

# Isotope-enabled Coupled Catchment-Lake Water Balance Model: Description and Validation

Belachew D., Aggarwal, P., ([d.belachew@iaea.org](mailto:d.belachew@iaea.org); [p.aggarwal@iaea.org](mailto:p.aggarwal@iaea.org)),  
Leavesley, G., David, O., , Patterson, D. Cralson, J.  
([ghleaves@engr.colostate.edu](mailto:ghleaves@engr.colostate.edu); [odavid@colostate.edu](mailto:odavid@colostate.edu);  
[pattersd@engr.colostate.edu](mailto:pattersd@engr.colostate.edu); [pspicata@rams.colostate.edu](mailto:pspicata@rams.colostate.edu))



Water  
Resources  
Programme

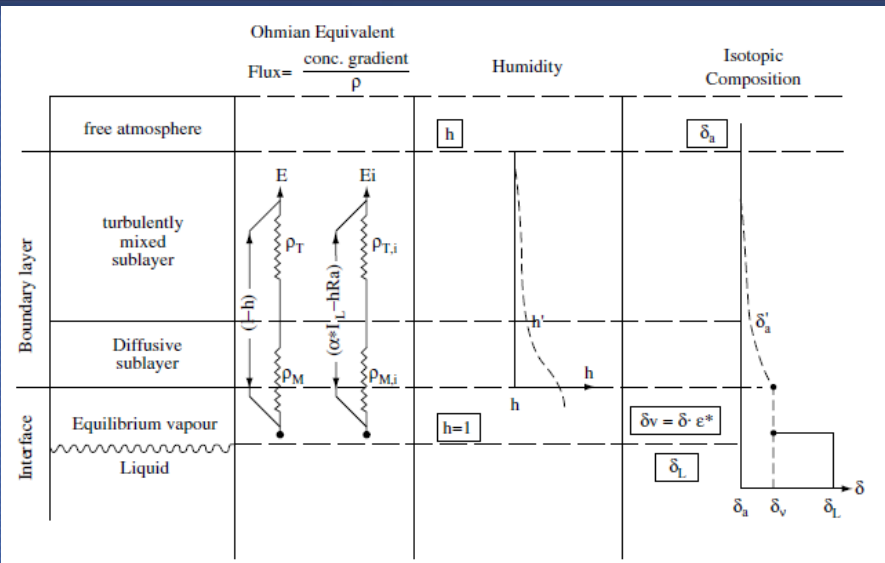


Fig. 4.2. The Craig-Gordon model of isotope fractionation during the evaporation from a free water surface.

Gat, 2010

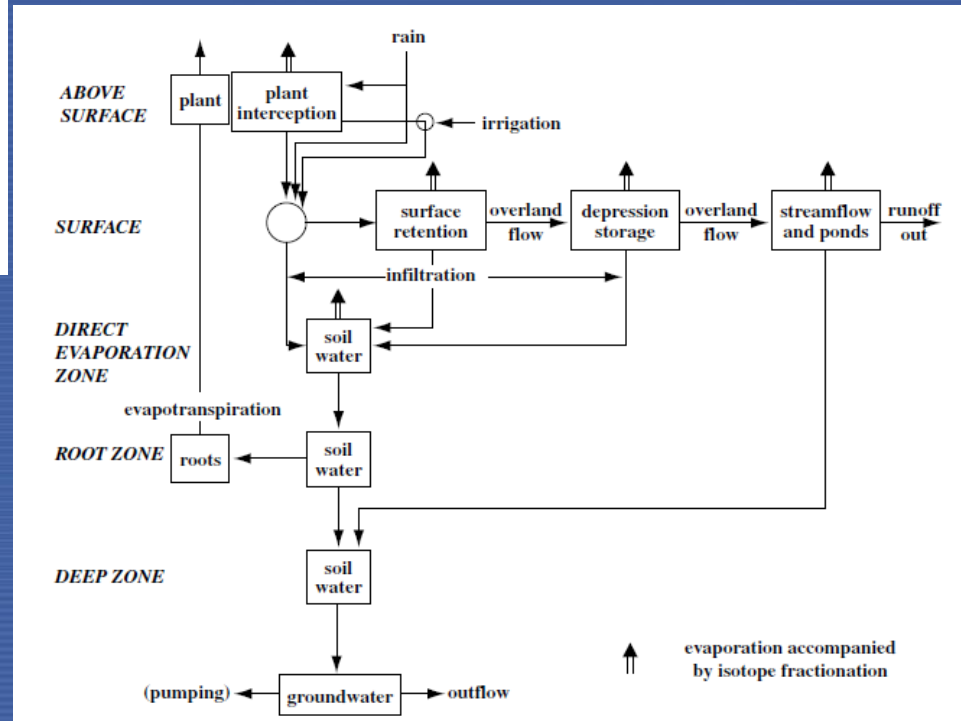


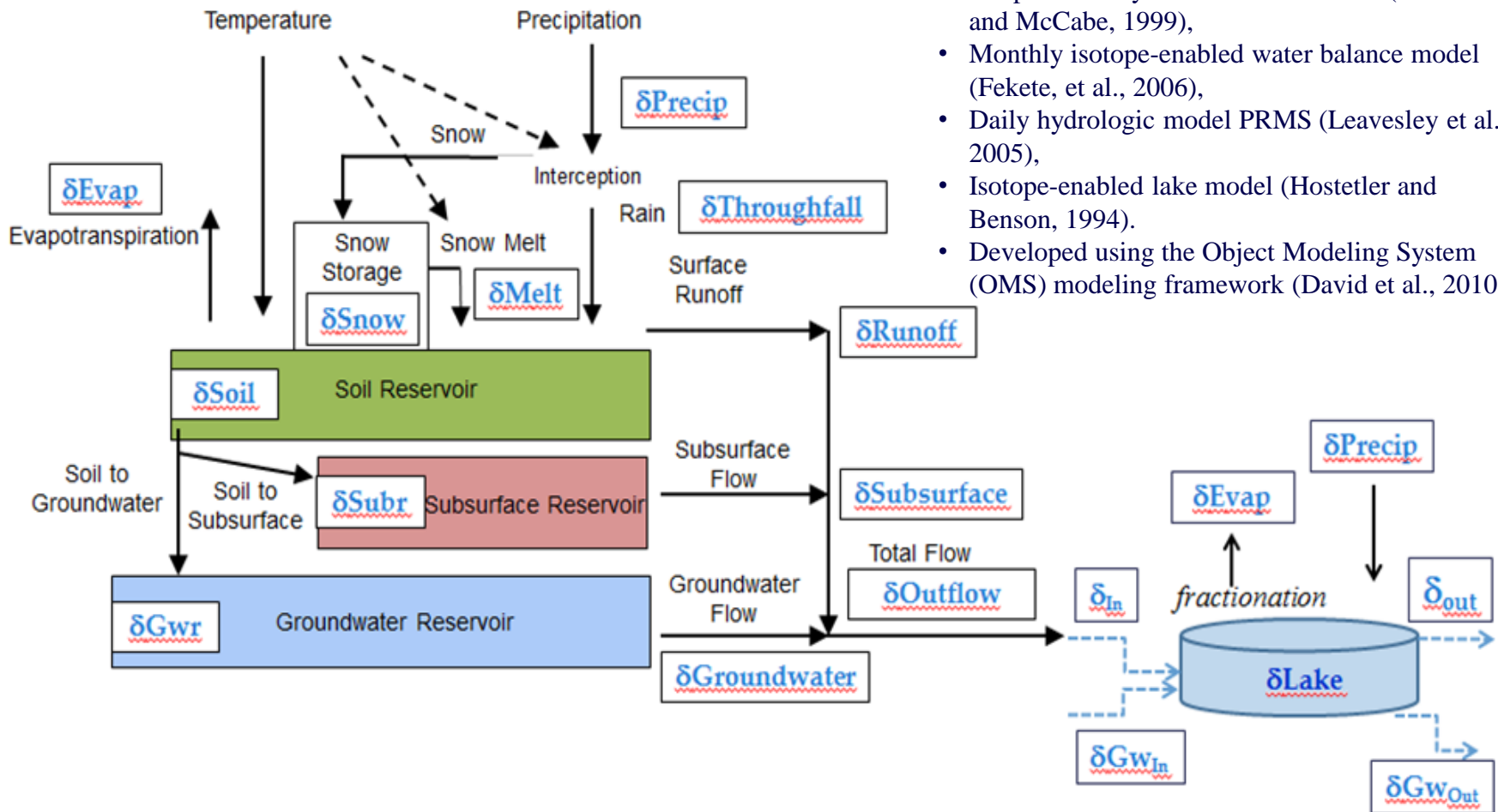
Fig. 1.4. Scheme of the water fluxes at the atmosphere/land-surface interface (adapted from Gat and Tzur, 1976).



Water Resources Programme

# IWBMIso

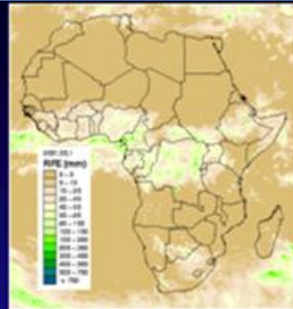
## IAEA Water Balance Model with Isotopes



- Simple monthly water balance model (Wolock and McCabe, 1999),
- Monthly isotope-enabled water balance model (Fekete, et al., 2006),
- Daily hydrologic model PRMS (Leavesley et al. 2005),
- Isotope-enabled lake model (Hostetler and Benson, 1994).
- Developed using the Object Modeling System (OMS) modeling framework (David et al., 2010).

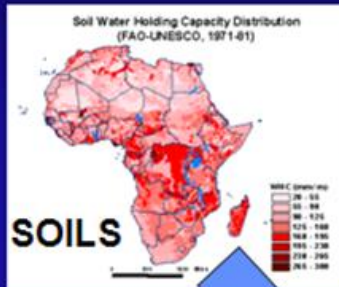
# Actual Evapotranspiration (VegET)

**PRECIPITATION  
(RFE)**



$$PE = \text{hamon\_coeff} * D2 * PT * \text{DAYS}$$

$$PT = (4.95 * \exp(0.062 * Ta)) / 100.$$



**VegET**

$$ETa = Ks * Kcp * ETo$$

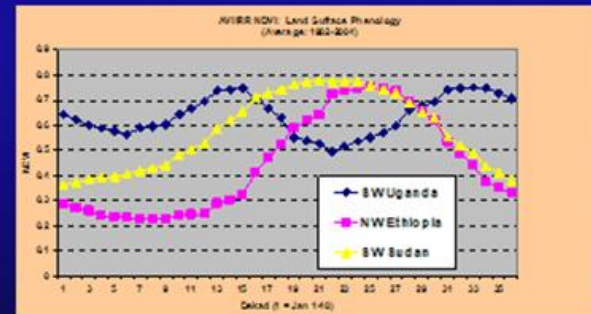
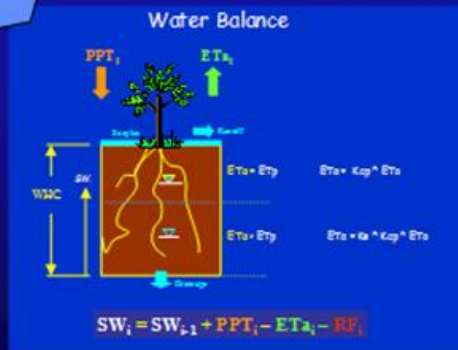
LAI

NDVI

Soil Stress Coefficient

LSP Water-Use Coefficient

**Water  
Balance  
Model**



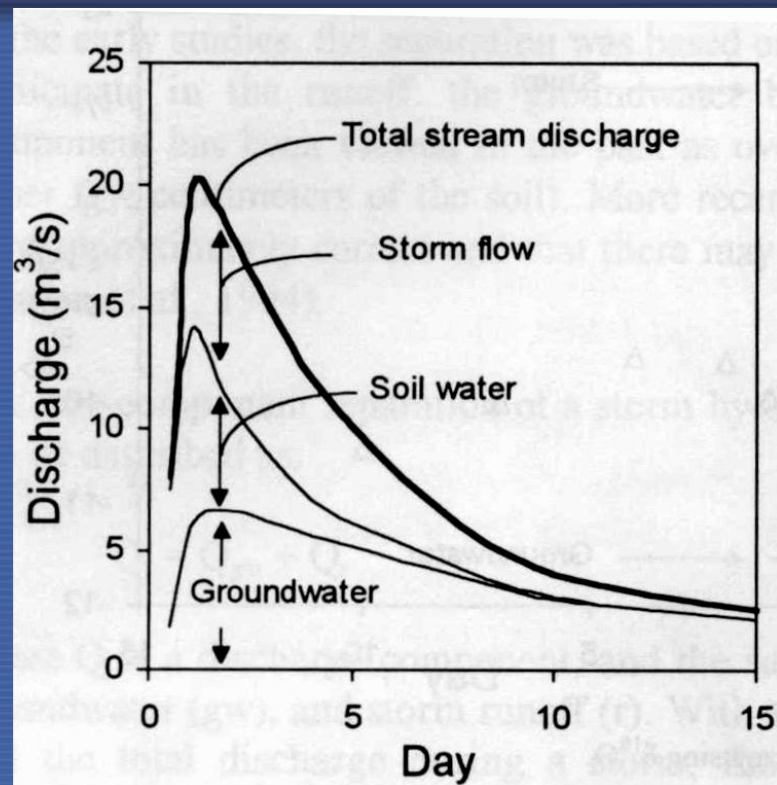
**Land Surface Phenology (LSP)**

# Flow Components

$$\underline{rodirect} = \underline{Prain} \times \underline{directfac}$$

$$\underline{ssflow} = \underline{ssflow\_coef} * \underline{ssres\_stor}$$

$$\underline{gwflow} = \underline{gwflow\_coef} * \underline{gwres\_stor}$$



$$Q(t) = Q(t_0)e^{-k(t-t_0)}$$

Boussinesq equation

$$\delta R = ((\underline{Rodirect} * \delta \underline{Rodirect}) + (\underline{Ssflow} * \delta \underline{Ssflow}) + (\underline{Gwflow} * \delta \underline{Gwflow})) / R$$

# Soil Moisture Fractionation

$$\delta E = [\delta L/\alpha - h \cdot \delta a - (\epsilon^* + \Delta\epsilon)] / [(1 - h) + \Delta\epsilon/1000]$$

Modelled as a drying water body from which water is removed only by evaporation

## Vapour flux equations

$$\frac{dN_i}{dN} = \frac{\frac{R}{\alpha} - hRa}{(1-h) \rho_i/\rho}$$



$$\delta = (\delta_o - A/B) f^B + A/B$$

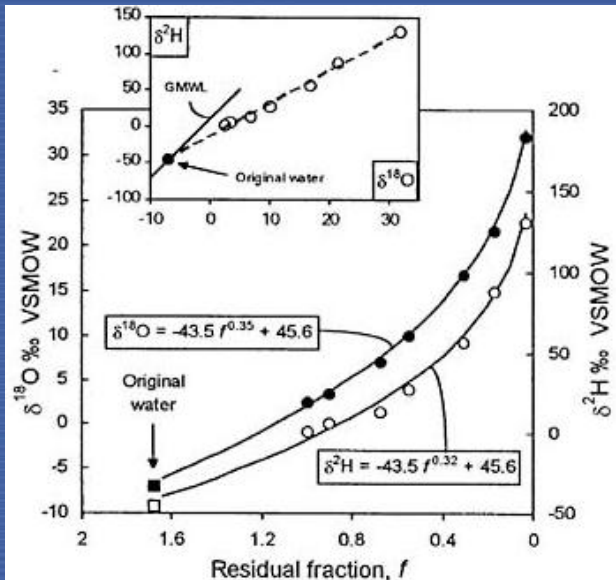
Assuming Const. Evapo. Cond.

$$A = (h\delta_a + \Delta\epsilon + \epsilon/\alpha) / (1 - h + \Delta\epsilon)$$

$$B = (h - \Delta\epsilon - \epsilon/\alpha) / (1 - h + \Delta\epsilon)$$

$$\alpha_{1-v} = e^{(C2/T2 + C1/T + C0)}$$

$$\delta_a = \delta_{ppt} / \alpha - (1 - 1/\alpha)$$



Gonfiantini & Fontes, 1963

$$\Delta\epsilon = \theta \cdot n \cdot Ck \cdot (1 - h)$$

$$Ck = ((D/Di)^n - 1) \cdot 1000$$

(Ck=Kinetic constant: 25.1 and 28.5 for O &D)

$$\Delta\epsilon^{18O}/\text{‰} = 14.2 (1 - h)$$

$$\Delta\epsilon^{2H}/\text{‰} = 12.5 (1 - h)$$

$$\epsilon = (\alpha - 1)$$

$n = 1$  for stagnant, and  
 $n = 1/2$ , for fully turbulent wind conditions

$$\alpha_{1-v} = e^{(C2/T2 + C1/T + C0)}$$

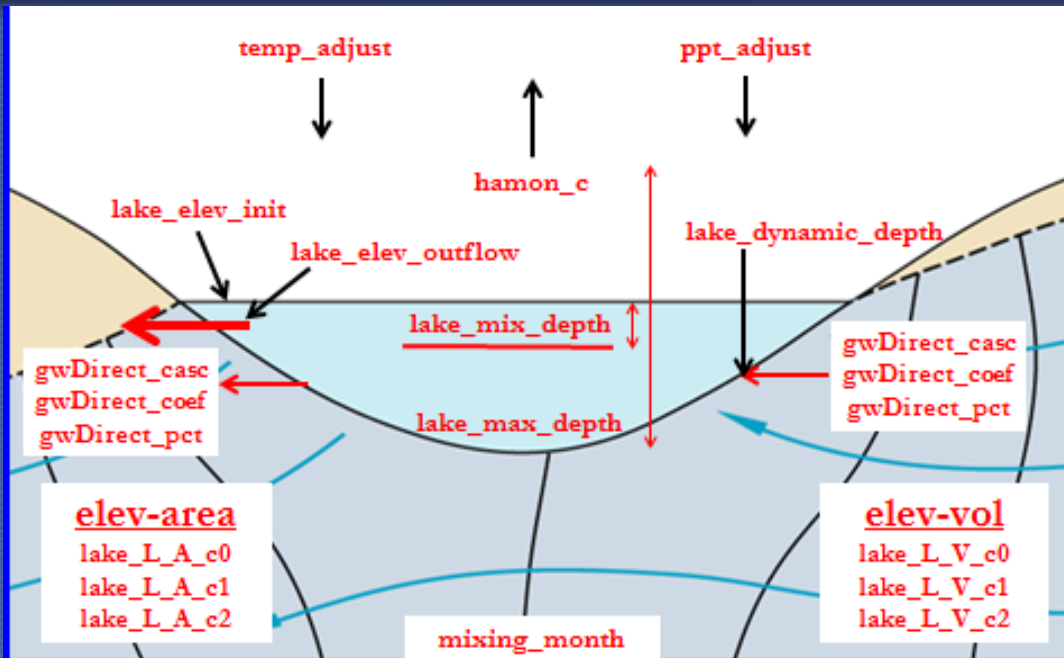
Majoube, 1971



Water Resources Programme

Gonfiantini, 1986

# IWBM Iso Lake Parameters



$$\delta_L \frac{dV_L}{dt} + V_L \frac{d\delta}{dt} = \delta_{IS} I_S + \delta_{IG} I_G + \delta_P P - \delta_{OS} O_S - \delta_{OG} O_G - \delta_E E$$

Where

$x = E/I$  (fraction of inflow water lost by evaporation)

$y = Q/I$  (fraction lost by isotopically non-fractionating outflows)

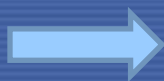
If  $I=Q=0$ , lake drying up due to Evap. only

$$\delta = \left( \delta_o - \frac{\delta_I + A*x}{1+B*x} \right) * f^{-\frac{1+B*x}{1-x-y}} + \frac{\delta_I + A*x}{1+B*x}$$



$$\delta = (\delta_o - A/B) f^B + A/B$$

If  $I=0$ , but  $Q \neq 0$



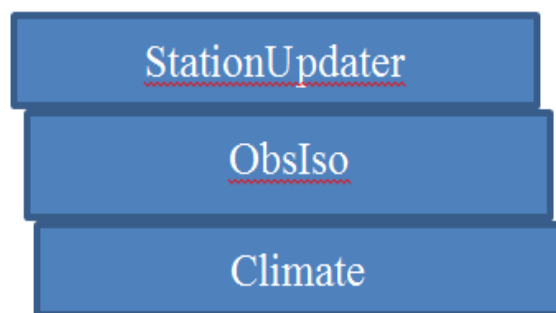
$$\delta = (\delta_o - A/B) f^{BZ} + A/B$$

E and infiltration, e.g. pond

$$Z = E/(E+Q)$$

# IWBMIso Model Components

Developed in the Object Modeling System (OMS) Framework on Java

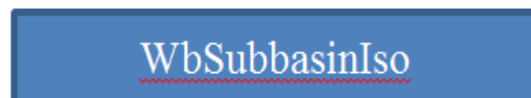


*Reads parameter and data files.*

*Estimates and assigns climate variables to HRUs.*



*Calculates water & isotope balances for each HRU.*



*Computes water & isotope balances for each subbasin by aggregating associated HRU water and isotope balances.*



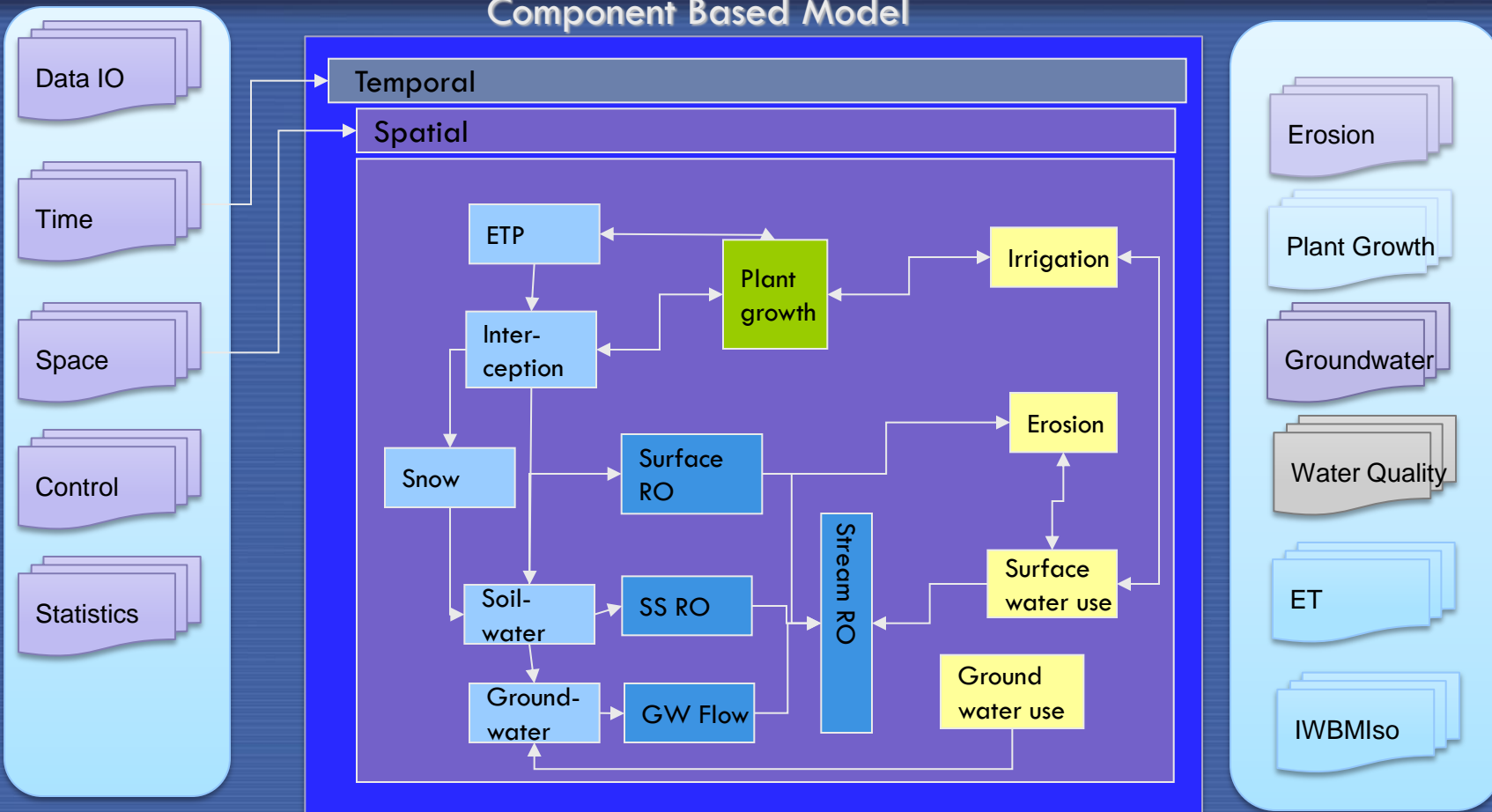
*Controls outputs.*



# System Components **OMS Principal Architecture**

# Science Components

## Component Based Model



Optimization

Uncertainty

Sensitivity

Calibration

Visualization

Reporting



# Model Components and Basic Information Flow

## Model Monthly Input Data File Generation

### Remotely Sensed and Atmospheric Model Data

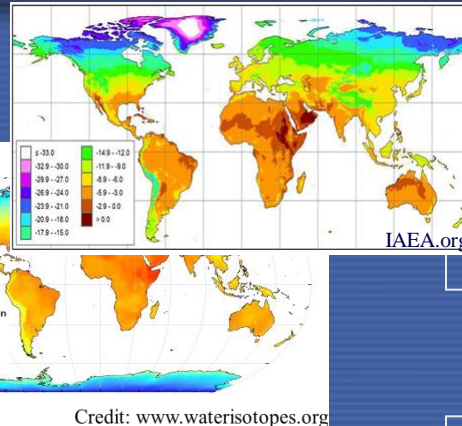
CRU: P, T, RH, WET

MODIS: NDVI, LAI, VCF

FAO Soil

Global Precip. Isotope

- *WATERISOTOPES.ORG*
- *IAEA*



Assimilated to create monthly time-series values for HRUs

### Field Data Measurements

Streamflow

- Discharge
- Diversions

Meteorological

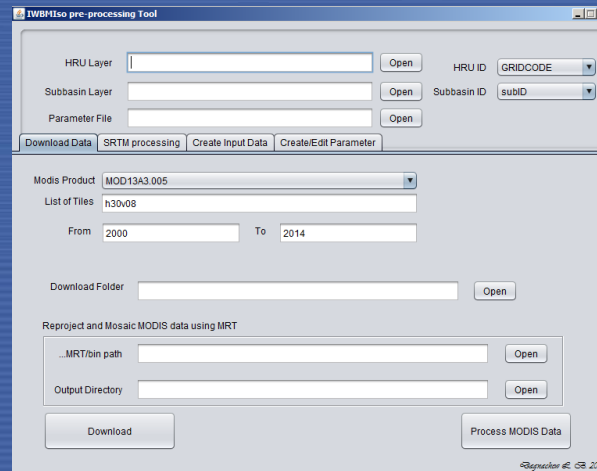
- Temperature
- Precipitation
- R Humidity

Water Bodies / Wetlands

- Surface Elevations
- Temperature
- Isotopes

Isotopes

- River and Tribs
- GW Wells
- Precipitation



# IWBMIso Code Snippet

The screenshot displays the NetBeans IDE interface for the project 'oms3.prj.wbm'. The main editor window shows the source code for 'WbHrusIso.java', specifically the 'fractionation' method. The code calculates various parameters based on input values and returns the 'iso\_f' value.

```
1548 *
1549 */
1550 private double fractionation(int i, int mo, double F, double d_init, int iso) {
1551     // int j= hru_subbasin[i];
1552     double rh = hru_rhm[i]; //rhavg[mo][j];
1553     double tmm_k = hru_temp[i] + 273.16;
1554     double eqfac_c2;
1555     double eqfac_c1;
1556     double eqfac_c0;
1557     double D;
1558     double hru_iso;
1559     double iso_air;
1560     double iso_f;
1561     if(iso==1) {
1562         eqfac_c2 = o18eqfac_c2;
1563         eqfac_c1 = o18eqfac_c1;
1564         eqfac_c0 = o18eqfac_c0;
1565         D = D018;
1566         hru_iso = hru_O18[i];
1567         // iso_air = do18_air[mo][j];
1568     } else {
1569         eqfac_c2 = h2eqfac_c2;
1570         eqfac_c1 = h2eqfac_c1;
1571         eqfac_c0 = h2eqfac_c0;
1572         D = D02;
1573         hru_iso = hru_H2[i];
1574         // iso_air = dh2_air[mo][j];
1575     }
1576     double alpha = Math.exp((eqfac_c2/(tmm_k*tmm_k)) + (eqfac_c1/tmm_k) + eqfac_c0);
1577     double teta = 1.0;
1578     double n = 0.5;
1579     double Ck = teta*(Math.pow(D,n) - 1);
1580     double ek = (1-rh)*Ck;
1581     double ee = (alpha-1);
1582     iso_air = hru_iso/alpha - (1-1/alpha)*1000.;
1583     double A = (rh*iso_air/1000.+ek+(ee/alpha))/(1-rh+ek);
1584     double B = (rh-ek-(ee/alpha))/(1-rh+ek);
1585     iso_f = (d_init/1000. - (A/B)*Math.pow(F, B) + A/B)*1000.;
1586     return iso_f;
1587 }
1588 }
```

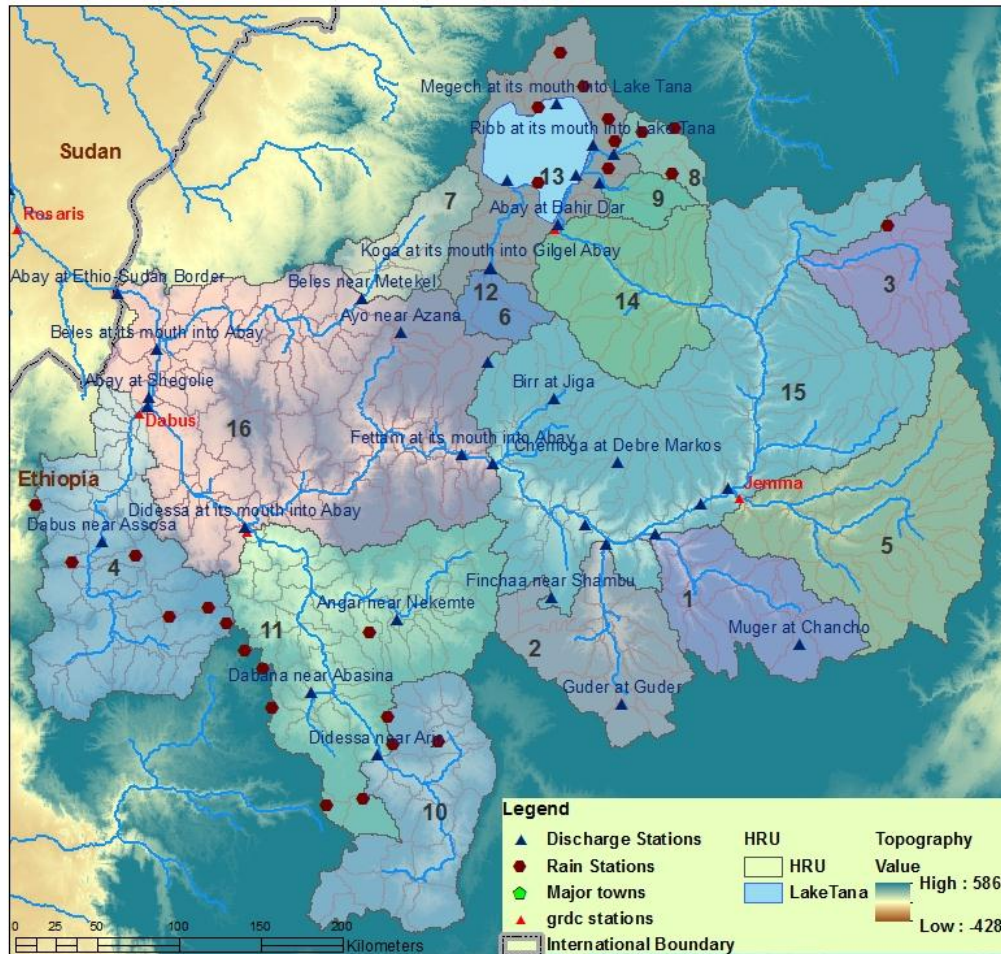
The bottom panel shows the execution output for two simulation runs:

```
896: 0.723286408522954 [0.7237507428446939/0.7208117897360071] c:1 d:0.0
: Running Simulation ...

897: 0.7233720401286385 [0.7237507428446939/0.7208117897360071] c:1 d:0.0
: Running Simulation ...
```

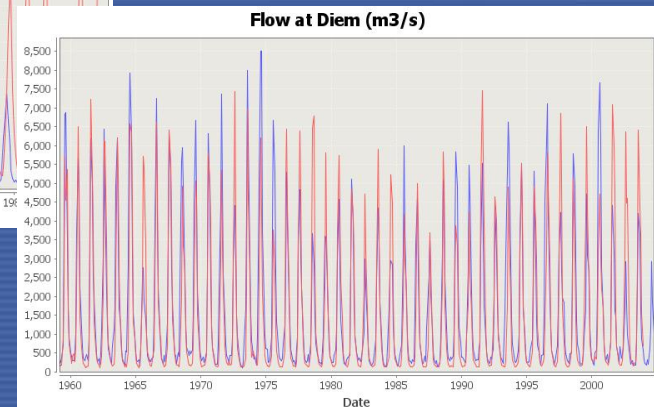
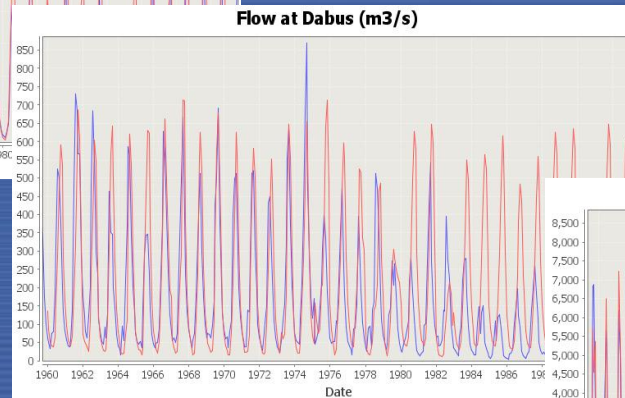
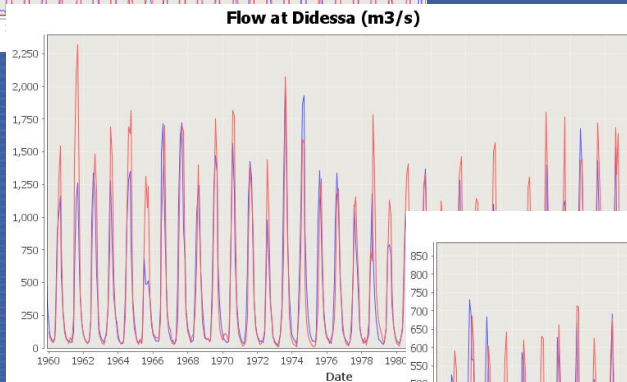
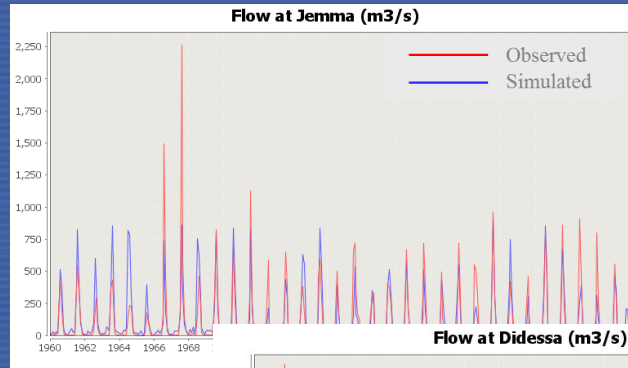
# Case Study 1

## Upper Blue Nile Basin, Ethiopia



16 Subbasins  
438 HRUs  
Catch. 174,800 km<sup>2</sup>  
Lake: 3280 km<sup>2</sup>

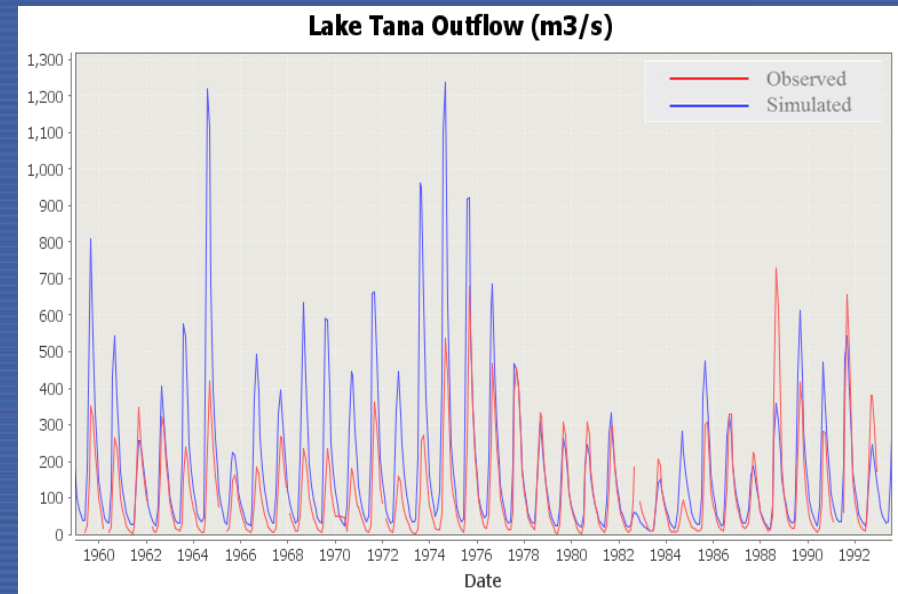
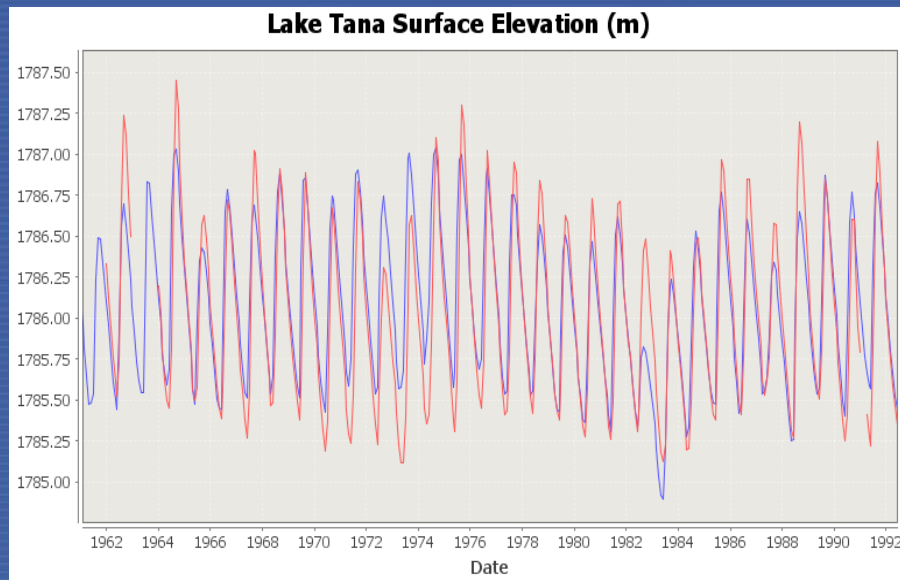
# Selected Model Calibration and Evaluation Results



Station	NSE Calibration (Period)	NSE Evaluation (Period)
Jemma	<b>0.74</b> (1975-1990)	<b>0.56</b> (1960-1974) <b>0.64</b> (1960-1992)
<u>Mugher</u>	<b>0.85</b> (1975-1990)	<b>0.55</b> (1960-1974) <b>0.68</b> (1960-1992)
<u>Didessa</u>	<b>0.77</b> (1975-1990)	<b>0.80</b> (1960-1974) <b>0.79</b> (1960-1992)
<u>Dabus</u>	<b>0.64</b> (1960-1974)	<b>-0.07</b> (1975-1992) <b>0.31</b> (1960-1992)
Diem	<b>0.76</b> (1975-1990)	<b>0.75</b> (1960-1974) <b>0.72</b> (1960-2003)

# Selected Model Calibration and Evaluation Results

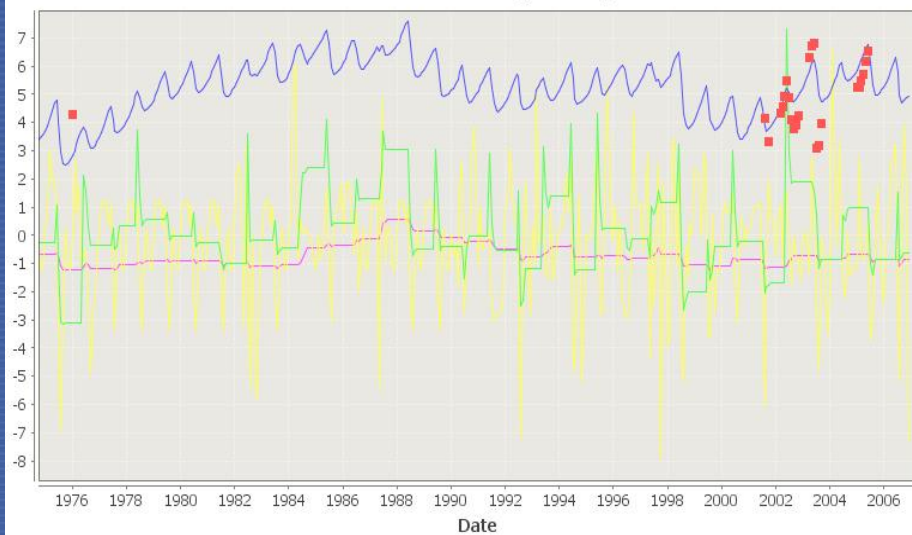
## Lake Tana



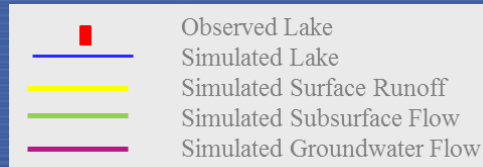
# Selected Model Calibration and Evaluation Results

## Lake Tana

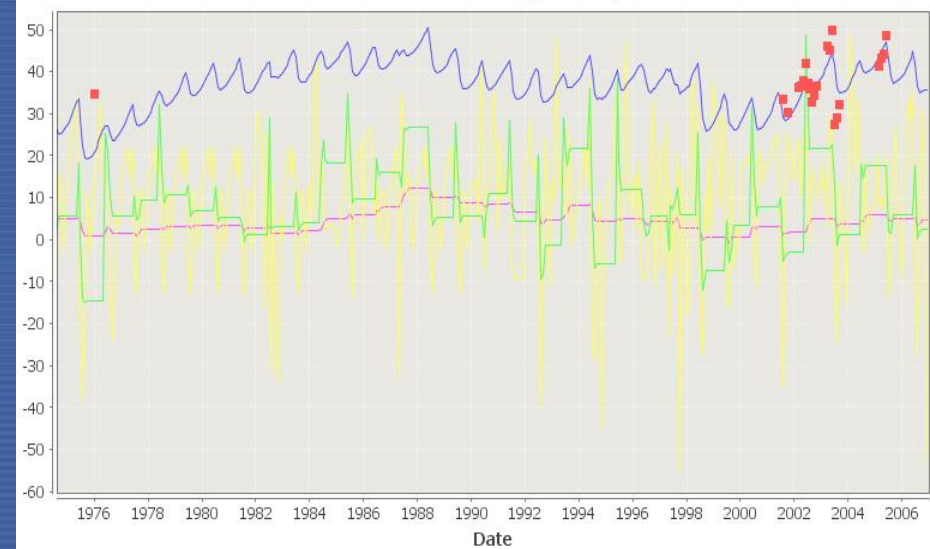
Lake Tana dO18 (permil)



isotope for

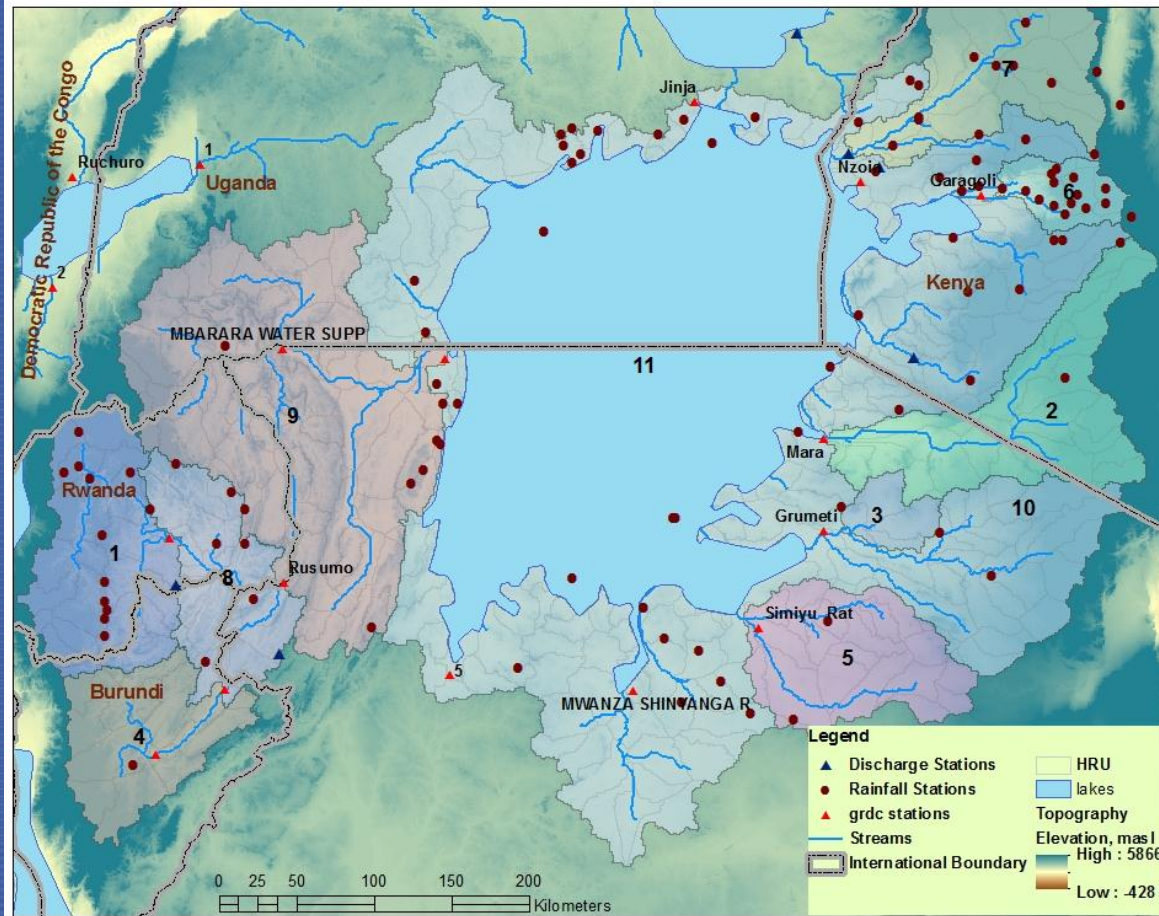


Lake Tana dH2 (permil)



# Case Study 2

## Lake Victoria, East Africa



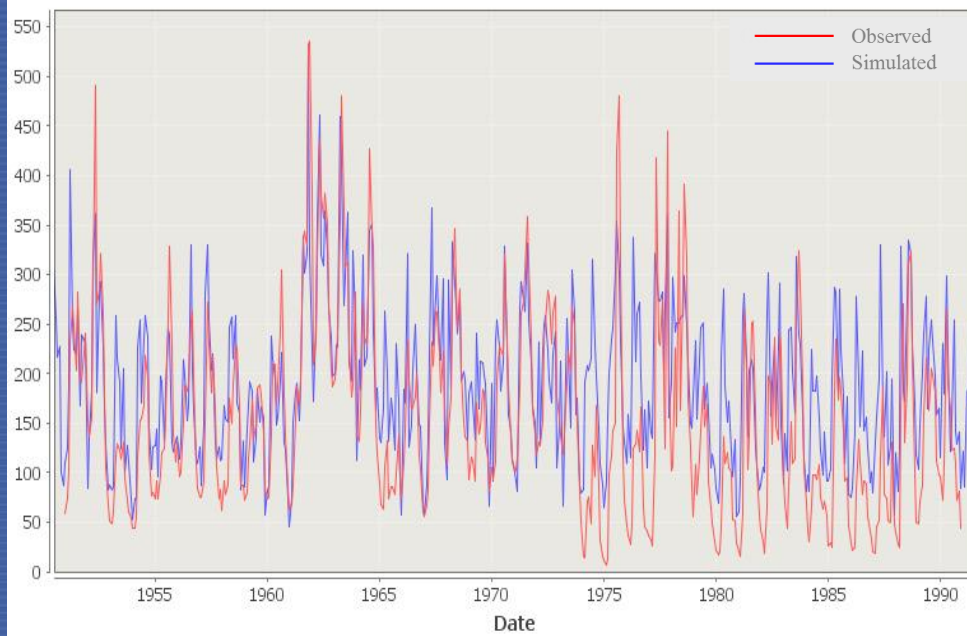
11 Subbasins  
368 HRUs  
Catch.: 252,000 km<sup>2</sup>  
Lake: 68,800 km<sup>2</sup>



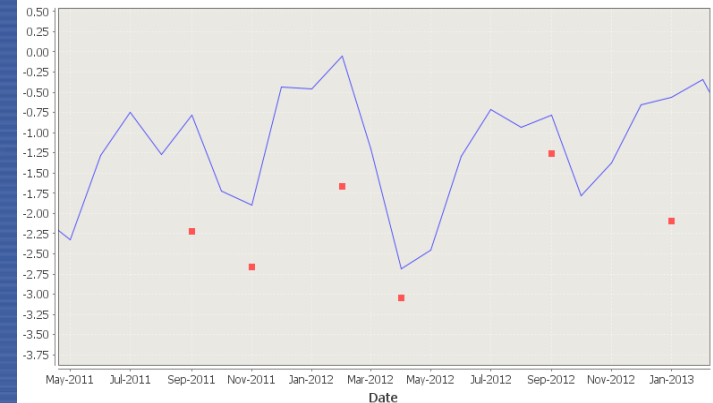
# Selected Model Calibration and Evaluation Results

## Nzoia Rive, tributary to L. Victoria, Kenya

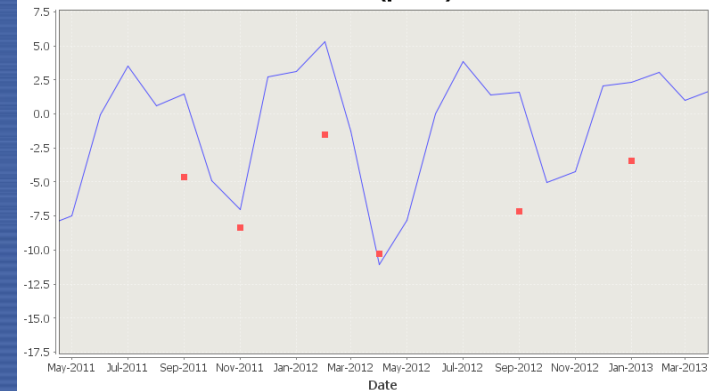
Flow at Nzoia (m3/s)



Nzoia dO18 (permil)



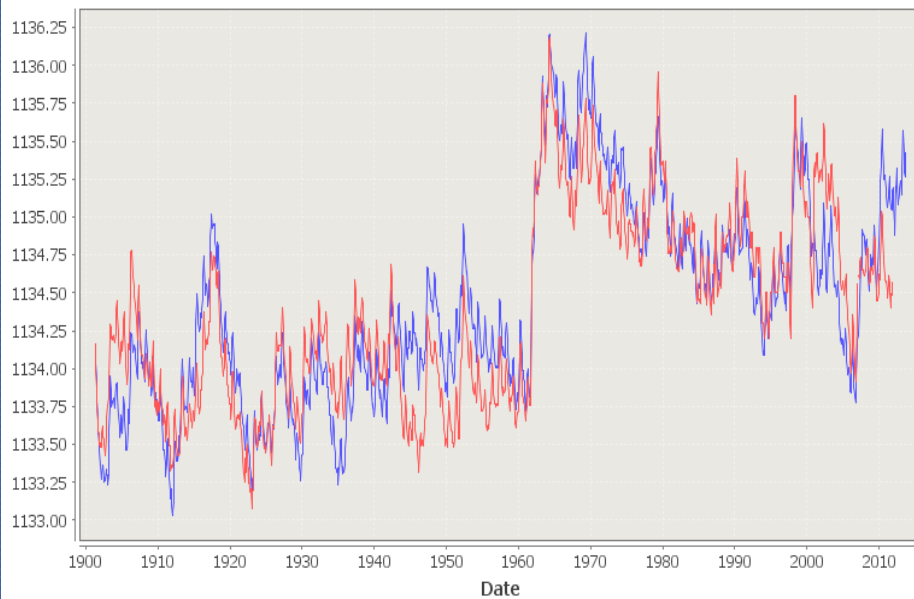
Nzoia dH2 (permil)



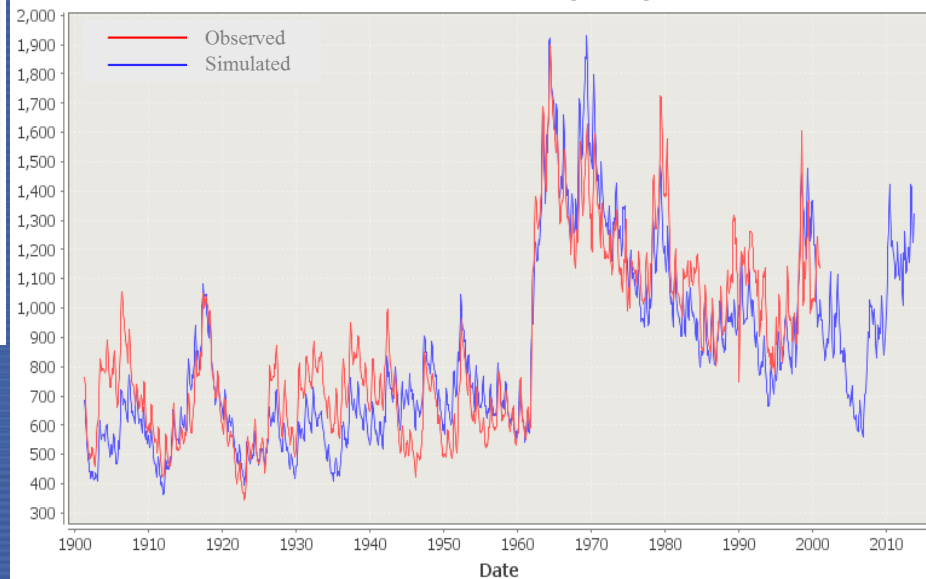
# Selected Model Calibration and Evaluation Results

## Lake Victoria

**Lake Surface Elevation (m)**



**Lake Victoria Outflow (m<sup>3</sup>/s)**



# Selected Model Calibration and Evaluation Results

## Lake Victoria

Lake Victoria dO18 (permil)



Date

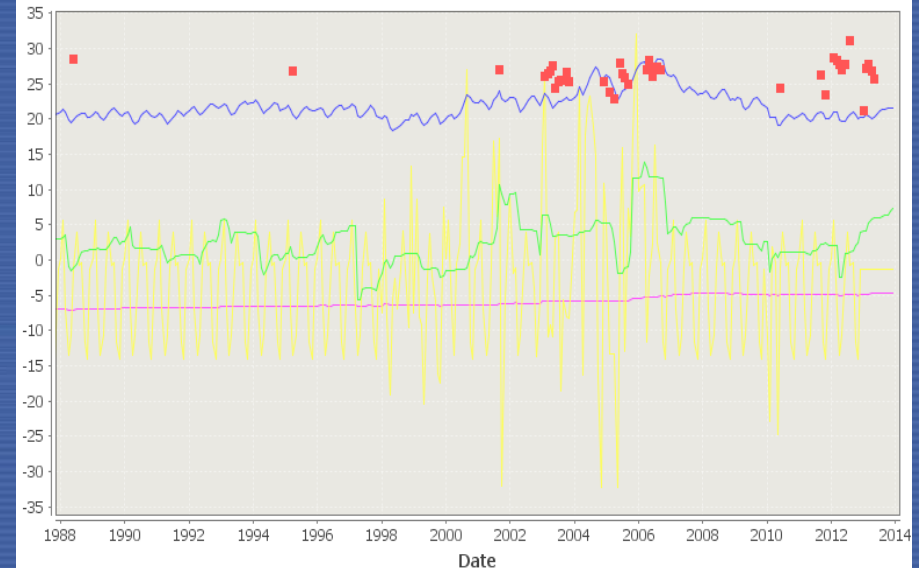
- Observed Lake
- Simulated Lake
- Simulated Surface Runoff
- Simulated Subsurface Flow
- Simulated Groundwater Flow

isotope for



Water  
Resources  
Programme

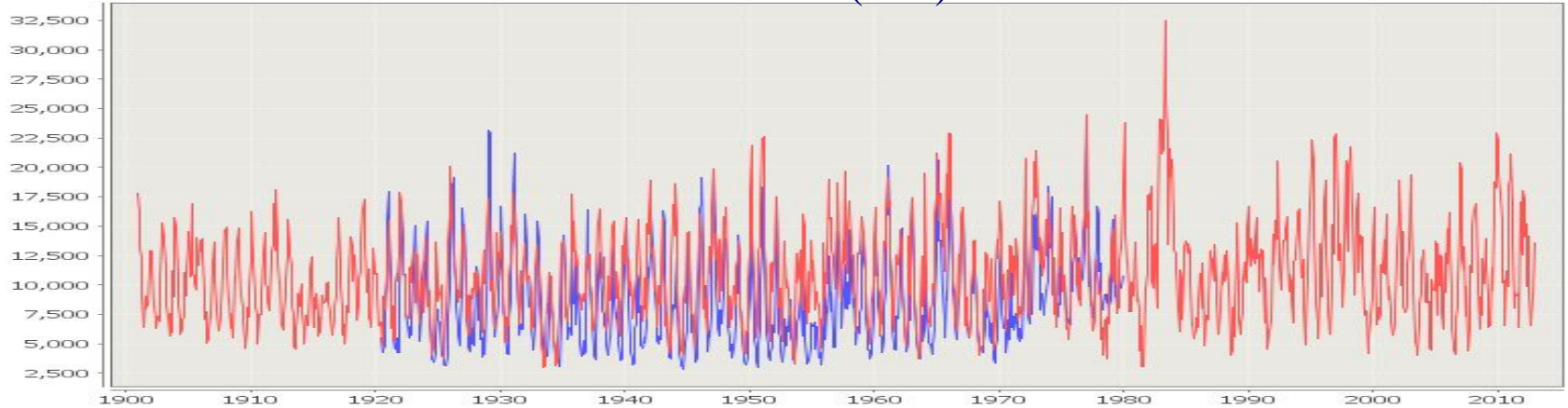
Lake Victoria dH2 (permil)



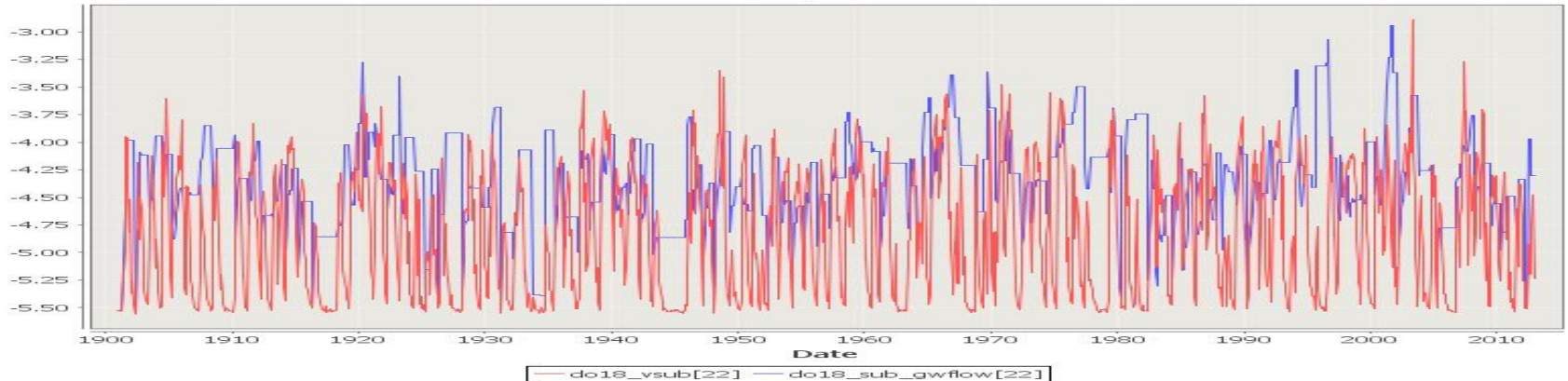
Date

# Parana River @ Corrientes, Argentina

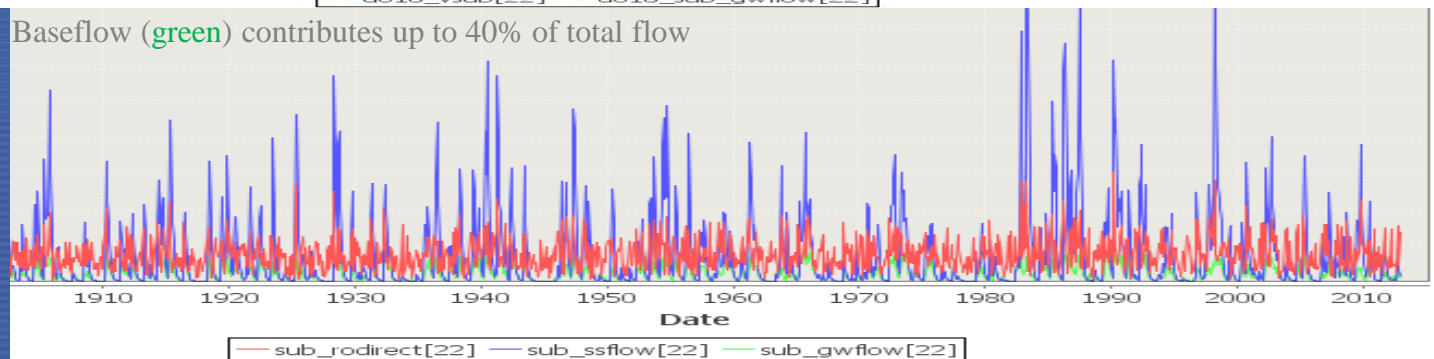
**Flow (cms)**



**Isotopes**



Baseflow (green) contributes up to 40% of total flow



# Model Deployment

## OMS Console

The screenshot shows the codeBeamer web interface. At the top, there's a navigation bar with 'codeBeamer' logo and the tagline 'Inland's free requirements, development and test management hosting'. Below that, there are tabs for 'Login', 'Projects', 'Wiki', 'Documents', 'Trackers', 'Reports', and 'Baselines'. The 'Wiki' tab is active, showing a search bar and a list of items including 'OMS3 Wiki #36439 v231 0'. The main content area shows a breadcrumb trail: 'framework > java > Modeling > Simulation'.

The screenshot shows the OMS3 Console application window. The title bar reads 'oms3.prj.wbm - wbm\_blue.luca - Console (OMS 3.4.7)'. The project path is 'oms3.prj.wbm - D:\oms'. The code editor shows a configuration file with the following content:

```
66 }
67 }
68 step {
69   parameter {
70     gwflow_coef(lower:0.005, upper:0.50, calib_strategy:MEAN, filter_param:"hru_subbasin", subset:"5,7,11,12")
71     sflow_coef(lower:0.005, upper:0.50, calib_strategy:MEAN, filter_param:"hru_subbasin", subset:"5,7,11,12")
72     soil2gw_max(lower:5.0, upper:25.0, calib_strategy:MEAN, filter_param:"hru_subbasin", subset:"5,7,11,12")
73     //gwDirect_coef(lower:0.0001, upper:0.025, calib_strategy:MEAN, filter_param:"hru_subbasin", subset: "5,7,8,
74     hamon_c(lower:0.8, upper:1.2, calib_strategy:MEAN, subset_col:"5,7,11,12", subset_row:"0-*")
75     directfac(lower:0.0, upper:0.50, calib_strategy:MEAN, filter_param:"hru_subbasin", subset:"5,7,11,12")
76     ppt_adjust(lower:0.8, upper:1.2, calib_strategy:MEAN, subset_col:"5,7,11,12", subset_row:"6-9")
77   }
78 }
79 objfunc(method:NS, timestep:MONTHLY_MEAN, period_range:"1-12", invalidDataValue:"-9999") {
80   sim(file:"out.csv", table:"Blue_luca", column:"lakesurf_elev[0]")
81   obs(file:"out.csv", table:"Blue_luca", column:"obs[13]")
82 }
83 }
84 }
```

The terminal output shows the following text:

```
354: 0.715517672581707 [0.7155851144084728/0.7152734212249652] c:1 d:0.011409147563829745
*****
Optimization terminated, OF value has not changed 0.01% in 5 shuffling loops.
*****
Final parameter estimates: 0.4912270066617432 0.46034101667710237 0.06135267649270177 1.163666820208614 0.8979181063534818
Final OF value: 0.715619764559789
Final parameter file: 'D:\oms\oms3.prj.wbm\output\Blue_luca\out\params-r2s3.csv'
```

The terminal ends with 'DONE. (856.28 seconds)'. The status bar at the bottom shows the file path 'D:\oms\oms3.prj.wbm\simulation\blueNile\wbmlakeiso\_blueNile2.sim' and the URL 'http://oms.javaforge.com'.

The screenshot shows the Object Modeling System (OMS) documentation page. The title is 'Object Modeling System (OMS)'. The text describes OMS as a pure Java, object-oriented modeling framework and model application based on components. It mentions that this is a collaborative project active since 2005, involving the University of Illinois at Urbana-Champaign and partner agencies and organizations involved with agro-environmental modeling. The page also includes a download section with a link to 'oms-3.2-console.zip' and a note that it is new. Below the download link, there are instructions to unzip the file, start the OMS3 Console, and install everything needed. It also provides links to 'Installation instructions' and 'Version 3.2 Release Notes'. The bottom part of the page states that the OMS3 framework goal is to provide features to the modeler to make it easy to create, integrate, and manage models that take full advantage of contemporary computing, management, and infrastructure, and that it is simple and intuitive for users.



# eRAMS Implementation of IWBMIso

localhost:8081/map/#

## Water Balance Modeling with IWBMIso (version 1.0)

Home My Account My Groups Resource Center dagnachew | BlueNile | Help | Sign Out

BlueNile\_Sc1

### MODIS Download

Modis Product: MOD13A3.005  
List of Tiles: h21v07,h21v08  
From: 2000-01-01 To: 2012-12-31

[Download](#) [Process](#) [Clear MODIS Data Cache](#)

#### Downloaded files

```
MOD13A3.A2005001.h21v07.005.2007355100315.f
MOD13A3.A2005001.h21v08.005.2007355100541.f
MOD13A3.A2005032.h21v07.005.2007365125402.f
MOD13A3.A2005032.h21v08.005.2007365130242.f
MOD13A3.A2005060.h21v07.005.2008015002011.f
MOD13A3.A2005060.h21v08.005.2008015002044.f
MOD13A3.A2005091.h21v07.005.2008025110839.f
MOD13A3.A2005091.h21v08.005.2008025111702.f
MOD13A3.A2005121.h21v07.005.2008039142334.f
MOD13A3.A2005121.h21v08.005.2008039092259.f
MOD13A3.A2005152.h21v07.005.2008050200734.f
MOD13A3.A2005152.h21v08.005.2008050201513.f
MOD13A3.A2005182.h21v07.005.2008058164908.f
MOD13A3.A2005182.h21v08.005.2008058165437.f
MOD13A3.A2005213.h21v07.005.2008060184722.f
```

### SRTM Extraction

Grid size: 90  
Top Lat:   
Bottom Lat:   
Left Long:   
Right Long:

[Generate](#) [Clear SRTM Data Cache](#)

Processed files

### Delineate Watershed

**Options & Settings**

DEM: nileDEM\_90m1\_clipped.tif  
Store results in folder: BlueNile/ [New Folder](#)

[Calculate Stream Network](#)

- Fill sinks
- Compute flow direction
- Compute flow accumulation
- Grid Analysis
- Stream Network - Peuker-Douglas
- Outlets
- Weighted Flow Accumulation Area
- Stream Network - Drop Analysis

[Close](#)

### Edit Parameters

scalar hamon\_c ntru nlake nmonths nsub ppt\_adjust temp\_adjust

id	hru_type	hru_area	hru_elev	hru_fat	hru_lon	hru_subbasin	who	cov
0	1	2615.09	1857.0	12.2222934215924	37.2307709601261		8	
1	1	4165.58	1822.0	11.7293571327135	37.2793189434884		8	
2	1	3227.35	1832.0	12.2449129848131	37.5842407548572		8	
3	1	18422.7	1964.0	11.9836767227037	36.955300666007		6	
4	1	5249.25	1897.0	12.2978813745188	37.5505112806977		6	
5	1	8774.96	1441.0	0.14116796424426	36.3228325983004		12	
6	1	14345.2	1935.0	12.3783155117984	37.0709168947275		6	
7	1	12349.5	1100.0	0.87426744739874	35.9177024991457		12	
8	1	15502.9	2098.0	0.21894112559988	37.5474064352655		10	
9	1	13080.5	1579.0	0.10008955598716	34.5524521138267		13	

Showing 1 to 10 of 847 entries Show 10 entries

### Regional DEM

Regional DEM: nileDEM\_90m1.tif

it AOIs: nileDEM\_90m1\_clipped.tif [Delete AOI](#)

[Create Work Directory](#)

### HRU Layer

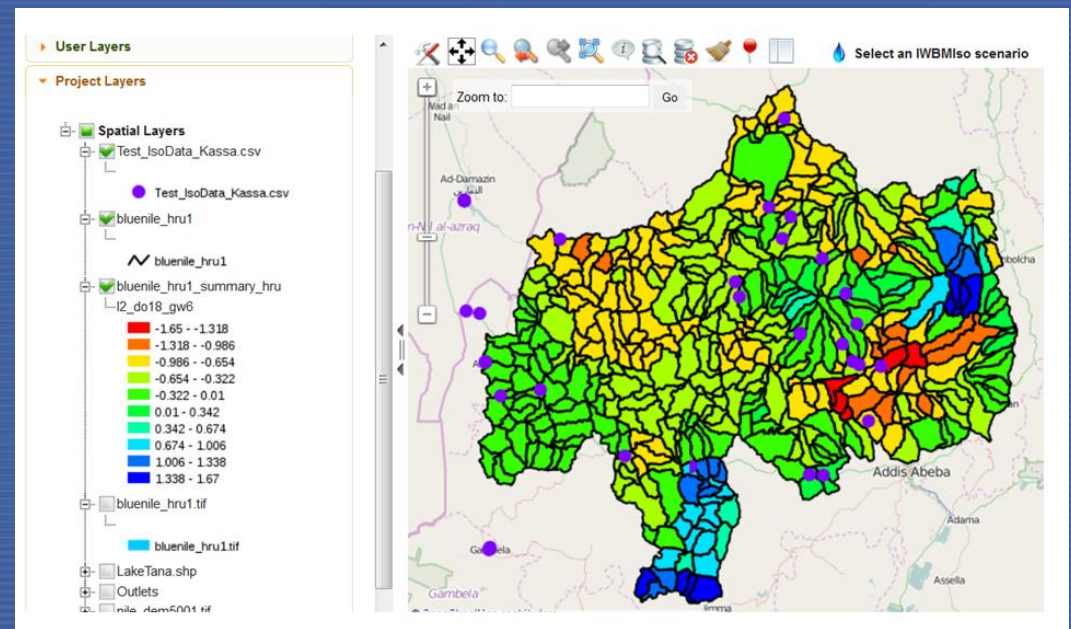
HRU: <Choose> Subbasin: <Choose>

[Create HRUs using Watershed Tools](#)



# eRAMS Implementation of IWBMIso

- HRU & Sub basin Delineation
- Data Downloading tools
- Global data pre-processing tools
- Simulation and Calibration
- Plotting and Comparison
- Map Generation
- Online and Offline versions
- ...



# Conclusions

IWBMIso:

Provides a quick and easy method for regional to global water balance assessment, especially in data scarce areas

Water stable isotopes used to constrain model calibration and to better estimate water balance components

Freely available, well-integrated with globally available free datasets

Cross-platform: Windows, OSX, Linux, smart phone, Browser

Modular and dynamic



# How to Get a copy

IWBMiso can be obtained via

- <http://www-naweb.iaea.org/napc/ih>
- Contact: [D.Belachew@iaea.org](mailto:D.Belachew@iaea.org)