Future Flows Hydrology: an ensemble of daily river flows and monthly groundwater levels for use for climate change impact assessment across Great Britain

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Supplementary Material

Table 1 Future Flows Hydrology river flow sites organised by regions

Region	Station (Hydrometric Register Number)	River Name	Station Name	Catchment area (km²)	Station (Hydrometric Register Number)	River Name	Station Name	Catchment area (km²)
SEPA North	2001	Helmsdale	Kilphedir	551.4	9003	Isla	Grange	176.1
	4003	Alness	Alness	201	10002	Ugie	Inverugie	325
	4005	Meig	Glenmeannie	120.5	11001	Don	Parkhill	1273
	6008	Enrick	Mill of Tore	105.9	12002	Dee	Park	1844
	7002	Findhorn	Forres	781.9	12003	Dee	Polhollick	690
	7004	Nairn	Firhall	313	12005	Muick	Invermuick	110
	7005	Divie	Dunphail	165	12008	Feugh	Heugh Head	229
	7006	Lossie	Torwinny	20	90003	Nevis	Claggan	69.2
	7009	Mosset Burn	Wardend Bridge	28.3	92002	Shiel	Shielfoot	256
	8004	Avon	Delnashaugh	542.8	93001	Carron	New Kelso	137.8
	8006	Spey	Boat o Brig	2861.2	94001	Ewe	Poolewe	441.1
	8009	Dulnain	Balnaan Bridge	272.2	95001	Inver	Little Assynt	137.5
	9001	Deveron	Avochie	441.6	97002	Thurso	Halkirk	412.8
	9002	Deveron	Muiresk	954.9				
SEPA East	13001	Bervie	Inverbervie	123	18005	Allan Water	Bridge of Allan	210
	13005	Lunan Water	Kirkton Mill	124	19006	Water of Leith	Murrayfield	107
	13007	North Esk	Logie Mill	732	19011	North Esk	Dalkeith Palace	137
	13008	South Esk	Brechin	488	20001	Tyne	East Linton	307
	13009	West Water	Dalhouse Bridge	127.2	21003	Tweed	Peebles	694
	14001	Eden	Kemback	307.4	21006	Tweed	Boleside	1500
	15006	Tay	Ballathie	4587.1	21009	Tweed	Norham	4390
	15014	Ardle	Kindrogan	103	21012	Teviot	Hawick	323
	15023	Braan	Hermitage	210	21013	Gala Water	Galashiels	207
	15024	Dochart	Killin	239	21015	Leader Water	Earlston	239
	15025	Ericht	Craighall	432	21017	Ettrick Water	Brockhoperig	37.5

Region	Station (Hydrometric Register Number)	River Name	Station Name	Catchment area (km²)	Station (Hydrometric Register Number)	River Name	Station Name	Catchment area (km²)
	16003	Ruchill Water	Cultybraggan	99.5	21021	Tweed	Sprouston	3330
	16007	Ruthven Water	Aberuthven	50	21022	Whiteadder Water	Hutton Castle	503
	17003	Bonny Water	Bonnybridge	50.5	21023	Leet Water	Coldstream	113
	17005	Avon	Polmonthill	195.3	21027	Blackadder Water	Mouth Bridge	159
	17015	North Queich	Lathro	23.1	21031	Till	Etal	648
	17016	Lochty Burn	Whinnyhall	14	21032	Glen	Kirknewton	198.9
	18001	Allan Water	Kinbuck	161				
SEPA West	77002	Esk	Canonbie	495	84003	Clyde	Hazelbank	1092.9
	77003	Liddel Water	Rowanburnfoot	319	84004	Clyde	Sills of Clyde	741.8
	77004	Kirtle Water	Mossknowe	72	84005	Clyde	Blairston	1704.2
	77304	Liddell Water	Newcastleton	207	84012	White Cart Water	Hawkhead	234.9
	78003	Annan	Brydekirk	925	84013	Clyde	Daldowie	1903.1
	78005	Kinnel Water	Bridgemuir	229	84015	Kelvin	Dryfield	235.4
	78006	Annan	Woodfoot	217	84016	Luggie Water	Condorrat	33.9
	78999	Evan Water	Beattock	80	84018	Clyde	Tulliford Mill	932.6
	79002	Nith	Friars Carse	799	84020	Glazert Water	Milton of Campsie	51.9
	79003	Nith	Hall Bridge	155	84022	Duneaton	Maidencots	110.3
	79006	Nith	Drumlanrig	471	84026	Allander Water	Milngavie	32.8
	80005	Dargall Lane	Loch Dee	2.1	84029	Cander Water	Candermill	24.5
	81002	Cree	Newton Stewart	368	84037	Douglas Water	Happendon	97
	81005	Piltanton Burn	Barsolus	34.2	85002	Endrick Water	Gaidrew	219.9
	81007	Water of Fleet	Rusko	77	85003	Falloch	Glen Falloch	80.3
	82001	Girvan	Robstone	245.5	89003	Orchy	Glen Orchy	251.2
	83005	Irvine	Shewalton	380.7	89004	Strae	Glen Strae	36.2
	83007	Lugton Water	Eglinton Castle	54.6	89005	Lochy	Inverlochy	47.7
	83010	Irvine	Newmilns	72.8	89008	Eas Daimh	Eas Daimh	4.5
	83011	Ayr	Wellwood	60	89009	Eas a' Ghaill	Succoth	9.7
EA North East	22001	Coquet	Morwick	569.8	27007	Ure	Westwick Lock	914.6
	22004	Aln	Hawkhill	205	27009	Ouse	Skelton	3315
	22009	Coquet	Rothbury	346	27021	Don	Doncaster	1256.2
	23004	South Tyne	Haydon Bridge	751.1	27034	Ure	Kilgram Bridge	510.2
	23006	South Tyne	Featherstone	321.9	27035	Aire	Kildwick Bridge	282.3
	23011	Kielder Burn	Kielder	58.8	27041	Derwent	Buttercrambe	1586
	24002	Gaunless	Bishop Auckland	93	27042	Dove	Kirkby Mills	59.2

Region	Station (Hydrometric Register Number)	River Name	Station Name	Catchment area (km²)	Station (Hydrometric Register Number)	River Name	Station Name	Catchment area (km²)
	24005	Browney	Burn Hall	178.5	27043	Wharfe	Addingham	427
	24009	Wear	Chester le Street	1008.3	27049	Rye	Ness	238.7
	25005	Leven	Leven Bridge	196.3	27055	Rye	Broadway Foot	131.7
	25007	Clow Beck	Croft	78.2	27071	Swale	Crakehill	1363
	25019	Leven	Easby	14.8	27084	Eastburn Beck	Crosshills	43.4
	25020	Skerne	Preston le Skerne	147				
EA Midlands	28008	Dove	Rocester Weir	399	28066	Cole	Coleshill	130
	28018	Dove	Marston on Dove	883.2	54001	Severn	Bewdley	4325
	28022	Trent	North Muskham	8231	54008	Teme	Tenbury	1134.4
	28030	Black Brook	Onebarrow	8.4	54018	Rea Brook	Hookagate	178
	28031	Manifold	Ilam	148.5	54022	Severn	Plynlimon flume	8.7
	28033	Dove	Hollinsclough	8	54036	Isbourne	Hinton on the Green	90.7
	28046	Dove	Izaak Walton	83	54038	Tanat	Llanyblodwel	229
	28055	Ecclesbourne	Duffield	50.4	54057	Severn	Haw Bridge	9895
EA Anglian	30018	Honington Beck	Honington	51.	33063	Little Ouse	Knettishall	101
	31010	Chater	Fosters Bridge	68.9	34002	Tas	Shotesham	146.5
	31020	Morcott Brook	South Luffenham	19.6	34006	Waveney	Needham Mill	370
	33012	Kym	Meagre Farm	137.5	34011	Wensum	Fakenham	161.9
	33014	Lark	Temple	272	34014	Wensum	Swanton Morley Total	397.8
	33018	Tove	Cappenham Bridge	138.1	34018	Stiffkey	Warham All Saints	87.8
	33019	Thet	Melford Bridge	316	35008	Gipping	Stowmarket	128.9
	33026	Bedford Ouse	Offord	2570	36005	Brett	Hadleigh	156
	33027	Rhee	Wimpole	119.1	36007	Belchamp Brook	Bardfield Bridge	58.6
	33029	Stringside	Whitebridge	98.8	37001	Roding	Redbridge	303.3
	33044	Thet	Bridgham	277.8	37011	Chelmer	Churchend	72.6
	33049	Stanford Water	Buckenham Tofts	43.5	37019	Beam	Bretons Farm	49.7
EA Thames	30018	Witham	Colsterworth	51.3	39057	Crane	Cranford Park	61.7
	38003	Mimram	Panshanger Park	133.9	39076	Windrush	Worsham	296
	38014	Salmon Brook	Edmonton	20.5	39081	Ock	Abingdon	234
	39001	Thames	Kingston	9948	39090	Cole	Inglesham	140
	39006	Windrush	Newbridge	362.6	39092	Dollis Brook	Hendon Lane Bridge	25.1
	39008	Thames	Eynsham	1616.2	39096	Wealdstone Brook	Wembley	21.8
	39016	Kennet	Theale	1033.4	39103	Kennet	Newbury	548.1

Region	Station (Hydrometric Register Number) River Name	Station Name	Catchment area (km²)	Station (Hydrometric Register Number) River Name	Station Name	Catchment area (km²)
	39034 Evenlode	Cassington Mill	430	39105 Thame	Wheatley	533.8
	39049 Silk Stream	Colindeep Lane	29	39131 Brent	Costons Lane Greenford	146.2
EA Southern	40003 Medway	Teston	1256.1	41011 Rother	Iping Mill	154
	40011 Great Stour	Horton	345	41022 Lod	Halfway Bridge	52
	40017 Dudwell	Burwash	27.5	41026 Cockhaise Brook	Holywell	36.1
	40023 East Stour	South Willesborough	58.8	42012 Anton	Fullerton	185
EA South West	43003 Avon	East Mills	1477.8	47008 Thrushel	Tinhay	112.7
	43005 Avon	Amesbury	323.7	47014 Walkham	Horrabridge	44.6
	43006 Nadder	Wilton	220.6	48003 Fal	Tregony	87
	43007 Stour	Throop	1073	49001 Camel	Denby	208.8
	43021 Avon	Knapp Mill	1706	50002 Torridge	Torrington	663
	44002 Piddle	Baggs Mill	183.1	50006 Mole	Woodleigh	327.5
	45001 Exe	Thorverton	600.9	50007 Taw	Taw Bridge	71.4
	45004 Axe	Whitford	288.5	51001 Doniford Stream	Swill Bridge	75.8
	45005 Otter	Dotton	202.5	52004 Isle	Ashford Mill	90.1
	45009 Exe	Pixton	159.7	52010 Brue	Lovington	135.2
	45011 Barle	Brushford	128	53005 Midford Brook	Midford	147.4
	46003 Dart	Austins Bridge	247.6	53006 Frome(Bristol)	Frenchay	148.9
	46005 East Dart	Bellever	21.5	53017 Boyd	Bitton	47.9
	46006 Erme	Ermington	43.5	53018 Avon	Bathford	1552
	47001 Tamar	Gunnislake	916.9			
EA Wales	55002 Wye	Belmont	1895.9	60002 Cothi	Felin Mynachdy	297.8
	55003 Lugg	Lugwardine	885.8	60004 Dewi Fawr	Glasfryn Ford	36.7
	55004 Irfon	Abernant	72.8	60006 Gwili	Glangwili	129.5
	55007 Wye	Erwood	1282.1	61001 Western Cleddau	Prendergast Mill	197.6
	55029 Monnow	Grosmont	354	62001 Teifi	Glan Teifi	893.6
	56002 Ebbw	Rhiwderyn	216.5	62002 Teifi	Llanfair	510
	56003 Honddu	The Forge Brecon	62.1	63001 Ystwyth	Pont Llolwyn	169.6
	56005 Lwyd	Ponthir	98.1	63004 Ystwyth	Cwm Ystwyth	32.1
	56007 Senni	Pont Hen Hafod	19.9	64001 Dyfi	Dyfi Bridge	471.3
	56013 Yscir	Pontaryscir	62.8	64002 Dysynni	Pont-y-Garth	75.1
	56019 Ebbw	Aberbeeg	71.7	65001 Glaslyn	Beddgelert	68.6
	57004 Cynon	Abercynon	106	65006 Seiont	Peblig Mill	74.4
	58005 Ogmore	Brynmenyn	74.3	66011 Conwy	Cwmlanerch	344.5

Region	Station (Hydrometric Register Number)	River Name	Station Name	Catchment area (km²)	Station (Hydrometric Register Number)	River Name	Station Name	Catchment area (km²)
	58007	Llynfi	Coytrahen	50.2	67005	Ceiriog	Brynkinalt Weir	113.7
	58008	Dulais	Cilfrew	43	67010	Gelyn	Cynefail	13.1
	58012	Afan	Marcroft Weir	87.8	67013	Hirnant	Plas Rhiwedog	33.9
	59001	Tawe	Ynystanglws	227.7				
	60009	Sawdde	Felin-y-cwm	77.5				
EA North West	68001	Weaver	Ashbrook	622	73006	Cunsey Beck	Eel House Bridge	18.7
	68003	Dane	Rudheath	407.1	73009	Sprint	Sprint Mill	34.6
	68005	Weaver	Audlem	207	73011	Mint	Mint Bridge	65.8
	69042	Ding Brook	Naden Reservoir	2.2	73013	Rothay	Miller Bridge House	64
	71001	Ribble	Samlesbury	1145	73014	Brathay	Jeffy Knotts	57.4
	71006	Ribble	Henthorn	456	74001	Duddon	Duddon Hall	85.7
	71009	Ribble	New Jumbles Rock	1053	74005	Ehen	Braystones	125.5
	72004	Lune	Caton	983	74006	Calder	Calder Hall	44.8
	72009	Wenning	Wennington	142	74007	Esk	Cropple How	70.2
	72014	Conder	Galgate	28.5	75017	Ellen	Bullgill	96
	72015	Lune	Lunes Bridge	141.5	76005	Eden	Temple Sowerby	616.4
	73003	Kent	Burneside	73.6	76007	Eden	Sheepmount	2286.5
	73005	Kent	Sedgwick	209	76008	Irthing	Greenholme	334.6

Table 2 Future Flows Hydrology groundwater sites

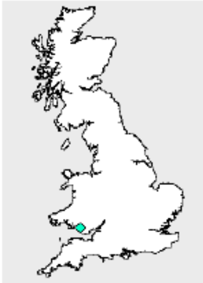
Observation Borehole (Hydrometric Register Number)	Observation Borehole Name	Aquifer
SY68/34	Ashton Farm	Chalk
TA10/63	Aylesby	Chalk
SU81/1	Chilgrove House	Chalk
SU34/8D	Clanville Lodge Gate	Chalk
SE94/5	Dalton Holme	Chalk
ST88/62A	Didmarton 1	Inferior Oolite
SD27/6B	Furness Abbey	Permo-Triassic Sandstone
TL89/37	Grimes Graves	Chalk
SJ62/112	Heathlanes	Permo-Triassic Sandstone
SK17/13	Hucklow South	Carboniferous Limestone
TR14/9	Little Bucket Farm	Chalk
SJ15/13	Llanfair Dyffryn Clwyd	Permo-Triassic Sandstone
TQ41/82	Lower Barn Cottage	Lower Greensand
TF03/37	New Red Lion	Lincolnshire Limestone
NX97/2	Newbridge	Permo-Triassic Sandstone
SU17/57	Rockley	Chalk
NY63/2	Skirwith	Permo-Triassic Sandstone
SU78/45A	Stonor Park	Chalk
NZ21/29	Swan House	Magnesian Limestone
TL33/4	Therfield Rectory	Chalk
TF81/2A	Washpit Farm	Chalk
TQ25/13	Well House Inn	Chalk
TV59/7C	West Dean No. 3	Chalk
SU01/5B	West Woodyates Manor	Chalk

Example of river flow catchment fact sheet - the Llynfi at Coytrahen (58007)

Catchment Fact Sheet 58007 Future Flows and Groundwater Levels

General Information

River Name	Llynfi	Catchment Area (km2)	50
Station Name	Coytrahen	SAAR (mm) 61-90	1769
Station Number	58007	Mean Annual Rain (mm) 62-91	1781
Grid Reference	SS891855	Mean Annual PE (mm) 62-91	614
EA Region	EA-W	Observed flow record	1970 to 2005



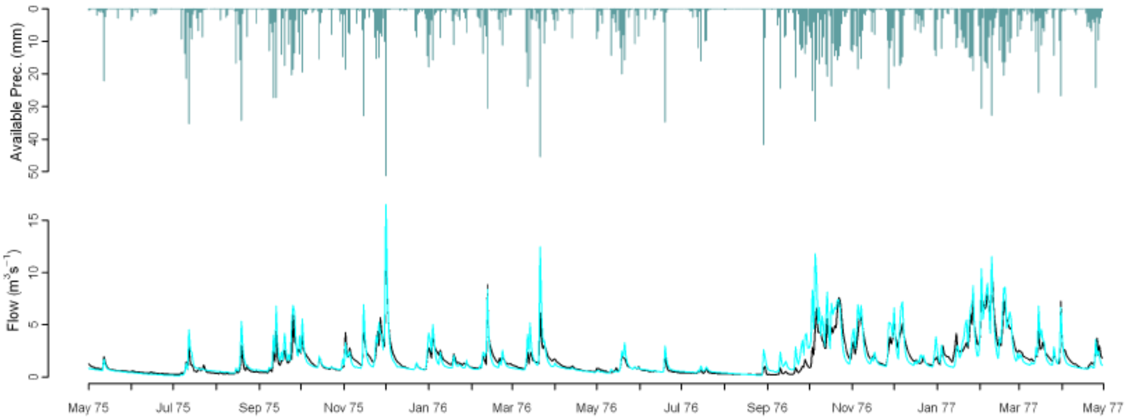
Observed Data

Comparison of gauged and simulated flow **Model used: CERF**

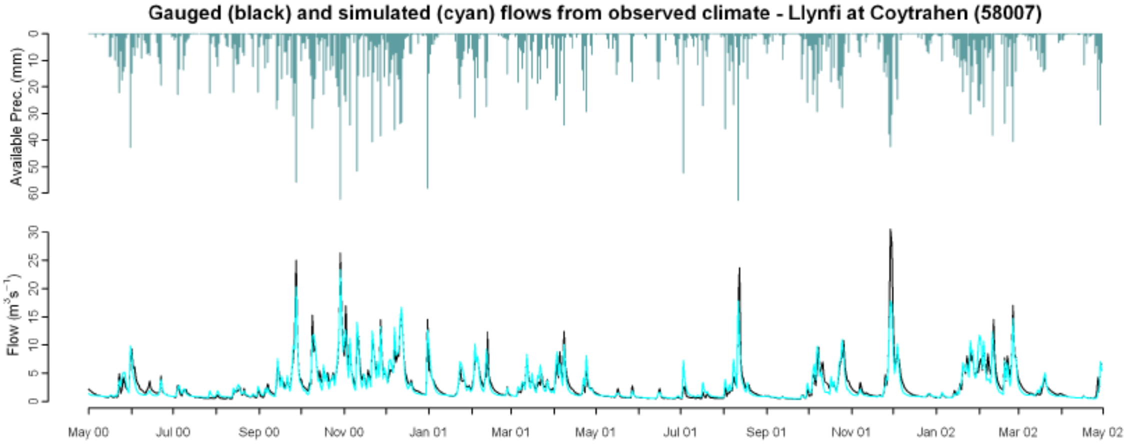
	Mean Annual	J	F	M	A	M	J	J	A	S	O	N	D	Nash Sutcliffe
MORECS (1971-2005)	-1.3	-0.1	-4.6	-8.9	-11.4	-6.2	-5.6	1.6	8.3	12.6	5.6	-1.7	-1.7	0.80
Performance Band	1	1	1	1	2	2	1	1	2	2	1	1	1	1
MORECS (1962-1991)	1.4	1.0	-1.7	-6.1	-12.0	-7.8	-1.2	2.3	9.7	24.7	7.1	-0.1	0.8	0.80

	Q90	Q75	Q50	Q25	Q5	RP2	RP5	RP10	RP20
MORECS (1971-2005)	9.9	5.6	-17.4	-9.5	13.9				
Performance Band	1	1	1	1	1				
MORECS (1962-1991)	9.8	6.4	-17.0	-7.6	16.2				

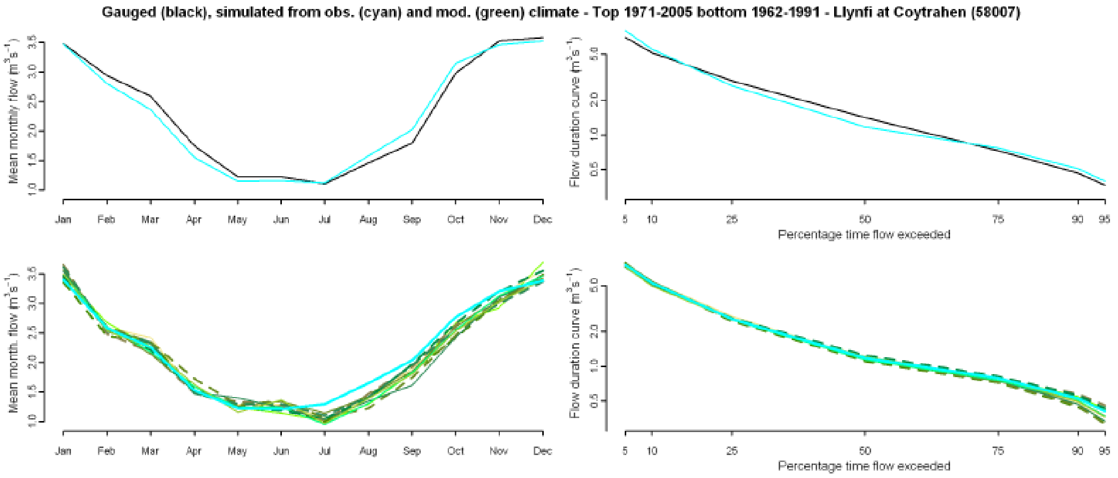
Gauged (black) and simulated (cyan) flows from observed climate - Llynfi at Coytrahen (58007)



Gauged (black) and simulated (cyan) flows from observed climate - Llynfi at Coytrahen (58007)



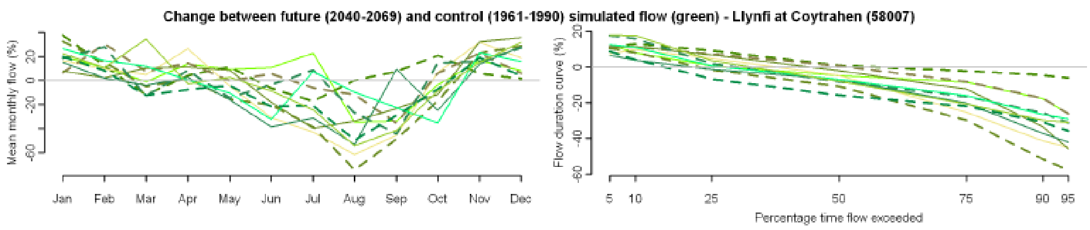
Comparison of gauged and simulated flow (observed and modelled climate)



Percentage difference between flow simulated from observed climate and Future Flows Climate

	afgcx	afixa	afixc	afixh	afixi	afixj	afixk	afixl	afixm	afixo	afixq
Annual	-1	-2	0	0	-2	-1	-3	-1	-3	-2	-2
January	3	-1	8	6	5	4	3	8	3	0	6
April	-1	-1	0	3	1	13	2	0	0	-1	6
July	-22	-18	-13	-17	-17	-14	-19	-11	-25	-22	-25
October	-3	-4	-10	-2	-9	-6	-5	-7	-5	-2	-8
Q90	4	-17	-8	11	-10	-15	-13	2	-6	3	-5
Q75	0	-10	-4	2	-8	-9	-5	0	-6	1	-1
Q50	1	-6	0	3	-4	-3	2	2	-4	4	1
Q25	0	-4	5	0	-3	1	0	2	-3	1	-1
Q5	-3	4	-1	-1	1	2	-4	2	-1	-5	-3
RP2	1	5	2	7	0	-5	4	-4	9	3	5
RP10	1	-1	-1	3	-4	-7	-1	-4	10	-3	-2

Climate change graphs for 2050s



Overview of the fact sheets and briefing note

The **fact sheets** are designed to provide a **brief overview** on the ability of the river flow or groundwater models to reproduce (simulate) some of the most important components of the water cycle when using observed and modelled climate. This overview is given by sets of **statistics** (measuring the differences between two time series) and **graphs** (providing a visual comparison). Detailed information on the meaning of the statistics and graphs is provided in the **Modelling protocol** report (Crooks et al., 2012, SC090016/PN4) accessible from the FF webpages (www.ceh.ac.uk). This briefing note summarises the **meaning** and **relative importance** of the statistics and graphs; it **does not** provide any **interpretation** for specific catchments/model.

One **fact sheet** is delivered **for each site and river flow or groundwater level model combination.** If two hydrological models are used to simulate flow at the same site, two catchment fact sheets are provided for this site. Note that different models use different methods of **calibration** ranging from **catchment specific** to **regionalised parameters**. The advantage of a regionalised parameter model is to extend the climate range under which the model parameters are evaluated; this is particularly important in a warming climate for catchments where evaporation processes may change from a surplus of summer precipitation over evaporation to a deficit. The advantage of catchment calibrated models is that they are designed to reproduce well the local hydrological processes. The calibration method may affect the statistical measures of model performance.

A catchment fact sheet is divided in three parts. **Top front page**: general information section with the main physical characteristics of the catchment, its location and the availability of observed flow data. **Front**: how well the observed flow time series are reproduced by the models when using **observed climate**; or a measure of the confidence in the hydrological model. **Back**: how well flow time series are reproduced by the models when using **modelled climate**; or a measure of the confidence in the climate/hydrological model combination. **Both front and back** must be looked at to fully understand the factors affecting the Future Flows Hydrology (FFH) time series. This is very important when the FFH time series are used to assess climate change impact on a catchment ecosystem. The FFH flow time series are in m^3s^{-1}.

Front page: Simulation from observed climate

Table

Summary of differences in modelling the flow with observed climate. Differences (except Nash Sutcliffe) give the % departure between statistics calculated from simulated and observed flow time series.

Names represent the considered statistics; Qx = % difference in flow percentile value (i.e. in flow exceeded x% of the time); Nash Sutcliffe measures if the modelled time series describes the observed time series better than the long term average. A value of 1 shows a perfect match.

Three parts of the hydrological regime are of interest: (i) Water balance, seasonality, and day to day variability (upper part of table); (ii) Low flows (flow percentiles Q75 and Q90); (lower left); (iii) High flows (flow percentiles Q25 and Q5) and flood peaks (RP2 to RP20, not all models) (lower right). Sets of statistics are given for two time periods. Statistics are only calculated when there is observed flow data which may be limited within the 1962-1991 period.

Differences include measurement errors and other factors affecting the observed flow but generally **the smaller the difference the better the model simulation**.

Graphs

The graphs illustrate how well the model simulates the flow time series by plotting together observed and simulated flow.

Two types of graphs are shown:

Hydrographs of **mean daily flow** for two 2-year periods (for most catchments representative of contrasting climatic conditions): (i) The 1975-1977 period illustrative of a dry episode and subsequent re-wetting; (ii) The 2000-2002 period illustrative of a wet episode and subsequent average conditions.

They give a visual assessment of the reproduction of different hydrological processes under contrasting conditions (e.g. drying during the recession phase; temporal variability typical of the flashiness of the catchment). Daily precipitation is also shown in these graphs.

Mean monthly flows and f**low duration curves** (shown on the back page). These graphs provide a visual assessment of how well the long-term variability and seasonality is reproduced by the simulation.

Model performance

Assessment of model performance is given for the statistics for the 1971-2005 period using three Bands as defined in Table 1 of the Modelling Protocol. Interpretation of the Performance Bands; (i) Define the purpose for which the FFH time series are being used; (ii) Select the statistics most relevant to the purpose; (iii) Assess the performance bands for these statistics. For example: for low flows look at the performance for Q90 possibly in conjunction with that in Jul, Aug and Sep;

Back page: Simulation from modelled climate

Because of the year-to-year variability of the climate of the UK (also called climate variability) it is possible that several climate time series differ while representing different plausible realisations of the climate. In addition, because knowledge of the physics of the atmosphere is limited and it is not yet feasible to accurately model small-scale climate features, it is now recommended that several climate models projections are considered together when assessing future projections in hydrology. For both reasons, an ensemble of climate models has been used to drive the FF hydrological models and generate an ensemble of FFH time series for each of the sites. The FFH ensemble is derived from the ensemble of Future Flows Climate (FFC) which contains information on both climate variability and climate modelling uncertainty; **no single projection should be considered in isolation of the others as this might mask some important information given by the other ensemble members**. Note that as FFC is derived from a climate model, the day-to-day sequencing of the climate and resulting flow is **not the same as that of observed flow when directly comparing time series**. Long-term statistics, such as the flow duration curves, should match more closely those derived from simulations using the observed climate.

Table

Summary of the percentage differences in modelling the flow with observed and modelled climate (FFC time series; note that FFC is a version of HadRM3-PPE where systematic biases in precipitation and temperature have been corrected, a snowmelt module has been applied and which has been downscaled at a hydrologically-relevant scale). Naming convention and units are as on the Front page.

Comparisons are made for a 30-year period representative of 1962-1991, called control. This gives an assessment of the difference introduced by the use of modelled rather than observed climate when simulating flow. This is important because FFH time series, as they project into the future, can only be derived from modelled climate. These differences help identify two possible features:

Systematic differences in the climate-hydrological chain for a **specific part of the regime**; e.g. if all summer flows show a large difference, this might suggest that modelled summer climate (rainfall and/or potential evaporation (PE)) is different from observed;

Systematic differences in the climate-hydrological chain for **specific ensemble member**; e.g. if all statistics associated with afixa show a large difference, this might suggest that afixa climate (rainfall and/or PE) has different characteristics from the observed climate;

In both cases, the statistics should only suggest caution when interpreting the results of the whole FF ensemble, in particular if runs/periods with large differences in the control period are associated with a future signal different from the rest of the FF ensemble. **Large differences in some statistics of the control runs should not be used to automatically reject one of the ensemble members**.

Graphs

Two sets of graphs are shown.

Mean monthly flows and flow duration curves (observed and modelled climate)

The upper pair of graphs gives a visual assessment of how well the long-term variability of observed flows is reproduced using the observed climate (1971-2005, or period of observed flow record if this is shorter). The lower pair shows how similar the flow simulated from the 11 modelled climate time series is to the flow simulated from observed climate for the control period (1962-1991).

Change in mean monthly flow and flow duration curve

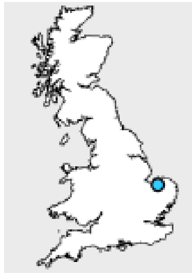
The lower pair of graphs shows the percentage change in mean monthly flow and flow exceeded x% of the time between two 30 year periods - the 1970s (1961-1990) and 2050s (2040 – 2069) for the 11 modelled climate series (FFC). The line of zero change is also shown. The range of change is indicative of uncertainty in the climate modelling

Example of groundwater level catchment fact sheet – Washpit Farm (TF81/2A)

Catchment Fact Sheet TF81/2A — Future Flows and Groundwater Levels

General Information

Borehole Name	Washpit Farm	Grid Reference	TF 81351960
Borehole ID	TF81/2A	Mean Annual Rainfall (mm)	730
Principal Aquifer	Chalk Group	Period of observed level data	1961 - 2005
EA Region	Anglian		

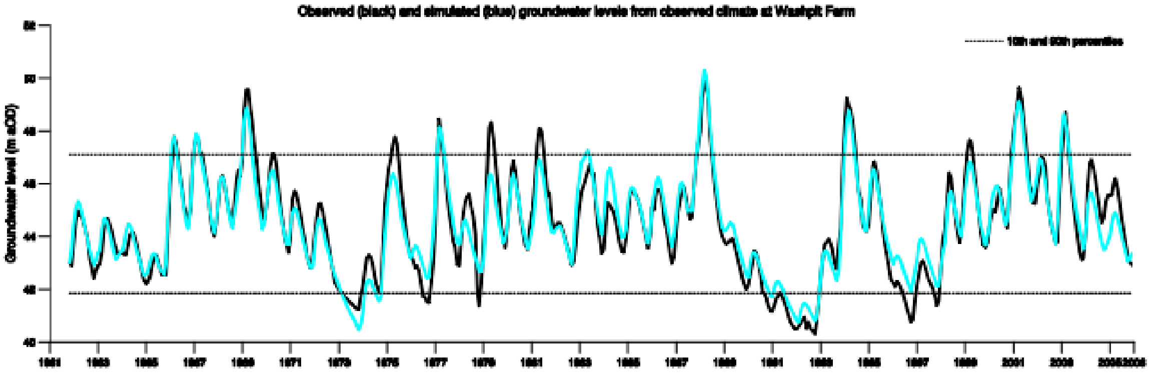


Observed Data — Comparison of observed and simulated levels (m) — Model used: R-Groundwater

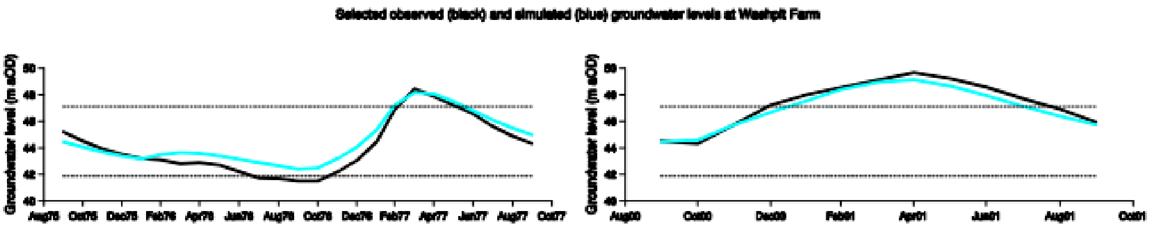
	Mean Annual	J	F	M	A	M	J	J	A	S	O	N	D	NSE	RMSE
1961 - 2005	0.01	0.17	0.12	0.00	-0.09	-0.21	-0.22	-0.15	-0.07	0.04	0.12	0.21	0.18	0.90	0.63
Performance	1	1	1	1	1	1	1	1	1	1	1	1	1	1	

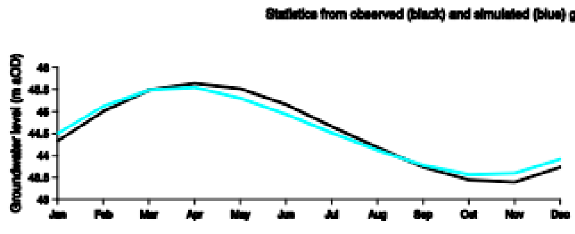
	L90	L75	L50	L25	L10
1961 - 2005	0.45	0.21	-0.02	-0.06	-0.30
Performance	1	1	1	1	1

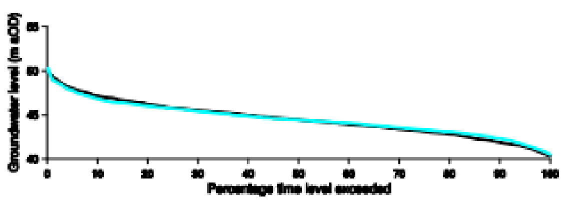
	%
Error (sim-obs) in range (max-min)	2.91
Performance	1



Comparison of observed and simulated levels (observed climate)

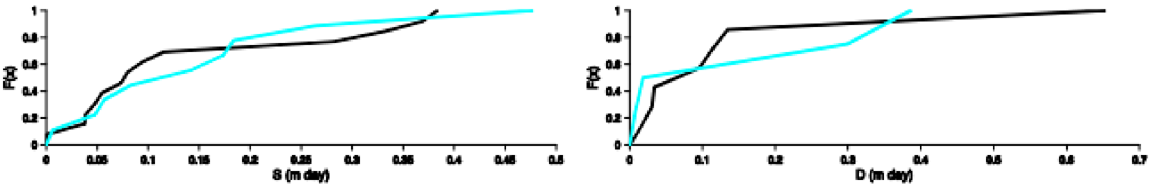






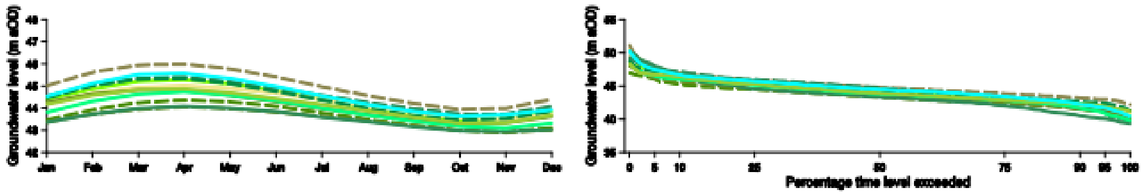
Catchment Fact Sheet TF81/2A Future Flows and Groundwater Levels

Surplus (S) and Deficit (D) distributions from observed (black) and simulated (blue) groundwater levels from observed climate at Washpit Farm



Difference (m) between levels simulated from observed climate and Future Flows Climate

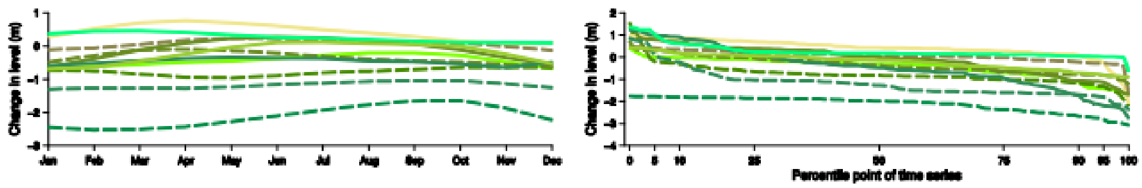
Comparison of groundwater levels simulated using observed climate (blue) and Future Flows Climate (green)



(m)	afgcx	afixa	afixc	afixh	afixi	afixj	afixk	afixl	afixm	afixo	afixq
Annual	-0.20	-0.92	-0.29	0.41	-0.50	-1.07	-1.07	-0.01	-0.65	-0.17	-0.45
Jan	-0.16	-1.08	-0.34	0.47	-0.29	-1.18	-1.18	-0.02	-0.73	-0.08	-0.37
Feb	-0.25	-1.21	-0.46	0.48	-0.48	-1.41	-1.40	-0.08	-0.81	-0.12	-0.55
Mar	-0.31	-1.29	-0.59	0.42	-0.71	-1.58	-1.54	-0.18	-0.89	-0.21	-0.70
Apr	-0.30	-1.22	-0.58	0.41	-0.78	-1.55	-1.51	-0.19	-0.85	-0.25	-0.72
May	-0.25	-1.06	-0.45	0.42	-0.75	-1.38	-1.34	-0.16	-0.76	-0.24	-0.65
Jun	-0.20	-0.91	-0.30	0.43	-0.68	-1.17	-1.14	-0.09	-0.65	-0.21	-0.55
Jul	-0.17	-0.78	-0.18	0.42	-0.57	-0.93	-0.97	0.01	-0.56	-0.19	-0.40
Aug	-0.16	-0.68	-0.11	0.40	-0.45	-0.74	-0.78	0.09	-0.48	-0.17	-0.29
Sep	-0.16	-0.63	-0.07	0.36	-0.37	-0.62	-0.69	0.13	-0.43	-0.19	-0.25
Oct	-0.16	-0.67	-0.08	0.30	-0.33	-0.64	-0.66	0.10	-0.46	-0.20	-0.31
Nov	-0.19	-0.78	-0.20	0.29	-0.37	-0.80	-0.76	0.03	-0.60	-0.18	-0.36
Dec	-0.10	-0.83	-0.21	0.47	-0.31	-0.92	-0.90	0.13	-0.61	-0.07	-0.26

Climate change graphs for 2050s

Change between future (2041–2070) and control (1961–1990) simulated levels at Washpit Farm



Future Flows and Groundwater Levels – SC090016 – Briefing Note for Borehole fact sheets

Overview of the fact sheets and briefing note

The **fact sheets** are designed to provide a **brief overview** on the ability of the river flow or groundwater models to reproduce (simulate) some of the most important components of the water cycle when using observed and modelled climate. This overview is given by sets of **statistics** (measuring the differences between two time series) and **graphs** (providing a visual comparison). Detailed information on the meaning of the statistics and graphs is provided in the **Modelling protocol** report (Crooks et al., 2012, SC090016/PN4) accessible from the FF web pages (www.ceh.ac.uk). This briefing note summarises the **meaning** and **relative importance** of the statistics and graphs. It **does not** provide any **interpretation** for specific catchments/model.

One **fact sheet** is delivered **for each site and river flow / groundwater level model combination.** If two hydrological models are used to simulate flow at the same site, two catchment fact sheets are provided for this site. Note that different models use different methods of **calibration** ranging from **catchment specific** to **regionalised parameters**. The advantage of a regionalised parameter model is to extend the climate range under which the model parameters are evaluated; this is particularly important in a warming climate for catchments where evaporation processes may change from a surplus of summer precipitation over evaporation to a deficit. The advantage of catchment calibrated models is that they are designed to reproduce well the local hydrological processes. The calibration method may affect the statistical measures of model performance.

A fact sheet is divided into three parts. **Top front page**: general information section with the main physical characteristics of the borehole, its location and the availability of observed level data. **Front**: how well level time series are reproduced by the models when using **observed climate**; or a measure of the confidence in the hydrological model. **Back**: how well level time series are reproduced by the models when using **modelled climate**; or a measure of the confidence in the climate/hydrological model combination. **Both front and back** must be looked at to fully understand the factors affecting the Future Flows Hydrology (FFH) time series. This is very important when the FFH time series are used to assess climate change impact on a catchment ecosystem. The FFH level time series are in m.

Front page: Simulation from observed climate

Table

Summary of differences in modelling groundwater levels with observed climate. Differences (except Nash Sutcliffe) are given in metres between statistics calculated from simulated and observed level time series.

Names represent the considered statistics; Lx = difference in level percentile value (i.e. in level exceeded x% of the time); Nash Sutcliffe measures if the modelled time series describes the observed time series better than the long term average. A value of 1 shows a perfect match.

Three parts of the hydrological regime are of interest: (i) Water balance and seasonality, (upper part of table); (ii) Low and high levels (level percentiles L90 to L10), (lower left); (iii) Difference in range in level (%), (lower right).

Differences include measurement errors but generally **the smaller the difference the better the model simulation**.

Graphs

The graphs illustrate how well the model simulates the level time series by plotting together observed and simulated levels.

Two types of graphs are shown:

Hydrographs of groundwater levels for the whole observed period and for two periods representative of contrasting climatic conditions: (i) The 1975-1977 period illustrative of a dry episode and subsequent re-wetting; (ii) The 2000-2001 period illustrative of a wet episode.

They give a visual assessment of the reproduction of different hydrological processes under contrasting conditions (e.g. drying during the recession phase);

Mean monthly levels and **level duration curves**. These graphs provide a visual assessment of how well the long-term variability and seasonality is reproduced by the simulation.

Model performance

Assessment of model performance is given for each of the statistics for the period of groundwater level observations using three Bands as defined in the Modelling Protocol. Interpretation of the performance Bands; (i) Define the purpose for which the Future Flows level time series are being used; (ii) Select the statistics most relevant to the purpose; (iii) Assess the performance bands for these statistics. Where several statistics have performance Band 2 or 3 then particular care should be taken in use of the FFH data.

Because of the year-to-year variability of the climate of the UK (also called climate variability) it is possible that several climate time series differ while representing different plausible realisations of the climate. In addition, because knowledge of the physics of the atmosphere is limited and it is not yet feasible to accurately model small-scale climate features, it is now recommended that several climate models projections are considered together when assessing future projections in hydrology. For both reasons, an ensemble of climate models has been used to drive the FF hydrological models and generate an ensemble of FFH time series for each of the sites. The FFH ensemble is derived from the ensemble of Future Flows Climate (FFC) which contains information on both climate variability and climate modelling uncertainty; **no single projection should be considered in isolation of the others as this might mask some important information given by the other ensemble members**. Note that as FFC is derived from a climate model, the day-to-day sequencing of the climate and resulting levels is **not the same as that of observed levels when directly comparing time series**. Long-term statistics, such as the level duration curves, should match more closely those derived from simulations using the observed climate.

Table

Summary of the differences in metres in modelling groundwater levels with observed and modelled climate (FFC time series; note that FFC is a version of HadRM3-PPE where systematic biases in precipitation and temperature have been corrected, a snowmelt module applied and which has been downscaled at a hydrologically-relevant scale). Naming convention and units are as on the Front page.

Comparisons are made for a 30-year period representative of 1962-1991, called control. This gives an assessment of the difference introduced by the use of modelled rather than observed climate when simulating levels. This is important because FF time series, as they project into the future, can only be derived from modelled climate. These differences help identify two possible features:

Systematic differences in the climate-hydrological chain for a **specific part of the regime**; e.g. if all summer levels show a large difference, this might suggest that modelled summer climate (rainfall and/or potential evaporation (PE)) is different from observed;

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In both cases, the statistics should only suggest caution when interpreting the results of the whole FF ensemble, in particular if runs/periods with large differences in the control period are associated with a future signal different from the rest of the FF ensemble. **Large differences in some statistics of the control runs should not be used to automatically reject one of the ensemble members**.

Graphs

Three pairs of graphs are shown.

Groundwater level surplus and deficit statistics (observed climate)

The top pair shows two additional statistics for groundwater levels, referred to as *surplus* and *deficit*. These are measures of the severity of an extreme event above and below a threshold level. The surplus and deficit are expressed in units of m.days and calculated as:

$$S = \int_{t_1}^{t_2} \left(h(t) - \tau\right) dt, \qquad D = \int_{t_1}^{t_2} \left(\tau - h(t)\right) dt$$

where, τ is the threshold groundwater level, and t_1 and t_2 are the start and end time of the period of extreme groundwater levels, h(t), above or below the threshold. This results in a number of S and D values for a given time-series, and upper and lower threshold values. The distributions of these values, expressed as an empirical cumulative distribution function, calculated from the observed and simulated groundwater level time-series are compared. The threshold values are defined as the 10^{th} and 90^{th} percentile value of the observed groundwater level time-series (shown on the front page).

Mean monthly flows and flow duration curves (modelled climate)

The middle pair shows simulated levels using the observed and modelled climate time series (1962-1991).

Change in mean monthly flow and flow duration curve

The bottom pair of graphs shows the change in metres in mean monthly levels and levels exceeded x% of the time between two 30 year periods - the 1970s (1961-1990) and 2050s (2041 – 2070) for the 11 modelled climate series. The range of change is indicative of uncertainty in the climate modelling.