FUTURE RIVER PROJECTIONS FOR A STEEP, RAPID RESPONDING, CATCHMENT ON THE WEST COAST OF THE UK

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SWAT 2015 CONFERENCE

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SWAT 2015
PULA / SARDINIA / ITALY

Contents

Introduction –General-

Hydrological and thermal regimes of rivers are expected to change, directly affecting freshwater ecosystems, water quality and human water use, volumes of primary production, and carbon cycling in epicontinental seas with low salinity.

Estuaries have high biochemical variability and extreme physical conditions.

Estuaries are subject to anthropogenic modifications make these systems extremely sensitive to climate change and difficult to study.

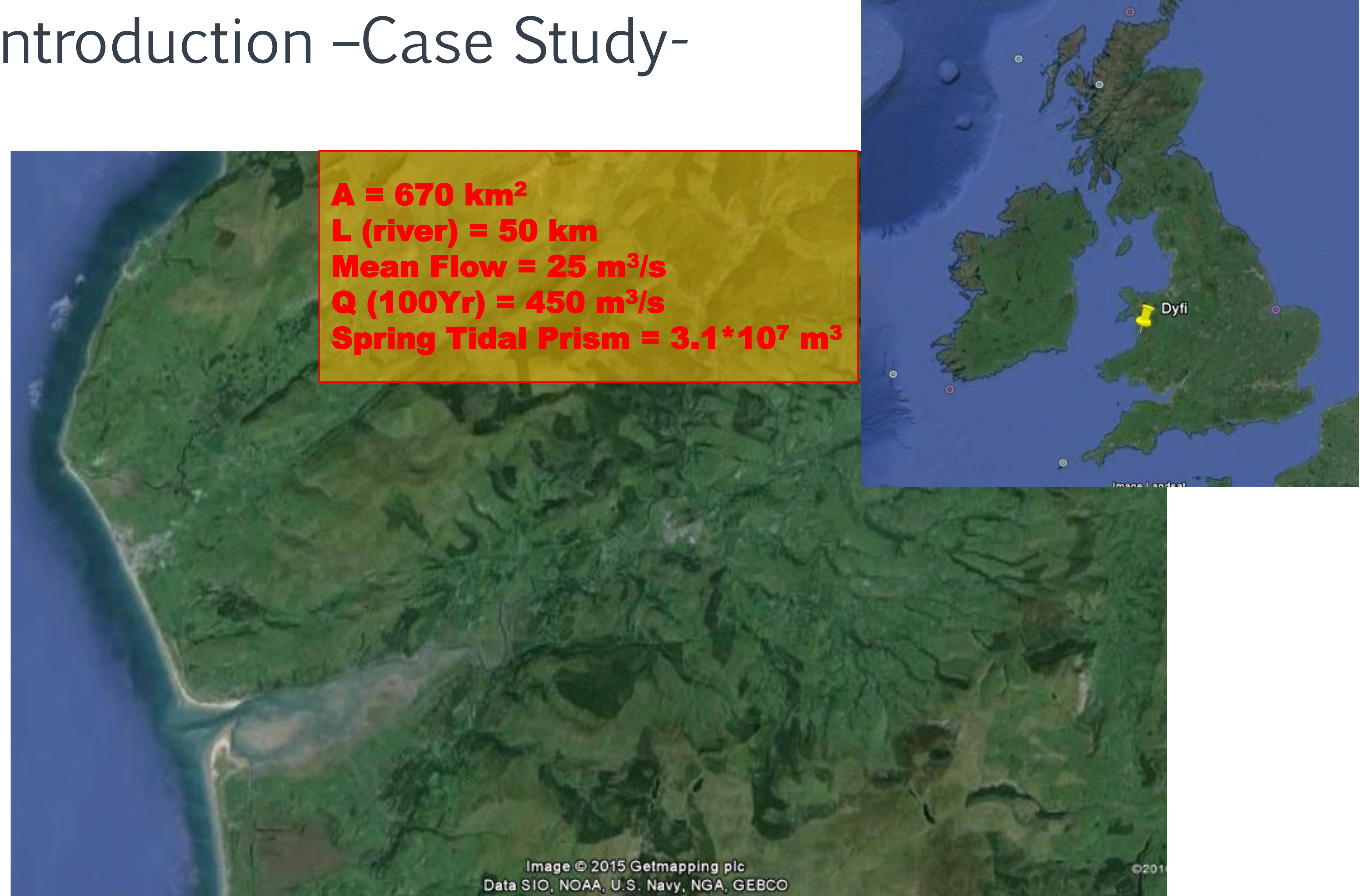
Introduction –UK-

- Changes in the flow regimes.
- Higher rates of pollutant concentrations in water.
- Lower oxygen levels in water.
- Changes in the migratory cycles of fish and on their life cycles.
- Sediment transport and morphodynamics, flooding, changes to beach profiles, and changes to salt marsh ecosystems.

Estuarine systems are extremely important to the UK:

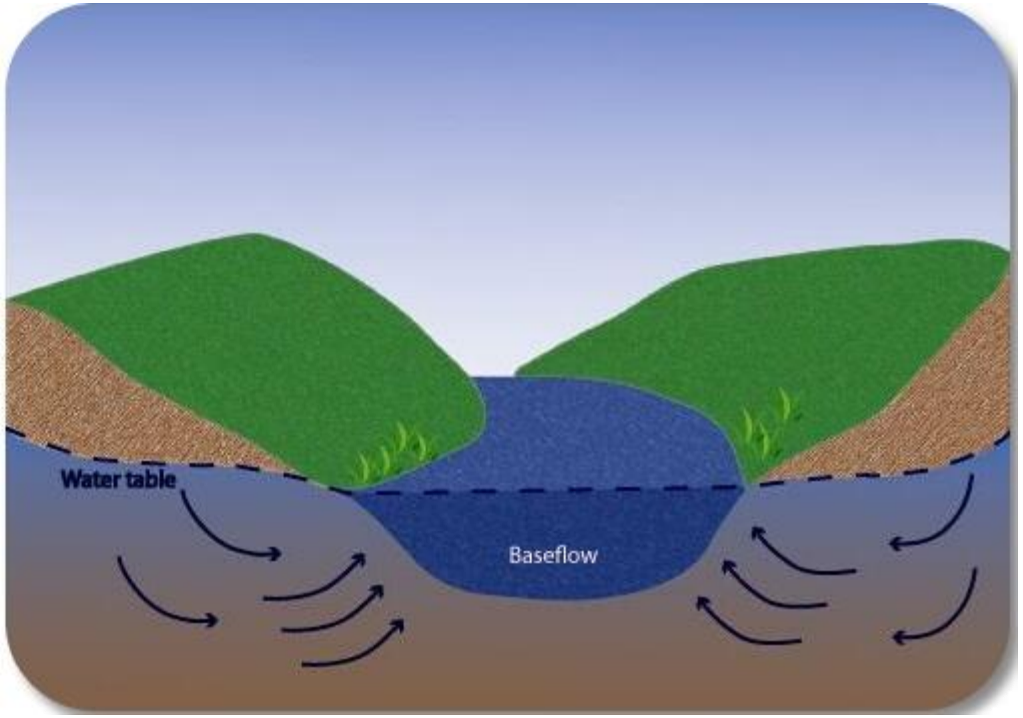
- Maintaining natural habitats.
- Flood prevention.
- Tourism and economic development.

Introduction –Case Study-



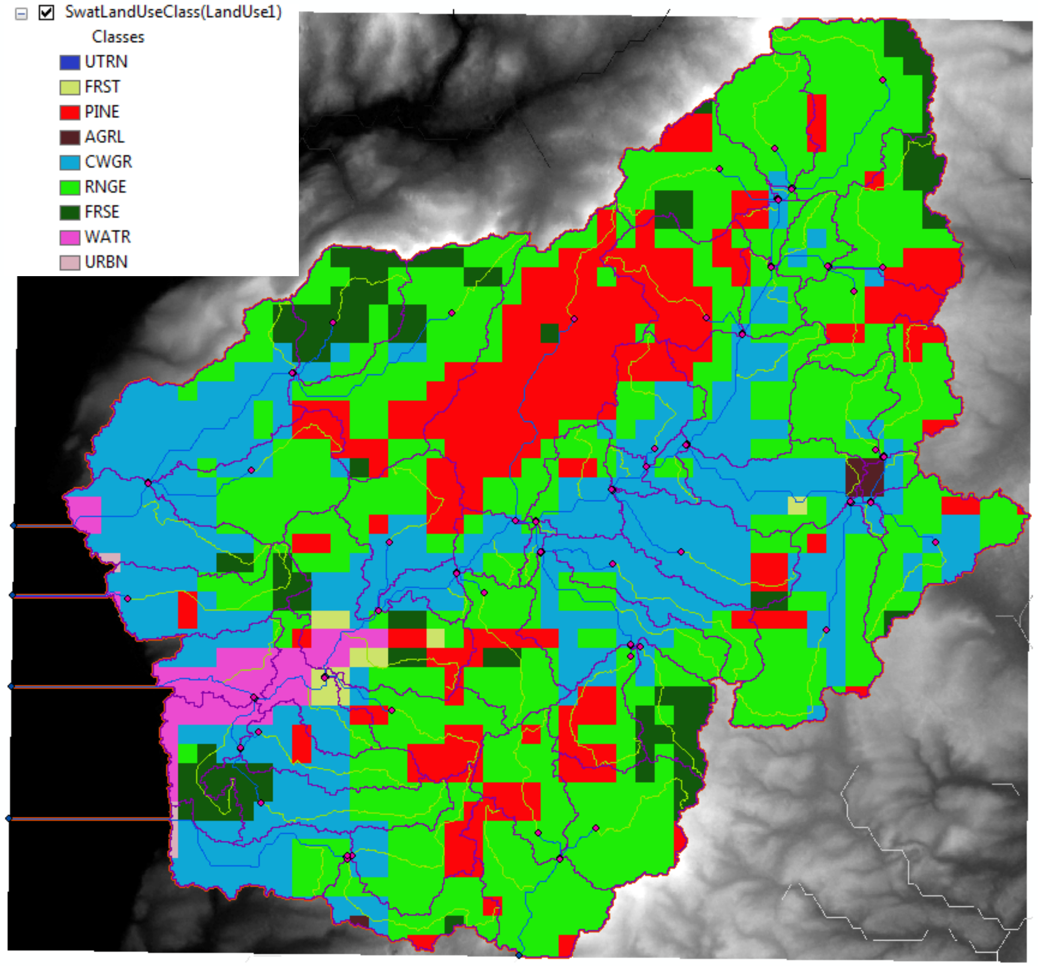
A = 670 km^2
L (river) = 50 km
Mean Flow = 25 m^3/s
Q (100Yr) = 450 m^3/s
Spring Tidal Prism = 3.1*10^7 m^3

Catchment model –SWAT-



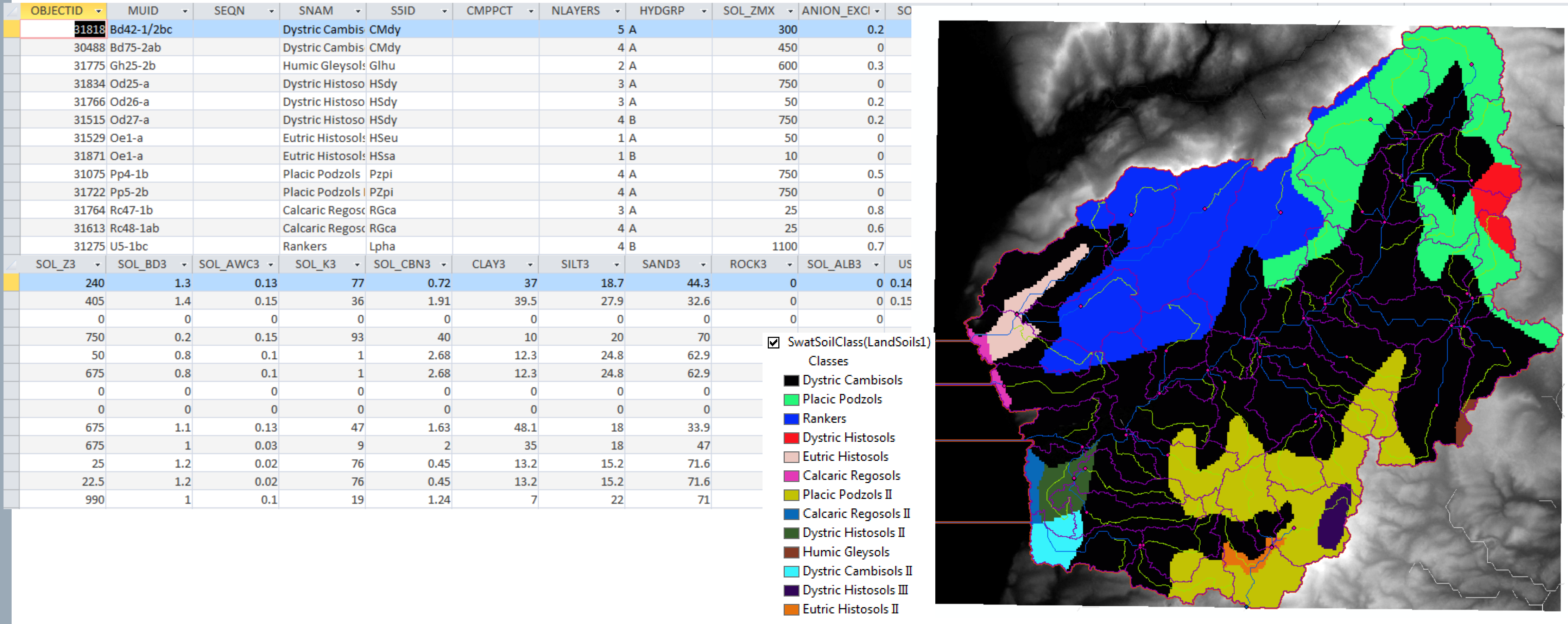
Catchment model –set up-

- Land Use: Land Cover Map 2007 from the Centre for Ecology and Hydrology of Wales (CEH - LCM2007).



Catchment model –set up-

- Soil Type: extracted from the FAO Database v 3.6.



OBJECTID	MUID	SEQN	SNAM	S5ID	CMPPCT	NLAYERS	HYDGRP	SOL_ZMX	ANION_EXCI	SO
31818	Bd42-1/2bc		Dystric Cambis	CMdy		5	A	300	0.2	
30488	Bd75-2ab		Dystric Cambis	CMdy		4	A	450	0	
31775	Gh25-2b		Humic Gleysols	Glhu		2	A	600	0.3	
31834	Od25-a		Dystric Histoso	HSdy		3	A	750	0	
31766	Od26-a		Dystric Histoso	HSdy		3	A	50	0.2	
31515	Od27-a		Dystric Histoso	HSdy		4	B	750	0.2	
31529	Oe1-a		Eutric Histosols	HSeu		1	A	50	0	
31871	Oe1-a		Eutric Histosols	HSsa		1	B	10	0	
31075	Pp4-1b		Placic Podzols	Pzpi		4	A	750	0.5	
31722	Pp5-2b		Placic Podzols	PZpi		4	A	750	0	
31764	Rc47-1b		Calcaric Regoso	RGca		3	A	25	0.8	
31613	Rc48-1ab		Calcaric Regoso	RGca		4	A	25	0.6	
31275	U5-1bc		Rankers	Lpha		4	B	1100	0.7	

SOL_Z3	SOL_BD3	SOL_AWC3	SOL_K3	SOL_CBN3	CLAY3	SILT3	SAND3	ROCK3	SOL_ALB3	US
240	1.3	0.13	77	0.72	37	18.7	44.3	0	0	0.14
405	1.4	0.15	36	1.91	39.5	27.9	32.6	0	0	0.15
0	0	0	0	0	0	0	0	0	0	
750	0.2	0.15	93	40	10	20	70			
50	0.8	0.1	1	2.68	12.3	24.8	62.9			
675	0.8	0.1	1	2.68	12.3	24.8	62.9			
0	0	0	0	0	0	0	0			
0	0	0	0	0	0	0	0			
675	1.1	0.13	47	1.63	48.1	18	33.9			
675	1	0.03	9	2	35	18	47			
25	1.2	0.02	76	0.45	13.2	15.2	71.6			
22.5	1.2	0.02	76	0.45	13.2	15.2	71.6			
990	1	0.1	19	1.24	7	22	71			

Catchment model –set up-

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

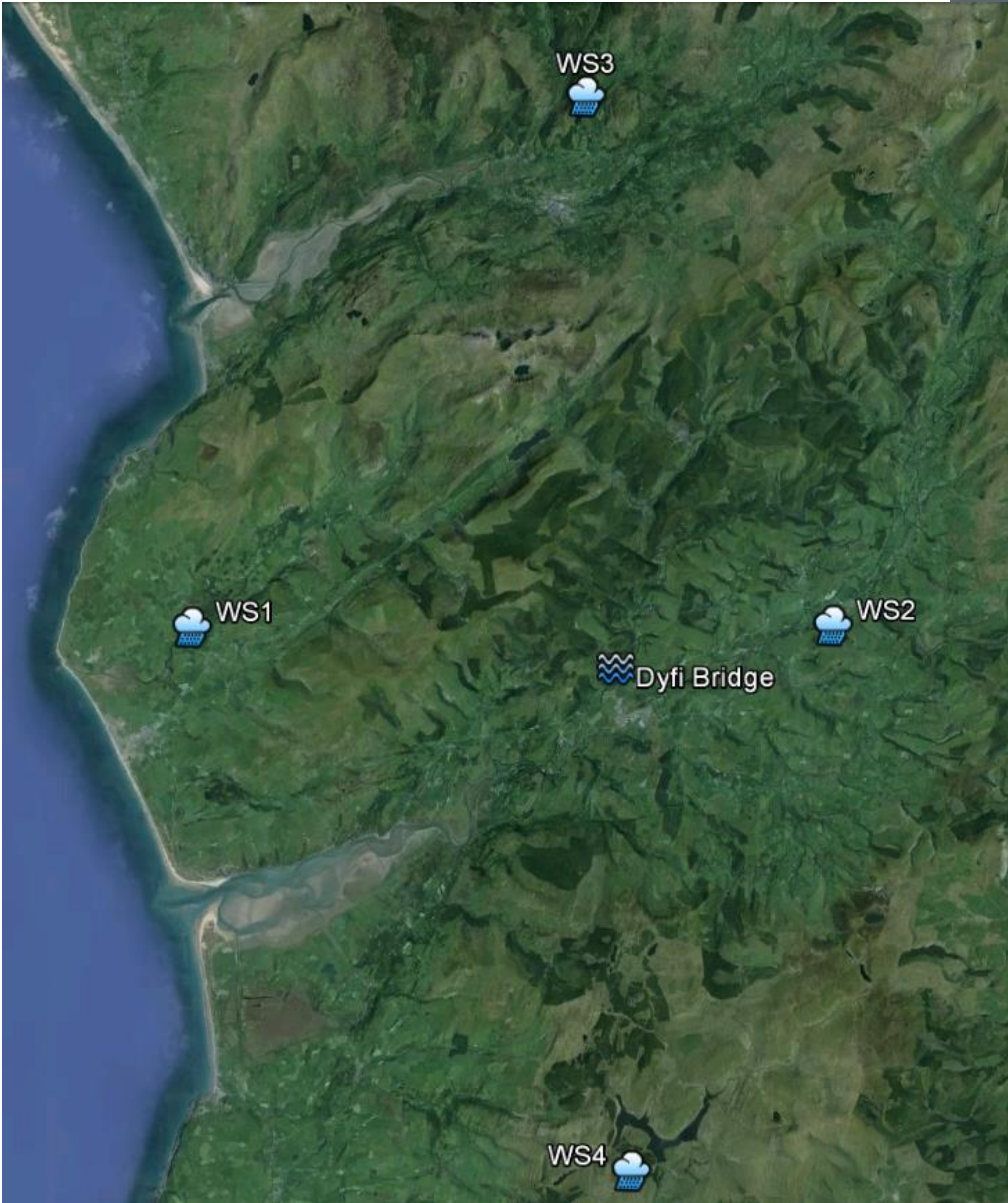
SWt -> humidity of the soil (mm H2O)
SW0 -> the base humidity of the soil (mm H2O)
t -> time (days)
Rday -> rainfall volume (mm H2O)
Qsurf -> the value of surface runoff (mm H2O)
Wseep -> seepage of water from soil into deeper layers (mm H2O)
Ea -> the value of evapotranspiration (mm H2O)
Qgw -> the value of underground runoff (mm H2O).

$$Q_j^{day} = \frac{1}{86.4}\sum_{i=1}^{k}(Q_{surf}^{i} + Q_{gw}^{i})\cdot A^{i}{}_{HRU} \ (m^3/s)$$

$$Q_j^{hour} = f(Q_{j-1}^{day}, Q_j^{day}, Q_{j+1}^{day}) \ (m^3/s)$$

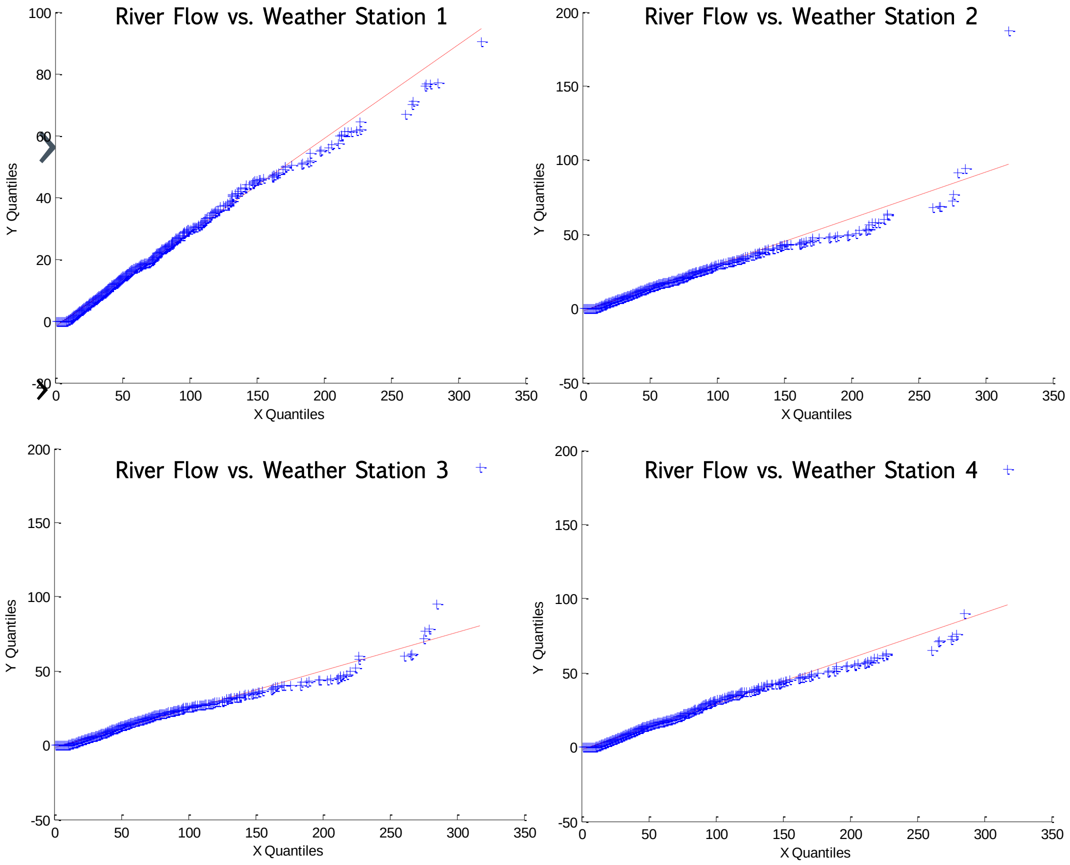
$$Q_k^{hour} = k\cdot\left(\frac{Q_j^{day} - Q_{j-1}^{day}}{24}\right) + \frac{Q_j^{day} + Q_{j-1}^{day}}{2} \quad k=0.1,2,3,....11$$

$$Q_k^{hour} = (k-12)\cdot\left(\frac{Q_{j+1}^{day} - Q_j^{day}}{24}\right) + Q_j^{day} \quad k=12,13,14,....23$$



Catchment model –set up-

- Weather data (Rainfall and Temperature) from 1997 to 2005. Good correlation between river flow and rain.



q-q plots comparing the River Flow and the data of rain from the weather station.

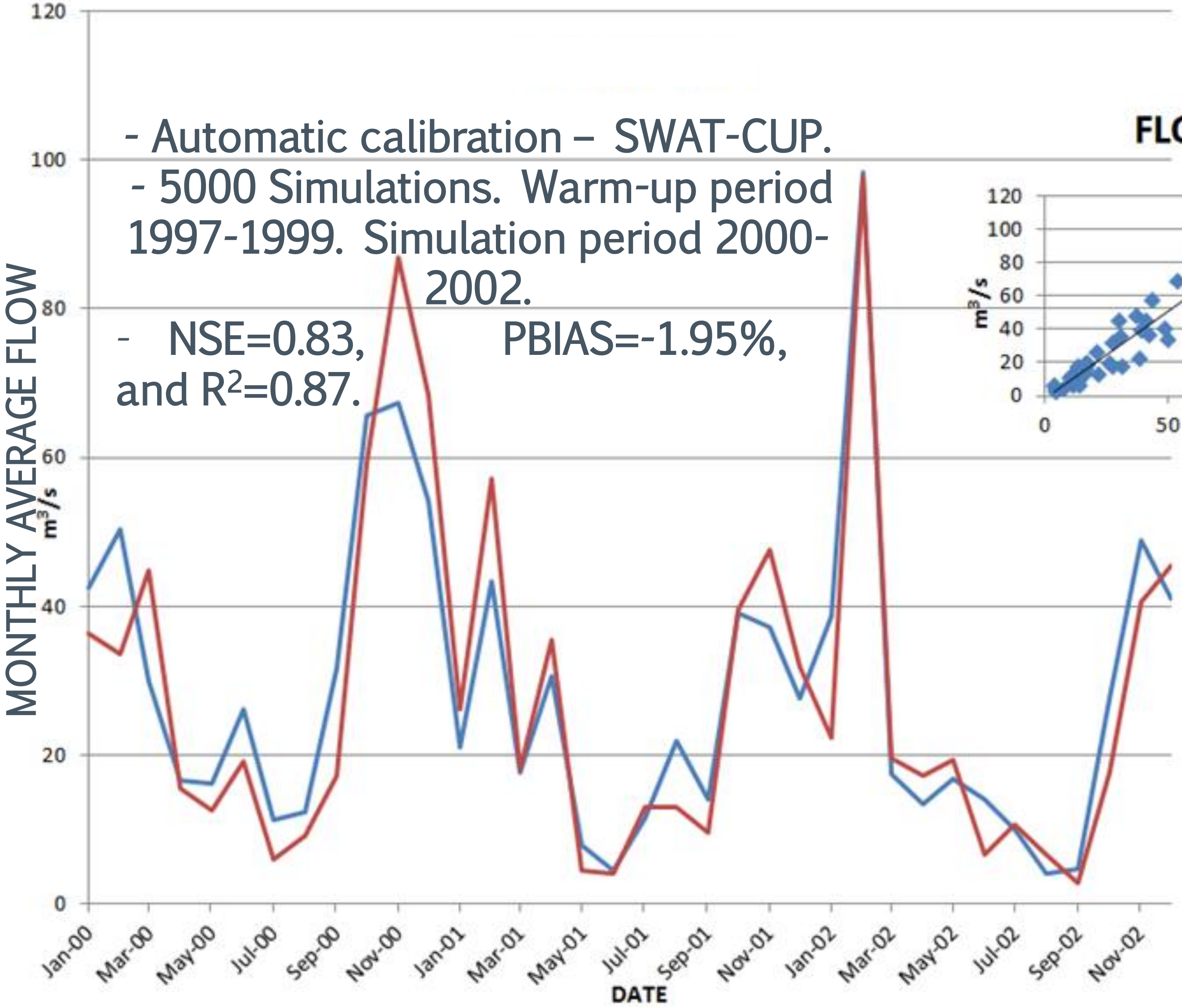
It is a graphical method to diagnose differences between the probability distribution of a population from which it was removed a random sample and a distribution used for comparison.

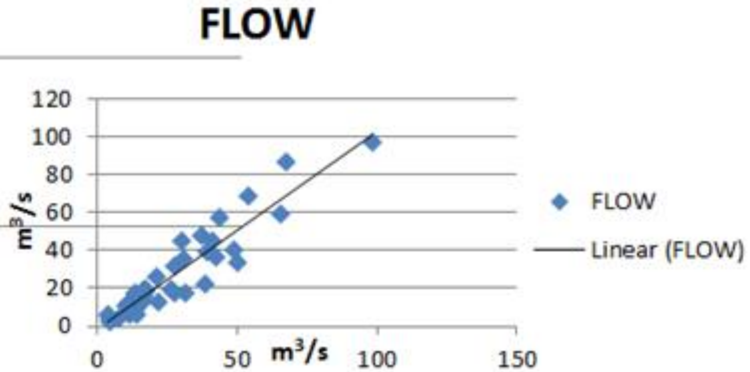
Catchment model –calibration & validation-

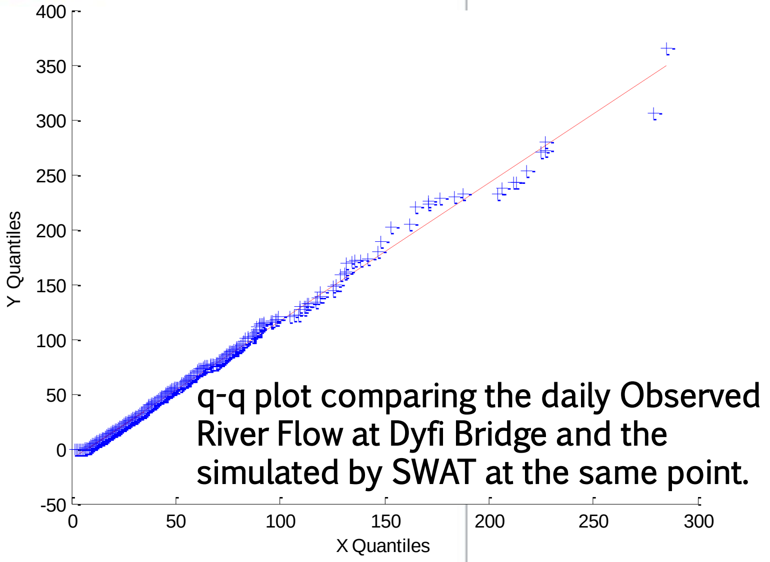
$$NSE = 1 - \frac{\sum_{t=1}^{T}(Q_{m,t} - Q_{s,t})^2}{\sum_{t=1}^{T}(Q_{m,t} - \overline{Q}_m)^2} \qquad PBIAS = \left[\frac{\sum_{t=1}^{T}(Q_{s,t} - Q_{m,t})}{\sum_{t=1}^{T} Q_{m,t}}\right] \times 100 \qquad R^2 = \left[\frac{\sum_{t=1}^{T}(Q_{m,t} - \overline{Q}_m)(Q_{s,t} - \overline{Q}_s)}{\sum_{t=1}^{T}\left[(Q_{m,t} - \overline{Q}_m)^2\right]^{0.5}\sum_{t=1}^{T}\left[(Q_{s,t} - \overline{Q}_s)^2\right]^{0.5}}\right]^2$$

Automatic calibration

- Automatic calibration – SWAT-CUP.
- 5000 Simulations. Warm-up period 1997-1999. Simulation period 2000-2002.
- NSE=0.83, PBIAS=-1.95%, and R^2=0.87.





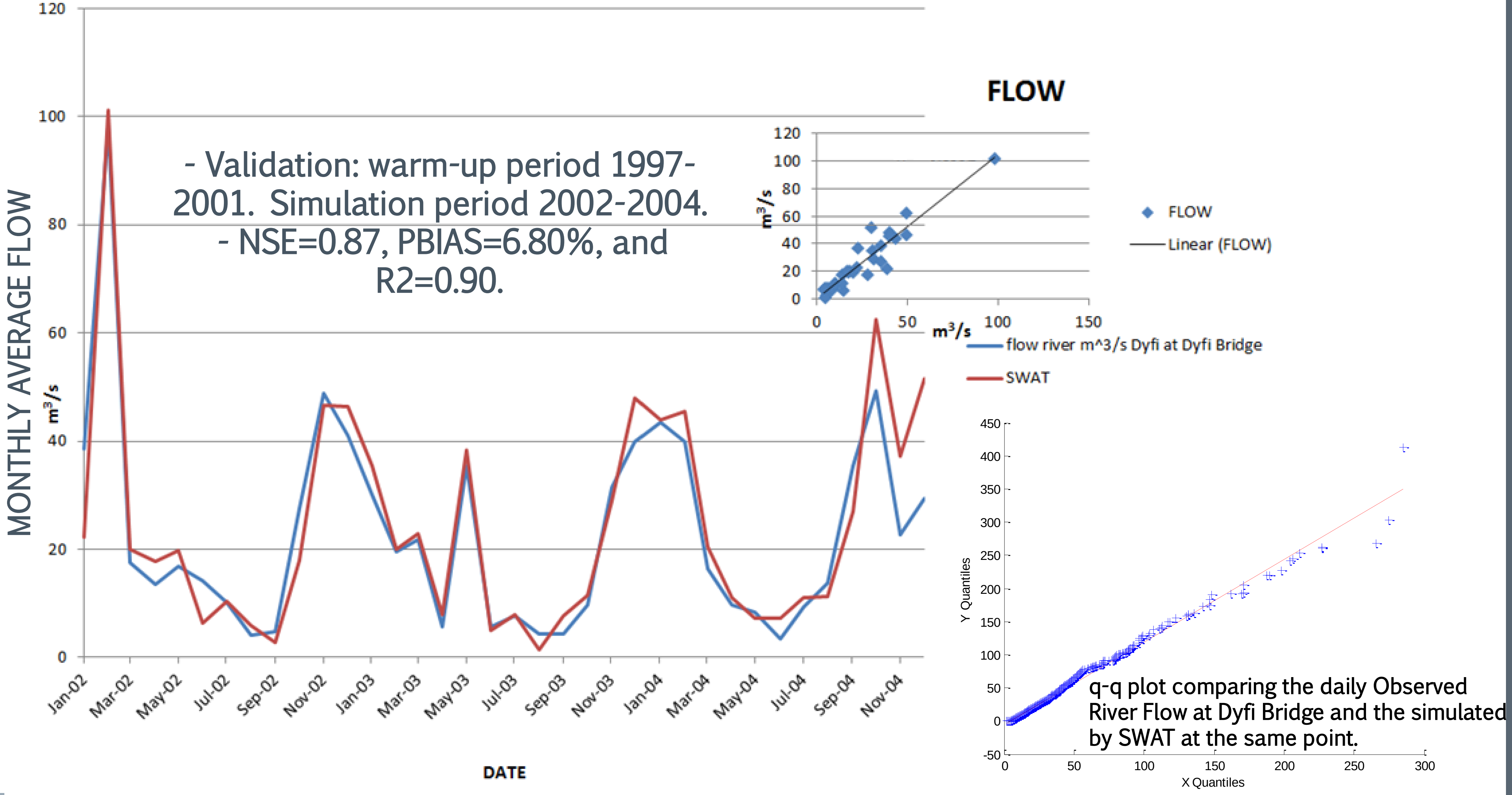


q-q plot comparing the daily Observed River Flow at Dyfi Bridge and the simulated by SWAT at the same point.

Catchment model –calibration & validation-

Validation

$$NSE = 1 - \frac{\sum_{t=1}^{T}\left(Q_{m,t} - Q_{s,t}\right)^2}{\sum_{t=1}^{T}\left(Q_{m,t} - \overline{Q}_m\right)^2} \qquad PBIAS = \left[\frac{\sum_{t=1}^{T}\left(Q_{s,t} - Q_{m,t}\right)}{\sum_{t=1}^{T} Q_{m,t}}\right] \times 100 \qquad R^2 = \left[\frac{\sum_{t=1}^{T}\left(Q_{m,t} - \overline{Q}_m\right)\left(Q_{s,t} - \overline{Q}_s\right)}{\sum_{t=1}^{T}\left[\left(Q_{m,t}-\overline{Q}_m\right)^2\right]^{0.5}\sum_{t=1}^{T}\left[\left(Q_{s,t}-\overline{Q}_s\right)^2\right]^{0.5}}\right]^2$$

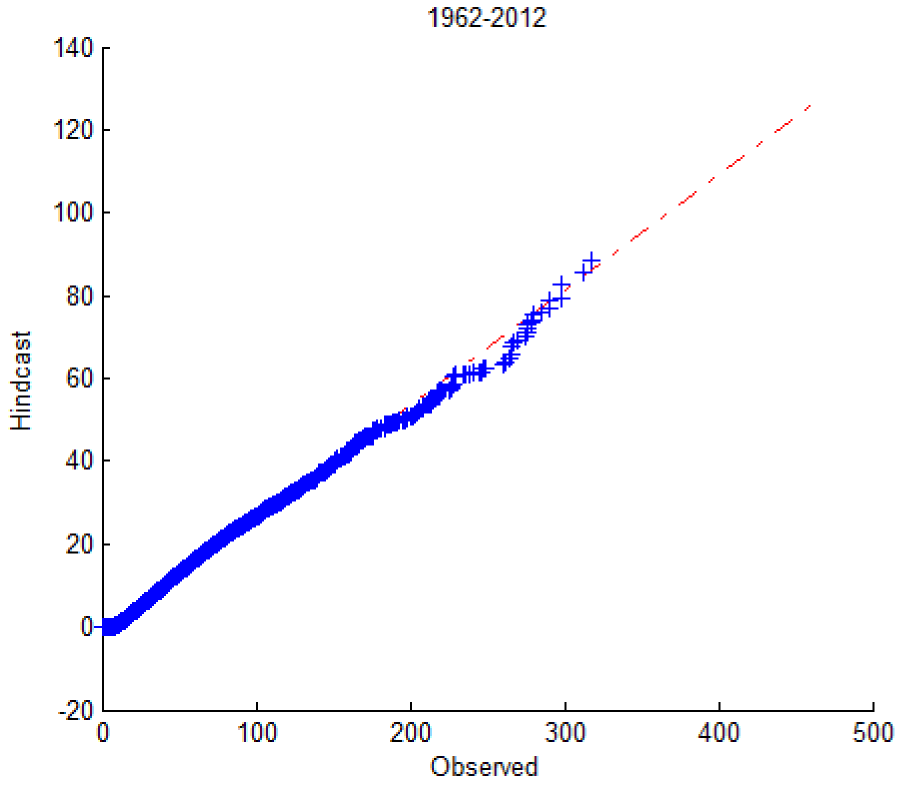


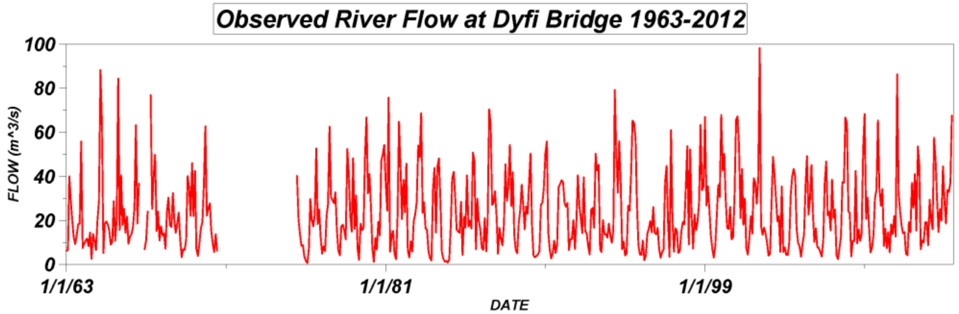
- Validation: warm-up period 1997-2001. Simulation period 2002-2004.
- NSE=0.87, PBIAS=6.80%, and R2=0.90.

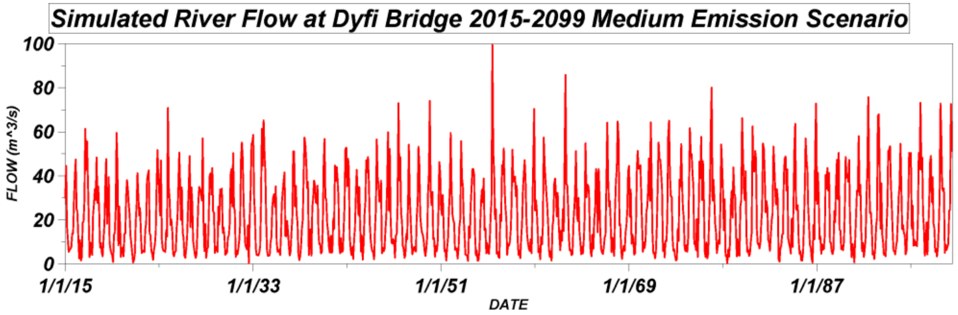
q-q plot comparing the daily Observed River Flow at Dyfi Bridge and the simulated by SWAT at the same point.

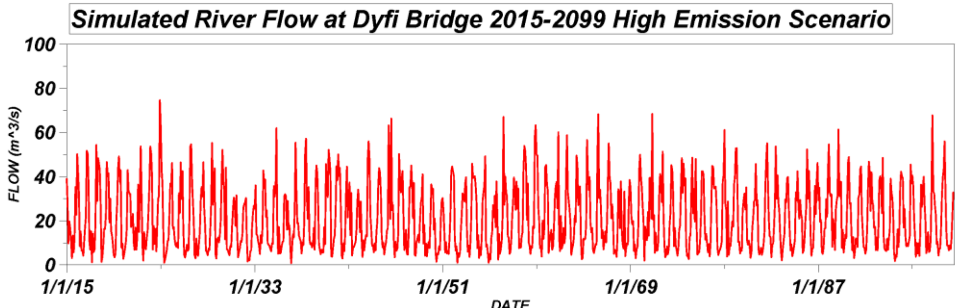
Climate Change Scenarios

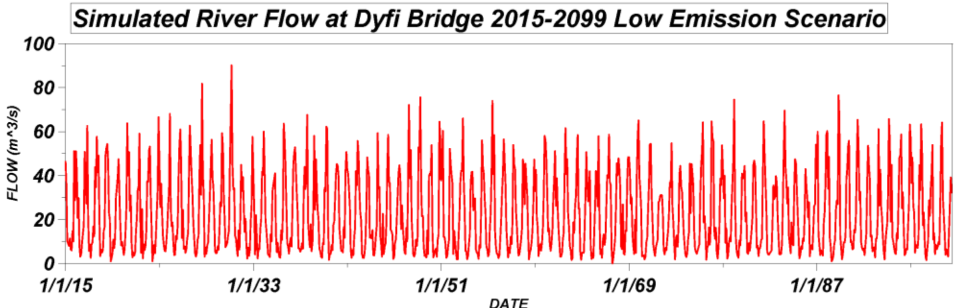
Three different scenarios (High, Medium and Low emission scenarios) proposed by the UKCP are evaluated in this study.


1962-2012

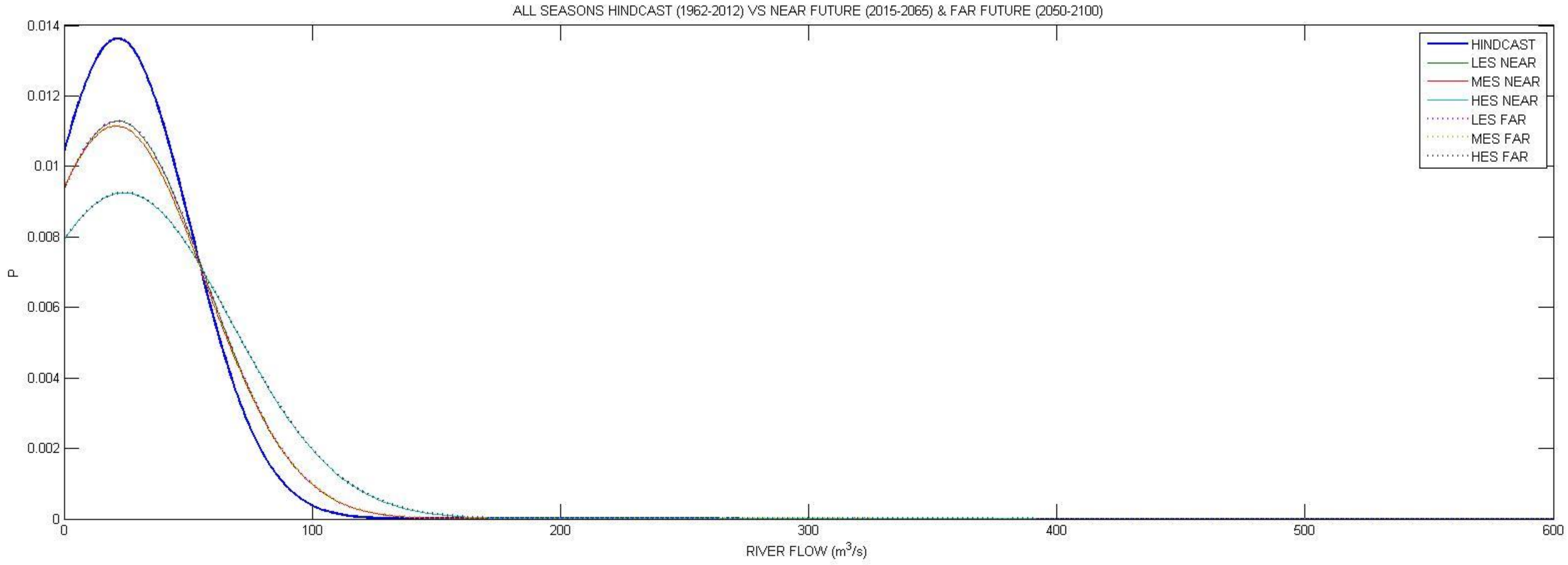

Observed River Flow at Dyfi Bridge 1963-2012


Simulated River Flow at Dyfi Bridge 2015-2099 Medium Emission Scenario


Simulated River Flow at Dyfi Bridge 2015-2099 High Emission Scenario

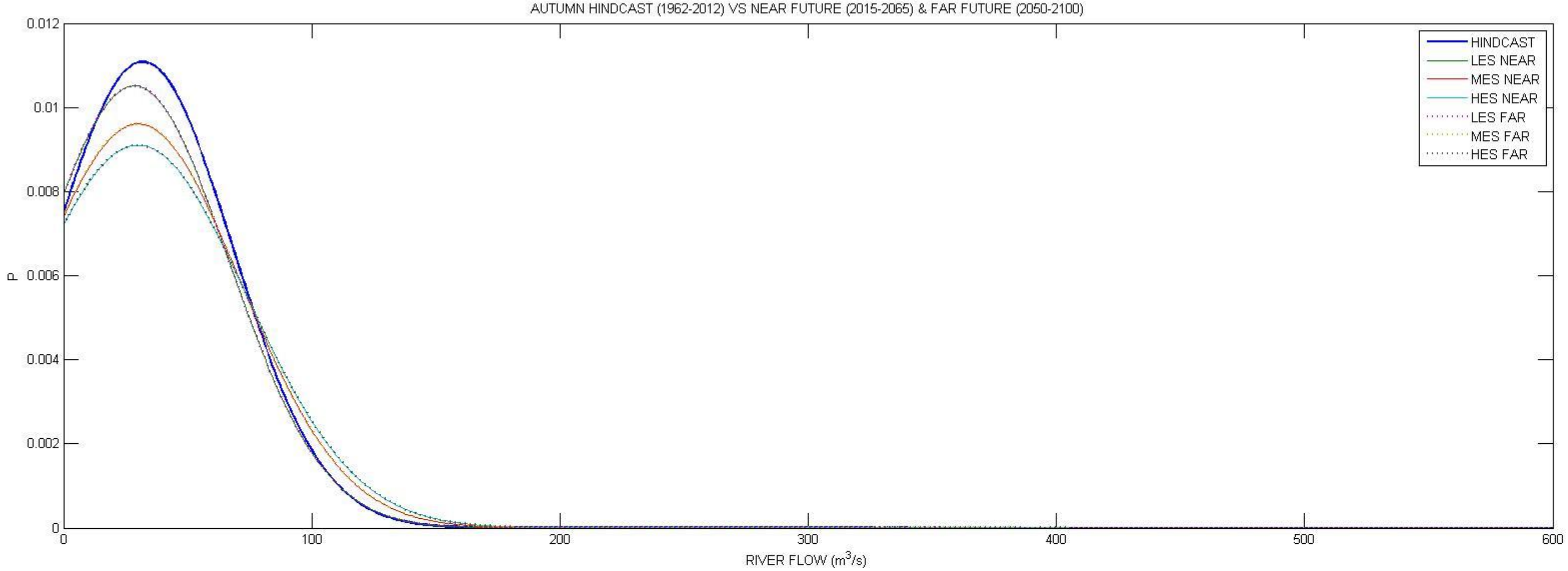

Simulated River Flow at Dyfi Bridge 2015-2099 Low Emission Scenario

Climate Change Scenarios –global study-



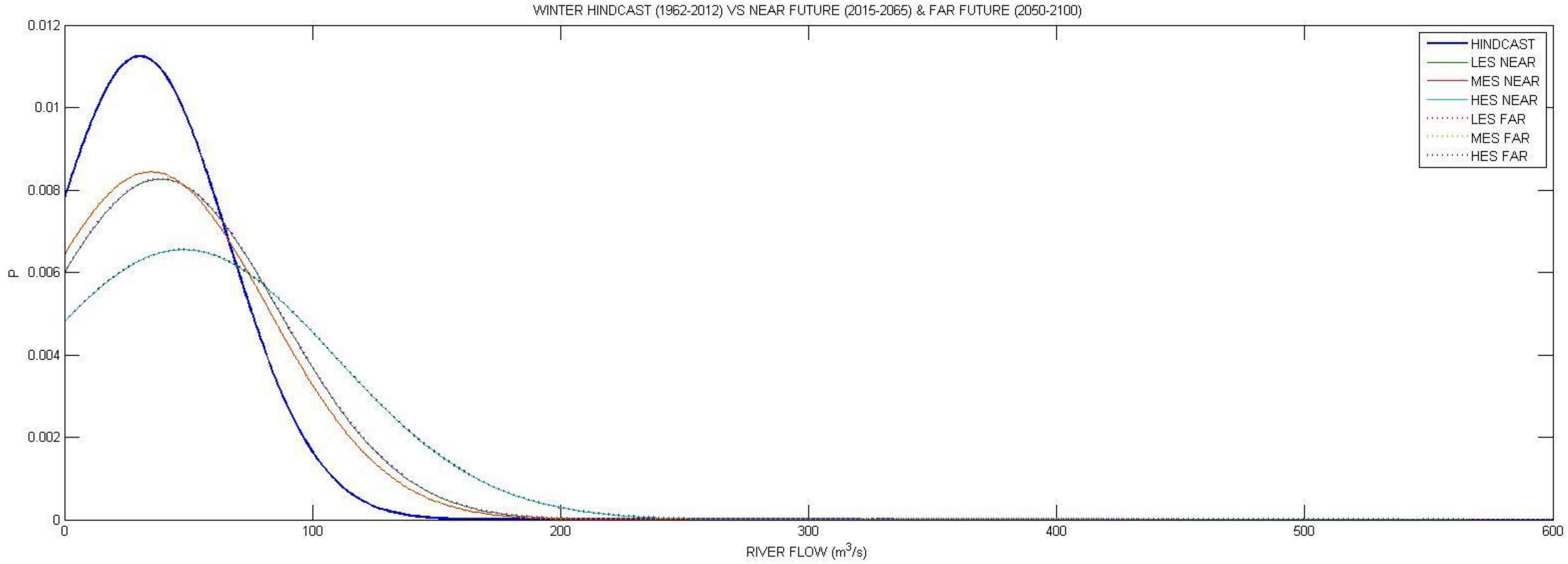
	ALL SEASONS (DAILY RIVER FLOW m^3/s)						
	HINDCAST	NEAR FUTURE (2015-2065)			FAR FUTURE (2050-2100)		
	1962-2012	LOW	MEDIUM	HIGH	LOW	MEDIUM	HIGH
DIFFERENT?	x	YES	YES	YES	YES	YES	YES
Ks test (5% significance level)	x	0.1792	0.1834	0.2074	0.1716	0.1826	0.2039
Pvalue	x	5.26E-257	3.67E-269	0	3.41E-235	5.76E-267	0
Mean	21.62385762	21.7105425	21.01938928	24.14433279	21.04345314	21.82892498	23.94697122
S.D.	29.27279063	35.35305347	35.78935062	43.11061271	33.61490328	36.42816815	41.29133154
Min	0.0002354	0.000002345	0.000006269	0.00001679	0.000003883	0.00004797	0.00001679
1st %ile	0.3326	0.0155	0.0173	0.0125	0.0141	0.0171	0.0139
25th %ile	5.1215	1.497	1.3795	0.9268	1.651	1.4363	0.926
Median	11.63	8.283	7.871	8.227	8.405	8.301	8.414
75th %ile	26.48	26.095	24.41	27.475	25.4275	25.5175	28.4375
99th %ile	148.088	174.298	177.5	209.5	162.146	179.661	201.784
Max	461.9	470.1	598.5	768	479.1	598.5	541.8
Summary	**In general a decreased of the minimum river flow and an increased of the maximum of the river flow is observed in all the scenarios. With these preliminary results, in the next tables seasonal variability will be studied.**						

Climate Change Scenarios –seasonal study-



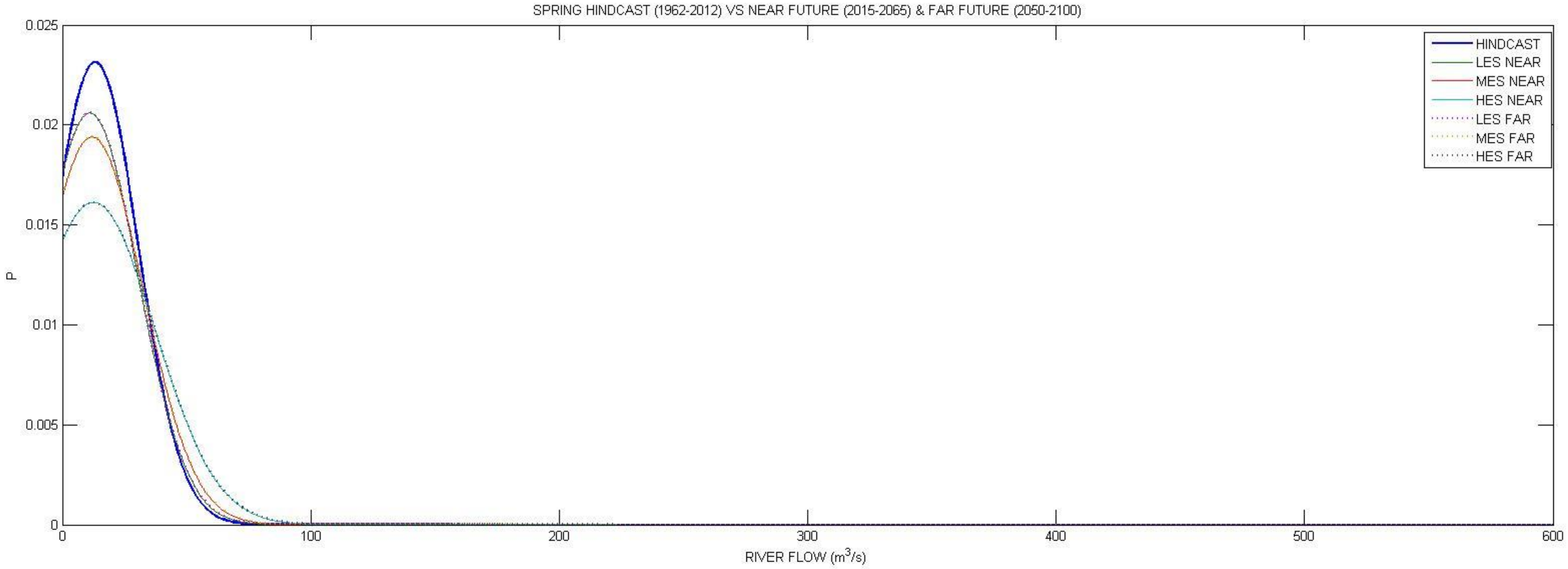
	AUTUMN (DAILY RIVER FLOW m^3/s)						
	HINDCAST	NEAR FUTURE (2015-2065)			FAR FUTURE (2050-2100)		
	1962-2012	LOW	MEDIUM	HIGH	LOW	MEDIUM	HIGH
DIFFERENT?	x	YES	YES	YES	YES	YES	YES
Ks test (5% significance level)	x	0.1964	0.1674	0.2198	0.1896	0.1502	0.2092
Pvalue	x	6.51E-77	5.97E-56	3.59E-96	1.09E-71	3.88E-45	3.50E-87
Mean	31.91178784	28.52757508	30.02119968	29.98056262	27.63917013	31.51569481	29.99288444
S.D.	36.00742714	37.95439494	41.53472056	43.83718764	36.87275634	42.16339343	42.6052457
Min	0.003971	0.00027	0.000303	0.0002075	0.0003942	0.001308	0.0003847
1st %ile	0.467	0.0526	0.0402	0.0259	0.0463	0.0813	0.0235
25th %ile	9.659	4.1515	5.0495	3.3172	4.3422	5.3122	3.749
Median	19.69	14.09	15.38	13.63	13.91	16.04	14.34
75th %ile	40.8025	38.9575	38.4975	38.6325	36.9575	41.75	40.3675
99th %ile	178.727	183.718	195.334	202.354	171.616	200.509	198.527
Max	461.9	364.3	598.5	483.2	443.9	598.5	541.8
Summary	**For the medium and the high emission scenario an increase of the river flow is observed.**						

Climate Change Scenarios –seasonal study-



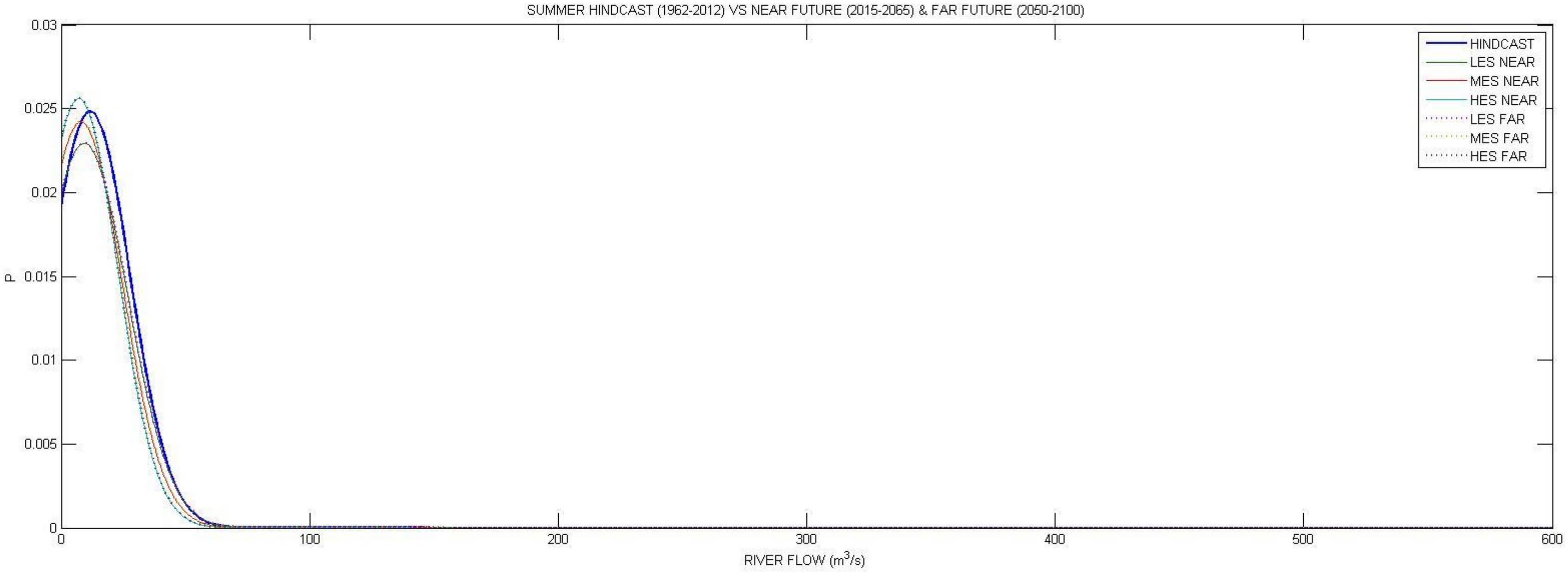
	WINTER (DAILY RIVER FLOW m^3/s)						
	HINDCAST	NEAR FUTURE (2015-2065)			FAR FUTURE (2050-2100)		
	(1962-2012)	LOW	MEDIUM	HIGH	LOW	MEDIUM	HIGH
DIFFERENT?	x	YES	YES	YES	YES	YES	YES
Ks test (5% significance level)	x	0.0828	0.0997	0.1403	0.0637	0.0757	0.1354
Pvalue	x	3.43E-14	2.10E-20	5.32E-40	1.41E-08	6.18E-12	2.88E-37
Mean	30.443571	38.7400115	34.9205729	47.9497315	35.5895395	35.4294952	46.4889759
S.D.	35.4885782	48.2639829	47.2835217	60.9150448	43.797712	47.1308726	56.5766359
Min	0.000529	1.765	1.108	1.697	1.679	2.232	2.703
1st %ile	0.4412	3.7523	3.0432	3.7377	3.5696	3.6053	4.0999
25th %ile	9.0307	8.6995	7.4748	10.72	8.458	8.107	10.86
Median	19.02	18.95	15.12	24.74	17.88	16.17	25.48
75th %ile	38.2375	49.6525	43.4625	60.535	45.72	44.62	58.97
99th %ile	184.305	231.241	219.264	293.164	207.396	215.4	279.344
Max	317.7	470.1	570.8	768	479.1	586.7	529.9
Summary	**Future increase in winter flow rates with all scenarios, and increasing with emission scenarios.**						

Climate Change Scenarios –seasonal study-



	SPRING (DAILY RIVER FLOW m^3/s)						
	HINDCAST	NEAR FUTURE (2015-2065)			FAR FUTURE (2050-2100)		
	1962-2012	LOW	MEDIUM	HIGH	LOW	MEDIUM	HIGH
DIFFERENT?	x	YES	YES	YES	YES	YES	YES
Ks test (5% significance level)	x	0.2692	0.2562	0.2425	0.2692	0.2562	0.2425
Pvalue	x	8.03E-149	7.82E-135	6.68E-121	8.03E-149	7.82E-135	6.68E-121
Mean	13.2030448	11.0776501	11.9754332	12.5176305	12.5450015	12.9004467	12.6788725
S.D.	17.2418015	19.3594806	20.5664606	24.7439688	22.7425846	23.0946026	25.4385528
Min	0.0007378	2.345E-06	6.269E-06	0.0001306	0.00002164	0.00004797	0.0002656
1st %ile	0.1298	0.0065	0.0104	0.0065	0.0065	0.0104	0.0065
25th %ile	3.9335	0.732	0.7894	0.8961	0.732	0.7894	0.8961
Median	8.041	3.817	4.299	4.417	4.377	4.536	4.18
75th %ile	15.79	12.62	13.585	12.915	12.62	13.585	12.915
99th %ile	85.1128	92.992	100.922	121.76	92.992	100.922	121.76
Max	290.5	250.7	229.8	437.2	305.4	272.3	507.1
Summary	**For the high emission scenario an increase of the river flow is observed.**						

Climate Change Scenarios –seasonal study-



	SUMMER (DAILY RIVER FLOW m^3/s)						
	HINDCAST	NEAR FUTURE (2015-2065)			FAR FUTURE (2050-2100)		
	1962-2012	LOW	MEDIUM	HIGH	LOW	MEDIUM	HIGH
DIFFERENT?	x	YES	YES	YES	YES	YES	YES
Ks test (5% significance level)	x	0.399	0.4407	0.5019	0.3942	0.4497	0.501
Pvalue	x	0	0	0	0	0	0
Mean	11.6480275	9.30376875	7.99139944	7.13137733	9.1449754	8.33038032	7.60246407
S.D.	16.0643573	17.388515	16.4673514	15.5687902	17.2968944	17.0887475	16.9249762
Min	0.0002354	0.00005777	0.0001134	0.00001679	3.883E-06	0.0001388	0.00001679
1st %ile	0.1461	0.0059	0.0063	0.0064	0.0048	0.0055	0.0053
25th %ile	2.723	0.467	0.467	0.467	0.467	0.467	0.467
Median	6.26	1.013	0.467	0.467	1.136	0.467	0.467
75th %ile	14.2	11.66	8.8105	6.955	11.15	8.8545	7.1805
99th %ile	79.0244	73.8246	71.1744	70.6358	73.6566	74.1626	75.4966
Max	246.1	307.7	373.9	245.6	331.5	373.9	345.9
Summary	**Future decrease in summer flow rates with all scenarios, and decreasing with emission scenarios.**						

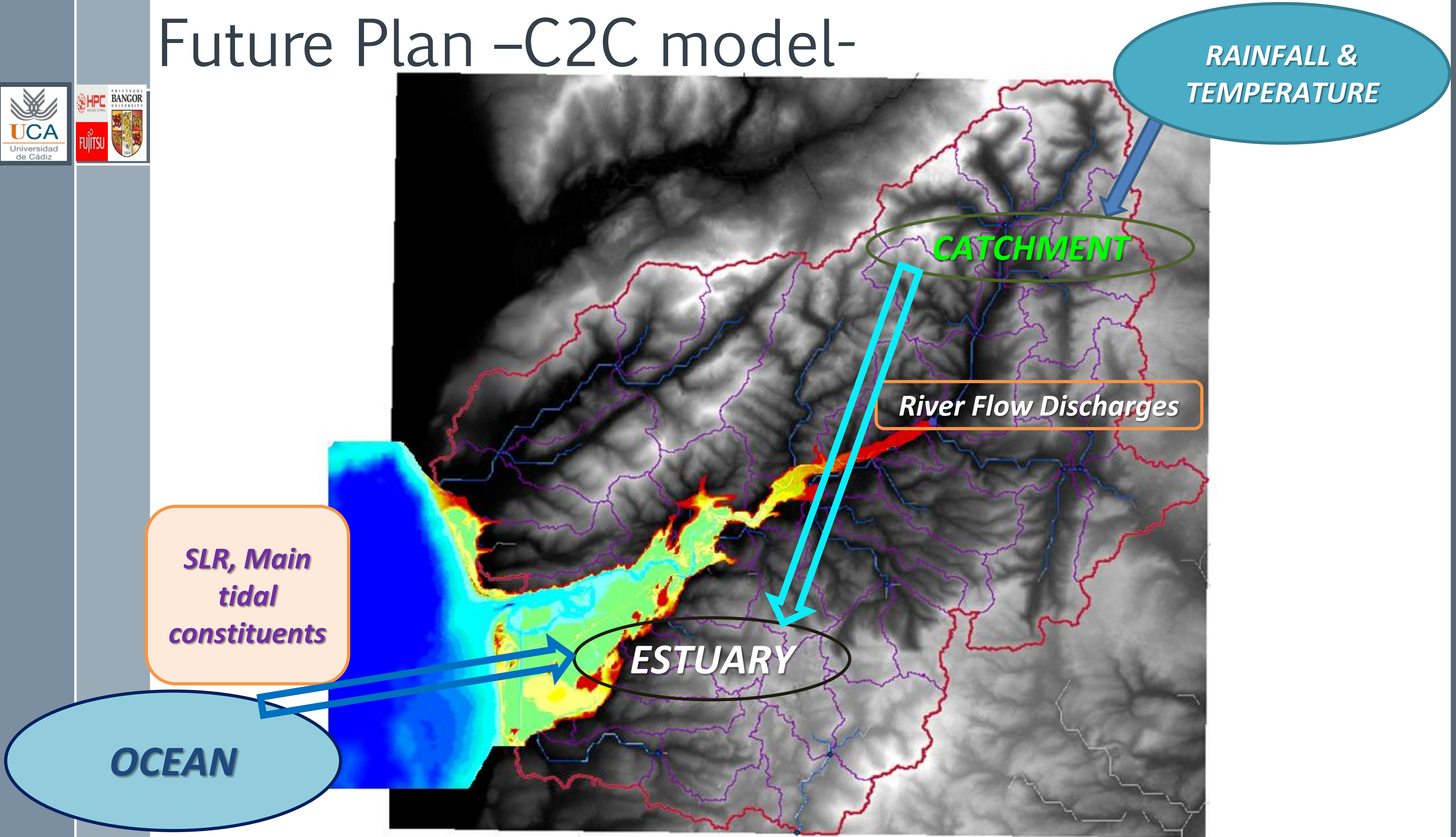
Conclusions

Summers will become drier on average with increasing emission scenarios.

Winters will become wetter on average with increasing emission scenarios.

The results are in agreement with previous climate studies of UK estuaries.

Future Plan –C2C model-



RAINFALL & TEMPERATURE

CATCHMENT

River Flow Discharges

ESTUARY

SLR, Main tidal constituents

OCEAN

THANK YOU VERY MUCH!

SUGGESTIONS AND QUESTIONS ARE APPRECIATED!

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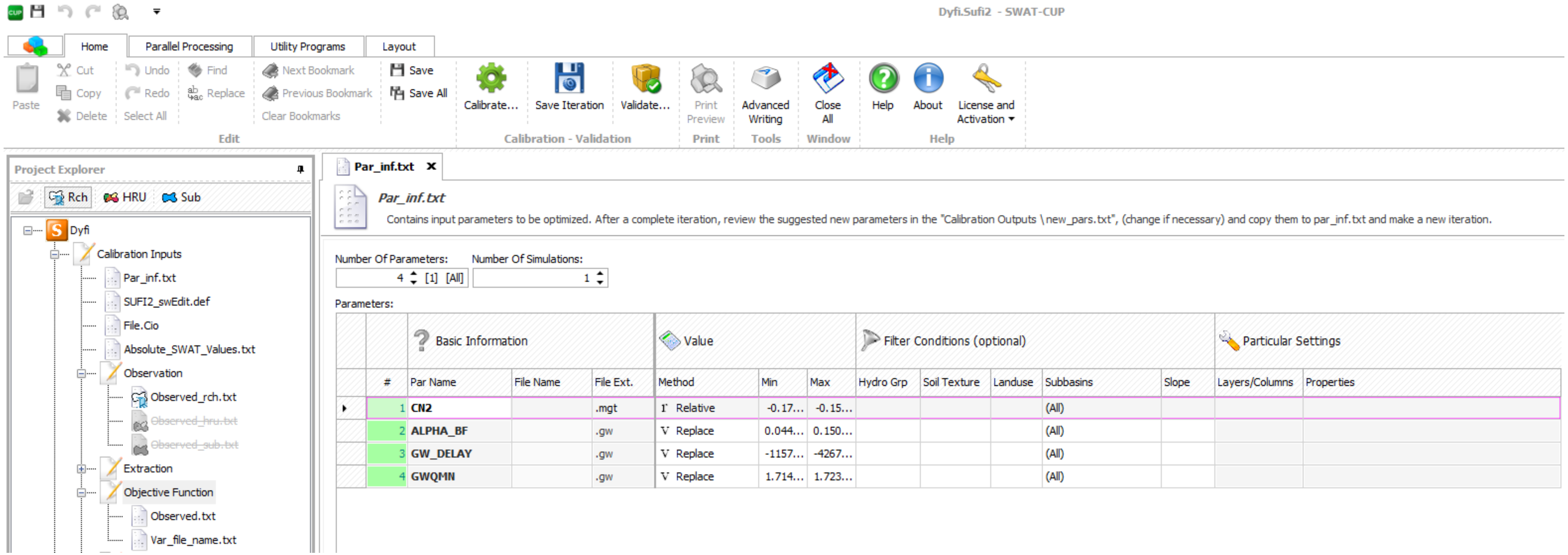
HPC

FUJITSU

PRIFYSGOL
BANGOR
UNIVERSITY

Catchment model -Calibration & Validation-



Par_inf.txt

Contains input parameters to be optimized. After a complete iteration, review the suggested new parameters in the "Calibration Outputs \ new_pars.txt", (change if necessary) and copy them to par_inf.txt and make a new iteration.

Number Of Parameters: 4 [1] [All]

Number Of Simulations: 1

Parameters:

	Basic Information			Value			Filter Conditions (optional)					Particular Settings	
#	Par Name	File Name	File Ext.	Method	Min	Max	Hydro Grp	Soil Texture	Landuse	Subbasins	Slope	Layers/Columns	Properties
1	CN2		.mgt	r Relative	-0.17...	-0.15...				(All)			
2	ALPHA_BF		.gw	V Replace	0.044...	0.150...				(All)			
3	GW_DELAY		.gw	V Replace	-1157...	-4267...				(All)			
4	GWQMN		.gw	V Replace	1.714...	1.723...				(All)			

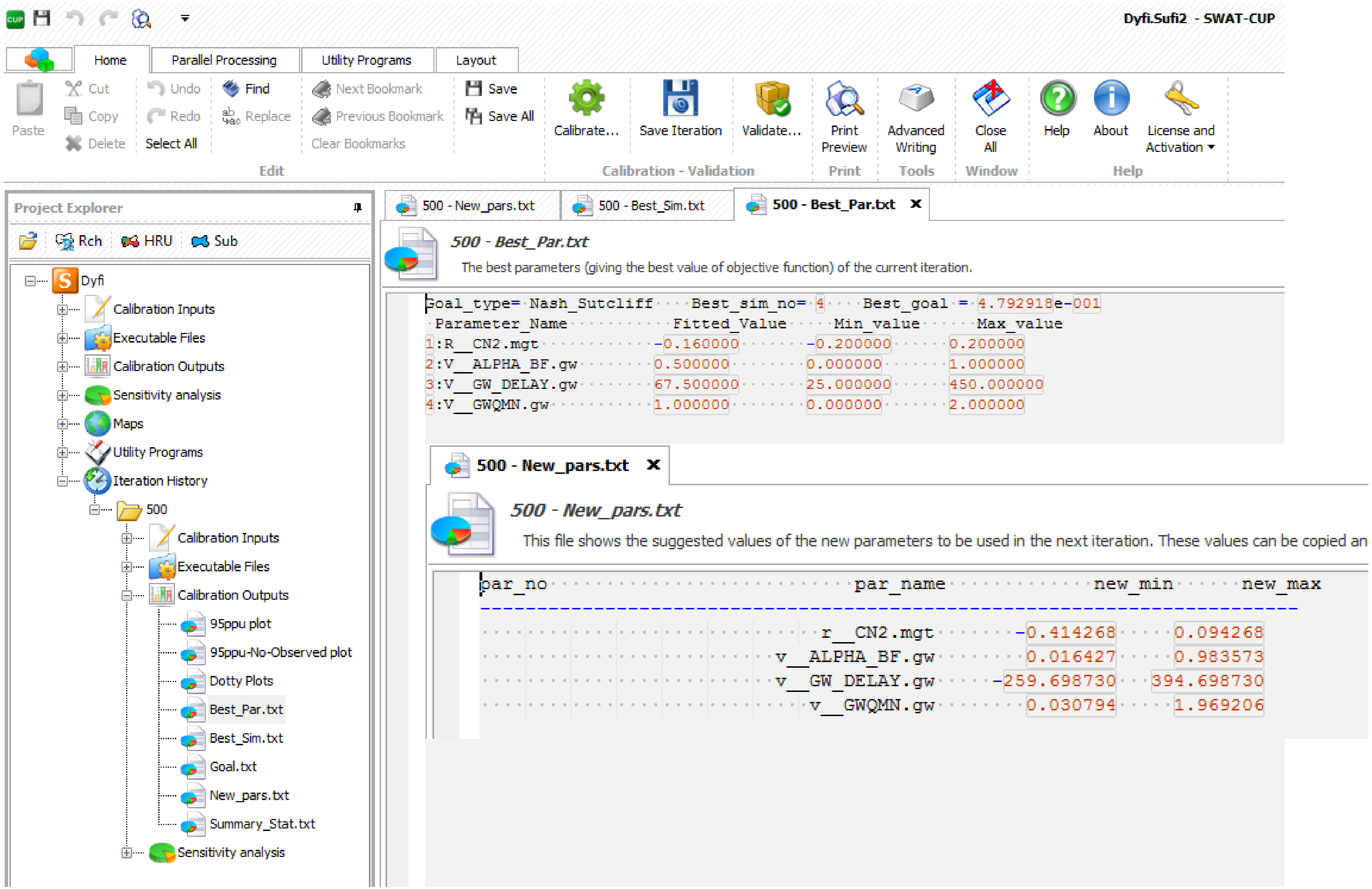
CN2: Initial SCS runoff curve number for moisture condition. The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. Divide you run-off from infiltration. CN2<0 infiltration dominated CN2>0 run-off dominated

ALPHA_BF: Baseflow alpha factor. Is the parameter to set up the baseflow for the river. Parameter to calculate the ground water (GW).

GW_DELAY: Estimated delay time.

GWQMN: Threshold depth of water in the shallow aquifer required for return flow to occur.

Catchment model -Calibration & Validation-



500 - Best_Par.txt

The best parameters (giving the best value of objective function) of the current iteration.

```
Goal_type= Nash_Sutcliff   Best_sim_no= 4   Best_goal = 4.792918e-001
 Parameter_Name            Fitted_Value    Min_value     Max_value
1:R__CN2.mgt               -0.160000       -0.200000     0.200000
2:V__ALPHA_BF.gw           0.500000        0.000000      1.000000
3:V__GW_DELAY.gw           67.500000       25.000000     450.000000
4:V__GWQMN.gw              1.000000        0.000000      2.000000
```

500 - New_pars.txt

500 - New_pars.txt

This file shows the suggested values of the new parameters to be used in the next iteration. These values can be copied an

```
par_no                          par_name          new_min       new_max
---------------------------------------------------------------------------
                              r__CN2.mgt        -0.414268      0.094268
                         v__ALPHA_BF.gw          0.016427      0.983573
                         v__GW_DELAY.gw       -259.698730    394.698730
                             v__GWQMN.gw         0.030794      1.969206
```

Soil Evaporation

- Actual soil water evaporation stimulated using exponential functions of soil depth and water content.

- *Potential soil water evaporation considering ground covering*

  E_s= potential soil water evaporation rate (mm/day)
  EA=soil cover index
  E_o=potential evaporation rate at the surface (mm/day)

$$E_s = (E_o)(EA) \qquad (91)$$

- *Potential soil water evaporation for a layer*

  SEV= potential soil water evaporation rate for layer (mm/day)
  EV=total soil water evaporation in mm from soil of depth Z in mm

$$SEV_i = EV_{Z(i)} - EV_{Z(i-1)} \qquad (94)$$

Plant Uptake and Transpiration

- SWAT model computes evaporation from soils and plants by $E_o = 128\ (h_o)$

- Plant transpiration function potential
  - Evapotranspiration and
  - Leaf area index (area of plant leaves relative to area of the HRU

- Potential evapotranspiration calculated with
  - Hargreaves
  - Priestley-Taylor
  - Penman-Monteith.

Lateral Flow

- The stream flow contribution below the surface but above saturated zone.
- It is calculated simultaneously with redistribution using a kinematic storage model.
- The model accounts for variation in conductivity, slope, soil water content, and allows flow upward to surface.
- *Kinematic storage model finite difference mass continuity equation:*

$$\frac{S_2 - S_1}{t_2 - t_1} = i\,L - \frac{q_{lat1} + q_{lat2}}{2} \qquad (49)$$

Si = drainable volume of water stored in the saturated zone mm^{-1}
q_{lat} = lateral flow in m^3h^{-1}
i = rate of water input to the saturated zone in m^2h^{-1}
L = hillslope length in m

Percolation

- Storage routing technique combined with a crack-flow model to predict flow through each soil layer.

- Cracked flow model allows percolation of infiltrated rainfall though soil water content is less than field capacity.

- Portion that does become part of layer stored water cannot percolate until storage exceeds field capacity.

- *Storage routing technique based on the following equation:*

$$SW_i = SW_{oi} \exp\left(\frac{-\Delta t}{TT_i}\right) \qquad (40)$$

Sw_i=soil water contents at end of the day (mm)
Sw_{oi}=soil water contents at beginning of the day
TT=travel time through layer (hr)

CN2	Initial SCS runoff curve number for moisture condition II. The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. Typical curve numbers for moisture condition II are listed in the following tables for various land covers and soil types (SCS Engineering Division, 1986). These values are appropriate for a 5% slope. The curve number may be updated in plant, tillage, and harvest/ kill operations. If CNOP is never defined for these operations, the value set for CN2 will be used throughout the simulation. If CNOP is defined for an operation, the value for CN2 is used until the time of the operation containing the first CNOP value. From that point on, the model only uses operation CNOP values to define the curve number for moisture condition II. Values for CN2 and CNOP should be entered for pervious conditions. In HRUs with urban areas, the model will adjust the curve number to reflect the impact of the impervious areas.

ALPHA_BF

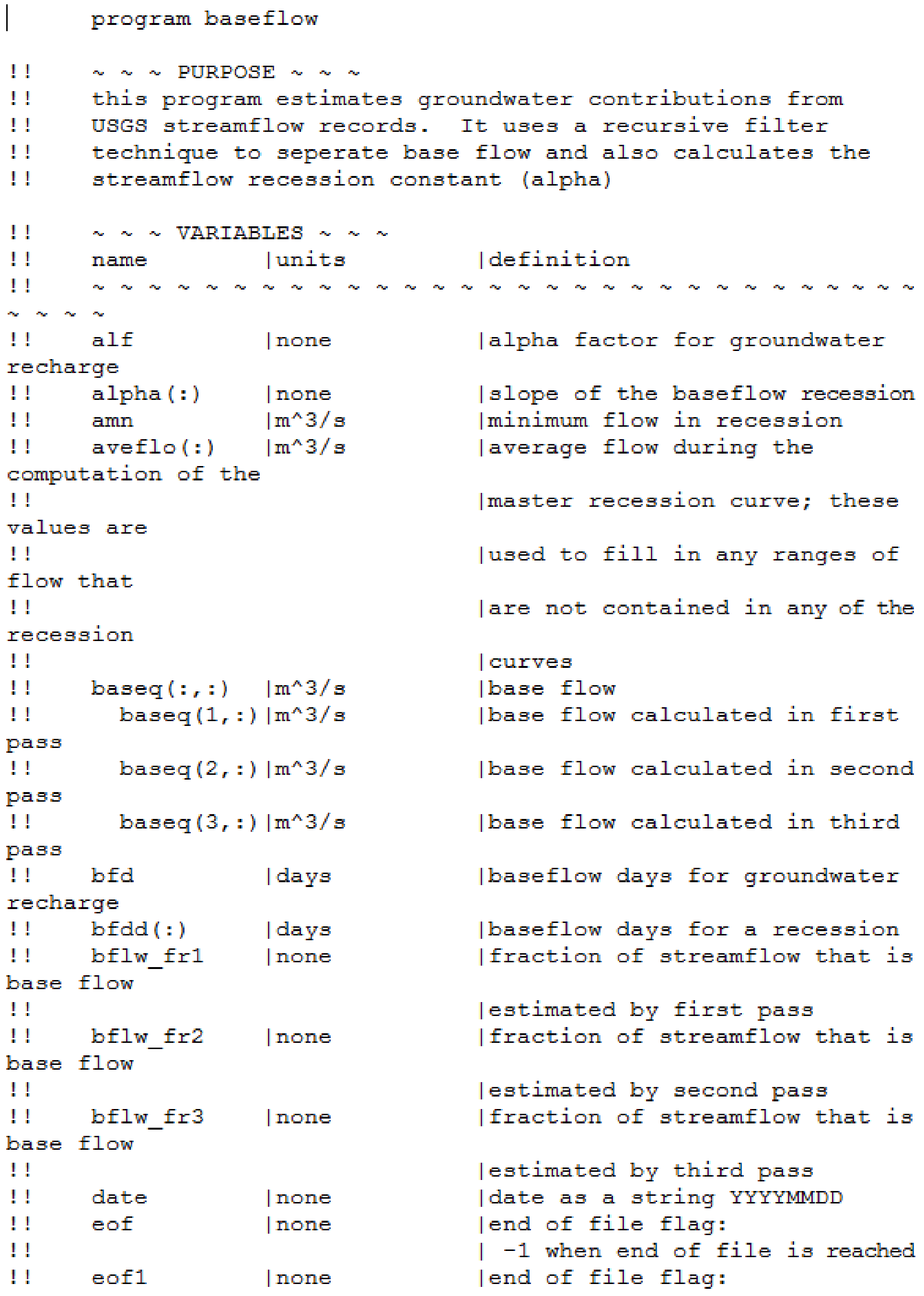
Baseflow alpha factor (1/days).

The baseflow recession constant, α_{gw}, is a direct index of groundwater flow response to changes in recharge (Smedema and Rycroft, 1983). Values vary from 0.1-0.3 for land with slow response to recharge to 0.9-1.0 for land with a rapid response. Although the baseflow recession constant may be calculated, the best estimates are obtained by analyzing measured streamflow during periods of no recharge in the watershed.

It is common to find the baseflow days reported for a stream gage or watershed. This is the number of days for base flow recession to decline through one log cycle. When baseflow days are known, the alpha factor can be calculated:

$$\alpha_{gw} = \frac{1}{N} \cdot \ln\left[\frac{Q_{gw,N}}{Q_{gw,0}}\right] = \frac{1}{BFD} \cdot \ln[10] = \frac{2.3}{BFD}$$

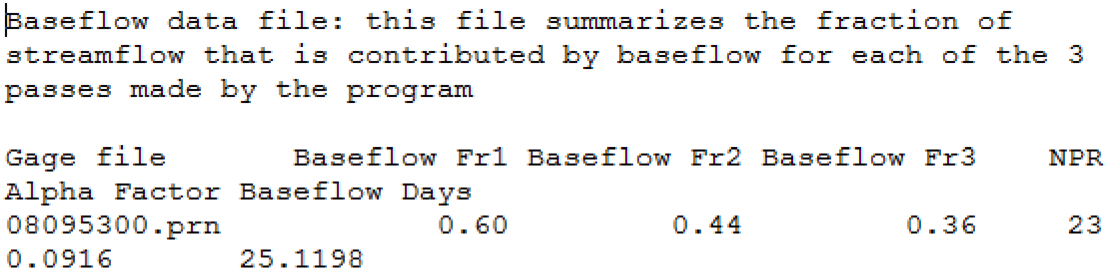
where α_{gw} is the baseflow recession constant, and BFD is the number of baseflow days for the watershed.



```
      program baseflow

!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this program estimates groundwater contributions from
!!    USGS streamflow records.  It uses a recursive filter
!!    technique to seperate base flow and also calculates the
!!    streamflow recession constant (alpha)

!!    ~ ~ ~ VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~
!!    alf         |none          |alpha factor for groundwater
recharge
!!    alpha(:)    |none          |slope of the baseflow recession
!!    amn         |m^3/s         |minimum flow in recession
!!    aveflo(:)   |m^3/s         |average flow during the
computation of the
!!                               |master recession curve; these
values are
!!                               |used to fill in any ranges of
flow that
!!                               |are not contained in any of the
recession
!!                               |curves
!!    baseq(:,:)  |m^3/s         |base flow
!!      baseq(1,:)|m^3/s         |base flow calculated in first
pass
!!      baseq(2,:)|m^3/s         |base flow calculated in second
pass
!!      baseq(3,:)|m^3/s         |base flow calculated in third
pass
!!    bfd         |days          |baseflow days for groundwater
recharge
!!    bfdd(:)     |days          |baseflow days for a recession
!!    bflw_fr1    |none          |fraction of streamflow that is
base flow
!!                               |estimated by first pass
!!    bflw_fr2    |none          |fraction of streamflow that is
base flow
!!                               |estimated by second pass
!!    bflw_fr3    |none          |fraction of streamflow that is
base flow
!!                               |estimated by third pass
!!    date        |none          |date as a string YYYYMMDD
!!    eof         |none          |end of file flag:
!!                               | -1 when end of file is reached
!!    eof1        |none          |end of file flag:
```



```
Baseflow data file: this file summarizes the fraction of
streamflow that is contributed by baseflow for each of the 3
passes made by the program

Gage file       Baseflow Fr1 Baseflow Fr2 Baseflow Fr3    NPR
Alpha Factor Baseflow Days
08095300.prn            0.60         0.44         0.36     23
0.0916       25.1198
```

GW_DELAY

The delay time, δ_{gw}, cannot be directly measured. It can be estimated by simulating aquifer recharge using different values for δ_{gw} and comparing the simulated variations in water table level with observed values. Johnson (1977) developed a simple program to iteratively test and statistically evaluate different delay times for a watershed. Sangrey et al. (1984) noted that monitoring wells in the same area had similar values for δ_{gw}, so once a delay time value for a geomorphic area is defined, similar delay times can be used in adjoining watersheds within the same geomorphic province.

GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O). Groundwater flow to the reach is allowed only if the depth of water in the shallow aquifer is equal to or greater than GWQMN.

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