River basin management**<br>(water shortage/ water pollution) |
| SOBEK | 1 D | hours | **River/ flood plain management**<br>(flood control, nature building) |
| WAQUA/ Delft2D | 2 D | minutes/ hours | **Estuarine and coastal seas management** |
| DELFT3D | 3 D | minutes/ hours | **(For stratified conditions)** |

# Type of problems



# RIBASIM: tool for balancing water supply and demand




Socio-economic scenarios
Domestic and industrial demand data (target years)
Crop plan data (target years)
Agriculture scenarios
Historical hydrological data
Multiple years
RIBASIM
Results
Model data base
Base year
Climate change scenarios
Change of hydrological data
Measure and strategy data
Interventions, management actions

# All kind of water activities included

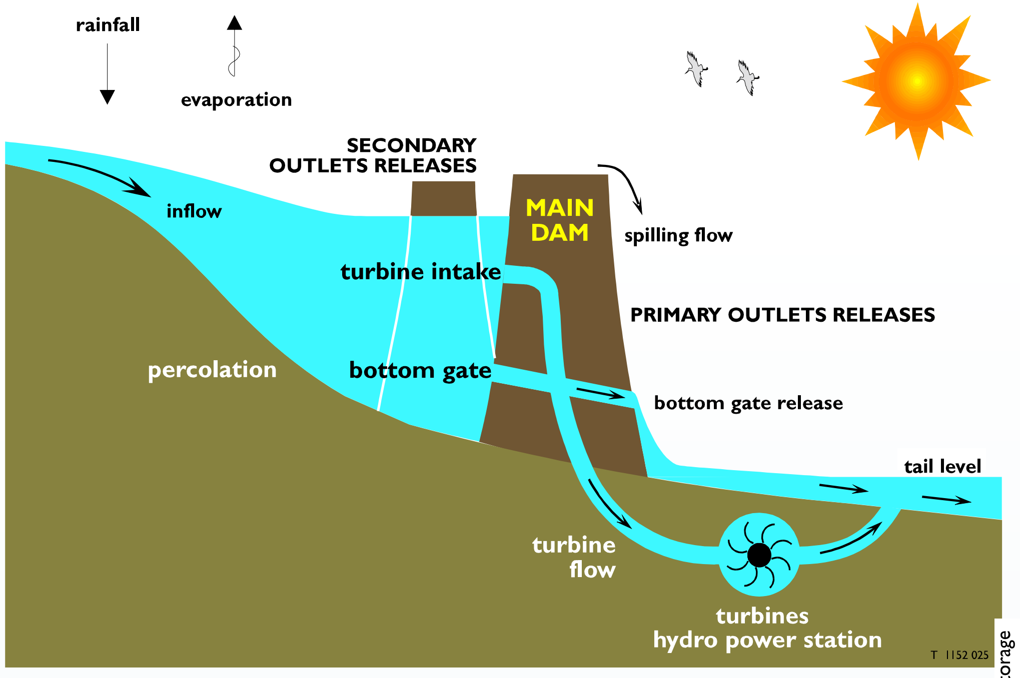
- Agriculture
- Domestic, municipal and industrial use
- Aquaculture
- Livestock (cattle)
- Recreation
- Nature conservation
- Environmental flow
- Transport of pollutants and heat
- Navigation
- Hydro-power production
- Cooling for power production
- Losses in river reaches and canals from evaporation and seepage :
- Groundwater recharge
- Water rights
- Sediment management

# Domestic, Municipal and Industrial water use

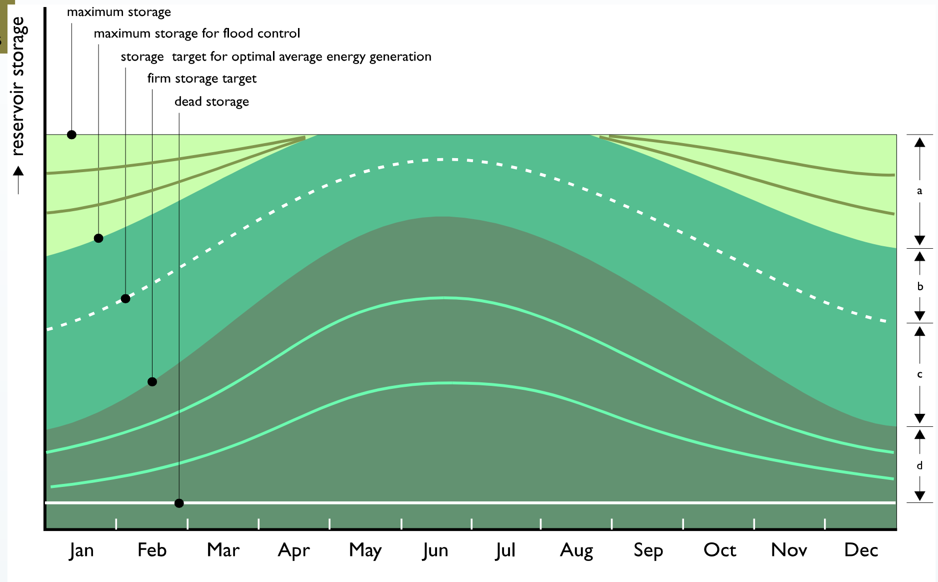

Agriculture water use


Infrastructure

# Dams and reservoirs with hydropower



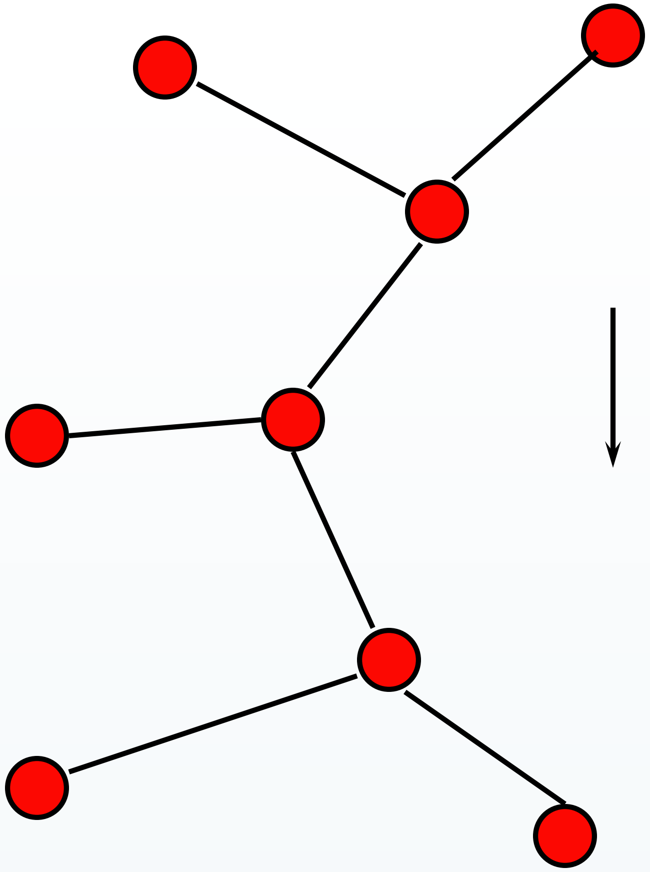

Surface water reservoir geometry



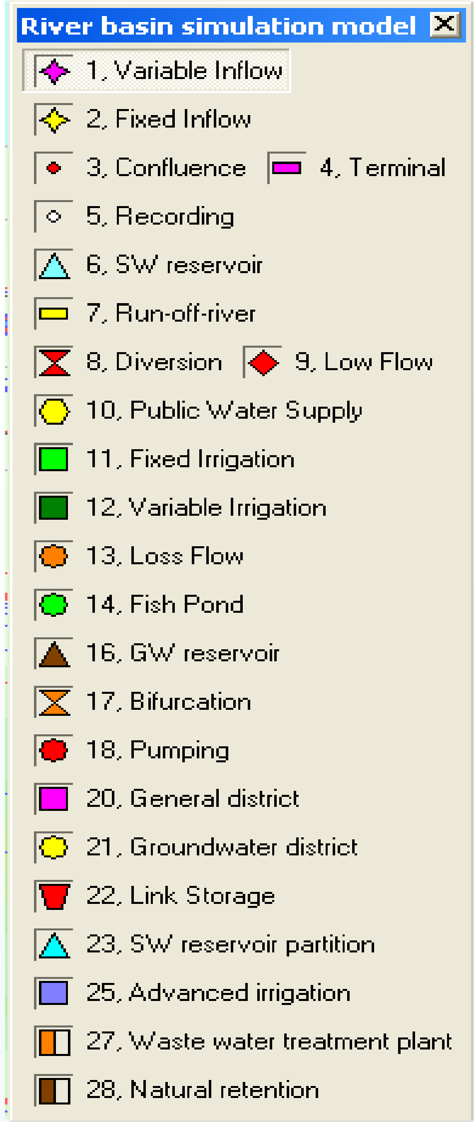

Reservoir operation rule curves

# Setup using nodes and links

- Nodes
  - infrastructure
  - users
  - control
- Links (branches)
  - transport of water



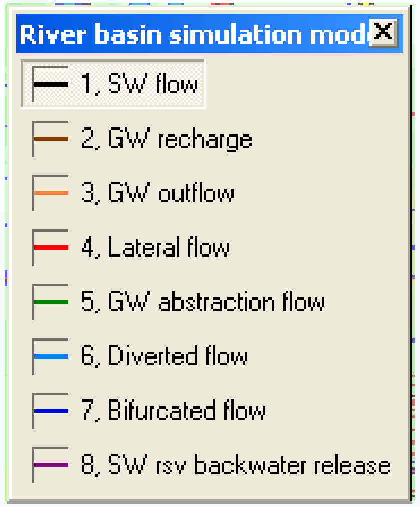
# Design network with nodes and links




## Various node types.

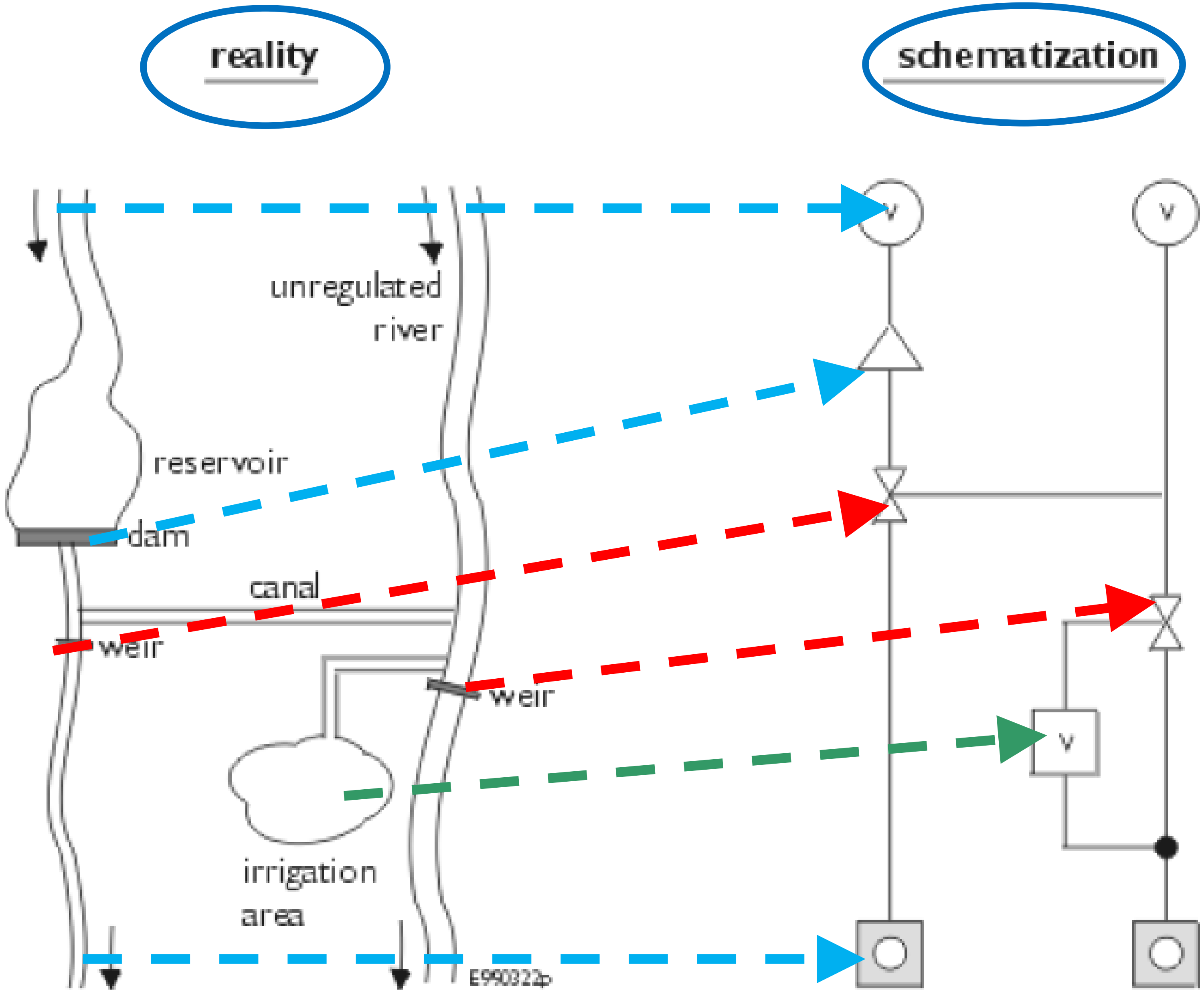
### Sub-divison in :

- Demand nodes : activities, users
- Control nodes : infrastructure
- Layout nodes : network completion

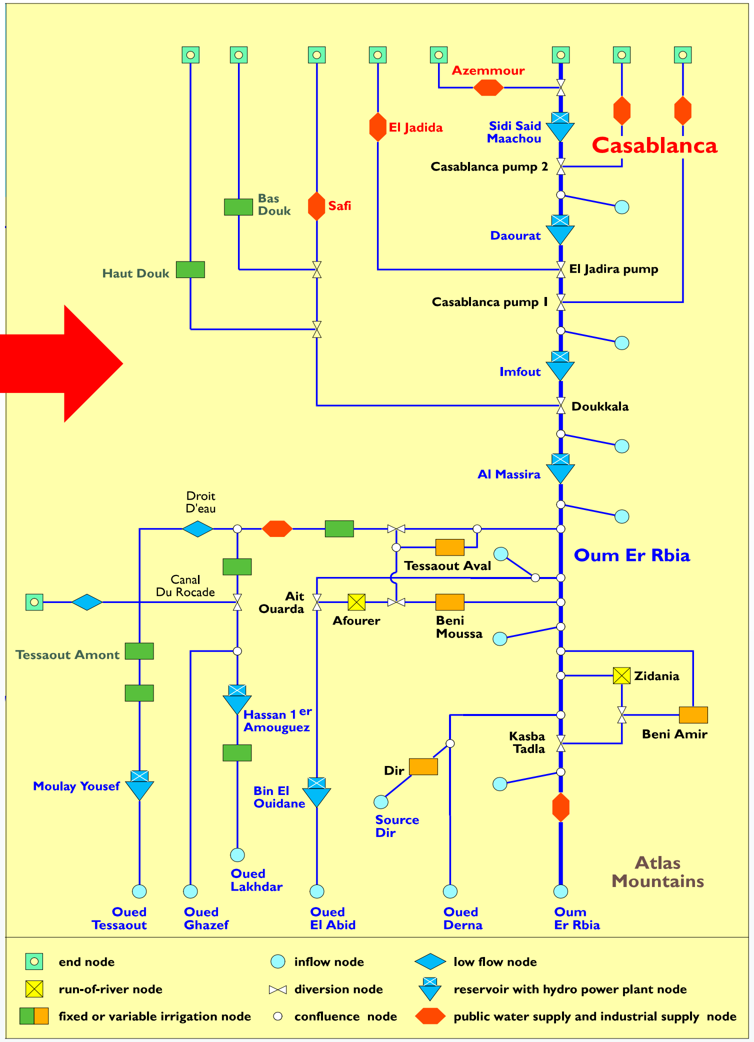



## Various link types

# Setup of schematization

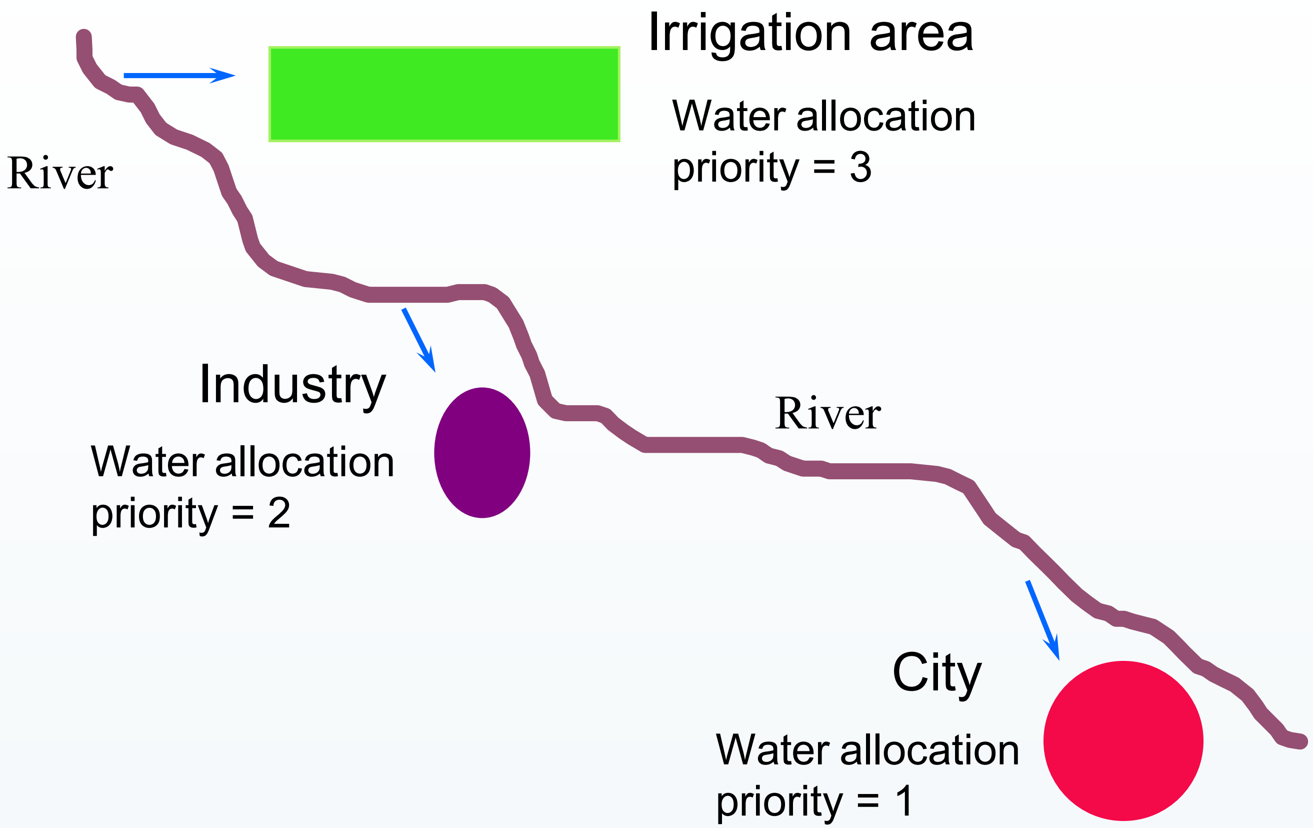


# Design network schematization

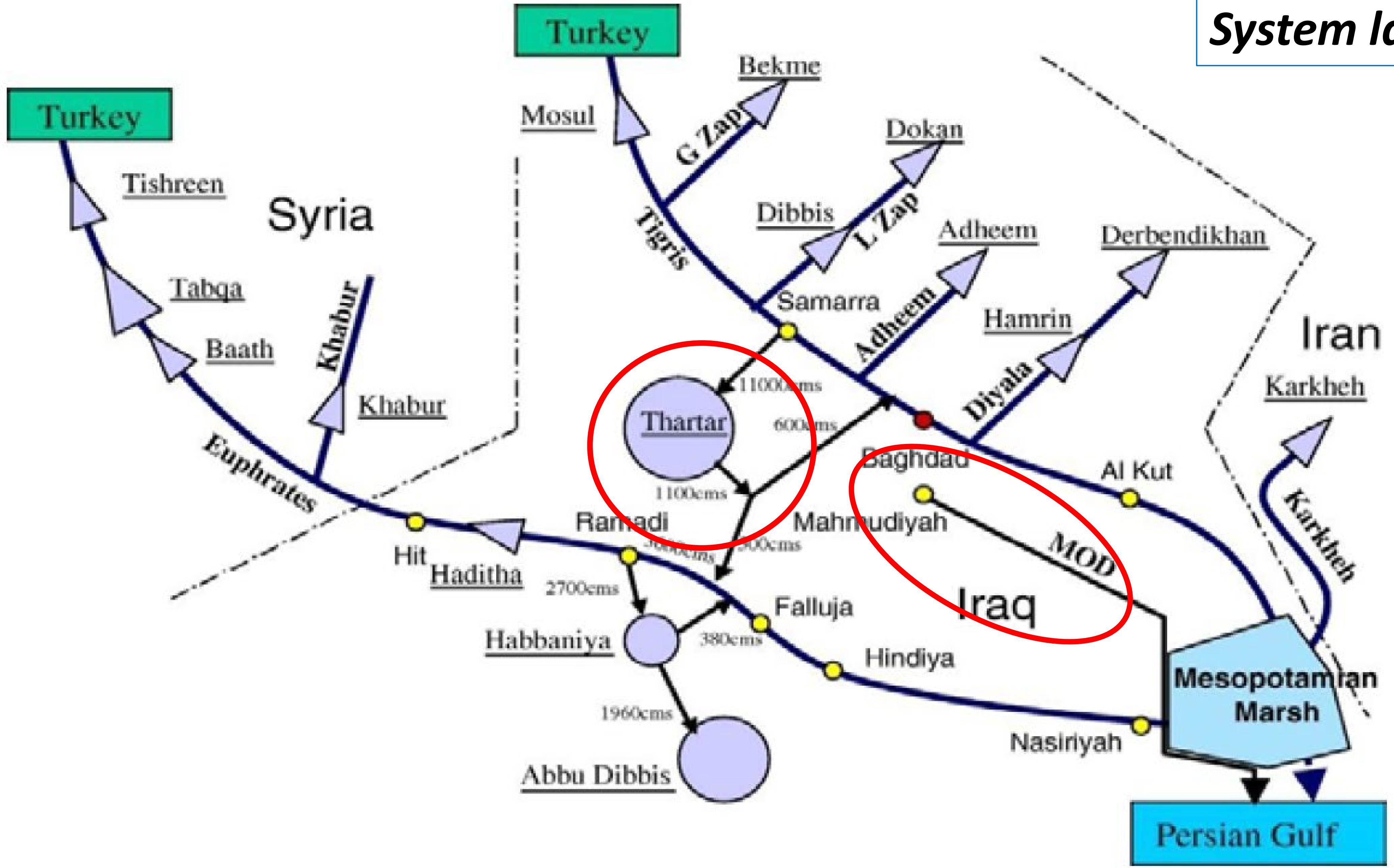



# Optimization of water allocation

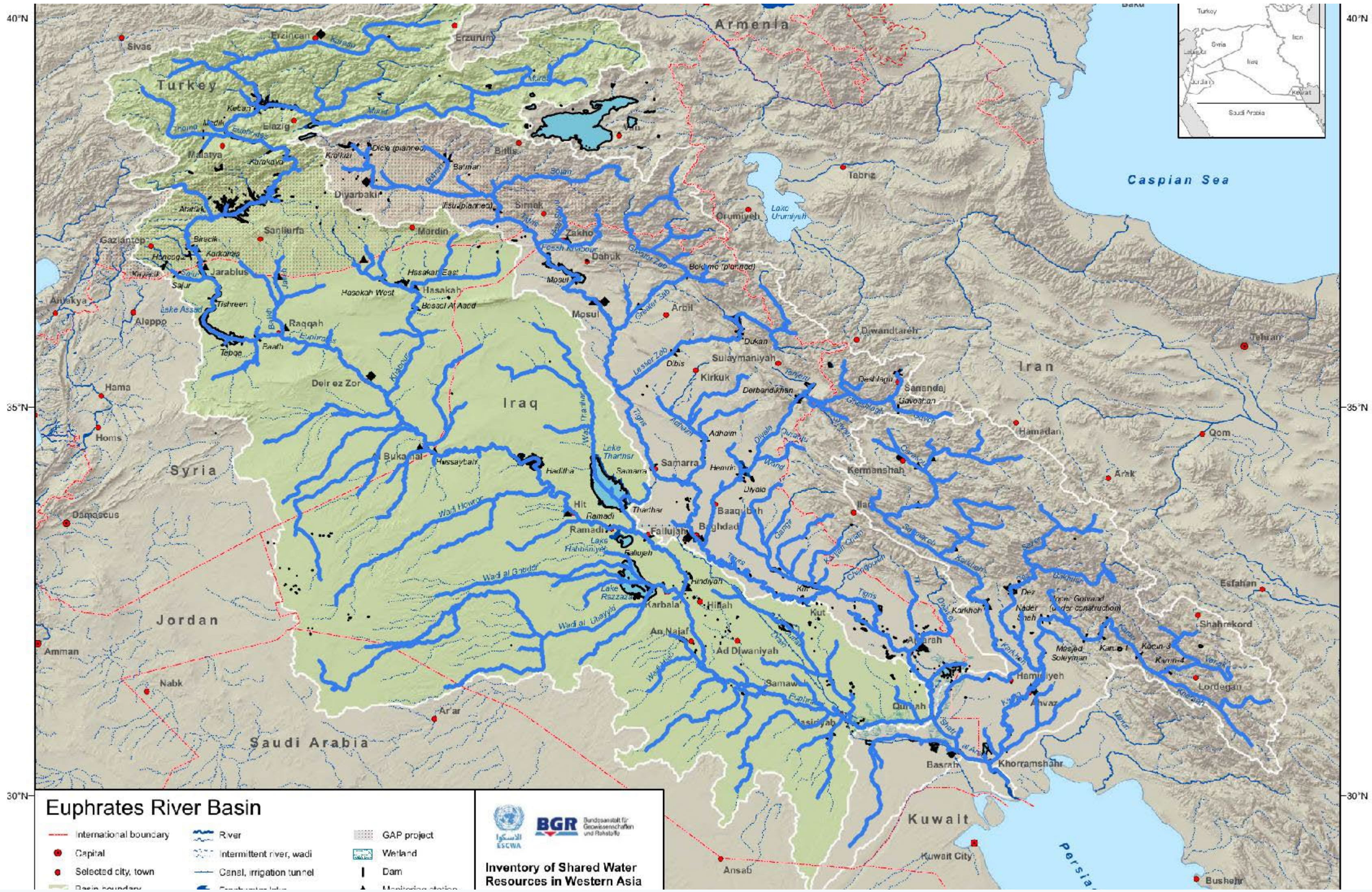
Water allocation basic principle: first come - first served
which can be overruled by water allocation priorities per user



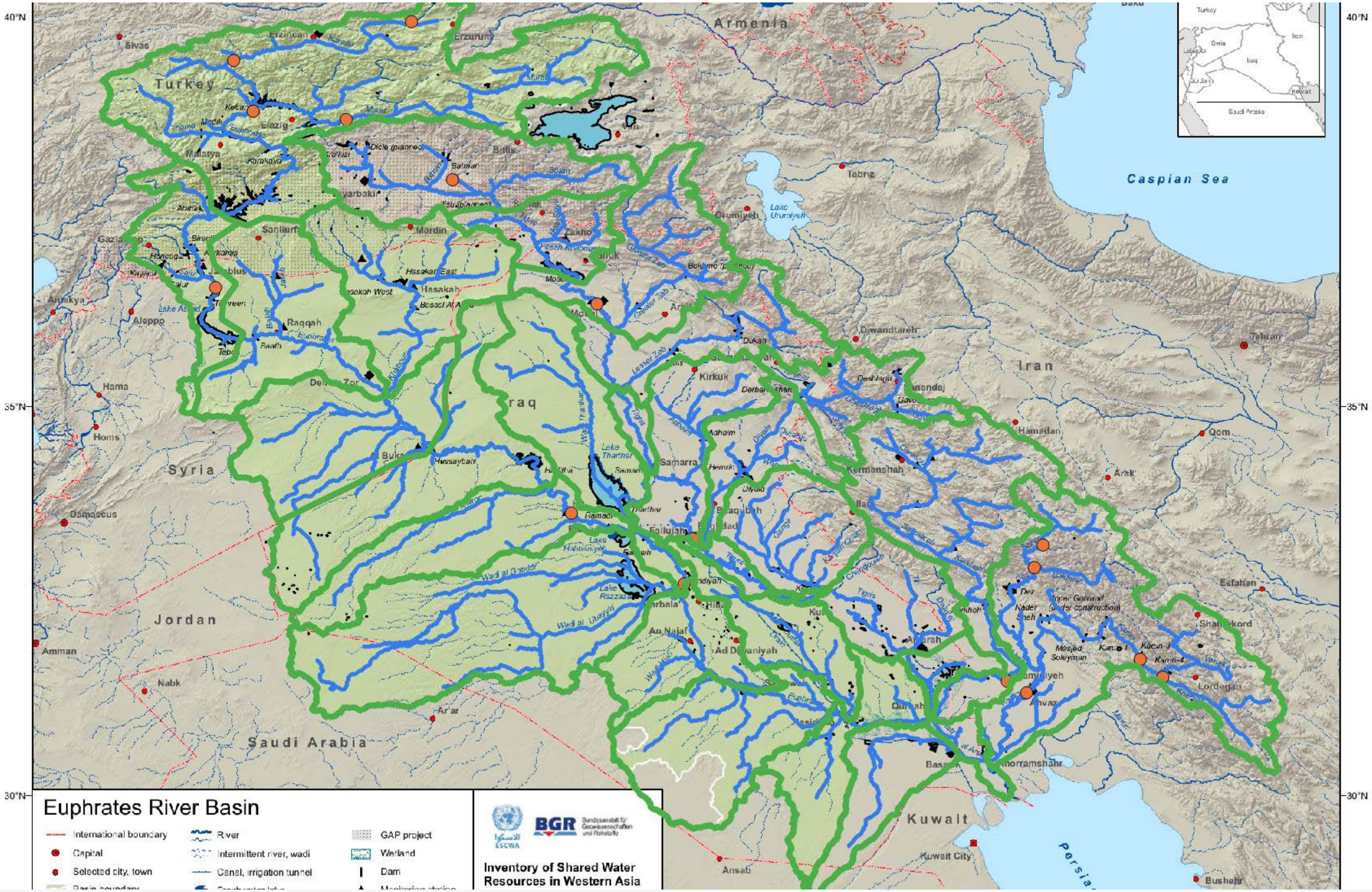
## *System layout*



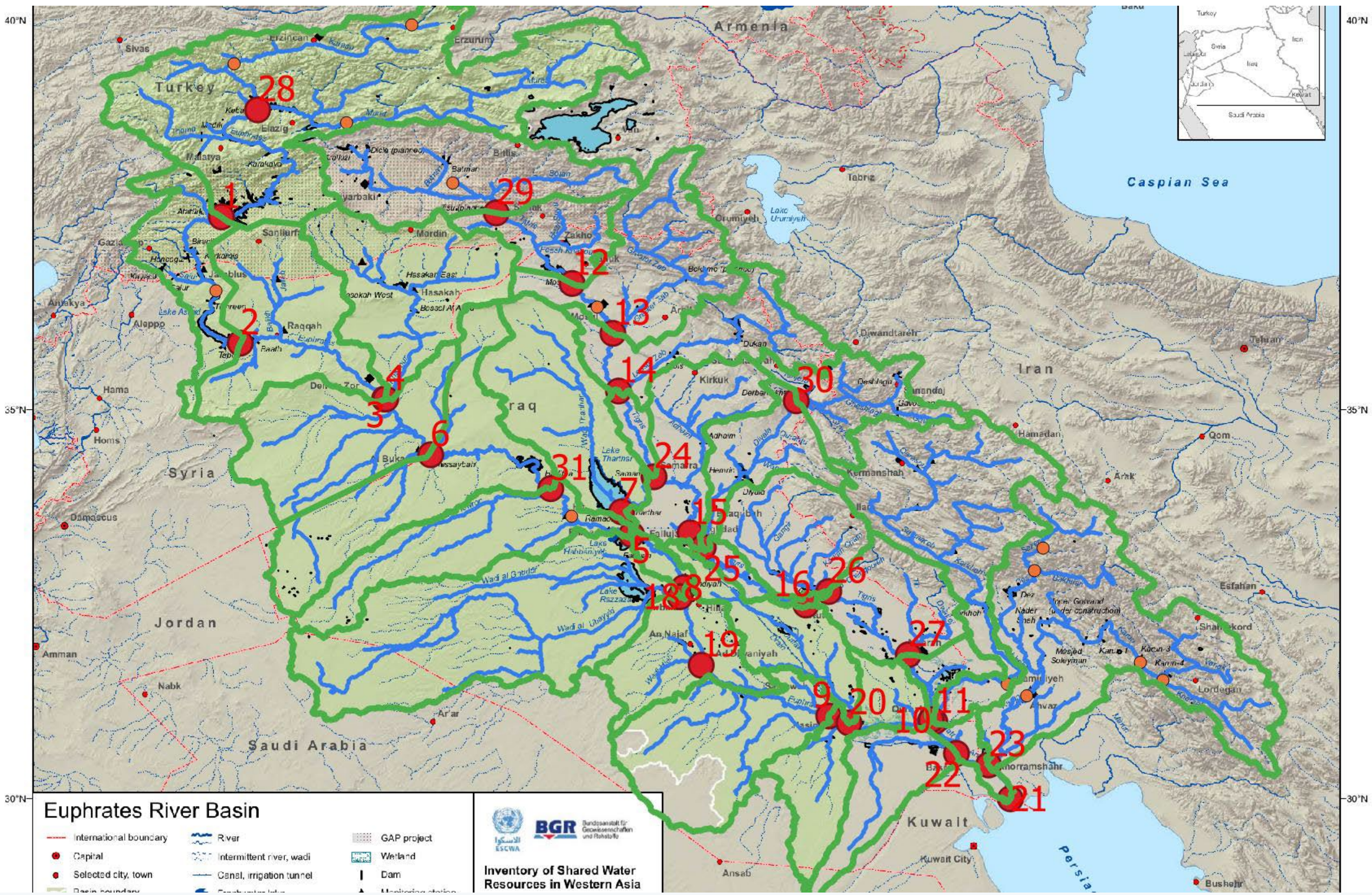
# Total basin with wflow drainage system

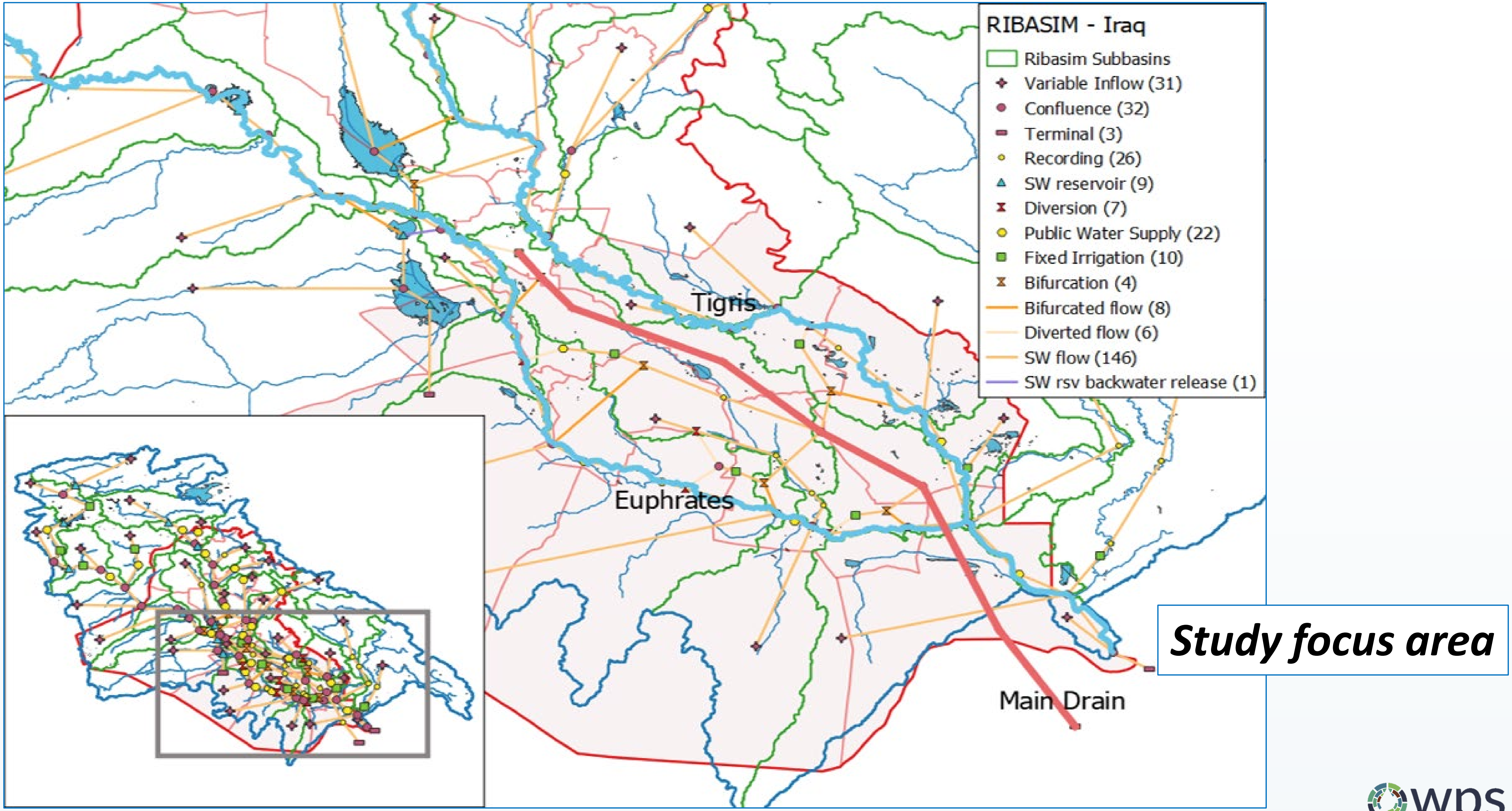


# Subbasin division used for wflow & RIBASIM



# Inflow points from wflow to RIBASIM




RIBASIM - Iraq
Ribasim Subbasins
Variable Inflow (31)
Confluence (32)
Terminal (3)
Recording (26)
SW reservoir (9)
Diversion (7)
Public Water Supply (22)
Fixed Irrigation (10)
Bifurcation (4)
Bifurcated flow (8)
Diverted flow (6)
SW flow (146)
SW rsv backwater release (1)
Tigris
Euphrates
Main Drain
Study focus area

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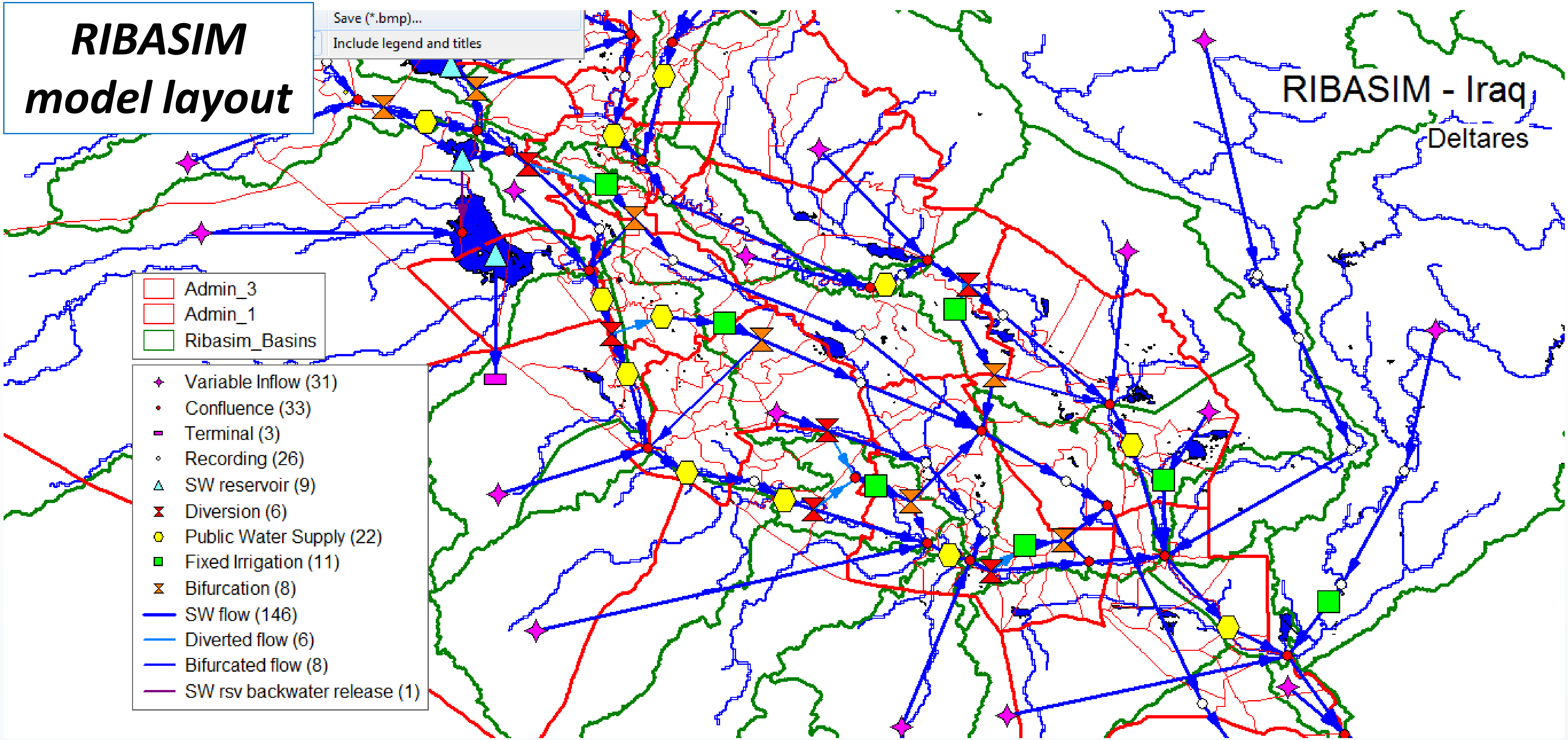
# *RIBASIM model layout*

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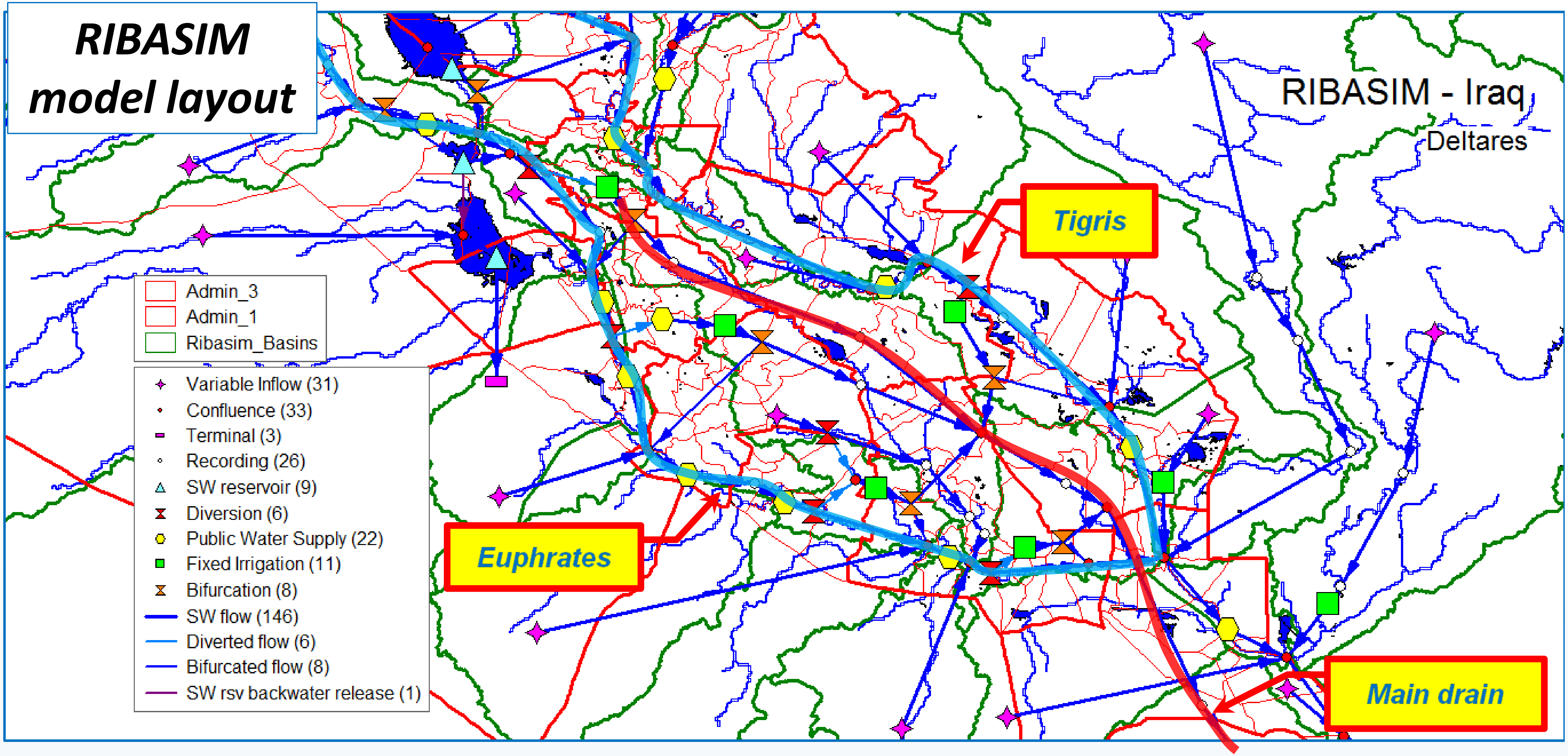
# RIBASIM model layout

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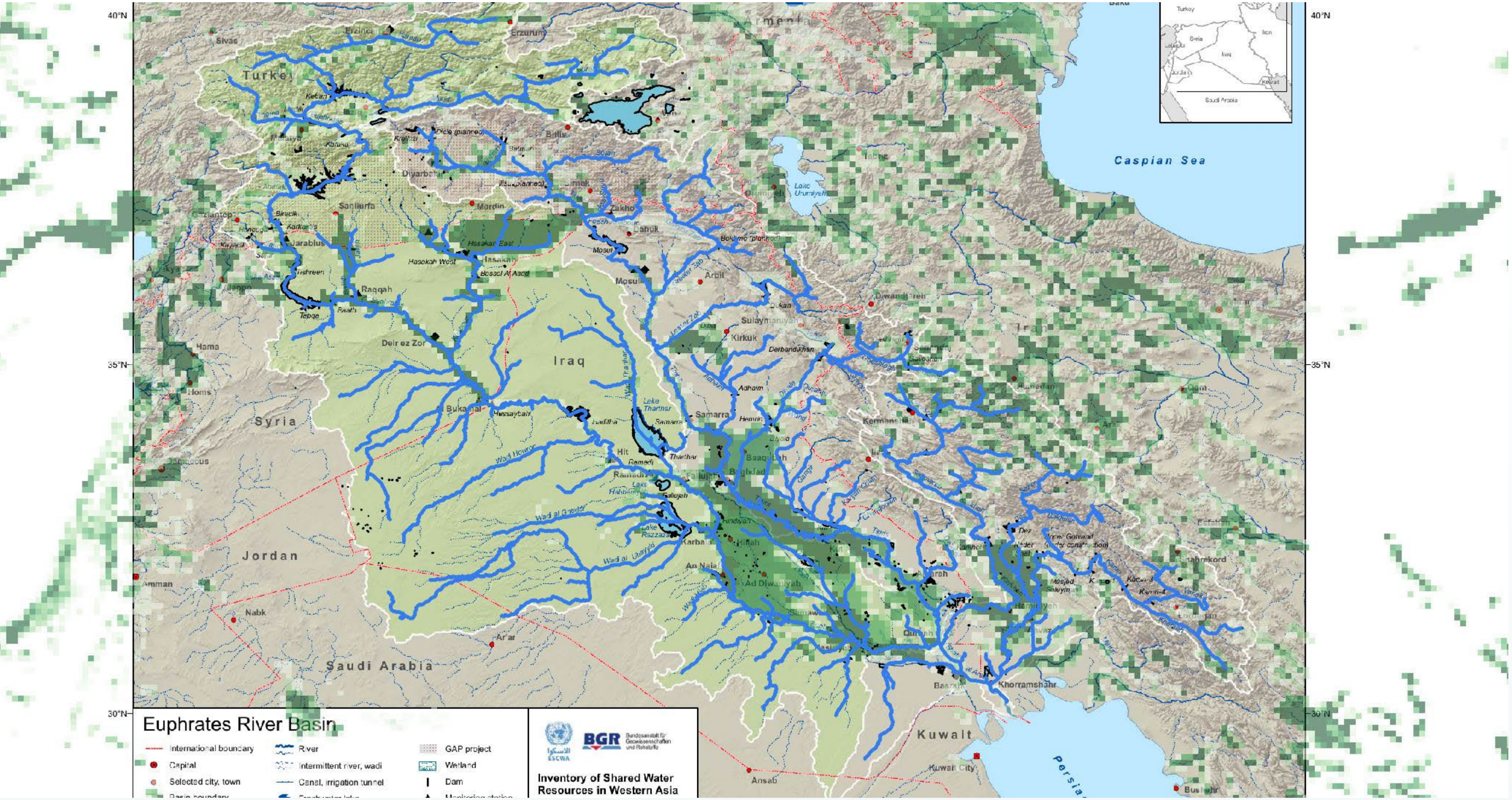
# Irrigated agriculture from the MIRCA2000 database

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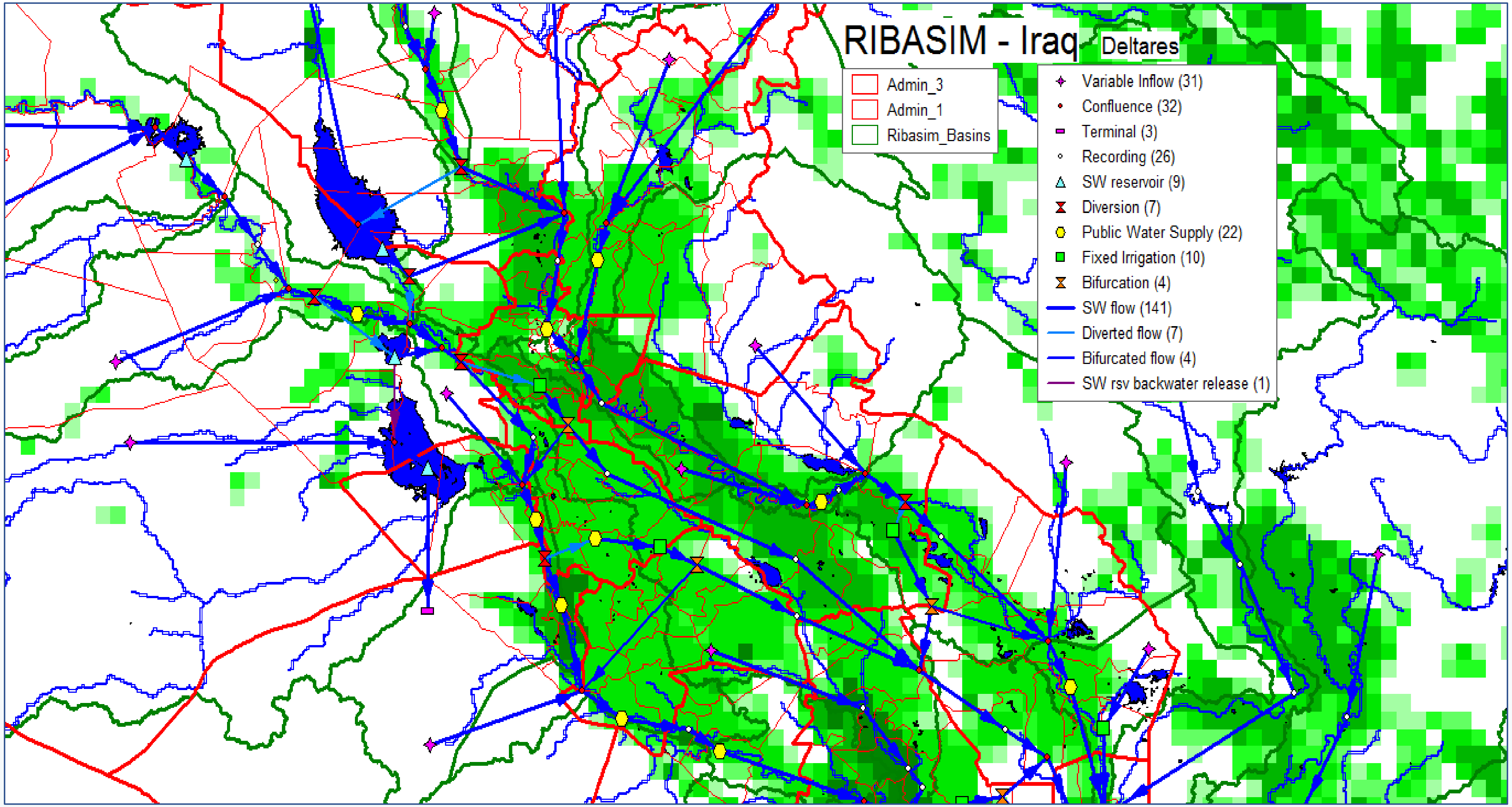
# RIBASIM detail of schematization with MIRCA2000 global irrigation data



# Iraq crop calendar (FAO)

***Calculation of irrigation demand is a combination of:***

- ***MIRCA2000 areas and***
- ***FAO irrigation data***

**IRAQ**

| Irrigated crop calendar | 2010 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Irrigated crops** | **Area** | **Crop area as percentage of the full control actually irrigated area by month** | | | | | | | | | | | |
| | **1000 ha** | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** |
| Wheat | 960 | 61 | 61 | 61 | 61 | | | | | | 61 | 61 | 61 |
| Rice | 48 | | | | | 3 | 3 | 3 | 3 | 3 | | | |
| Barley | 362 | 23 | 23 | 23 | 23 | | | | | | | 23 | 23 |
| Maize | 113 | | | | | 7 | 7 | 7 | 7 | 7 | | | |
| Other cereals | 20 | | | | | 1 | 1 | 1 | 1 | 1 | | | |
| Vegetables | 261 | | | | | 17 | 17 | 17 | 17 | 17 | | | |
| Fruits° | 190 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Citrus° | 32 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Oil crops (sunflower & sesame) | 19 | | | | | 1 | 1 | 1 | 1 | 1 | | | |
| Potatoes | 13 | | | | | 1 | 1 | 1 | 1 | 1 | | | |
| Pulses | 12 | | | | | 1 | 1 | 1 | 1 | 1 | | | |
| Cotton | 21 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| **Harvested irrigated crop area [$AHI_{full}$]** | **2 050** | | | | | | | | | | | | |
| **Area equipped for full control irrigation actually irrigated [$AAI_{full}$]** | **1 564** | **99** | **99** | **99** | **100** | **47** | **47** | **47** | **47** | **47** | **77** | **99** | **99** |
| **Cropping intensity (%) = 100 x [$AHI_{full}$]/[$AAI_{full}$]** | **131** | | | | | | | | | | | | |
| **Area equipped for full control irrigation [$AEI_{full}$]** | **3 525** | * | | | | | | | | | | | |
| **% of full control equipped actually irrigated = 100 x [$AAI_{full}$]/[$AEI_{full}$]** | **44** | | | | | | | | | | | | |
| **Total area equipped for irrigation [$AEI_{tot}$]** | **3 525** | * | These areas refer to the year 1990 | | | | | | | | | | |
| | | ° | These areas originate from AT2050/2080 | | | | | | | | | | |

**Narrative Iraq**

$AEI_{tot}$ and $AEI_{full}$ equal to 3 525 000 ha in 1990 (FAO, 2003) of which it is likely that a significant amount has been abandoned due to waterlogging, salinity and conflicts (FAO, 2012). In this country, irrigation started when Sumerians built a canal to irrigate wheat and barley in Mesopotamia. These two crops are still the main irrigated ones. A partial $AHI_{full}$ is 1 828 000 ha in 2010 according the Annual Abstract of Statistics 2010-2011 (COS, 2011). $AHI_{full}$ was completed by adding the missing crops' areas (fruits including citrus) from AT 2050/2080 (FAO, 2011). As a result, $AHI_{full}$ is estimated at 2 050 000 ha in 2010. Wheat and barley, the two main irrigated crops, are grown in winter, that is outside the common irrigation period. Thus $AAI_{full}$ was calculated to be 1 564 000 ha, which is the total area of winter crops (wheat and barley), permanent crops (fruits and citrus) and cotton which are cultivated simultaneously. The resulting cropping intensity is 131 percent. Some vegetables, maize, rice and other cereals, oil crops (sesame and sunflower), potatoes and pulses are grown and irrigated during summer, between May and September.

**References**

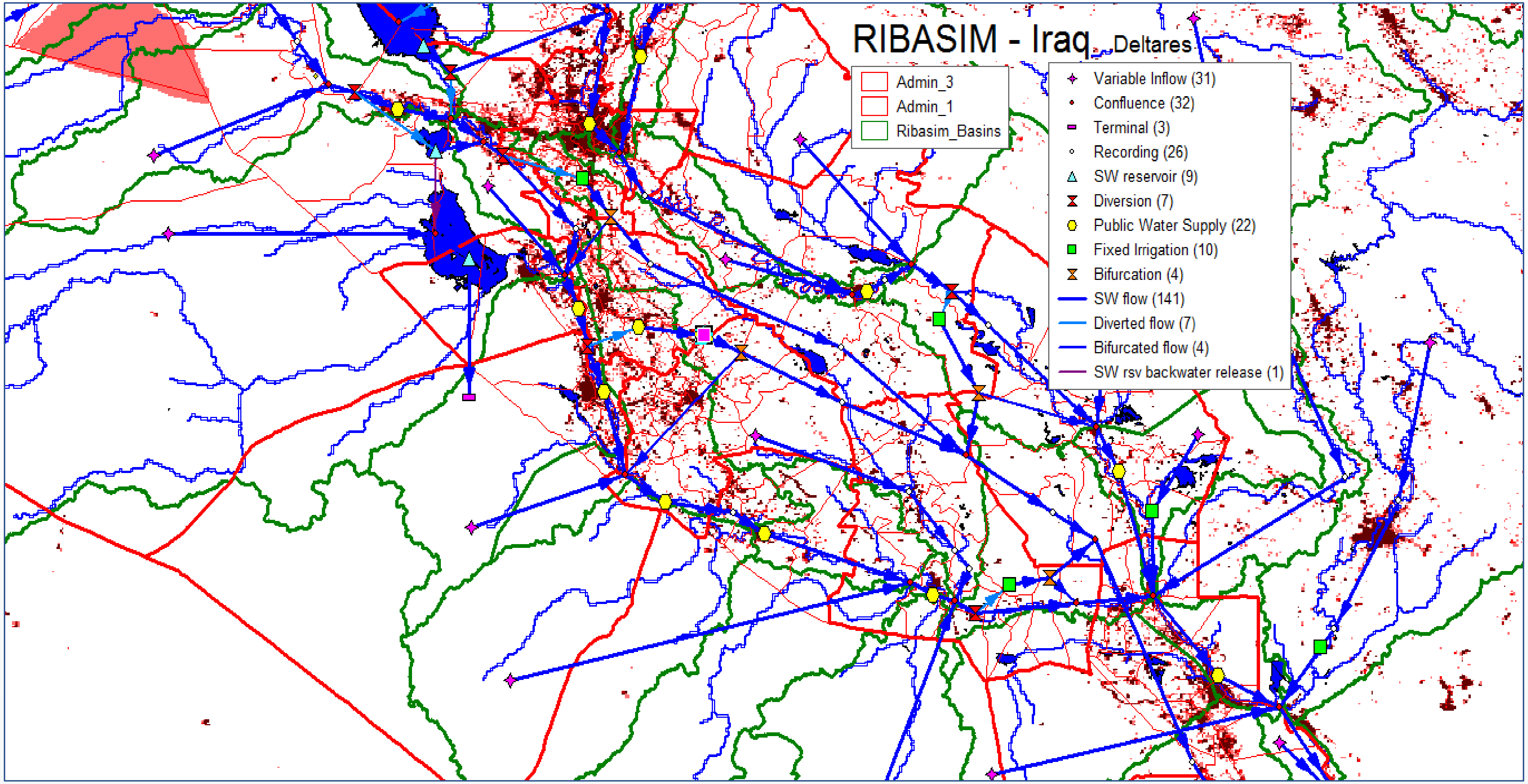

**Central Organization of Statistics [CSO]**. 2011. *Annual Abstract of Statistics 2010-2011*. Available at http://cosit.gov.iq/english/annual_abstract_of_statistics2010-2011.php, accessed in December 2012.

**FAO**. 2003. *Towards sustainable agricultural development in Iraq: The Transition from Relief, Rehabilitation and Reconstruction to Development*. Rome, 222 pp.

**FAO**. 2011. *World agriculture: towards 2050/2080.* FAO, Global Perspective Studies Unit. Rome. (Internal document).

**FAO**. 2012. AQUASTAT, FAO's global information system on water and agriculture. http://www.fao.org/nr/aquastat

# Population global dataset (red dots) shown in the RIBASIM schematization

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# Per capita water demand for the PWS nodes per month

| Node name | Population | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PWS_Baghdad | 7214932 | 250 | 250 | 250 | 300 | 300 | 350 | 350 | 350 | 350 | 300 | 300 | 250 |
| PWS_Basrah | 2734182 | 250 | 250 | 250 | 300 | 300 | 350 | 350 | 350 | 350 | 300 | 300 | 250 |
| PWS_Thi-Qar | 2052004 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |
| PWS_Suleymaniyah | 1950883 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |
| PWS_Ninewa | 3470532 | 250 | 250 | 250 | 300 | 300 | 350 | 350 | 350 | 350 | 300 | 300 | 250 |
| PWS_Kerbala | 1164306 | 250 | 250 | 250 | 300 | 300 | 350 | 350 | 350 | 350 | 300 | 300 | 250 |
| PWS_Missan | 1104636 | 250 | 250 | 250 | 300 | 300 | 350 | 350 | 350 | 350 | 300 | 300 | 250 |
| PWS_Erbil | 2226644 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |
| PWS_Diyala | 1418079 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |
| PWS_Anbar | 1688401 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |
| PWS_Babylon | 1901527 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |
| PWS_Najaf | 1381598 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |
| PWS_Qadissiya | 1543161 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |
| PWS_Muthanna | 786857 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |
| PWS_Wassit | 1268739 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |
| PWS_Salah-El-Din | 1346946 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |
| PWS_Kirkuk | 1365152 | 250 | 250 | 250 | 300 | 300 | 350 | 350 | 350 | 350 | 300 | 300 | 250 |
| PWS_Dahuk | 1799155 | 200 | 200 | 200 | 250 | 250 | 300 | 300 | 300 | 300 | 250 | 250 | 200 |

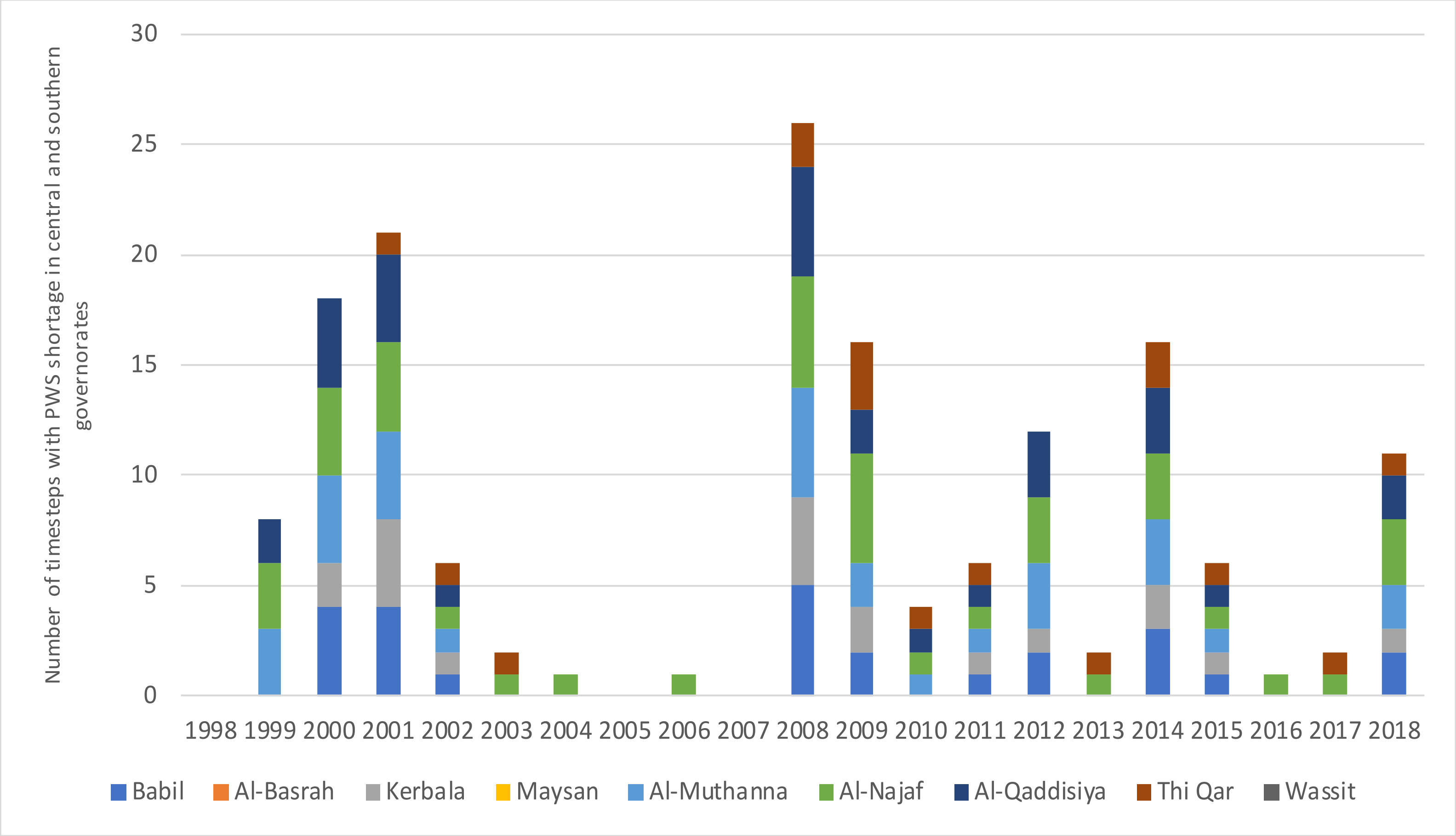
# RIBASIM modelling results

Result parameters on various **spatial and time levels**

- % of time steps that a shortage occurs for various users (**supply reliability**) like irrigation, firm energy, minimum flow requirements, domestic, municipal and industrial use
- **Energy** production (firm, sec.) and consumption
- **Water balances**
- **Reservoir** behaviour
- **Crop yield and crop production costs**
- **Flow and flow composition** at any location and time
- **Water quality** parameters
- …

•>>> Format of maps, reports, charts.

# Model simulations results – 1
# Number of timesteps per year with PWS shortage

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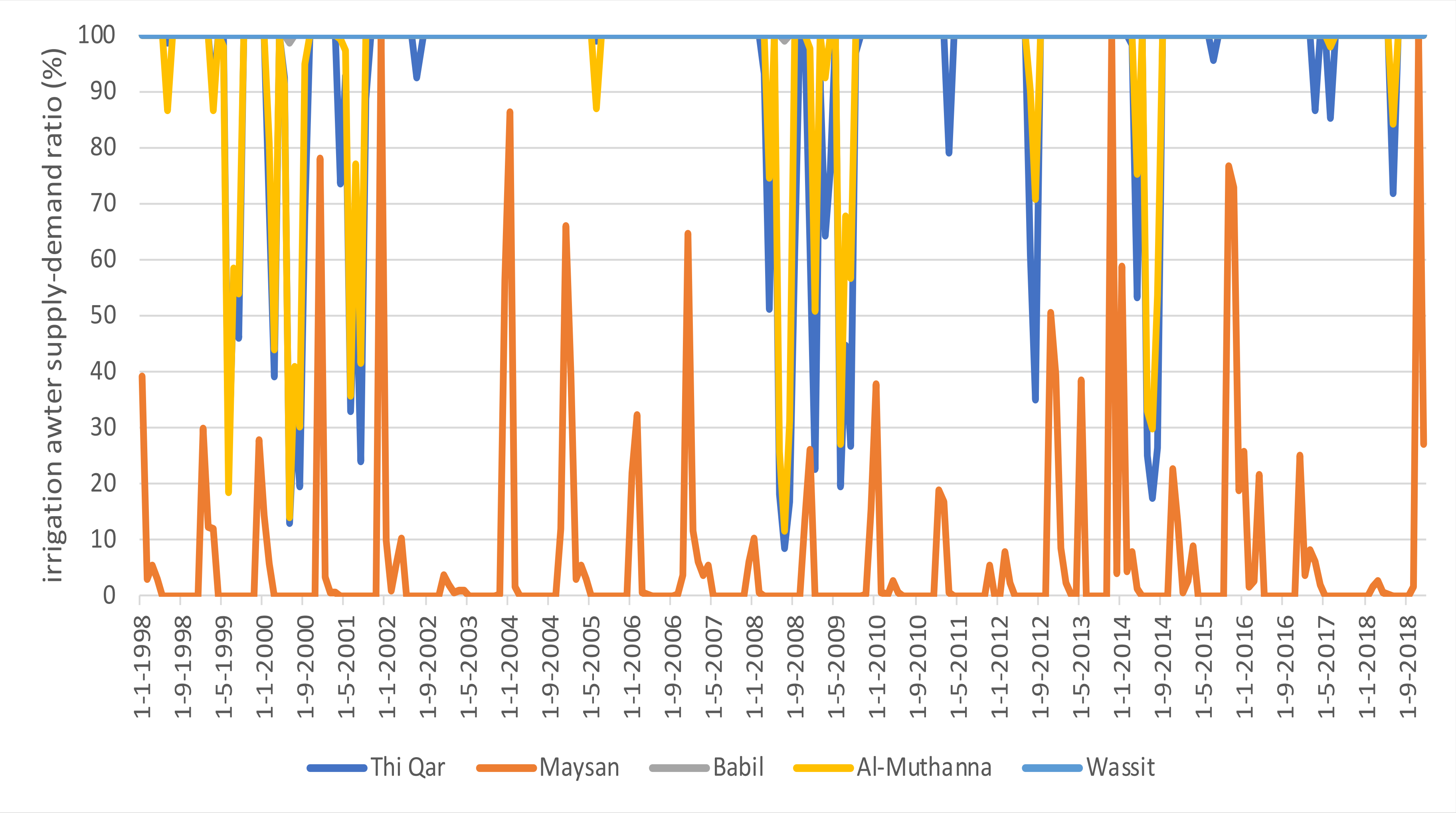
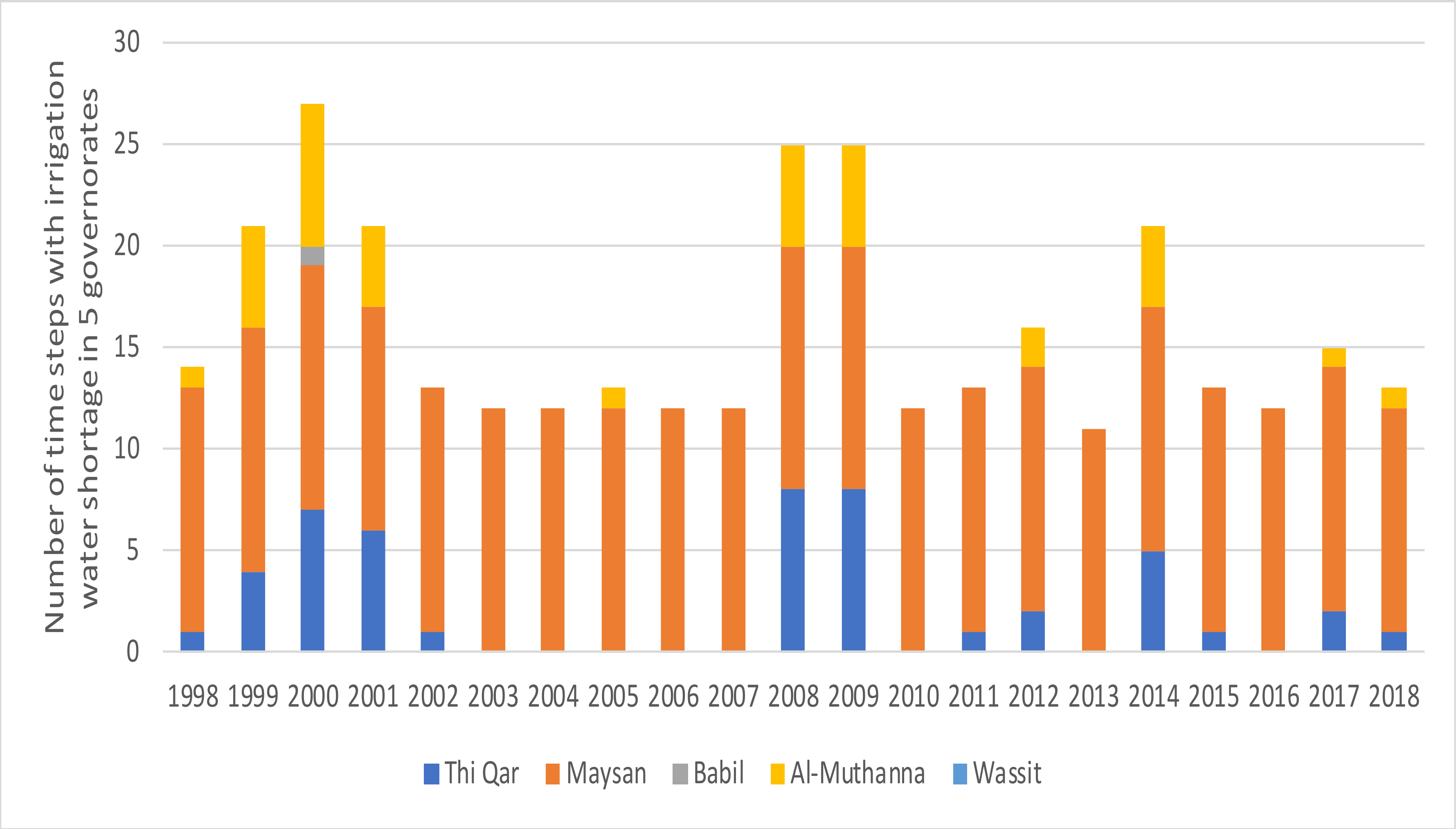
# Model simulations results – 2
# Supply-demand ratio (%) for irrigation water supply



# Model simulations results – 3
# Number of timesteps per year with irrigation water shortage



## Discussion on model limitations

- Interactive discussion:
  - What limitations do you see in the model concepts?
  - What limitations do you see in data availability?
  - What will be the principal sources of error?
  - Ways of improvement do you suggest?