The SWAT model and a web-based information system to assess the water balance of Sardinia (Italy)

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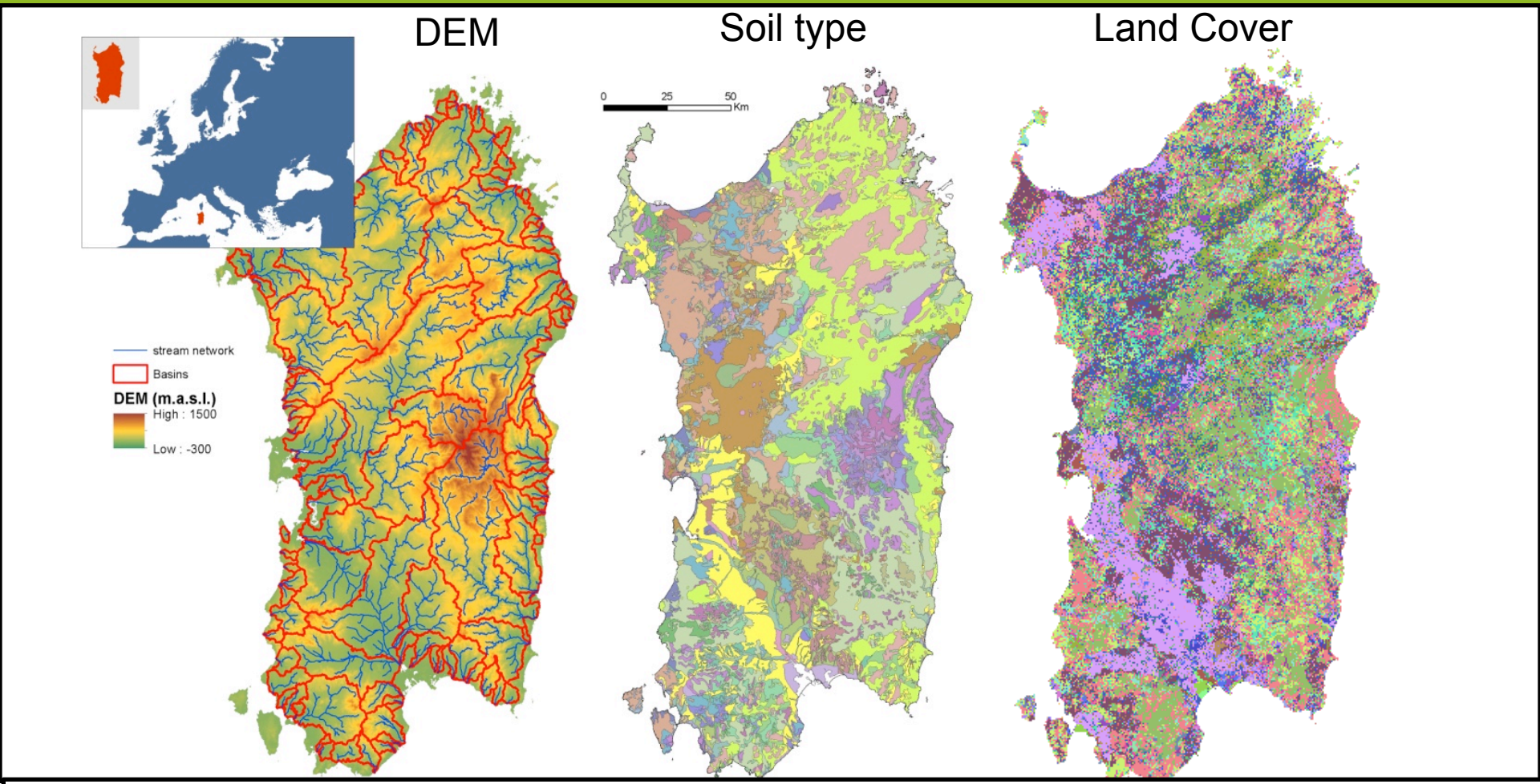
Objectives

- Develop a regional observation and assessment system based on SWAT for the management of water resources in Sardinia taking into consideration the present situation and climate change

This is achieved through:

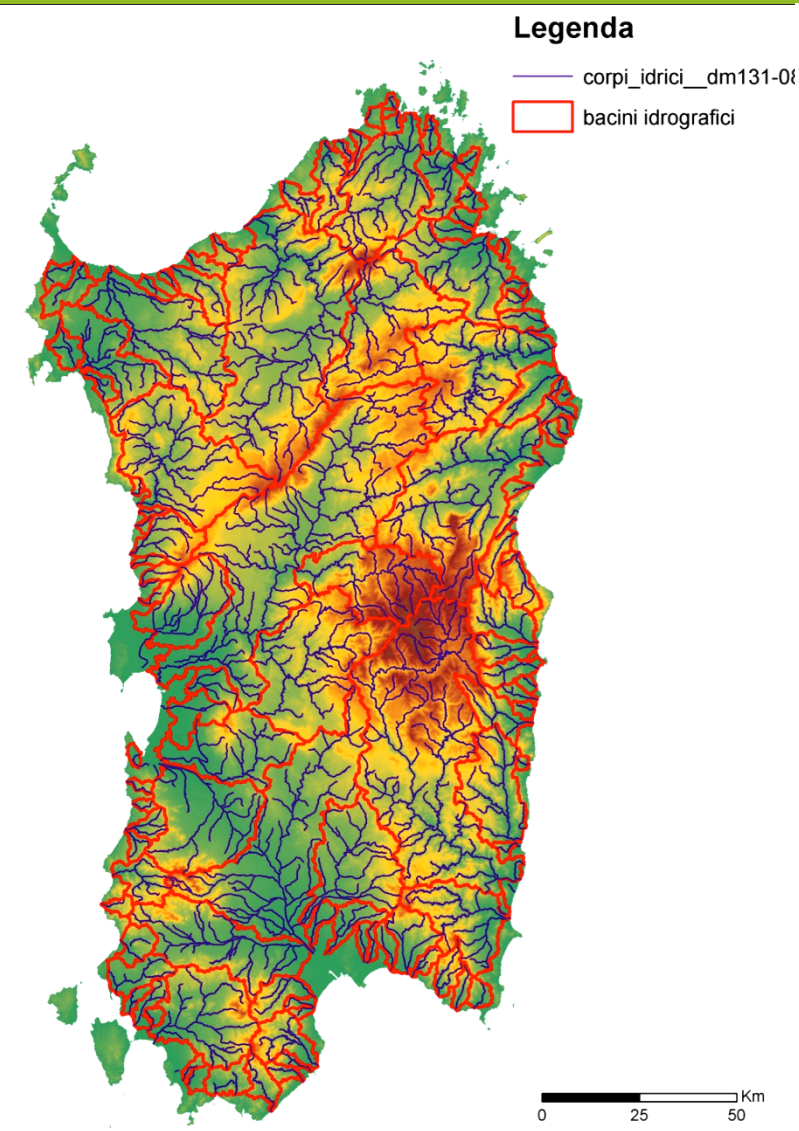
- the set up, calibration and validation of the SWAT model for Sardinia;
- the set up of automatic procedure to feed the model with climate change scenarios;
- develop a web-based Information System made of a SW, a computing, and storage infrastructure to assess water resources.

Set of the model



Sardinia (ITALY) is a semiarid region located in the Mediterranean, with a total area of 24090 km^2. Mild temperatures all year around, one hot/dry season, and one wet season with a dominant north-westerly wind, makes its climate typical Mediterranean.

Watershed delineation



Main watersheds: 108 (Area > 10 km^2)
Subbasins: 1356

Main issue concerns:

- delineation of flat areas with low slopes where often the automatic delineation fails to recognize the watershed or sub-watershed limits;
- presence of many artificial channels that cross several hydraulic limits;
- Often river's path was modified from their natural course.

Solution:

- manual reshape of watershed and sub watershed limits;
- use of a optimized river network to condition the the automatic delineation.

Climate date

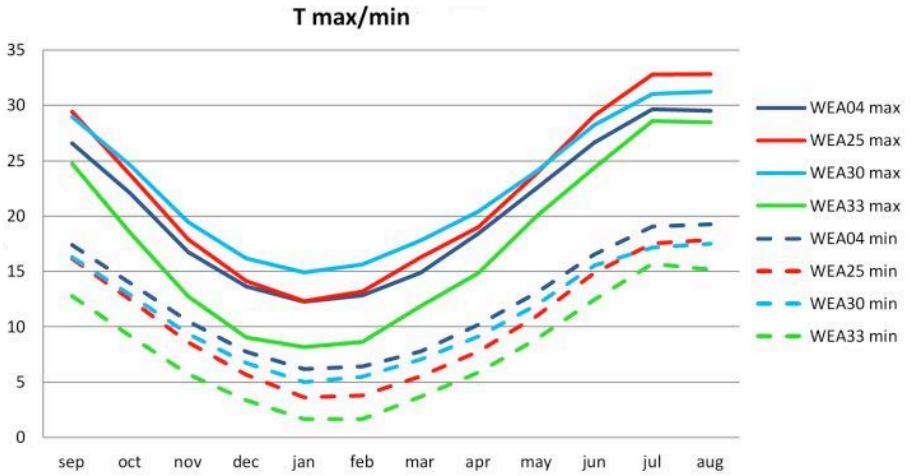
Simulation period **1922-2008**

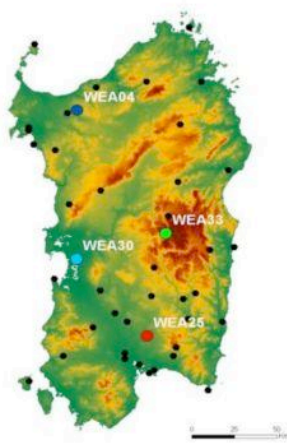
49 TMP gages

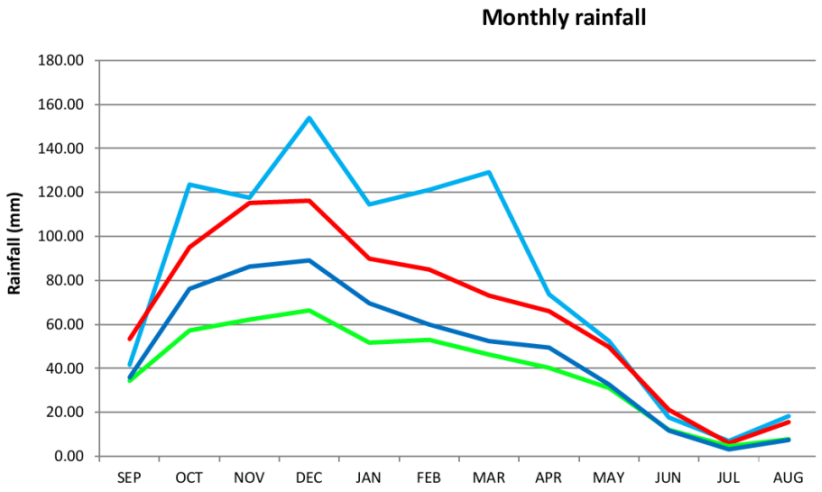
243 PCP gages

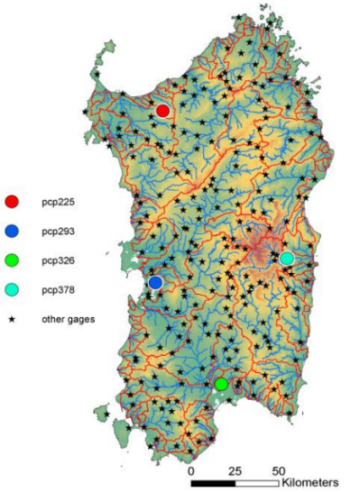
27 stream flow monitoring stations

- 23 for calibration
- 4 for validation









Calibration

SWATCUP was employed using the "SUFI2" routine. The Nash Sutcliffe objective function was chosen to measure the model performance.

Nash Sutcliffe index

$$NS = 1 - \frac{\sum_i (Q_m - Q_s)_i^2}{\sum_i (Q_{m,i} - \overline{Q}_m)^2}$$

- ∞, NS, 1

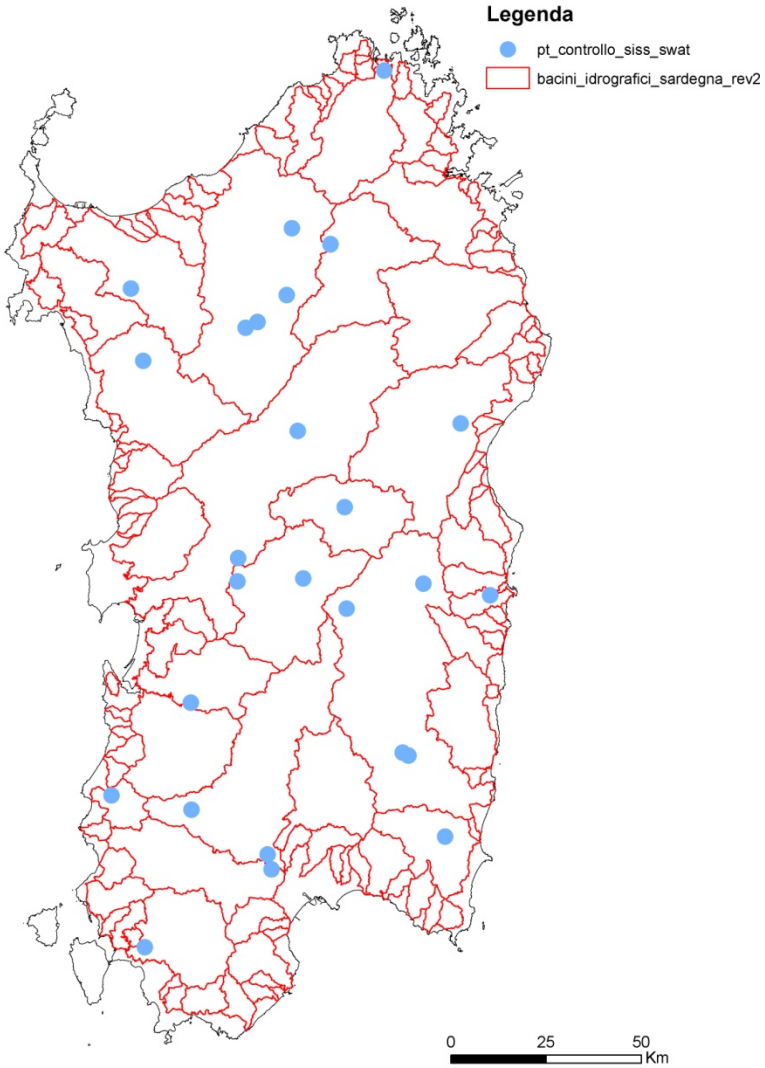
1 = perfect match between simulated and measured data

ISSUES:

- The process is time consuming (1 run = ~ 2,5 hours)

- Regional approach: in our regional model, soil and land cover condition all control points.

Control points



STAZIONE	COD_SISS
Mannu di S.Sperate a Monastir	2
Cixerri a Uta	3
Rio di Palmas a Monti Pranu	4
Fluminimaggiore a Fluminimaggiore	6
Tirso a Rifornitore Tirso Ponte Statale	7
Taloro a Passerella Gavoi	8
Tirso a S.Chiara D'Ula	9
Araxisi (Tirso) a Orto Sciavico	10
Flumineddu (Tirso) ad Allai	11
Temo a Reinamare	12
Mannu di Porto Torres a Pedras Alvas	13
Mannu di Ozieri a P.te della Legna	14
Rio Buttule (Coghinas) a Buttule	15
Mannu di Ozieri (Coghinas) a Fraigas	16
Mannu di Berchidda (Coghinas) a Berchidda	17
Rio di Oschiri (Coghinas) a Concarabella	18
Coghinas a Muzzone	19
Liscia a Liscia	20
Cedrino a Cedrino	21
Foddeddu a Corongiu	22
Flumendosa a Gadoni	26
Flumineddu a Stanali	29
Sa Picocca a M.te Acuto	30
Mogoro a S.Vittoria	31
Rio Leni (Fluminimannu) a Villacidro	35
Alto Flumendosa AGGREGATA	43
Flumendosa a Monte Scrocca AGGREGATA	50

Calibration - first run

OUTLET	STAZIONE	START 0
9	LISCIA	-0.13
146	COGHINAS A MUZZONE	0.70
160	BERCHIDDA	0.82
175	CONCABELLA	0.69
236	MANNU A PEDRA ALVAS	0.52
257	MANNU DI OZIERI FRAIGAS	0.68
317	RIO BUTTULE A BUTTULE	0.66
328	MANNU DI OZIERI PONTE LEGNA	0.62
381	TEMO DIGA	0.70
471	RIFORNITORE TIRSO	0.11
480	PONTE CEDRINO	0.63
601	TALORO A PASSERELLA GAVOI	0.08
703	ARAXISI A ORTO SCIAVICO	0.47
711	FLUMINEDDU (TIRSO) ALLAI	0.46
715	ALTO FLUMENDOSA AGGREGATA	0.40
747	FODDEDDU A CORONGIU	0.57
755	FLUMENDOSA A GADONI	0.88
879	MOGORO A SANTA VITTORIA	-0.57
889	FLUMINEDDU A STANALI	0.46
933	M. SCROCCA AGGREGATA	0.86
1050	SA PICCOCCA MONTE ACUTO	-1.90
1070	MANNU DI S. SPERATE A MONASTIR	-2.05
1113	CIXERRI A UTA	0.24
1175	MONTI PRANU	-1.17
	MEDIA	0.20

Main parameters used in the calibration

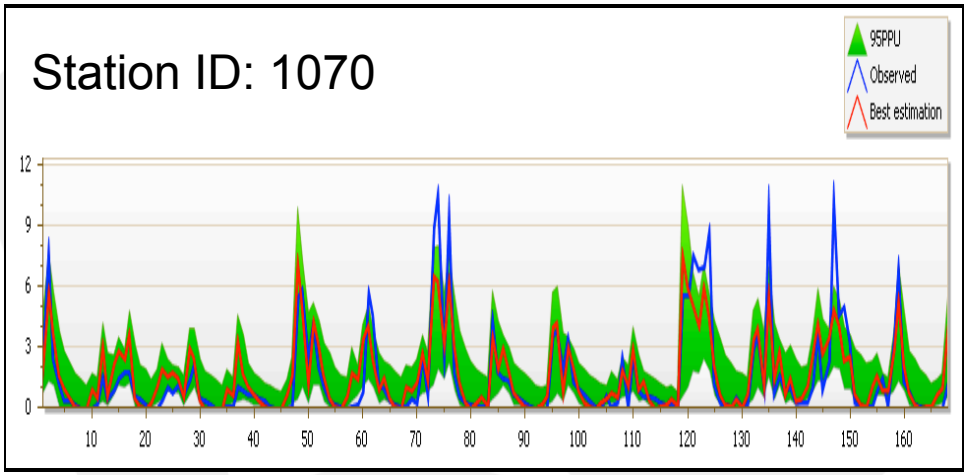
CN2
ESCO
AWC
Alpha_BF
GW_DELAY
GWQMN
GW_REVAP
SOL_K
….

Calibration - result

SISS	STAZIONE	RUN 22
9	LISCIA	**0.60**
146	COGHINAS A MUZZONE	**0.72**
160	BERCHIDDA	**0.84**
175	CONCABELLA	**0.69**
236	MANNU A PEDRA ALVAS	**0.60**
257	MANNU DI OZIERI FRAIGAS	**0.75**
317	RIO BUTTULE A BUTTULE	**0.74**
328	MANNU DI OZIERI PONTE LEGNA	**0.72**
381	TEMO DIGA	**0.70**
471	RIFORNITORE TIRSO	**0.58**
480	PONTE CEDRINO	**0.71**
601	TALORO A PASSERELLA GAVOI	**0.59**
703	ARAXISI A ORTO SCIAVICO	**0.70**
711	FLUMINEDDU (TIRSO) ALLAI	**0.75**
747	FODDEDDU A CORONGIU	**0.57**
755	FLUMENDOSA A GADONI	**0.88**
879	MOGORO A SANTA VITTORIA	**0.76**
889	FLUMINEDDU A STANALI	**0.46**
933	M. SCROCCA AGGREGATA	**0.86**
1050	SA PICCOCCA MONTE ACUTO	**0.80**
1070	MANNU DI S. SPERATE A MONASTIR	**0.71**
1113	CIXERRI A UTA	**0.73**
1175	MONTI PRANU	**0.66**
	Average	**0.70**

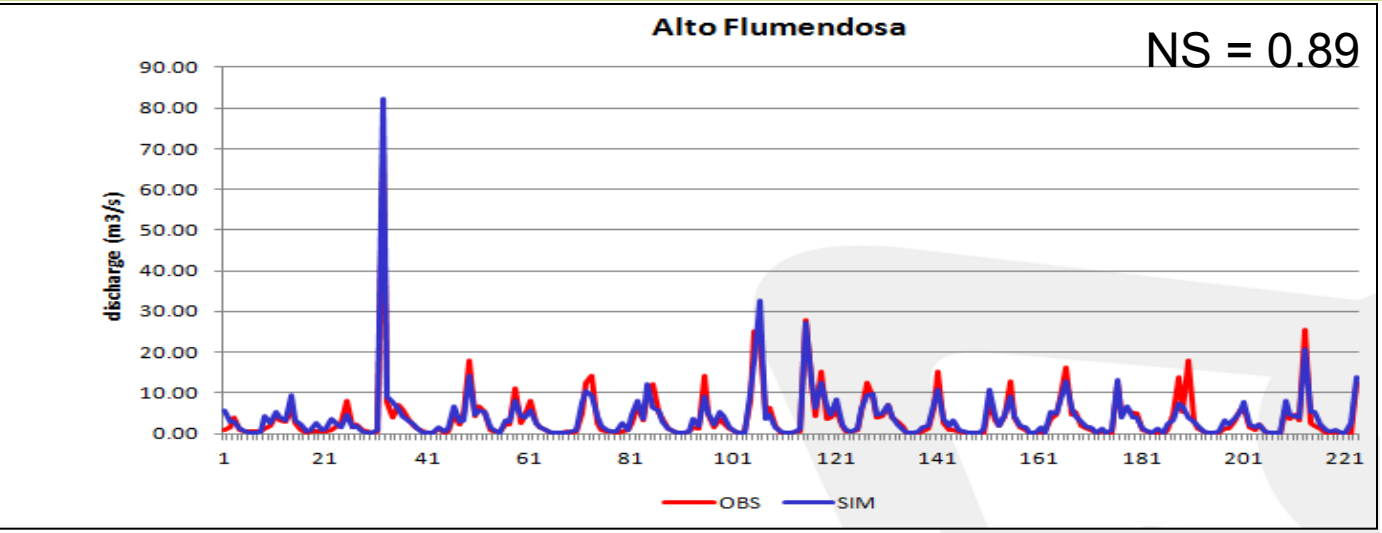
The performance ranges from 0.46 to 0.88.

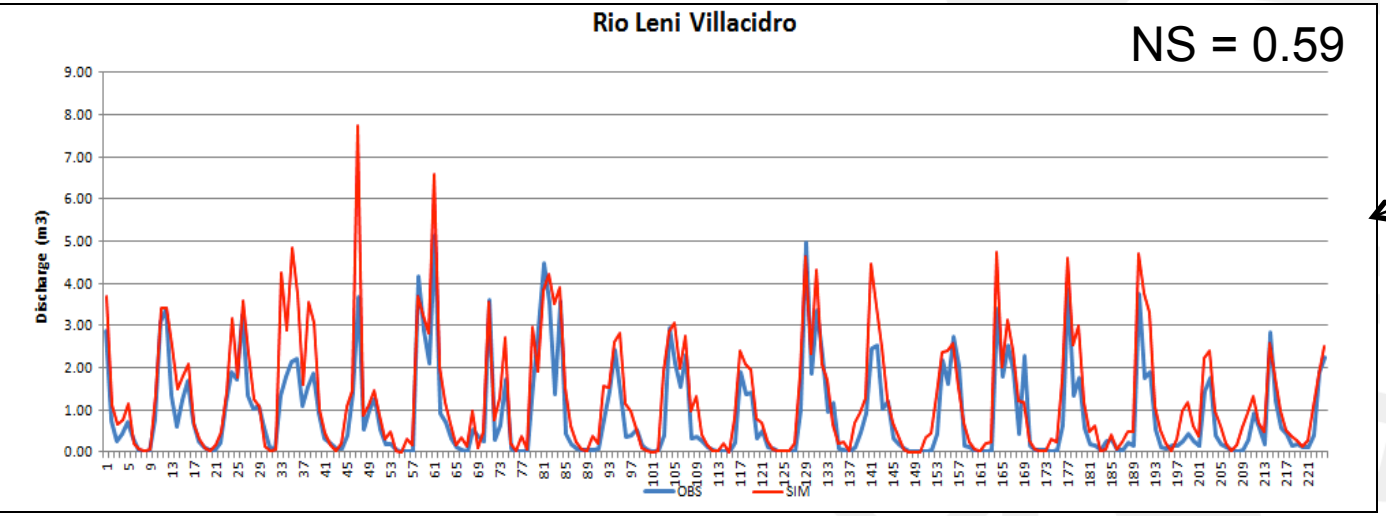
NS mean 0.70

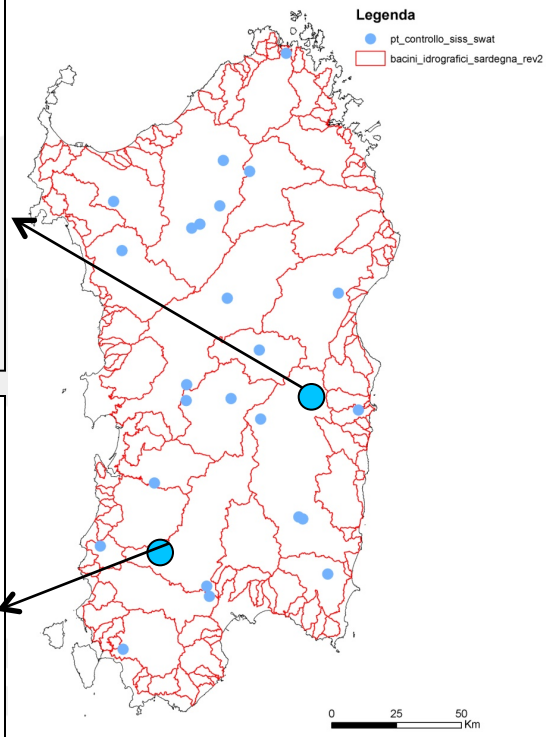


Station ID: 1070. NS is 0.70 with a P-factor of 0.77 and a R-factor of 1.09 obtained after 300 iterations.

Validation


Alto Flumendosa
NS = 0.89
discharge (m3/s)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1
21
41
61
81
101
121
141
161
181
201
221
OBS
SIM


Rio Leni Villacidro
NS = 0.59
Discharge (m3)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
OBS
SIM


Legenda
pt_controllo_siss_swat
bacini_idrografici_sardegna_rev2
0
25
50
Km

The Information System

Results are exposed on a web Information System, namely **BASHYT** (http:swat.crs4.it/). This is a software that exposes applications on the web based on complex models such as SWAT. It works in tandem with ArcSWAT.

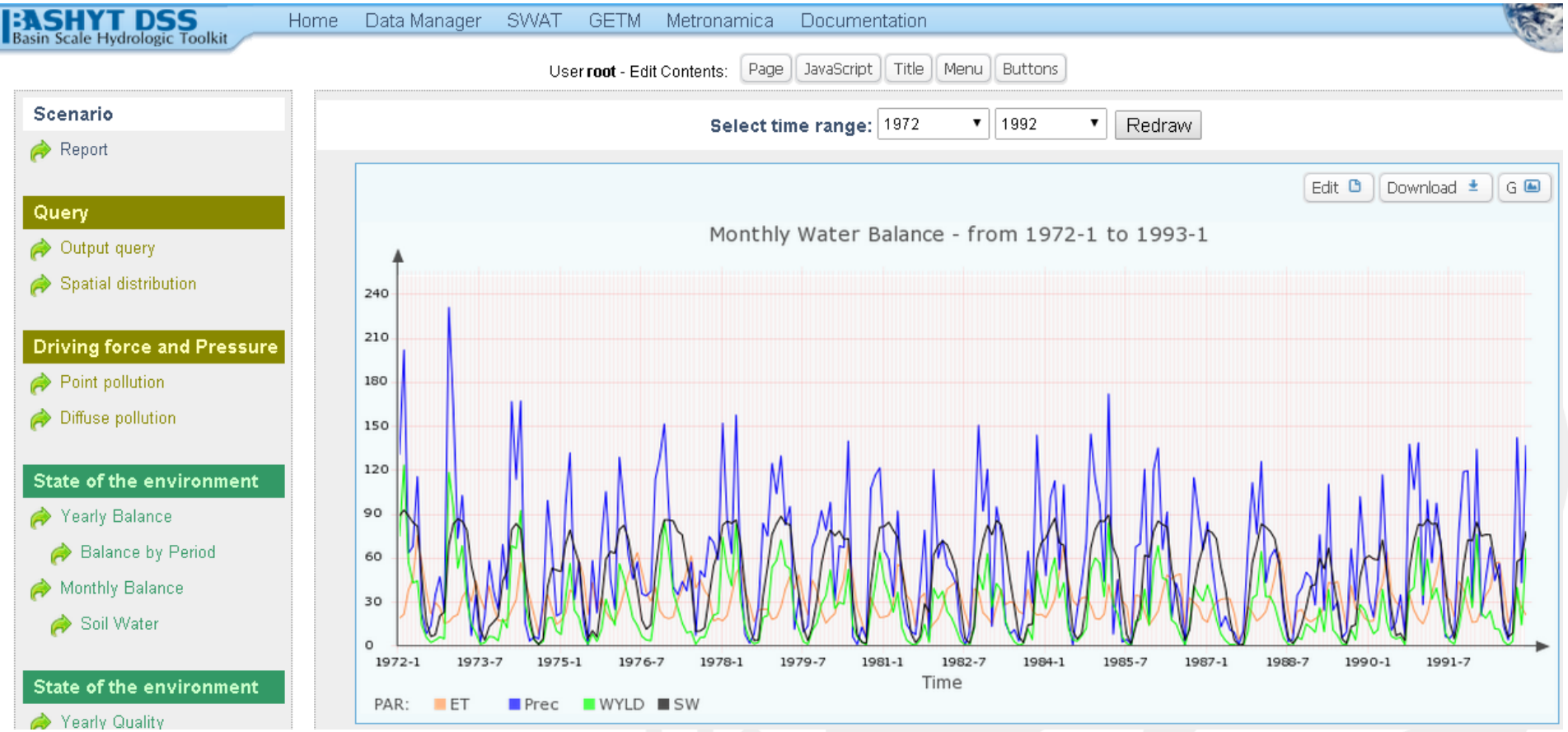
BASHYT combines client and server side technologies, to access and efficiently use complex specialized functionalities and computation and storage resources.

BASHYT is up and running at: **http://swat.crs4.it/**

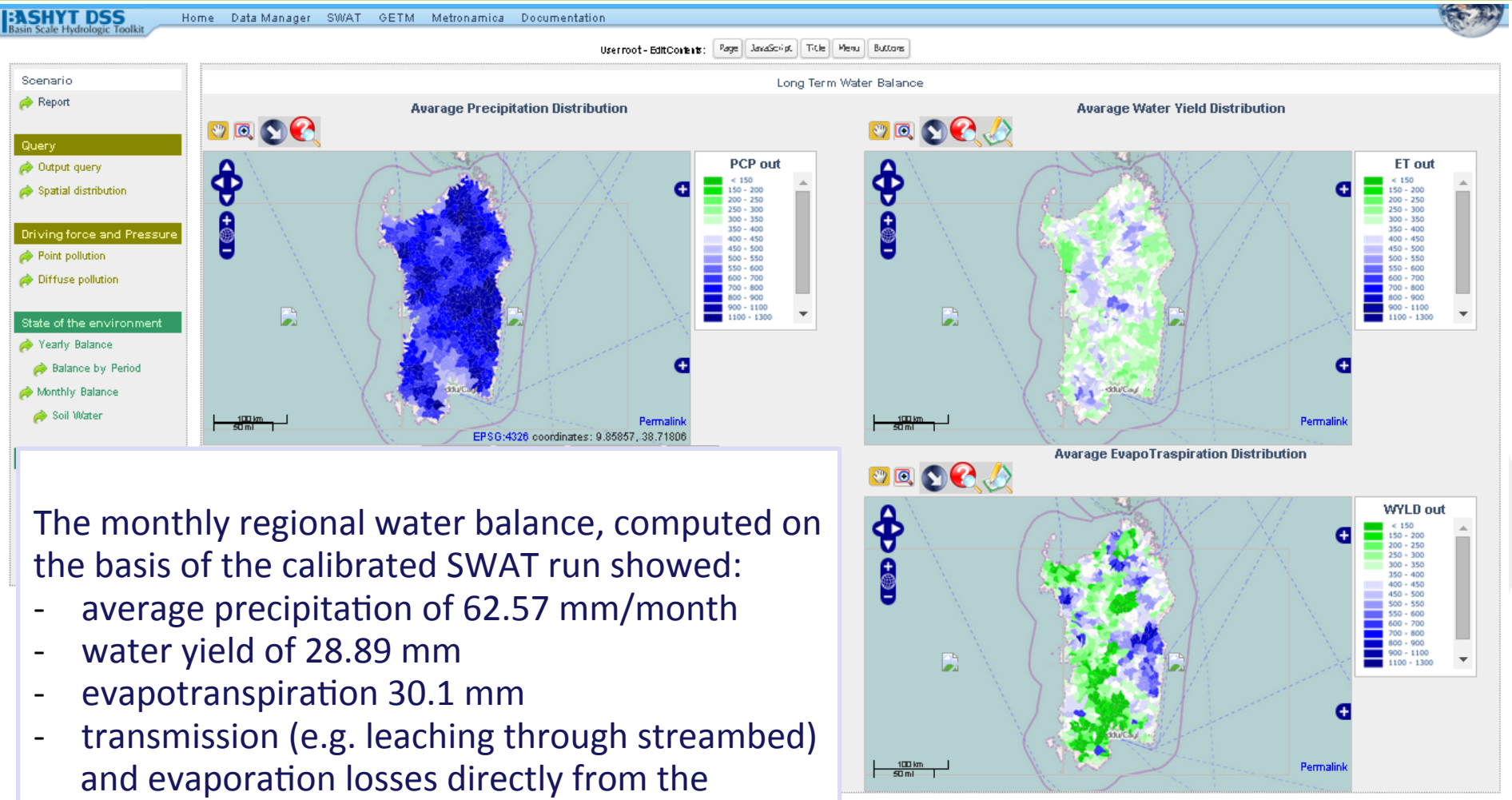
Register to use the system

BASHYT

Results of the regional application can be analysed with charts and maps.



Example of a web application



The monthly regional water balance, computed on the basis of the calibrated SWAT run showed:

- average precipitation of 62.57 mm/month
- water yield of 28.89 mm
- evapotranspiration 30.1 mm
- transmission (e.g. leaching through streambed) and evaporation losses directly from the stream 3 mm.

Enseble climate scenarios

The Ensembles Prediction Systems is based on global Earth System Models (ESMs) developed in Europe for use in the generation of multi-model simulations of future climate.

The Ensemble project provides climate predictions developed in the context of regional models, first at spatial scales of 50 – 20 km at a European-wide scale.

Almost 2 centuries have been covered. We have used for our tests 2 time frames: **1971 – 2000** and **2041 - 2070**

Climate change scenarios

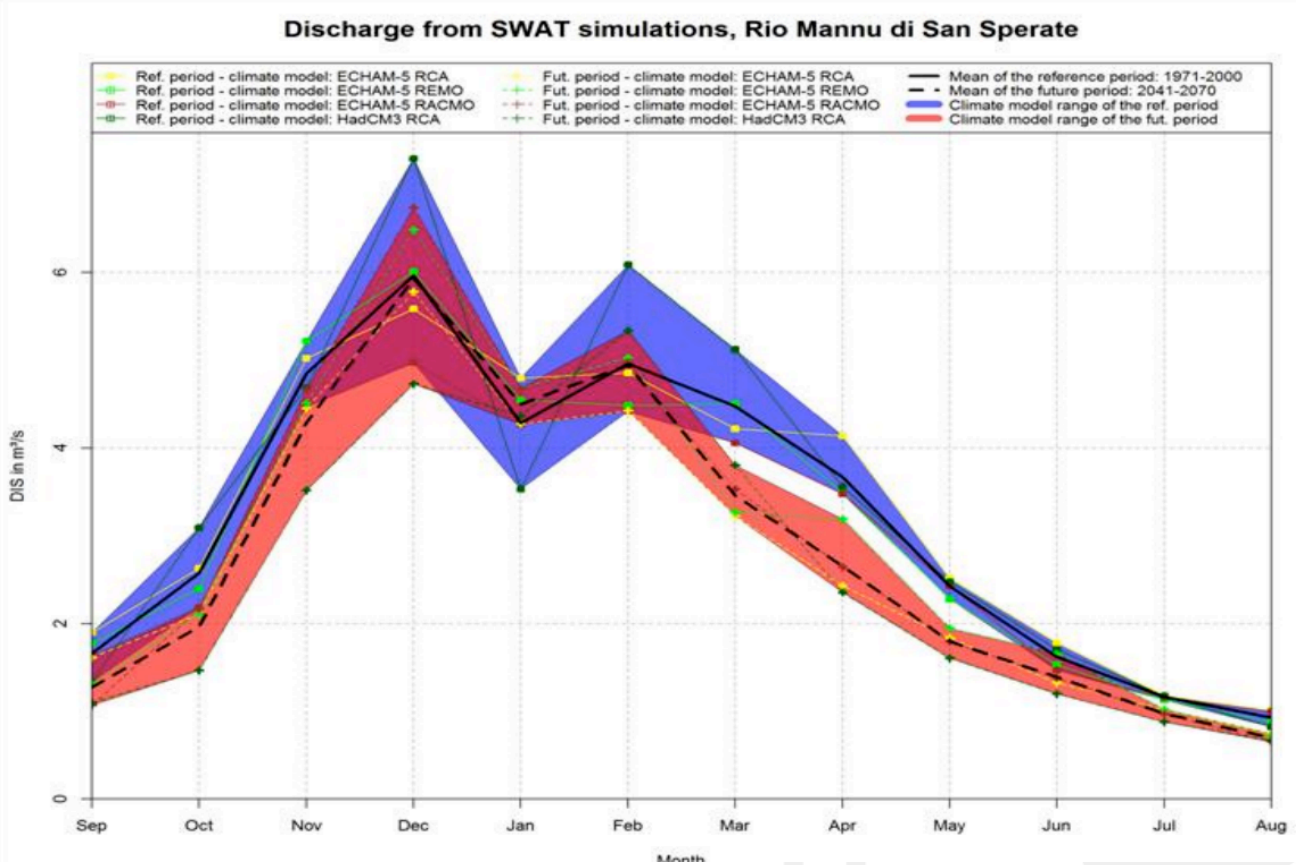
Within **BASHYT** a automatic procedure:

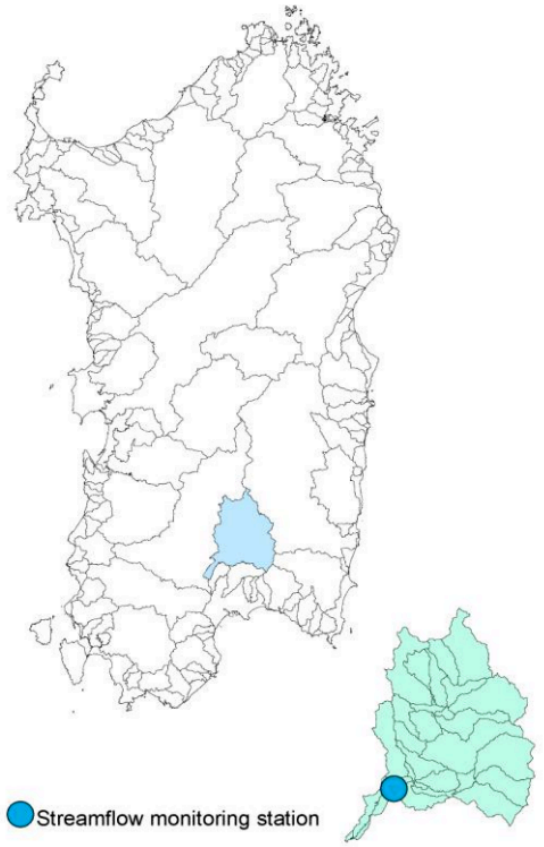
- gets climate data (TMP, PCP) and their location as input;
- process this data to fit the SWAT Model specification (re-write the TXTINOUT files);
- run the model;
- extract output data and load it to a database.

4 models (of 14 available) have been used as test:

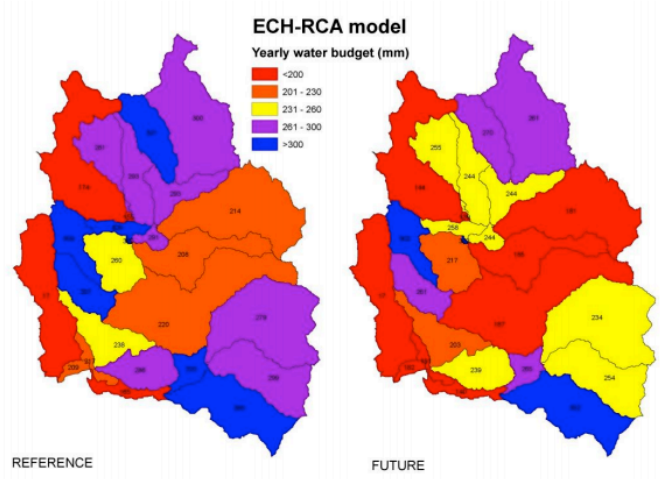
1. **ECH-RMO**: KNMI-RACMO2_A1B_ECHAM5-r3 - KNMI
2. **ECH-REM**: MPI-M-REMO_SCN_ECHAM5 - MPI
3. **ECH-RCA**: C4IRCA3_A1B_HadCM3Q16 - C4I
4. **HCH-RCA**: SMHIRCA_A1B_ECHAM5-r3 - SMHI_ECHAM5

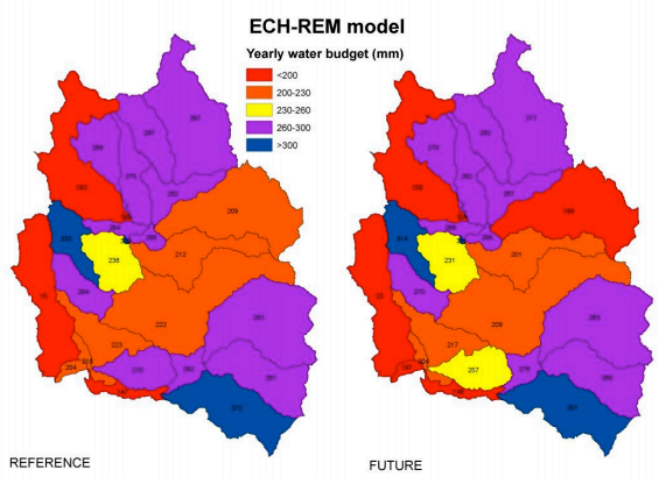
Climate change scenarios

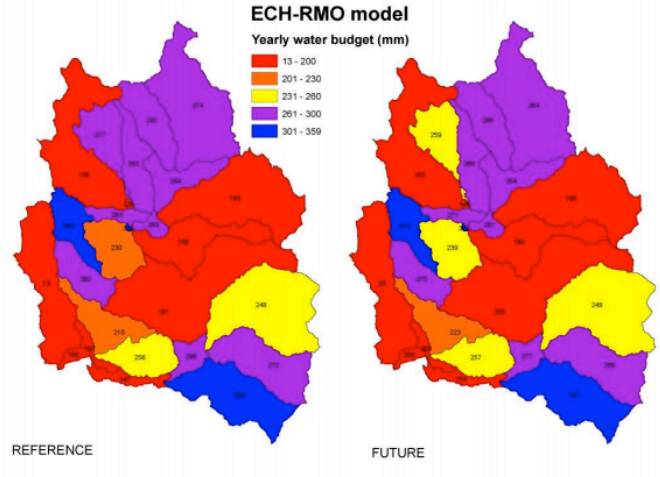


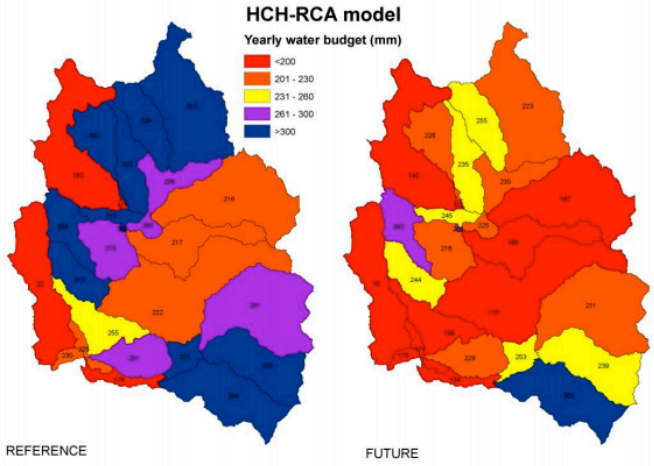


Climate change scenarios









Results. In the future:

- Water availability is decreasing
- Increase of draught periods (longer and more frequent)
- higher probability of occurrence of intense precipitations with high surface runoff values.
- Increase of the N. of low flow days and higher peacks of daily flow

Conclusions

Reliable model prediction is based on the acquisition of **large quality dataset** and the use of a rigourous methodological approach:

- The SWAT model was set up for the entire Sardinia. Calibration and validation results confirm a good model fit with real data;
- Climate scenarios, although run on a small catchment within Sardinia, highlight that the water budget is going to lower values for the future and therefore water availability is decreasing.

Shifting environmental applications from the desktop oriented approach to the web based paradigm **enhances flexibility in the whole system**, **extends the use of data** and **the sharing of experiences, fostering user participation**.

Acknowledgment

Aknowledgments:

RAS - Regione Autonoma della Sardegna (Italy). http://www.regione.sardegna.it/

CLIMB Project: http://www.climb-fp7.eu/home/home.php

EnviroGRIDS Project: http://envirogrids.net/

Data Analysis

14 Climate models

- Complete daily data
- Incomplete daily data
- Missing data

Istitution/Model	Country	Note
CNRM-ARPEGE-new	France	No data – Only ancillary
CNRM-ARPEGE-old	France	No data – Only ancillary– Lustrum step
DMI	Denmark	
DMI-BCM	Denmark	No data – Only ancillary – Start: 1961
DMI-ECHAM5	Denmark	Last time interval: 2091-2099 (9 years instead of 10)
ETHZ	Switzerland	Last time interval: 2091-2099 (9 years instead of 10)
GKSS-IPSL	Germany	No Daily step
HadRM3Q0	UK	
HadRM3Q16	UK	
HadRM3Q3	UK	
ICTP	Italy	
KNMI	Netherlands	Is present a yearly simulation (1950-1950)
METNO	Norway	Last time interval:2041-2050
METNO-HadCM3Q0	Norway	Last time interval:2041-2050
REM (MPI)	**Germany**	
SMHI-BCM	Sweden	Start: 1961-1970
SMHI-ECHAM5	Sweden	
SMHI-HadCM3Q3	Sweden	
VMGO	Russia	Last time interval: 2021-2030 (pr); 2011-2020 (tasmin, tasmax)

Variables

REM - (MPI) ECHAM5 Model

Climatic variable processed

ECHAM5 (Max Planck Institute for Metereology) is the 5th generation of the ECHAM general circulation model. It can be used in various configurations which differ in the vertical extent of the atmosphere as well as the relevant processes.

Variable	Name	Units	Availability	Downloaded
tasmax	**Daily maximum 2-m temperature**	**K**	**high**	**Yes**
tasmin	**Daily minimum 2-m temperature**	**K**	**high**	**Yes**
prc	Convective precipitation	kg m-2 s-1	high	Yes
pr	**Precipitation**	**kg m-2 s-1**	**high**	**Yes**
prhmax	Max hourly precipitation rate	kg m-2 s-1	high	Yes
hurs	**2-meter relative humidity**	**1**	**high**	**Yes**
hursmax	Daily maximum 2-m relative humidity	1	high	Yes
hursmin	Daily minimum 2-m	1	high	Yes
wss	**10-meter wind speed**	**m s-1**	**high**	**Yes**
wssmax	10-meter daily max. wind speed, without gust	m s-1	high	Yes
wsgsmax	10-meter daily max. wind speed incl. gust	m s-1	high	Yes
rss	**Net SW surface radiation**	**W m-2**	**medium**	**No**
rsds	Downward SW surface radiation	W m-2	medium	No
clt	Total cloudiness (Fraction)	1	scarse	No
mrro	Total runoff	kg m-2 s-1	medium	Yes
mrros	Surface runoff	kg m-2 s-1	medium	Yes
mrross	Drainage (deep runoff)	kg m-2 s-1	medium	Yes

THE CWE ENVIRONMENT

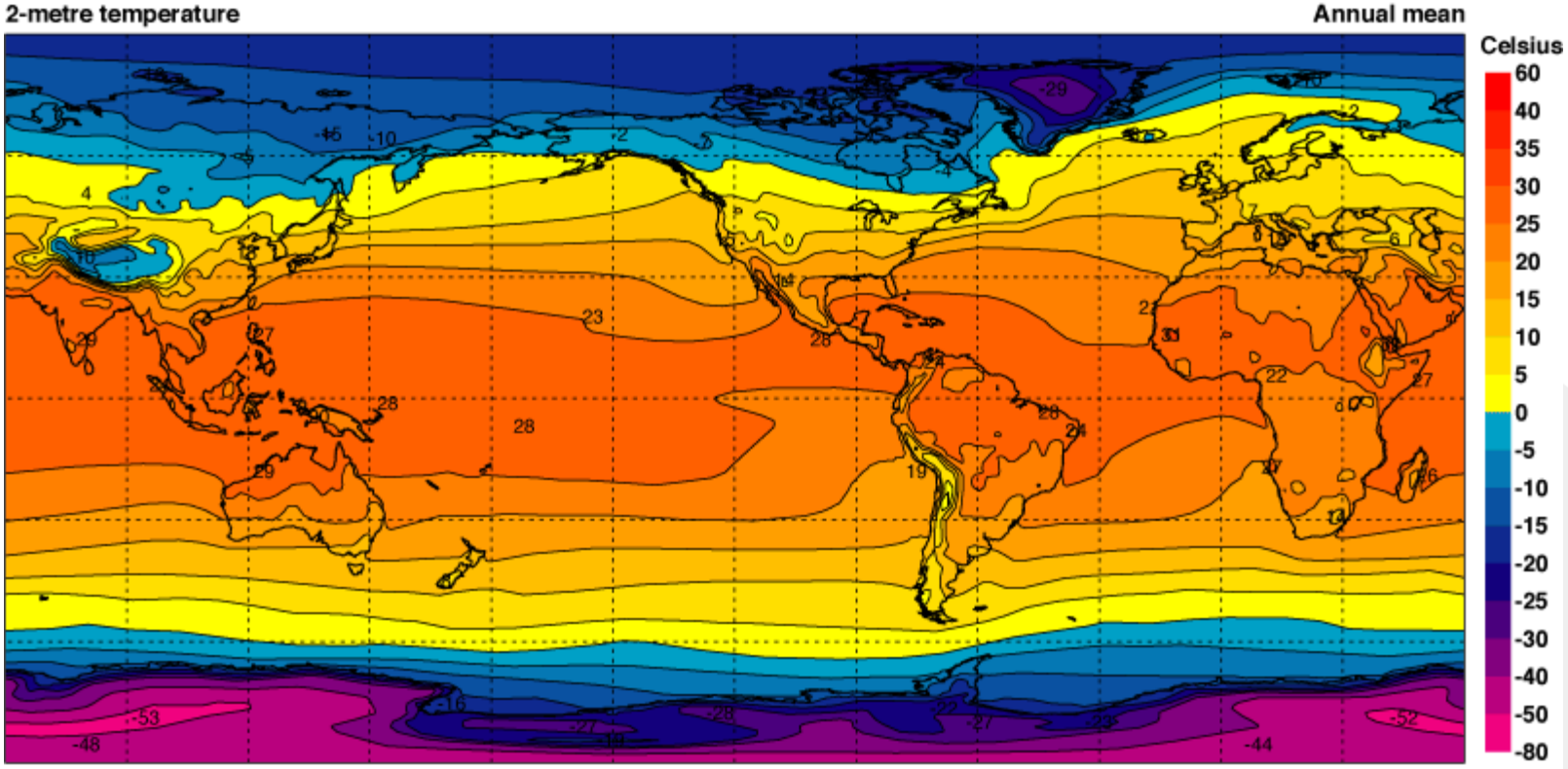
The SWAT model is run on the Portal for the best 4 Atmospheric models of the Ensemble project:

1. **RacMO (RMO)**: KNMI-RACMO2_A1B_ECHAM5-r3 - **KNMI**
2. **REMo (REM)**: MPI-M-REMO_SCN_ECHAM5 - **MPI**
3. **RCA 3** (RCA): C4IRCA3_A1B_HadCM3Q16 - **C4I**
4. **SMHE (SMHE)** ECH_RCA SMHIRCA_A1B_ECHAM5-r3 - **SMHI_ECHAM5**

A tool has been developed to access the model skill from the hydrological point of view.
It calculates for each month:

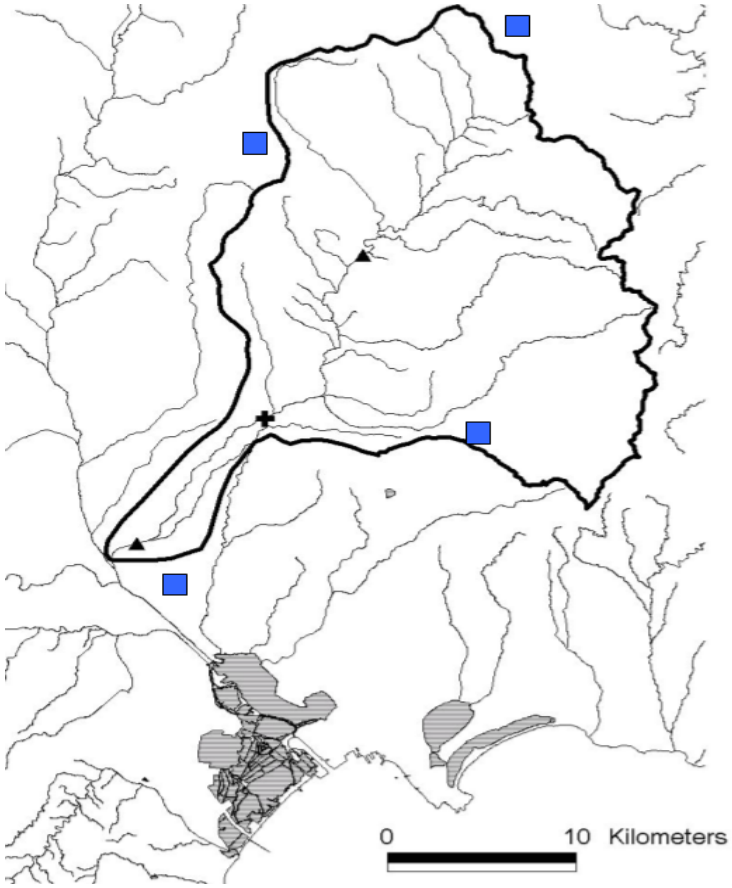
1. **PWW** i: Probability of a Wet day to be fallowed by a wet day for month i
2. **PDW** i: Probability of a Dry day to be fallowed by a wet day for month i
3. **N Dry** i: Average Number of Dry days for month i
4. **N Wet** i: Average Number of Wet days for month I
5. **PCP-AVG** i: Average Precipitaion
6. **PCP-STD** i: Standard Deviation
7: **PCP-SKW** i: Skewness of the sample
8. **Max PCP** i: Maximum Precipitation

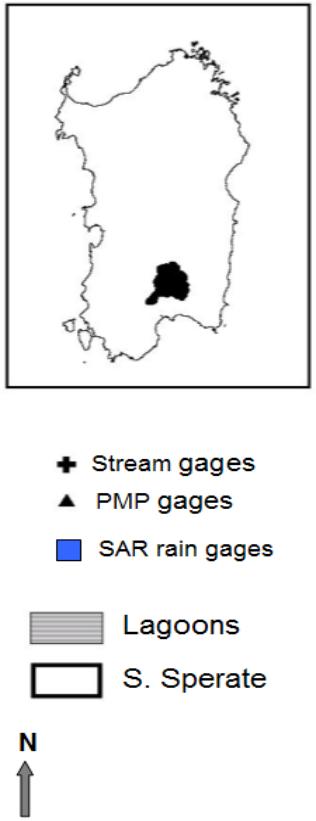
The enseble climate models

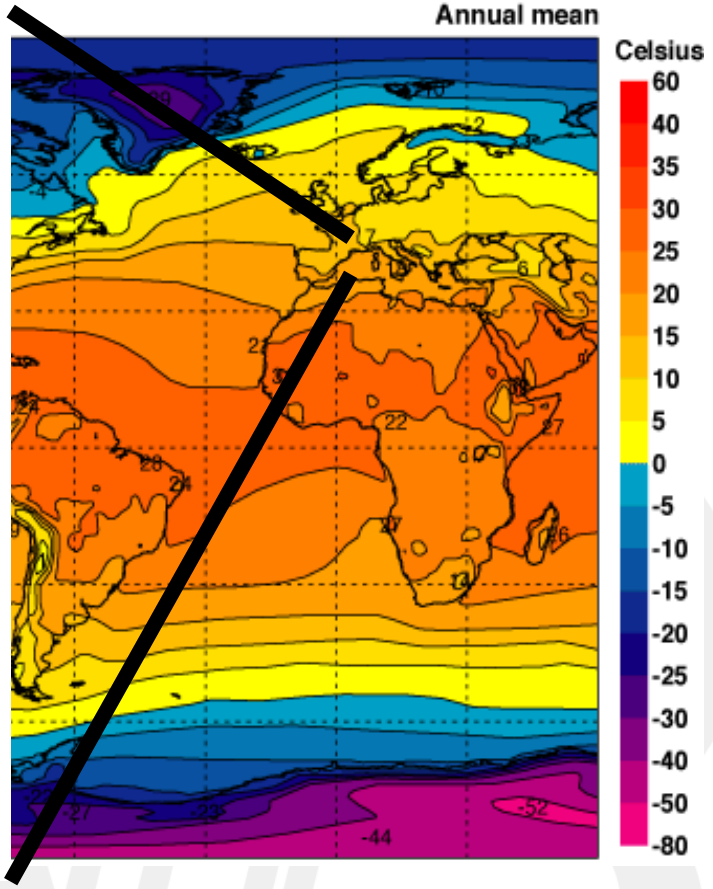


http://www.ecmwf.int/research/era/ERA-40_Atlas/docs/section_B/charts/B03_LL_YEA.html

From large to basin scale







Comparing Atmospheric forcing

BASHYT DSS
Basin Scale Hydrologic Toolkit

Home | Data Manager | SWAT | **Scenarios** | GETM | Documentation

Default

Statistics

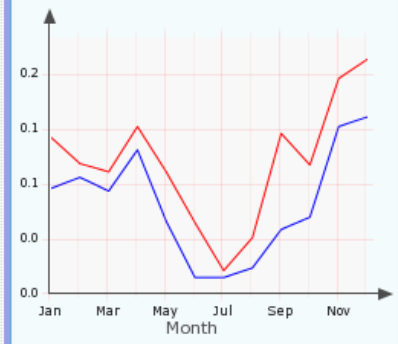
Prev | Next | Edit | Download

Station	Month	PWW	PDW	N Dry days	N Wet day	PCP AVG	PCP STD	SKW	PCP Max
1	Jan	0.077	0.114	25	6	1.145	3.03	0.0	33.8
1	Feb	0.085	0.095	23	5	1.418	4.813	12.893	67.8
1	Mar	0.075	0.089	26	5	1.081	2.893	0.0	27.8
1	Apr	0.105	0.122	23	7	1.842	4.873	6.135	41.0
1	May	0.053	0.089	26	5	0.964	2.868	0.0	23.4
1	Jun	0.012	0.052	28	2	0.684	3.073	0.0	27.2
1	Jul	0.012	0.017	30	1	0.175	1.166		16.2
1	Aug	0.019	0.041	29	2	0.476	2.587	0.0	30.2
1	Sep	0.047	0.117	25	5	1.433	5.678	11.876	76.6
1	Oct	0.056	0.094	26	5	1.528	5.41	7.66	50.8
1	Nov	0.122	0.157	21	9	2.503	5.946	10.538	59.0
1	Dec	0.129	0.171	21	9	2.455	5.344	8.877	56.8

1 Edit

Edit | Download | G

PDW and PWW



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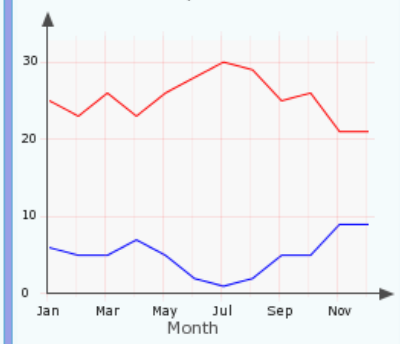
N. Dry and Wet



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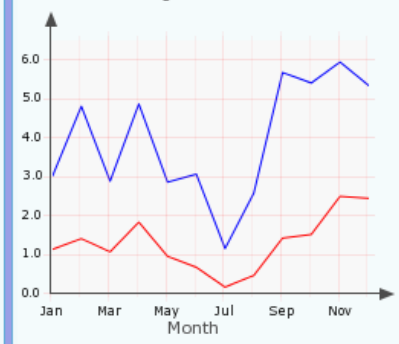
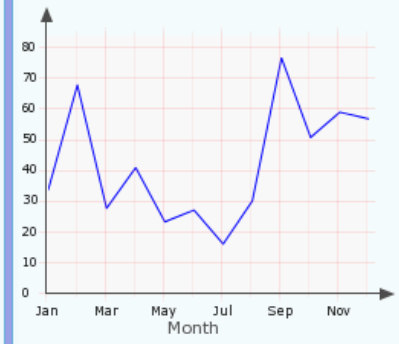
PCP Average and Std. deviation



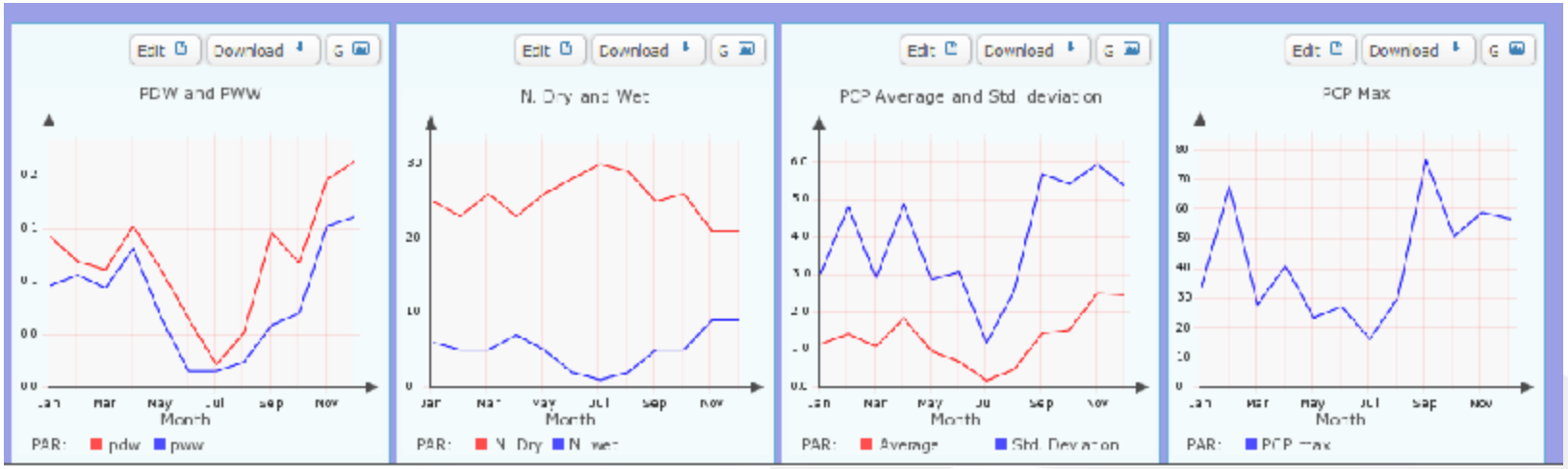
Edit | Download | G

PCP Max

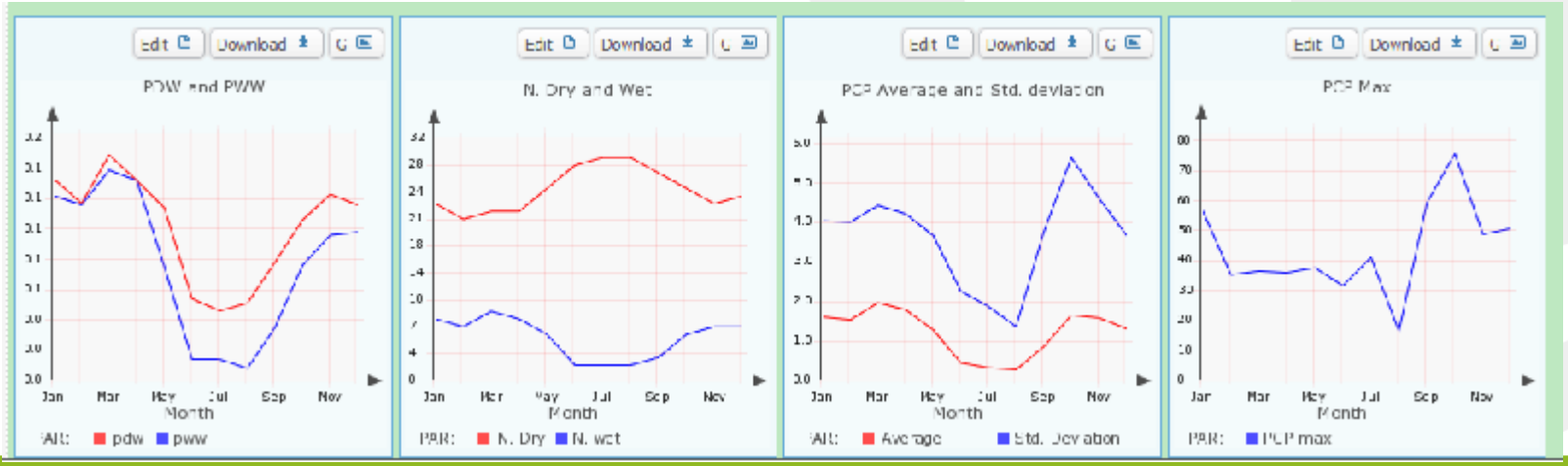


Comparing Atmospheric forcing

History / Default



REM Model



Comparing Atmospheric forcing

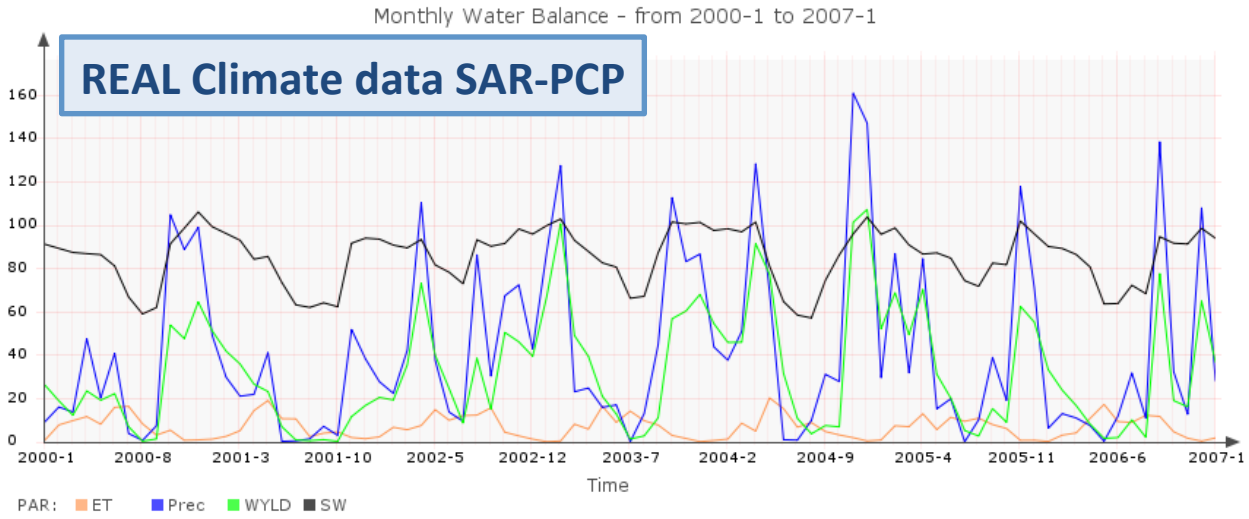
History/default

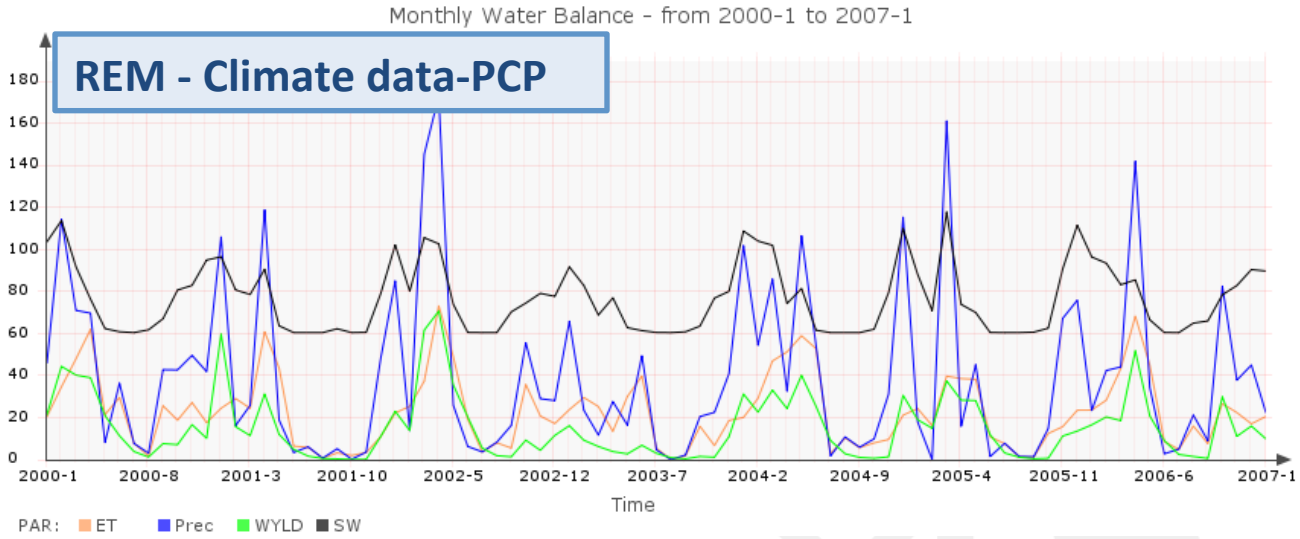
Station	Month	PWW	PDW	N Dry days	N Wet day	PCP AVG	PCP STD	PCP Max
1	Jan	0.077	0.114	25	6	1.145	3.03	33.8
1	Feb	0.085	0.095	23	5	1.418	4.813	67.8
1	Mar	0.075	0.089	26	5	1.081	2.893	27.8
1	Apr	0.105	0.122	23	7	1.842	4.873	41.0
1	May	0.053	0.089	26	5	0.964	2.868	23.4
1	Jun	0.012	0.052	28	2	0.684	3.073	27.2
1	Jul	0.012	0.017	30	1	0.175	1.166	16.2
1	Aug	0.019	0.041	29	2	0.476	2.587	30.2
1	Sep	0.047	0.117	25	5	1.433	5.678	76.6
1	Oct	0.056	0.094	26	5	1.528	5.41	50.8
1	Nov	0.122	0.157	21	9	2.503	5.946	59.0
1	Dec	0.129	0.171	21	9	2.455	5.344	56.8

REM

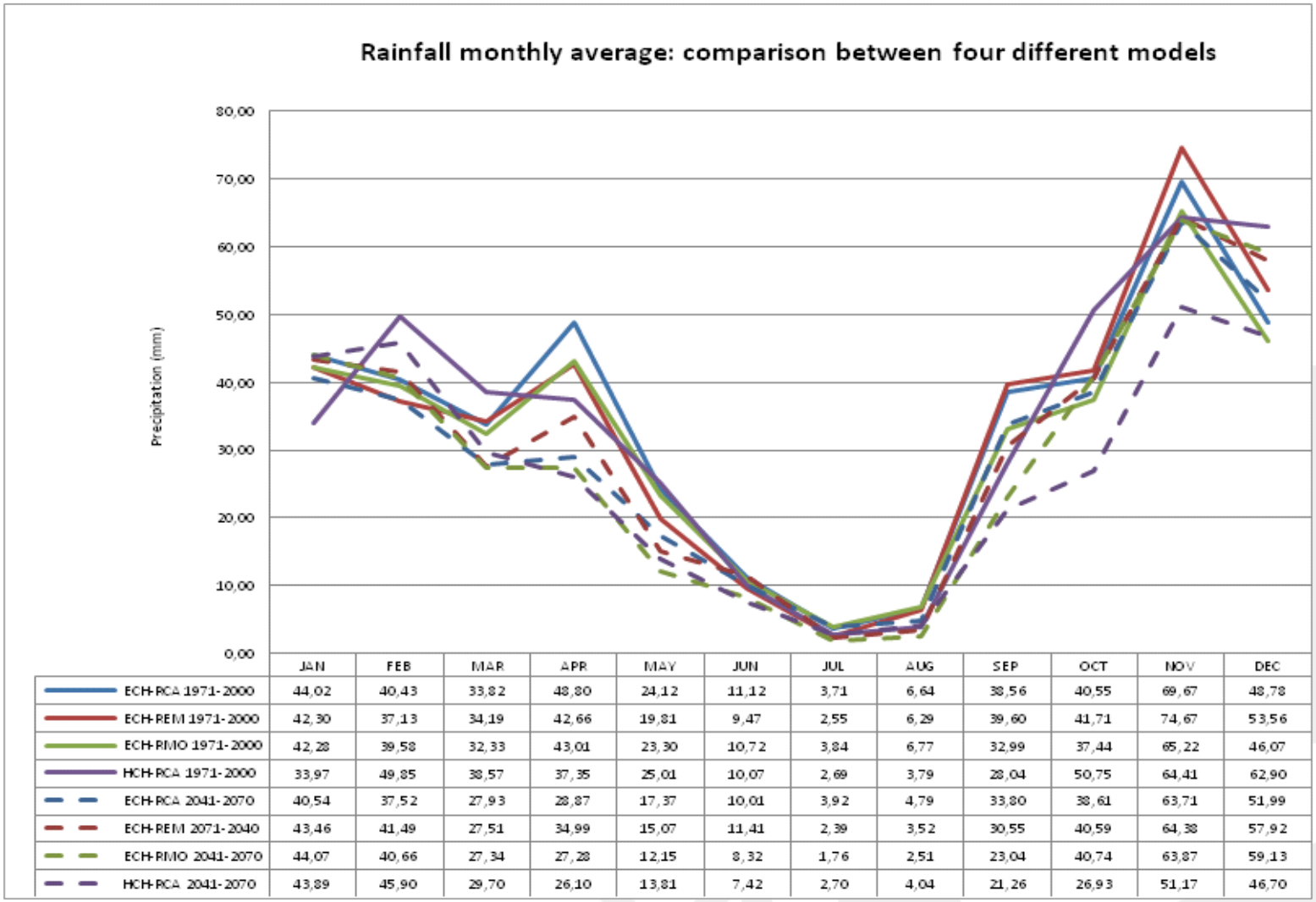
Station	Month	PWW	PDW	N Dry days	N Wet day	PCP AVG	PCP STD	PCP Max
1	Jan	**0.122**	**0.133**	23	8	1.61	4.042	**56.5**
1	Feb	**0.116**	**0.117**	21	7	1.54	4.016	35.3
1	Mar	**0.139**	**0.149**	22	9	1.965	4.431	**36.5**
1	Apr	**0.132**	**0.132**	22	8	1.79	4.22	36.0
1	May	**0.075**	**0.114**	25	6	1.282	3.669	37.6
1	Jun	0.014	0.054	28	2	0.447	2.259	**31.6**
1	Jul	0.014	0.046	29	2	0.326	1.873	**41.1**
1	Aug	0.008	0.051	29	2	0.277	1.365	16.5
1	Sep	0.035	0.078	27	3	0.855	3.758	59.3
1	Oct	**0.076**	**0.106**	25	6	1.657	5.644	**75.7**
1	Nov	0.096	0.123	23	7	1.587	4.615	48.8
1	Dec	0.098	0.116	24	7	1.313	3.679	50.7

SWAT output


Monthly Water Balance - from 2000-1 to 2007-1
REAL Climate data SAR-PCP
160
140
120
100
80
60
40
20
0
2000-1
2000-8
2001-3
2001-10
2002-5
2002-12
2003-7
2004-2
2004-9
2005-4
2005-11
2006-6
2007-1
Time
PAR: ET Prec WYLD SW

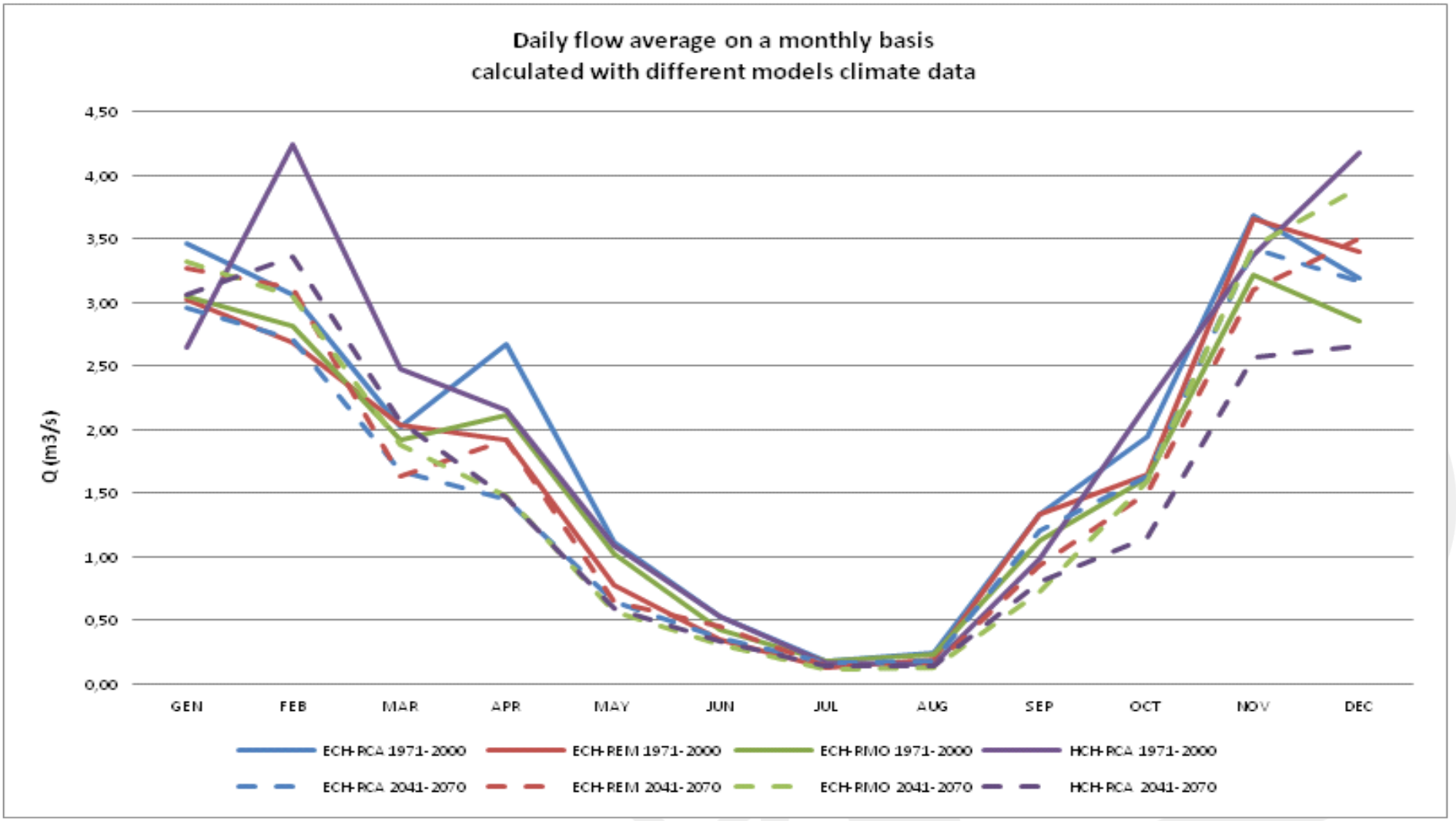

Monthly Water Balance - from 2000-1 to 2007-1
REM - Climate data-PCP
180
160
140
120
100
80
60
40
20
0
2000-1
2000-8
2001-3
2001-10
2002-5
2002-12
2003-7
2004-2
2004-9
2005-4
2005-11
2006-6
2007-1
Time
PAR: ET Prec WYLD SW

SWAT output



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ECH-RCA 1971-2000	44,02	40,43	33,82	48,80	24,12	11,12	3,71	6,64	38,56	40,55	69,67	48,78
ECH-REM 1971-2000	42,30	37,13	34,19	42,66	19,81	9,47	2,55	6,29	39,60	41,71	74,67	53,56
ECH-RMO 1971-2000	42,28	39,58	32,33	43,01	23,30	10,72	3,84	6,77	32,99	37,44	65,22	46,07
HCH-RCA 1971-2000	33,97	49,85	38,57	37,35	25,01	10,07	2,69	3,79	28,04	50,75	64,41	62,90
ECH-RCA 2041-2070	40,54	37,52	27,93	28,87	17,37	10,01	3,92	4,79	33,80	38,61	63,71	51,99
ECH-REM 2071-2040	43,46	41,49	27,51	34,99	15,07	11,41	2,39	3,52	30,55	40,59	64,38	57,92
ECH-RMO 2041-2070	44,07	40,66	27,34	27,28	12,15	8,32	1,76	2,51	23,04	40,74	63,87	59,13
HCH-RCA 2041-2070	43,89	45,90	29,70	26,10	13,81	7,42	2,70	4,04	21,26	26,93	51,17	46,70

SWAT output


Daily flow average on a monthly basis
calculated with different models climate data
Q (m3/s)
4,50
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
GEN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
ECH-RCA 1971-2000
ECH-REM 1971-2000
ECH-RMO 1971-2000
HCH-RCA 1971-2000
ECH-RCA 2041-2070
ECH-REM 2041-2070
ECH-RMO 2041-2070
HCH-RCA 2041-2070

Further conclusions

Comparing the Ensemble output for the test area with the measured data, all models have shown to reppresent precipitation AVG and STD quite well.

With regards to the other variables analysed that help describing the precipitation patterns(PWW, PWD, Maximum PCP, etc.), the enseble models have highlithed some differences with the measured data. This has an impact also on the simumlated water balance by SWAT.

All Climate models have shown that future precipitation patterns are changing, and this will need to be considered in model prediction and water management policies.