



River Severn Drought Order Environmental Assessment Report

APPENDICES

August 2026

APPENDICES CONTENTS

ANNEX 1: Habitat Regulations Assessment (separate report)

APPENDIX A: Designated sites in Hydrological continuity with the River Severn.....	3
APPENDIX B: Environmental Flow Indicators explained.....	13
APPENDIX C: Flow Duration Curves (for comparison).....	19
APPENDIX D: Hydrological Technical Report – River Severn Drought Order.....	24
APPENDIX E.1: Acute scenario: Hydrographs.....	123
APPENDIX E.2: Acute scenario: Environmental Flow Indicator FDCs	128
APPENDIX E.3: Acute scenario: Comparison Summary Statistics.....	137
APPENDIX E.4: Acute scenario: Reservoir Operations.....	140
APPENDIX F.1: Chronic scenario: Hydrographs.....	142
APPENDIX F.2: Chronic scenario: Environmental Flow Indicator FDCs.....	146
APPENDIX F.3: Chronic scenario: Comparison Summary Statistics.....	155
APPENDIX F.4: Chronic scenario: Reservoir Operations.....	158
APPENDIX G: Water Quality current environment information.....	160
APPENDIX H: Physico-Chemical Water Quality.....	202
APPENDIX I: SIMCAT Water Quality Modelling Technical Report - Severn Drought Order.....	205
APPENDIX J: Ecological Technical report - River Severn Drought Order.....	230
APPENDIX J.1: Macroinvertebrate HEV & drought response graphs.....	262
APPENDIX K: Fish Technical report – River Severn Drought Order.....	289
APPENDIX L: Water Quality Improvements at Netheridge.....	325
APPENDIX M: Water Quality Assessment of the Upper Severn Estuary (RoC).....	334
APPENDIX N: Recommended Monitoring Programme.....	338
APPENDIX O: Additional Fisheries Information: Severn Estuary HRA.....	358

Appendix A

Designated sites in Hydrological continuity with the River Severn

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
Upper Severn					
1	Plynlimon	SN 790870 SN 830950	SSSI	An important upland area with extensive areas of blanket bog where the River Severn rises. As it's the source of the river is above the regulated stretches therefore the Drought Order will not have any impact on this site. The Environment Agency created additional ponds and wetland sites within this area.	All Flows
2	Dol-Ilys, Llanidloes	SN 9608 8576	County Wildlife Site	An old in-filled oxbow lake. Great crested newts present. Possibly fed by gravels since mimics river levels. Second pond created by NRA below farm (SN 968 859) which is fed by gravels.	All Flows
3	River Severn, Dolwen (including Llandinam gravels)	SO 0219 8804	Montgomery Wildlife Trust Reserve Proposed geological/geomorphological SSSI. Geological Conservation Review (GCR) site	Braided river channel with gravel beds and associated shingle banks (including Llandinam gravels), also contains old oxbows. Conservation importance for invertebrates on shingle banks, birds including little ringed plover, otters and spawning salmonids. Affected by flooding Still not yet designated as a SSSI however is included as one of 19 GCR sites included in the Fluvial Geomorphology of Wales. There is no individual site report available giving further details. Deep pond created by NRA at Lower Gwerneirin farm, Llandinam SO 022 901	All Flows
3b	Pwll Penarth	SO138 126	MWT reserve on STW sewage works	3 acre wetland created by NRA. Water levels in continuity with river levels. Penarth weir holds up river levels	Al flows
4	Red House, Abermule	SO 1499 9398 (EA report SJ 170967)	Montgomery Wildlife Trust Reserve	A large wet meadow including oxbow, river terraces, reed swamp and carr (wet) woodland. This is connected to the river but also gets flooded. The biggest issue affecting this site is the loss of water supply from the canal via leakage due to canal repairs.	All Flows and leakage from Montgomery canal

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
5	Montgomery Canal	SO 139 925 (EA report SJ 245100!)	SSSI and SAC all along its length to Llanymynech for floating water plantain Luronium natans and other aquatic plants and invertebrates	The canal runs adjacent to River Severn to Buttington. It is fed by water taken from the Severn at Newtown, and the River Tanat at Carreghofa. All water abstracted is returned to the River Severn. This site is at risk from low flows in the river. Abstractions which feed the canal are regulated by NRW licenses. This site will be addressed in more detail in the Habitats Regulations Assessment.	All Flows
6	Dolydd Hafren, Forden	SJ 2083 0106	Montgomery Wildlife Trust Reserve	100 acres flood plain, old oxbows, shingle, arable and grassland. Marsh vegetation including Welsh mudwort Limosella australis. Invertebrates associated with shingle and bird interest – little ringed plovers, barn owls. Connected to River Severn flows.	Flood and especially low flows
9	Severn-Vyrnwy confluence	SJ 327 158	No designation but Countryside Agency Land Management Initiative area	Severn Vyrnwy Project was an initiative which created additional wetlands through land management measures such as CSS and HLS. The Environment Agency created additional ponds and wetland sites within this area. SJ279158 and SJ283155	Flood and low flows
10	Loton Loop	SJ 3640 1590 (EA report SJ349167)	Loton Park water Meadows local wildlife site local Wildlife Site (River Severn Melverley to Shrawardine	Floodstorage area High wildlife value including botany, insects and wintering waterfowl. Ditch feeds to and from River Severn therefore is linked hydraulically.	Flood primarily
11	Military training area at Nesscliff	SJ 3700 1600	Potential County Wildlife Site but not designated at present.	Waterfowl and Priority species used site. Southern section definitely hydraulically linked.	All Flows
	River Severn Montford Bridge to Shrewsbury	SJ489141276 3	River Severn Montford bridge to Shrewsbury local wildlife site	Riparian habitats rich in a variety of species including, kingfisher, sand martin, otter, club tailed dragonflies, bats, salmon, trout, eels, lamprey and botanical species	

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
12	River Severn Shrewsbury to Emstrey	SJ5136114113	River Severn Shrewsbury to Emstrey local wildlife site	Riparian habitats rich in a variety of species including, kingfisher, sand martin, otter, club tailed dragonflies, bats, salmon, trout, eels, lamprey and botanical species	
	River Severn Emstrey to Cressage bridge	SJ5704905385	River Severn Emstrey to Cressage Bridge local wildlife site	Riparian habitats rich in a variety of species including, kingfisher, sand martin, otter, club tailed dragonflies, bats, salmon, trout, eels, lamprey and botanical species	Flood primarily
Middle Severn					
12	Attingham Park, Shrewsbury	SJ 552 091	SSSI	Wetland habitats including wet woodland. Monitoring already in place but very basic and only checked once a week. The Environment Agency have working with the National Trust (estate owners) to effect on-going wetland and flood plain habitat improvements associated with the Rivers Tern and Severn.	Flood primarily
13	Cound Brook	SJ 565 062	Local wildlife site	Cound Bk supports white-clawed crayfish, salmon, trout, rich dragonfly assemblage	All flows
14	Cressage	SJ 591 051	River Severn (Cressage bridge to Coalport) local wildlife site-	Siltbed of River Severn with willow carr. Riparian habitats rich in a variety of species including, kingfisher, sand martin, otter, club tailed dragonflies, bats, salmon, trout, eels, lamprey and botanical species	All flows
	River Severn, Leighton	SJ 610 048	River Severn (Cressage bridge to Coalport) local wildlife site- riparian habitats rich in a variety of species	Welsh mudwort <i>Limosella australis</i> found along the banks of the River Severn near Leighton. Otter, club tailed dragonflies, kingfisher, sand martins, bats, salmon, trout, eels	All flows

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
			mentioned in County Flora.		
15	River Severn Meadow (W. Bank)	SO 743 854	Local Wildlife Site	Woodlands and wet meadows, only meadow in hydrological continuity.	All flows but flood primarily
16	River Severn Quatford to Wyre	SO74467853 88	River Severn Quatford to Wyre local wildlife site	Riparian habitats rich in a variety of species including, kingfisher, sand martin, otter, club tailed dragonflies, bats, salmon, trout, eels, lamprey and botanical species	All flows
16	Borle Brook	SO 751 817	Local Wildlife Site	Dingle woodlands, steep sides, wet at bottom. Stream is in continuity with River Severn.	All flows
17	Dowles Brook	SO 778 763	Included in Wyre Forest SSSI	The brook provides varied habitat, with the banks being good for bryophytes. White-clawed crayfish, salmon, bullhead, and brook lamprey present in stream.	All flows
18	Grimley Brick pits.	SO 840 605	SSSI	This site consists of a number of old clay workings on the banks of the River Severn. Wide range of wetland habitats and important for specialised aquatic plants, wintering wildfowl and breeding bird assemblages as well as a varied invertebrate fauna. They remain wet because of seasonal flooding and impeded drainage.	Flood primarily
19	Northwick Marsh	SO 835 579	SSSI and Special Wildlife Site	Species-rich marsh occupying disused brick-pits, used for grazing. Site also includes part of the river bank. Marsh is extensively flooded in winter and spring.	All flows but primarily flooding
20	River Teme	SO 121 848 to SO 850 525	SSSI (also supports Habitat Directive species)	Second largest tributary of the River Severn. Represents near-natural biologically rich river type associated with sandstone and mudstone. Supports significant river plant, fish, bird and invertebrate communities and also otters. EC Habitats Directive Species: twaite shad; sea lamprey; salmon; bullhead, grayling and white-clawed crayfish.	All flows
21	River Clun	SO 395 767 to SO 402 738	SSSI and SAC	Stream, floodplain, grassland and woodland of 14.93 ha. Designated a SAC due to presence of Freshwater Pearl Mussel <i>Margaritifera margaritifera</i> which are dependent on low sediment and nitrate levels, fast flows of cool water and clean gravels. It also relies on the	All flows

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
				presence of trout and Atlantic salmon for part of its breeding cycle therefore the river's hydrological continuity with the River Severn and the estuary is important. Also supports white-clawed crayfish, brook lamprey, bullhead and otter. This site will be addressed in more detail in the Habitats Directive Assessment	
22	Droitwich Canal	SO883625, SO922630, SO848599	Special Wildlife Site	Canal supporting salt loving flora. Tributary of River Severn.	All flows
23	Staffordshire & Worcestershire Canal	SO830763 SO853819 SO810710	Special Wildlife Site	Canal supporting wildlife. Tributary of River Severn.	All flows
24	The Werps, Banks of River Severn	SO 670 040	County Wildlife Site	River bank.	All flows
25	Shrawley Wood	SO 808660	SSSI	A large tract of ancient woodland with streams & pools in connectivity with River Severn which add to the site's conservation interest	All flows
26	Redstone LNR (The Bogs)	SO 811703	LNR and Special Wildlife Site	Marshland and flood plain adjacent to River Severn.	Flood primarily
27	Bournes Dingle and Turnmill Pond Complex	SO841618	Special Wildlife Site	Mosaic of habitats including wetlands adjacent to the River Severn.	Flood primarily
Lower Severn					
28	Upton Ham	SO 860 400	SSSI	Unimproved flood meadow, regularly flooded during the winter. Good for waders. White-legged damselfly and club-tailed dragonfly breed along this section of river.	Flood primarily
29	Severn Ham	SO 885 325	SSSI	Traditionally managed flood meadow subject to annual winter flooding	Flood primarily

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
30	Old River Severn, Upper Lode	SO 880 331	SSSI, Special Wildlife Site	Old meander in the River Severn cut off from the main river when the Upper Lode lock was constructed; it now forms a quiet backwater; only linked to the Severn at its southern end.	All flows
31	Mythe Composite Site	SO 886 343	Key Wildlife Site	Lakes, gravel pits, reservoirs & Mythe Brook. Directly adjacent to River Severn	All flows
32	Ripple Meadow	SO 869 362	Special Wildlife Site	Improved flood meadow.	Flood primarily
33	Queenhill Brickpit and Uckingham Pool	SO 863 374	Special Wildlife Site	Pool on western bank of River Severn supporting rich flora	All flows
34	Brickpits Plantation & Sandford Pits	SO 846 446	Special Wildlife Site	Disused brickpits with a carr fringe; adjacent to River Severn.	All flows
35	Clifton Arles Complex	SO 847 455	Special Wildlife Site	Wet woodland on flood plain of River Severn.	Flood primarily
36	Ashmoor Common	SO 854 464	SSSI	Marshy grassland floodplain with wetland bird interest. Site is important for studies of river landform and history of the River Severn	Flood primarily
37	Kempsey Upper Ham and Lower Ham	SO 849 498, SO 845 484	Special Wildlife Sites	Improved River Severn meadow. Improved alluvial hay meadow adjacent to the River Severn	Flood primarily
38	Gloucester & Sharpness Canal	SO 750 088	Key Wildlife Site	Canal; tributary of River Severn.	All flows
39	Severn Stoke Meadow	SO 851 443	Special Wildlife Site	Alluvial flood meadow; now arable	Flood primarily
40	Ripple Lake & Napps	SO 874 364	Special Wildlife Site	Wet woodland; close to River Severn	All flows
41	Coombe Hill Canal	SO 870 269	SSSI	Disused canal with a range of flanking habitats. Supports a variety of rare plants and invertebrates, particularly beetles. Situated in a low	All flows but flood primarily

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
				lying area of the River Severn floodplain and whole area subject to extreme winter flooding.	
42	Ashleworth Ham	SO 833 263	SSSI	Grassland of the Severn floodplain. Important refuge for wintering wildfowl. Floods annually.	Flood primarily
43	Chaceley Meadow	SO 857306	SSSI	Unimproved herb-rich neutral grassland occasionally flooded in winter.	Flood primarily
44	Sud Meadow	SO817187	Key Wildlife Site	Semi-natural grassland classified as grazing marsh. Directly adjacent to River Severn.	Flood primarily
45	Alney Island	SO 820 190	LNR	Flood meadows adjacent to River Severn.	Flood primarily
46	Over Ponds & Osier Bed	SO 820193, SO 817194	Key Wildlife Site	Ponds and willow carr; part of Alney Island Local Nature Reserve; in the middle of River Severn.	All flows
47	Walham Ponds (Maisemore) Brickpits	SO 825204	Key Wildlife Site	Wet woodland directly adjacent to River Severn.	All Flows
48	Longford Brickpits	SO 826210	Key Wildlife Site	Lakes, gravel pits and reservoirs with bird and invertebrate interest. Adjacent to River Severn.	All flows
49	Ashleworth Quay Brickpits	SO 819249	Key Wildlife Site	Wet woodland directly adjacent to River Severn.	All flows
50	Sandhurst Brickpits	SO 817233	Key Wildlife Site	Wet woodland directly adjacent to River Severn.	All flows
51	Groundless Pool	SO 791161	Key Wildlife Site	Pond directly adjacent to River Severn; designated for plant interest.	All flows
52	Small Reserve	SO 855287	Key Wildlife Site Gloucestershire Wildlife Trust	Mud-flat of River Severn; bird interest.	All flows
53	Walmore Common	SO 753 154	SSSI, SPA and Ramsar.	Unimproved and improved neutral grassland, marshy grassland and open water ditches. Holds internationally important numbers of Berwick's Swans over winter. This site will be addressed in more detail in the Habitats Directive Assessment	All flows

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
54	Severn & Avon Vale Project		No designation but Countryside Agency Land Management Initiative area	The Severn Avon Vale Project was an initiative which created additional wetlands through land management measures eg CSS and HLS and the Agency has created numerous additional ponds and wetland sites within this area.	Flood primarily
Severn Estuary					
55	Beachley & Sedbury Saltmarshes	Key Wildlife Site	ST 546906	Saltmarsh with plant and invertebrate interest; on banks of the River Severn.	All flows
56	Purton Timber Ponds	Key Wildlife Site	SO683038	Lakes, gravel pits and reservoirs; part of Gloucester and Sharpness Canal, near to canal mouth.	All flows
57	Beachley Grassland	Key Wildlife Site	ST 545922	Grazing marsh & ditches adjacent to the River Severn.	All flows
58	Sharpness Docks	Key Wildlife Site	SO 675025	Quay and dismantled railway designated for plant interest. Quay only (small proportion of the site) could be affected.	All flows
59	Severn Estuary	SSSI, SPA, Ramsar & cSAC	ST 480830	The Severn Estuary forms part of a larger area which includes the Upper Severn Estuary SSSI, Taf/Ely Estuary SSSI and Birdgewater Bay NNR and proposed SSSI. This larger area is also a Special Protection Area and part is a Special Area of Conservation and Ramsar site. The Severn Estuary lies on the south west coast of Britain at the mouth of four major rivers (the Severn, Wye, Usk and Avon) and many lesser rivers. The immense tidal range (the second highest in the world) and classic funnel shape make the Severn Estuary unique in Britain and very rare worldwide. The intertidal zone of mudflats, sand banks, rocky platforms and saltmarsh is one of the largest and most	All flows

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
				important in Britain. The estuarine fauna includes: internationally important populations of waterfowl; invertebrate populations of considerable interest; and large populations of migratory fish, including the nationally rare and endangered Allis Shad <i>Alosa alosa</i> . This site will be addressed in more detail in the Habitats Directive Assessment	

Appendix B

Environmental Flow Indicators explained

Environmental Flow Indicator

What is the EFI?

- The Environmental Flow Indicator (EFI) plays a crucial role in the management of Water Resources
- The EFI is defined as a percentage deviation from the natural river flow represented using an annual flow duration curve (FDC). This percentage deviation is dependent on two factors: the actual flow as represented on the FDC, and an assessment of the ecological sensitivity of the river to changes in flow
- EFIs are used to indicate where abstraction (and flow regulation) pressure may start to cause an undesirable effect on river habitats and species. They don't indicate where the environment is damaged from abstraction
- Non-compliance with the EFI helps to indicate where flow may not support Good Ecological Status (GES) under the Water Framework Directive (WFD)
- In Abstraction Licensing Strategies (ALS) EFIs help to indicate where water may be available for future abstraction without causing unacceptable risk to the environment

Development

The UK Technical Advisory Group on the WFD (UKTAG) is responsible for developing environmental standards and conditions to underpin implementation of the WFD. Proposed environmental standards for river flow were first developed as part of a project undertaken for UKTAG in 2005-2006 (Acreman et al, 2005). These proposed standards were then directly used by UKTAG¹ and are available on the UKTAG website.

The standards vary by river type and flow with, for example, a more stringent standard at lower flows and for river types deemed to be more sensitive to abstraction. They identify percentage deviation from natural flow (that supports GES) for differing river 'types' and at different flows: low flows (Q95) and flows above Q95. A summary of the outputs from this report is given in Table 1

River type	Flow > Q95		Flow < Q95	
	<i>Mar - Jun</i>	<i>Jul - Feb</i>	<i>Mar - Jun</i>	<i>Jul - Feb</i>
Predominantly clay. South East England, East Anglia and Cheshire	25%	30%	15%	20%
Chalk catchments; predominantly gravel beds; base-rich	15%	20%	10%	15%
Hard limestone and sandstone; low-medium altitude; some oligotrophic hard rock	20%	25%	15%	20%
Non-calcareous shales; pebble bedrock; Oligomeso-trophic; Stream order 1 and 2 bed rock and boulder; ultra-oligo trophic torrential	15%	20%	10%	15%
	<i>Oct – Apr</i>	<i>May – Sep</i>	<i>Oct - Apr</i>	<i>May - Sep</i>

¹ [UK Environmental Standards and Conditions Report \(Phase 1\) | wfd uktag](#)

Salmon spawning & nursery (not chalk rivers)	15%	20%	10%	15%

Table 1: Flow standards for UK river types for supporting good ecological status given as the percentage allowable abstraction of natural flow (UKTAG, 2008).

These UKTAG river flow standards were translated into the EFI for use in England and Wales as part of the Resource Assessment Methodology (RAM) framework (AMEC 2013). This adaptation was necessary for use within the Environment Agency's existing abstraction regulatory regime. As part of this approach, the UKTAG river types were translated into Abstraction Sensitivity Bands (ASBs).

There are three abstraction sensitivity bands assigned to each water body in England and Wales: ASB1 – low sensitivity; ASB2 – moderate sensitivity, and ASB3 – high sensitivity. Each of the ASB allows a different deviation from natural flow, allowing less abstraction in water bodies of higher sensitivity and more in water bodies of lower sensitivity. Each of these sensitivity bands was developed from assessment of 3 components: Physical typology, Macroinvertebrate typology, and Fish typology.

The EFI is assessed at four conditions, ranging from naturally low flows (Q95, the flow which is exceeded 95% of the time) to naturally higher flows (Q30, the flow which is exceeded 30% of the time). Table 2 shows the percentages of flow that can be abstracted at three different sensitivities to abstraction (abstraction sensitivity bands) at different flows.

	high flow		low flow	
Abstraction Sensitivity Band	Q30	Q50	Q70	Q95
ASB3. high sensitivity	24%	20%	15%	10%
ASB2. moderate sensitivity	26%	24%	20%	15%
ASB1. low sensitivity	30%	26%	24%	20%

Table 2: Percentage allowable abstraction from natural flows at different abstraction sensitivity bands.

Use in Abstraction Licensing Strategies

Abstraction Licensing Strategies (ALS) set out how the Environment Agency will license new abstractions and manage existing abstractions to meet environmental obligations – in particular, water body objectives set out in the River Basin Management Plans. In the ALS, the EFI helps to indicate where water may be available for future abstraction without causing risk to the environment. Water availability is detailed in these licensing strategies developed for each catchment which are available on the www.gov.uk website. This is based on resource availability assessments expressed as a surplus or deficit of water resources in relation to the EFI. This is calculated by taking the natural flow of a river, adding back in discharges and taking away existing abstractions. From this 'scenario flows' can be produced showing predicted river flow at both recent actual and fully licensed rates of abstraction. The difference between the fully licensed scenario flow and EFI shows the amount of water which is available for abstraction and when it is available.

The strategies set out the hands off flow and other conditions that will be applied to licences. 'Hands-off flows' allow a more effective use of water from the environment by enabling abstraction to cease at set flows, but also enable abstraction from periods of time when more water is available.

The strategies also include any local constraints that potential abstractors will need to be aware of such as higher levels of environmental protection for designated conservation sites, or where local information has

shown that different amounts of water are available in the catchment.

Use in Water Body Classification

The EFI is used in the hydrological classification to identify the water bodies where reduced river flows may be causing or contributing to a failure of good ecological status. This is called the flow compliance assessment and it is carried out for each WFD water body. Compliance is assessed at low flows (Q95) using recent actual abstraction scenario.

The flow compliance assessment shows where specific scenario flows are below the EFI, and indicates by how much. This is used to identify where flows may not be supporting good ecological status (GES) and target further investigation of what measures are needed to achieve GES.

The degree of non-compliance has been split into three compliance bands, each band indicating the level of certainty that flow conditions does not support GES. The compliance bands help to prioritise action where the abstraction pressure, and therefore the risk of not supporting GES, are greatest. The percentage below natural flow for each compliance band is shown in Table 3.

	Flow adequate to support GES	Flow not adequate to support GES: Moderate Confidence		Not adequate to support GES: High Confidence
Abstraction Sensitivity Band	<i>Compliant with EFI</i>	<i>Non-compliant Band 1</i> (up to 25% below the EFI at Q95)	<i>Non-compliant Band 2</i> (25-50% below the EFI at Q95)	<i>Non-compliant Band 3</i> (more than 50% below the EFI at Q95)
ASB3 high sensitivity	<10%	<35%	<60%	>60%
ASB2 moderate sensitivity	<15%	<40%	<65%	>65%
ASB1 low sensitivity	<20%	<45%	<70%	>70%

Table 3: The percentage difference from natural flows for each compliance band and how this relates to supporting good ecological status (GES). Percentages given are the range below natural flow for the relevant abstraction sensitivity band.

Glossary

Abstraction Sensitivity Bands (ASB)	There are three possible abstraction sensitivity bands assigned to each water body in England and Wales: ASB1 – low sensitivity; ASB2 – moderate sensitivity and ASB3 – high sensitivity. Each of the ASB has a different EFI associated with it allowing less abstraction in high sensitive sites and more in sites with lower sensitivity. Each of these sensitivity bands was developed from assessment of 3 components: Physical typology – using river ‘types’. Macroinvertebrate typology – using expected Lotic index for Flow Evaluation (LIFE) scores Fish typology – using identification of a fish ‘guild’ expected under particular physical parameters. Scores and confidence ratings from each component are combined to give the overall ASB for the waterbody.
Good Ecological Status	Good Ecological Status (GES) defines a water body as only being a little way from being in its totally natural state. GES covers a variety of elements that give an indication of the health of a water body and its ability to support life. Hydrology is a supporting element for good ecological status - but in some situations, flow may be the limiting element for biology and for achieving good ecological status.
Natural Flows	The river flow that would have occurred without any human influences. This is calculated by starting with a gauged flow/recent actual flow and adding back in the abstractions and taking out the discharges. It can also be calculated from other surface water or groundwater models.
Scenario Flow	The scenario flow that is generated by denaturalising the natural flow taking into account abstractions and discharges operating at their recent actual rate (recent actual scenario) or abstractions operating at their full licensed limit and discharges operating at their recent actual rate (fully licensed scenario).
Waterbody	A manageable unit of surface water, being the whole (or part) of a stream, river or canal, lake or reservoir, transitional water (estuary) or stretch of coastal water. A ‘body of groundwater’ is a distinct volume of underground water within an aquifer.

External References

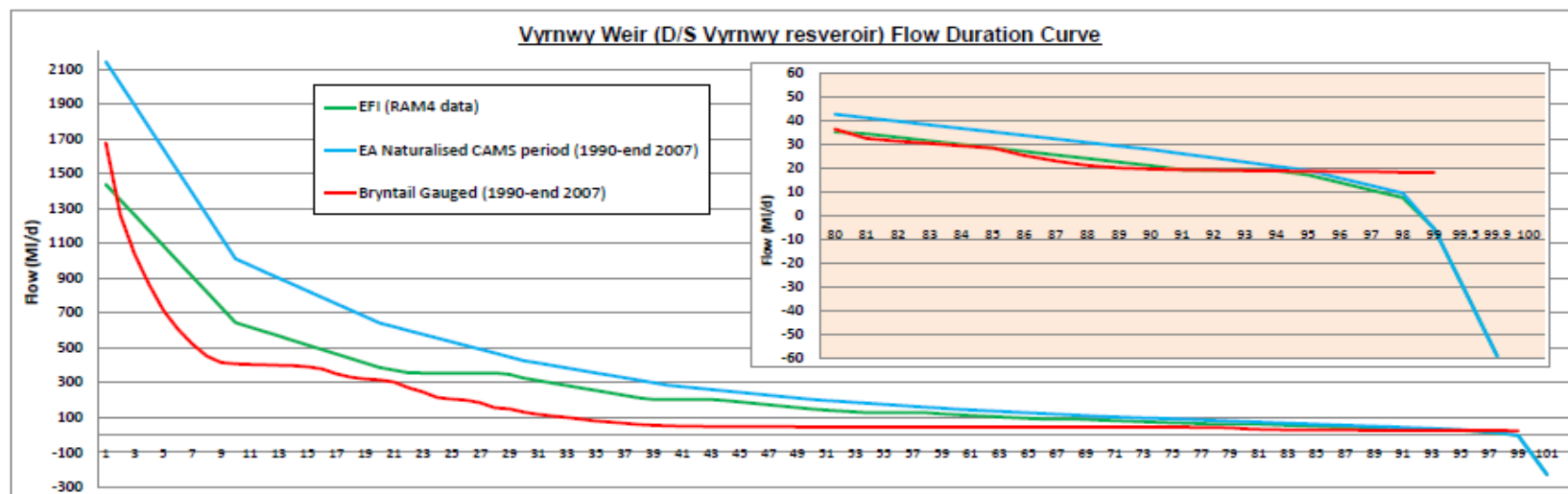
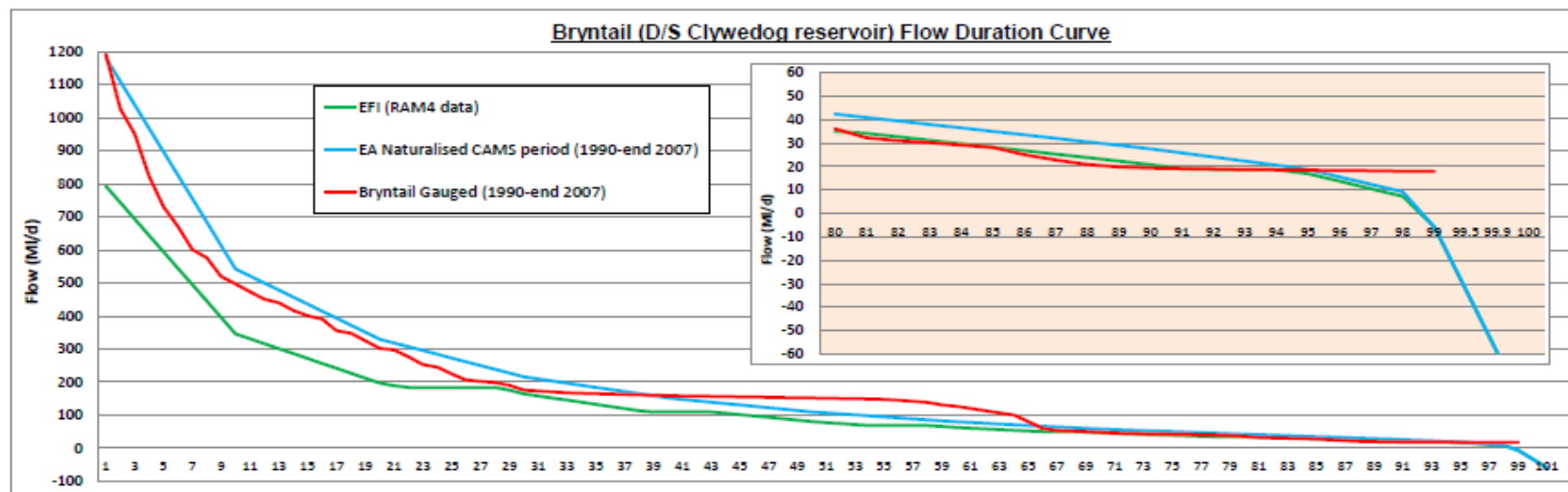
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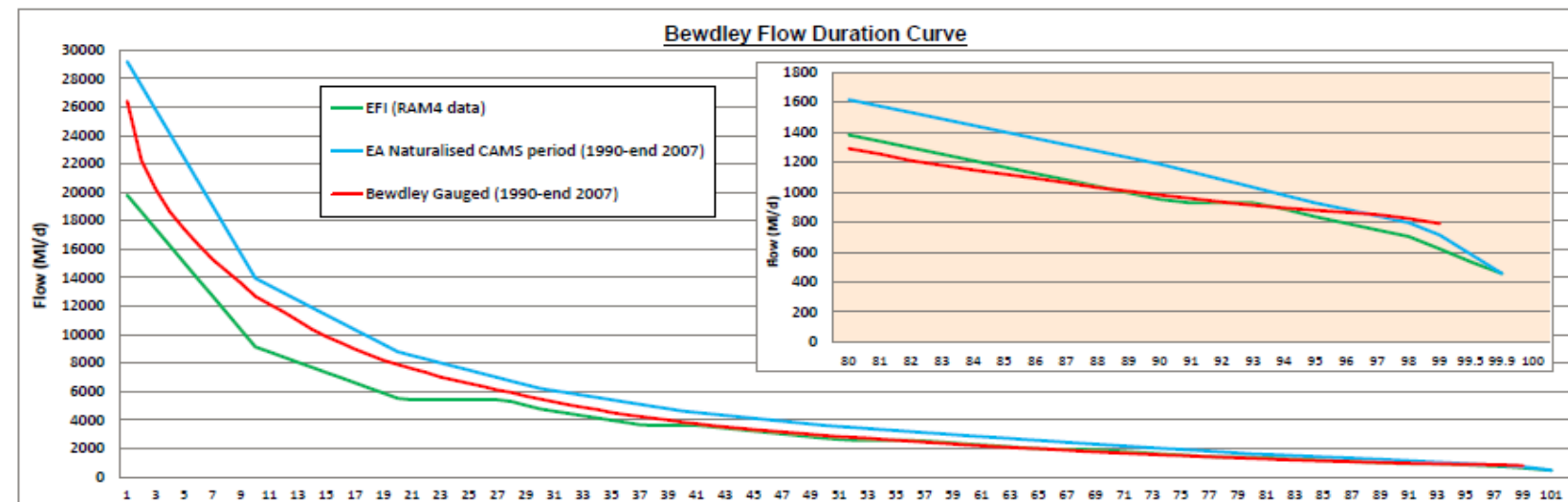
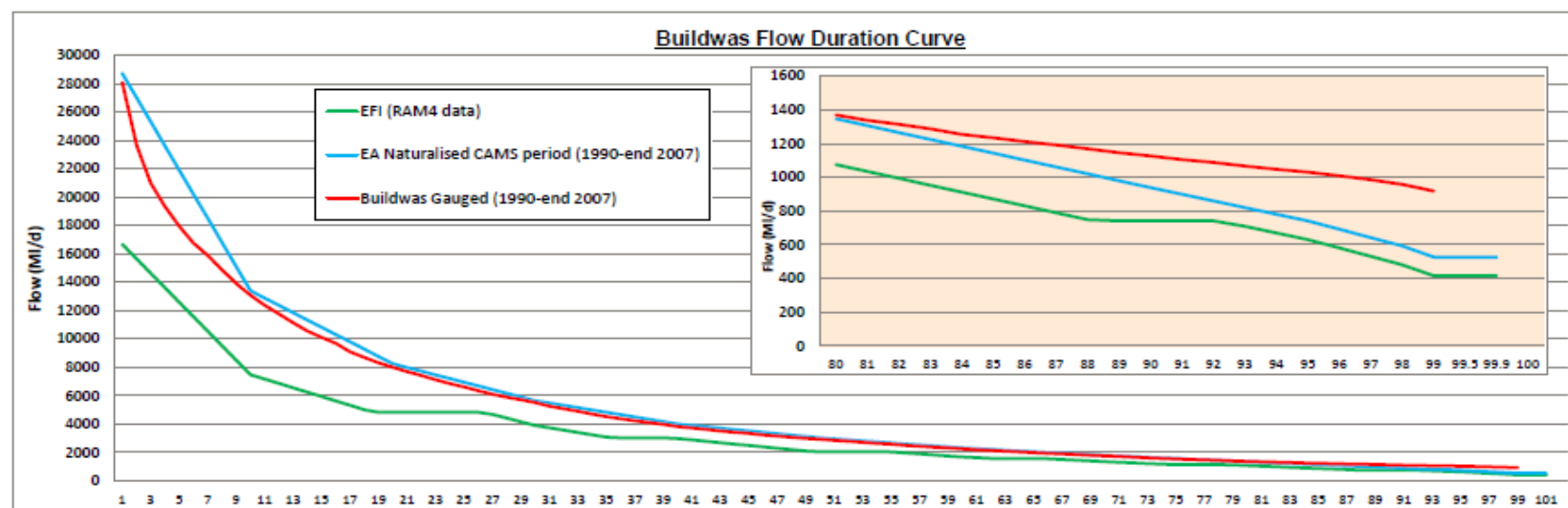
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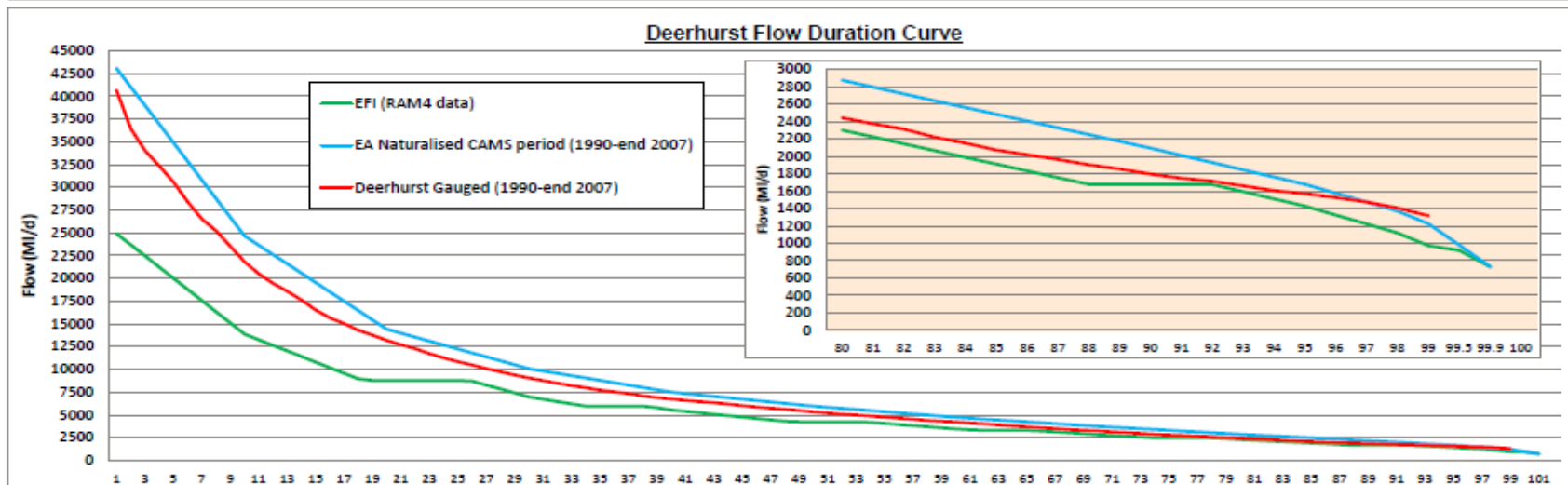
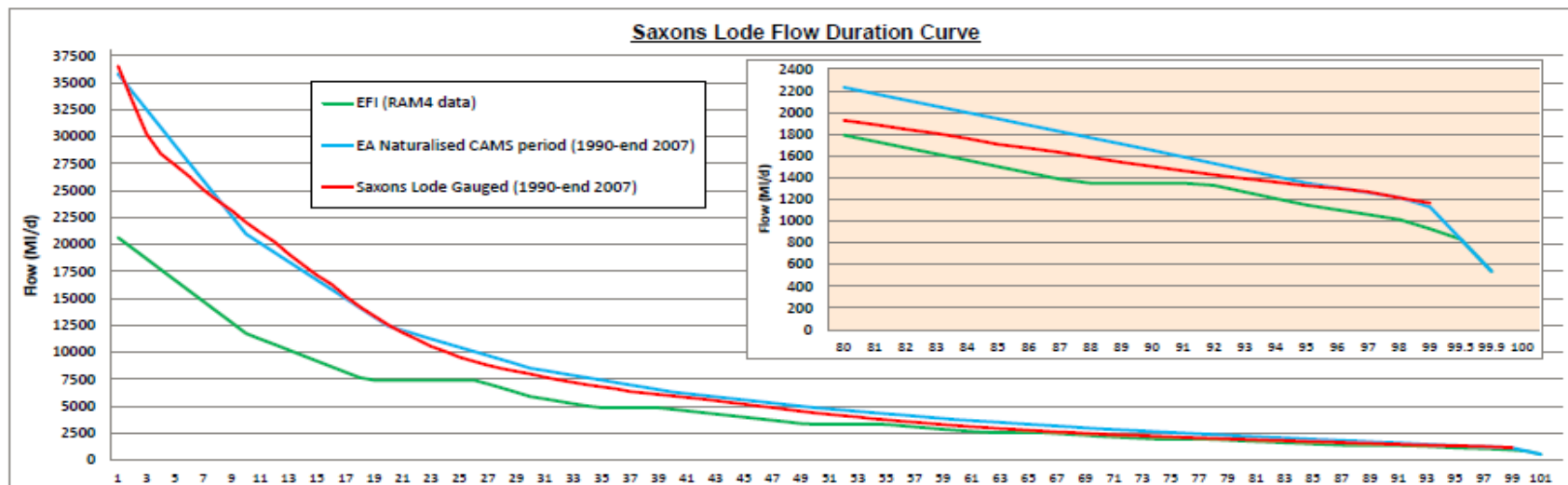
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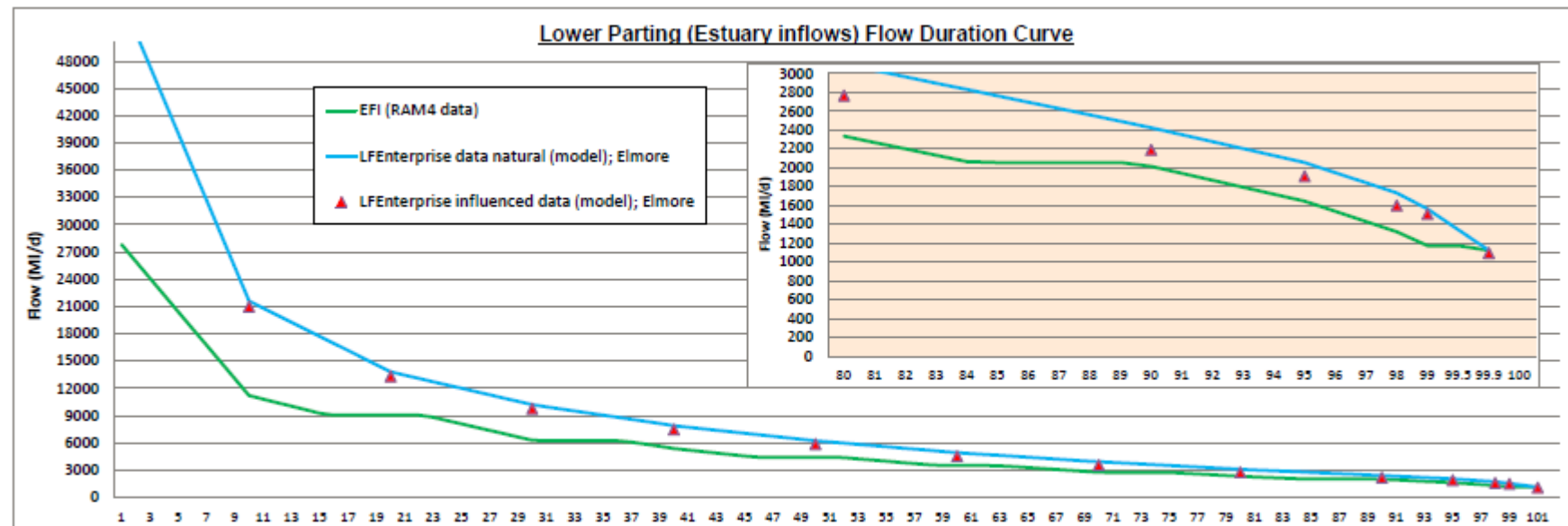
Appendix C

Flow Duration Curves (for comparison)









Appendix D

Hydrology Technical Report – River Severn Drought Order

RIVER SEVERN DROUGHT ORDER: HYDROLOGY ASSESSMENT

SUMMARY

The River Severn Drought Order is the Environment Agency's last resort option to manage the ongoing development of a critical drought event, encompassing a dual purpose of maintaining public water supply and supporting the environment along the main River Severn. It aims to extend the length of time regulation releases can be made in the absence of significant rainfall by carefully managing remaining storage in Llyn Clywedog reservoir. The River Severn Drought Order primarily lowers River Severn flows in the short term in order to protect against the magnitude of potential regulation failure should the drought persist beyond the systems design capabilities and protecting against a subsequent dry winter and lack of recharge to safeguard the following years water resources.

The River Severn Drought Order has been operated in different forms during 1976, 1984 and 1989. Conditions along the River Severn have altered significantly since the last operation, with increased abstraction demands, higher prescribed flows at Bewdley (as part of the regulation operation), improved water quality, greater emphasis on environment protection and changing organisations and responsibilities amongst the core regulation group.

Adopting the worst case precautionary approach, if the Severn Drought Order were not operated ('Do Nothing' scenario) and a drought continued long enough, water in Clywedog could be exhausted and subsequently the Regulation System would quickly fail (failure to meet prescribed flows at Bewdley) causing significant flow crashes. The upper River Severn is likely to dry up as reservoir releases fail, the whole River Severn would experience record minimum low flows and sections of the lower River Severn (upper Estuary outside the Natural Site Network) could also be at risk of drying up, depending on the operations of the Gloucester and Sharpness Canal and remaining baseflow. Water levels would be significantly depleted, causing localised loss of habitat, higher sediment deposition, dissolved oxygen problems and creating extensive barriers for fish migration and boat navigation.

Alternatively, during a 'Do Nothing' Acute (one summer impact) event, if the drought did not continue long enough to reach regulation failure then flows would be maintained at normal statutory requirements, which would be more beneficial to the environment and water users than operating the River Severn Drought Order. However, this option would be a game of chance, if a drought continued the consequences of not managing remaining water resources could be serious and impact subsequent years, shown by the lower minimum flows under the Chronic 'Do Nothing' scenario. The Severn Drought Order is only activated once storage in Llyn Clywedog has already reached critically low levels, conditions not experienced since 1989, with non-regulated rivers likely to be already seriously impacted.

Modelling operation of the River Severn Drought Order under an Acute and Chronic drought scenario, indicated regulation failure cannot be prevented but the impacts can be reduced. Flows under the River Severn Drought Order operation were maintained above the modelled 'Do Nothing' scenario after regulation failure began, supporting the need for the Severn Drought Order to limit the severity of prolonged droughts. In the case of the Chronic scenario, operating the Severn Drought Order in the first year safeguards enough water to potentially protect against regulation failure and significantly increase minimum flows in a subsequent year. Also restoring more varied flows in the upper reaches of the River Severn earlier than the 'Do Nothing' scenario.

The actual impact of the River Severn Drought Order alone (up until regulation failure) would be a reduction in flows along the whole River Severn by a minimum 120 Ml/d during the

peak of a drought, modelled at an average 140 MI/d to counter in human tolerance (forecast errors, public water supply abstraction changes etc). The actual impacts on the environment and water users would be limited and localised if this were the only alteration. If regulation failure were reached, the Severn Drought Order maintained higher flows, benefiting the environment and water users. The additional volume provided per day would be dependent on factors at the time, such as baseflow, remaining Regulation resources and length of the drought.

In reality, droughts of these severities will involve a full range of impacts to consider, the true magnitude and duration of which cannot be predicted with certainty until a real event. The worst affected reach would be the Lower Tidal Severn, and particularly around the channel split in Gloucester. The degree of impact will vary significantly according to the Gloucester and Sharpness Canal abstraction volumes. Close liaison and cooperation between all the partners involved would be required and all options to mitigate the impacts discussed. Once again, if regulation failure were reached, the Severn Drought Order could maintain higher flows than 'Do Nothing' and help safeguard some flows into the Severn Estuary.

River Severn Hydrology: Current Environment

Flow gauge information			Flow gauge statistics 1990-2007 (MI/d)*				Notes on data quality
Gauge name	River	Record start date	Q95	Q50	Q5	BFI	
Bryntail (2109)	Clywedog	01/06/1977	19	152	730	0.48	Data quality good at all ranges, perhaps lacking more low flow spot flow gauging verification.
Dolwen (2118)	Severn	13/06/2000	85	355	1916	0.44	Site can suffer from silt build up and drowns out at highest flows.
Abermule (2014)	Severn	01/06/1962	170	677	4574	0.44	Good gauge for all flows. Some problems associated with weed growth along banks. Some evidence that flows occur through the gravel bed.
Vyrnwy Weir (2003)	Vyrnwy	01/01/1920	25	47	715	0.36	Reliable gauge producing good quality data at most flows. Not prone to drown out.
Llanyblodwel (3038)	Tanat	11/05/1973	48	314	2115	0.48	Good reliable gauge with slight over estimation at highest flows.
Llanymnech (2028)	Vyrnwy	17/12/1969	232	958	6707	0.44	Reasonable gauge although not all high flows can be measured. Site has become unstable since gravel removed from bed.
Montford (2005)	Severn	01/10/1953	643	2084	14066	0.48	Site rated as fair. Reliable but very prone to weed growth.
Buildwas (2134)	Severn	01/03/1984	1030	2927	17955	0.56	Reliable gauge producing good quality data at most flows.
Bewdley (2001)	Severn	01/04/1921	881	2904	17424	0.53	Reliable gauge producing good quality data at most flows.
Saxons Lode (2032)	Severn	05/06/1970	1327	4372	27381	0.57	Good at low flows with a fall in quality towards higher flows, still rated as fair. Site affected by high tides and tidal gates on the Avon.
Deerhurst (2606)	Severn	01/12/1995	1571	5327	30600	0.57	Caution needed at the high flow end but low flow recording of good quality. Can cope with tides/reverse flows.
Haw Bridge	Severn						Caution needed due to tidal impacts and substantial bed movement.

River Severn Catchment

The River Severn is the longest in Great Britain at 354km, with the second greatest tidal range in the world (14.5 meters). It rises on the slopes of Plynlimon in the Cambrian Mountains of Wales and flows first southwards through the Hafren Forest to Llanidloes, where the River Clywedog joins. It then flows north-eastwards, meandering through a broad valley before emerging onto the Shropshire floodplain, at its confluence with the River Vyrnwy. From here it flows eastwards to Shrewsbury, enclosing the town in a large loop, before turning to flow south-westwards through the narrow Ironbridge Gorge and onwards to Bridgnorth. The River Severn then passes from Shropshire into Hereford and Worcester in a southerly direction where it deepens and widens, and continues over the Gloucestershire border to Tewkesbury and Gloucester. At this point the river is subject to a tidal influence from the Severn Estuary. It then flows in a south-westerly direction and begins to widen out into the upper estuary downstream of Longley, before discharging into the sea in the Bristol Channel.

It's highly artificial, covers various geologies and topographies, and particularly around the Estuary remains highly dynamic. The River Severn provides countless micro habitats and flow niches; attempting to model and assess the impacts on every reach and niche would be inappropriate and without baseline data, highly inaccurate.

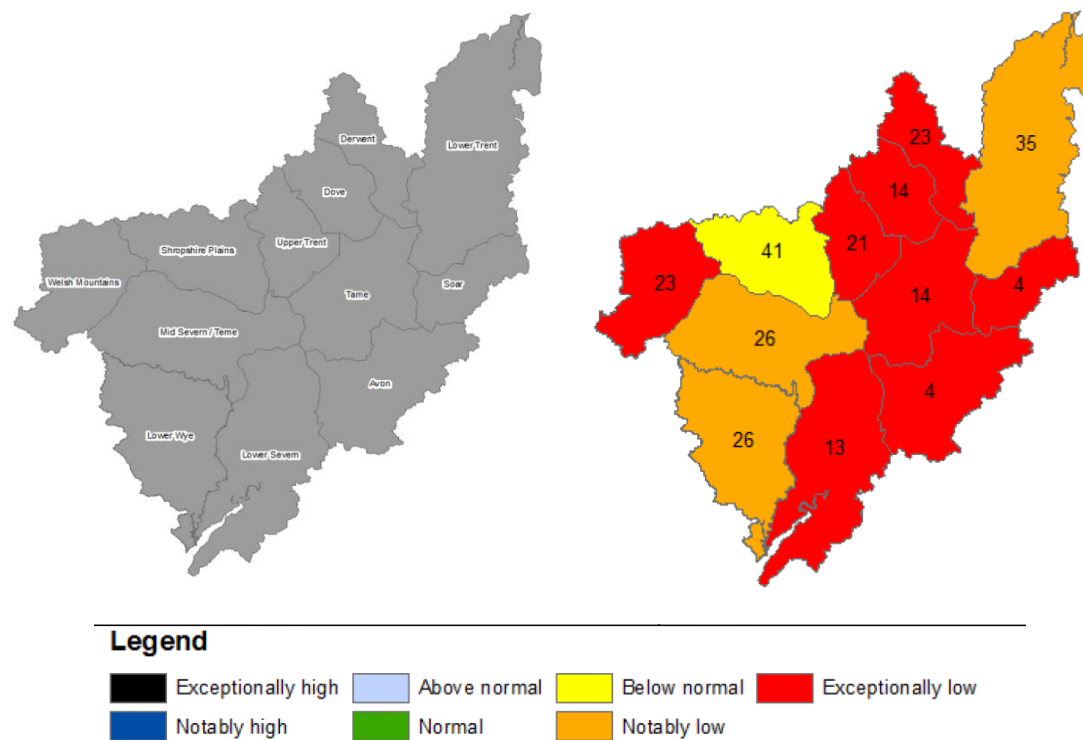
Rainfall

Within the Severn catchment, rainfall generally decreases from north to south and from west to east. Superimposed upon this pattern is a marked increase in rainfall totals with altitude. Annual totals average up to 2400 mm on the high ground around the headwaters of the Severn, decreasing to below 700 mm on the North Shropshire Plain and to less than 600 mm around the head of the Severn Estuary. When compared to population density, the highest water demand is located in the area's receiving lower rainfalls. Annual variability can be large with a standard deviation of 100 mm being common for mean annual totals of 600 to 700 mm.

The Environment Agency use Long Term Average (LTA) rainfall figures based on the 1961-1990 period to assess whether a shortage or abundance of rainfall has been received over a catchment each month. This helps predicts the onset of drought (or flood) conditions and enables planning to help prepare and mitigate against the worst impacts. The Severn catchment is split into 6 rainfall catchment areas for reporting, shown in the wider context of the West Midlands area in Figure 4;

Welsh Uplands
Shropshire Plains
Mid Severn/Teme
Avon
Lower Severn
Lower Wye

Figure 1: West Midlands Area Rainfall Catchments



Total rainfall for the 12 hydrological areas across the Midlands for the current month. Figures are percentage relative to historic averages. TBR rainfall data based on 1 km gridded rainfall dataset derived from rain gauges. Environment Agency, 100026380, 2018.

Figure 1 is taken from the June 2018 Midlands Water Situation Report, produced by the Environment Agency.

Winter rainfall and associated run off normally generates sufficient flows to meet the seasonal abstraction and environmental demands placed on the River Severn. However, during most summers flows have to be augmented by releasing water from the River Severn Regulation System. The combination of complex abstractions and Severn Regulation makes the River Severn a heavily influenced and artificial watercourse.

Flows

Flows downstream of both Llyn Clywedog and Lake Vyrnwy are subject to large and often sudden variations in flows, as releases are altered to satisfy downstream need. Both sites conform to minimum flow requirements to protect the environment as much as possible; Llyn Clywedog requires 18.2 MI/d be maintained while Lake Vyrnwy requires 41.876MI/d, although currently if Cownwy Weir (parallel tributary) flows exceed 20 MI/d then releases directly from Lake Vyrnwy can be reduced to 21.876 MI/d.

Regulation releases can be seen through steps in the flow duration curves for some distance downstream of the major reservoirs, increasing flows significantly above what would naturally occur. Releases have largely smoothed out or been removed (abstracted) by Bewdley, although volumes at low flows remain elevated above natural downstream of Bewdley. This artificial elevation in flows, particularly low

flows, illustrates what the Severn Regulation system is designed to achieve, balancing abstraction needs with environmental protection.

Assessment Points: Hydrology current environment

Bryntail is a heavily artificial flow site, the flat V weir is constructed directly downstream of Llyn Clywedog on rock immediately downstream of the Van Lode fault. The 49km² catchment is largely afforested and steep, draining Ordovician and Silurian shales and slates whilst being substantially Drift free. The steep topography and geology combine with the high rainfall to make the catchment naturally flashy, although the reservoir storage smooths the effects.

Flows at Bryntail are constantly impacted by regulation, Hydropower, flood and other releases from the reservoir. Appendix C contains the naturalised and gauged flow duration curves and illustrates how the high to mean flows are reduced and then returned to the system in a stepped approach from mid to low flows. The flow regime is affected and natural flow variation lost, but Q95 (flow exceeded for 95% of time) and lower flows (often dry weather/drought related) are protected and raised above what would naturally occur. Subsequently, the environment and ecology is prevented from experiencing drought conditions, as the compensation flow of 18.2 Ml/d is maintained.

Vyrnwy Weir is a rectangular notch weir located directly downstream of Lake Vyrnwy, a reservoir built to provide water supply to Liverpool. The catchment artificially incorporates nearly all the flows from the Cownwy and Marchnant tributaries, which have recently been amended so that 25% of the flow plus a hands-off flow continues to flow past the abstraction point and into the River Vyrnwy downstream of the gauging station. The 94.3km² (natural catchment size excluding the Cownwy and Marchnant) catchment is steep and notably wet, draining Drift free Silurian and Ordovician slates and shales. The topography and geology make the catchment very responsive to rainfall.

Flow is artificial, particularly dominated by controlled releases from the reservoir during low flows. Appendix C contains the naturalised and gauged flow duration curves and also illustrates how the high to mean flows are reduced. However, unlike Clywedog, due to the large public water supply abstractions from Vyrnwy, the mid to lower flows do not display the same stepped return of flows to the system, as the majority of this water is transferred directly out of the catchment. The benefits from the compensation flow are displayed in the more infrequent percentiles, Q95 flows are protected and raised above what would naturally occur.

Buildwas is a multiple ultra-sonic cross-configuration gauging station, just upstream of Ironbridge gorge in Shropshire. The 3723.7km² catchment is a diverse mixture of moorland and forestry in the upper reaches and predominantly mixed farming in the lower lying reaches. Mixed Palaeozoic formations underlie the headwaters and Permian Sandstones dominate the lower reaches with extensive Drift cover of Boulder Clay, sand and gravels.

The flow regime at Buildwas remains close to natural behaviour under normal conditions (Appendix C), until Q80 onwards when regulation releases can be seen to elevate flows above what could naturally be expected. The site is therefore behaving relatively naturally with flow variation and volumes until dry/summer periods, illustrating how the stepped nature of flows immediately downstream of the reservoirs is gradually smoothed out as it travels downstream.

Once baseflows naturally begin declining, the regulation releases artificially prevent flows at this site from ever dropping to what would have naturally occurred. In effect, when tributaries of the River Severn are beginning to display natural summer/low flow effects, flows at Buildwas are artificially protected (increased) under normal regulation operation. This can be confusing when trying to understand the impacts of drought on the flow dependant environment, as the lowest flows are less likely to occur at the peak of a dry period because the highest regulation releases will be made during these times.

Bewdley is a 20-path ultrasonic gauging station, used as the flow trigger site where the five day rolling mean of 850MI/d and daily mean of 727MI/d (minimum flow target) is maintained for Severn Regulation. The 4334km² catchment is a combination of moorland, forestry and mixed farming, consisting of impermeable Palaeozoic rocks and river gravels in the west and Drift covered Carboniferous to Liassic sandstones and marls in the north.

Flows this far down the main river are largely artificial. Significant public water supply abstractions take place upstream, removing significant portions of the regulation releases which taken between 3 and 4 days travel time from Clywedog reservoir. Although flows are artificial, they do mirror the naturalised FDC (Appendix C). The gauged FDC (1990-2007) shows the EFI is normally achieved (minor deviations due to stepped representation of the EFI) and from Q97 regulation releases elevate flows above what would naturally occur.

Saxons Lode is a Multipath ultrasonic gauging station that can be affected by high tides travelling up the estuary, and operation of tidal gates on the Avon at Tewkesbury. The 6860.6km² catchment is diverse, mainly agriculture and forestry with some industrial development in the East. Broad flood peaks are experienced, and geology is largely Triassic Mudstone (Mercia) including Keuper Marl, Dolomitic Conglomerate and Rhaetic.

Saxons Lode flows incorporate inputs from the River Teme and River Stour (large effluent returns), whilst including further significant public water supply abstraction. Low flows remain artificially supported by regulation, although to a lesser degree as major abstractions have already removed the majority of additional water. Appendix C shows the effect is to return flows from Q95 back towards the natural flow, rather than notably elevating it. The graph also shows the current flow regime (gauged FDC) satisfies the EFI at all times.

Deerhurst is a cross path ultrasonic gauging station commissioned in 1995, designed to measure low to medium flows affected by tides. The older Haw Bridge gauge is located downstream, a velocity-area station affected by substantial bed movement and unable to adjust flows to account for tidal action. The sites are often used interchangeably, as Haw Bridge provides a much longer record and includes important historic drought events. Deerhurst and Haw Bridge are the furthest downstream continuous flow gauging stations on the River Severn. In 2015 a side-looking ADCP (Acoustic Doppler Current Profiler) flow gauge was installed. It relies on an Index Velocity relationship that relates the 'index' velocity, measured by the gauge, to the mean velocity of the river. This in turn is multiplied by the cross-sectional area to calculate the flow.

The Deerhurst catchment is 9866.3km² and greatly diverse due to its size. The geology is predominantly Paleozoic slates in the welsh headwaters, Permo-Triassic sediments in the middle reaches and Jurassic and Liassic clays from the Avon catchment down. Flows are substantially modified by this point, with further public water supply abstractions and effluent returns (additional effluent received from the

Avon and Thames). Low flows are artificially supported by regulation but to a lesser degree than Bewdley.

Appendix C shows how flows from around Q96 onwards are elevated back to what would naturally have occurred. The current flow regime (gauged FDC) meets the EFI requirements at all times and therefore demonstrates that inflows to the Severn Estuary are still protected at this location.

In order to assess flows further downstream, and represent inflows to the Severn Estuary more accurately, further sites were selected and Low Flows Enterprise data used to represent expected normal and/or natural conditions for comparison. This does represent a change away from the techniques used to assess all the upstream assessment points so greater caution needs to be applied.

One of the largest potential abstractions between Deerhurst and the Severn Estuary is the Canal and River Trust abstraction to the Gloucester and Sharpness Canal, taken from the East channel where the River Severn splits. Bristol Water then abstract directly from the canal, for which the Canal and River Trust have a Commercial Agreement to make best endeavours to meet the public water supply needs, and hold an abstraction licence from the canal itself on their behalf. The Canal and River Trust abstraction is now licensed by the Environment Agency, which acts to safeguard the Severn Estuary inflows under routine flow regimes (supported by RoC stage 3 assessment). There is however an understanding that severe droughts represent exceptional circumstances and operations may fail to meet the Operating Agreement, close liaison between the Environment Agency and the Canal & River Trust will be required, with the option to close the canal to navigation being considered.

The complex interaction and variability of abstraction coupled with a lack of actual flow data downstream of the canal abstraction, make it very difficult to assess with confidence what the true impact on the lower River Severn would be. Abstractions can range from 0MI/d to >398MI/d (maximum licensed volume), although high demand abstractions normally average around 300 MI/d. Drought reports from the 1976 and 1989 event report 680MI/d was abstracted for brief periods during the lowest flows, causing Estuary inflows to reduce to zero for short periods. At the time this was deemed as acceptable, however with new regulations and the need to safeguard the Natura Sites Network Severn Estuary, requirements have changed.

The channel bifurcation (channel split) itself raises additional modelling and impact assessment challenges. Monitoring (between 1997-2007) indicates an approximate flow split of 40% down the East channel and 60% down the West channel. Therefore, low flows occurring due to the drought would become further divided and flow velocity decreased. Post drought reports from 1976 highlighted a considerable siltation problem around the channel bifurcation, with no flow passing down the West channel.

Appendix C shows data for Elmore, the furthest downstream point Low Flows Enterprise can model (owing to tidal influences), plotted against modelled data for Lower Parting to focus on the Estuary inflows. The EFI used is in accordance with the WFD guidance for transitional waterbody's and conforms with the Stage 3 Review of Consents. Due to the large tidal range (second largest in the world) of the Estuary, flow requirements are less sensitive than represented by a normal watercourse so will not match those plotted at Deerhurst.

The flow duration curve suggests flows consistently remain below what would have naturally occurred, meeting only at the severest drought. This could involve errors relating to how the regulation system and Gloucester and Sharpness Canal abstraction is represented within Low Flows Enterprise.

The current flow regime (influenced FDC) at Elmore/Lower Parting does suggest the EFI requirements are met at all times, with only Q99-Q100 showing marginal results. Appendix C therefore indicates normal flow operation protects the lower River Severn and subsequently inflows to the Severn Estuary. Greater confidence could be achieved by investigating how the Gloucester and Sharpness Canal abstraction has been represented (likely to be average abstraction, not accounting for severe droughts) inside Low Flows Enterprise, to verify the results being shown.

Historic Drought events

Baseline - Historic Drought Records

There is no exact definition of what constitutes a drought, and classification is often dependant on meteorological, hydrological (and environment), agricultural or water supply impacts. The Centre for Ecology & Hydrology report notable drought years in England and Wales as being; 1902, 1905, 1921, 1933-1934, 1943-44, 1949, 1953, 1955, 1962-65 (three dry winters), 1971, 1973, 1975-76, 1984, 1989-90, 1991-92, 1995-97, 2003 and 2004-06 (Rodda and Marsh, 2011).

These consisted of;

1975-1976 two separate drought order applications

29 July: Lower Bewdley prescribed flow from 727MI/d to 545MI/d and remove the compensation release obligation (18 MI/d) from Llyn Clywedog for 6 months. Granted 6 August and operated.

20 August: Abandon prescribed flow at Bewdley and move to releasing 2% of remaining storage per day subject to Bewdley not exceeding 545MI/d. Granted 3 September but never operated, significant rainfall returned.

1984 one drought order application

1 August: Cap Llyn Clywedog releases to 2% of storage (no reference to prescribed flow reduction at Bewdley, flow records do not consistently fall below 850MI/d). Granted 18 August and operated.

1989 one drought order application

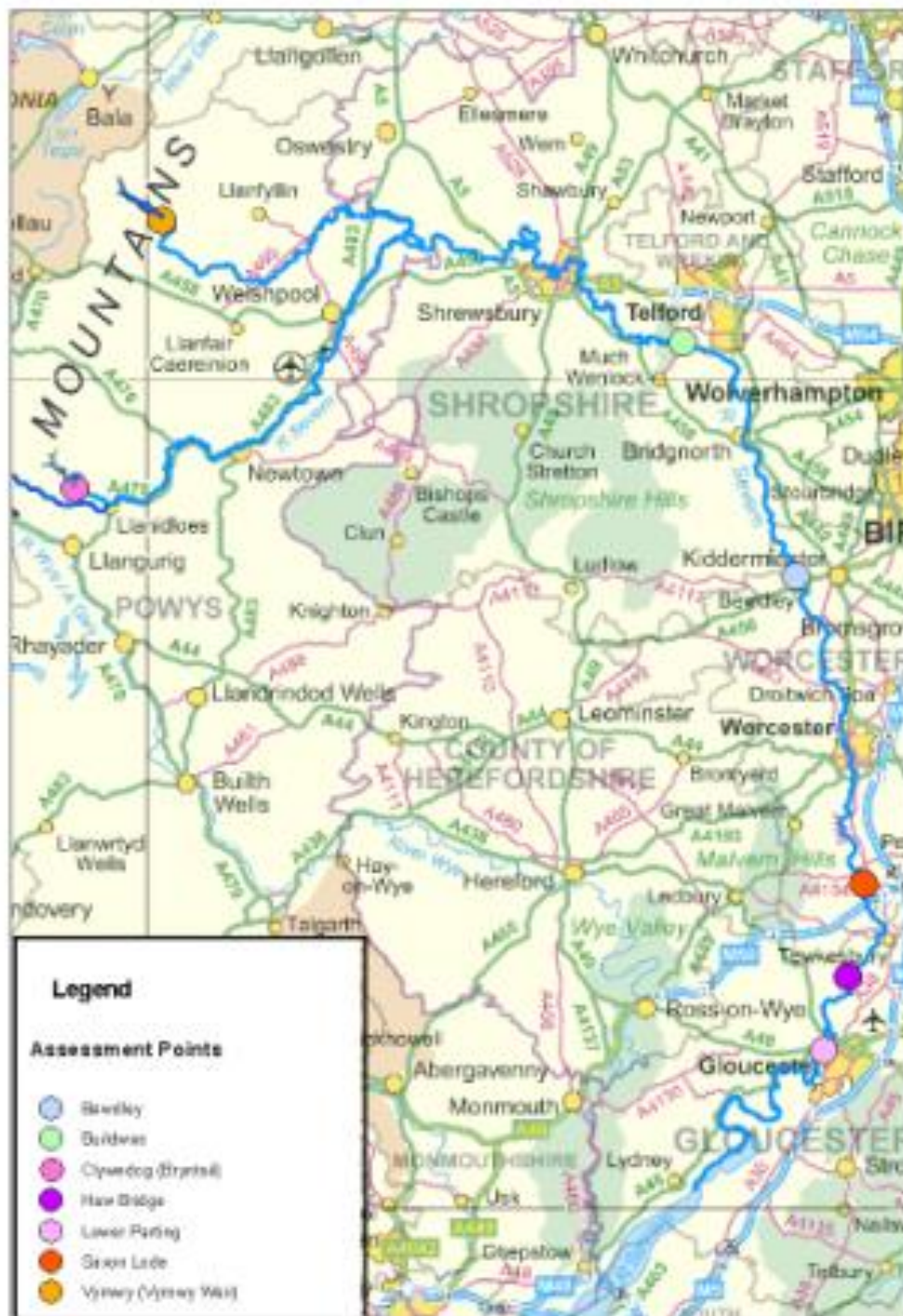
31 August details agreed, application made on 11 September. Lower Bewdley prescribed flow reduced from 850MI/d to 730 MI/d over a 5 day mean. Granted 30 September.

In more than 30 years, and most notably during the 1995-96, 2022 and 2025 drought events, the River Severn Drought Order has not been required. This reflects the current robustness of the system and ongoing development of further resources in the Shropshire Groundwater Scheme.

Conceptualisation of the River Severn

Six assessment points (APs) were selected along the main River Severn (Figure 2) to assess the impacts on flows at key points along the river system. All sites were located at gauging stations to enable model data to be considered against actual recorded flows and existing Environmental Flow Indicators (CAMS).

Figure 2: Main River Severn Flow Assessment Points



In order to model the potential impacts of the Gloucester and Sharpness Canal abstraction on River Severn flows during severe drought, an average abstraction profile was manually inserted into Aquator. Flows were estimated both upstream of the canal abstraction and channel bifurcation (U/S Sharpness) and downstream (Lower Parting). The maximum abstraction represented was 300 Ml/das it represents likely dry weather operation. Final conclusions will be based around the 'worst case' likely effects (assuming maximum abstraction), with further work suggested to improve the conceptualisation and understanding for drought management.

A number of methods have been used to present and interpret the modelled flow data, and attempt to assess whether flows are significantly impacted. Hydrographs have been produced to assess the daily changes and duration of the event. Data has also been converted into flow duration curves for comparison against actual flow records, and assessment against Catchment Abstraction Management Strategies (CAMS) Environmental Flow Indicators to attempt to quantify the significance of any flow changes.

Flow duration curves are useful for illustrating the duration and magnitude of low flow/drought events (i.e. the rarity), however caution is needed when comparing different time periods as the results will be skewed. The existing data sets are all based around the CAMS period 1990 to 2007 (18 years). The modelled data is a theoretical 1975 to 1977 (only 3 years), a much shorter record and largely low flow biased. Therefore, consideration of adverse impacts will only be taken of the mid to low flows, using a precautionary guidance only principle to the results/conclusions.

The aim of the flow analysis is to identify, with the best certainty possible at this time, what impact the drought order in isolation is having on the modelled drought scenarios. The 'Do Nothing' model runs are used as the baseline prediction of what could happen if no management strategies were undertaken to alleviate the developing conditions, therefore focus will be on the difference between the 'Do Nothing' model and the drought order and full combination models.

Hydrology scenario drought magnitude and setting the scene

The 1975-76 drought remains a primary benchmark for drought planning due to its hydrological severity and spatial impact.

Owing to the size of the River Severn catchment and complexity of the water demands upon storage at Llyn Clywedog it is difficult to calculate return periods specifically for the River Severn Drought Order. The nature of the Welsh Mountains is to receive the highest rainfall, however it could be localised groundwater recessions in the Shropshire Plains down to the Severn Estuary that trigger the high regulation need and depletion of Llyn Clywedog storage. The opposite could also be true, with a lack of rainfall over the Welsh Mountains preventing sufficient recharge during a high regulation season primarily triggering the need for a Severn Drought Order. Very different return periods would be produced according to which rainfall catchment areas you include in calculations and what time periods you are using.

The drought scenarios created to test the Severn Drought Order were all based on the 1975-1976 drought event as a starting point.

By the end of August, the whole Severn catchment return period was 1 in 100 year over an accumulated 11 month period.

Flow Modelling Analysis

'Do Nothing' models were used as the baseline comparison instead of a natural flow series for this investigation. Aquator contains discharges built into the natural background flow of the model, making it difficult to accurately separate and naturalise the flow series for a theoretical event. CAMS period (18 years) naturalised flow duration curves were used for some comparison analysis, but modelled flows were obviously skewed by the theoretical drought, which needs to be understood to ensure the correct context for interpretation.

The River Severn is a highly regulated and artificial watercourse, natural flow regimes can no longer be expected along the main river although flow targets exist to

protect the environment. The Severn Corridor CAMS identified current and fully licensed management of water resources along the main River Severn is acceptable to the Environmental Flow Indicators (EFI).

The Review Of Consents (RoC) stage 3 (2009) conducted a Habitats Directive appropriate assessment into the current flow regime entering the Severn Estuary. Investigations concluded the current licensing policy and operation of the Severn Regulation system protect and maintain adequate flows (in accordance with WFD transitional waterbody flow targets). The Appropriate Assessment concluded current flow regime was having no significant impact on the Severn Estuary features, with the exception of severe drought conditions, which were not assessed. These findings were signed off by Natural England and the Countryside Council for Wales in 2009.

Building on the foundations of RoC, CAMS and WFD assessments of the River Severn, the River Severn Drought Order investigation focused on a 'Do Nothing' scenario as a baseline instead of a naturalised flow series. Representing a more realistic comparison of likely flows during a severe drought event if no Drought management actions were taken when operating regulation releases from Llyn Clywedog reservoir.

It is important to emphasise that the particular drought order management scenarios being assessed are theoretical. They were developed as a means of assessing the likely worst case environmental impacts associated with managing water resources during a very severe drought, providing a guide on flow trends and likely periods of operation. Models cannot predict to a high level of accuracy exactly what a drought will look like (e.g. timing and duration) until the antecedent conditions are known.

Model Data: Acute Scenario

Severn Regulation impacts

The relevant Appendices contains the graphs illustrating the regulation system operations for the three main scenarios, throughout the theoretical period 1975 to the end of 1979.

Do Nothing Model

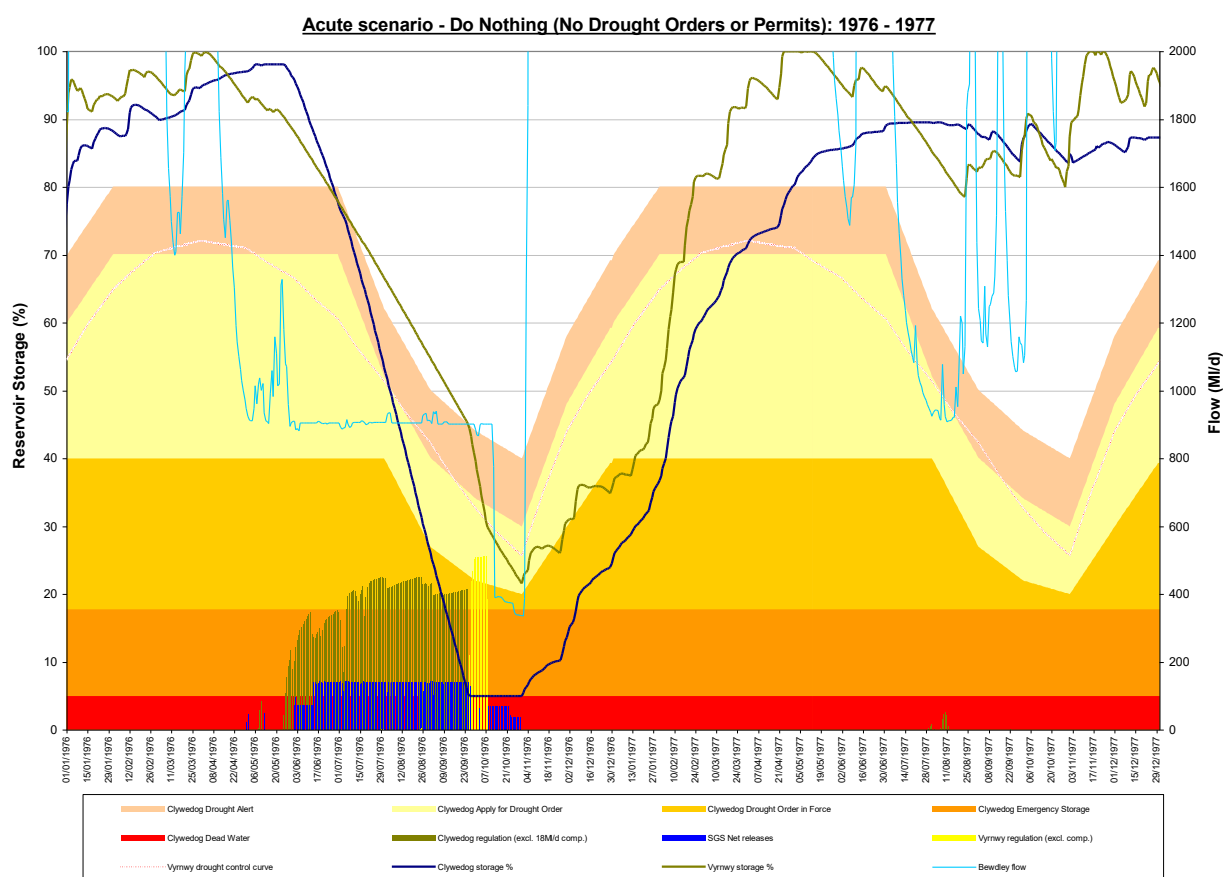


Figure 3 shows the modelled impacts on reservoir storage, alongside the regulation releases made from Clywedog, Vyrnwy and the Shropshire groundwater Scheme under the Do Nothing model

Figure 3 presents modelled regulation operation if the Severn Drought Order were not operated, and therefore high regulation releases were maintained from Clywedog, regardless of the storage levels.

The graph shows operationally, Clywedog provides the primary support with over 400 MI/d up until dead water (5%) is reached; SGS runs in parallel at the current maximum net release of 140 MI/d. Therefore once Clywedog fails only Vyrnwy bank can be utilised to meet the 850 MI/d flow target at Bewdley, with regulation releases peaking at 513 MI/d. The regulation system fails 16 days after Clywedog, a combined consequence of Vyrnwy regulation ceasing as the bank is exhausted and SGS individual licence maximum's being reached causing significant reductions in releases. In a real event, the operation of these sources is likely to be different, but the model does allow system failure and worse case to be tested.

Continuous regulation releases begin on the 25 May 1976, and continue for 152 days until 30 October. A total of 166 regulation days and 70,220 MI combined releases were modelled during 1976, with Clywedog providing 66% of the resource, SGS providing 25% and Vyrnwy providing 9%. For context, during the real 1976 event 39,000 MI were released over 121 days of regulation. The highest regulation year on record was 1989 with 48,600 MI being released over 125 days. More regulation resources have been developed since both these drought events, so the number of

regulation days is more representative for comparison of severity, with modelling indicating an increase in regulation days of 41-45 days.

Clywedog provides 125 days regulation support before failure on 29 September. From continuous activation on 25 May at 98% full, it takes 33 days of >300 MI/d releases to cross the Drought Alert curve (27 June), 70 days to cross the Drought Order application curve (3 August), 96 days before crossing the Drought Order in force (29 August) curve and 108 days before crossing the emergency storage (10 September) curve. Clywedog storage remains in dead water for 36 days, during which no regulation or compensation flow releases would be possible.

Vyrnwy reservoir provided 13 days of regulation support between 26 September and 8 October. The drought control curve is crossed on 8 October at 30% storage, marking the end of regulation support. Minimum storage is reached on 31 October at 22%, but dead water is avoided and minimum compensation flows are maintained throughout.

SGS activates on 1 June and provides 152 days continuous regulation support until 30 October. Maximum 140 MI/d net discharges are made from 14 June until individual licence maximums are reached on 28 September (Montford licence) and 22 October (Leaton licence), with net discharges halved on both occasions as some phases deactivate. The combined licence annual limit is not exceeded, which could suggest with different operation during a real event, additional discharges (<80 MI/d) could be maintained for longer. However, the model indicates the spare licence is within the phases that continued to pump at maximum deployable output until regulation was no longer required, so it might not be physically possible to provide more water than is modelled. The final option would be to apply for the SGS drought order, which seeks to exceed the licence quantities.

Clywedog recovers above the emergency storage curve on 7 December 1976 and after almost a year (307 days) crosses above the Drought Alert curve on 30 April 1977. Vyrnwy recovers above the drought control curve on 10 February 1977 and exceeds 90% storage on 19 March 1977, Clywedog takes until 17 July 1977 to exceed 90% storage.

Environment Agency Drought Order in isolation Model

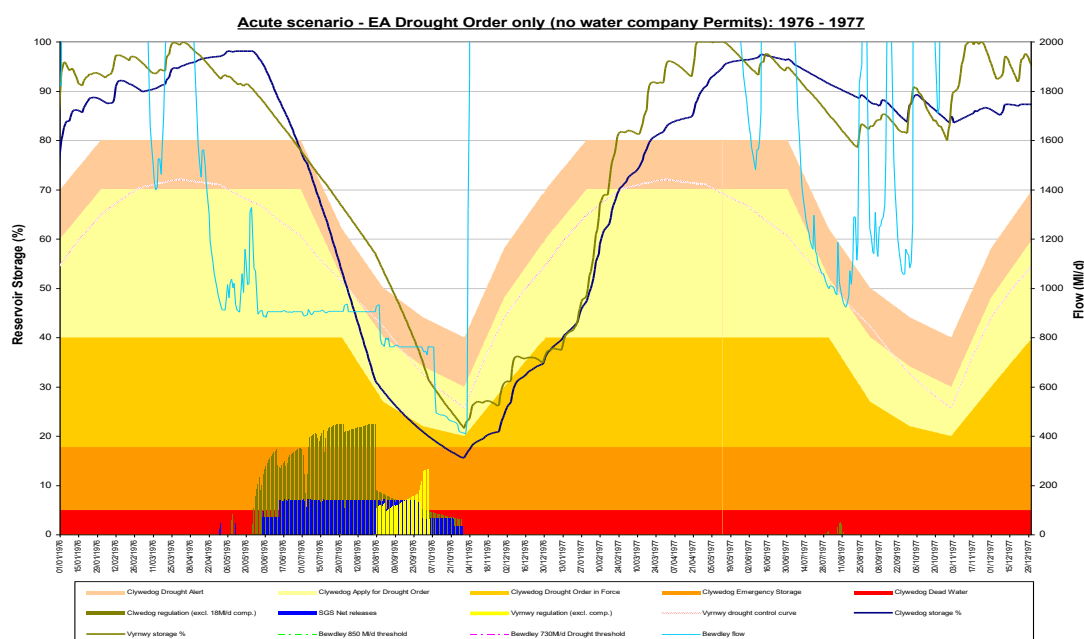


Figure 4 shows the modelled impacts on reservoir storage, alongside the regulation releases made from Clywedog, Vyrnwy and the Shropshire groundwater Scheme under the Environment Agency Drought Order in isolation model

Figure 4 presents modelled regulation operation if the Severn Drought Order were operated but no other drought permits or orders were active.

Clywedog provides the primary support until the Drought Order in force curve is approached and the model activates the drought order on 25 August 1976, as storage reaches 31%. SGS operation is very similar to the 'Do Nothing' model, with maximum net discharges already being made. Operationally, the lost Clywedog resource (releases now capped at 300 Ml/d) is again taken from the Vyrnwy bank, although the Bewdley prescribed flow has decreased to 730 Ml/d, reducing the pressure slightly.

The regulation system still fails (failure measured as not achieving Bewdley prescribed flows) with the drought order in operation, again resulting from the combined loss and reductions in Vyrnwy and SGS regulation support. Subsequently flows begin to crash 3 days earlier than under the 'Do Nothing' model. This appears to be caused by moving greater demand to the Vyrnwy bank earlier, as Clywedog releases are capped at 300 Ml/d and SGS is already at maximum deployable output. Vyrnwy bank therefore exhausts faster and again coincides with SGS licence maximums being reached.

The beneficial difference from the 'Do Nothing' model is Clywedog never reaches dead water and therefore continues to make both compensation and regulation releases throughout. The results of this can also be seen down the whole system, with all minimum flows being higher than the 'Do Nothing' model.

A total of 166 regulation days and 64,557 Ml combined releases were modelled during 1976, with Clywedog providing 63% (40748 Ml) of the resource, SGS providing 27% (17708 Ml) and Vyrnwy providing 9% (6102 Ml).

The continuous regulation period is only 1 day longer, but lower prescribed flows at Bewdley result in the combined regulation releases being reduced by 8% to 64,557 MI during 1976. This equates to a storage saving at Clywedog of 11%, with the minimum storage of 16% being reached on 31 October. By avoiding dead water, regulation support from Clywedog also increases to 158 days.

The initial dates and time periods of Clywedog operation remain the same until the drought order is activated. The saving in storage appears to move key points by about one month. Emergency storage is reached on 15 October instead of the 10 September, recovery back above the emergency storage is achieved on 6 November instead of 7 December, and storage recovers above the Drought Alert curve on 21 March 1977 instead of 30 April. The drought order remains active within the model for 144 days, stopping on 15 January 1977 when storage (41%) crosses above the drought order in force curve.

Vyrnwy reservoir provided 44 days (31 day increase) of regulation support between 23 August and 5 October with releases peaking at 267 MI/d (246 MI lower than 'Do Nothing'), almost half the 'Do Nothing' model and therefore more sustainable, explaining the increased time Vyrnwy bank could be utilised. The drought control curve is crossed on 4 October, with the minimum storage remaining the same at 22% (31 October), recovery dates are the same as 'Do Nothing' modelling. SGS again activates on 1 June, providing 1 extra days regulation up to 31 October. Near maximum 140 MI/d net discharges are still made from 14 June and again step back when individual licence maximums are reached, slightly later on 29 September (Montford licence) and 24 October (Leaton licence). The maximum combined licence is not reached.

Clywedog storage remains below the Drought Alert curve for 267 days in total, with the drought order being active for 144 days of this critical period. Clywedog storage is able to recover faster than the 'Do Nothing', as levels were not drawn down as far. Storage exceeds 90% on 27 April 1977, over two months earlier than under 'Do Nothing'.

Severn Corridor Flow Impacts

This section includes a breakdown of modelled regulation behaviour, hydrographs for the main River Severn and the main conclusions from the hydrological analysis.

Assessment Point 1, Bryntail

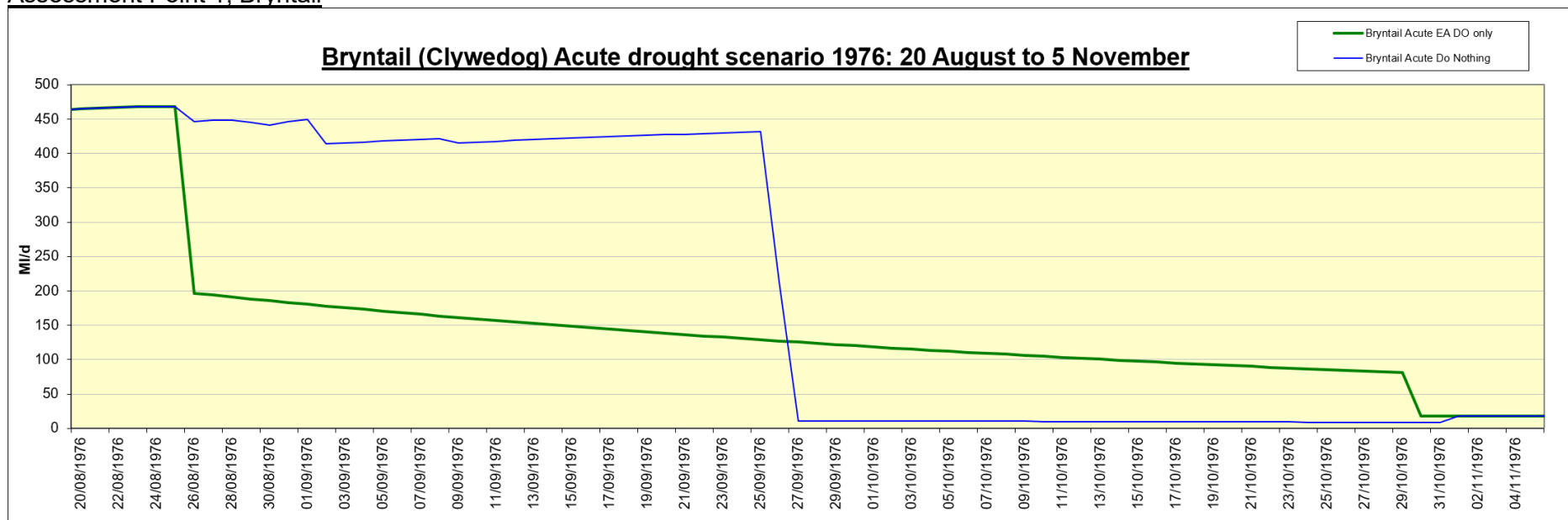


Figure 5 shows the modelled impacts on flows at Bryntail, immediately downstream of Clywedog dam. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 5 presents a close up of the hydrographs at Bryntail from 20 August and 5 November 1976, the critical period of low flows. **Appendix E.1** contains the full modelled hydrographs from 1975 to 1979.

Table 5

	Acute Do Nothing MI/d	Acute EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975- 1977)	(1975- 1977)	(1990- 2007)	(1990-2007)
Q30*	163	163	176	216
Q95	18	18	18	19
Q99	9	18	18	-6
Q99.9	9	18	-	-59

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

The most significant impact of the 'Do Nothing' model is that compensation flow fails on 27 September 1976, crashing from 214 MI/d to 11 MI/d in one day. The failure lasts for 35 days with flows consistently <10 MI/d, a minimum flow of 8.67 MI/d occurs on 31 October. Compensation flow is restored from 1 November, but flow variation (flows above compensation) does not occur until 30 July 1977. Up until this point, 306 days in total, the reservoir is essentially intercepting all the runoff in order to refill while regulation is not required.

Appendix E.2 plots just the modelled flow duration curves against one another, the significant Q values are contained in Table 5. The graph illustrates how the 'Do Nothing' model produces larger high flows (e.g Q5 to Q25); greater regulation (>200 MI/d) is maintained from Clywedog for longer if the drought order is never applied, as no attempt is made to prolong the resource and plan for a continuing drought. The mid to lower flows (Q52 to Q73) are then reduced compared to the drought order modelling, illustrating how 'Do Nothing' has already caused Clywedog to use up the regulation water in larger but shorter term releases as the drought developed. Once the critical drought flows are reached from Q97 onwards (short term), the 'Do Nothing' model shows lower flows than the drought order models, representing how dead water has been reached at Clywedog and releases are no longer physically possible.

Generally the 'Do Nothing' flow duration curve is lower than the gauged and naturalised record. This is largely due to the different time period used (biased towards low flows), but does illustrate how the modelled drought event itself, 'Do Nothing', has reduced the natural background flows, regardless of any abstraction activity. This flow response would be expected in a real event. The most significant observation in the modelled data is the failure of the compensation flow.

Appendix E.3 attempts to quantify the significance of flow changes to the Environmental Flow Indicators provided by CAMS. High flows are failed as a result of the time period used, which excludes a balanced portrayal of high/flood flows and can therefore be excluded from assessment. The important failures from Q60 to Q94, the majority of which is high risk (>30% migration from EFI), represent the loss of flow variation which would realistically be caused by a natural drought event,

although the duration would vary with each unique drought. It is important to stress these failures would be an unavoidable natural consequence of drought, something that would be normal in the cycle of the natural world regardless of man's intervention.

The failure of the compensation flow is represented from Q97, although no EFI failure is observed, it is likely the ecology and habitat has adapted to rely on the minimum flow of 18.2 MI/d, so this period would be classed as a significant flow failure.

Environment Agency Drought Order model

The Environment Agency Drought Order model shows no compensation flow failure. Flow variation is lost whilst the reservoir refills, flat lining at compensation flows from 30 October to 11 June 1977. A total of 224 days, an 82 day improvement from the 'Do Nothing' model.

Appendix E.2 shows how higher flow occurrences (e.g Q5 to Q25) reduce as regulation releases are capped (<300 MI/d) through the drought order activation. The mid to lower flows (Q52 to Q73) are increased as the stored water is then released in smaller amounts over a longer period. Once the critical drought flows are reached from Q97 onwards, the drought order model displays higher flows than 'Do Nothing', representing how dead water is avoided and compensation flows maintained as a minimum.

Generally the Environment Agency drought order flow duration curve is lower than the gauged and naturalised record. However, with the exception of the higher flows (time period has an impact), operating the drought order brings Bryntail flows closer to the gauged and naturalised flow duration curve than the 'Do Nothing' model.

Appendix E.3 shows no significant flow failure beyond the 'Do Nothing' baseline.

Assessment Point 2, Vyrnwy

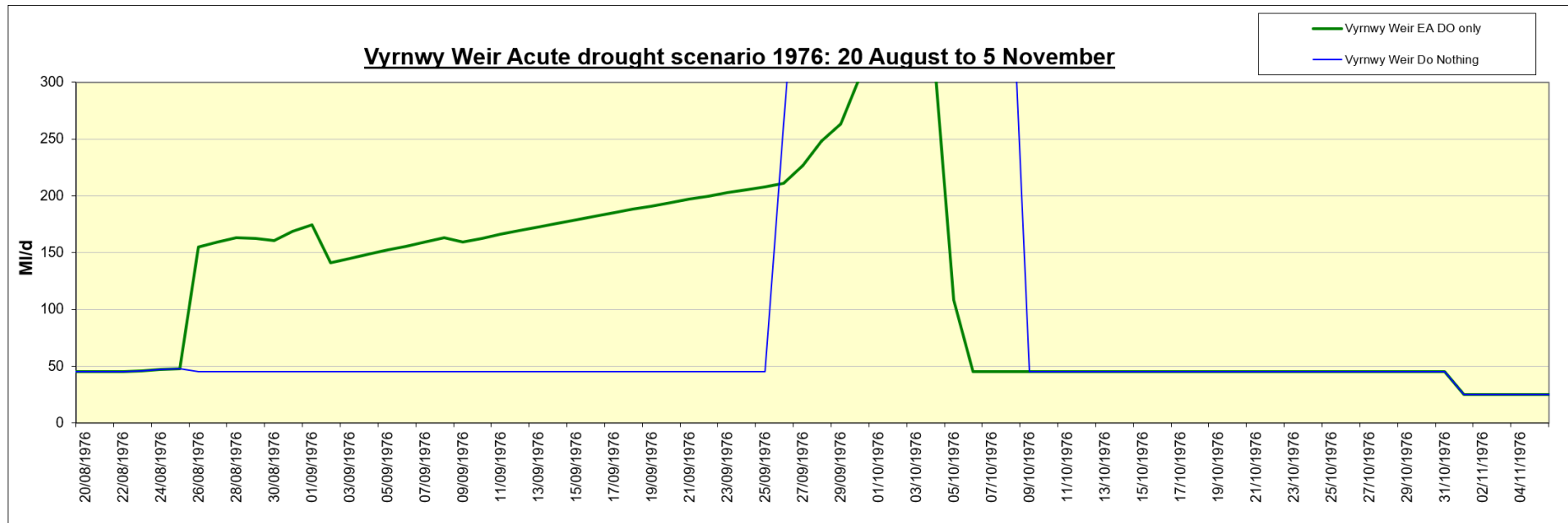


Figure 6 shows the modelled impacts on flows at Vyrnwy, immediately downstream of Reservoir dam. Vyrnwy would not be directly impacted by the operation of an Environment Agency drought order, however changes in the regulation operation would indirectly impact on flows at this AP. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 6 presents a close up of the hydrographs at Vyrnwy from 20 August and 5 November 1976, the critical period of low flows. Appendix E.1 contains the full modelled hydrographs from 1975 to 1979.

Table 6

	Acute Do Nothing MI/d	Acute EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	45	45	131	426
Q95	25	25	25	30
Q99	25	25	24	0
Q99.9	25	25	-	0

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

The 'Do Nothing' model does not cause compensation flow failure (below 25 MI/d expected at Vyrnwy Weir) at any point. The existing operation rules require a minimum of 45 MI/d compensation flow be maintained, however if 20 MI/d is flowing at Cownwy Weir then the flow at Vyrnwy Weir itself is reduced to 25 MI/d and water added to the Vyrnwy bank. The minimum 25 MI/d flow value is not failed at any point.

Continuous compensation flows of 25 MI/d began on 1 November and continued until (flows above 25 MI/d) 24 April 1977, a total 174 days without flow variation as the reservoir refills.

Appendix E.1 shows the main difference is variations in higher flows (Q18 to Q22) as larger, less sustainable regulation releases are made. These releases occur when Clywedog runs out of water, forcing Vyrnwy to take over primary regulation support until its own resources are exhausted (i.e. Vyrnwy bank). Very little difference is obvious between the mean to low flows.

Generally the 'Do Nothing' flow duration curve is lower than the gauged and naturalised record for higher to mid flows; attributable to the time period used. From Q40 onwards there is little difference between the 'Do Nothing' model and gauged flows, just a slight increase in minimum compensation flows from around Q68 to Q80. With the exception of infrequent low/drought flows (Q98 onwards), the whole gauged and modelled flow duration curves are lower than the naturalised curve.

Appendix E.3 shows that nearly the full flow duration curve creates high risk failures of the EFI, however the gauged flows show a similar failure attributed to the heavily modified nature of the waterbody. As with the gauged flows, from around Q95 onwards flows cross above the EFI and satisfy the recommended flow requirements. These infrequent low flows represent the critical drought impact, concluding no significant impact on flows.

Environment Agency Drought Order model

The Environment Agency Drought Order model also shows no compensation flow failure. Flow variation is lost for the same period, 1 November to 24 April 1977, a total of 174 days. No improvements or deterioration from 'Do Nothing' modelling.

Appendix E.1 shows the main difference is some reductions in higher flows (Q18 to Q22) as regulation releases are made more sustainable at lower volumes for longer periods. Flow trends are very similar to 'Do Nothing' when compared against gauged and naturalised Appendix E.2, as well as the EFI failure Appendix E.3 testing. No significant additional EFI failures are created by the drought order.

Assessment Point 3, Buildwas

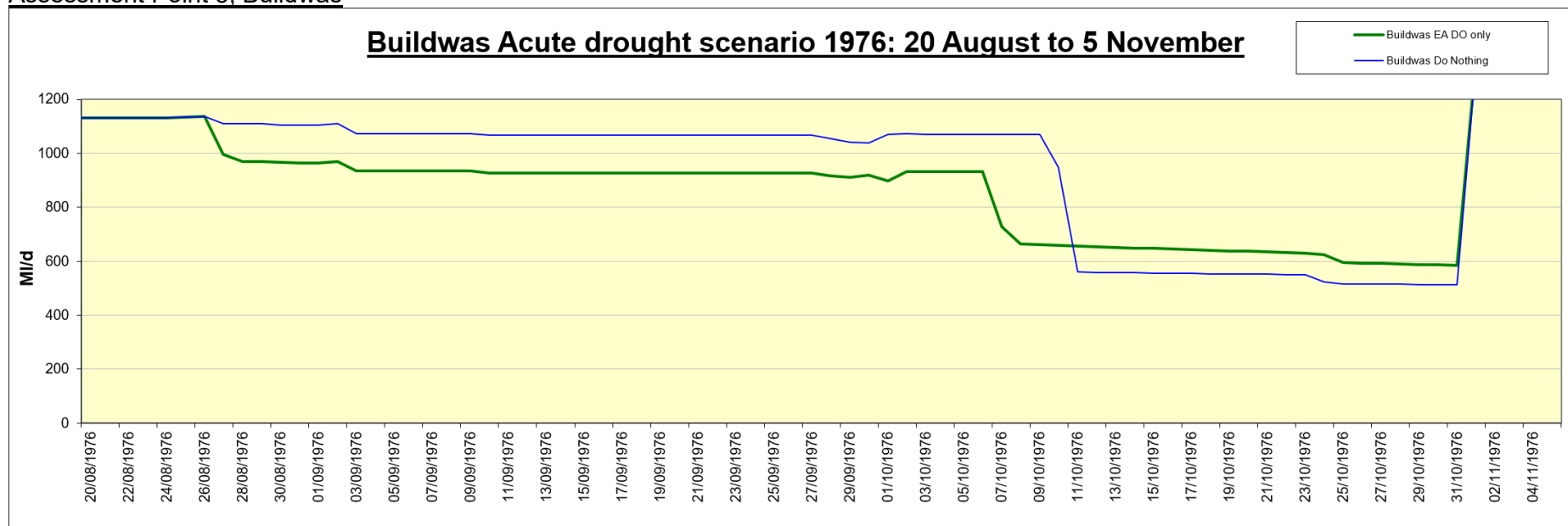


Figure 7 shows all the modelled impacts on flows at Buildwas, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 7 presents a close up of the hydrographs at Buildwas from 20 August and 5 November 1976, the critical period of low flows. Appendix E.1 contains the full modelled hydrographs from 1975 to 1979.

Table 7

	Acute Do Nothing MI/d	Acute EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	4978	4978	5511	5646
Q95	1068	934	1030	742
Q99	551	635	919	527
Q99.9	513	586	-	527

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

Under the 'Do Nothing' model maximum regulation is continued with no management intervention to protect and prolong flow support, subsequently the regulation system beings to fail and flows crash once upstream resources become exhausted. At the most critical point, only 36 MI/d of regulation support is possible, sourced from SGS.

Prior to the regulation system failure, the 'Do Nothing' model flows at Buildwas average (mathematical average) at 1075 MI/d. The impacts of regulation failure first impact on Buildwas on 10 October 1976, halving flows to an average of 540 MI/d. A minimum modelled flow of 512.1 MI/d occurs on 31 October. The flow depression lasts 22 days in total before rainfall significantly elevates flows from 1 November 1976.

Appendix E.2 shows how the regulation releases have largely smoothed out along the FDC by the location of Buildwas. The first notable difference between the models occurs during low flows (90 percentiles), representing the variations in regulation operations between the models. Initially the 'Do Nothing' FDC shows higher flows being maintained for longer, until flows crash to be the lowest from Q98. Again this represents how under the 'Do Nothing' model, regulation releases are not cut back in order to prolong flow support, therefore higher releases are made until system failure is reached.

Generally the 'Do Nothing' flow duration curve is lower than the gauged and naturalised record up until around Q85, although mid-range flows do move closer to the gauged record before drifting away again. The majority of this can be attributed to the different time periods used. From Q90 to Q98 flows are very similar or higher than the gauged record, until the flow crash occurs from Q98. the 'Do Nothing' FDC crosses above the naturalised FDC from Q85, illustrating how regulation support artificially increases low flows. Importantly, even when the flow crash occurs at Q98, the 'Do Nothing' flows are not reduced below the naturalised FDC (1990 to the end of 2007). This suggests even with a drought of significantly higher magnitude than the 1995-1996 event, when the regulation system fails flows still do not exceed the minimum that could have been expected under natural conditions during 1995-1996.

Appendix E.3 shows that nearly the full flow duration curve satisfies the EFI target, only a short period of low risk failure occurs around Q65 to Q71. The low flow period,

including the flow crash, meet the EFI objective. Considered with the observation against the naturalised FDC, no significant impact on flow is concluded.

Environment Agency Drought Order model

The first impacts of operating the drought order are picked up at Buildwas on 27 August 1976, 2 days after taking affect at Clywedog. The average (mathematical average) flow maintained is 935 MI/d, a 140 MI/d (13%) decrease from the 'Do Nothing' model. The drought order is active for 45 days before benefits from the small but continued regulation releases from Clywedog are observed.

Flows still crash as a result of regulation failure (remaining resource can no longer meet demand), impacts are observed on 7 October, 3 days earlier than 'Do Nothing'. However the benefits from the drought order is evident from 11 October, when modelled flows remain higher than 'Do Nothing' by an average 89 MI/d (16% increase) until flow recovery on 1 November. Flow depression lasts for a total 25 days, 21 of which are higher than 'Do Nothing'.

Appendix E.2 shows the drought order reduces flows below 'Do Nothing' from Q93 until Q98 (5% duration), after which flows are increased using the drought order. No additional EFI failures are observed, therefore no significant flow impact is concluded.

Assessment Point 4, Bewdley

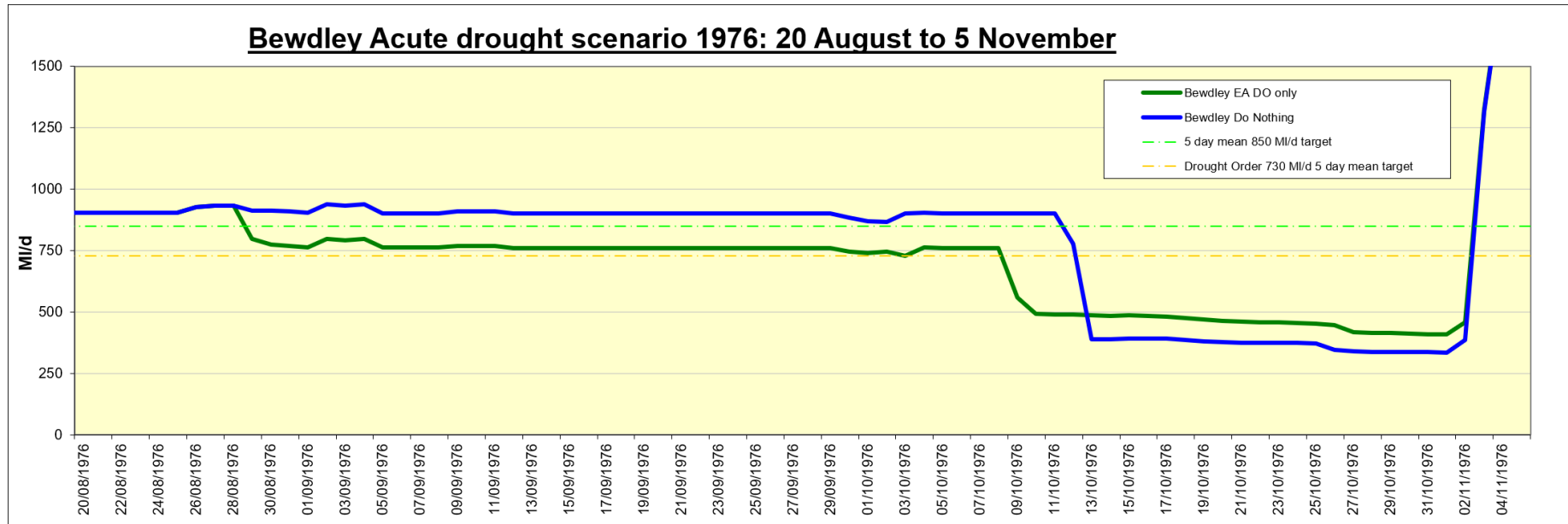


Figure 8 shows all the modelled impacts on flows at Bewdley, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 8 presents a close up of the hydrographs at Bewdley from 20 August and 5 November 1976, the critical period of low flows. Appendix E.1 contains the full modelled hydrographs from 1975 to 1979.

Table 8

	Acute Do Nothing MI/d	Acute EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30	4988	4982	5470	6211
Q95	901	762	881	930
Q99	375	458	791	715
Q99.9	337	411	-	458

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Due to the lack of runoff entering the system under the Acute scenario, modelled flows show a decline in volume when compared to Buildwas. Under normal conditions you would expect the river to accrete downstream, as the catchment area increases and tributaries enter the system. However, due to the severe shortage of rainfall being modelled, abstractions are removing more than can be naturally replaced or supported by the regulation system. Until regulation failure occurs or the drought order is implemented, this does not prevent the normal regulation flow targets from being maintained and no detrimental impacts would be expected.

Do Nothing model

Leading up to regulation failure, 'Do Nothing' flows at Bewdley average (mathematical average) at 903 MI/d. The impacts of regulation failure are first observed on 12 October 1976, more than halving flows to an average of 368 MI/d. Flow depression lasts 22 days with a minimum flow of 336 MI/d occurring on 1 November, flow recovery begins on 3 November 1976. Flows fell below the critical 1 day 650 MI/d target for 21 days in total.

Appendix E.2 shows the same trends in flow behaviour/response as Buildwas. Once again the 'Do Nothing' model flows appear higher than the gauged record between Q94 and Q98, and from Q97 of the naturalised FDC. 'Do Nothing' flows crash at Q98 as the regulation system begins to fail.

Appendix E.3 shows the whole mid to low flow (Q40-Q90) range fails to meet the EFI. This is due to the unavoidable loss of flow variation expected during a severe drought event, and represents the lack of runoff and reduced baseflow entering the system. Flow variation would be created naturally as thunderstorms and rainfall events occurred, but these modelled FDC's represent only a 3 year period and rainfall has been altered to produce more extreme droughts than we have on our flow records. The range of significance to this analysis is more likely to be Q90 onwards, as the approximately 70 days of impact represent only 6% of the 3 year period used to calculate the FDC, which would also largely be represented within the lowest flows of the FDC.

Applying this principle, between Q90 and Q98 the EFI is not significantly failed under 'Do Nothing'. However, once regulation failure impacts at Q98, flows drop into the High Risk (>30% lower than EFI) band. Although this banding system is only a guide

on whether the impact could be significant, when considered against the 1 day minimum 650 MI/d flow target at Bewdley and the minimum flow ever recorded at Bewdley of 518 MI/d (recorded in September 1976), the magnitude becomes apparent. The short term flow crash experienced under 'Do Nothing' is a significant flow impact.

Environment Agency Drought Order model

The first impacts of operating the drought order show on 29 August 1976, 4 days after taking affect at Clywedog. The average (mathematical average) flow maintained is 764 MI/d, a 139 MI/d (15%) decrease from the 'Do Nothing' model. Flows crash on 9 October, 3 days earlier than 'Do Nothing'. However the benefits from the drought order is evident from 13 October, when modelled flows remain higher than 'Do Nothing' by an average 90 MI/d (24% increase) until flow recovery on 3 November. Flow depression lasts for a total 25 days (all below 650 MI/d), 21 of which are higher than 'Do Nothing', resulting in the drought order having been active for 45 days before a benefit was observed.

Appendix E.2 shows the drought order only reduces flows below 'Do Nothing' from Q94 until Q98, after which flows are higher than 'Do Nothing'. A minor additional EFI failure occurs between Q94 and Q96, however it is within 10% of the EFI and for a very short period. From Q98 the drought order reduces the EFI failure to be within 30% of the EFI.

The aim of this assessment is to identify whether the drought order itself is having a significant detrimental flow impact, separating its individual impact away from that being naturally caused by the drought event ('Do Nothing' model). Therefore, no significant flow impact is concluded for the drought order. No significant additional impact is caused and flow benefits are evident during the most critical period.

Assessment Point 5, Saxons Lode

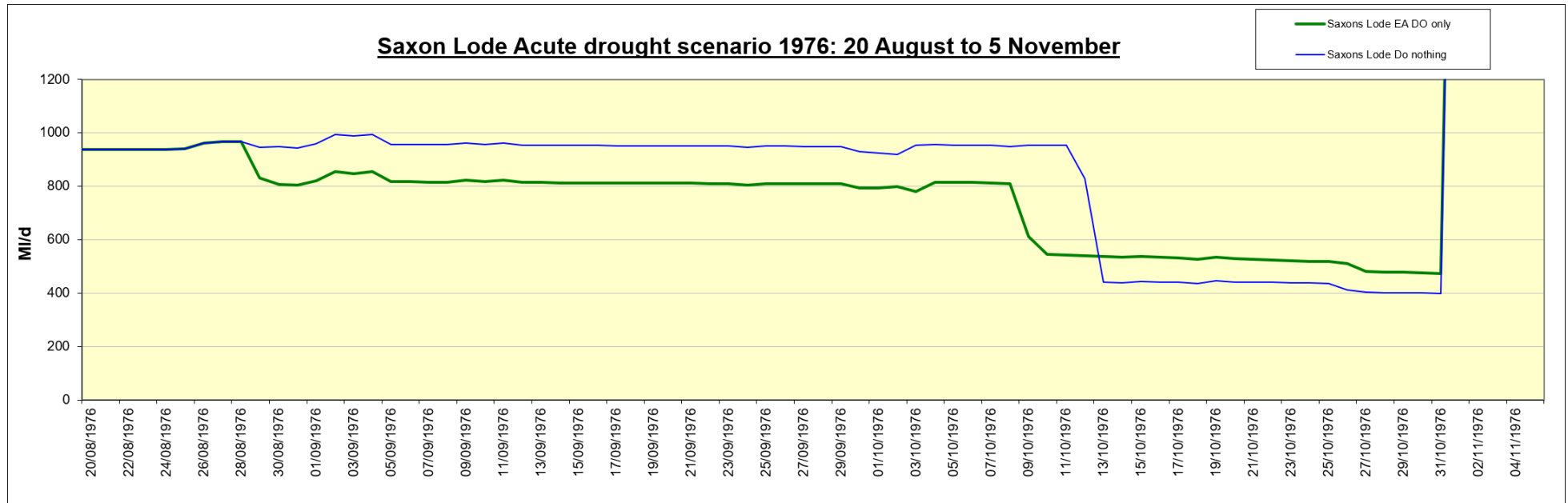


Figure 9 shows all the modelled impacts on flows at Saxons Lode, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 9 presents a close up of the hydrographs at Saxons Lode from 20 August to 5 November 1976, the critical period of low flows. Appendix E.1 contains the full modelled hydrographs from 1975 to 1979.

Table 9

	Acute Do Nothing MI/d	Acute EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	7551	7551	7992	8523
Q95	946	817	1327	1350
Q99	440	526	1167	1131
Q99.9	400	475	-	536

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

Prior to regulation failure, 'Do Nothing' flows at Saxons Lode average (mathematical average) at 954 MI/d, showing some flow accretion has occurred. Flows crash on 12 October 1976, halving to an average of 428 MI/d. Flow depression lasts 20 days with a minimum flow of 399 MI/d occurring on 31 October, flow recovery begins on 1 November 1976. Events are slightly shorter and earlier than at Bewdley and Buildwas. Considering the downstream location, this is likely to be caused by input flows from the Teme and Stour, and could represent earlier rainfall over these catchments reaching Saxons Lode before flows along the main Severn corridor receive separate recharge.

Appendix E.2 shows the 'Do Nothing' FDC as the highest until Q98. The whole FDC is lower than gauged and naturalised, compared against Buildwas and Bewdley this shows how the major abstractions have removed the main portion of additional regulation releases made under 'Do Nothing'.

Appendix E.3 shows the EFI is failed from Q51 onwards, although the magnitude of failure reduces (improves) from Q90 until the crash at Q98. Due to the low flow biased period (3 years) used to generate the FDC's, only the Q90 to Q100 should be considered for this assessment. The effects of regulation can be observed as the FDC artificially flat lines due to the flow support. EFI failure ranges from High Risk (>30% lower than EFI) to being within less than 10% of the EFI where impact would be unlikely, until flows crash back into the High Risk band after Q98. Although short term and with varying magnitude, overall the underlying drought ('Do Nothing') is causing significant flow impacts.

Environment Agency Drought Order model

Impacts of operating the drought order are observed on 29 August 1976, 4 days after taking affect at Clywedog. The average (mathematical average) flow maintained is 814 MI/d, a 140 MI/d (15%) decrease from the 'Do Nothing' model. Flows crash on 10 October, 3 days earlier than 'Do Nothing'. Benefits from the drought order are evident from 14 October, when modelled flows remain higher than 'Do Nothing' by an average 90 MI/d (21% increase) until flow recovery on 1 November. Flow depression lasts for 23 days, 19 of which are higher than 'Do Nothing'. The drought order was active for 46 days before a benefit was observed.

Appendix E.2 shows the drought order reduces flows by an additional 15% below 'Do Nothing' from Q94 until Q98, after which flows increase 21% above the 'Do Nothing'. No additional EFI failures are caused, but the magnitude of failure is increased between Q94 and Q98, remaining over the Medium Risk (>20% below the EFI) band for longer than 'Do Nothing'. Flow benefit is evident from Q98. It is important to note the EFIs and risk banding system used only provide a best guide on whether flows are significantly altered, how this translates into environmental impact is largely determined by the ecological assessment.

The modelled drought order does create a short term increase in potentially significant flow impacts. This will need to be carefully considered in context of the duration it occurs for (an extra 4% over 3 years, or 46 days in total) and the resulting flow benefits it subsequently enables (21% increase over 19 days). Whether the increased duration of flow impact translates into adverse impacts on the environment needs to be assessed against the ecology, taking into account whether this could cause more harm than allowing the 'Do Nothing' minimum flows/levels from occurring.

Assessment Point 6, Haw Bridge/Deerhurst

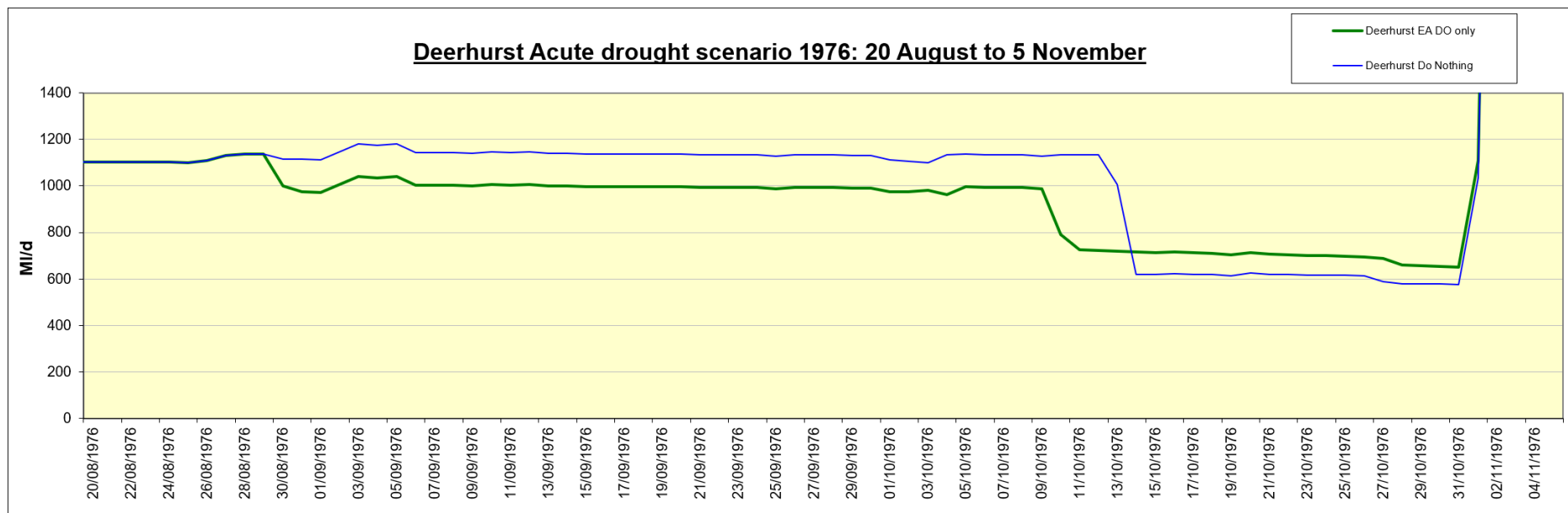


Figure 10 shows all the modelled impacts on flows at Deerhurst, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 10 presents a close up of the hydrographs at Deerhurst from 20 August to 5 November 1976. Appendix E.1 contains the full modelled hydrographs from 1975 to 1979.

Deerhurst was built closely downstream from the flow gauge Haw Bridge, but designed to cope with the reversed flows created by the tidal movements up the Severn Estuary. Deerhurst is the furthest downstream flow gauge in operation and represents the last location from which flows into the Estuary can be measured and regulated to. Flows at Deerhurst include inputs from the River Avon and public water supply abstractions. The channel bifurcation (channel split) and intake for the Sharpness and Gloucester Canal are located downstream.

Table 10

	Acute Do Nothing MI/d	Acute EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	9501	9501	7992	8523
Q95	946	817	1327	1350
Q99	440	526	1167	1131
Q99.9	400	475	-	536

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

Leading up to the modelled regulation failure, 'Do Nothing' flows at Deerhurst average (mathematical average) at 1136 MI/d. Flows crash on 13 October 1976, almost halving to an average of 608 MI/d. Flow depression lasts 19 days with a minimum flow of 577 MI/d occurring on 31 October, flow recovery begins on 1 November 1976.

As with all the upstream assessments, Appendix E.2 shows the 'Do Nothing' FDC as the highest until Q98. Between Q24 and Q40 the modelled flows exceed the gauged FDC, but remain below the natural and gauged for at all other flows.

Appendix E.3 shows the EFI is again largely failed from Q51 onwards, although the magnitude of failure reduces (improves) from Q93 until the crash at Q98. Adopting the same principle of focusing on the Q90 onwards, EFI failure ranges from High Risk (>30% lower than EFI) to briefly achieving the EFI at Q98, before flows immediately drop to be just within the High Risk band. The trends are very similar to Saxons Lode, although the magnitude of EFI failures from Q98 onwards are less. However, the underlying drought conditions ('Do Nothing') are causing significant flow impacts.

Environment Agency Drought Order model

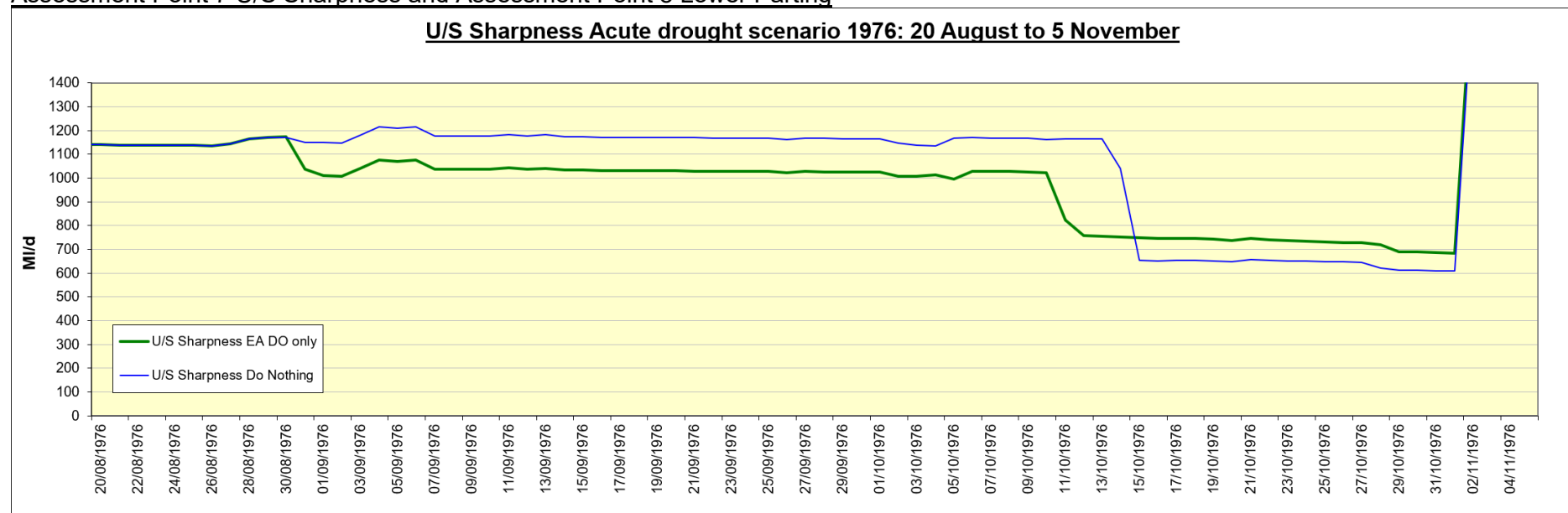
Impacts from the drought order are observed on 31 August 1976, 6 days after taking affect at Clywedog (2 days later than observed at Saxons Lode) although flows still crash on 10 October, 3 days earlier than 'Do Nothing'. The slight discrepancy of 6 days when compared against 4 days at Saxons Lode is likely to be a buffering affect from the River Avon inflows, as well as the increased travel distance.

The average (mathematical average) flow maintained is 996 MI/d, a 140 MI/d (12%) decrease from the 'Do Nothing' model. Flow benefits from the drought order are evident from 14 October, when modelled flows become higher than 'Do Nothing' by an average 90 MI/d (15% increase) until flow recovery on 1 November. Flow depression lasts for 22 days, 18 of which are higher than 'Do Nothing'. The drought order was active for 45 days before a benefit's observed.

Appendix E.2 shows the same trend as Saxons Lode. The Severn Drought Order reduces flows by an additional 12% below 'Do Nothing' between Q94 and Q98, after which flows increase 15% above the 'Do Nothing'. No additional EFI failures are caused, but the magnitude of failure is increased between Q94 and Q98, remaining over the Medium Risk (>20% below the EFI) band for longer than under 'Do Nothing'. Flow benefit is evident from Q98.

The modelled drought order does create a short term increase in significant flow impacts. To determine whether this creates an adverse environmental impact careful consideration is again needed in context with the duration (an extra 4% over 3 years, 45 days in total) and resulting flow benefits it subsequently enables (15% increase over 18 days).

Assessment Point 7 U/S Sharpness and Assessment Point 8 Lower Parting



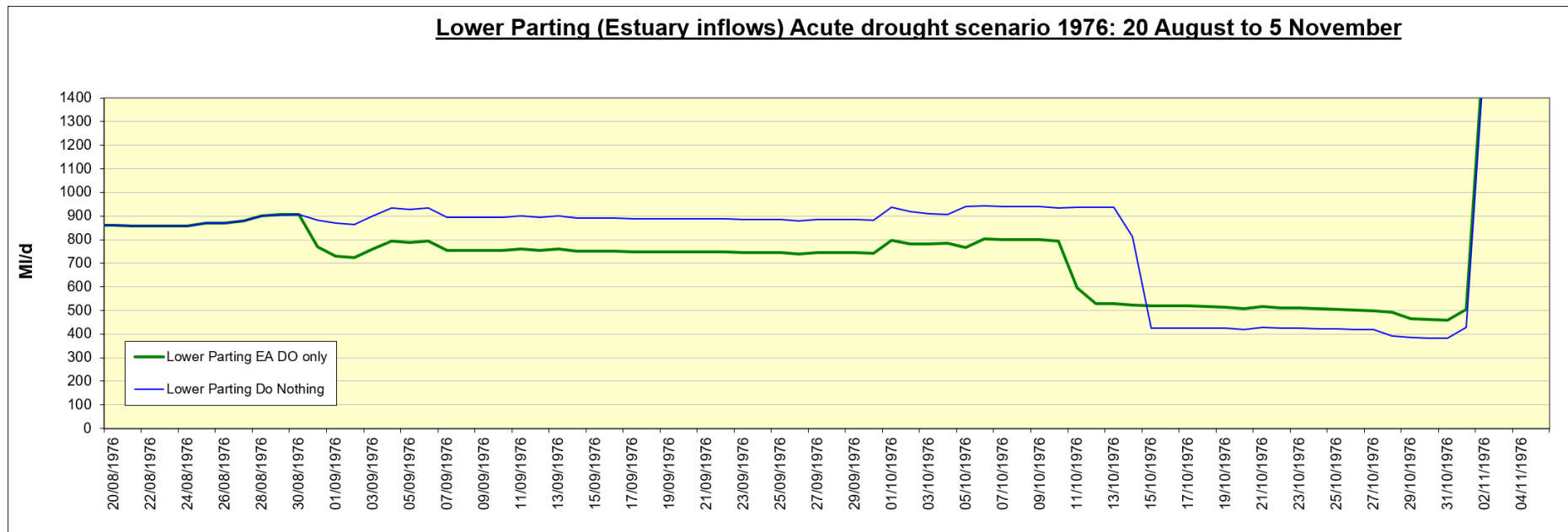


Figure 11 shows all the modelled impacts on flows at U/S Sharpness and Lower parting. Both are downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS) but U/S Sharpness is located upstream of the Gloucester and Sharpness canal abstraction while Lower Parting is downstream. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 11 presents two close up hydrographs, U/S Sharpness and Lower Parting from 20 August to 5 November 1976. Appendix E.1 contains the full modelled hydrographs from 1975 to 1979.

Deerhurst is the furthest downstream flow gauge from which to calibrate data, all downstream flows are estimated from models, previous analysis and observations and need to be considered with greater caution.

One of the potentially largest abstractions between Deerhurst and the Severn Estuary is the Canal and River Trust abstraction to the Gloucester and Sharpness Canal, taken from the East channel where the River Severn splits. The variability of abstraction coupled with a lack of actual flow data downstream of the canal abstraction make it very difficult to assess with confidence what the true impact on the lower River Severn would be.

In order to model the potential impacts of the Gloucester and Sharpness Canal abstraction on River Severn flows during severe drought, an average abstraction profile was manually inserted into Aquator. Flows were estimated both upstream of the canal abstraction and channel bifurcation (U/S Sharpness) and downstream (Lower Parting). The maximum abstraction represented was 300 MI/d, although it is recognised this could be a significant under estimation and final conclusions will be based around the 'worst case' likely effects (assuming maximum abstraction), with further work suggested to improve the conceptualisation and understanding for drought management.

Table 11

	U/S Sharpness		Lower Parting		Low Flows Enterprise	
	Acute Do Nothing MI/d	Acute EA DO in isolation MI/d	Acute Do Nothing MI/d	Acute EA DO in isolation MI/d	Modelled Influenced MI/d	Modelled Natural MI/d
	(1975-1977)	(1975-1977)	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	1170	1033	983	893	9772	10213
Q95	648	732	370	735	1910	2056
Q99	616	706	319	729	1509	1564
Q99.9	609	684	304	528	1096	1123

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

Leading up to the modelled regulation failure, 'Do Nothing' flows average (mathematical average) at 1170 MI/d for U/S Sharpness and 904 MI/d at Lower Parting. Flows crash on 14 October 1976, down to an average of 640 MI/d at U/S Sharpness and significantly lower to 415 MI/d at Lower Parting. Flow depression lasts 19 days with minimum flows of 609 MI/d and 382 MI/d occurring on 1 November, flow recovery begins on 2 November 1976.

As with all the upstream assessments, Appendix E.1 shows the 'Do Nothing' FDC as the highest until Q98. Appendix E.3 shows the EFI at Lower Parting is failed from Q50 onwards, crossing into High Risk failure from Q83 with marginal improvement

between Q96 and Q98 until flows crash. Bearing in mind EFIs provide a guide only and the short time period used to generate the scenario FDCs, it is still likely the natural drought event would have detrimental impacts on the lower River Severn. Even more so when considered against the unknown abstraction maximum's for the Gloucester and Sharpness Canal, and the natural channel bifurcation splitting flows through Gloucester.

Likely significant effects concluded.

Environment Agency Drought Order model

Impacts from the drought order are first observed on 31 August 1976, 6 days after taking affect at Clywedog. Flows crash on 11 October, 3 days earlier than 'Do Nothing'.

The average (mathematical average) flow maintained is 1031MI/d at U/S Sharpness and 762MI/d at Lower Parting, between 139-142 MI/d (12-16%) decrease from the 'Do Nothing' model. Flow benefits from the drought order are evident from 15 October, when modelled flows become higher than 'Do Nothing' by an average 90-91 MI/d (12-18% increase) until flow recovery on 2 November. Flow depression lasts for 22 days, 18 of which are higher than 'Do Nothing'. The drought order was active for 46 days before a benefit's observed.

Appendix E.1 again shows the Severn Drought Order reduces flows further below 'Do Nothing' largely between Q94 and Q98, after which obvious flow gains are achieved above the 'Do Nothing'. No additional EFI failures are caused and despite the minor extension of High Risk (>30% below the EFI) failure, results show the 'Do Nothing' drought baseline would already be causing likely significant effects. The additional failure is assessed as minor in context, and flow benefits are evident from Q98.

CONCLUSIONS: ACUTE SCENARIO

The Acute drought scenario represents a dry summer and winter (1975) preceding the summer drought (theoretical 1976) event. The modelled drought is broken in November with the return of high rainfall. It is important to note the rainfall creates significant flow recovery, and if the drought period continued the duration of flow gain would also increase until complete regulation system failure (all three sources exhausted) was reached. Similarly, if rainfall was to return earlier than modelled then regulation failure would be avoided and flow benefits of the Severn Drought Order may not be observed (refer to the Chronic scenario).

The most difficult stretch to assess with confidence is the lower Severn, from the channel bifurcation down to the Severn Estuary. Owing to the proximity to the Nationala Sites Network site and its importance for migratory fish and navigation, impacts could have the greatest significance to the catchment as a whole. The Canal & River Trust abstraction is now licenced. Post drought reports from 1976 and 1989 indicate large abstractions to the canal were taken during the peak of the droughts, in 1989 drying up flows down the West channel and allowing only a few centimetres to pass over the Llanthony Weir. An Operating Agreement was created in 1998 to help safeguard the Severn Estuary, and assessments have shown that under routine flow regimes there is sufficient flow reaching the Estuary. The difficulty is managing a severe drought, which falls outside normal operation and would require close liaison and management between interested parties.

Baseline, Do Nothing

The 'Do Nothing' model represents the baseline drought conditions if all routine abstractions and discharges were operating but no Environment Agency actions were taken to prolong Clywedog storage and therefore extend the potential regulation period. The model represents the unavoidable drought conditions and impacts that would occur if the Severn Drought Order was not operated. It clearly illustrates how critical Clywedog's role is in the Severn regulation system, providing the largest portion of water of the three regulation sources.

An annual total of 166 regulation days and 70,220 MI combined releases were modelled during the Acute 'Do Nothing' drought scenario, with 152 days of continuous regulation; Clywedog provided 66% (46374 MI), SGS 25% (17744 MI) and Vyrnwy 9% (6102 MI) of the total resource.

SGS provides a steady and continuous support, currently limited to a net of approximately 140 MI/d. Therefore, once Clywedog is exhausted only Vyrnwy bank contains large enough volumes to replace the 500+ MI/d regulation can require. However, the Vyrnwy bank is a short term resource when large releases are required and can only provide a temporary replacement to Clywedog. Modelling has shown during high regulation requirements, if Clywedog is exhausted and significant rainfall does not arrive, the regulation system will begin to fail and flows decline. The speed and degree of failure and resultant flow crashes will vary according to the climatic conditions, abstraction demand and how much resource remains individually in the Vyrnwy bank and SGS licence.

'Do Nothing' models regulation failure to begin on 29 September, 16 days after Clywedog reached dead water. Once Vyrnwy bank became exhausted, SGS also began to reach its 'individual' licence limits. In reality, SGS could be operated differently to utilise the group licence surplus (7756 MI) more effectively, and/or the Environment Agency could consider applying the SGS Drought Order. It is important to note the additional daily quantities from SGS would be too small to prevent the

eventual regulation failure, but early optimisation of the scheme could help delay a River Severn Drought Order application and exhausting Llyn Clywedog.

Significant flow impacts are observed under 'Do Nothing' at Bryntail, Bewdley, Saxons Lode, Deerhurst and the lower River Severn (most notably Lower Parting, downstream of the Gloucester and Sharpness Canal abstraction). It can therefore be assumed a drought of this severity is going to put the most flow stress on the Upper Severn (dependant on reservoir operation), and from around Bewdley downstream. Flows around Bewdley are likely to be most affected at and downstream of the major abstractions points.

Bryntail identified significant flow impact; although the EFI (derived from natural flow) is not failed the local habitat and ecosystems will have adapted to rely on this residual flow. As Clywedog reaches dead water the 18.2 Ml/d compensation flow requirement can no longer be made between 27 September and 1 November, a total of 35 days. The model does not show flows drying up entirely at Bryntail, however in reality this is likely to occur immediately downstream of the dam under such a severe drought (i.e. little/no baseflow expected). It is unclear where flows would begin to buffer from the limited tributary inputs, but with such a severe drought affecting the whole catchment it could be some distance downstream before significant flow returns.

Another consideration at Bryntail and downstream is the longer term effect on flow variation. Under 'Do Nothing', including the 35 days of little/no flow, there is a total of 306 continuous days (almost a full year) when only the compensation flow is released. The minimum flow occurs because the reservoir is intercepting all upstream runoff to refill, a vital process to prepare for the year ahead. The model shows September right through to the following July as being affected, in reality this period will vary according to how much recharge is received over what duration.

From Bewdley, it can be expected the whole River Severn downstream would be affected to varying degrees by the natural drought event. As a result of the regulation system failing, flows are shown to fall approximately 500 Ml/d over 2 days. Flows crash between 12 and 14 October, with depressions lasting between 19 and 22 days before natural recharge is modelled in early November. Bewdley predicts a daily minimum flow of 336 Ml/d, 182 Ml/d lower than ever recorded, Saxons Lode predicts a daily minimum 399 Ml/d, 316 Ml/d below existing records and Deerhurst predicts a daily minimum 577 Ml/d, 398 Ml/d below existing records.

The minimum daily flow prediction at U/S Sharpness is 609Ml/d and 382Ml/d at Lower Parting, downstream of the Gloucester and Sharpness Canal abstraction. The variability of abstraction quantities and limited data make it difficult to assess whether flows could be reduced significantly further still. This lower section of the River Severn, around Lower Parting, is most at risk to likely significant effects from a severe drought.

In reality, it is unclear what the minimum flows would be if the regulation system did fail. Aquator (version 3) has known problems with the naturalised flows, and discharges are currently built into the background flows so cannot be altered. Therefore exact flow predictions need to be assessed with caution. However, the flow response is the important result for future planning. Should Clywedog fail, the remaining regulation support has a short life and is unlikely to cope. Minimum flows will depend on climatic conditions and abstraction demands at the time of failure, but the River Severn flows can be expected to rapidly decline to baseflow rates until rainfall returns.

The degree of adverse impact resulting from significant flow impacts will depend on the duration of the event and demand management at the time. It is important to note that whilst satisfactory Naturalised flows could not be extracted from Aquator at this time, once the flows crash they are effectively representing the baseflow expected in the absence of regulation support, flows maintained above this level are therefore in the best interest of supporting the environment.

River Severn Drought Order

This model represents the conditions if all routine abstractions and discharges (including licence conditions) were operating, the Environment Agency activated the Severn Drought Order at Clywedog, but no other drought permits or orders were in force. Whilst this may not be entirely realistic for a drought of this magnitude, it is necessary in order to isolate and assess the impacts caused solely by the Environment Agency's Severn Drought Order, by comparison to the 'Do Nothing' scenario. The aim of the Severn Drought Order is to prolong Clywedog storage and therefore extend the potential regulation period, rather than risk running out of water and subsequently having no/little control over events.

Operating the Severn Drought Order under the Acute scenario does cause the regulation system to begin failing 2-3 days earlier than 'Do Nothing'. The drought order lowers the prescribed flow at Bewdley from 850 MI/d to 730 MI/d (over a 5 day mean), which only reduces regulation pressure by 120 MI/d. Capping the releases at Clywedog at 300 MI/d is necessary but creates a regulation deficit to achieve 730 MI/d, which Vyrnwy bank and SGS supplement earlier than under 'Do Nothing'. The available resource remains the same so inevitably the regulation system begins to fail slightly earlier as a result of Clywedog's reduced contribution.

The Severn Drought Order prevents Clywedog from reaching dead water, which has various benefits to the whole Severn catchment. Avoiding dead water enables the 18.2 MI/d compensation flow to Bryntail to be made throughout, preventing 35 days of little/no flows for this section of watercourse. Due to the 11% storage saving, Clywedog refills faster over the winter (exceeds 90% in April 1977) and therefore flow variation is returned in mid-June, 49 days earlier than under 'Do Nothing'.

Downstream, flows are reduced for between 45-48 days before the obvious flow benefits are observed. During this period, flows were reduced from 'Do Nothing' by 139-142 MI/d, equating to 13-15% flow reductions. Bryntail showed a significant improvement as discussed. Vyrnwy showed no change and Buildwas continued to show no significant flow impacts against the EFI. At Bewdley, no significant deterioration in flows beyond the unavoidable drought impacts were observed. Both Saxons Lode and Deerhurst showed the initial flow reductions caused a small increase in the duration of Medium Risk EFI failure, related to the 140 MI/d reduction in flows. At Lower Parting the EFI failure is assessed as High Risk and more prolonged than upstream, however operating the Severn Drought Order only creates a minor increase in duration of this failure. It is difficult to assess whether these lead in flow reductions (prior to any regulation failure) are significant to the environment, and needs to be balanced against the subsequent flow gains it achieves.

Once the regulation system begins to fail, the Severn Drought Order shows clear benefits. Protecting the storage in Clywedog over the previous 45-48 days enables small but continuous releases between 91-63 MI/d (reduces per day according to remaining storage) to be made throughout the critical flow depression period. Under 'Do Nothing' only small SGS releases were possible at this point. The regulation support Clywedog continues to provide does have a limited life, but the Acute

scenario shows minimum flows are increased by 72-75 MI, and produce an average flow gain of 89-90 MI/d.

Modelling supports the aim of the Severn Drought Order. By operating the drought order and regulating to a lower flow target at Bewdley, Clywedog avoids reaching dead water and compensation flows at Bryntail are protected. The drought order does not prevent regulation system failure from occurring if the drought persists, but does enable Clywedog to continue providing regulation support at a reduced rate throughout the Acute scenario, subsequently maintaining higher flows during the worst period. Longer term, the Severn Drought Order enables the reservoir to refill faster, reducing the impacts on flow variation in the upper catchment and preparing the system for a subsequent drought/regulation season.

Model Data: Chronic Scenario

Severn Regulation impacts

The Acute scenario attempted to model a prolonged one season drought. The question was evident that if significant rainfall arrived earlier than modelled then the flow benefits would never be recognised. This raised the question, “what would be the point, and would it cause more harm than good?” The Chronic scenario was built to investigate this question. By introducing rainfall earlier in the existing Acute scenario the flow benefits were removed, the dry period was then extended over the critical recharge season to produce a more long term drought to test the Severn Drought Order.

Do Nothing Model

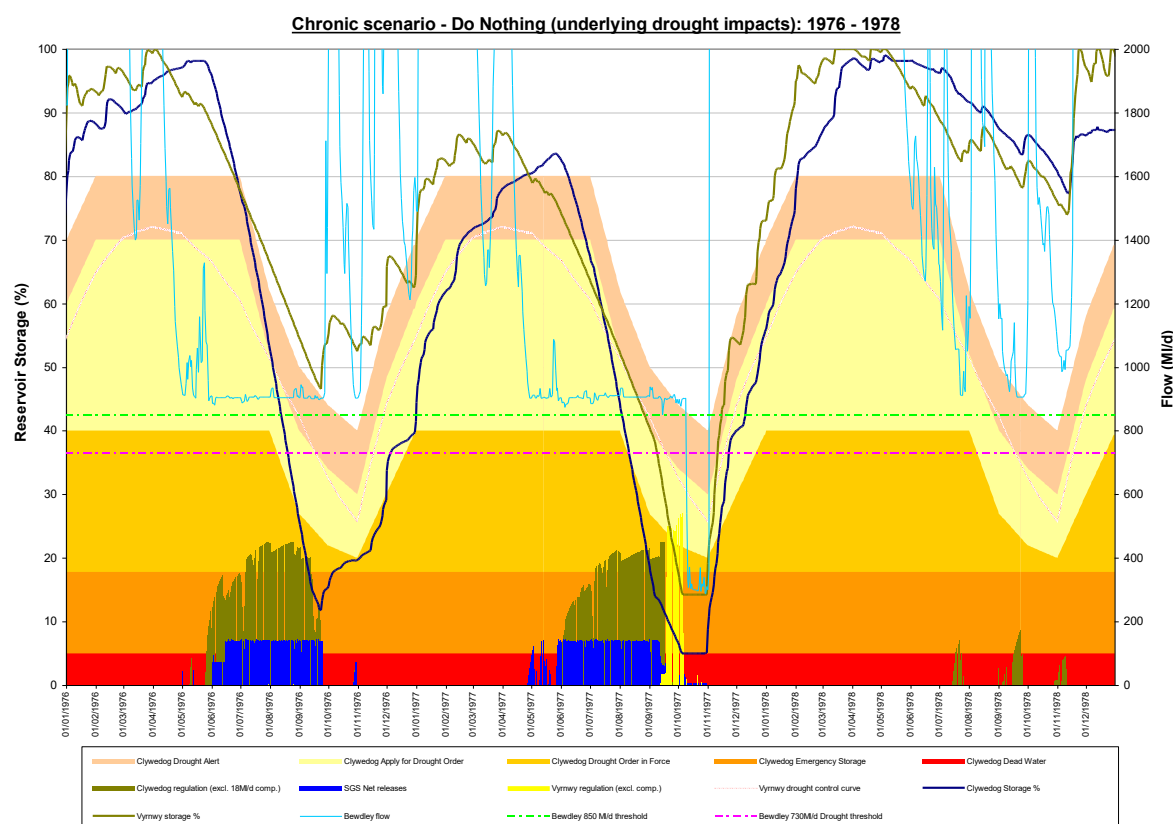


Figure 12 shows the modelled impacts on reservoir storage, alongside the regulation releases made from Clywedog, Vyrnwy and the Shropshire groundwater Scheme under the Do Nothing Chronic model.

Figure 12 presents modelled regulation operation if the Severn Drought Order were not operated, but the Chronic drought scenario were allowed to run its course.

The baseline shows how the drought impacts are spread over the two year period. During the first summer (1976), 59030 MI of regulation is used over 135 days, the majority (74%) sourced from Clywedog. Clywedog storage is drawn down into emergency storage 12%, but rainfall returning in October (Acute delayed until November) prevents dead water from being reached. As dead water is avoided, compensation flows are maintained throughout and no detrimental flow impacts result.

SGS provides a full 135 days of regulation support, with 122 days of continuous releases beginning in June (1976). A total 15595 MI are provided, 26% of the total resource. No individual annual, or group 5 year licence limits are exceeded, although the heavy usage would be noted by the Environment Agency and the risk to the following year planned for (e.g. familiarise with the option to apply for the SGS drought order).

Throughout the recharge season Clywedog reaches a maximum 84% on 26 May 1977, with continuous regulation releases beginning on 27 May 1977. This helps illustrate the impact of allowing Clywedog to draw down so far in any year, without at least taking preventative measures. Just using Figure 19 it is clear how important obtaining complete recharge is ahead of a full regulation season.

During the critical drought season (1977) Clywedog provides the primary support up until dead water (5%) is reached on 18 September. As with the Acute scenario, Vyrnwy bank can only replace the high releases for a limited time, and SGS cannot provide additional water as maximum rates are already discharging. The regulation system begins to fail (determined as Bewdley prescribed flow failure) 19 days after Clywedog, initially as Vyrnwy bank exhausts, and then further declines as individual SGS Licences are reached.

A total of 187 regulation days and 69,959 MI combined releases were modelled during the chronic drought year (1977), with Clywedog providing 59% (39620 MI) of the resource, SGS providing 27% (18085 MI) and Vyrnwy providing 14% (9254 MI).

Clywedog provides 114 days regulation support from 27 May 1977 to 18 September, when dead water is reached. Due to the reservoir only being 84% full when continuous regulation begins, it takes only 13 days of <280 MI/d releases to cross the Drought Alert curve (9 June), 31 days to cross the Drought Order application curve (27 June), 78 days before crossing the Drought Order in force (13 August) curve and 98 days before crossing the emergency storage (2 September) curve. Clywedog storage remains in dead water for 42 days.

Vyrnwy reservoir provided 23 days of regulation support between 13 September and 6 October reaching a minimum storage of 14%, dead water is avoided. SGS activates on 26 April and provides 187 days continuous regulation support until 30 October. Maximum 140 MI/d net discharges are made continuously from 28 May until individual licence maximums are reached on 12 September, 30 September and 9 October, with net discharges halved on each occasion. The combined licence annual limit is not exceeded, which could suggest with different operation some mitigation options are available.

The SGS individual licences are put under significant pressure during the 1977 drought, regulating for 187 days in total. Although the group and 5 year rolling licence is not exceeded, once again it appears to be the individual licence limits which are reached, causing different phases to shut down as the season progresses. SGS support first steps back from 12 September, reducing from the net 140 MI/d to 64 MI/d by the 14 September. Further reductions begin on the 30 September, down to 31 MI/d by the 2 October, then down to only 7 MI/d between 9 and 30 October. In reality this could potentially be operated differently to utilise more of the group licence.

Clywedog recovers above dead water on 18 September and above the emergency storage curve on 9 November 1976, but doesn't exceed the Drought Alert curve until

3 February 1978 (239 days below). Vyrnwy recovers above the drought control curve on 9 November 1977 and exceeds 90% storage on 28 January 1978; Clywedog takes until 13 March 1978 to exceed 90% storage.

Environment Agency Drought Order in isolation Model

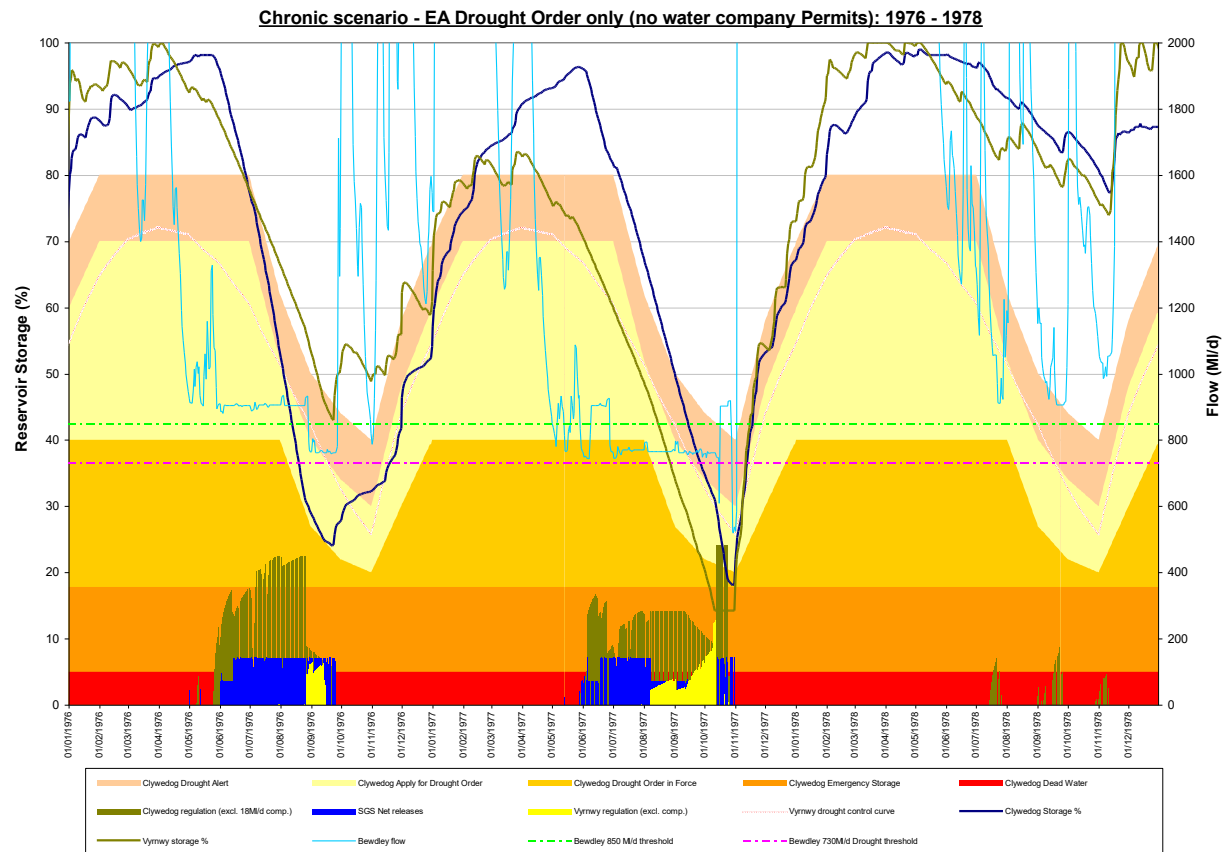


Figure 13 shows the modelled impacts on reservoir storage, alongside the regulation releases made from Clywedog, Vyrnwy and the Shropshire groundwater Scheme under the Environment Agency Drought Order in isolation model.

Figure 13 presents modelled regulation operation if the Severn Drought Order were operated but no other drought permits or orders were active.

Drought impacts are spread over the two year period, with the Severn Drought Order being activated separately both years. Figure 20 illustrates how, similarly to the Acute scenario, activating the Severn Drought Order between 25 August 1976 and 14 February 1977 (total 173 days) protects Clywedog storage. In 1976 neither emergency storage or dead water is reached (minimum storage 24%), allowing regulation releases to remain around 150 Ml/d. Rainfall returns in October, before Vyrnwy bank becomes exhausted and therefore no resultant flow crashes are observed downstream.

Using the Severn Drought Order in 1976 saves an additional 15% storage at Clywedog; by May 1977 this has enabled Clywedog to reach 96% before the continuous regulation season begins. During 1977 the Severn Drought Order bounces on and off three times; 24 February (Clywedog 84%) – 4 June, 24 June (Clywedog 84%) - 1 October and 24 October (Clywedog 19%) - 1 February. It is unclear what the model is responding to on the first two occasions as Clywedog

storage remains above the trigger curve until 22 October 1977; flow response at Bewdley confirms Aquator is applying the Severn Drought Order conditions, although rainfall flow response masks a large portion of activity.

In reality these early occasions should be discounted as error and only the last activation on 24 October appears linked to Clywedog storage (19% storage; trigger curve 21%). Due to these anomalies timings and volumes will not be analysed in the same detail as the Acute scenario, but used more as an illustration of flow behaviour and trends that could occur in reality. Operation during a real event would be managed differently, preventing unnecessary 'yo yoying' of drought order operations.

The utilisation of the Severn Drought Order in 1976 enables healthy storage to be reached at Clywedog ahead of the 1977 event. The extra 15% storage, and activation of the Severn Drought Order again in 1977, prevents Clywedog reaching emergency storage and dead water. Although the timings and volumes could be inaccurate, the Chronic scenario is demonstrating how the water saved from the previous year can then be released back into the system if a subsequent drought occurs the following year. Under 'Do Nothing', Clywedog storage does not enable these higher releases to be made as the resource is exhausted.

When the Severn Drought Order goes off for the second time on 12 October 1977, Clywedog releases spike back up to 481 MI/d for 12 days before the drought order reactivates as storage reaches 19%. In reality, such high releases are extremely unlikely when storage is so low, however it demonstrates the spare resource Aquator is then feeding back into the system. In reality, this storage could be released at a lower rate for longer, and prevent the short term flow crashes observed after the 24 October. However if the Severn Drought Order had not been activated on the previous two occasions, there would be less storage in Clywedog and therefore these releases may not be triggered/possible, although more water would still be available than under 'Do Nothing'.

Ignoring the initial two Severn Drought Order activations, Clywedog trigger curves indicate the third activation on 24 October is correct. Clywedog storage has reached 19% (Drought Order in Force curve threshold 21%) and would activate the Drought Order requirement. This could indicate the savings made the previous year delay the requirement in the consecutive year by almost 2 months.

A more conservative interpretation, owing to the additional savings made by the two suspect drought order activations in 1977, would be the Severn Drought Order may not be required until late September/early October, which is still a month later than the previous year. Comparing this to storage in the 'Do Nothing' model, Clywedog crosses the Drought Order in Force curve on 13 August 1977, whereas the Severn Drought Order crosses on 22 October 1977. This would appear to also support the observation that a drought order application could be delayed by over a month in the consecutive year of drought, in real terms this could also create important stalling time for rainfall to arrive.

SGS operation is significantly different in 1977 compared to 'Do Nothing' as a response to the Severn Drought Order reducing prescribed flows at Bewdley for longer periods and therefore reducing the pressure on the regulation system. SGS operates for 155 days in total (32 days less than 'Do Nothing'); releases are stepped back to 71 MI/d on 8 August 1977 due to reduced demand. This saves enough licence capacity to increase back to 140 MI/d between 13 and 30 October, as Clywedog releases are stepped back again as both the Severn Drought Order is activated and emergency storage approaches.

Based on the modelled regulation releases during 1977, a total of 157 regulation days and 60,530 MI combined releases were modelled during the chronic drought year (1977), with Clywedog providing 65% (39179 MI) of the resource, SGS providing 25% (15337 MI) and Vyrnwy providing 10% (6015 MI).

Corridor Flow Impacts

The main focus of interpretation and graphing will be the modelled 1977 drought, the impacts and flow behaviour for Chronic 1976 will be very similar to the Acute scenario, just with shorter duration periods and no flow benefits being observed. The main aim of producing a Chronic scenario was to test what could happen if a second drought was to follow in 1977, and assess the more accumulative flow impact where possible.

Due to modelling anomalies relating to when the Severn Drought Order is activated by Aquator, the affected results have to be analysed in terms of general flow behaviour and trends, using judgement to suggest how the results might differ if the drought order were operated more realistically. The 'Do Nothing' baseline is unaffected by this issue, as no drought orders or permits are operated. Therefore the baseline can be used for comparison. EFI testing has been plotted for the assessment points, but not analysed in detail as the duration of low flows under Severn Drought Order operation will be incorrect due to the modelling anomaly.

Assessment Point 1, Bryntail

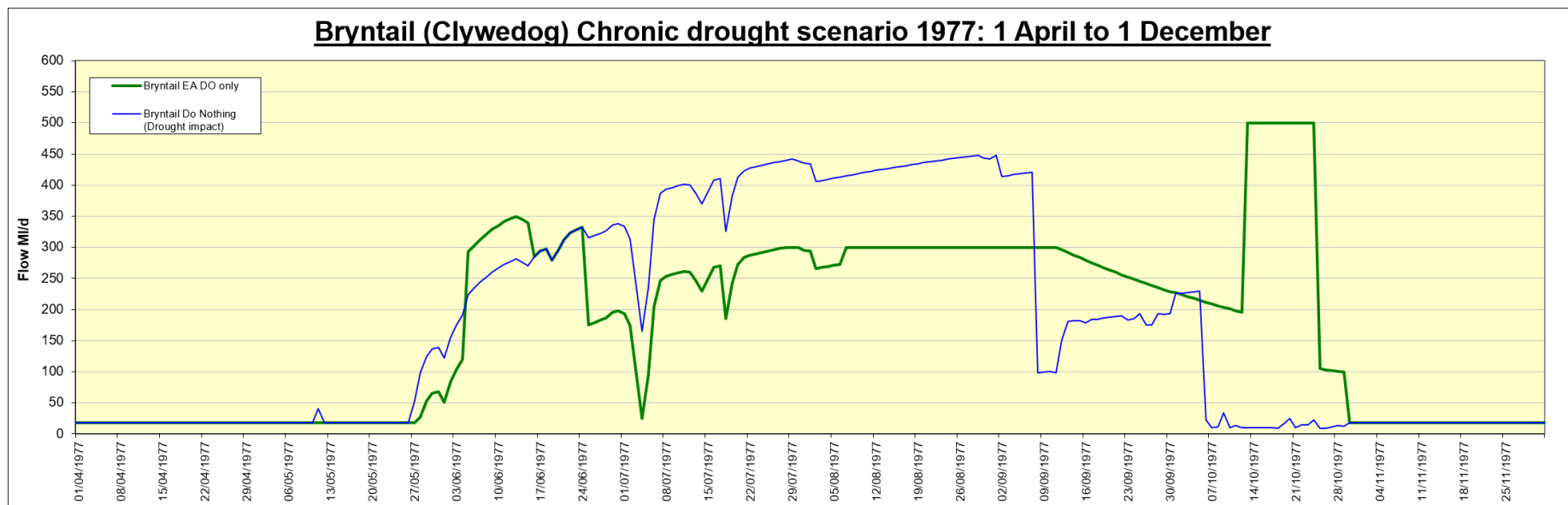


Figure 14 shows the modelled impacts on flows at Bryntail, immediately downstream of Clywedog dam. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 14 presents a close up of the hydrographs at Bryntail from 1 April to 1 December 1977, the critical period of low flow interest. Appendix F.2 contains the full period.

Table 12

	Chronic Do Nothing MI/d	Chronic EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	174	175	176	216
Q95	18	18	18	19
Q99	10	18	18	-6
Q99.9	9	18	-	-59

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

No compensation flow failure is observed in 1976. Flow variation is lost for 245 days while Clywedog refills, with similar implications to the Acute scenario, although variation returns when regulation commences in 1977. No overall no adverse impacts would be expected.

The 1977 event is more significant to Bryntail; Clywedog reaches dead water on 18 September resulting in compensation flow failure. 'Do Nothing' models 42 days of dead water until 30 October, slightly longer than the Acute scenario, increasing the risk of flows drying up entirely in the upper section although Aquator suggests a minimum flow of 9 MI/d.

Appendix F.3 shows a mainly High Risk EFI failure between Q60 and Q94, although the lower flows satisfy the EFI. As with Acute we know the flows fall significantly below the 18.2 compensation flow the environment has adapted to, this whole period should therefore be considered as a High Risk failure.

The time period used to calculate the FDCs is significantly shorter than the 18 years of varied flow used to generate the naturalised flow and subsequent EFI, therefore it can only be used as a guide for lower flow failures. The Chronic scenario does span over two significant drought periods, and therefore it is likely to create lower flows for longer than observed in the Acute. The FDC shows the compensation flow of 18.2 MI/d featuring from Q63, due to the lack of flow variation created by the reservoir refilling and then reaching dead water, it is fair to assume this flow frequency is representative.

Environment Agency Drought Order model

The Environment Agency Drought Order model shows no compensation flow failure, as dead water is avoided in both drought years. No significant change is observed in 1976 flow variation compared to 'Do Nothing', as variation returns as regulation begins in 1977.

Despite the suspect timings of 1977, Clywedog storage is protected by the Severn Drought Order and spare resources are evident in releases made in October 1977, therefore compensation flow is expected to be maintained and higher flows and greater flow variation from 'Do Nothing' would be expected as a result. Although

suspect, this is reflected by Appendix F.3 reduced EFI failures between Q62 and Q65, and Q98+.

No significant flow impact beyond the 'Do Nothing' baseline is concluded.

Assessment Point 2, Vyrnwy

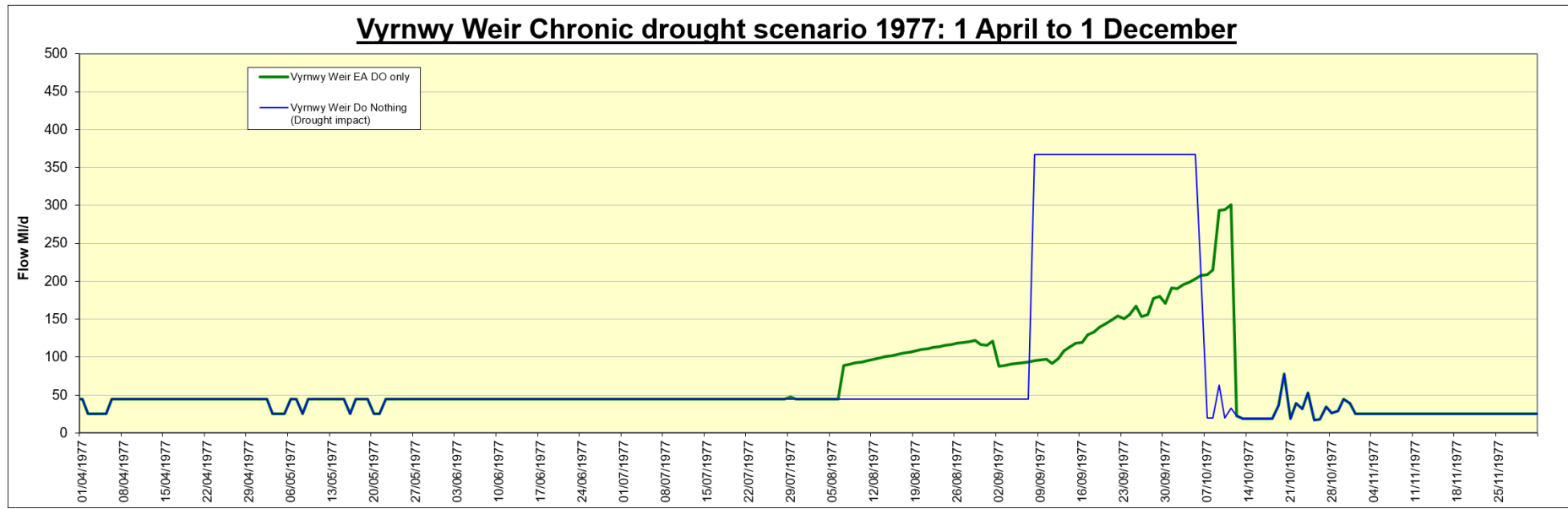


Figure 15 shows the modelled impacts on flows at Vyrnwy, immediately downstream of Reservoir dam. Vyrnwy would not be directly impacted by the operation of an Environment Agency drought order, however changes in the regulation operation would indirectly impact on flows at this AP. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 15 presents a close up of the hydrographs at Vyrnwy from 1 April to 1 December 1977, the critical period of low flows. Appendix F.2 contains the full modelled hydrographs from 1975 to 1979.

Table 13

	Chronic Do Nothing MI/d	Chronic EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	45	45	131	426
Q95	25	25	25	30
Q99	20	25	24	-3
Q99.9	18	18	-	-228

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

The 'Do Nothing' model does not cause compensation flow failure (below 25 MI/d expected at Vyrnwy Weir) during 1976.

Figure 22 shows during 1977 the higher compensation flow of 45 MI/d is maintained for the majority of the period between April and September, demonstrating how flows at Cownwy Weir would be low due to the drought conditions, triggering the higher rate at Vyrnwy Weir. Flows peak in 1977 between 8 September and 6 October, as releases of 368 MI/d are made. There is a period immediately following these high releases, between 7 and 26 October, when Vyrnwy Weir flows appear to intermittently fail the compensation flow. Storage is critically low at 14%, but reaches this on other occasions whilst not failing the compensation flow. Therefore it's unclear whether this is just modelling 'noise' built in to account for human error, or genuine failure as flows bounce between 17.46 MI/d and 77.57 MI/d over 20 days.

As with Acute, Appendix F.3 shows nearly the full flow duration curve creating high risk failures of the EFI, until Q95 when flow exceeds, similar to the gauged record. The irregular compensation flow failures occur in the most infrequent percentiles and therefore satisfy the EFI. The environment will have adapted to the residual flow, although it's unclear whether they are genuine failures, occurring irregularly and at most lasting for 7 continuous days. Flow impact will be concluded as a precautionary measure, highlighting the potential issue as needing mitigation/management in a real event.

Environment Agency Drought Order model

The Severn Drought Order model also shows no compensation flow failure during 1976, but a similar period of intermittent compensation failure in 1977. The period is slightly shorter at 15 days (maximum 7 days continuously), occurring between 12 and 26 October 1977. In reality it is unlikely this would occur, action would be taken to protect the compensation flow during regulation, and United Utilities would operate their own drought management procedures. However, for precaution it will be concluded as having a flow impact.

Assessment Point 3, Buildwas

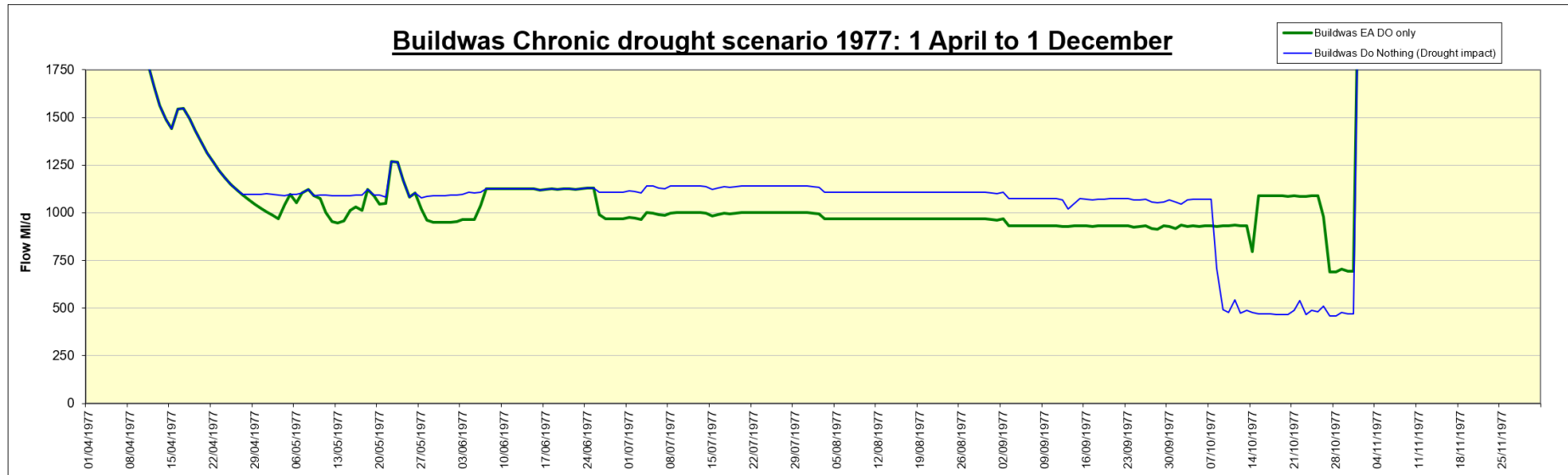


Figure 16 shows all the modelled impacts on flows at Buildwas, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 16 presents a close up of the hydrographs at Buildwas. Appendix F.1 contains the full modelled hydrographs from 1975 to 1979

Table 14

	Chronic Do Nothing MI/d	Chronic EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	3345	3345	5511	5646
Q95	1067	934	1030	741
Q99	471	910	919	527
Q99.9	459	691	-	527

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

Appendix F.1 shows flow deterioration between June and October 1976, but no flow crashes as the regulation system continues to support until rainfall returns on 29 September. Flows during this period average (mathematical average) at 1070 MI/d.

The 1977 drought is more significant and illustrates how taking no precautions the previous year, followed by a second drought event, results in a more serious flow crash than the Acute scenario. A minimum flow of 459 MI/d occurs on 27 October, 53 MI lower than the Acute 'Do Nothing' minimum. The main difference seems to be the reduced SGS releases (only 7 MI/d at this point) as individual licence limits have been met, Clywedog and Vyrnwy resources have already been exhausted.

Prior to the regulation system failure in 1977, the 'Do Nothing' model flows at Buildwas average (mathematical average) at 1086 MI/d. The impacts of regulation failure first impact on Buildwas on 8 October, halving flows to an average of 481 MI/d (59 MI/d lower than the Acute scenario). The flow depression lasts 24 days in total before rainfall elevates flows from 1 November.

Appendix F.3 shows more high to mid EFI failures, but due to different time periods being compared it's the low flows that have more relevance. From Q79 onwards the EFI is satisfied, even after flows crash from Q98. Although the minimum flows appear significantly lower than normal conditions, the duration is still relatively short and remains above natural flows. No significant impact on flow is concluded.

Some consideration should be made of the impacts on water levels, especially through Ironbridge Gorge, which forces flow along a narrow section and therefore will be more sensitive to level changes.

Environment Agency Drought Order model

Appendix F.1 shows the first impacts from activating the Severn Drought Order in 1976 occur on 27 August. Flows during this period average (mathematical average) at 931 MI/d, 139 MI/d lower than 'Do Nothing'. No flow crashes occur as recharge arrives on 26 September, therefore no flow benefits are gained in 1976 by activating the Severn Drought Order. The flow impacts will be the same as assessed for the Acute scenario, minus the benefits.

The flows during 1977 need to be considered with caution as the Severn Drought Order operation dates appear unrealistic. A minimum flow of 689 MI/d occurs on 28 October, 230 MI higher than 'Do Nothing'. However, if the Severn Drought Order were not to activate on the first two occasions during 1977, then Clywedog storage would be drawn down faster to support the higher prescribed flow at Bewdley, leaving less spare resource to maintain the flow currently modelled. It is more likely the 'Do Nothing' flows would be matched for longer leading up to the flow crash, at which point the Severn Drought Order should enable the lower prescribed flows to continue as currently modelled, still showing clear benefits from 'Do Nothing'. The high releases made from 12 October would be unlikely, continuing instead at the lower prescribed flow rate until the inevitable flow crash, which is likely to occur sooner than shown and possibly result in lower minimum flows, as a direct consequence of using regulation resources more heavily earlier in the year.

Appendix F.3 is likely to alter, reducing the duration of drift from the 'Do Nothing' leading up to Q98, and probably bringing the flow crash forward to around Q99. Even so, no significant additional EFI failure would be created and flow benefits are likely to be achieved.

No significant adverse impact on flow is concluded.

Assessment Point 4, Bewdley

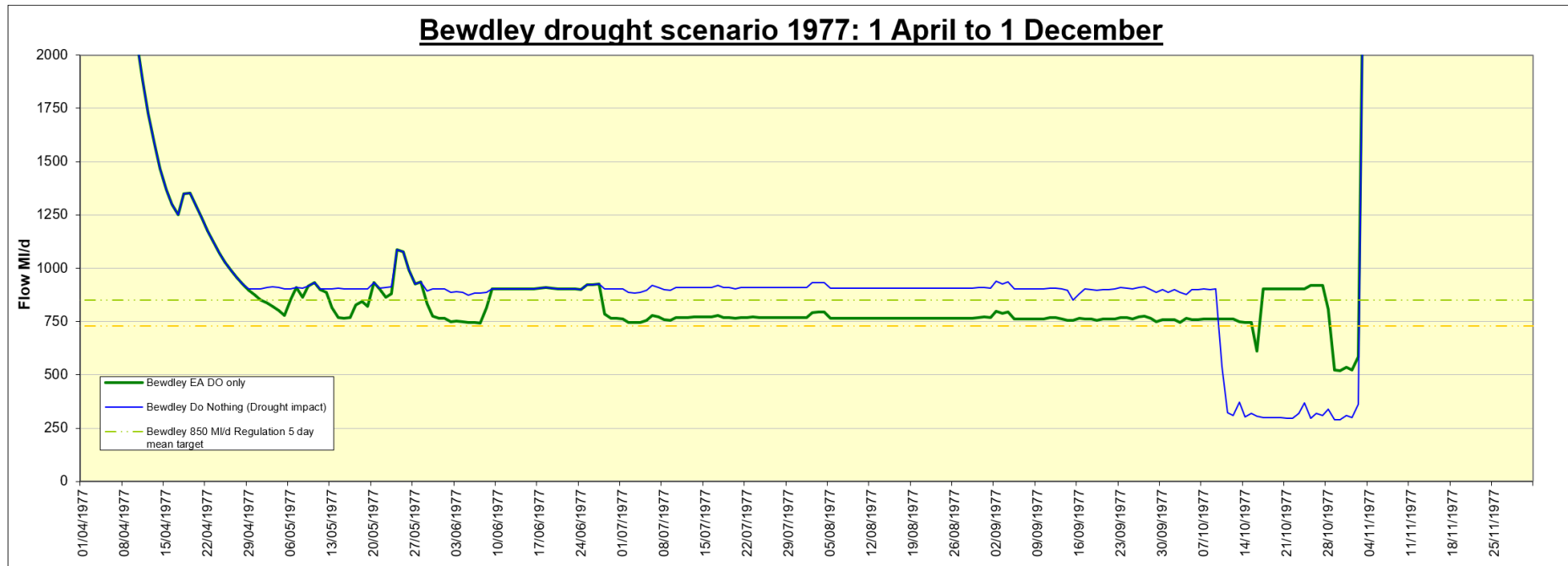


Figure 17 shows all the modelled impacts on flows at Bewdley, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 17 presents a close up of the hydrographs at Bewdley from 1 April and 1 December 1977, the critical period of low flows. Appendix F.1 contains the full modelled hydrographs

Table 15

	Chronic Do Nothing MI/d	Chronic EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	3250	3250	5470	6211
Q95	895	762	881	930
Q99	304	745	791	715
Q99.9	289	521	-	458

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

The same flow loss between Buildwas and Bewdley is shown by the Chronic scenario, demonstrating the high abstraction demand from the Severn and lack of natural runoff during such a severe drought. This does not prevent the normal regulation flow targets from being maintained (when the Severn Drought Order is not active) and no detrimental impacts would be expected.

Do Nothing model

Appendix F.1 shows the reduced flows between June and October 1976, but the 850 MI/d prescribed flow is maintained throughout. Flows during this period average (mathematical average) at 908 MI/d, with recharge arriving on 28 September.

During 1977 the drought begins to impact flows from the end of April, steadying out to an average (mathematical average) 903 MI/d for 163 days. Regulation failure causes flows to crash on 10 October, more than halving flows to an average of 314 MI/d (54 MI/d lower than the Acute scenario) with a minimum flow of 289 MI/d occurring on 29 October. Flow depression lasts 24 days (all below the critical 650 MI/d 1 day target) before rainfall elevates flows from 3 November.

The increased severity of the flow crash between Acute and Chronic is due to the reduced SGS releases as individual licence limits have been reached earlier, Clywedog and Vyrnwy resources have already been exhausted.

Appendix F.3 shows extensive EFI failure under 'Do Nothing', for the high to mid flow range this just demonstrates how Chronic has created a scenario with a higher duration of suppressed flows. The loss of flow variation would be a natural consequence of drought, and in reality the 3 year period being considered would still only truly account for a small frequency of low flows when a longer record is analysed. Having shown the prescribed 850 MI/d flow was maintained up until flows crashed, other than a loss of flow variation no significant impact would be expected up to this point. Therefore only the Q98 onwards should be considered relevant to this assessment. Appendix F.3 shows the Q98 flows fall significantly from satisfying the EFI to the High Risk band. Both the scale of flow change and EFI failure support the conclusion of significant flow impact.

Environment Agency Drought Order model

Appendix F.1 shows the first impacts from activating the Severn Drought Order in 1976 occur on 29 August. Flows during this period average (mathematical average) at 769 MI/d, 139 MI/d lower than 'Do Nothing'. No flow crashes occur as recharge arrives on 28 September, ending the drought before flow benefits are gained. The flow impacts will be the same as assessed for the Acute scenario, minus the subsequent benefits.

The flows during 1977 need to be considered with caution due to the modelling issues. A minimum flow of 520 MI/d occurs on 30 October, 231 MI higher than 'Do Nothing'. If the first two Severn Drought Order activations were discounted as error, the same flow trend discussed at Buildwas would be expected, but with slightly lower flows due to higher abstractions around this area. Overall, flows should still be maintained around the 730 MI/d prescribed flow mark after the 'Do Nothing' flows crash, utilising the water saved during the 1976 drought order activation. A flow crash would still be inevitable if the drought continued, likely to occur sooner than currently modelled and possibly to lower flows, depending on how much regulation water was still available. The high releases shown from 17 October would be removed.

The duration of reduced flows prior to the flow crash should be significantly reduced (currently around 105 days) as the Severn Drought Order is operated for a shorter (more accurate) period.

Appendix F.3 would also alter, reducing the duration of drift from the 'Do Nothing' leading up to Q98, as the combined duration of Severn Drought Order operation would be reduced (i.e. less time regulating to lower 730 MI/d prescribed flows). If the drought continued long enough for a flow crash to occur, the flow drop on the FDC would likely shift closer to Q99 (occurring sooner and so for slightly longer), reducing the benefits slightly.

Due to modelling issues it is difficult to assess flow impacts with certainty. However, if the corrective assumptions being made are reasonable, and taking into account the Acute assessment, no further adverse flow impacts would be expected, while more significant flow gains (than Acute) could be achieved if the drought continued for long enough.

No significant adverse impact on flow is concluded.

Assessment Point 5, Saxons Lode

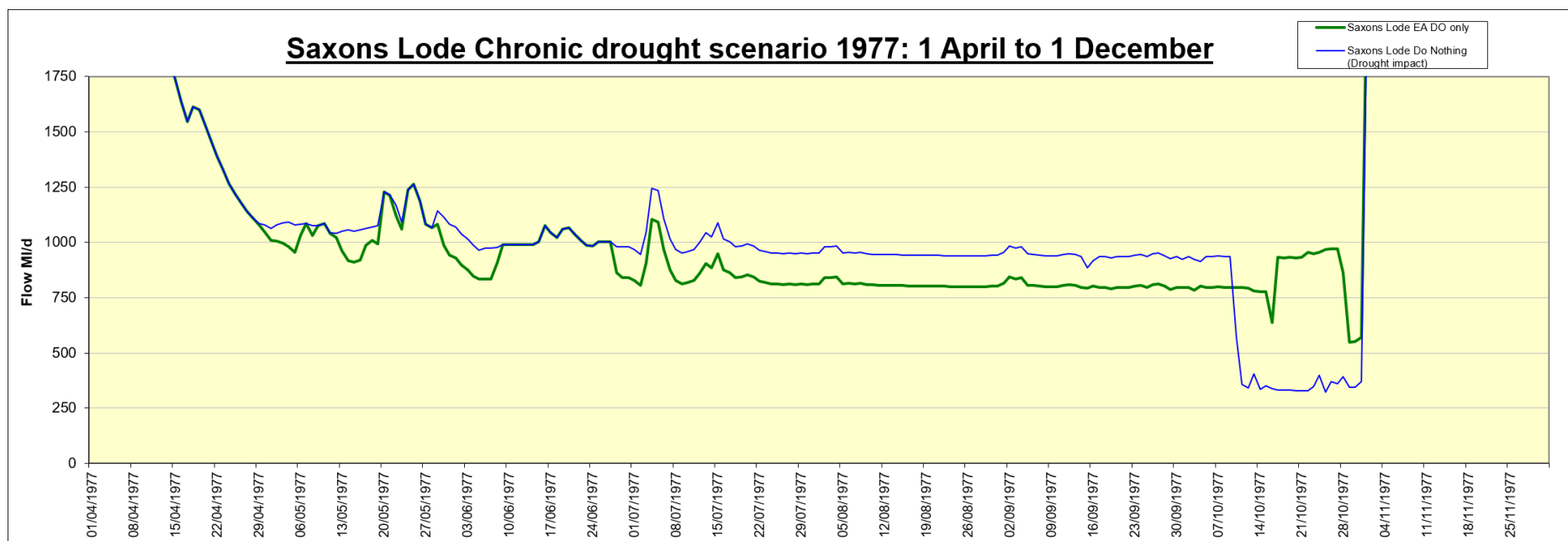


Figure 18 shows all the modelled impacts on flows at Saxons Lode, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 18 presents a close up of the hydrographs at Saxons Lode from 1 April to 1 December 1977, the critical period of low flows. Appendix F.1 contains the full modelled hydrographs.

Table 16

	Chronic Do Nothing MI/d	Chronic EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	3938	3938	7991	8523
Q95	939	804	1327	1350
Q99	344	791	1167	1131
Q99.9	328	551	-	536

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

Appendix F.1 shows reduced flows between June and October 1976, but no flow crash occurs. Flows during this period average (mathematical average) at 961 MI/d, with recharge arriving on 15 September.

During 1977 the drought begins to impact flows from the end of April, steadying out to an average (mathematical average) 941 MI/d for approximately 160 days. Regulation failure causes flows to crash on 10 October, more than halving flows to an average of 350 MI/d (78 MI/d lower than the Acute scenario) with a minimum flow of 323 MI/d occurring on 25 October. Flow depression lasts 22 days before rainfall elevates flows from 1 November, 2 days earlier than upstream Bewdley, which is likely due to more localised rainfall feeding down the lower tributaries.

Appendix F.3 shows almost complete EFI failure, as discussed at Bewdley, Q98 onwards should be considered the most relevant to this assessment. Flows up to Q98 already show Low Risk (>10% below EFI) failure, significantly falling to High Risk failure along the FDC. Significant flow impact is concluded.

Environment Agency Drought Order model

Appendix F.1 shows the first impacts from activating the Severn Drought Order in 1976 occur on 29 August. Flows during this period average (mathematical average) at 823 MI/d, 138 MI/d lower than 'Do Nothing'. No flow benefits are achieved as recharge arrives on 15 September, 13 days earlier (localised rainfall) than Bewdley. Flow impacts from activating the Severn Drought Order would be the same as assessed for the Acute scenario, minus the subsequent benefits.

The flows during 1977 need to be considered with caution due to the modelling issues. A minimum flow of 547 MI/d occurs on 29 October, 224 MI higher than 'Do Nothing'. If the first two Severn Drought Order activations were discounted as error, the same flow trend discussed at Buildwas and Bewdley would be expected.

Flows preceding the critical period ('Do Nothing' flow crash) should still be maintained around the 823 MI/d being modelled (118 MI/d lower than 'Do Nothing'), but for a shorter time period as the Severn Drought Order would be activated later. The high releases shown from 17 October would be removed. A flow crash would still be inevitable if the drought continued, likely to occur sooner than currently

modelled and possibly to lower flows, depending on how much regulation water was still available.

Appendix F.3 would alter, again reducing the duration of drift from the 'Do Nothing' leading up to Q98. If the drought continued long enough for a flow crash to occur, the flow drop on the FDC is likely to shift closer to Q99 (occurring sooner and so for slightly longer), marginally reducing the duration of benefit.

Due to modelling issues it is difficult to assess flow impacts with certainty. However, if the corrective assumptions being made are reasonable, then the flow impact conclusions from the Acute scenario should be applied. Using the Acute scenario conclusions as a precautionary measure, a minor increase in the duration of Medium Risk EFI failure could be expected, however in the Chronic scenario the flow benefits achieved if the drought continued, would be greater than Acute.

Assessment Point 6, Haw Bridge/Deerhurst

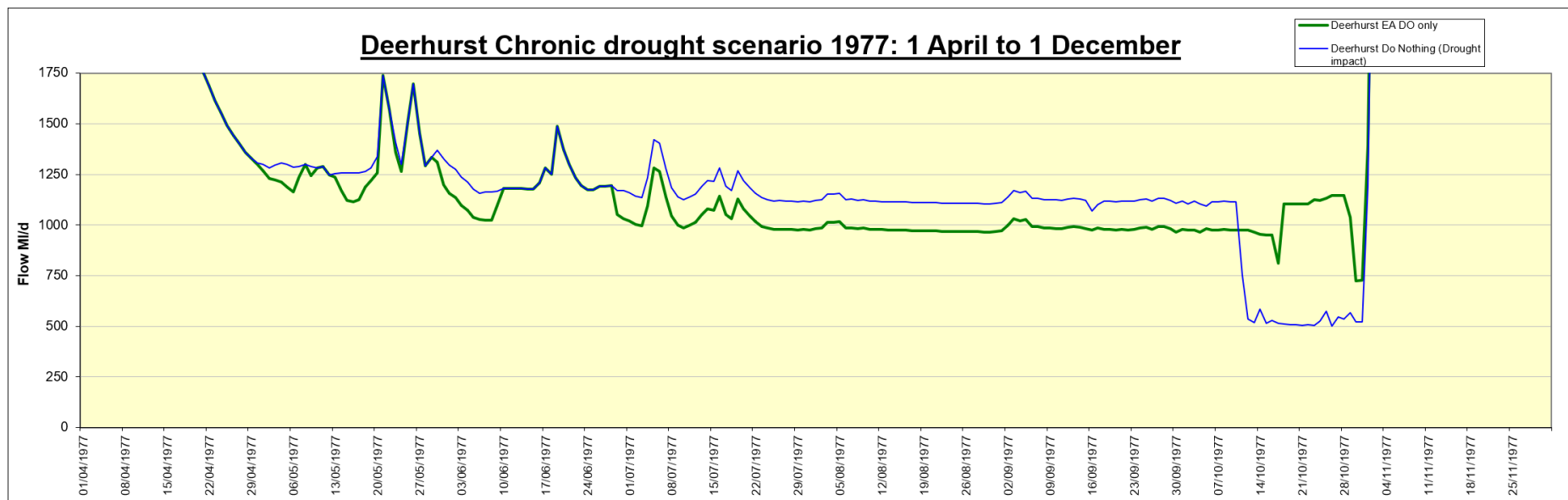


Figure 19 shows all the modelled impacts on flows at Deerhurst, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 19 presents a close up of the hydrographs at Deerhurst from 1 April to 1 December 1977. Appendix F.1 contains the full modelled hydrographs

Table 28

	Chronic Do Nothing MI/d	Chronic EA DO in isolation MI/d	Gauged MI/d	Naturalised MI/d
	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	4418	4418	9054	10079
Q95	1108	979	1571	1680
Q99	520	966	1317	1224
Q99.9	505	727	-	730

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

Appendix F.1 shows reduced flows between June and October 1976, but no flow crash occurs. Flows during this period average (mathematical average) at 1150 MI/d, with recharge arriving on 16 September.

The 1977 drought impacts on flows from the end of April, with occasional rainfall spikes until August. The average (mathematical average) flows for this period are 1118 MI/d (approximately 160 days). Regulation failure causes flows to crash on 11 October, more than halving flows to an average of 537 MI/d (71 MI/d lower than the Acute scenario) with a minimum flow of 499 MI/d occurring on 26 October. Flow depression lasts 21 days before rainfall elevates flows from 1 November, 2 days earlier than upstream Bewdley, which is likely due to more localised rainfall feeding down the lower tributaries.

Appendix F.3 shows almost complete EFI failure, similar to Saxons Lode, although the lowest flow frequency shows a slightly reduced magnitude of failure. Flows up to Q98 are outside the Low Risk band, but significantly fall into the High Risk failure moving along the FDC. Significant flow impact is concluded.

Environment Agency Drought Order model

Appendix F.1 shows the first impacts from activating the Severn Drought Order in 1976 occur on 30 August. Flows during this period average (mathematical average) at 1011 MI/d, 138 MI/d lower than 'Do Nothing'. No flow benefits are achieved as recharge arrives on 16 September. Flow impacts from activating the Severn Drought Order would be the same as assessed for the Acute scenario, minus the subsequent benefits.

Flows modelled for 1977 need to be considered with caution due to the modelling issues. A minimum flow of 723 MI/d occurs on 30 October, 224 MI higher than 'Do Nothing'. Discounting the first two Severn Drought Order activations as error, the same flow trend discussed at Buildwas, Bewdley and Saxons Lode would be expected.

Flows preceding the critical period ('Do Nothing' flow crash) should still be maintained around the 980 MI/d being modelled (139 MI/d lower than 'Do Nothing'), but for a shorter time period as the Severn Drought Order would be activated later. The high releases shown from 18 October would be removed. A flow crash would

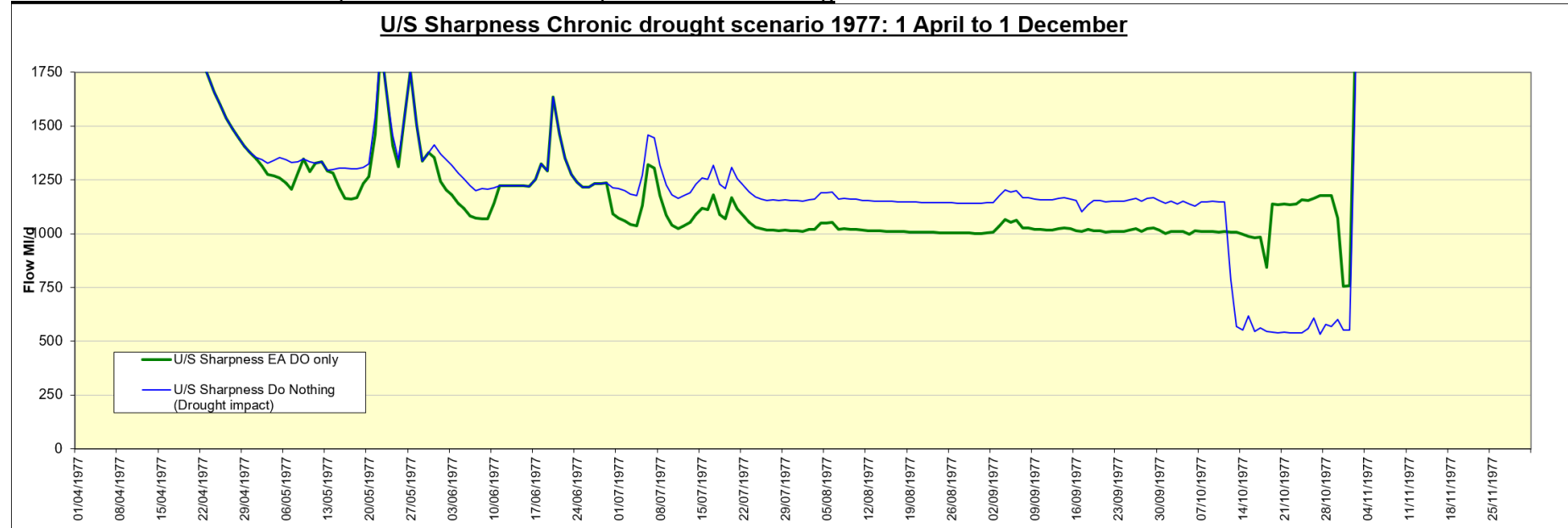
still be inevitable if the drought continued, likely to occur sooner than currently modelled and possibly to lower flows, depending on how much regulation water was still available.

Appendix F.3 would alter, again reducing the duration of drift from the 'Do Nothing' leading up to Q98. If the drought continued long enough for a flow crash to occur, the flow drop on the FDC is likely to shift closer to Q99. This would marginally reduce the duration of benefit, although flows may remain within the Low Risk band.

Due to modelling issues it is difficult to assess flow impacts with certainty. As with upstream assessment points, if the corrective assumptions being made are reasonable, then the flow impact conclusions from the Acute scenario should be applied.

Using the Acute scenario conclusions as a precautionary measure, a minor increase in the duration of Medium Risk EFI failure could be expected. Importantly, the subsequent flow benefits achieved should be greater than observed in the Acute scenario.

Assessment Point 7 U/S Sharpness and assessment point 8 Lower Parting



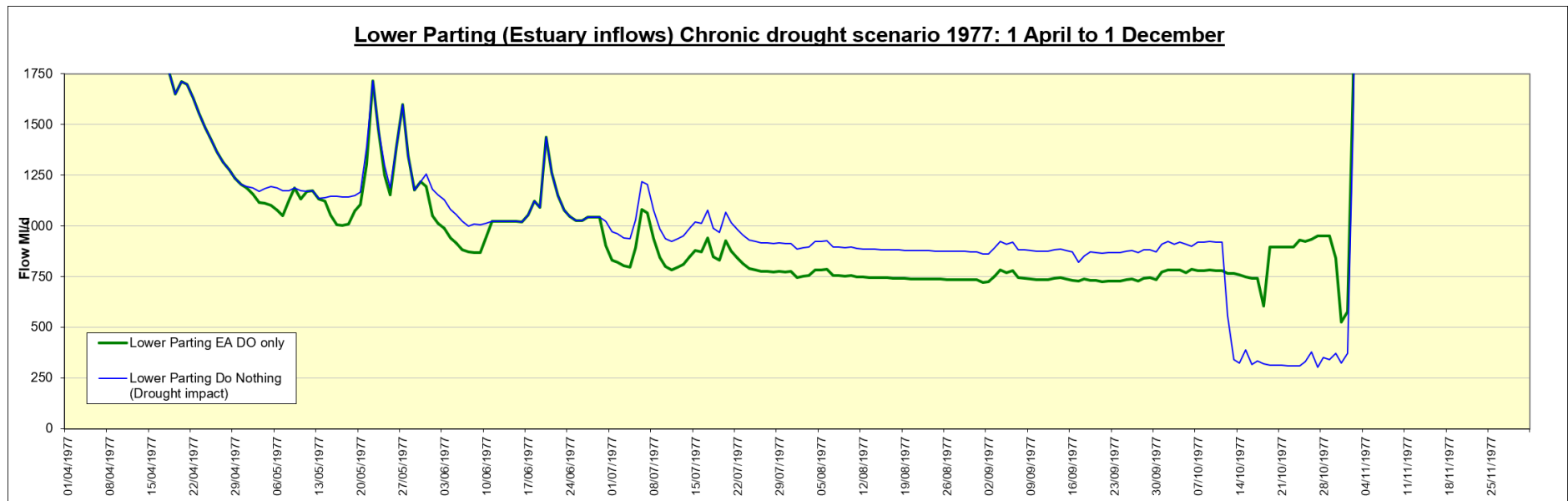


Figure 20 shows all the modelled impacts on flows at U/S Sharpness and Lower parting. Both are downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS) but U/S Sharpness is located upstream of the Gloucester and Sharpness canal abstraction while Lower Parting is downstream. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 20 presents two close up hydrographs, U/S Sharpness and Lower Parting, from 20 1 April to 1 December 1977. Appendix F.1 contains the full modelled hydrographs from 1975 to 1979

As discussed for the Acute modelling, Deerhurst is the furthest downstream flow gauge from which to calibrate data. All subsequent downstream flows are estimated from models, previous analysis and observations and need to be considered with greater caution. The greatest caution has been applied to assessing flows downstream of the Gloucester and Sharpness Canal abstraction (represented with a maximum 300MI/d), as variations could be large and alter the results significantly. Worse case assumptions have been applied to ensure a precautionary assessment is undertaken.

Table 17

	U/S Sharpness		Lower Parting		Low Flows Enterprise	
	Chronic Do Nothing MI/d	Chronic EA DO in isolation MI/d	Chronic Do Nothing MI/d	Chronic EA DO in isolation MI/d	Modelled Influence d MI/d	Modelled Natural MI/d
	(1975-1977)	(1975-1977)	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	1209	1117	983	893	9772	10213
Q95	578	1005	370	735	1910	2056
Q99	547	1000	319	729	1509	1564
Q99.9	532	755	304	528	1096	1123

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

Appendix F.1 shows reduced flows between June and October 1976, but no flow crash occurs. Flows during this period average (mathematical average) at 1179 MI/d, with recharge arriving on 16 September.

During the 1977 drought, flows prior to the modelled regulation failure averaged (mathematical average) 1176 MI/d for U/S Sharpness and 914 MI/d at Lower Parting. Regulation failure causes flows to crash on 12 October, more than halving flows to an average of 570 MI/d at U/S Sharpness (70 MI/d lower than the Acute scenario) and 343 MI/d at Lower Parting Sharpness (297 MI/d lower than the Acute scenario). Flow depression lasts 20 days with minimum flows of 532 MI/d and 304 MI/d occurring on 27 October, flow recovery begins on 2 November 1977.

Appendix F.3 shows almost complete EFI failure, with flows from Q30 onwards (Acute scenario identified failure from Q50) being mainly within the High Risk (>30% drift from EFI) failure band. EFIs are not definitive and only a short time period was used to generate the modelled FDCs, however these results suggest it is likely the natural drought event would have significant detrimental impacts on the lower River Severn. Further increased when considered against the unknown abstraction maximums for the Gloucester and Sharpness Canal, and the natural channel bifurcation splitting flows through Gloucester.

Likely significant effects concluded for the baseline drought conditions, these would be deemed as unavoidable consequences.

Environment Agency Drought Order model

Appendix F.1 shows the first impacts from activating the Severn Drought Order in 1976 occur on 31 August. Flows during this period average (mathematical average) at 1041 MI/d for U/S Sharpness and 759 MI/d for Lower Parting, 138 MI/d lower than 'Do Nothing'. No flow benefits are achieved by operating the Severn Drought Order as recharge arrives on 16 September. Flow impacts from activating the Severn Drought Order are considered to be the same as assessed for the Acute scenario.

Flows modelled for 1977 need to be considered with caution due to the modelling issues already highlighted (discount first two drought order activations). A minimum flow of 755 MI/d at U/S Sharpness and 528 MI/d at Lower Parting is modelled between 31 October and 1 November, 223-224 MI higher than 'Do Nothing', demonstrating an obvious flow benefit to the River Severn.

Flows preceding the critical period ('Do Nothing' flow crash) should still be maintained around the 1037 MI/d at U/S Sharpness and 1079 MI/d at Lower Parting being modelled (138-135 MI/d lower than 'Do Nothing'), but for a shorter time period and the high releases shown from 19 October would be removed. A flow crash would still be inevitable if the drought continued, likely to occur sooner than currently modelled and possibly to lower flows, depending on how much regulation water was still available.

Appendix F.3 would alter, again reducing the duration of drift from the 'Do Nothing' leading up to Q98. The EFI would still not be satisfied but the magnitude of failure would remain similar, managing to stay within the Low Risk band compared to the 'Do Nothing' which is clearly into the High Risk failure band. If the drought continued long enough for a flow crash to occur, the flow drop on the FDC is likely to shift closer to Q99, marginally reducing the duration of benefit. However, the flow benefits are clearly beneficial for this section of the River Severn and the conclusions for Acute scenario lead in time can be applied.

CONCLUSIONS: CHRONIC SCENARIO

The Chronic drought scenario represents a dry summer and winter (1975) preceding a drought summer (1976), which triggers the need for a Severn Drought Order but significant rainfall returns before true flow benefits are achieved, a second drought summer follows (1977). The main focus of the Chronic scenario is the second drought year (1977), and what impact applying a Severn Drought Order one year without achieving flow benefits could have on a consecutive drought year.

As highlighted in the Acute scenario conclusions, the greatest uncertainty remains around the Gloucester and Sharpness Canal abstractions and its impact on the lower River Severn during a severe drought. The River Severn splits between U/S Sharpness and Lower parting, with monitoring (between 1977-2007) indicating approximately 40% of flow goes down the East channel and 60% down the West channel. Low flows occurring due to the drought would become further divided and flow velocity decreased encouraging siltation and saline intrusion. The degree of flow loss and subsequent impacts is unclear without more data/monitoring, however this stretch of the River Severn could potentially be at high risk during a severe drought and likely significant effects have been concluded as a precautionary measure.

Baseline, Do Nothing

The 'Do Nothing' model predicts the drought conditions and unavoidable impacts on the current environment, if the Severn Drought Order was not operated. The model presents the best available flow predictions for a worse case theoretical drought of long term duration.

The Chronic scenario once again proved the importance of Clywedog as the primary source of Severn regulation water. Modelling highlighted that if Clywedog becomes exhausted, Vyrnwy bank can only offer a short term replacement for the large volumes of regulation required, and SGS does not have enough capacity to replace the reservoir volumes. It also appears likely during such a drought, that Vyrnwy storage would also become critically low and could pose another resource issue that would need careful management with the appropriate water company. The key message appears to again be, once Clywedog becomes exhausted the whole regulation system is likely to fail. Forward planning is needed during any event, considering the impact on the subsequent year if resources are drawn down too low.

The 1976 drought event does not appear to have any significant flow impacts under 'Do Nothing', owing to the continued high releases being made as part of normal Severn regulation. To some degree this is a game of chance, if rainfall had not arrived, events would have followed the Acute scenario, however on this occasion recharge was received and so no adverse flow impacts were observed along the Severn corridor. Significant flow impacts were observed during the 1977 drought ('Do Nothing') at Bryntail, Bewdley, Saxons Lode and Deerhurst, the same locations identified in the Acute scenario.

Bryntail is potentially at high risk of significant flow impact, as the 18.2 MI/d compensation flow is failed for 42 days between 18 September and 10 October. Modelling indicates a minimum flow of 9 MI/d, however with no releases being made from the reservoir, the area immediately downstream of the dam is likely to become dry, extending downstream until significant natural baseflow returns.

As a precautionary measure, Vyrnwy Weir was concluded as having a significant flow impact. Over 20 days (7 to 26 October) during 1977, irregular compensation flow failures were recorded, all below the minimum 25 MI/d compensation flow. A minimum 17.46 MI/d occurred on 25 October. It's unclear whether this is modelling error, although storage was at 14% and 7 continuous days recorded compensation flow failure.

From Bewdley, it can be expected the whole River Severn downstream would be affected to varying degrees by the naturally developing drought. If the regulation system failed, flows are shown to fall up to 600 MI over 2 days. Flows crash between 8 and 11 October 1977, with depressions lasting between 21 and 24 days before natural recharge occurs in early November. Bewdley predicts a minimum flow of 289 MI/d, 229 MI/d lower than ever recorded, Saxons Lode predicts a minimum 323 MI/d, 392 MI/d below existing records and Deerhurst predicts a minimum 499 MI/d, 476 MI/d below existing records. Greater uncertainty surrounds the lower River Severn as discussed, assuming a maximum 300 MI/d abstraction to the Gloucester and Sharpness Canal, a minimum daily flow of 532MI/d at U/S Sharpness and 304MI/d at Lower Parting was modelled. The magnitude of predicted flow impact is certainly significant, the degree of adverse impact would depend on the duration of the event and sensitivity of the environment.

In reality, it is not possible to exactly predict what the minimum flows would be if the regulation system did fail and they should be viewed as advisory only. All drought events are unique with varying prevailing conditions and abstraction demands

creating different responses to the same rainfall patterns. However, the flow behaviour is the important result for drought planning. Should Clywedog fail, the remaining regulation support has a short life and is unlikely to cope. Once the regulation system goes into failure, minimum flows can be expected to rapidly decline to baseflow rates until rainfall returns, highlighting the need to operate the River Severn Drought Order.

Severn Drought Order

This model represents the conditions if the Environment Agency operated the Severn Drought Order at Clywedog, all routine abstractions and discharges were active, but no other drought permits or orders were in force.

The modelled 1976 drought event and Severn Drought Order operation appear reliable and results could be used with reasonable confidence. Flow impacts for the 1976 portion of the event were concluded to be the same as the Acute scenario, but without the immediate flow gain being achieved.

During 1977 the Severn Drought Order is modelled to bounce on and off on 3 occasions, 24 February – 4 June, 24 June to 12 October and 24 October – 1 February, all which reduce the prescribed flow at Bewdley to the 730 MI/d. The first two activations appear false, as Clywedog storage was at 84% on both occasions, whilst the Drought Order in force curve would be crossed at 40%. The third activation on 24 October, although slightly late, is an accurate response to Clywedog storage.

It is unclear what the Aquator model is responding to on these occasions. The system is complex and Aquator was not designed to isolate the Environment Agency's Severn Drought Order for testing. A number of other triggers and linkages to system failures elsewhere could have caused these false activations.

As a result the 1977 flow results had to be assessed subjectively, making informed assumptions about how differently the flows would have responded if the Severn Drought Order had only been activated on one occasion, likely during October. It is more likely the 'Do Nothing' flows would be matched for longer leading into the critical flow period, drawing Clywedog storage down further earlier in the regulation season as a result. Flows would then be lowered to maintain the Bewdley drought flow target (730 MI/d 5 day mean) as modelled, continuing at this flow beyond the 'Do Nothing' flow crash (as modelled). The high flows in mid-October would be removed, instead maintaining the drought order prescribed flow. If the drought continued the regulation system would still inevitably fail, potentially sooner and to lower flows than currently modelled as less regulation water would be available due to higher flow maintenance earlier in the season (removing the false drought order activations).

Although the results could not be analysed in great detail owing to the modelling anomaly, the flow behaviour and trends were still valuable. By activating the Severn Drought Order in 1976, although no flow benefits were immediately achieved 16% storage was saved at Clywedog. This enabled the reservoir to reach 96% before regulation began in 1977, translating to longer regulation at 730MI/d (5 day mean) after the 'Do Nothing' model showed system failure and flow crashes. Modelling also suggests a greater protection of the minimum flows during any subsequent regulation failure, as Clywedog and SGS continue to have more resources to give than under 'Do Nothing'.

With the exception of Bryntail, where compensation flows are protected with obvious benefits, significant flow impacts were difficult to conclude with certainty for 1977,

due to the modelling issues. A precautionary approach was adopted, assuming a very similar impact as assessed under the Acute scenario due to the reduced flows leading into the critical drought period (which are likely to be of similar duration), but with a greater flow benefit being achieved as the drought developed. Significant flow impacts were concluded at Saxons Lode, Deerhurst the lower River Severn (U/S Sharpness and Lower Parting).

As a precautionary measure, Vyrnwy Weir was also concluded as having a significant flow impact, similar to the 'Do Nothing' model. The number of days was reduced, but over 15 days (12 to 26 October), irregular compensation flow failures were recorded, all below the normal compensation (and Drought Permit) flow target of 25 MI/d. A minimum 17.46 MI/d occurred on 25 October. Storage again reached 14% and flows failed on 7 consecutive days.

Modelling supports the aim of the Severn Drought Order, and demonstrated the long term benefits it's operation can create in a subsequent drought year. By operating the drought order in 1976, no flow benefits are immediately observed, but the storage saved is carried over into the subsequent regulation season (1977). This more long term saving is translated into preventing regulation system failure for longer than under 'Do Nothing' (opposite to Acute scenario), and potentially maintaining higher minimum flows during any subsequent regulation system failure, if the drought were to continue.

Interestingly, although the Severn Drought Order operation appears wrong (premature activations), it does demonstrate what could be expected if the control curves were altered and the Severn Drought Order were considered at an earlier point in a developing drought. The duration of reduced prescribed flow would be significantly increased, however the flow benefits during critical periods could be more substantial as larger quantities of water were available. Would need to be considered in balance with other catchment interests, as this would impact on water company abstractions and depends on whether the reduced prescribed flow is considered to have an adverse impact on the environment.

ESTUARY INFLOW ASSESSMENT

Background and methodology

Deerhurst and Haw Bridge represent the furthest downstream location from which flow data can be accurately measured and Severn regulation operation can be assessed with confidence. All downstream flow and Severn Estuary inflows are assessed using computer models, which provide the best available information based on known abstractions and discharges.

Haw Bridge records go back to 1971 and record the impacts of historic droughts, however the site is impacted by tidal back water. Deerhurst was operational from 1995, constructed to cope with the tidal influences experienced in this section. Flow data from the gauging stations is plotted and assessed for upstream comparison, however the downstream modelled location 'Lower Parting' represents the Estuary inflows used to assess the overall impact on the Severn Estuary.

In order to assess the impact of the drought order on the Severn Estuary, flow targets were used to provide a guide on how significant the flow decreases could be to the environment. This only provides a guide on flow quantity, what this 'looks like' on the ground and how it impacts the ecology remains very difficult to assess and historic drought events need to be used to inform final conclusions.

Stage 3 RoC used the WFD transitional waterbody flow targets (2008 report by SNIFFER) as an aid to assess the current flow regime, assessing gauged and modelled (Low Flows 2000) natural flows to conclude no likely significant effect. The WFD Sensitivity Ranking (sensitivity to abstraction) for the Severn Estuary came out as low, reflecting the large tidal range and area involved.

WFD and CAMS both calculate recommended 'Environmental Flow Indicator' (EFI) targets based on the expected natural flow (removal of abstractions and discharges) and how sensitive a watercourse ecosystem is perceived to be to abstraction (based on ecological and biological evidence). The sensitivity of the ecosystem determines how far below the natural flow duration curve (FDC) the EFI will be set, providing an indication of a minimum flow requirement before environmental damage 'could' start to occur.

Using the same methodology as the Review of Consents (RoC), both the Good and Moderate ecological status EFIs were updated with current natural data (naturalised via decomposition at Deerhurst and modelled Low Flows Enterprise data at Lower Parting/Elmore) and plotted against the modelled drought scenarios. It is important to note that as with all the flow assessment work, the drought scenario FDC's are based on short time periods which skew the whole FDC towards lower flows, realistically only the values from the 90th percentile will be useful to this investigation.

In an attempt to provide more context around the modelled drought impacts, additional FDC's were plotted at Deerhurst to show what the WFD flow targets 'would be,' using the 'Do Nothing' scenarios as the alternative natural/baseline flow (Aquator design makes it difficult to separate a truly naturalised flow sequence). However these were not included as the flow reductions permitted were unrealistic and potentially damaging to the environment.

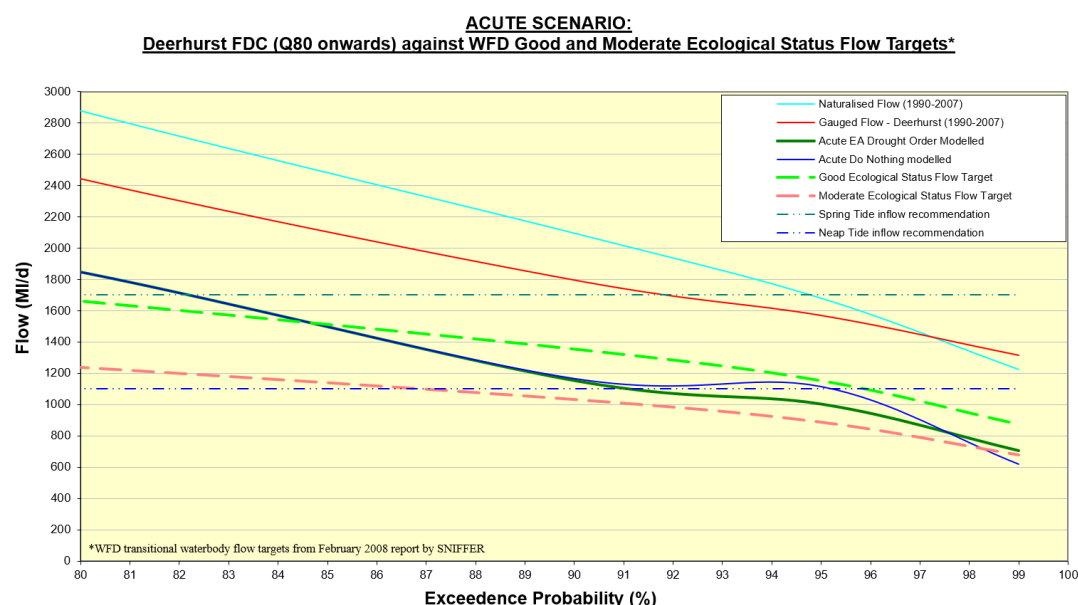
WFD flow targets provide a general guide to Estuary sensitivity to abstraction and freshwater inflows, however site specific targets should be utilised where available. An investigation was undertaken (Hutcherson and Wade) into the residual flow requirements to the Upper Severn Estuary in 1992, concluding the tide height to be

highly influential (due to saline water movement) on how much freshwater inflow would be required to restrict the amount of saline intrusion up the River Severn. A Neap tide flow target of 1200MI/d and Spring tide flow target of 1800MI/d were recommended to help support the Severn Estuary environment, and protect freshwater abstractions. These flow targets have also been included in the assessment for completeness.

Acute Scenario: Deerhurst

Figure 30 show how under the current flow regime (abstractions and discharges as they exist today), Severn Regulation operation supports flows above the Severn Estuary's Good Ecological Status (GES) FDC at all times/flows, and above what would naturally occur from the 97th percentile. This supports the RoC findings and confirms that Severn Regulation is supporting WFD achievement and raising the lowest and most drought related flows above what would naturally occur at the Deerhurst location.

Figure 30: Assessment Point 6 Deerhurst



Testing against the residual flow targets, the graphs demonstrate that even under natural conditions the Spring Tide inflow target would be failed by up to 576 MI for 5% (Q95) of the time (approximately 37 days over the 2 year period). The current flow regime slightly increases this period to 8% (Q92) of the time (average 58 days), but reduces the magnitude of failure to 483 MI, an improvement of 93 MI. Both natural and current flows consistently support the Neap Tide inflow target at Deerhurst.

Acute Scenario: Haw Bridge/Deerhurst Do Nothing

This investigation is primarily concerned with flows during the severe drought scenarios modelled. The 1990-2007 flow records from Haw Bridge and Deerhurst gauging station were used for comparison, in line with CAMS and RoC, but it is important to note the most significant drought represented was 1995/96 (owing to the time period used), when the Severn Drought Order was not used. This will make the modelled drought scenarios appear disproportionately more severe than ever recorded before, however the Deerhurst gauge represents the best available data for this investigation.

At Deerhurst, using the gauged record (1990-2007) for comparison, a drought of acute magnitude could be reducing the expected Q95 low flows by up to 670MI, a 43% reduction. The minimum flows modelled following regulation failure suggest flows could drop as much as 980MI lower, a 74% reduction. These flow reductions should only be used as a worse case indication of the magnitude of flow reduction possible during a severe drought.

Using the existing WFD EFIs as a guide, the Acute scenario drought event could cause deterioration from GES for approximately 15% of the 3 year period being considered, equating to about 164 days in total. There is some marginal deterioration below MES for approximately 2% of the period, approximately 22 days over 3 years.

The range of flow deterioration varies, taking account of only the 90th percentile and higher; deterioration from GES is between 155-200MI. In context of the sensitivity of the Severn Estuary, the magnitude of deterioration and the length of time it occurs for should not be significant. Short term impacts will vary according to the time of year deterioration occurs, which cannot be accurately predicted although is more likely between September and November.

WFD allows for movement within a band, and the 2% (22 days) change into MES would be very short term and in context of modelling errors, would not be considered conclusive. WFD directive article 4.6 also allows for temporary deterioration caused by exceptional natural events, such as prolonged droughts. The 'Do Nothing' scenario represents the closest to baseline and unavoidable drought events as we can currently model, and therefore results are considered to fall under article 4.6.

Assessing flows against the Spring and Neap Tide targets shows some failures, as expected during a natural drought event. The Spring Tide inflow target could be at risk of failure for an additional 10% or 110 days over the 3 year period (from Q82), a total 168 days. Risk of failing the Neap Tide inflow target, possibly more significant, could occur for 5% (Q95) of the time, approximately 55 days. It is important to note the risk is increased, but would only impact the environment if the low flows occurred in conjunction with the relevant tidal conditions. These failure risks would mainly translate into allowing further upstream movement of saline water during natural tidal fluctuations, and alter the amount of inundation along the River Severn channel.

Impacts are likely to vary according to channel variations and be short term in nature. The main impacts (saline intrusion and reduced wetted perimeter) are likely to be experienced along the Lower Tidal Severn channel, outside of the National Sites Network designated site. The impacts under the 'Do Nothing' scenario demonstrate the majority of these impacts would be of natural cause.

River Severn Drought Order

The Severn Drought Order causes no additional GES deterioration or failures of the Spring Tide inflow target. The overall magnitude of deterioration does alter slightly, reflecting the lowered prescribed flow at Bewdley for a greater length of time whilst protecting a higher minimum flow. Operating the Severn Drought Order prevents any potential deterioration below MES, an improvement on the 'Do Nothing' scenario.

Operating the Severn Drought Order and lowering the prescribed flows does increase the risk of failing the Neap Tide inflow target by an additional 4% (Q91) compared to the 'Do Nothing' scenario. This could increase risk up to 9% over the 3 year period, a total 99 days (a 44 day increase), actual impacts would vary according to when Neap tides occurred in relation to the low flows.

Figure 31: Assessment Point 7 U/S Sharpness and Assessment Point 8 Lower Parting

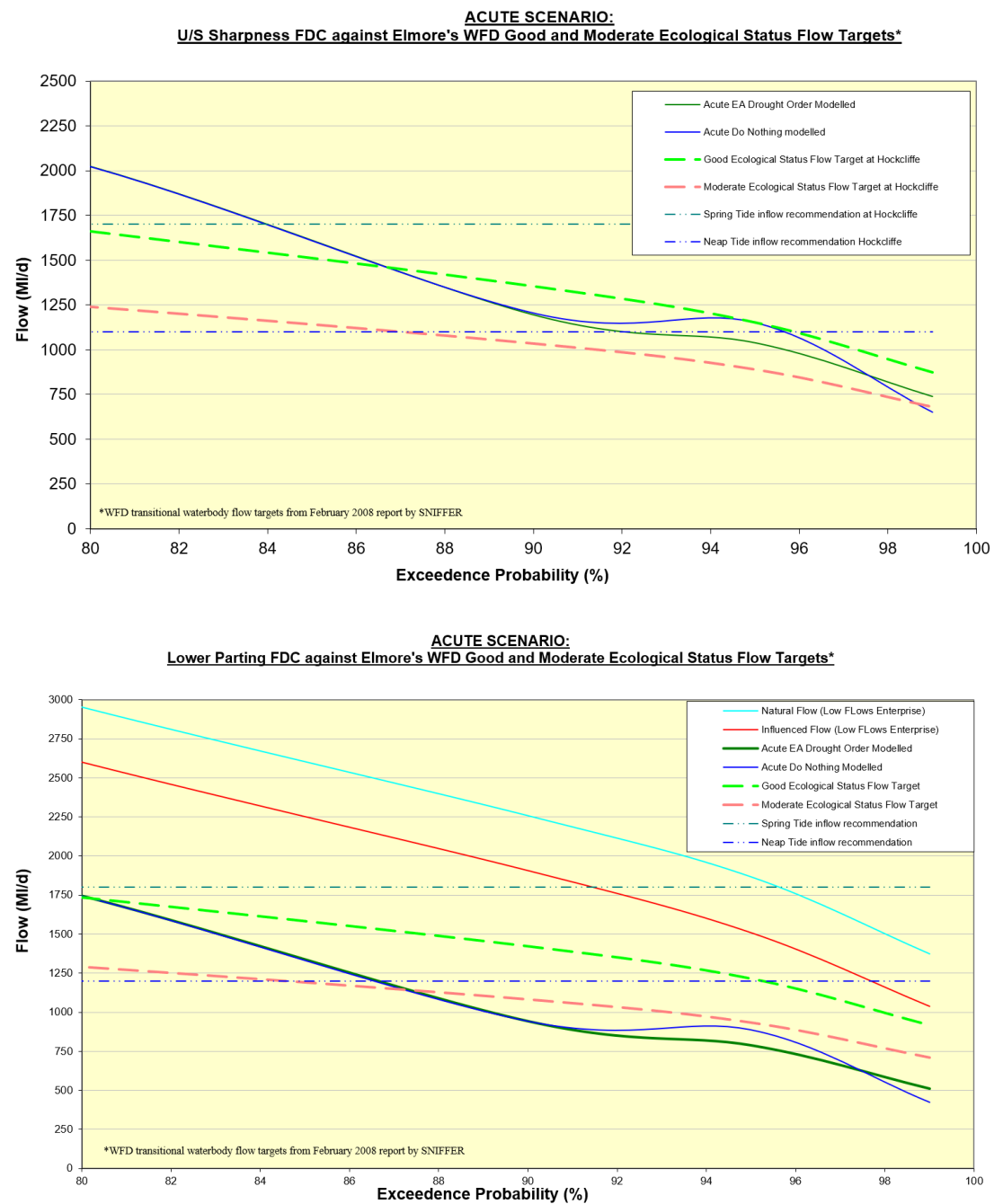


Figure 31 provides close ups from the 80th percentile

U/S Sharpness is located upstream of the Gloucester and Sharpness Canal and therefore reflects the more natural flow accretion as the catchment area increases. Lower Parting is located downstream of the large abstraction for the Gloucester and Sharpness Canal, the large decrease in flows demonstrates the magnitude of impact this abstraction has. It is important to note a maximum 300 MI/d abstraction has been modelled based on recent actual abstraction.

Low Flows Enterprise has been used to model a natural and influenced (with abstractions and discharges) FDC at Lower Parting (no gauging stations present) for comparison, the error margin will be higher than at Deerhurst due to the lack of real data for calibration, but does represent the best available data at this time.

Lower Parting (Figure 31) flows suggest under current conditions, Severn Regulation operation still supports flows above the Severn Estuary's Good Ecological Status (GES) FDC at all times/flows. Unlike Deerhurst, low flows are not restored to being higher than would naturally occur. This represents the influence of large abstractions for the Gloucester and Sharpness Canal, and subsequently to Bristol Water (from the canal).

As with Deerhurst, the graphs suggest that even under natural conditions the Spring Tide inflow target would be failed at certain times of the year. Lower Parting flows, and therefore freshwater inflows to the Estuary, fall below the Spring Tide inflow target by up to 427 MI for 4% (Q96) of the time (approximately 15 days a year). As shown at Deerhurst, the modelled influenced flow regime increases this period to 8% (Q92) of the time (approximately 29 days a year), however, unlike Deerhurst the magnitude of failure is increased to 762 MI. Modelled natural flows appear to support the Neap Tide inflow target at all times, however the modelled influenced data suggests a risk of 2% (average 7 days per year) failure by up to 162 MI, which is a deterioration from flow conditions at Deerhurst.

Acute Scenario: Estuary inflows

Do Nothing

Comparing the U/S Sharpness FDC against the Lower Parting highlights the impact the Gloucester and Sharpness Canal abstraction can have during low flows, and the risk it could pose during a severe drought. As this assessment is focusing on the Severn Estuary impacts, the Lower Parting FDC will be used to represent the potential worse case.

Using the WFD EFIs as a guide, the Acute 'Do Nothing' scenario drought event could cause deterioration from GES for approximately 20% of the 3 year period being considered, equating to about 219 days in total. Deterioration below MES could also occur for approximately 13% of the period, approximately 142 days over 3 years. It is difficult to conclude how much of the failure is genuinely additional to Deerhurst, and how much the short time period used skews the results, however it is evident that flows would be significantly lower at this location as a result of the additional large abstraction to the Gloucester and Sharpness Canal.

The range of flow deterioration varies, taking account of only the 90th percentile and higher; deterioration from GES is between 480-621MI and deterioration from MES is between 142-387MI. Assessing flows against the Spring and Neap Tide targets shows additional failures expected during a natural drought event. The Spring Tide inflow target could be at risk of failure for an additional (compared to normal flow regime) 13% or 142 days over the 3 year period (from Q79), a total 200 days. Risk of failing the Neap Tide inflow target could occur for an additional 11% (Q87) or 120 days over the 3 year period (from Q87), a total 135 days.

Severn Drought Order

The Severn Drought Order causes no additional GES or MES deteriorations, or additional Spring or Neap Tide inflow target failures. Results indicate the Severn Drought Order would not create a significant extra burden on the Severn Estuary environment, beyond the stress already resulting from the natural drought event. Should regulation failure occur, benefits would be achieved for the Severn Estuary by increasing the minimum flows experienced.

SEVERN ESTUARY CONCLUSIONS: ACUTE SCENARIO

The Severn Estuary, being the furthest downstream section of the River Severn, will be impacted by the greatest number of accumulated abstractions and discharges of all the assessment points considered. The River Severn has flowed 345km in length to reach the Estuary. The size of the catchment, significance in terms of water resource supply, and variation of habitat environment make it difficult to assess with great accuracy.

The droughts of 1976 and 1989 have shown that inflows to the Severn Estuary can be seriously depleted for short periods, as a result of reduced rainfall and a combination of abstractions from the River Severn. The worst impacts were observed from the natural channel split in Gloucester down to the Severn Estuary. The channel split divides flows, with the Canal & River Trust abstracting from the East channel at varying quantities. Significant flow reductions at this location have depleted water levels to the extent where little to no flows were passing over the downstream weirs.

Slower flows during low flow periods increase the amount of sediment deposition and evidence shows the lower section of the River Severn is the most vulnerable to short term siltation problems.

Previous drought reports found evidence to indicate the Severn Estuary National Sites Network site is not highly sensitive to changes in the freshwater inflows, with impacts being largely restricted to the lower tidal River Severn, outside the designated site.

To assess the Severn Estuary freshwater inflows Haw Bridge/Deerhurst flows were considered initially, then modelled data from U/S Sharpness and Lower Parting. Haw bridge and Deerhurst are the furthest downstream flow gauges with continuous flow records, enabling calibration of models and accurate assessment of the regulation system. Deerhurst was constructed to cope with the tidal influences of the Severn Estuary, and currently provides the best available flow data. However it is over 45 km (in channel) upstream of the Severn Estuary National Sites Network site and excludes the significant abstraction for the Gloucester and Sharpness Canal (and subsequent Bristol Water abstraction from the canal). U/S Sharpness was modelled to provide an indication of possible flows just upstream of the abstraction point and channel split, while Lower Parting was modelled as the main assessment point for the impacts on the Severn Estuary, incorporating the canal abstraction and representing the most likely inflows to the National Sites Network site.

Comparing the U/S Sharpness flow duration curve (FDC) against the Lower Parting FDC clearly demonstrates the impact the Gloucester and Sharpness Canal abstraction can have. As highlighted in the main River Severn conclusions, the greatest modelling uncertainty remains around the Gloucester and Sharpness canals varying abstraction and its impact on the lower River Severn during a severe drought.

An average monthly abstraction profile was calculated from recent actual data provided by the Canal & River Trust, however there is the potential for greater or lesser abstraction than was modelled. The recent actual data has been used to represent the abstraction within modelling.

Do Nothing

The 'Do Nothing' scenario represents the possible flows if no drought orders or permits were applied to help manage the developing drought, but all normal abstractions and discharges continue (includes Gloucester and Sharpness Canal 300

MI/d abstraction), as would be expected in reality. Modelling has shown that initial flow conditions would be better under the 'Do Nothing' scenario, however if the drought continued and resources ran out, flow crashes and subsequent minimum flows would be severe and resilience for the following year greatly reduced by not operating the River Severn Drought Order.

Comparing the modelled drought flows at Deerhurst to the gauged record (1990-2007) illustrates some of the potential flow reductions that could be considered unavoidable during a severe drought event. Deerhurst Q95 flows could fall by up to 670MI, a 43% reduction. If a drought were to continue long enough for regulation resources to be exhausted, then comparisons indicate minimum flows could drop as much as 980MI, a 74% reduction. The potential magnitude of flow reduction in the lower reaches of the River Severn is significant, through the natural lack of baseflow and runoff, and exacerbated by the impacts of upstream abstractions.

'Do Nothing' Results indicate the natural drought event could cause temporary failure of the WFD Good Ecological Status (GES) and Moderate Ecological Status (MES) flow targets. Inflows to the Severn Estuary (as modelled at Lower Parting) could experience short term (20% of 3 year period, equating to 219 days) deterioration from GES, ranging from 480-621MI from the 90th percentile. Of this period, 142 days (13% over 3 year period) of 142-387MI MES deterioration could also be experienced. The magnitude of the failures is significant, but the WFD flow deterioration would be temporary and as a direct result of an exceptional natural drought event (covered by WFD Directive article 4.6), as proven by the consistent GES maintained during normal flows and the same abstractions.

'Do Nothing' Results indicate the natural drought event could increase the number of days Estuary inflows failed to meet the recommended Spring and Neap tide flow targets. At Deerhurst, the Spring Tide inflow target could be at risk of failure for an additional 10% or 110 days over the 3 year period (from Q82), and 5% (Q95) or 55 days for the Neap Tide inflow target, when compared to the normal flow regime. Once the Gloucester and Sharpness Canal abstraction is accounted for at lower Parting, the risk of failures increases. The Spring Tide inflow target could be at risk of failure for an additional (compared to normal flow regime) 13% or 142 days over the 3 year period (from Q79), a total 200 days. Risk of failing the Neap Tide inflow target could occur for an additional 11% (Q87) or 121 days over the 3 year period (from Q87), a total 136 days.

It is important to note the 'risk' from tidal inflow target failures is increased, but potential impacts would only result if the low flows arrived in conjunction with the relevant tidal conditions. These failure risks would mainly translate into allowing further upstream movement of saline water during natural tidal fluctuations, and alter the amount of inundation along the River Severn channel. Evidence from previous droughts and the sensitivity of the Severn Estuary would indicate that lower freshwater inflows would not have a significant effect on the National Sites Network site itself, especially considering the short term and temporary nature of the lowest flows.

In terms of river levels, although it is not possible to accurately predict the decrease in levels at this time, using the 1976 drought event as a benchmark, it is likely that flows around the natural channel split could be particularly low and hardly passing over the weirs. Low and slow flows would also increase silt deposition and cause the channel to become clogged until high rainfall and flows returned. This would mainly impact the lower Tidal River Severn and have obvious impacts to fish migration and navigation in the short term.

The 'Do Nothing' scenario provides the benchmark comparison for assessing whether the River Severn Drought Order would have any additional positive or negative impacts on the Severn Estuary National Site Network site. Modelling shows some temporary deterioration below the transitional waterbody WFD flow targets, and some increased Spring and Neap tide flow targets are to be expected.

Severn Drought Order

The Severn Drought Order causes no additional GES or MES deteriorations compared to the 'Do Nothing' scenario. The overall magnitude of deterioration does alter slightly, reflecting the lowered prescribed flow at Bewdley for a greater length of time whilst protecting higher minimum flows.

Operating the Severn Drought Order creates no additional Spring Tide inflow target failures compared to the 'Do Nothing' scenario. At Deerhurst, the risk of failing the Neap Tide inflow target is increased by 4% (Q91) compared to the 'Do Nothing' scenario, however no additional increase is observed at Lower Parting due to the lower flows already being experienced under the 'Do Nothing' scenario.

If regulation failure were to occur (sources became too low to support any prescribed flow at Bewdley), the results show the River Severn Drought Order would maintain higher minimum flows during the critical drought period than possible under the 'Do Nothing' scenario. This benefit supports the drought orders design purpose, and would support both abstractors and the environment.

The Severn Estuary has a low sensitivity to freshwater inflows, and results show no additional harm (based on existing flow targets) would be caused beyond the naturally occurring drought effects. Benefits could also be achieved by operating the drought order, if the event out lasted the remaining water resources. **No likely significant effect is concluded.**

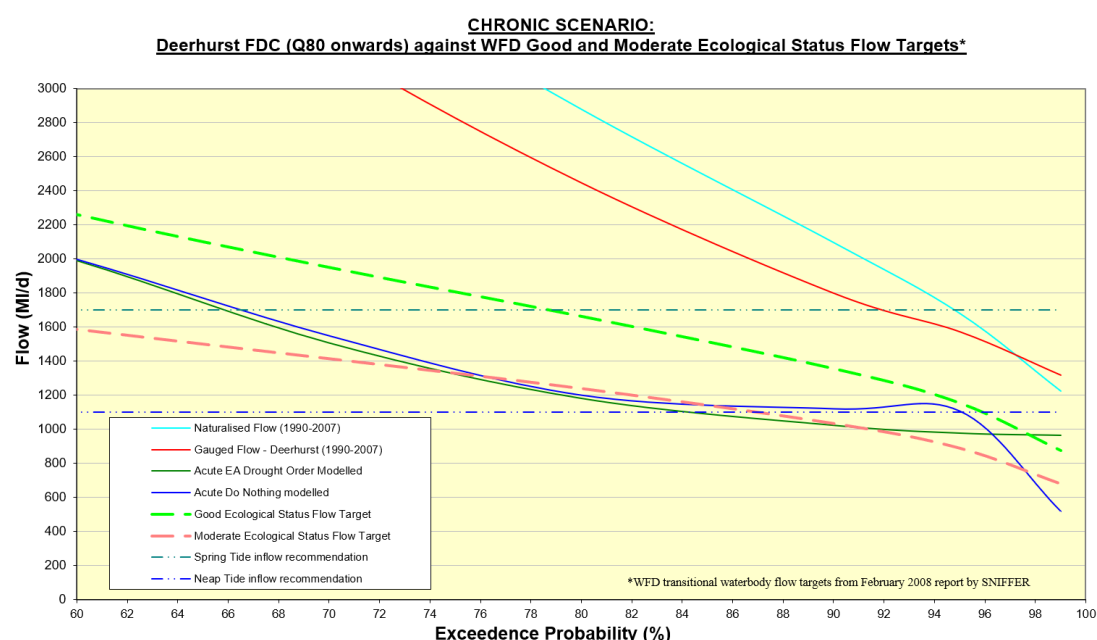
Chronic Scenario

The modelled Chronic drought scenarios represent what could happen if an acute drought year were followed by a further dry winter and second severe drought summer. Where appropriate (e.g. excluding the 'Do Nothing' scenarios) the River Severn Drought Order is operated during both summers. The duration of the initial acute drought summer has been reduced to exclude obvious flow benefits from the first year to test the long term value and regulation implications of the River Severn Drought Order.

Assessment Point 6 Deerhurst

Modelling errors were identified with the Chronic scenario where the drought order activates on and off falsely before the operation curves indicate a need. Due to this greater uncertainty the Chronic results will be assessed more generally for guidance and flow behaviour trends, rather than specific details and duration of impact, as the uncertainty is too high to use with confidence.

Figure 32: Assessment Point 6 Deerhurst



Do Nothing

At Deerhurst a drought of this magnitude, compared with the gauged record (Haw Bridge/Deerhurst 1990-2007), could be reducing the expected Q95 low flows by up to 463 MI (30% reduction) and the minimum flows by 797 MI (61% reduction). The greater magnitude compared to the Acute modelling reflects the greater length of time for which the Chronic drought (scenario) is predicted to last.

As with the Acute scenario, it's important to note the gauged record used for comparison only includes the 1995/96 drought event, and all modelled flow reductions should only be used as a guide.

The existing WFD EFIs suggest the Chronic 'Do Nothing' scenario drought event could cause deterioration from GES for approximately 60% of the 3 year period being considered, reflecting the long term lack of runoff being simulated and two consecutive drought events exacerbating the natural underlying event. There is some marginal deterioration below MES between Q76-84, but the more reliable

deterioration would be for a minimal 3% (Q97) of the 3 year period, when flows crash as the regulation sources are exhausted.

Assessing flows against the Spring and Neap Tide target shows more potential failures than under the Acute scenario, representative of a more prolonged/reoccurring drought. Comparing the flows against the gauged (Haw Bridge/Deerhurst 1990-2007) record suggests the Spring Tide inflow target could be at risk of failure for an additional 25% over the 3 year period (33% in total, from Q67). Risk of failing the Neap Tide inflow target could increase to 5% (Q95) of the 3 year period. It is important to note the risk is increased, but would only impact the environment if the low flows occurred in conjunction with the relevant tidal conditions. The impacts on the ground would be very similar to those discussed for the Acute scenario, largely impacting the lower tidal River Severn.

Severn Drought Order

Due to the false activations of the Severn Drought Order during modelling the slight drift away from 'Do Nothing' prior to around Q80 should be discounted. The FDC general trend after Q80 is likely to be similar to what could be expected, reflecting the lead in time when the Severn Drought Order is lowering prescribed flows by approximately 140 MI/d. This is followed by clear flow benefits when the water saved from the previous year's Severn Drought Order usage can be returned to the system to prevent/greatly reduce the flow crash observed if the drought order were not activated in the first year.

No additional WFD deterioration is caused, some minor increases in duration are evident but not significant in context of modelling uncertainty. Most significantly, the FDC suggests that during the most critical low flow periods (second summer) of the Chronic scenario, the Severn Drought Order would be protecting and returning flows above GES, and therefore complying with WFD at the height of drought. This cannot be concluded with great confidence, but the flow trend suggests the benefits to downstream flow and the Estuary, measured at Deerhurst, could be very beneficial to the Severn Estuary as opposed to taking no action and allowing the drought to run its course.

Operating the Severn Drought Order and lowering the prescribed flows does increase the risk of failing the Neap Tide inflow target by an additional 10% (Q85) compared to the 'Do Nothing' scenario. This could increase risk up to 15% over the 3 year period, but again the actual impacts would vary according to whether the Neap tides occurred at the same time as the low flow events.

Figure 33: Assessment Point 7 U/S Sharpness and Assessment Point 8 Lower Parting

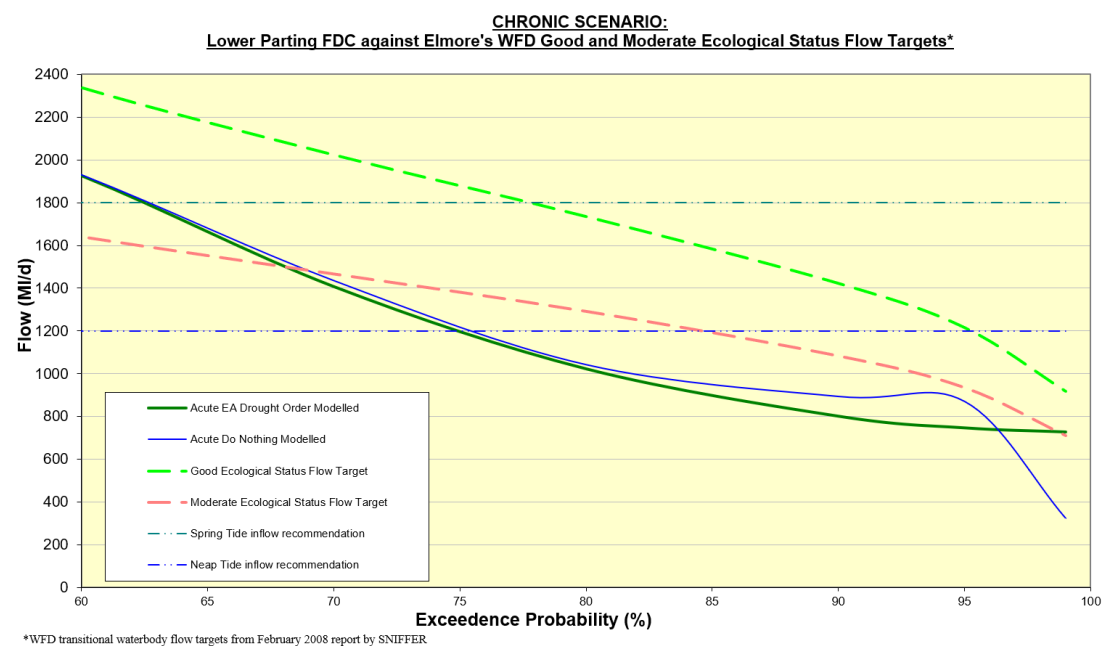
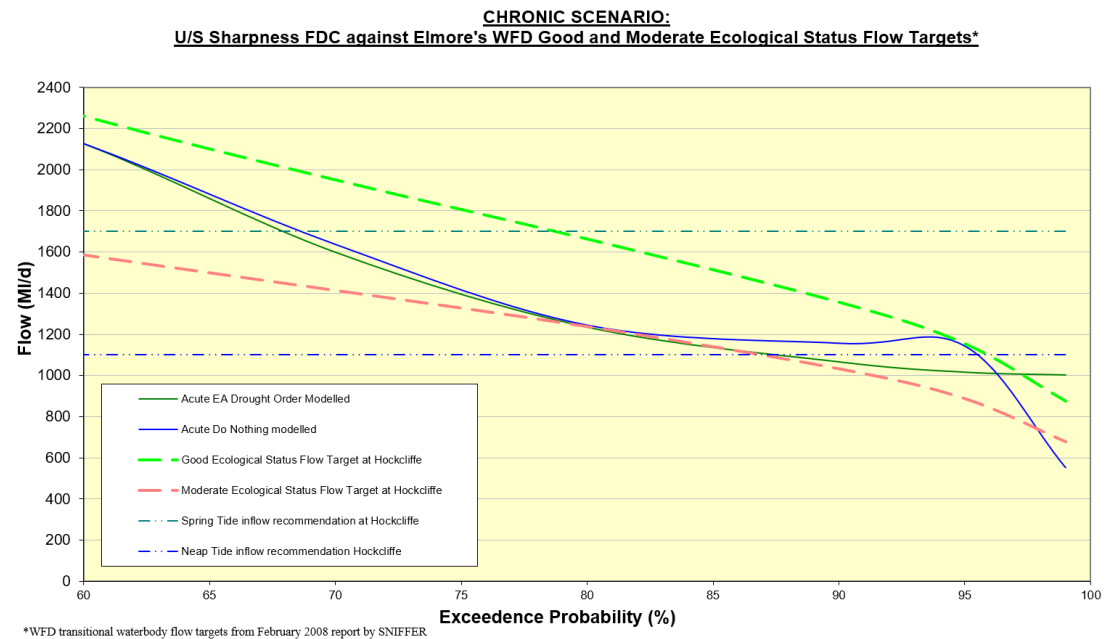


Figure 33 provides close ups from the 80th percentile.

As previously discussed (current environment section and Acute Scenario), U/S Sharpness is located upstream of the Gloucester and Sharpness Canal abstraction and Lower Parting is located downstream, therefore representing more realistic Severn Estuary inflows. Natural and influenced data plotted is modelled from Low Flows Enterprise, as no continuous flow gauges exist this far into the tidal influences of the Severn Estuary.

Do Nothing

Once again, comparing the U/S Sharpness FDC against the Lower Parting clearly demonstrates the impact the Gloucester and Sharpness Canal abstraction can have during low flows/drought conditions.

The WFD EFIs suggest the Chronic scenario drought event could cause deterioration from GES for approximately 62% of the 3 year period being considered, with 31% accounting for deterioration below MES. Compared to Deerhurst, the MES deterioration at Lower Parting is more conclusive, although due to modelling errors the duration is likely to be an over estimate.

Using the Low Flows Enterprise influenced data as a comparison, the Spring Tide inflow target could be at risk of failure for an additional 29% over the 3 year period (37% in total, from Q67). Risk of failing the Neap Tide inflow target could increase to 25% (Q95) over the 3 year period.

Severn Drought Order

Due to the modelling errors the slight drift away from 'Do Nothing' prior to around Q80 should be discounted.

Compared to the benchmark 'Do Nothing' scenario, no additional WFD deterioration is caused but some minor increases in duration are evident, but not significant in context of modelling uncertainty. Flows at Deerhurst suggested the lowest flows could achieve GES for the Severn Estuary by operating the Severn Drought Order. However Lower Parting illustrates how the large abstraction for the Gloucester and Sharpness Canal could significantly reduce the benefit of operating the Severn Drought Order to the Severn Estuary, as flows hardly achieve MES at this location.

Operating the Severn Drought Order creates no additional risk of Spring or Neap tide inflow targets.

Compared to the 'Do Nothing' scenario, there are still obvious flow benefits experienced during the most critical periods of the drought. The regulation failure identified in the 'Do Nothing' scenario is almost avoided, and without modelling errors is likely to have been prevented by operating the River Severn Drought Order.

SEVERN ESTUARY CONCLUSIONS: CHRONIC SCENARIO

The Chronic scenario represents a theoretical dry winter (1975) followed by a drought summer (1976) where the Severn Drought Order triggers are crossed. In scenarios where the drought order is operated, no flow benefit is gained in the first year due to the arrival of autumn recharge. Winter rainfall remains below average, resulting in a subsequent severe drought summer (1977) where the River Severn Drought Order is triggered again.

Modelling errors were identified with the Chronic scenario where the drought order activates falsely, well before the operation curves indicate a need. Due to this greater uncertainty the Chronic results were assessed more generally for guidance and flow behaviour trends, rather than specific details and duration of impact as the uncertainty is too high to use results with confidence.

The specific impacts likely on the ground for the Severn Estuary National Sites Network site, and lower tidal Severn if a Chronic drought occurred, are likely to be very similar to those discussed for the Acute scenario. The same areas would be at high risk from the same issues, such as saline intrusion, sediment deposition, lowered water levels reducing passage over weirs and reduced habitat at watercourse margins. However the environment would have been stressed to differing degrees over two subsequent summer drought events, and several dry winters. The accumulated stress on the environment and limited water resources is therefore likely to be greater, although the activation of the Severn Drought Order in the first year has been shown to safeguard water for a subsequent drought year sufficiently enough to make significant flow benefits compared to the 'Do Nothing' option.

As previously highlighted, the greatest modelling uncertainty remains around the Gloucester and Sharpness Canal abstraction and its impacts on the lower tidal River Severn during a severe drought. There is the potential for greater or lesser abstraction than modelled, and close liaison would be required during a real event to manage all the conflicting interests to balance the water user and environment needs appropriately.

Do Nothing

The 'Do Nothing' scenario represents the possible flows if no River Severn Drought Order or water company drought permits were operated to manage the developing drought. All normal abstractions and discharges continue (Gloucester and Sharpness Canal 300 MI/d abstraction included), and the Severn Regulation system is operated to continue maintaining 850 MI/d at Bewdley. As with the Acute scenario, initial flow conditions appear better under the 'Do Nothing' scenario, however if the drought continued and resources ran out, flow crashes and subsequent minimum flows would be severe.

The main difference with the Chronic two summer drought scenario, is the resilience for the second/following years drought is greatly reduced by not operating the River Severn Drought Order. Resources are allowed to expire during the first drought, significantly reducing the refill capacity of Clywedog and therefore entering the subsequent drought with insufficient resources to cope.

Comparing the modelled drought flows at Deerhurst to the gauged record (1990-2007) suggests Q95 flows could fall by up to 463MI, a 30% reduction. If the drought continued long enough to exhaust regulation resources, comparisons indicate minimum flows could fall by up to 797MI, a 61% reduction. When compared against the Acute scenario, the reductions are smaller, which reflects the longer term nature

of the Chronic scenario and how the duration spreads the impacts over the FDC. Even so, the potential magnitude of flow reduction in the lower reaches of the River Severn is significant and likely to have temporary adverse impacts.

'Do Nothing' results indicate the natural drought event could cause temporary failure of Good Ecological Status (GES) and Moderate Ecological Status (MES) flow (WFD transitional waterbody) targets. Deerhurst could experience deterioration from good ecological status (GES) for up to 60% (Q40) of the 3 year period, some marginal deterioration below MES between Q76-84 but the more reliable deterioration would be for a minimal 3% (Q97) of the 3 year period. However in terms of inflows to the Estuary, Lower Parting needs to be used, reflecting the Gloucester and Sharpness Canal abstraction. Inflows to the Severn Estuary could deteriorate below GES for 62% of the 3 year period being considered, with 31% of time accounting for deterioration below MES. It is important to note that higher or lower abstraction is possible for the canal.

Assessing flows against the recommended Spring and Neap Tide flow target shows more potential failures than modelled under the Acute scenario, to be expected over the more prolonged period of a chronic drought. Comparing Deerhurst flows against the gauged (1990-2007) record suggests the Spring Tide inflow target could be at risk of failure for an additional 25% over the 3 year period (33% in total, from Q67). Using Low Flows Enterprise influenced data as a comparison for Lower Parting and the Estuary inflows, the Spring Tide inflow target could be at risk of failure for an additional 29% over the 3 year period (37% in total, from Q67). At Deerhurst, risk of failing the Neap Tide inflow target could increase to 5% (Q95) over the 3 year period, and 25% (Q95) at Lower Parting and into the Severn Estuary.

It is important to note the 'risk' of failure is increased, but would only translate into impacts to the environment if the low flows occurred in conjunction with the relevant tidal conditions. The impacts on the ground would be very similar to those discussed for the Acute scenario, largely impacting the lower tidal River Severn. Evidence from previous droughts and the sensitivity of the Severn Estuary would indicate that lower freshwater inflows would not have a significant effect on the National Sites Network site itself.

Severn Drought Order

Due to the false activations of the Severn Drought Order during modelling the slight drift away from 'Do Nothing' prior to around Q80 should be discounted. The FDC general trend after Q80 is likely to be similar to what could be expected, reflecting the lead in time when the Severn drought order is lowering prescribed flows by approximately 140 MI/d, followed by clear flow benefit when the water saved from the previous year's Severn Drought Order usage can be returned to the system to prevent/greatly reduce the flow crash observed if the drought order is not activated.

No additional WFD deterioration is caused, some minor increases in duration are evident but not significant in context of modelling uncertainty. Flows at Deerhurst suggested the lowest flows could achieve GES for the Severn Estuary by operating the Severn Drought Order, however due to the large abstraction for the Gloucester and Sharpness Canal, Lower Parting shows the scale of this benefit to the Severn Estuary has reduced to only just achieving MES. When compared to the option to 'Do Nothing', the benefit is still clear and with mitigation work with the canals and River Trust this benefit could be increased to the Severn Estuary if abstraction could be significantly reduced at critical periods.

Operating the Severn Drought Order and lowering the prescribed flows does increase the risk of failing the recommended Neap Tide target at Deerhurst by an additional 10% (Q85) compared to the 'Do Nothing' scenario. However by Lower Parting there is no additional failure compared to the 'Do Nothing' scenario, suggesting the underlying drought has already caused the failures that would directly impact on the Severn Estuary.

Results show no additional harm (based on existing flow targets) beyond the naturally occurring drought effects would be caused by operating the River Severn Drought Order. Significant flow benefits would be achieved during the second years summer drought, when water saved during the initial year's drought order operation could be used for regulation, delaying the need for a second drought order operation and potentially preventing regulation failure from occurring. **No likely significant effect is concluded.**

OVERALL SEVERN ESTUARY CONCLUSIONS

Flow modelling incorporates all normal abstractions and discharges, what could happen if no drought orders or permits were operated and if the River Severn Drought Order but no water company drought permits were operated. The results cannot account for temperature variations or sudden storm events, likely during a real event, but not predictable or quantifiable at this stage. It is understood that prolonged high temperatures and sudden high rainfall events would further exacerbate the stresses already being encountered.

To assess the Severn Estuary inflows, Deerhurst was considered but modelled data for Lower Parting was used for the final conclusions, due to its location and consideration of the Gloucester and Sharpness Canal abstraction. Water framework Directive (WFD) 'transitional waterbody' flow targets (in line with RoC) and the 1992 Spring and Neap tide flow recommendations were used to assess the likely flow impacts on the Severn Estuary, from the River Severn Drought Order.

Acute and Chronic 'Do Nothing' results indicate the natural drought event could cause temporary failure of the WFD Good Ecological Status (GES) and Moderate Ecological Status (MES) flow targets. The magnitude of the flow failures is significant, but the deterioration would be short term. The 'Do Nothing' results also indicate the natural drought event could increase the number of days Estuary inflows failed to meet the recommended Spring and Neap tide flow targets. However, the actual number of days affected would depend on whether the low flows occurred on the same days as the Spring and Neap tides.

The River Severn channel splits between U/S Sharpness and Lower Parting, monitoring data (spot gaugings between 1977-2007) indicates approximately 40% of flow goes down the East channel and 60% down the West channel, where the Canal and River Trust abstract. Low flows occurring during the drought would become divided and flow velocity would decrease further, encouraging siltation and saline intrusion around this location. The magnitude of flow reductions is likely to be significant to the lower tidal Severn in the short term, however once recharge returns the flows would be expected to recover and WFD targets would be restored and maintained. The lower tidal River Severn has been identified as potentially being at high risk during a severe drought, however this reach is outside the National Sites Network designation area.

The impact on the Severn Estuary National Sites Network site will be limited to localised dependence on freshwater inflows and impacts on Hydromorphology, as the freshwater channel wetted perimeters and general flow velocity would be reduced. Only features and species intolerant to salinity or dependant on freshwater inundation are likely to be impacted. In context of the sensitivity of the Severn Estuary, the high magnitude deteriorations would be short term and therefore unlikely to have a significant impact. The degree of impact to migratory species will vary according to the time of year the deterioration occurs (more likely between September and November) and what other weather conditions occur (e.g. high temperatures).

The risks and failures modelled under the 'Do Nothing' scenarios (acute and chronic droughts) represent the natural drought effects, which are considered a direct result of an exceptional natural drought event and come under article 4.6 of the WFD. These results have therefore been used as the benchmark for what impacts could occur during acute or chronic droughts, and used to assess what additional impacts the River Severn Drought Order could have.

The Severn Drought Order caused no additional GES or MES deteriorations compared to the 'Do Nothing' scenario for either acute or chronic modelling. The overall magnitude and duration of deterioration altered slightly, reflecting the lowered prescribed flow at Bewdley for a greater length of time whilst protecting higher minimum flows under both Acute and Chronic droughts. The results also showed operating the Severn Drought Order creates no additional Spring or Neap tide inflow target failures at Lower Parting, compared to the 'Do Nothing' scenario.

If regulation failure were to occur (sources became too low to support any prescribed flow at Bewdley), the results show the River Severn Drought Order would maintain higher minimum flows during the critical drought period than possible under the 'Do Nothing' scenario. This illustrates how lowering the prescribed flow can prolong the remaining storage in Clywedog, leaving some water for regulation during the most critical period of the drought event. This would benefit both abstractors and the environment.

Modelling the Chronic scenario showed if two consecutive drought order years occur, utilising the Severn Drought Order in the first year would significantly improve the ability to protect the River Severn flow and Severn Estuary inflows in the subsequent year. The water saved by operating the drought order during the first drought summer, would be available for regulation in the second year. This would delay the need for a drought order in the second year as Clywedog storage would be higher, and greatly reduce the risk of regulation failure compared to the 'Do Nothing' option. These results support the need for operating the River Severn Drought Order, and allay modelling concerns that no flow benefits would be gained unless Regulation failure was reached.

It is also important to highlight the potential risk of not operating the River Severn Drought Order during severe events when water company drought permits are active. If this were to occur, and the drought extended into regulation failure, then flows would crash to minimums lower than the 'Do Nothing' scenario. This would potentially cancel out benefits of not operating the drought order, by increasing the magnitude of flow reductions and threatening supplies and flows for the following year/s.

Historic drought flows and naturalised flow sequences down to Deerhurst gauging station indicate the Severn Drought Order has not created a significant extra burden on the main River Severn, compared to what would have naturally occurred in the past. During the worst periods of drought the Regulation system was maintaining higher flows than could naturally have occurred, even with the drought order operational. However flow data is not available further downstream of Deerhurst, so the true impacts of the Gloucester and Sharpness Canal cannot be quantified from flow data. Several drought reports state flows around the channel split and inflows to the Estuary were reduced to almost zero by the canal abstraction for short periods in 1976 and 1989.

Modelled acute and chronic scenarios have concluded no additional WFD or tidal flow target failures are caused by activating the River Severn Drought Order, when compared to the 'Do Nothing' scenario. All flow and level reductions would be temporary and short term, with flow benefits to the environment by operating the Severn Drought Order. **Therefore, no likely significant effect is concluded for the River Severn Drought Order in isolation.**

FLOW CONCLUSIONS

It is important to acknowledge the River Severn is a large and highly complicated system. Models are very important, but can never truly represent the real situation and results need to be considered with this in mind. The Aquator model is the best available tool we have at this time, but was not specifically designed to predict drought flows and demands. Deliberate error was built into the model to account for weather forecast and lag time difficulties encountered in real life, but how the Environment Agency operates the different regulation sources is likely to differ during a real event. The results are an indication of the potential worse case scenario's and help us identify important trends and problems to inform better drought management, they cannot provide the exact flows or timings that will be encountered.

It also needs to be understood the drought scenarios created have never occurred in recorded history, so all results and impacts are theoretical. Every drought event will be unique and produce different challenges. In particular, the exact timing and severity of a drought cannot be guaranteed.

All routine abstractions and discharges, including the high demand expected and higher than normal abstraction by the Gloucester and Sharpness Canal were incorporated into the Severn Drought Order modelling. This may have created an unfair test/representation of the singular impacts from the Severn Drought Order, as 'other' water users and high demands were already being incorporated.

The 'Do Nothing' models represent what could occur during droughts of these magnitudes, and all impacts have been assessed against improvements or deteriorations from this baseline. It needs to be remembered that droughts are natural events, and cannot be prevented only managed. 'Do Nothing' is considered to represent what would occur if no drought management action was taken to protect water supplies or the environment.

Modelling has helped illustrate how robust the Severn regulation system is today, modelling pushed the system into very rare drought magnitudes in order to trigger the need for the Severn Drought Order. In reality, having three separate sources allows Clywedog to be rested early in the season if there is deemed to be a high regulation risk and the catchment is more likely to experience dry/drought conditions. All the actions available to the Environment Agency allow time to be 'brought' to prolong the resource available from Clywedog whilst recharge is awaited, lowering the probability of needing to utilise the drought order at present.

Real drought events have shown how the antecedent conditions at the commence of the regulation season are the critical factor in whether a Drought Order will be required if dry weather persists. For the West Midlands area, historic droughts have shown that two subsequent dry years are critical in reducing groundwater levels and therefore baseflows to rivers in the second year. Natural baseflow in the catchment is the primary driver for how much regulation support will be required in the absence of rainfall, low/below average baseflow will result in high regulation releases being required to supplement the deficit. Consistent releases of over 400 Ml/d can cause Clywedog to cross the SDO in a single season if dry weather persists, as shown by modelling and the 1976 drought event. In order for baseflow to have naturally receded to significantly low levels, a long term shortage of rainfall (i.e. drought event) needs to have occurred, likely to be of magnitude greater than a 1 in 20 year over more than 6 months for the whole River Severn catchment scale.

Once Clywedog is releasing large volumes in the absence of recharge, it is clear from real events (e.g. 1976) and modelling, that storage depletes quickly.

Approximately 1% is lost per day when 500 MI/d is released, which supports the original design and 100 day rule applied to Clywedog operation. With appropriate management, which could include a drought order under rare circumstances, Clywedog is likely to avoid dead water during a one season drought and maintain some level of regulation support. The recharge season immediately following a drought/high regulation season will be critical in determining how it performs if a second drought year follows. If the drought order was operated during the first drought year and sufficient recharge is received, the water saved in Llyn Clywedog could be critical in providing significant flow improvements above the drought baseline in the subsequent drought event, demonstrated by the Chronic scenario modelling.

Modelling has shown that with prolonged droughts and insufficient recharge, the regulation system could fail (i.e. individual licences/sources begin to run out of water) even with the Severn Drought Order in operation. Depending on remaining storage in Vyrnwy bank and SGS, modelling suggests activating the Severn Drought Order could cause regulation system failure at the same time/earlier than if no action were taken (shown by Acute scenario), as pressure is diverted to the alternative sources earlier. However, even when this occurs and the Bewdley prescribed flow of 730 MI/d (5 day mean) is failed, the water saved in Clywedog storage then enables a higher residual flow to be maintained than if the Severn Drought Order had not been activated.

Modelling has also identified the Severn Drought Order could be operated during a drought, without flow benefits being immediately achieved (refer to the Chronic scenario). The environmental cost would be to have created additional flow stress during an already stressed period. The Environment Agency acknowledges this is a risk that would always need to be assessed against long term weather forecasts, carefully balanced against the potential flow damage not operating the Severn Drought Order could allow to happen.

Modelling the Chronic scenario has helped to demonstrate that if the Severn Drought Order is operated during an event when recharge occurred before flow benefits were achieved, the resources saved one year could be critical in safeguarding against a consecutive drought or high regulation season the following year. Therefore, even though short term savings may not be translated into immediate flow benefits, the Severn Drought Order could have an important long term role and potentially be more beneficial in long term droughts than shorter acute events. Modelling suggested the storage savings made during the first Severn Drought Order year, could prevent or significantly delay regulation failure in the following drought.

Both the Acute and Chronic modelling identified a lack of conceptualisation and data around the Gloucester and Sharpness Canal abstraction and the relationship with Bristol Water abstraction from the canal. A maximum abstraction of 300MI/d based on recent actual data was manually applied to the Aquator model, although post drought reports for 1976 and 1989 suggest abstraction to the canal increased to 680MI/d for short periods, subsequently drying up inflows to the Estuary. The situation is further complicated by the channel bifurcation through Gloucester dividing flows approximately 60:40, with the canal abstraction taking from the smaller East channel.

Real drought events (e.g. 1976) identify regulation beginning from April to early June, but reservoir storage and/or flows are not considered at significant risk until mid-July onwards, when formal drought order applications were made. Variations of the Severn Drought Order typically came into force in early August through into

September. Modelling identified that with the additional regulation resources now available, this risk is likely to be delayed towards the end of August/early September, although abstraction demand is an important factor.

The Severn Drought Order will reduce Severn corridor flows for a given period, but even under the rare drought magnitudes modelled, it prevents complete regulation failure at Clywedog. Ultimately the water saved early on enables the minimum flows to be increased along the whole Severn catchment when the regulation system goes into unavoidable failure as the drought continues. This reduces the severity of drought stress on flows during the most critical period. Importantly, the reduction in flow caused by the drought order prior to the obvious benefits, does not lower flows below the modelled baseflow (baseflows shown after regulation failure in 'Do Nothing' scenario), and is therefore still maintaining an artificially elevated flow (above natural) benefit along the River Severn.

Forward planning is needed during any event, considering the impact on the subsequent year if resources are drawn down too low.

Limitations/Assumptions

The River Severn is the longest river in Great Britain, has the second largest tidal range in the world, and involves numerous complex abstractions and discharges as well as artificial flow regulation. Modelling the flow response of such a complex catchment made up of so many variables is very difficult with high confidence. This investigation can only provide a snapshot of potential impacts at a limited number of locations due to the scale of catchment being considered, it is acknowledged that local variation could be significant.

Modelling can only provide a somewhat black and white interpretation of a set of events. The reality is all drought events are unique and how we respond operationally will be different to a model, according to what information and confidence we have in forecasts at the time. The flow modelling should only be used as a guide for some possible worse case drought events to highlight the risks and help the Environment Agency better plan for drought and water resource management.

Droughts of these magnitudes have never occurred within our records of flows and rainfall, therefore cannot be calibrated with accuracy. Historic droughts and previous operation of the River Severn Drought Order does provide an initial baseline, but it must be acknowledged that water resource management and demand has changed since these events and the severity and length of these actual events has been increased. The results should be used as a guide to identify potential trends and highlight monitoring needs and potential remediation, however they cannot be used as a definitive prediction of how flows will behave.

Historic data is varied and flow records in particular rarely go back as far as the 1975-1976 event, particularly in the lower River Severn. Monitoring and methodologies have also changed since records began, making it very difficult to accurately compare datasets without accumulating further errors and uncertainty.

Aquator can model Severn Regulation rigidly to meet the basic prescribed flow criteria at Bewdley, but in reality forecasts and travel times do not allow for such high accuracy. Parameters within Aquator were adjusted to build in some natural error, but sudden changes in releases from all regulation sources are still evident, but unlikely to occur in reality. SGS in particular, is modelled to on off operate, where as in reality the resource requires preparation and then would be utilised as

continuously as possible, stepping other resources back where needed, in order to increase operational efficiency and staff resources. These variations need to be acknowledged and understood when using the modelling results.

Flows from effluent returns is significantly different between Aquator and SIMCAT and needs to be investigated further to determine which model/method should be utilised for drought management and prediction in the future. Modelling identified that Aquator's minimum flows were significantly lower (approximately half) in the lower River Severn/Severn Estuary inflows than SIMCAT could replicate. Further investigation identified that even if all natural runoff were switched off within SIMCAT, effluent alone would maintain flows significantly higher than Aquator was predicting. The greatest uncertainty was around the Severn Estuary inflows, and the worst case flows from Aquator were adopted in accordance with Habitats Regulations.

Modelling and interpretation clearly identified gaps in baseline drought data and a true understanding between how changes in flows would impact ecology on the ground. Best available methods were adopted, but expert opinion had to be adopted regularly in the absence of clear flow targets and models to predict ecological impacts based on flow reductions for a regulated river.

In an attempt to provide an indication of possible impacts Environmental Flow Indicators were used to provide a rough indication of significance. Risk bands were calculated by subtracting 10% per band from the original EFI. Although the EFI methodology is widely used, the modelled drought scenarios only included 3 years' worth of flow data to calculate flow duration curves from. This produces a low flow biased FDC, skewing flows lower where as a longer period would have incorporated more higher range flows, likely reducing EFI failures. This limitation was taken into account when assessing the results where possible, but will have added to the uncertainty around concluding significant flow impacts on ecology.

Overall the highest uncertainty in flow data surrounds the Lower River Severn and Severn Estuary inflows, also the highest environmental risk area. A lack of continuous monitoring and the tidal influences makes it very difficult to determine what the full impacts could be.

Monitoring Recommendations

Baseline monitoring

Maintain existing River Severn continuous flow gauges and ensure they are well calibrated to low flows

- Bryntail - critical
- Dolwen – critical
- Abermule
- Vyrnwy Weir – critical
- Llanymynech
- Buildwas – critical
- Bewdley – critical
- Saxons Lode – critical
- Haw Bridge
- Deerhurst – critical

Need cross sectional and inundation monitoring along the River Severn, frequency once every 5 years – investigate whether this could be combined with flood teams existing monitoring programme with additional drought monitoring for events only.

Spot flow gaugings around the channel split in Gloucester, to gain confidence around the percentage of flow split and improve conceptual understanding inside the appropriate models. Select a location up and downstream of the Gloucester and Sharpness Canal abstraction for the West channel to help quantify its impact.

Event Monitoring - additional

Spot Flow gaugings of tributaries in the Upper reaches of the River Severn, around Llyn Clywedog.

Level monitoring over weirs within the River Severn channel split (unclear who owns/maintains them).

Spot Flow gaugings of inflows to the Severn Estuary, as far downstream as possible and accounting for tide activity.

Mitigation options (only relevant where significant impact determined)

The River Severn Drought Order would be a last resort option for the Environment Agency in an attempt to sustain the remaining water resources of the River Severn. All other appropriate action should have been taken, the Environment Agency West Midlands area would have declared 'Drought status' and communicated the implications publicly through the media, wide spread flow restrictions (HoFs) and irrigation bans (S57) may be in force and the Montgomery Canal abstractions reduced (as part of the abstraction licence.).

Additional options could be considered, although they may not prevent the need for the River Severn Drought Order, they may delay its need and/or provide greater flexibility within the regulation system. Some options to consider are;

Consider approaching United Utilities for an 'overdraft' on the Vyrnwy Bank. This would only be beneficial if there were sufficient excess storage in Lake Vyrnwy, and if UU were willing and able to loan the water to the River Severn catchment, at low risk to the water supply need.

Hold regular meetings with the Canal and River Trust, particularly regarding the Gloucester and Sharpness Canal abstraction and encourage closing the canal to navigation to preserve water resources (water supply to Bristol would need to be maintained).

Explore the option for emergency augmentation to the lower River Severn and Estuary of utilising water company bankside storage for abstraction, reducing abstraction pressure in the short term and using Vyrnwy bank to refill. This would only be beneficial in emergency situations, when sufficient storage is available in Vyrnwy bank to repay, and there was not sufficient travel time to simply rely on releases from Lake Vyrnwy. This emergency option would be short term (days to a week) and incur additional costs to the Environment Agency, who would need to pay Severn Trent water for using the water.

Seek additional reductions from abstractors up to 20%. Some water companies may be able to rely on supplies other than the River Severn (i.e. rest their Severn abstraction through transfers). Each drought is different and conditions elsewhere could be worse than on the Severn. However, scope for reducing demand on the Severn may be restricted by priorities elsewhere and this option is unlikely to be achievable in a large scale drought event.

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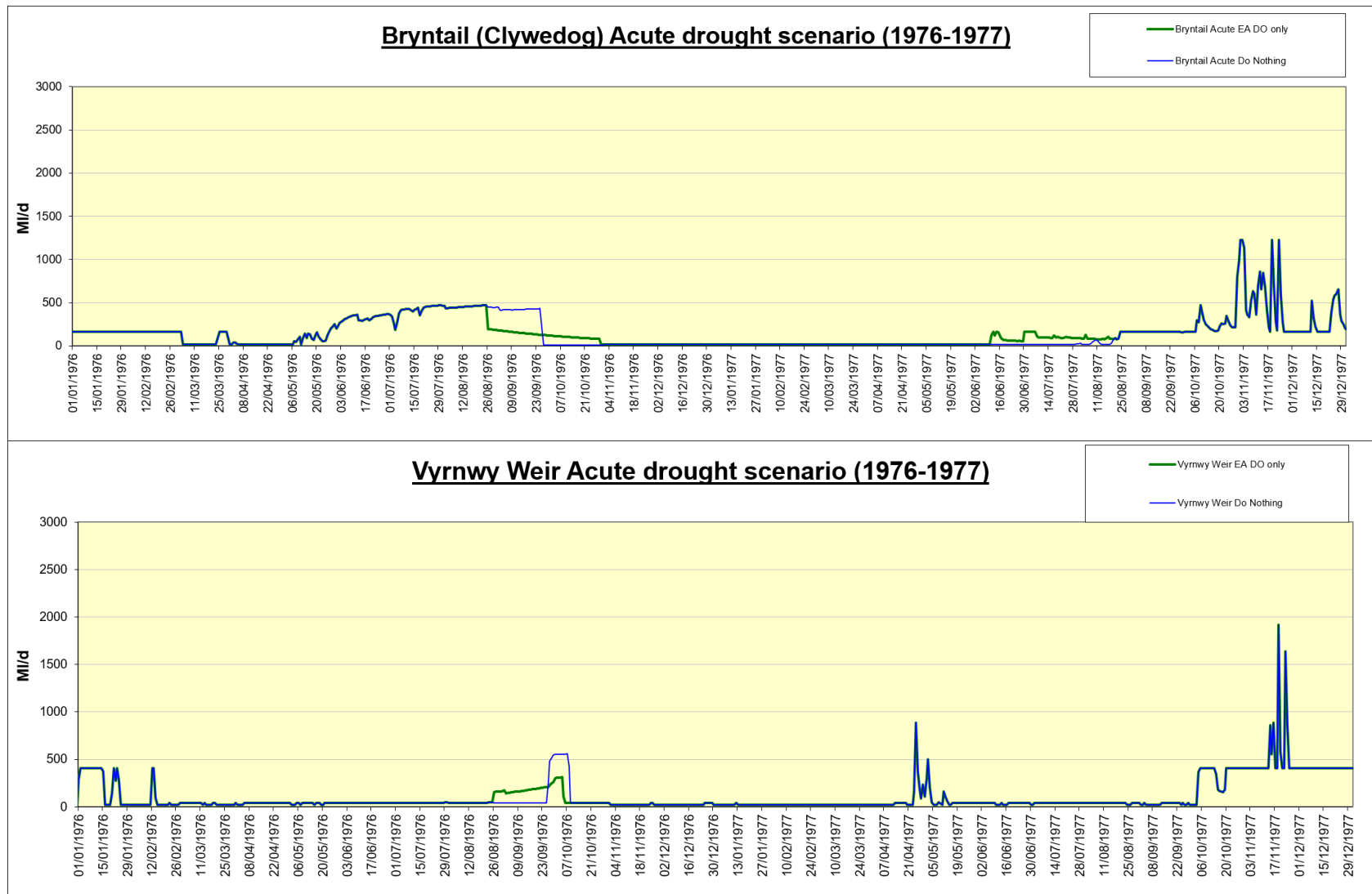
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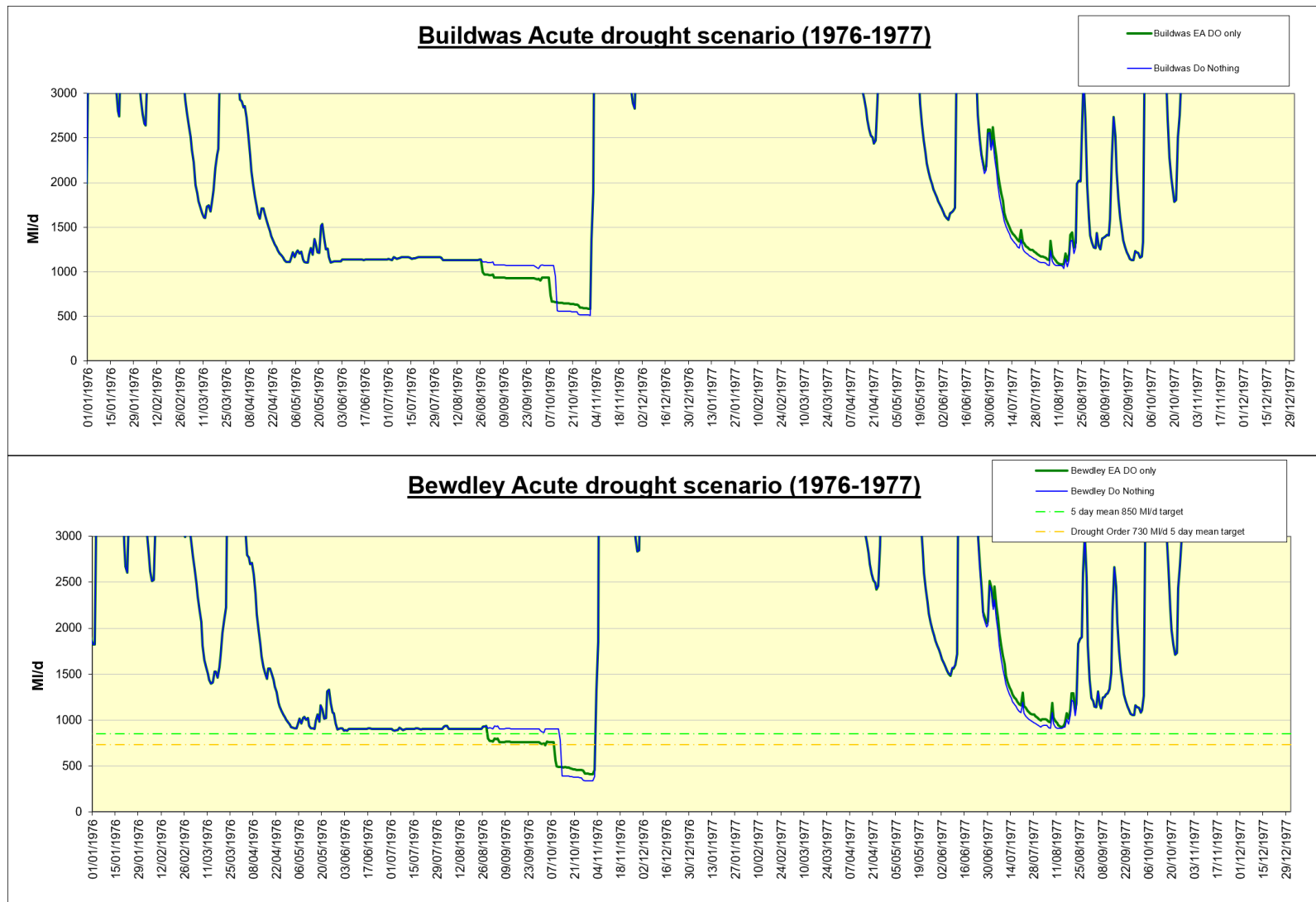
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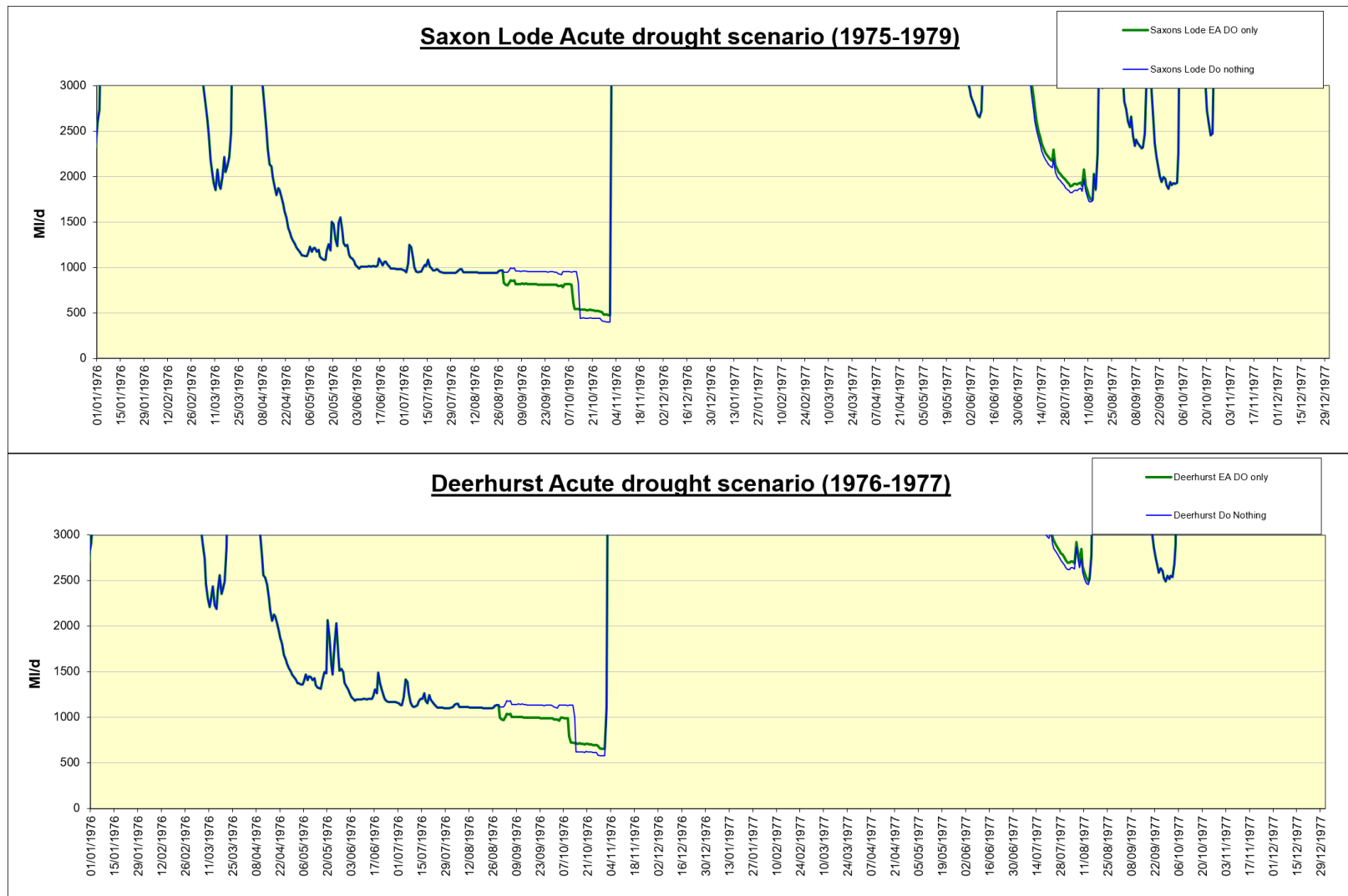
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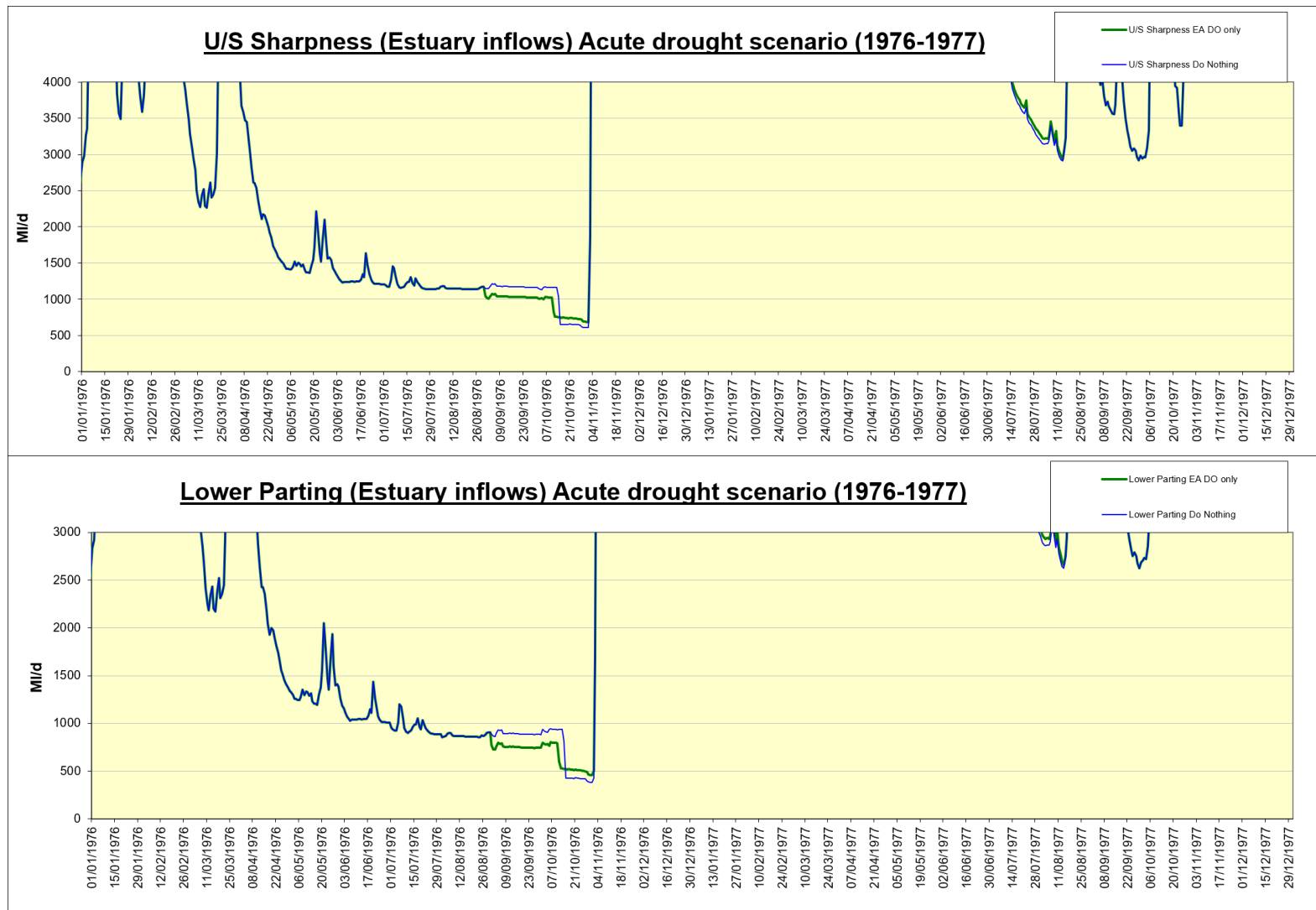
Appendix E.1

Acute scenario: Hydrographs



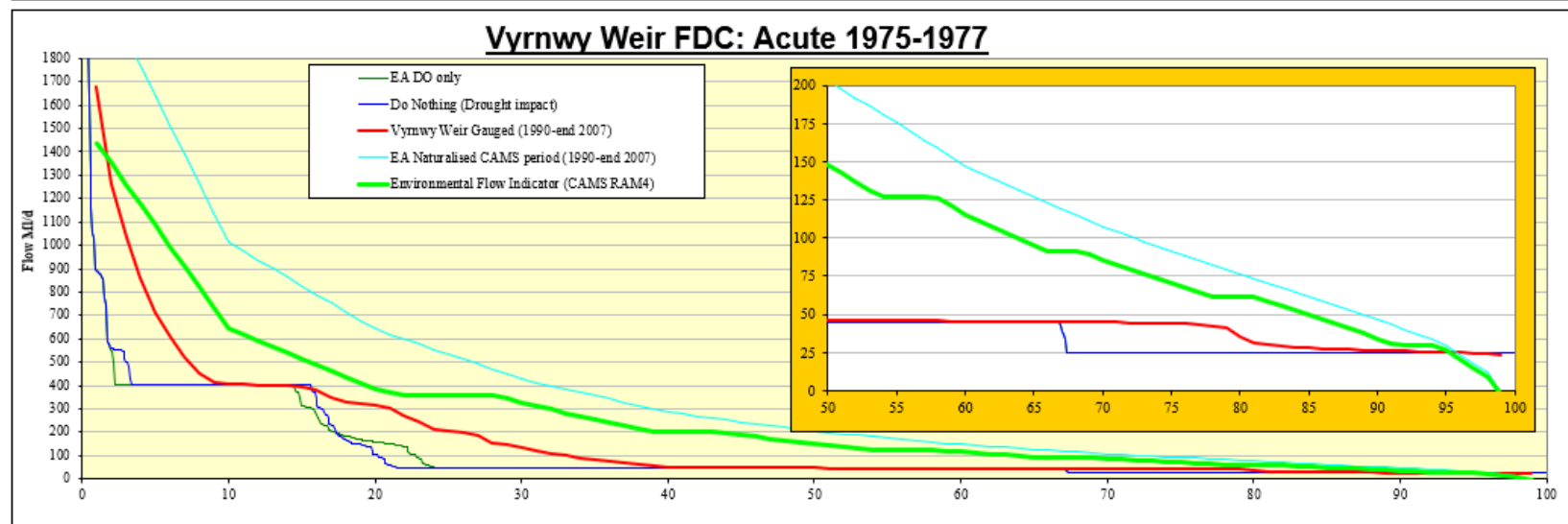
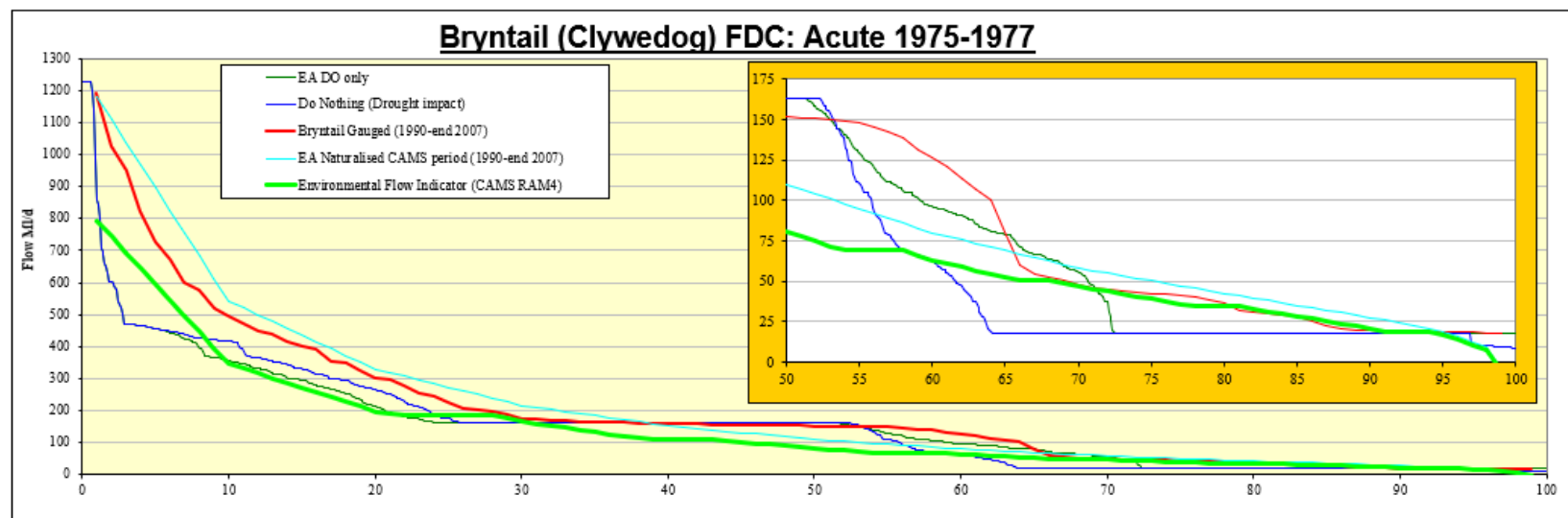


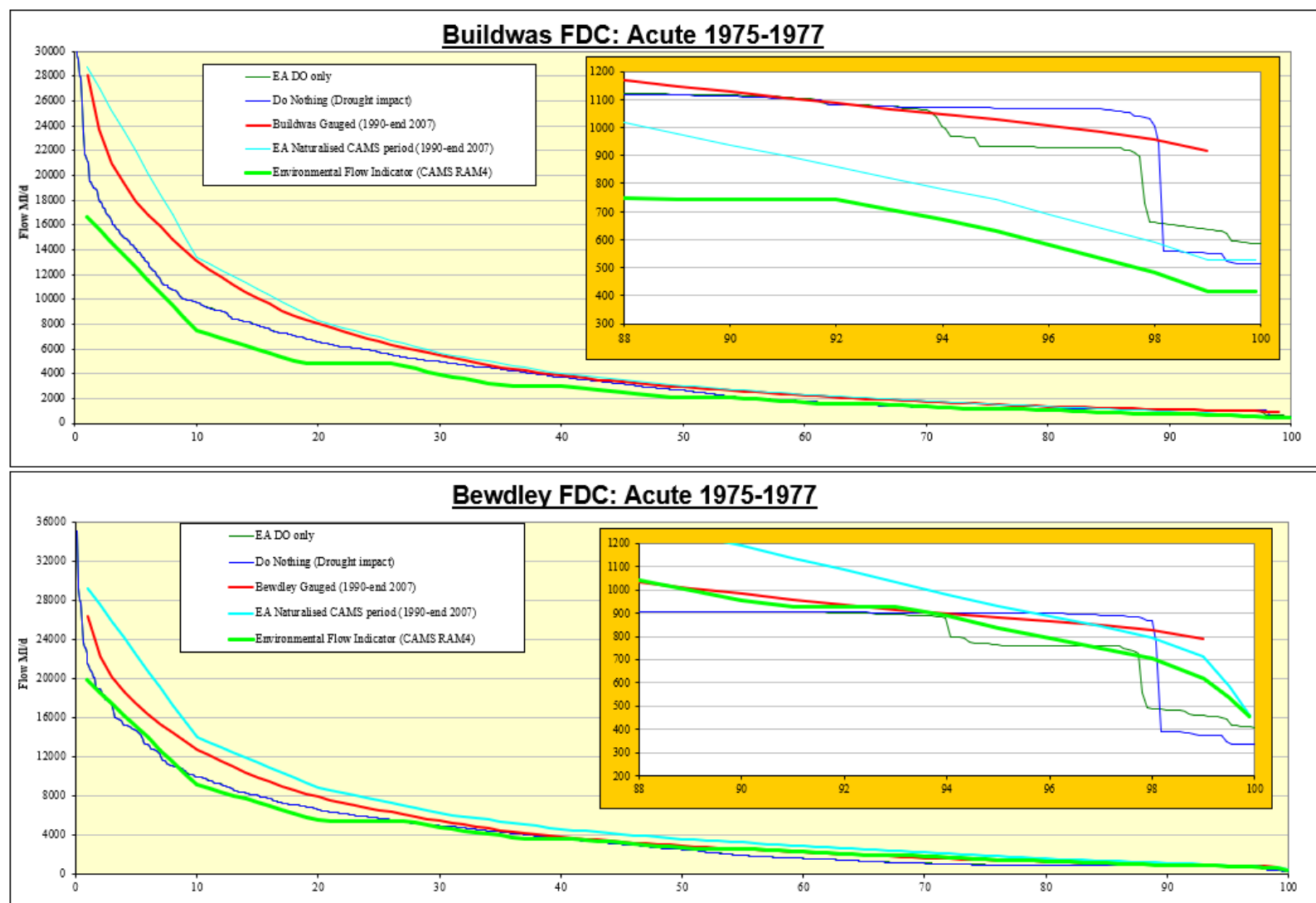


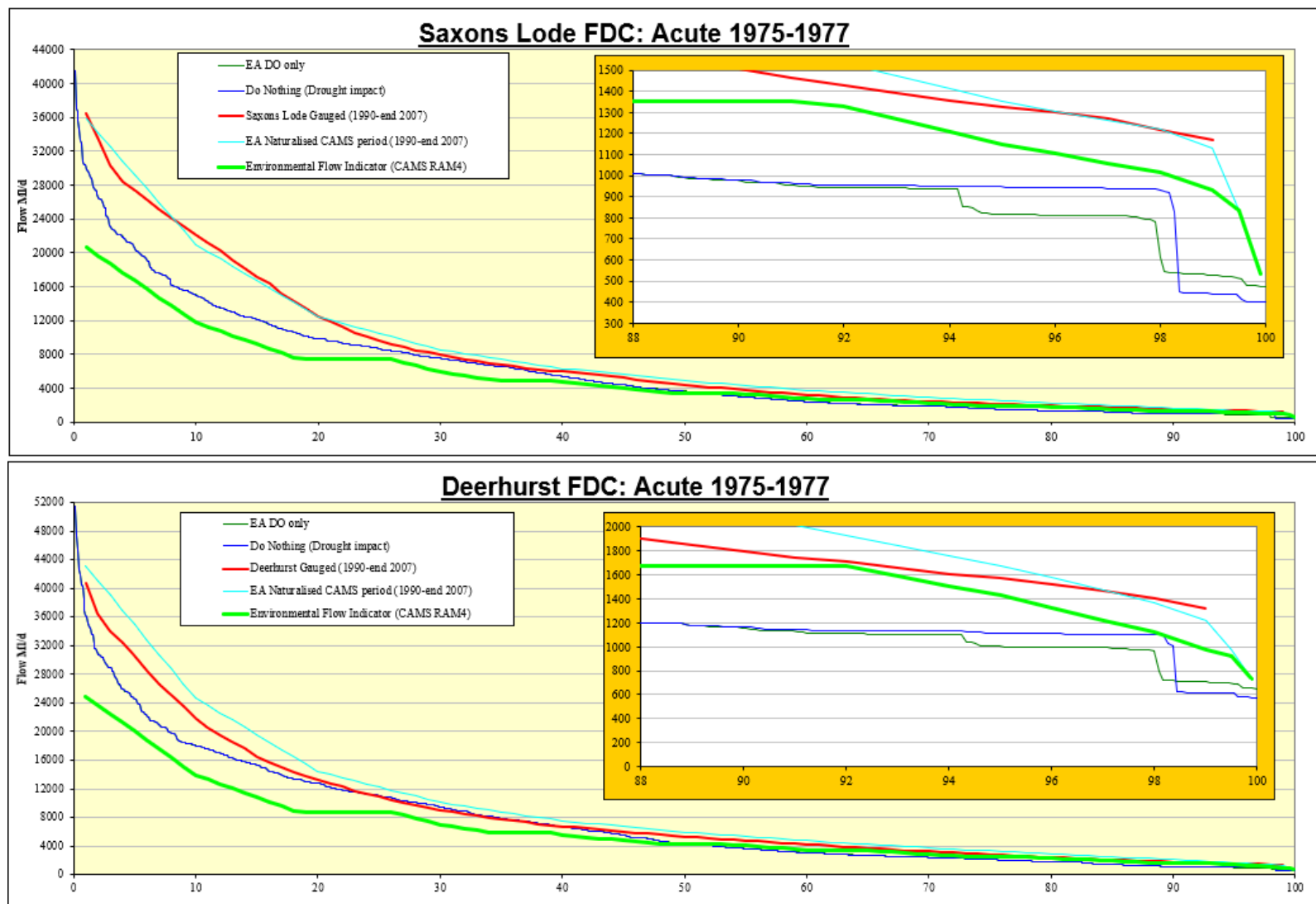


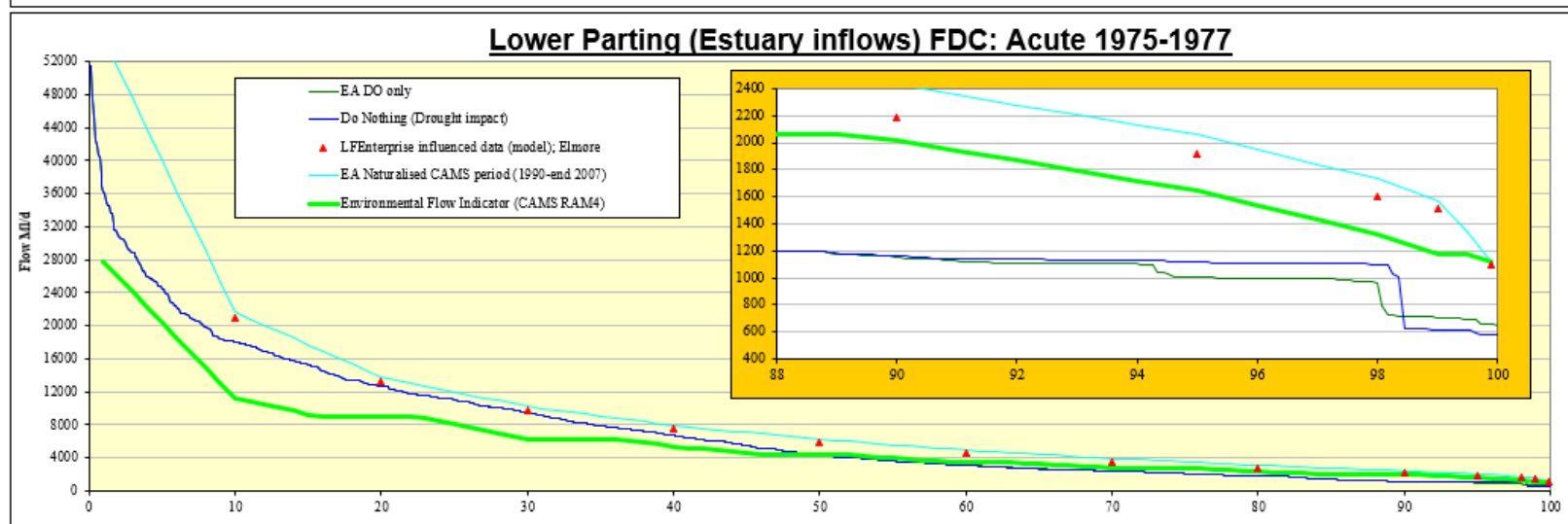
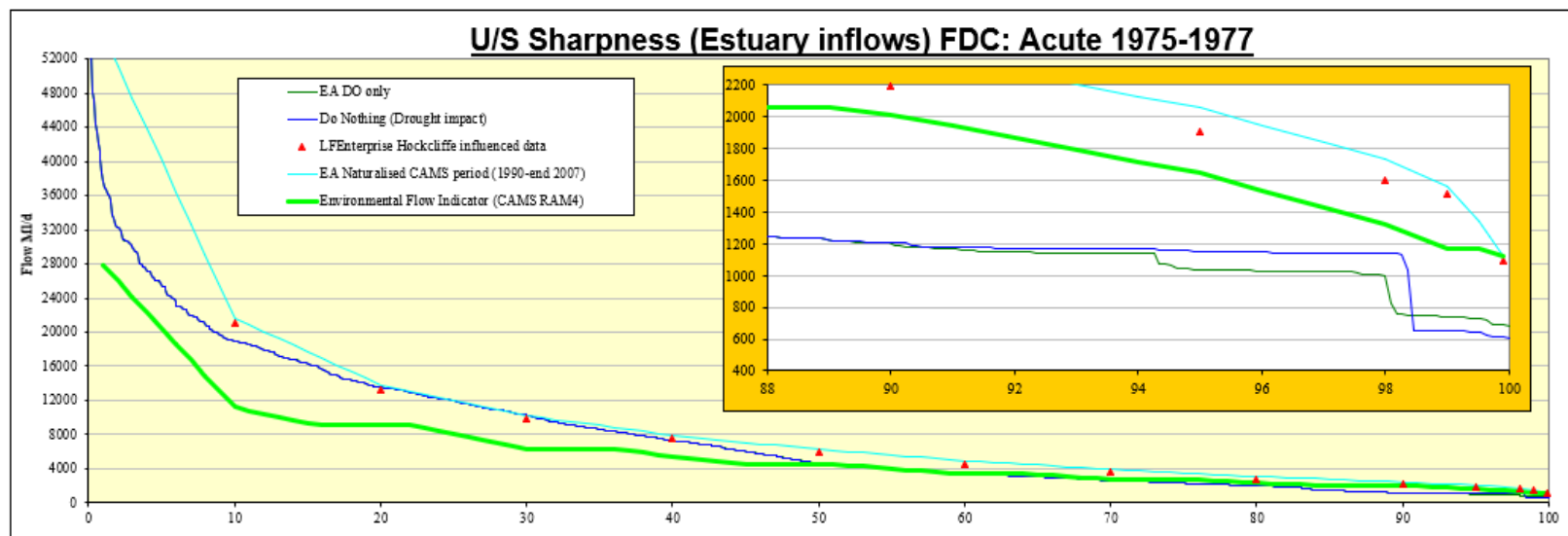
Appendix E.2

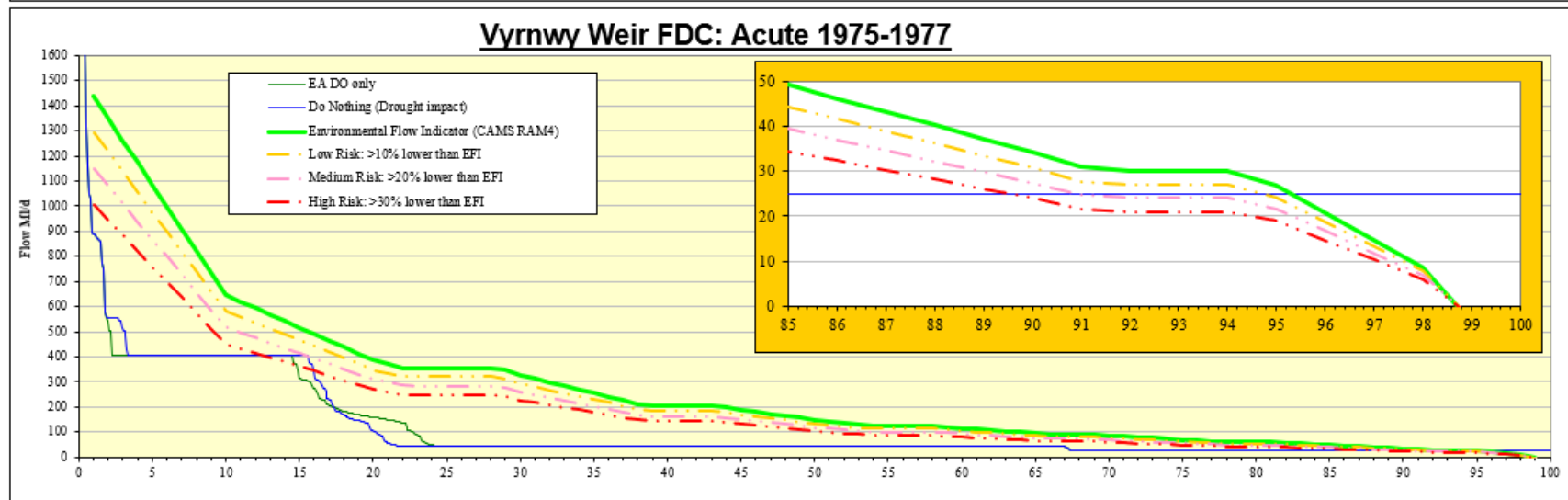
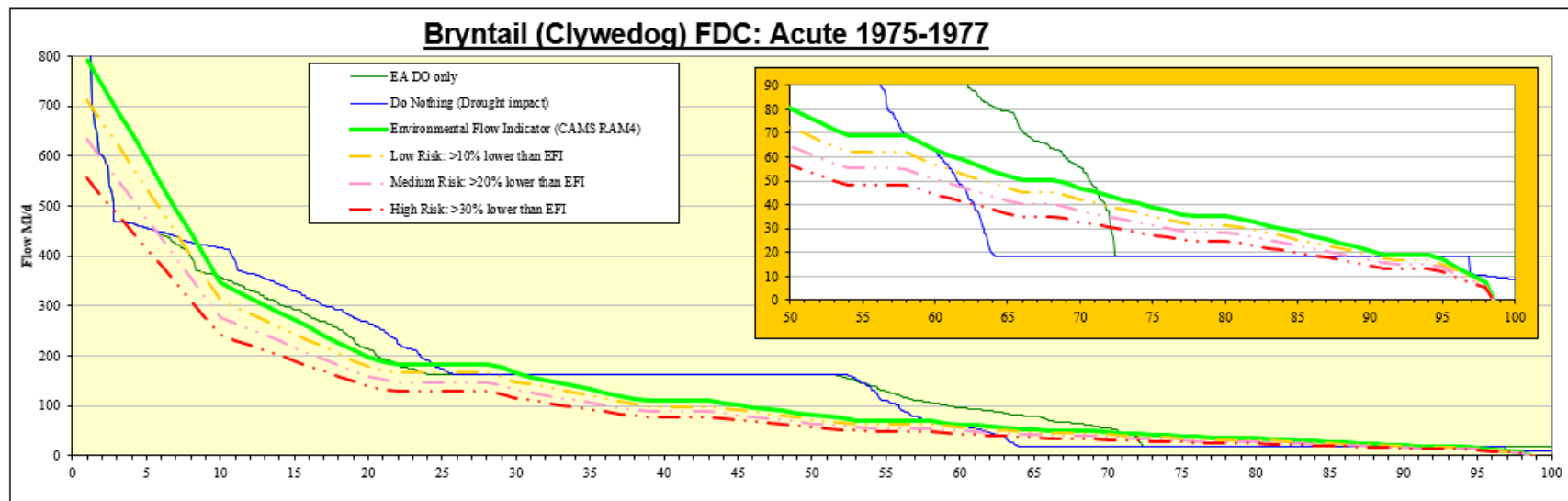
Acute scenario: Environmental Flow Indicator Flow Duration Curves

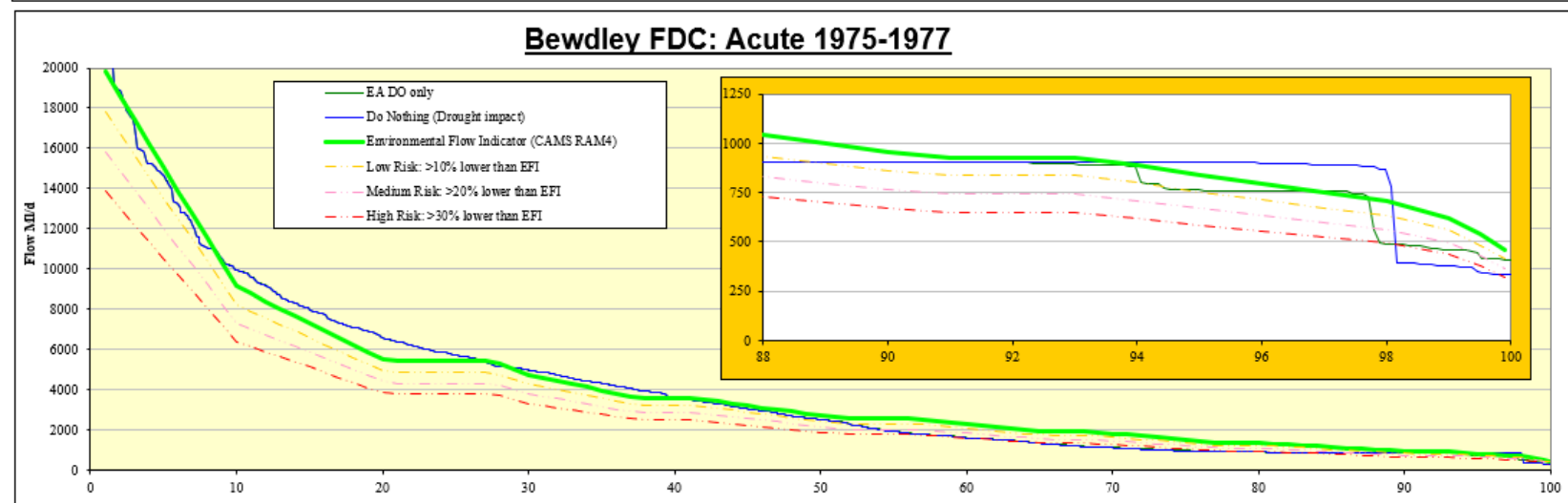
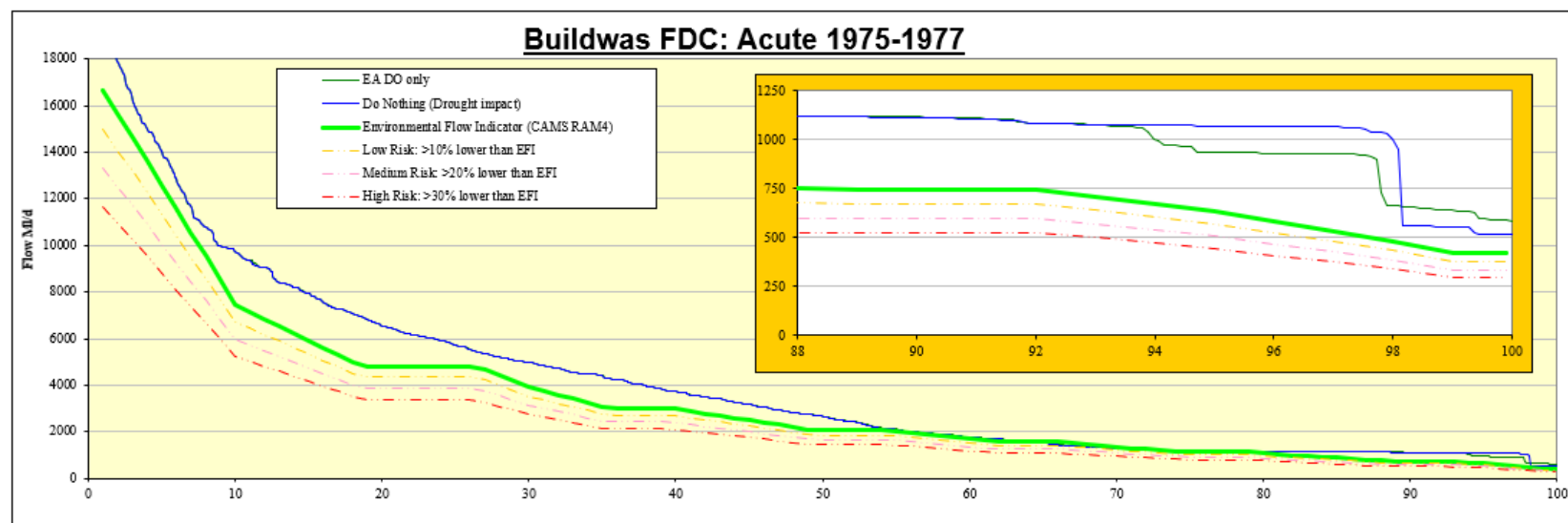


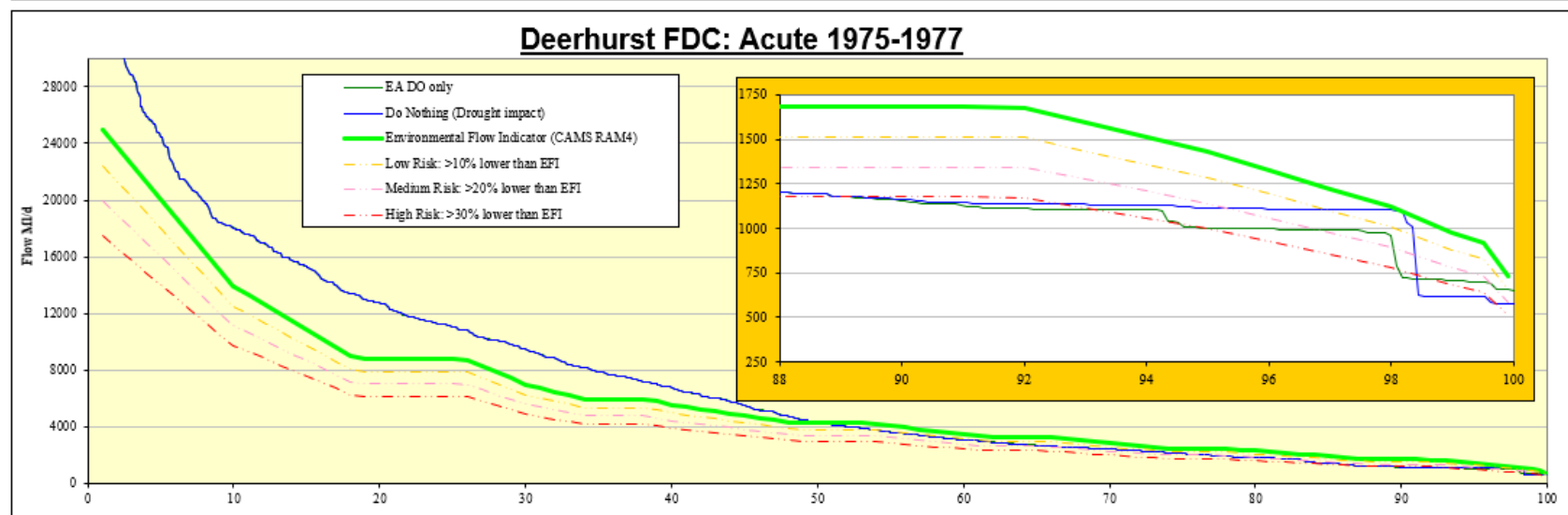
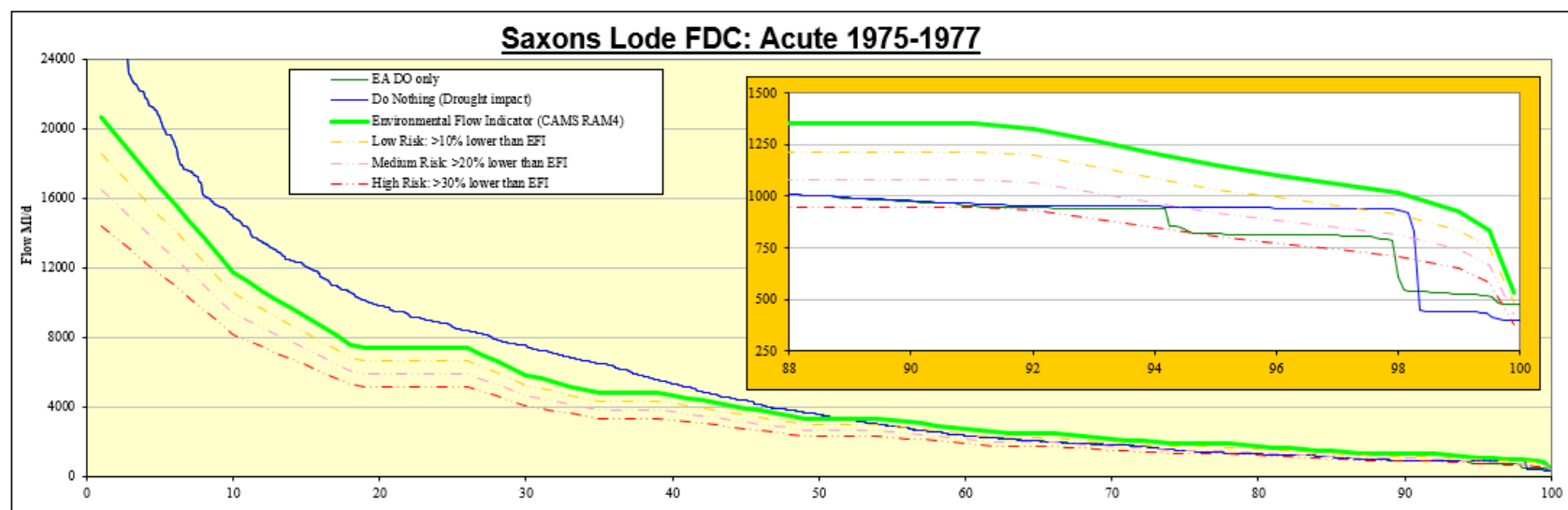


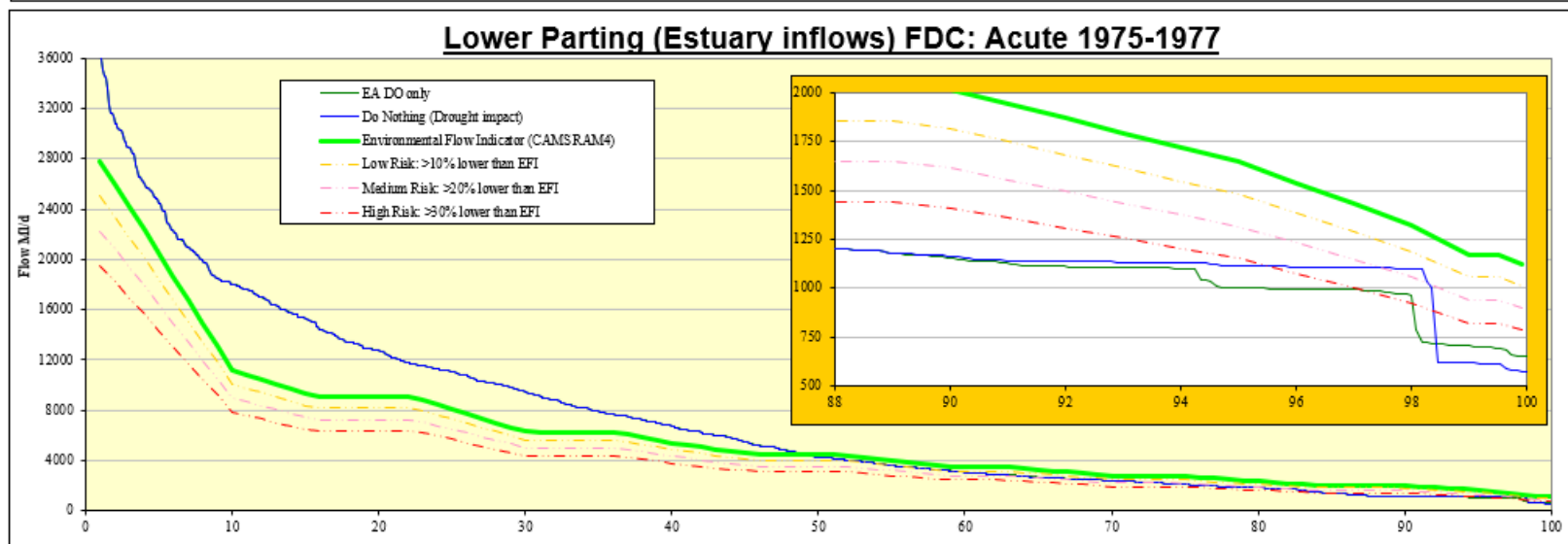
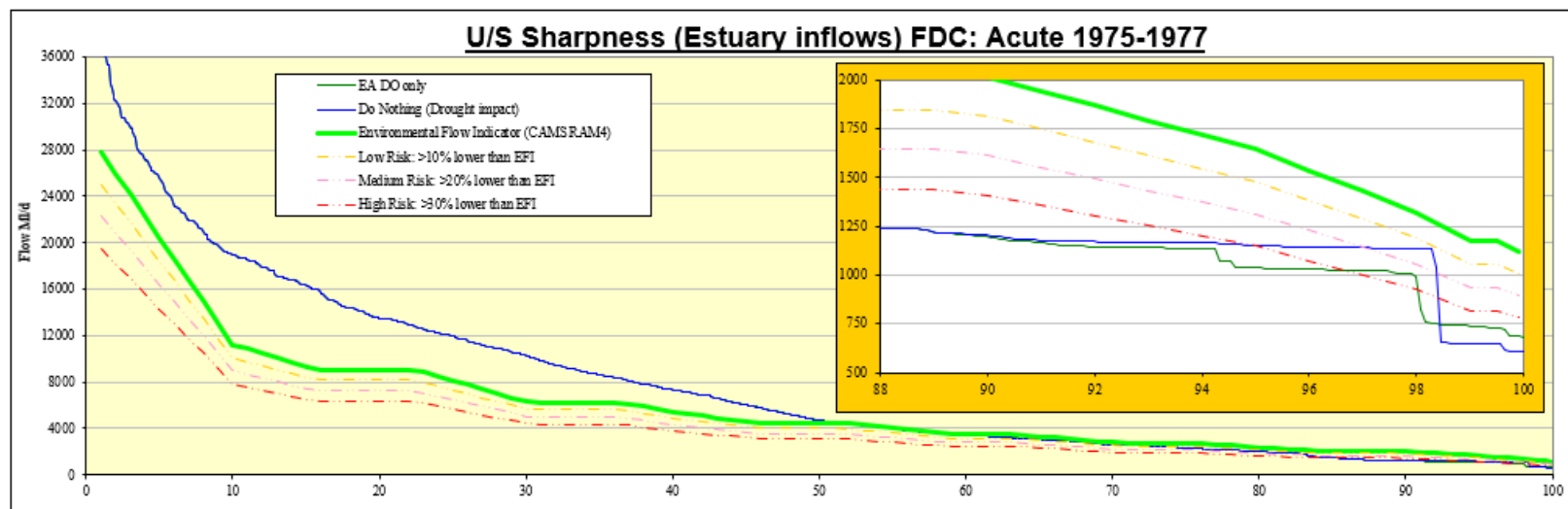












Appendix E.3

Acute scenario: Comparison Summary Statistics

ACUTE Scenario

Severn Regulation system

1975

	No. Days of regulation	Total regulation releases (MI)	SGS MI	Clywedog releases MI	Vyrnwy releases MI	Min. Clywedog Storage %	Max. Clywedog Storage %	Min. Vyrnwy Storage %	Max. Vyrnwy Storage %
Do Nothing	91	19004.99	15.69	18989.29	0.00	63.02	100.00	71.42	100.00
EA DO in isolation	91	19004.99	15.69	18989.29	0.00	63.02	100.00	71.42	100.00

1976

	No. Days of regulation	Total regulation releases (MI)	SGS MI	Clywedog releases MI	Vyrnwy releases MI	Min. Clywedog Storage %	Max. Clywedog Storage %	Min. Vyrnwy Storage %	Max. Vyrnwy Storage %
Do Nothing	166	70219.46	17743.50	46374.36	6101.60	5.00	98.10	21.54	99.91
EA DO in isolation	166	64556.77	17707.60	40747.57	6101.60	15.61	98.10	21.55	99.91

1977

	No. Days of regulation	Total regulation releases (MI)	SGS MI	Clywedog releases MI	Vyrnwy releases MI	Min. Clywedog Storage %	Max. Clywedog Storage %	Min. Vyrnwy Storage %	Max. Vyrnwy Storage %
Do Nothing	11	217.25	0.00	217.25	0.00	26.04	89.58	37.09	100.00
EA DO in isolation	11	217.25	0.00	217.25	0.00	36.71	97.47	37.10	100.00

1978

	No. Days of regulation	Total regulation releases (MI)	SGS MI	Clywedog releases MI	Vyrnwy releases MI	Min. Clywedog Storage %	Max. Clywedog Storage %	Min. Vyrnwy Storage %	Max. Vyrnwy Storage %
Do Nothing	42	3064.46	0.00	3064.46	0.00	77.37	99.02	73.94	100.00
EA DO in isolation	42	3064.46	0.00	3064.46	0.00	77.37	99.02	73.94	100.00

1979

	No. Days of regulation	Total regulation releases (MI)	SGS MI	Clywedog releases MI	Vyrnwy releases MI	Min. Clywedog Storage %	Max. Clywedog Storage %	Min. Vyrnwy Storage %	Max. Vyrnwy Storage %
Do Nothing	2	16.85	0.00	16.85	0.00	83.30	100.00	79.03	100.00
EA DO in isolation	2	16.85	0.00	16.85	0.00	83.30	100.00	79.03	100.00

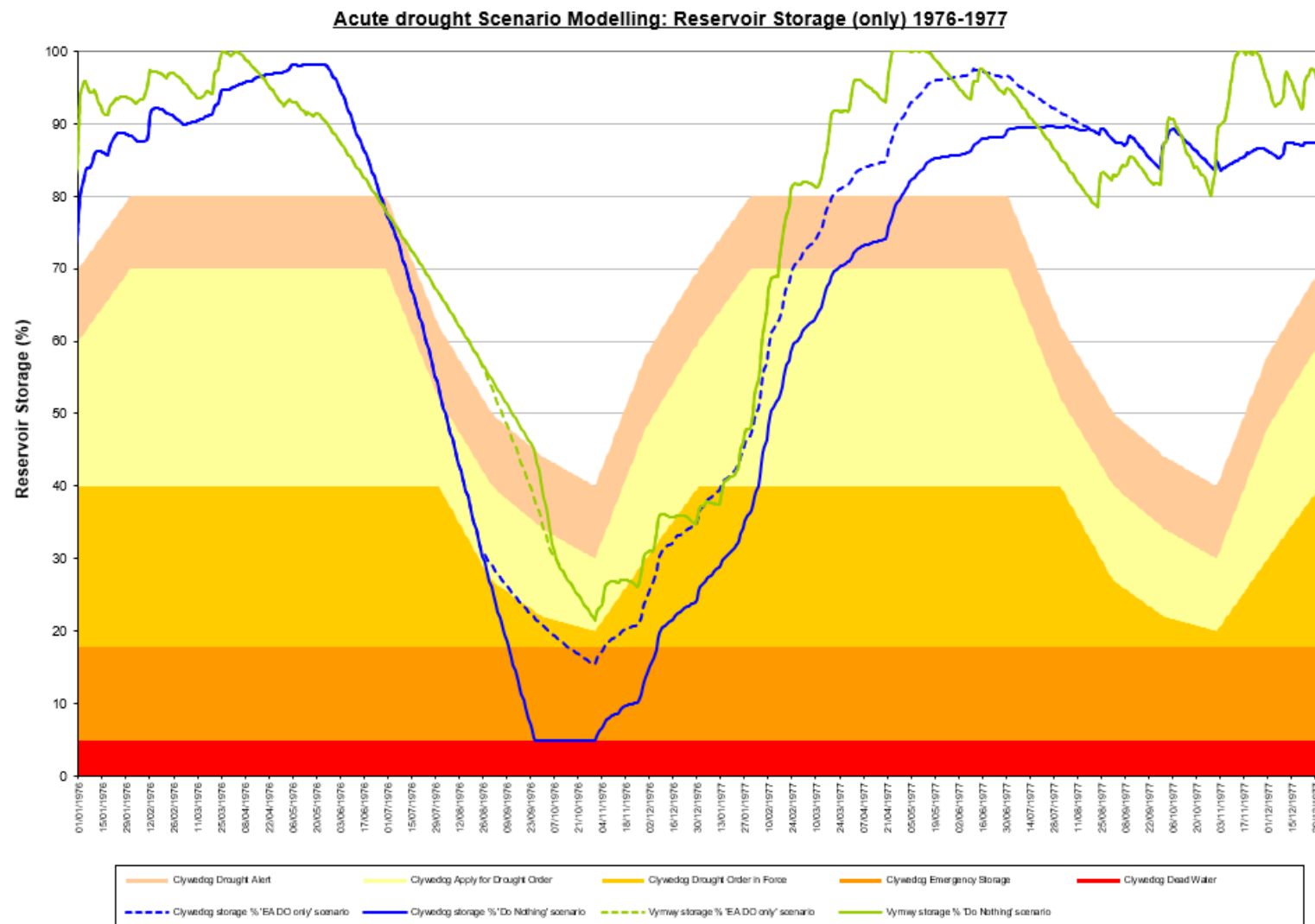
ACUTE Scenario

Minimum Flows

1975									Bewdley Flow Failures	
Do Nothing EA DO in isolation	Bryntail (Clywedog)	Vyrnwy	Buildwas	Bewdley	Saxons Lode	Deerhurst	Sharpnes	Lower Parting	Total 850 MI/d failures	Total 730 MI/d failures
	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	s min. flow MI/d	min. flow MI/d		
	18.20	25.00	1002.62	891.14	1250.07	1685.23	1808.54	1511.64	0	0
EA DO in isolation	18.20	25.00	1002.62	891.14	1250.07	1685.23	1808.54	1511.64	0	0
1976									Bewdley Flow Failures	
Do Nothing EA DO in isolation	Bryntail (Clywedog)	Vyrnwy	Buildwas	Bewdley	Saxons Lode	Deerhurst	Sharpnes	Lower Parting	Total 850 MI/d failures	Total 730 MI/d failures
	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	s min. flow MI/d	min. flow MI/d		
	8.67	25.00	512.05	335.89	398.89	576.92	608.86	382.44	22	21
EA DO in isolation	18.20	25.00	584.12	409.00	473.06	652.15	684.09	458.76	66	26
1977									Bewdley Flow Failures	
Do Nothing EA DO in isolation	Bryntail (Clywedog)	Vyrnwy	Buildwas	Bewdley	Saxons Lode	Deerhurst	Sharpnes	Lower Parting	Total 850 MI/d failures	Total 730 MI/d failures
	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	s min. flow MI/d	min. flow MI/d		
	18.20	25.00	1033.77	907.95	1716.80	2457.90	2906.90	2623.15	0	0
EA DO in isolation	18.20	25.00	1079.41	922.15	1747.29	2487.35	2920.05	2623.15	0	0
1978									Bewdley Flow Failures	
Do Nothing EA DO in isolation	Bryntail (Clywedog)	Vyrnwy	Buildwas	Bewdley	Saxons Lode	Deerhurst	Sharpnes	Lower Parting	Total 850 MI/d failures	Total 730 MI/d failures
	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	s min. flow MI/d	min. flow MI/d		
	18.20	25.00	969.18	905.04	1423.58	1807.88	1934.38	1735.80	0	0
EA DO in isolation	18.20	25.00	969.18	905.04	1423.58	1807.88	1934.38	1735.80	0	0
1979									Bewdley Flow Failures	
Do Nothing EA DO in isolation	Bryntail (Clywedog)	Vyrnwy	Buildwas	Bewdley	Saxons Lode	Deerhurst	Sharpnes	Lower Parting	Total 850 MI/d failures	Total 730 MI/d failures
	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	s min. flow MI/d	min. flow MI/d		
	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15	2300.25	0	0
EA DO in isolation	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15	2300.25	0	0

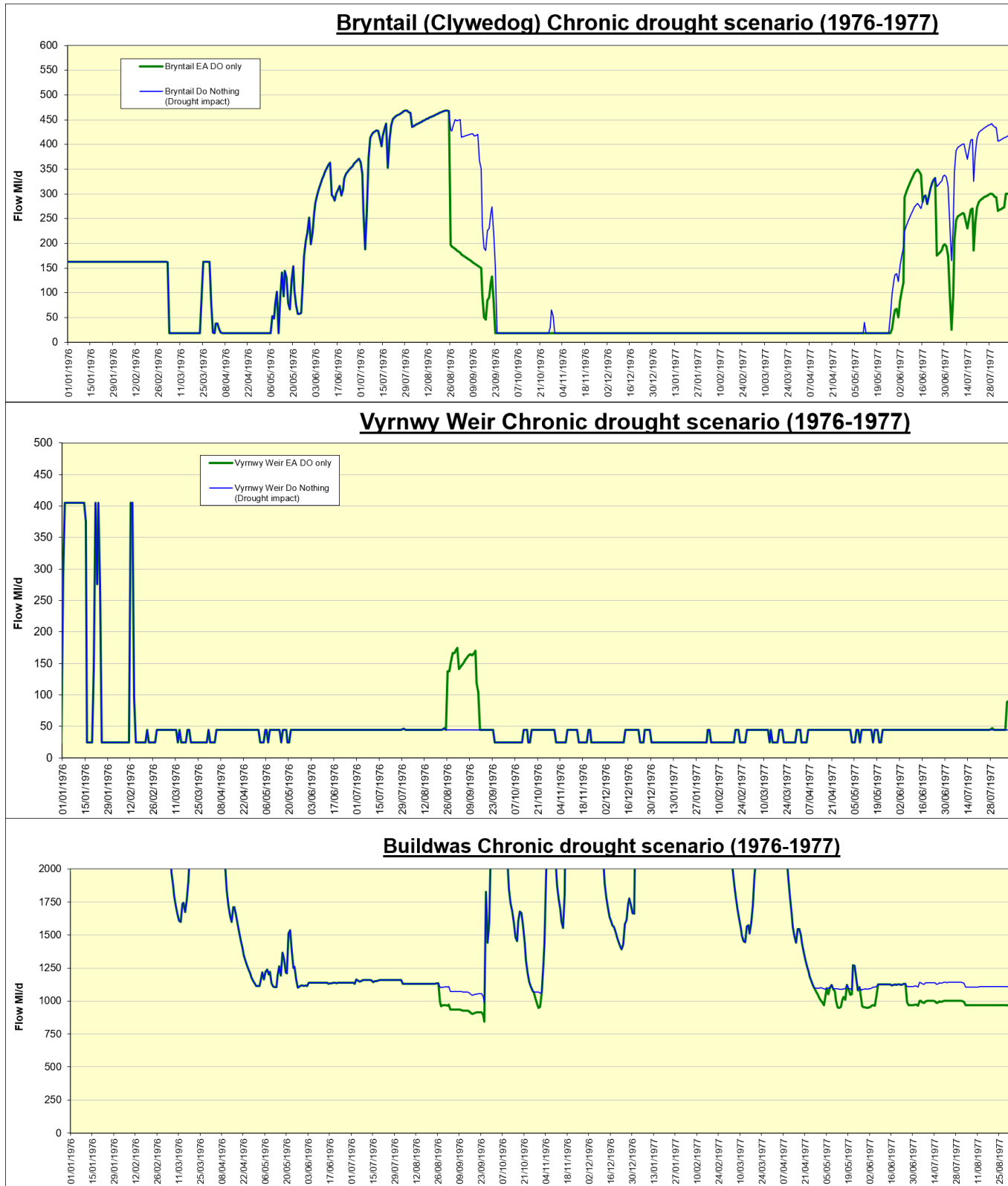
Appendix E.4

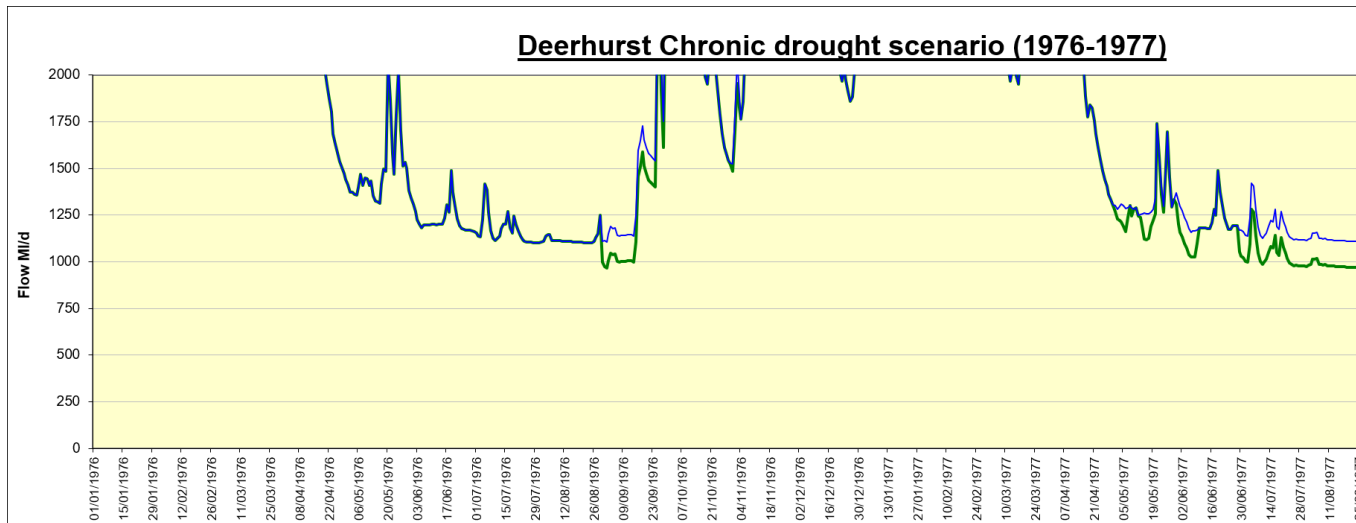
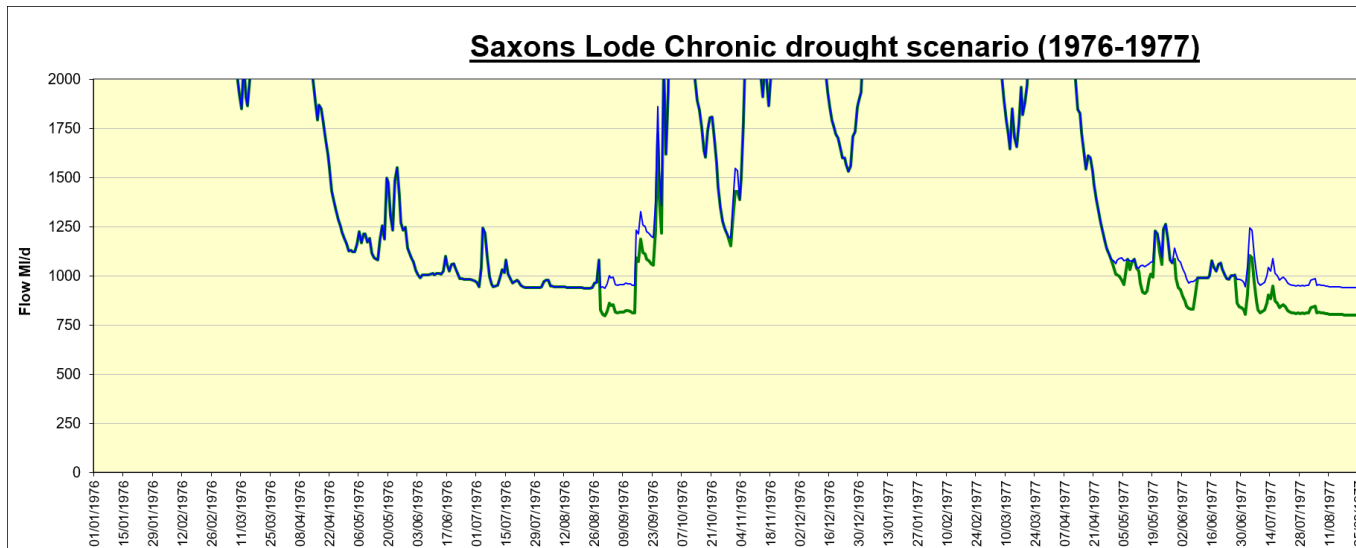
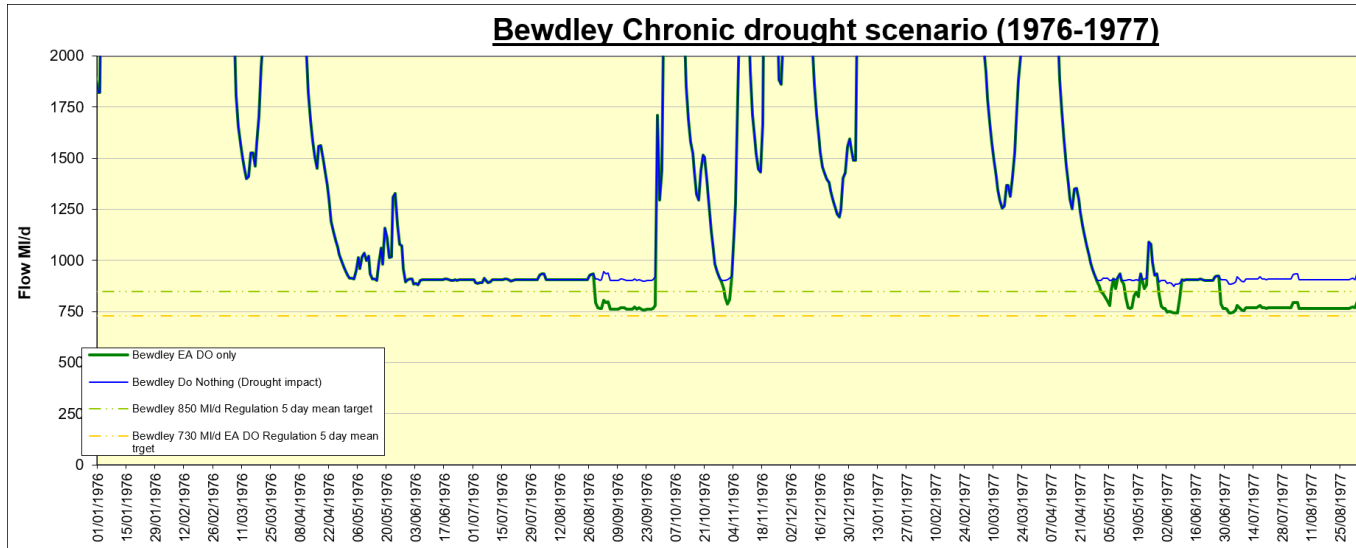
Acute scenario: Reservoir Operations

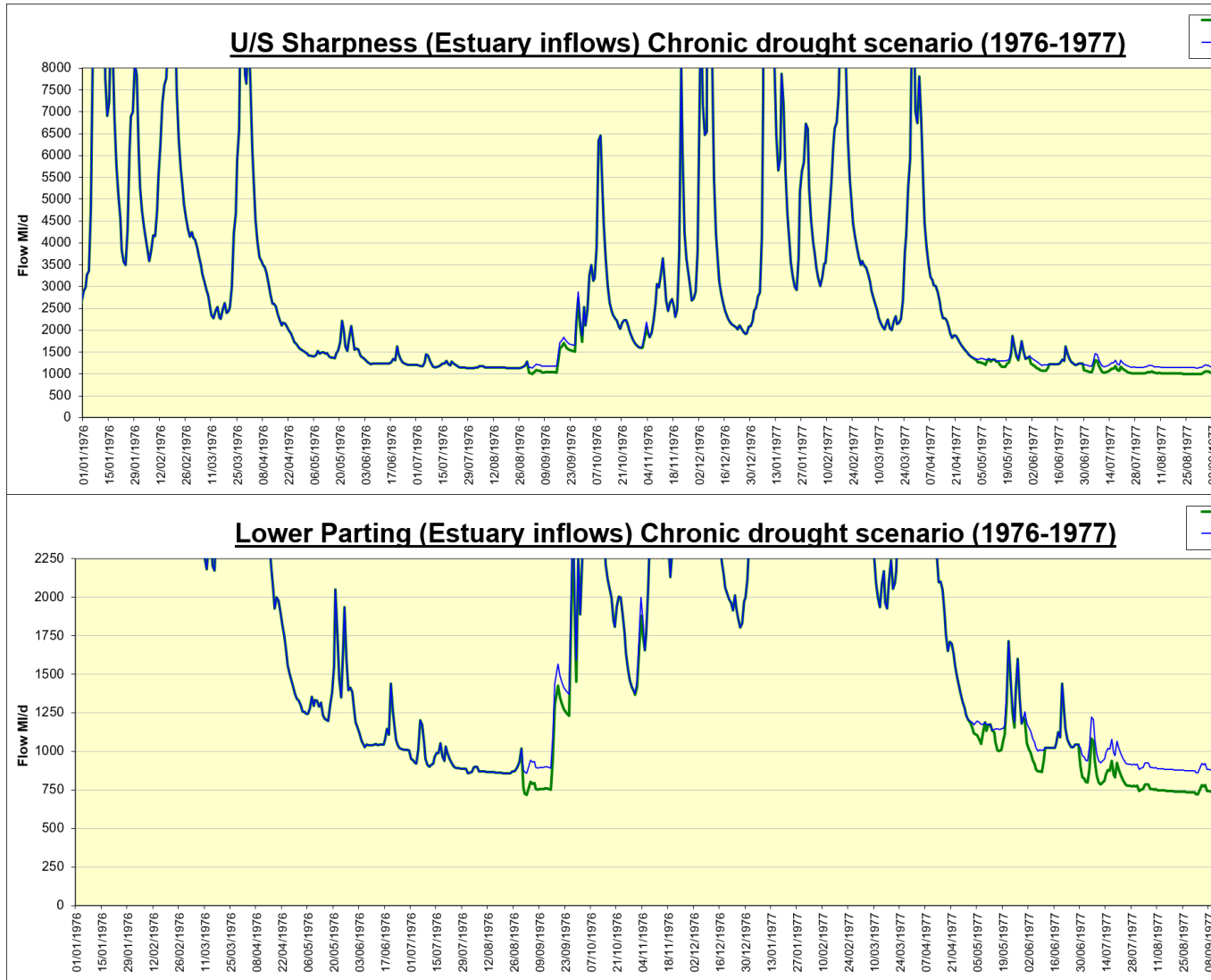


Appendix F.1

Chronic scenario: Hydrographs

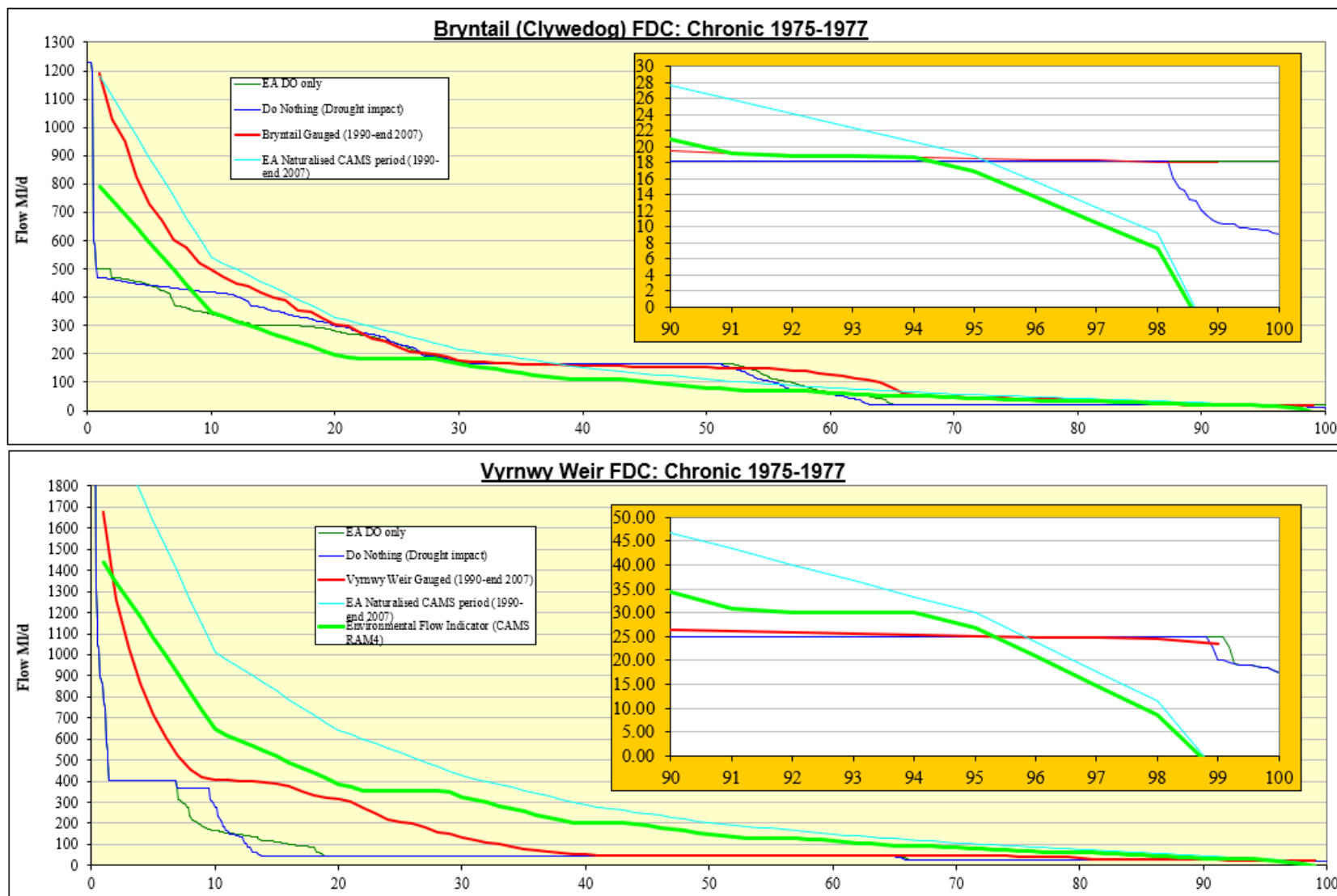


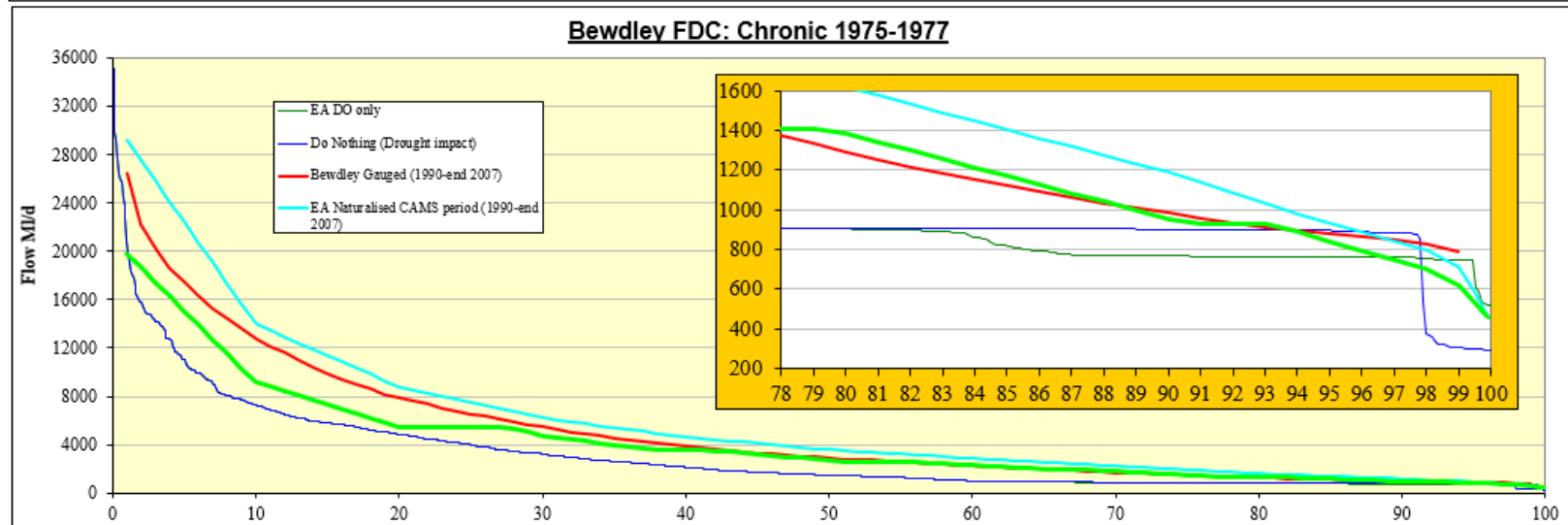
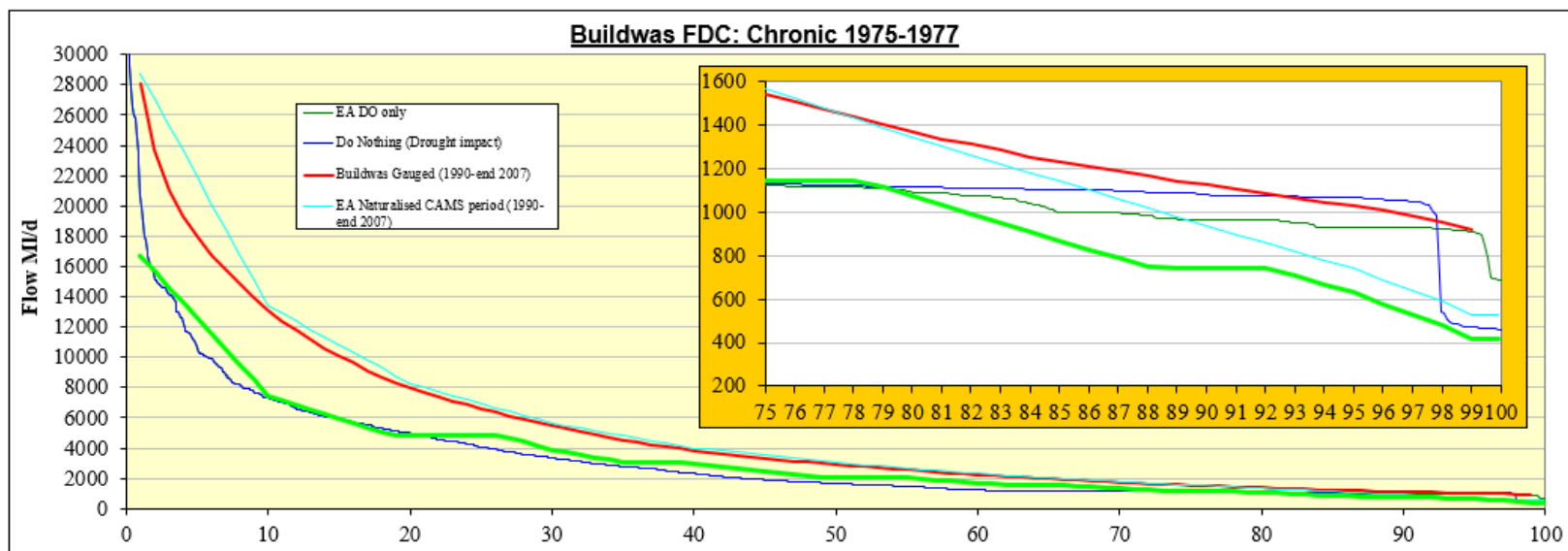


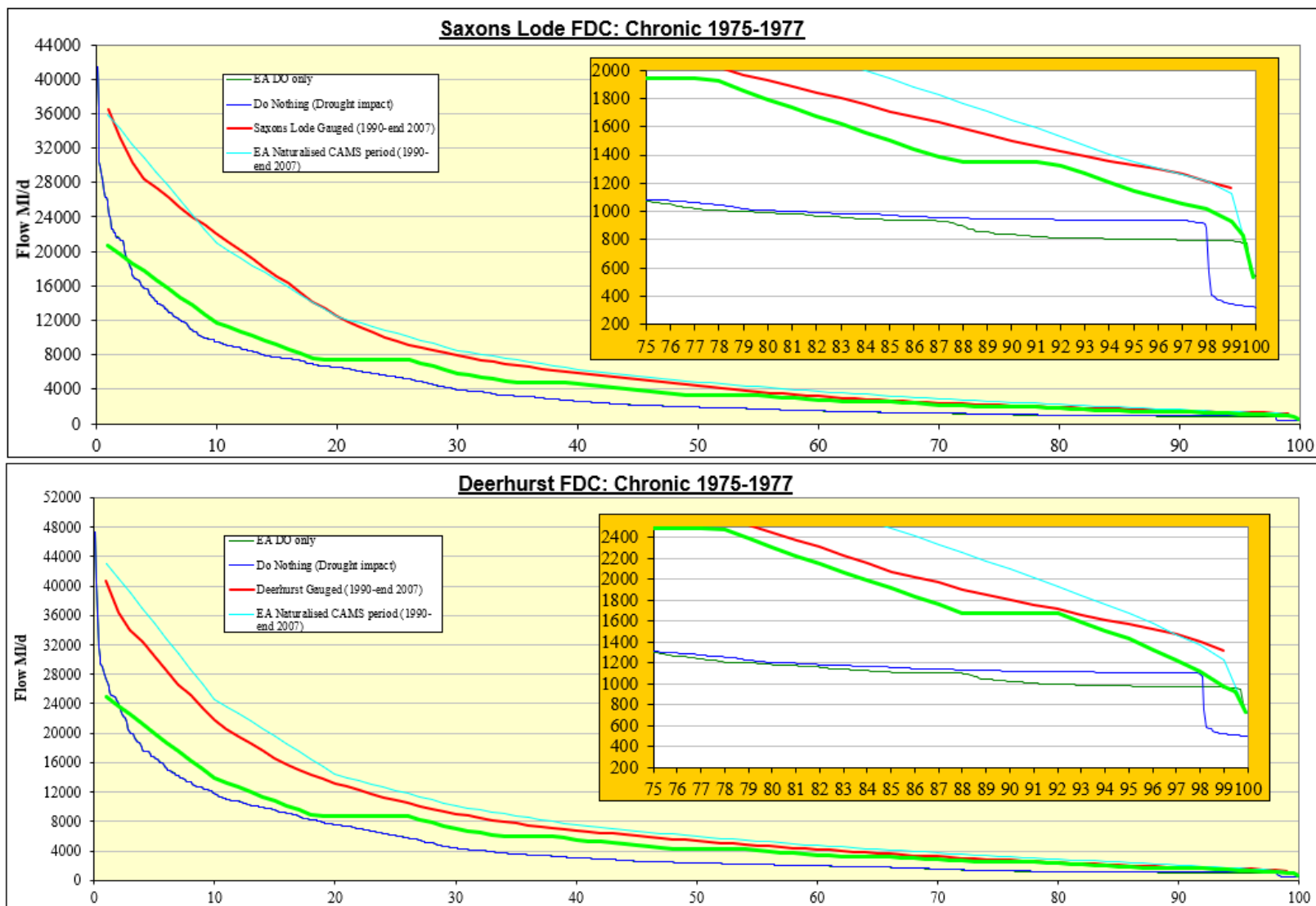


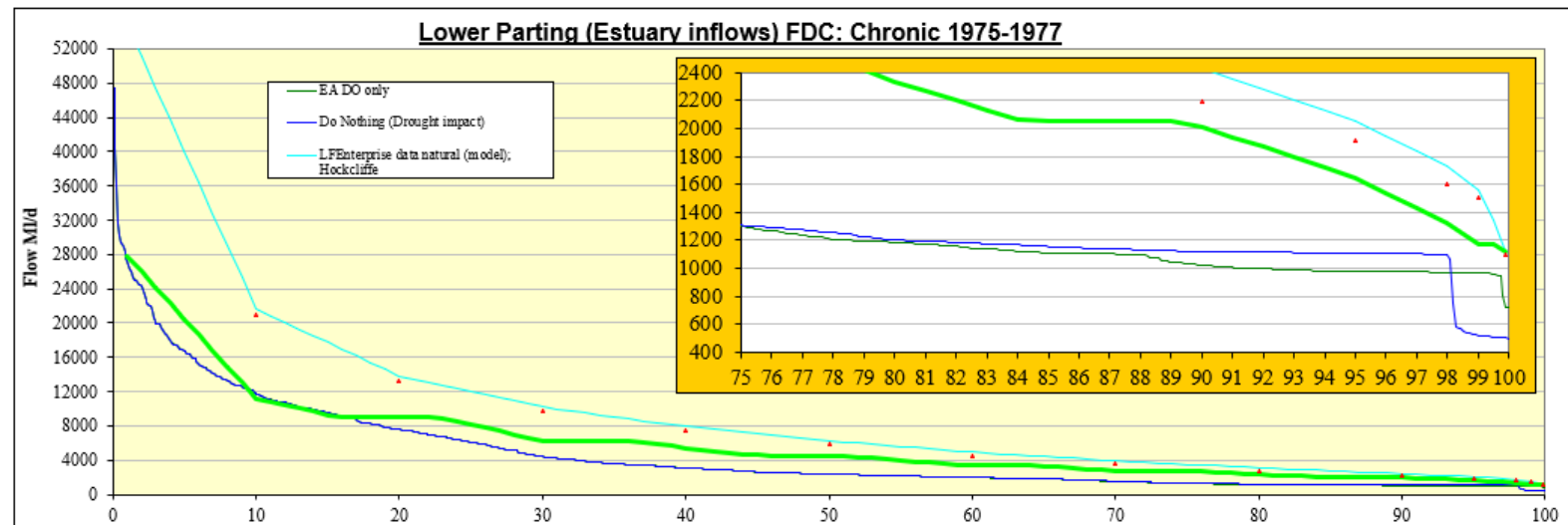
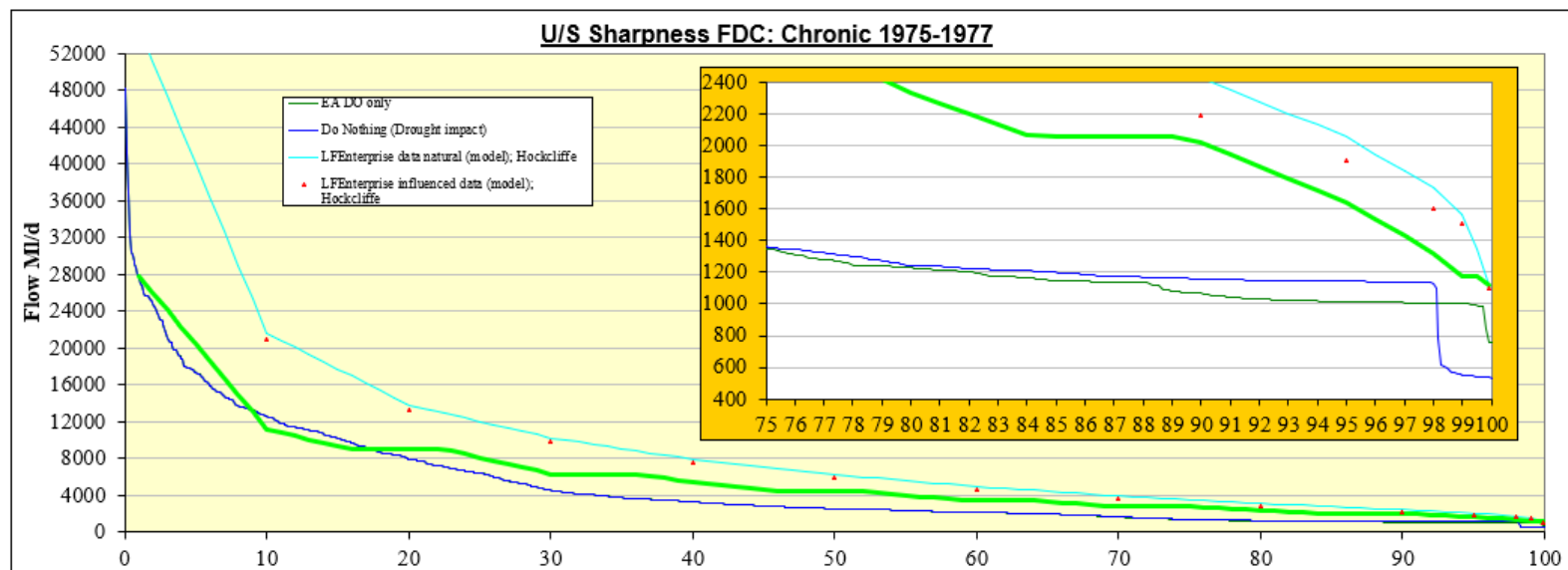
Appendix F.2

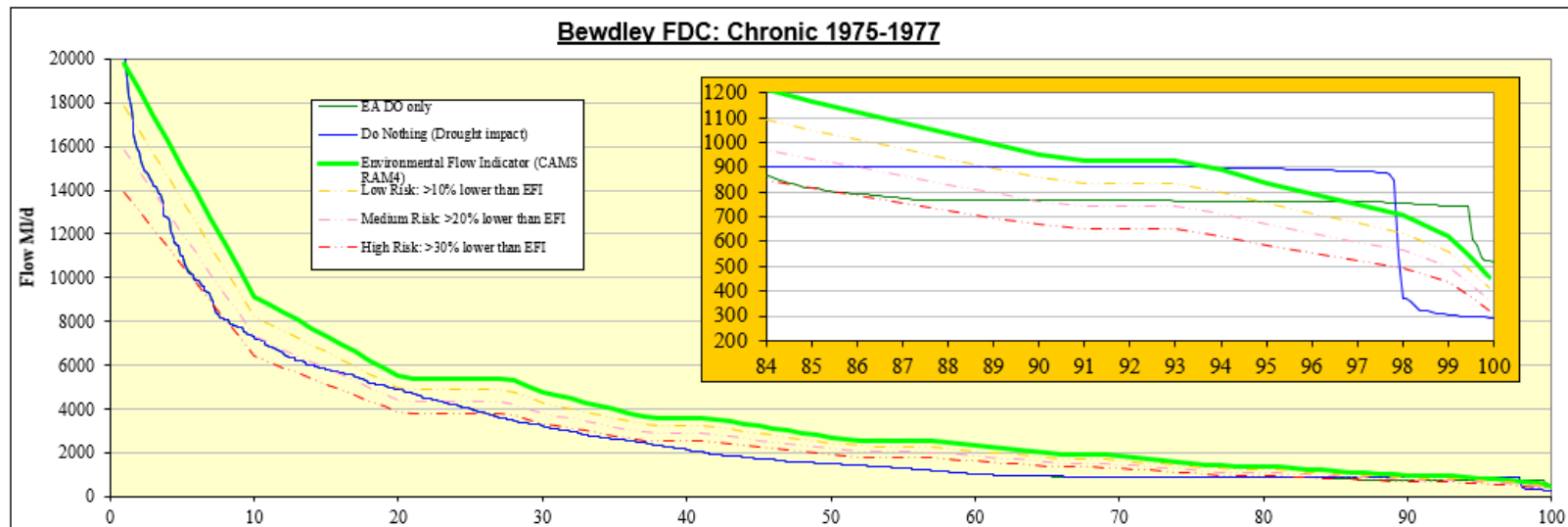
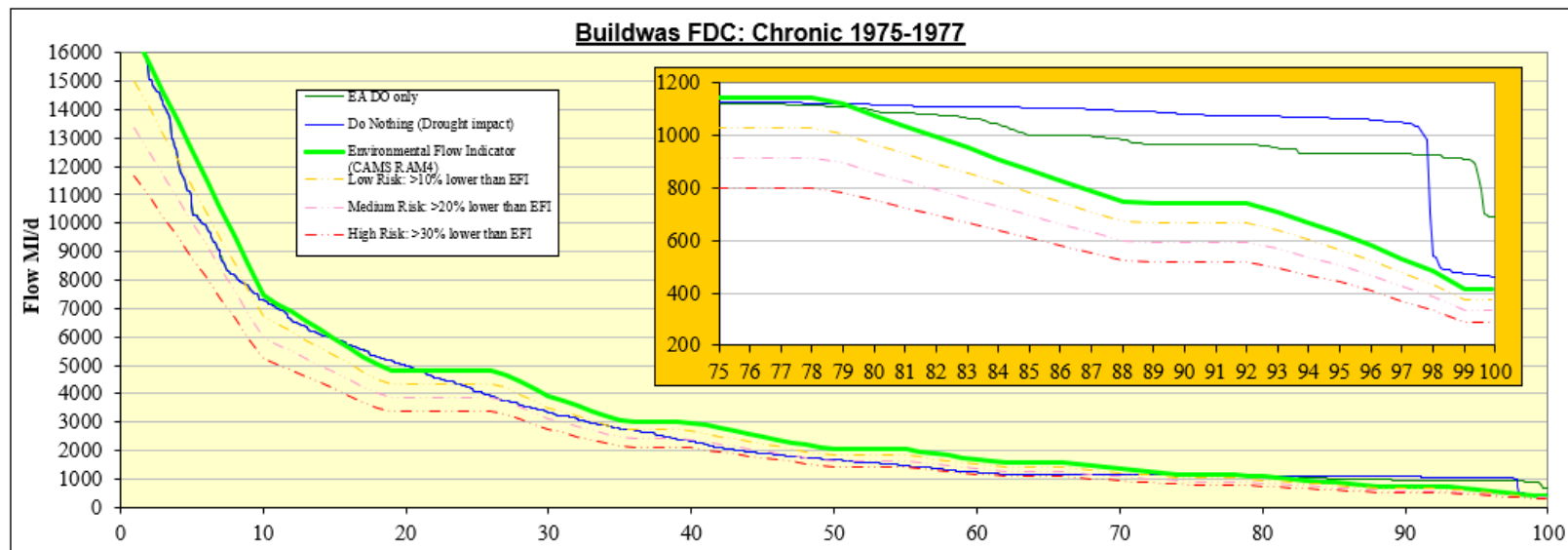
Chronic scenario: Environmental Flow Indicator Flow Duration Curves

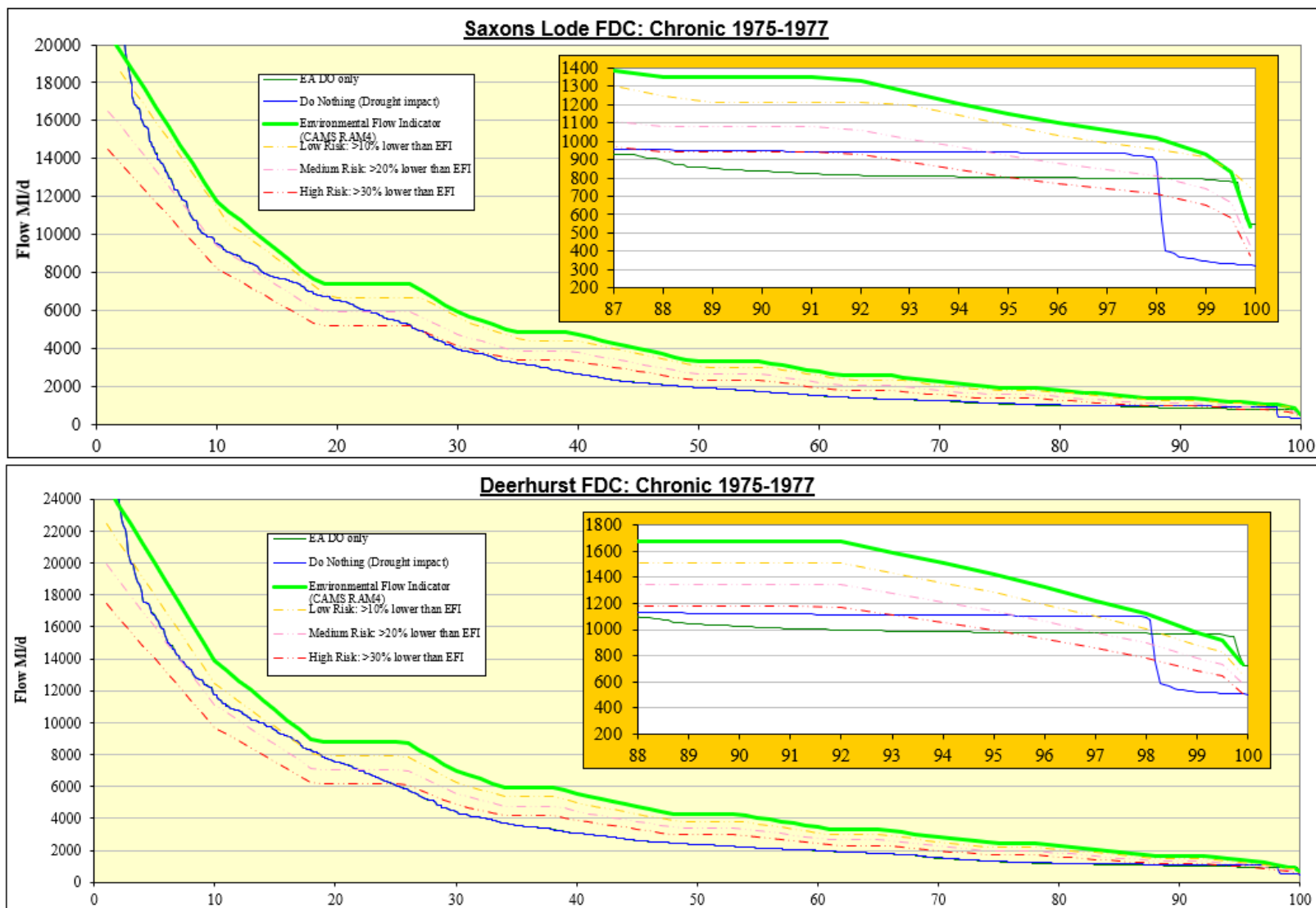


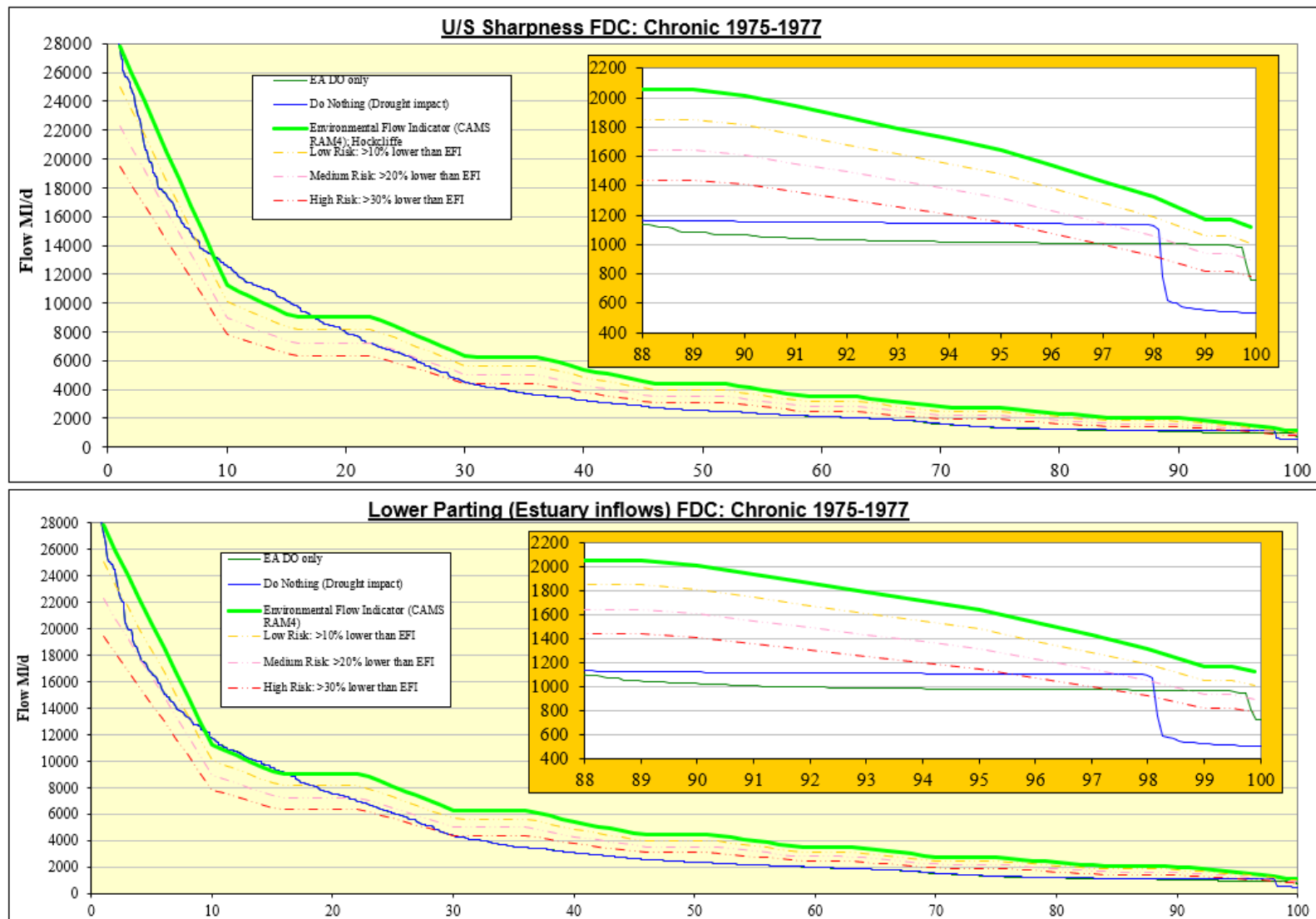












Appendix F.3

Chronic scenario: Comparison Summary Statistics

CHRONIC Scenario

Severn Regulation system

1975

	No. Days of regulation	Total regulation releases (MI)	SGS MI	Clywedog releases MI	Vyrnwy releases MI	Min. Clywedog Storage %	Max. Clywedog Storage %	Min. Vyrnwy Storage %	Max. Vyrnwy Storage %
Do Nothing	91	19004.99	15.69	18989.29	0.00	63	100	71	100
EA DO in isolation	91	19004.99	15.69	18989.29	0.00	63	100	71	100

1976

	No. Days of regulation	Total regulation releases (MI)	SGS MI	Clywedog releases MI	Vyrnwy releases MI	Min. Clywedog Storage %	Max. Clywedog Storage %	Min. Vyrnwy Storage %	Max. Vyrnwy Storage %
Do Nothing	135	59029.62	15594.95	43429.22	5.45	12	98	47	100
EA DO in isolation	130	54500.82	15213.55	37122.22	2165.05	24	98	43	100

1977

	No. Days of regulation	Total regulation releases (MI)	SGS MI	Clywedog releases MI	Vyrnwy releases MI	Min. Clywedog Storage %	Max. Clywedog Storage %	Min. Vyrnwy Storage %	Max. Vyrnwy Storage %
Do Nothing	179	66958.50	18085.26	39619.47	9253.77	5	84	14	87
EA DO in isolation	157	60530.28	15337.05	39178.75	6014.47	18	96	14	84

1978

	No. Days of regulation	Total regulation releases (MI)	SGS MI	Clywedog releases MI	Vyrnwy releases MI	Min. Clywedog Storage %	Max. Clywedog Storage %	Min. Vyrnwy Storage %	Max. Vyrnwy Storage %
Do Nothing	42	3064.46	0.00	3064.46	0.00	56	99	73	100
EA DO in isolation	42	3064.46	0.00	3064.46	0.00	67	99	73	100

1979

	No. Days of regulation	Total regulation releases (MI)	SGS MI	Clywedog releases MI	Vyrnwy releases MI	Min. Clywedog Storage %	Max. Clywedog Storage %	Min. Vyrnwy Storage %	Max. Vyrnwy Storage %
Do Nothing	2	16.85	0.00	16.85	0.00	83	100	79	100
EA DO in isolation	2	16.85	0.00	16.85	0.00	83	100	79	100

CHRONIC Scenario

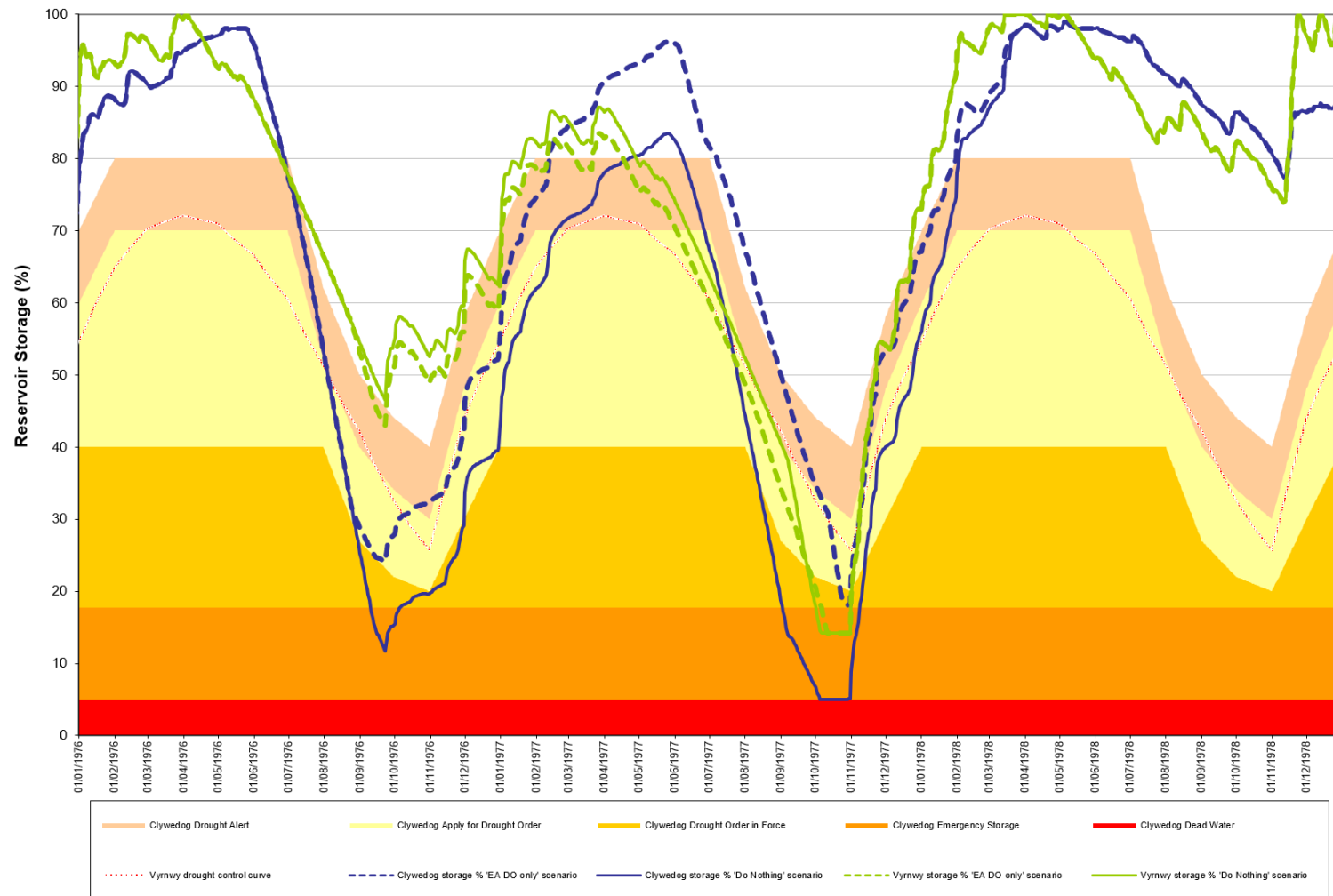
Minimum Flows

1975									Bewdley Flow Failures	
Do Nothing EA DO in isolation	Bryntail (Clywedog)	Vyrnwy	Buildwas	Bewdley	Saxons Lode min. flow	Deerhurst	Sharpness	Lower Parting	Total 850 MI/d failures	Total 730 MI/d failures
	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d		
	18.20	25.00	1002.62	891.14	1250.07	1685.23	1808.54	1511.64	0	0
EA DO in isolation	18.20	25.00	1002.62	891.14	1250.07	1685.23	1808.54	1511.64	0	0
1976									Bewdley Flow Failures	
Do Nothing EA DO in isolation	Bryntail (Clywedog)	Vyrnwy	Buildwas	Bewdley	Saxons Lode min. flow	Deerhurst	Sharpness	Lower Parting	Total 850 MI/d failures	Total 730 MI/d failures
	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d		
	18.20	25.00	985.42	880.96	937.14	1101.07	1136.47	857.19	0	0
EA DO in isolation	18.20	25.00	845.42	757.59	797.87	966.00	1001.10	719.04	33	0
1977									Bewdley Flow Failures	
Do Nothing EA DO in isolation	Bryntail (Clywedog)	Vyrnwy	Buildwas	Bewdley	Saxons Lode min. flow	Deerhurst	Sharpness	Lower Parting	Total 850 MI/d failures	Total 730 MI/d failures
	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d		
	9.07	17.46	458.88	289.05	322.65	499.35	531.55	303.93	25	24
EA DO in isolation	18.20	17.46	689.70	519.89	547.16	723.37	755.36	527.74	140	6
1978									Bewdley Flow Failures	
Do Nothing EA DO in isolation	Bryntail (Clywedog)	Vyrnwy	Buildwas	Bewdley	Saxons Lode min. flow	Deerhurst	Sharpness	Lower Parting	Total 850 MI/d failures	Total 730 MI/d failures
	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d		
	18.20	25.00	969.18	905.04	1423.58	1807.08	1933.58	1735.80	0	0
EA DO in isolation	18.20	25.00	969.18	905.04	1423.58	1807.08	1933.58	1735.80	0	0
1979									Bewdley Flow Failures	
Do Nothing EA DO in isolation	Bryntail (Clywedog)	Vyrnwy	Buildwas	Bewdley	Saxons Lode min. flow	Deerhurst	Sharpness	Lower Parting	Total 850 MI/d failures	Total 730 MI/d failures
	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d	min. flow MI/d		
	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15	2300.25	0	0
EA DO in isolation	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15	2300.25	0	0

Appendix F.4

Chronic scenario: Reservoir Operations

Chronic drought scenario Modelling: Reservoir Storage (only) 1976 - 1978



Appendix G

Water Quality Current Environment Information

WATER QUALITY

Environment Agency

Current Environment: Water Quality

The following sections provide a description of the chemical and nutrient quality of the River Severn.

Water Quality Assessment Schemes

Up until 2009, for over twenty years the Environment Agency used the General Quality Assessment (GQA) scheme to assess river water quality in terms of chemistry, biology and nutrients. This helped drive environmental improvements by dealing with the main sources of pollutants, such as point source discharges from sewage treatment works (STWs).

However, the Water Framework Directive (WFD) has introduced a new approach to assessing the whole water environment, integrating water quality, quantity and physical habitat with ecological indicators that will help direct action to where it is most needed, tackling diffuse as well as point source issues. The WFD water quality assessment uses a new tougher methodology based on a far wider range of assessments than GQA classification. The classification uses a principle of 'one out, all out' which means that the poorest individual result drives the overall classification. It reports on over 30 measures, grouped into ecological status (including biology and physico-chemical such as phosphate and pH) and chemical status. Unlike GQA, WFD incorporates estuaries, coastal waters, groundwater and lakes as well as rivers.

The changes to the way water quality is assessed means that WFD classification appears significantly different to the GQA assessment of water quality. Therefore care needs to be taken when comparing the two schemes. In 2009, both schemes were run in parallel and 2009 was the last year that GQA classification was determined.

The Environment Agency published a River Basin Management Plan (RBMP) for the River Severn District in December 2009, in which WFD baseline classification (cycle 1) was made available. A second cycle RBMP was published in 2015 with updated classification information. The third cycle RBMP is due for publication in 2021.

At the original publication date of this report we had only recently moved from one classification scheme to another, so this section includes a discussion of both the GQA and WFD schemes, focusing on the physico-chemical elements.

GQA Assessment Points

The GQA scheme used 23 discrete GQA riverine assessment reaches for the River Severn from the headwaters in the Welsh Hills at Cwm Ricket to near

the tidal limit at Llanthony Weir in Gloucester. A single monitoring point was used to classify each GQA reach.

Table 1 GQA assessment reaches

GQA Reach No.	Reach name	Monitoring point name	Monitoring site number	Grid reference		Length (km)
				From	To	
1	Cwm Ricket Ford to conf A Clywedog	Llanidloes Felindr	00074380	SN 8619 8670	SN 9541 8477	12
2	Conf A Clywedog to conf A Cerist	Dolwen	00072250	SN 9541 8477	SO 0250 9149	15
3	Conf A Cerist to Conf Mochdre Bk	Caersws	00070450	SO 0250 9149	SO 0865 9080	12
4	Conf Mochdre Bk to Newtown STW	Fbr Back Lane	00067800	SO 0865 9080	SO 1397 9275	7.4
5	Newtown STW to conf The Mule	Aberbechan	00065870	SO 1397 9275	SO 1594 9480	3.5
6	Conf The Mule to Welshpool STW	Caerhowel	00064480	SO 1594 9480	SJ 2352 0726	20
7	Welshpool STW to conf A Vyrnwy	Llandrinio	00060200	SJ 2352 0726	SJ 3280 1586	25
8	Conf A Vyrnwy to conf R Perry	Montford Br	00056710	SJ 3280 1586	SJ 4402 1863	19
9	Conf R Perry to Monkmoor STW outfall	Shelton intake	00055140	SJ 4402 1863	SJ 5210 1328	25
10	Monkmoor STW outfall to R Tern conf	Atcham	00052182	SJ 5210 1328	SJ 5532 0915	10
11	Conf R Tern to conf Much Wenlock Bk	Cressage	00049650	SJ 553 091	SJ 641 044	14
12	Conf Much Wenlock Bk to Coalport STW	Coalport	00045702	SJ 641 044	SJ 710 013	12
13	Coalport STW to conf R Worfe	Apley Forge	00044720	SJ 710 013	SO 724 952	6
14	Conf R Worfe to conf R Stour	Bewdley	00038360	SO 724 952	SO 812 707	30
15	Conf R Stour to conf R Salwarpe	Holt Fleet	00034302	SO 812 707	SO 841 601	22
16	Conf R Salwarpe to Worcester STW	Worcester Bridge	00030850	SO 841 601	SO 847 532	3.8
17	Worcester STW to conf R Teme	Depot Bath Road	00030090	SO 847 532	SO 850 521	1.3
18	Conf R Teme to Hatfield Bk	Kempsey	00029500	SO 850 521	SO 846 489	3.4
19	Hatfield Bk to Ripple supply intake	Upton on Severn	00027540	SO 846 489	SO 865 399	13
20	Ripple supply intake to conf R Avon	Tewkesbury	00026230	SO 865 399	SO 888 331	8.5
21	Conf R Avon to conf River Chelt	Hawbridge	00025085	SO 888 331	SO 848 262	10
22	Conf R Chelt to Ashleworth	Ashleworth	00024062	SO 848 262	SO 819 250	3.5
23	Ashleworth to Llanthony Weir	Llanthony Bridge	00021202	SO 819 250	SO 823 182	8.2

WFD water bodies & assessment points

There are 11 WFD river water bodies covering the River Severn from source to the tidal limit, these are listed in Table 2. Unlike the GQA scheme, where only one monitoring point per stretch was used for assessment purposes, WFD water bodies can use multiple monitoring points in the waterbody. Data are used from each monitoring point to calculate a classification for the whole waterbody by taking the median (the middle value) of all the monitoring point classifications within the waterbody. This is representative of typical conditions for the waterbody, not the best or the worst.

WFD water bodies do however incorporate the monitoring points previously used for GQA. WFD water bodies and the monitoring points were reviewed for the second cycle 2015 RBMP. Table 3 compares the WFD (cycle 1 and 2) and GQA monitoring points.

Table 2. River Severn: River Water Bodies

Waterbody ID	Waterbody Name	Length (kms)
GB109054044790	R Severn - source to conf Afon Dulas	16.33
GB109054049310	R Severn - conf Afon Dulas to conf R Camlad	51.01
GB109054049700	R Severn - conf R Camlad to conf Bele Bk	27.17
GB109054049142	R Severn - conf Bele Bk to conf Sundorne Bk	53.9
GB109054049141	R Severn - Sundorne Bk to conf M Wenlock-Farley Bk	31.53
GB109054049143	R Severn conf M Wenlock-Farley Bk to conf R Worfe	15.92
GB109054049145	R Severn - conf R Worfe to conf R Stour	33.48
GB109054049144	R Severn - conf R Stour to conf River Teme	30.25
GB109054039760	R Severn - conf R Teme to conf R Avon	29.5
GB109054044404	R Severn - conf R Avon to conf Upper Parting	27.57
GB109054032750	R Severn (E Channel) - Horsbere Bk to Severn Est	4.56

Table 3. Comparison of GQA and WFD Monitoring Points

WFD Monitoring Points						
Waterbody ID	Cycle 1 Monitoring Site	Cycle 2 Monitoring Point (In stated Waterbody)	Site Name	Easting	Northing	GQA point
GB109054044790	00074380	Yes	R.Severn Llanidloes Felindre Bridge	294400	283901	Yes
GB109054049310	00072250	Yes	R.Severn Dolwen	299700	285200	Yes
GB109054049310	00070450	NO	R.Severn At Caersws	303200	291700	Yes
GB109054049310	00067800	Yes	R.Severn Foot Bridge Back Ln Cp	310520	291640	Yes
GB109054049310	00065870	NO	R.Severn Cil Gwrgan Bridge Aberbechan	314368	293368	Yes
GB109054049310	00064480	Yes	R.Severn At Caerhowel Bridge	319670	298150	Yes
GB109054049700	00061340	Yes	R.Severn Maginnis Bridge	325890	311510	No
GB109054049142	29949160	NO	Leaton Brook At Leaton	347300	318000	Yes*
GB109054049142	29266040	NO	Rea Brook At Coleham	349700	312262	Yes*
GB109054049142	00060200	NO	R.Severn At Llandrinio	329843	316977	Yes
GB109054049142	00056710	NO	R.Severn Montford Bridge	343200	315300	Yes
GB109054049142	00055460	Yes	R.Severn Isle Of Bicton	346800	316400	No
GB109054049142	00055140	NO	R.Severn Shelton Intake	346432	313458	Yes
GB109054049141	25877190	NO	Devil's Dingle Bk - Footbrdg To Bk Ctge	363700	304700	No
GB109054049141	00052182	Yes	R.Severn Atcham	354000	309300	Yes
GB109054049141	00049650	Yes	R.Severn At Cressage	359380	304550	Yes
GB109054049143	00045702	Yes	R.Severn At Coalport	370200	302100	Yes
GB109054049143	00044720	Yes	R.Severn At Apley Forge	370674	298325	Yes
GB109054049145	24239020	NO	Borle Brook Conf With R.Severn	375300	281600	Yes*
GB109054049145	00041180	Yes	R.Severn Hampton Loade Bridge	374600	287050	No
GB109054049145	00038360	Yes	R.Severn At Bewdley	378750	275450	Yes
GB109054049144	22147580	NO	Barbourne Brook B4550 Bridge Blackpole	386850	257850	Yes*
GB109054049144	22146950	NO	Barbourne Brook At Perdiswell Park	385500	257690	Yes*
GB109054049144	22146620	NO	Barbourne Brook At Bilford Road Worcs	385450	257150	Yes*
GB109054049144	22145580	NO	Barbourne Brook At A449 Bridge Gheluvet	384470	256480	Yes*
GB109054049144	00034302	Yes	Holt Fleet Meadows Holt Fleet	382330	263400	Yes
GB109054049144	00030850	Yes	R Severn Worcester Bridge	384650	254750	Yes
GB109054049144	00030090	Yes	R.Severn Rear Oil Depot Bath Rd Worcs	385100	252320	Yes

GB109054039760	00029500	NO	R Severn (Upper) Kempsey (Mid)	384690	249280	Yes
GB109054039760	00028400	NO	R Severn (Upper) Severn Stoke	384860	244490	No
GB109054039760	00027540	Yes	R Severn - Upton On Severn	385160	240750	Yes
GB109054039760	00026230	Yes	R Severn (Upper) Tewkesbury	388870	233720	Yes
GB109054039760	06147180	NO	Norton Brook Ds Morganite Crucible	389420	251020	No
GB109054039760	13397040	NO	Hatfield Brook Kempsey	384910	249030	Yes*
GB109054044404	00025312	NO	R Severn (Lower) Chaceley Stock	386550	229740	No
GB109054044404	00025085	Yes	R Severn (Lower) Haw Bridge	384550	227850	Yes
GB109054044404	00024062	Yes	R Severn (Lower) Ashleworth	381900	225060	Yes
GB109054044404	00017500	Yes	R Severn (Lower) Maisemore Weir	381800	221700	No
GB109054032750	00021202	Yes	R Severn (Lower) Severn Rd Foot Bridge	382330	218240	Yes

*these monitoring sites are on a tributary of the River Severn.

GQA Chemistry and Nutrients (Riverine)

An overview of the historical GQA for chemistry and nutrients, and compliance with the River Ecosystem Classification (REC) is provided in the following sections. GQA and REC methodologies are summarised in Appendix H.

Chemistry and nutrient GQA summary data for the periods 1996 (chemistry only), 2000, 2003 and 2006 are summarised in Table 4. REC compliance for 2006 is also given.

In 2007, during the build up towards WFD reporting, the GQA scheme underwent change and fewer statistics were produced. The main changes to the scheme were a reduction in monitoring (fewer sites monitored in England) and the removal of Biochemical Oxygen Demand (BOD) monitoring at most sites in England from the beginning of 2008.

GQA monitoring from 2007 onwards is provided in Table 5. Due to the removal of BOD from the assessment, Table 4 and Table 5 cannot be directly compared. Therefore GQA results prior to 2007 have been recalculated with the BOD removed and these are provided in Table 6 along with data post 2007 to allow for direct comparison. The removal of BOD from the assessment can elevate the GQA grade of a stretch if the BOD was previously the poorest element within the assessment.

Overview of Physico-Chemical Quality (Riverine)

From the rural landscape of Wales with flow from clean mountain sources such as the River Vyrnwy and inputs from abandoned mining areas, to the more urbanised impacts of the River Stour which receives effluent from the textile industry of Kidderminster, the river experiences many different impacts on water quality. Despite this, the Severn qualified as a clean river, recording GQA grades of A and B down to Ashleworth, then dropping to C from Ashleworth to Gloucester (GQA 2009). The river is also a Salmonid designated fishery under the Freshwater Fish Directive from its source to the confluence with the River Vyrnwy and supports Cyprinid fish populations throughout the remainder of its course.

GQA 1996 -2006

Chemistry

All but one of the reaches achieved compliance with the designated REC River Quality Objective (RQO) in 2006. The non-complaint stretch, Newtown STW to confluence of The Mule was only marginally above the target. In terms of GQA chemical quality, the upper reaches of the River Severn down to Newtown STW recorded mainly grade A, very good quality. A slight decline to good was observed in reach 5 in 2006, downstream of Newton STW, however, quality improved again to very good downstream of Welshpool. The impact of Shrewsbury Monkmoor STW and the Perry and Tern tributaries being evident as GQA grades drop downstream, from very good to good/fairly good for all years. 2006 grades show an improvement from B to A for reaches 13 to 18, Coalport to Kempsey. The final 5 stretches from the Hatfield Brook to Llanthony Weir are on the whole good quality for all years.

Nutrients

Phosphate (P) and nitrate (N) both showed the same trend with concentrations increasing with distance downstream.

Levels of nitrates are very low/low in the upper Severn reaches increasing to moderately low in the middle stretches and declining again to moderate downstream of the confluence with the River Worfe and generally remaining at this level down to Llanthony weir.

Phosphates also are very low/low in the upper Severn reaches, with a slight improvement over time observed. Levels increase downstream of Monkmoor; however they improved over time from very high to high. Another step increase was observed downstream of Coalport where levels stayed consistently at very high down to Llanthony weir.

GQA 2007 – 2009

Chemistry (removal of BOD element from the GQA assessment)

With the removal of BOD from the classification scheme in 2007, the River Severn was reported as being very good quality from source down to the confluence with the River Avon where it drops to good class B. Deterioration to fairly good was seen from Ashleworth to Llanthony Weir.

Nutrients

Phosphate (P) and nitrate (N) showed the same trend as in previous years, with concentrations increasing with distance downstream. No obvious trend is observed in the nitrate grades for each reach, however when comparing grades from 1995 to 2009, levels of phosphates decreased for some stretches. Phosphates improved from low to very low for stretches 2 and 4, and GQA grades improved downstream of the Perry confluence, Monkmoor STW and Coalport, due in part to improvements in nutrient discharges in a number of STWs.

Table 4. Chemistry and Nutrient GQA, and RE compliance for the River Severn

GQA Reach No.	Reach name	RQO compliance (2006)	Chemistry				Nutrients					
			1996	2000	2003	2006	P 2000	P 2003	P 2006	N 2000	N 2003	N 2006
1	Cwm Ricket Ford to conf A Clywedog	RE1 Compliant	A	A	A	A	1	2	1	1	1	1
2	Conf A Clywedog to conf A Cerist	RE1 Compliant	A	A	A	A	2	2	2	1	1	2
3	Conf A Cerist to Conf Mochdre Bk	RE1 Compliant	A	A	A	A	2	2	2	2	1	2
4	Conf Mochdre Bk to Newtown STW	RE1 Compliant	A	A	A	A	2	2	2	2	1	2
5	Newtown STW to conf The Mule	RE1 Marginal	B	A	A	B	3	3	2	2	2	2
6	Conf The Mule to Welshpool STW	RE1 Compliant	A	A	A	B	3	3	2	2	2	2
7	Welshpool STW to conf A Vyrnwy	RE1 Compliant	A	A	A	A	3	3	3	3	2	2
8	Conf A Vyrnwy to conf R Perry	RE1 Compliant	B	A	A	A	3	3	3	3	2	2
9	Conf R Perry to Monkmoor STW outfall	RE2 Compliant	B	A	A	A	4	3	3	3	2	3
10	Monkmoor STW outfall to conf R Tern	RE2 Compliant	B	B	C	B	4	4	4	3	3	3
11	Conf R Tern to Much Wenlock Bk	RE2 Compliant	C	B	B	B	5	5	4	4	3	3
12	Conf Much Wenlock Bk to Coalport STW	RE2 Compliant	B	B	B	B	5	5	4	3	3	3
13	Coalport STW to conf R Worfe	RE2 Compliant	B	B	B	A	5	5	5	3	3	3
14	Conf R Worfe to R Stour	RE2 Compliant	B	B	B	A	5	5	5	4	3	4
15	Conf R Stour to conf R Salwarpe	RE2 Compliant	B	B	B	A	5	5	5	4	4	4
16	Conf R Salwarpe to Worcester STW	RE2 Compliant	B	B	B	A	5	5	5	4	4	4
17	Worcester STW to conf R Teme	RE2 Compliant	B	B	B	A	5	5	5	4	4	4
18	Conf R Teme to conf Hatfield Bk	RE2 Compliant	B	B	B	A	5	5	5	4	4	4
19	Hatfield Bk to Ripple supply intake	RE2 Compliant	B	B	B	B	5	5	5	4	4	4
20	Ripple supply intake to conf R Avon	RE2 Compliant	B	B	B	B	5	5	5	4	4	4
21	Conf R Avon to conf R Chelt	RE2 Compliant	B	B	B	B	5	5	5	4	4	4
22	River Chelt confluence to Ashleworth	RE2 Compliant	B	B	B	B	5	5	5	4	4	5
23	Ashleworth to Llanthony weir	RE2 Compliant	B	C	B	B	5	5	5	4	4	4

Table 5. Chemistry and Nutrient GQA, and RE compliance for the River Severn 2007-2009 (modified GQA scheme)

GQA Reach No.	Reach name	Chemistry			Nutrients					
		2007	2008	2009	P 2007	P 2008	P 2009	N 2007	N 2008	N 2009
1	Cwm Ricket Ford to conf A Clywedog	A	A	A	1	1	1	1	1	1
2	Conf A Clywedog to conf A Cerist	A	A	A	1	1	1	2	1	1
3	Conf A Cerist to Conf Mochdre Bk	A	A	A	2	2	2	2	2	1
4	Conf Mochdre Bk to Newtown STW	A	A	A	1	1	1	2	2	1
5	Newtown STW to conf The Mule	A	A	A	2	2	2	2	2	2
6	Conf The Mule to Welshpool STW	A	A	A	2	2	2	2	2	2
7	Welshpool STW to conf A Vyrnwy	A	A	A	3	3	3	2	2	2
8	Conf A Vyrnwy to conf R Perry	A	A	A	2	2	2	2	2	2
9	River Perry Confluence to Monkmoor STW outfall	A	A	A	2	2	2	3	3	2
10	Monkmoor STW outfall to River Tern confluence	A	A	A	3	3	3	3	3	3
11	River Tern confluence to Much Wenlock Bridge	A	A	A	4	4	4	3	3	3
12	Much Wenlock Bridge to Coalport STW	A	A	A	4	4	4	3	3	3
13	Coalport STW to River Worfe Confluence	A	A	A	4	4	4	3	3	3
14	River Worfe confluence to River Stour confluence	A	A	A	4	4	4	3	3	3
15	River Stour confluence to River Salwarpe confluence	A	A	A	5	5	5	4	4	4
16	River Salwarpe confluence to Worcester STW	A	A	A	5	5	5	4	4	4
17	Worcester STW to River Teme confluence	A	A	A	5	5	5	4	4	4
18	River Teme confluence to Hatfield Brook confluence	A	A	A	5	5	5	4	4	4
19	Hatfield Brook confluence to Ripple supply intake	A	A	A	5	5	5	4	4	4
20	Ripple supply intake to River Avon confluence	B	B	B	5	5	5	4	4	4
21	River Avon confluence to River Chelt confluence	B	B	B	5	5	5	4	4	4
22	River Chelt confluence to Ashleworth	B	B	B	5	5	5	4	4	4
23	Ashleworth to Llanthony weir	C	C	C	5	5	5	4	4	4

Table 6. Chemical GQA Grades (1996-2006 recalculated)

GQA Reach No.	Reach name	Chemistry													
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	Cwm Ricket Ford to conf A Clywedog	A	A	A	A	A	A	A	A	A	A	A	A	A	A
2	Conf A Clywedog to conf A Cerist	A	A	A	A	A	A	A	A	A	A	A	A	A	A
3	Conf A Cerist to Conf Mochdre Bk	A	A	A	A	A	A	A	A	A	A	A	A	A	A
4	Conf Mochdre Bk to Newtown STW	A	A	A	A	A	A	A	A	A	A	A	A	A	A
5	Newtown STW to conf The Mule	A	A	A	A	A	A	A	A	A	A	A	A	A	A
6	Conf The Mule to Welshpool STW	A	A	A	A	A	A	A	A	A	A	A	A	A	A
7	Welshpool STW to conf A Vyrnwy	A	A	A	A	A	A	A	A	A	A	A	A	A	A
8	Conf A Vyrnwy to conf R Perry	A	A	A	A	A	A	A	A	A	A	A	A	A	A
9	Conf R Perry to Monkmoor STW outfall	B	A	A	A	A	A	A	A	A	A	A	A	A	A
10	Monkmoor STW outfall to conf R Tern	B	A	A	A	A	A	B	A	B	B	B	A	A	A
11	Conf R Tern to Much Wenlock Bk	B	B	A	A	A	A	A	A	B	B	B	A	A	A
12	Conf Much Wenlock Bk to Coalport STW	A	A	A	A	A	A	A	A	B	A	B	A	A	A
13	Coalport STW to conf R Worfe	B	B	A	A	A	A	A	A	B	A	A	A	A	A
14	Conf R Worfe to R Stour	B	A	B	B	B	A	A	B	B	B	A	A	A	A
15	Conf R Stour to conf R Salwarpe	A	A	A	A	A	A	A	A	A	A	A	A	A	A
16	Conf R Salwarpe to Worcester STW	A	B	B	B	B	A	A	C	A	A	A	A	A	A
17	Worcester STW to conf R Teme	B	B	B	B	A	A	A	B	A	A	A	A	A	A
18	Conf R Teme to conf Hatfield Bk	A	B	B	B	A	A	A	B	A	A	A	A	A	A
19	Hatfield Bk to Ripple supply intake	A	B	B	B	B	A	A	B	B	B	B	A	A	A
20	Ripple supply intake to conf R Avon	B	B	B	B	B	B	B	B	B	B	B	B	B	B
21	Conf R Avon to conf R Chelt	B	B	B	A	A	A	B	B	B	B	A	B	B	B
22	River Chelt confluence to Ashleworth	B	B	B	B	A	A	B	B	B	B	A	B	B	B
23	Ashleworth to Llanthony weir	B	C	B	B	A	A	A	A	B	B	A	C	C	C

Water Framework Directive (WFD)

The environmental objectives of the WFD relevant to surface waters are:

- to prevent deterioration of the status of surface waters
- to achieve objectives and standards for protected areas
- to aim to achieve good status for all water bodies or, for heavily modified water bodies and artificial water bodies, good ecological potential and good surface water chemical status
- the cessation of discharges, emissions and losses of priority hazardous substances into surface waters

The Directive sets a target of aiming to achieve at least 'good status/potential' in all waters. For surface waters there are two separate classifications for water bodies; ecological and chemical. For a surface waterbody to be overall 'good', both ecological and chemical status must be at least 'good'. Ecological status is recorded on a scale high, good, moderate, poor and bad; chemical status is recorded as good or fail.

Some surface water bodies are designated as 'artificial' or 'heavily modified' because they have been created or modified for a particular use such as water supply, flood protection, navigation or urban infrastructure. By definition, artificial and heavily modified water bodies are not able to achieve natural conditions. Instead the classification and objectives for these water bodies, and the biology they represent, are measured against 'ecological potential' rather than status. Whilst good ecological status is defined as a slight variation from undisturbed natural conditions in natural water bodies, artificial and heavily modified water bodies are unable to achieve natural conditions. Instead, artificial and heavily modified water bodies have a target to achieve good ecological potential, which recognises their important uses, whilst making sure ecology is protected as far as possible. Ecological potential is also measured on the scale high, good, moderate, poor and bad. The chemical status of these water bodies is measured in the same way as for natural water bodies.

Waterbody status classifications are based on a set of building blocks. These building blocks are:

- the waterbody and monitoring networks
- the designation of artificial and heavily modified water bodies
- the standards and boundaries used in assessment
- the tools used to derive classification results for individual elements from monitoring data

A number of significant changes to the original building blocks used in the 2009 River Basin Management Plans were introduced for the second cycle of river basin management planning. These were:

- Updated standards were used to determine good status for nutrients and some chemical substances.
- New chemical standards were introduced as a result of the 2013 Environment Quality Standards Directive (EQSD) amendments.
- A second generation of biological classification tools to ensure biological classification were better at reflecting local conditions.

- The size and shape of some water bodies changed so that they became more logical management units (a number of very small streams had been removed that were less than 1km in length or with a catchment of less than 10 km²). These water bodies still remained protected by law from pollution, modification and abstraction and could be improved where local actions and assessments deem it to be a priority.
- The process to designate heavily modified waterbodies improved.

These changes will make a difference to the number of water bodies reported as being in high, good, moderate, poor and bad ecological status. All of these changes were introduced so that the second cycle plans were based on the best possible evidence.

Since the publication of the second cycle River Basin Management Plans, river basin planning has continued to evolve. The third cycle plans, updated in 2022, retain the core objectives of the Water Framework Directive while placing greater emphasis on addressing the significant pressures affecting the water environment and delivering coordinated action through catchment-based approaches.

The principal developments since the second cycle include:

- Updated classifications and monitoring data have been used to provide a more current assessment of the condition of surface waters and groundwater.
- Greater focus has been placed on tackling the main reasons water bodies fail to achieve good status, including pollution from wastewater, agriculture, urban runoff, physical modifications to watercourses and the impacts of climate change.
- River basin planning is now more closely aligned with wider environmental policy, including the Environment Act, the Environmental Improvement Plan and national programmes for improving water quality, biodiversity and climate resilience.
- Catchment-based partnerships have become increasingly important in identifying and delivering local improvements, bringing together regulators, water companies, local authorities, land managers, businesses and communities.
- The third cycle plans place greater emphasis on identifying the investment and actions required to achieve long-term environmental objectives and to prevent deterioration of the water environment.

These developments ensure that the third cycle plans are based on the latest available evidence and provide an updated framework for protecting and improving the water environment while supporting sustainable economic growth and resilience to future environmental pressures.

A summary of compliance with good ecological status/potential and good chemical status is given in Table 7. The Cycle 2 2015 results reflect the changes outlined above.

Table 7. Compliance with WFD Objectives

Waterbody ID	Waterbody Name	Cycle 2 2015		Cycle 3 2019 (EA) / 2021 (NRW)		Cycle 3 – 2024 (NRW) Cycle 4 – 2025 (EA)	
		Overall Status / Potential		Overall Status / Potential		Overall Status / Potential	
		Ecological Status / Potential	Chemical Status	Ecological Status / Potential	Chemical Status	Ecological Status / Potential	Chemical Status
GB109054049880		Moderate (Potential)		Moderate (Potential)		Moderate (Potential)	

	Vrynwy - Lake Vrynwy to conf Afon Cownwy	Moderate (Potential)	Good	Moderate (Potential)	High	Moderate (Potential)	High
GB109054049720	Afon Vrynwy – conf Afon Cownwy to conf Afon Banwy	Moderate (Potential)		Good (Potential)		Moderate (Potential)	
		Moderate (Potential)	Good	Good (Potential)	High	Moderate (Potential)	High
GB109054049851	Afon Banwy	Poor (Status)		Poor (Status)		Good (Status)	
		Poor (Status)	Fail	Poor (Status)	High	Good (Status)	High
GB109054049852	Afon Vrynwy DS of Banwy confluence	Moderate (Status)		Good (Status)		Good (Status)	
		Moderate (Status)	Fail	Good (Status)	High	Good (Status)	High
GB109054049800	Afon Vrynwy – conf Afon Tanat to conf R Severn	Moderate (Potential)		Moderate (Potential)		Moderate (Potential)	
		Moderate (Potential)	Fail	Moderate (Potential)	High	Moderate (Potential)	High
GB109054044760	Afon Clywedog – Clywedog Dam to R Severn	Moderate (Potential)		Moderate (Potential)		Moderate (Potential)	
		Moderate (Potential)	Good	Moderate (Potential)	High	Moderate (Potential)	High
GB109054044790	Severn – source to conf Afon Dulas	Good (Status)		Poor (Status)		Moderate (Status)	
		Good (Status)	Good	Poor (Status)	High	Moderate (Status)	High
GB109054049310	Severn – conf Afon Dulas to conf R Camlad	Moderate (Potential)		Moderate (Potential)		Moderate (Potential)	
		Moderate (Potential)	Fail	Moderate (Potential)	High	Moderate (Potential)	High
GB109054049700	Severn – conf R Camlad to conf Bele Bk	Moderate (Potential)		Moderate (Potential)		Moderate (Potential)	
		Moderate (Potential)	Good	Moderate (Potential)	High	Moderate (Potential)	High
GB109054049142	Severn – conf Bele Bk to conf Sundorne Bk	Moderate (Status)		Moderate (Status)		Moderate (Status)	
		Moderate (Status)	Good	Moderate (Status)	Fail	Moderate (Status)	Fail
GB109054049141	Severn – Sundorne Bk to conf M Wenlock-Farley Bk	Moderate (Status)		Moderate (Status)		Moderate (Status)	
		Moderate (Status)	Good	Moderate (Status)	Fail	Moderate (Status)	Fail
GB109054049143	Severn conf M Wenlock-Farley Bk to conf R Worfe	Moderate (Status)		Moderate (Status)		Moderate (Status)	
		Moderate (Status)	Good	Moderate (Status)	Fail	Moderate (Status)	Fail
GB109054049145	Severn – conf R Worfe to conf R Stour	Poor (Status)		Poor (Status)		Moderate (Status)	
		Poor (Status)	Good	Poor (Status)	Fail	Moderate (Status)	Fail
GB109054049144	Severn – conf R Stour to conf River Teme	Moderate (Potential)		Moderate (Potential)		Moderate (Potential)	
		Moderate (Potential)	Good	Moderate (Potential)	Fail	Moderate (Potential)	Fail
GB109054039760	Severn – conf R Teme to conf R Avon	Moderate (Potential)		Moderate (Potential)		Poor (Potential)	
		Moderate (Potential)	Good	Moderate (Potential)	Fail	Poor (Potential)	Fail
GB109054044404	Severn – conf R Avon to conf Upper Parting	Moderate (Potential)		Moderate (Potential)		Moderate (Potential)	
		Moderate (Potential)	Good	Moderate (Potential)	Fail	Moderate (Potential)	Fail
GB109054032750	Severn (E Channel) – Horsebere Bk to Severn Est	Moderate (Potential)		Moderate (Potential)		Moderate (Potential)	
		Moderate (Potential)	Good	Moderate (Potential)	Fail	Moderate (Potential)	Fail

In the WFD classification scheme, physico-chemical elements are supporting elements. Only biological elements are recorded on the full scale, high to bad. Physico-chemical elements are not reported below moderate status. Table 8 gives the actual status of the physico-chemical elements for each River Severn waterbody. The status of each element will be in most cases calculated from a number of sample points within the waterbody.

It should be noted that where the term phosphate (P) is used, the parameter measured in rivers and the WFD targets are set for Orthophosphate (reactive as P), however for simplicity we use the term phosphate in this report. Similarly, Nitrogen, Total Oxidised as N (TON) may be more generically discussed as nitrate.

Table 8. WFD Waterbody Physico-Chemical Element Status

Water Body ID	Water Body Name	Cycle 3 – 2019 (EA) / 2021 (NRW)		Cycle 3 – 2024 interim (NRW) / Cycle 4 – 2025 (EA)	
		Ecological Status / Potential	Physico-Chemical Element Status	Ecological Status / Potential	Physico-Chemical Element Status
GB109054049880	Vrynwy - Lake Vrynwy to conf Afon Cownwy	Moderate (Potential)	Ammonia – Good DO – High pH – High Phosphate – Good Temp – High	Moderate (Potential)	Ammonia – Good DO – High pH – High Phosphate – Good Temp – High
GB109054049720	Afon Vrynwy – conf Afon Cownwy to conf Afon Banwy	Good (Potential)	Ammonia – Good DO – High pH – High Phosphate – Good Temp – High	Moderate (Potential)	Ammonia – Good DO – High pH – High Phosphate – Good Temp – High
GB109054049851	Afon Banwy	Poor (Status)	Ammonia – Good DO – High pH – High Phosphate – Good Temp – High	Good (Status)	Ammonia – Good DO – High pH – High Phosphate – Good Temp – High
GB109054049852	Afon Vrynwy DS of Banwy confluence	Good (Status)	Ammonia – Good DO – High pH – High Phosphate – Good Temp – Good	Good (Status)	Ammonia – Good DO – Not assessed pH – High Phosphate – Good Temp – Good
GB109054049800	Afon Vrynwy – conf Afon Tanat to conf R Severn	Moderate (Potential)	Ammonia – High DO – High pH – High Phosphate – not assessed Temp – Good	Moderate (Potential)	Ammonia – High DO – High pH – High Phosphate – Moderate Temp – Good
GB109054044760	Afon Clywedog – Clywedog Dam to R Severn	Poor (Potential)	Ammonia – High DO – High pH – High Phosphate – Good Temp – High	Moderate (Potential)	Ammonia – High DO – High pH – High Phosphate – High Temp – High
GB109054044790	Severn – source to conf Afon Dulas	Good (Status)	Ammonia – High DO – High pH – High Phosphate – Good Temp – High	Moderate (Status)	Ammonia – High DO – High pH – High Phosphate – High Temp – High
GB109054049310	Severn – conf Afon Dulas to conf R Camlad	Moderate (Potential)	Ammonia – High DO – High pH – High Phosphate – Good	Moderate (Potential)	Ammonia – High DO – High pH – High Phosphate – Good

			Temp – High		Temp – Good
GB109054049700	Severn – conf R Camlad to conf Bele Bk	Moderate (Potential)	Ammonia – Not Assessed DO – Not Assessed pH – Not Assessed Phosphate – Not Assessed Temp – Not Assessed	Moderate (Potential)	Ammonia – High DO – High pH – High Phosphate – Good Temp – Good
GB109054049142	Severn – conf Bele Bk to conf Sundorne Bk	Moderate (Status)	Ammonia - High DO - High pH - High Phosphate - Moderate Temp - Good	Moderate (Status)	Ammonia - High DO - High pH - High Phosphate - Moderate Temp - Good
GB109054049141	Severn – Sundorne Bk to conf M Wenlock-Farley Bk	Moderate (Status)	Ammonia - High DO - High pH - High Phosphate - Poor Temp - Good	Moderate (Status)	Ammonia - High DO - High pH - High Phosphate - Moderate Temp - Good
GB109054049143	Severn conf M Wenlock-Farley Bk to conf R Worfe	Moderate (Status)	Ammonia - High DO - High pH - High Phosphate - Poor Temp - Good	Moderate (Status)	Ammonia - High DO - High pH - High Phosphate - Moderate Temp - Good
GB109054049145	Severn – conf R Worfe to conf R Stour	Poor (Status)	Ammonia - High DO -High pH - High Phosphate - Moderate Temp - Good	Moderate (Status)	Ammonia – Not assessed DO – Not assessed pH – Not assessed Phosphate – Not assessed Temp – Not assessed
GB109054049144	Severn – conf R Stour to conf River Teme	Moderate (Potential)	Ammonia - High DO - High pH - High Phosphate - Moderate Temp - Moderate	Moderate (Potential)	Ammonia - High DO - High pH - High Phosphate - Moderate Temp - Good
GB109054039760	Severn – conf R Teme to conf R Avon	Moderate (Potential)	Ammonia - High DO - Good pH - High Phosphate - Poor Temp - High	Poor (Potential)	Ammonia - High DO - High pH - High Phosphate - Moderate Temp - Good
GB109054044404	Severn – conf R Avon to conf Upper Parting	Moderate (Potential)	Ammonia - High DO - High pH- High Phosphate - Moderate Temp - High	Moderate (Potential)	Ammonia - High DO - High pH - High Phosphate - Moderate Temp - Good
GB109054032750	Severn (E Channel) – Horsebere Bk to Severn Est	Moderate (Potential)	Ammonia - High DO - High pH - High Phosphate - Moderate Temp - High	Moderate (Potential)	Ammonia - High DO - High pH - High Phosphate - Moderate Temp - Moderate

The phosphate and ammonia status of the individual WFD monitoring points on the main River Severn for each waterbody are provided in Tables 9 and 10.

Table 9. Phosphate Monitoring Point Status

Waterbody ID	Site	Site Name	Cycle 2 2015 (NRW) 2019 (EA) – classification (Data start year 2012 Data End year 2014)				Cycle 3 interim 2024 (NRW) 2025 (EA)– classification (Data start year 2020 Data End year 2023)			
			Phosphate Status	Mean (mg/l)	Std Dev	C2 EQS Limit for Good (mean)	Phosphate Status	Mean (mg/l)	Std Dev	C3 EQS Limit for Good (mean)
GB109054044790	00074380	R.Severn Llanidloes Felindre Bridge	Good	0.0156	0.021	0.028	High	0.0044	0.004	0.028
GB109054049310	00072250	R.Severn Dolwen	Good	0.0133	0.007	0.028				
GB109054049310	00067800	R.Severn Foot Bridge Back Ln Cp	Good	0.0158	0.019	0.03	High	0.0108	0.006	0.030
GB109054049310	00064480	R.Severn At Caerhowel Bridge	Good	0.0353	0.021	0.038	Good	0.0321	0.008	0.038
GB109054049700	00061340	R.Severn Maginnis Bridge					Good	0.0421	0.014	0.048
GB109054049142	00056710	R.Severn Montford Bridge								
GB109054049142	00055460	R.Severn Isle Of Bicton	Moderate	0.101	0.078	0.052	Moderate	0.0858	0.0479	0.052
GB109054049142	00055140	R.Severn Shelton Intake								
GB109054049141	00052182	R.Severn Atcham	Moderate Poor	0.220	0.129	0.054	(2022) Moderate	0.138	0.069	0.054
GB109054049141	00049650	R.Severn At Cressage	Poor	0.1667	0.994	0.061	Moderate	0.1125	0.386	0.061
GB109054049143	00045702	R.Severn At Coalport	Moderate	0.153	0.085	0.062	(2022) Bad	1.118	4.874	0.062
GB109054049143	00044720	R.Severn At Apley Forge	Poor	0.233	0.100	0.064	Moderate	0.134	0.059	0.064
GB109054049145	00041180	R.Severn Hampton Loade Bridge								
GB109054049145	00038360	R.Severn At Bewdley	Moderate	0.139	0.0707	0.068	(2022) Moderate	0.118	0.044	0.068
GB109054049144	00034302	River Severn Holt Fleet Meadows Holt Fleet	Moderate	0.148	0.052	0.071	(2022) Moderate	0.132	0.040	0.071
GB109054049144	00030850	R Severn Worcester Bridge	Moderate	0.1662	0.075	0.072				0.072

GB109054049 144	000300 90	R.Severn Rear Of Oil Depot Bath Rd Worcs									
GB109054039 760	000295 00	R Severn (Upper) Kempsey (Mid)									
GB109054039 760	000284 00	R Severn (Upper) Severn Stoke (New Spt)									
GB109054039 760	000275 40	R Severn - Upton On Severn	Poor	0.200	0.086	0.075	Moderate	0.178	0.083	0.075	
GB109054039 760	000262 30	R Severn (Upper) Tewkesbury	Moderate	0.176	0.079	0.076	Moderate	0.157	0.090	0.076	
GB109054044 404	000253 12	R Severn (Lower) Chaceley Stock									
GB109054044 404	000250 85	R Severn (Lower) Haw Bridge	Poor	0.211	0.086	0.079	Moderate	0.183	0.086	0.079	
GB109054044 404	000240 62	R Severn (Lower) Ashleworth	Moderate	0.190	0.078	0.079	Poor	0.194	0.073	0.079	
GB109054044 404	000175 00	R Severn (Lower) Maisemore Weir	Moderate	0.153	0.064	0.077	Not Classified	Not Classified	Not Classified	0.077	

Table 10. Ammonia Monitoring Point Status

Waterbody ID	Site	Site Name	Cycle 2 2015 – classification (Data start year 2012 Data End year 2014)					Cycle 3 interim 2024 – classification (Data start year 2020 Data End year 2023)				
			Ammonia Status	Mean	Std Dev	90 %ile	C2 EQS Limit for Good (90 %ile)	Ammonia Status	Mean	Std Dev	90 %ile	C3 EQS Limit for Good (90 %ile)
GB109054044790	00074380	R.Severn Llanidloes Felindre Bridge	High	0.0176	0.011	0.0309	0.3	High	0.0144	0.018	0.0285	0.3
GB109054049310	00072250	R.Severn Dolwen	High	0.0160	0.005	0.0229	0.3					
GB109054049310	00067800	R.Severn Foot Bridge Back Ln Cp	High	0.0291	0.022	0.0546	0.3	High	0.0185	0.012	0.0317	0.3
GB109054049310	00064480	R.Severn At Caerhowel Bridge	High	0.0286	0.025	0.0568	0.3	High	0.0192	0.011	0.0290	0.3
GB109054049700	00061340	R.Severn Maginnis Bridge						High	0.0358	0.015	0.0515	0.3
GB109054049142	00056710	R.Severn Montford Bridge										
GB109054049142	00055460	R.Severn Isle Of Bicton	High	0.048	0.068	0.107	0.6	High	0.0335	0.0221	0.0605	0.6
GB109054049142	00055140	R.Severn Shelton Intake										
GB109054049141	00052182	R.Severn Atcham	High	0.0428	0.045	0.0890	0.6	(2022) High	0.0585	0.0631	0.1226	0.6
GB109054049141	00049650	R.Severn At Cressage	High	0.0365	0.0324	0.00.0725	0.6	High	0.038	0.279	0.711	0.6
GB109054049143	00045702	R.Severn At Coalport	High	0.0373	0.0316	0.0730	0.6	(2022) High	0.0529	0.0495	0.107	0.6
GB109054049143	00044720	R.Severn At Apley Forge	High	0.0637	0.0820	0.139	0.6	High	0.045	0.026	0.078	0.6
GB109054049145	00041180	R.Severn Hampton Loade Bridge										
GB109054049145	00038360	R.Severn At Bewdley	High	0.045	0.036	0.088	0.6	(2022) High	0.046	0.041	0.093	0.6
GB109054049144	00034302	Holt Fleet Meadows Holt Fleet	High	0.049	0.039	0.095	0.6	(2022) High	0.045	0.023	0.073	0.6

GB10905404914 4	0003085 0	R Severn Worcester Bridge	High	0.067	0.056	0.131	0.6	High	0.049	0.048	0.100	0.6
GB10905404914 4	0003009 0	R.Severn Rear Of Oil Depot Bath Rd Worcs										
GB10905403976 0	0002950 0	R Severn (Upper) Kempsey (Mid)										
GB10905403976 0	0002840 0	R Severn (Upper) Severn Stoke (New Spt)										
GB10905403976 0	0002754 0	R Severn - Upton On Severn	High	0.074	0.043	0.127	0.6	High	0.067	0.033	0.110	0.6
GB10905403976 0	0002623 0	R Severn (Upper) Tewkesbury	High	0.053	0.042	0.102	0.6	(2022) High	0.073	0.056	0.138	0.6
GB10905404440 4	0002531 2	R Severn (Lower) Chaceley Stock										
GB10905404440 4	0002508 5	R Severn (Lower) Haw Bridge	High	0.063	0.034	0.106	0.6	High	0.064	0.040	0.113	0.6
GB10905404440 4	0002406 2	R Severn (Lower) Ashleworth	High	0.061	0.036	0.106	0.6	(2022) High	0.064	0.35	0.109	0.6
GB10905404440 4	0001750 0	R Severn (Lower) Maisemore Weir	High	0.068	0.035	0.113	0.6	Not Classifie d	Not Classifie d	Not Classifie d	Not Classifie d	0.6

Looking at the individual monitoring point status rather than the waterbody element status reveals that cycle 2 and 3 ammonia is actually high along the entire length of the River Severn.

Phosphate class, from Montford Bridge downwards, declines from high to Moderate in cycle 2 and down to poor by (Lower) Ashleworth in cycle 3. Above Montford Bridge all monitoring points are good status in both cycle 2 and 3. phosphate classification in cycle 2 onwards uses the updated environmental quality standards which are specific to each monitoring location. This has impacted upon the classification as many points on the River Severn now have more stringent quality standards. The relative trend of declining classification from upstream to downstream is still apparent. The actual mean phosphate quality of the cycle 2 monitoring points is shown in Table 9 for comparative purposes.

Chemical status

From the 2019 assessment of chemical status onwards, we changed some methods and increased our evidence base. Due to these changes, all water bodies now fail chemical status and the assessment is not comparable to pre 2019 assessments.

The four groups of global pollutants; ubiquitous, persistent, bioaccumulative, and toxic substances (uPBTs) that caused the significant change in chemical classification are: polybrominated diphenyl ethers (PBDEs - a group of brominated flame retardants); Mercury; certain Polycyclic aromatic hydrocarbons (PAHs) and Perfluorooctane sulfonate (PFOS) a group of per- and polyfluoroalkyl substances (PFAS).

As of 2025 all River Severn water bodies in Wales (GB109054049700 - Severn – conf R Camlad to conf Bele Bk and upwards on Table 8) have pass statuses for chemicals.

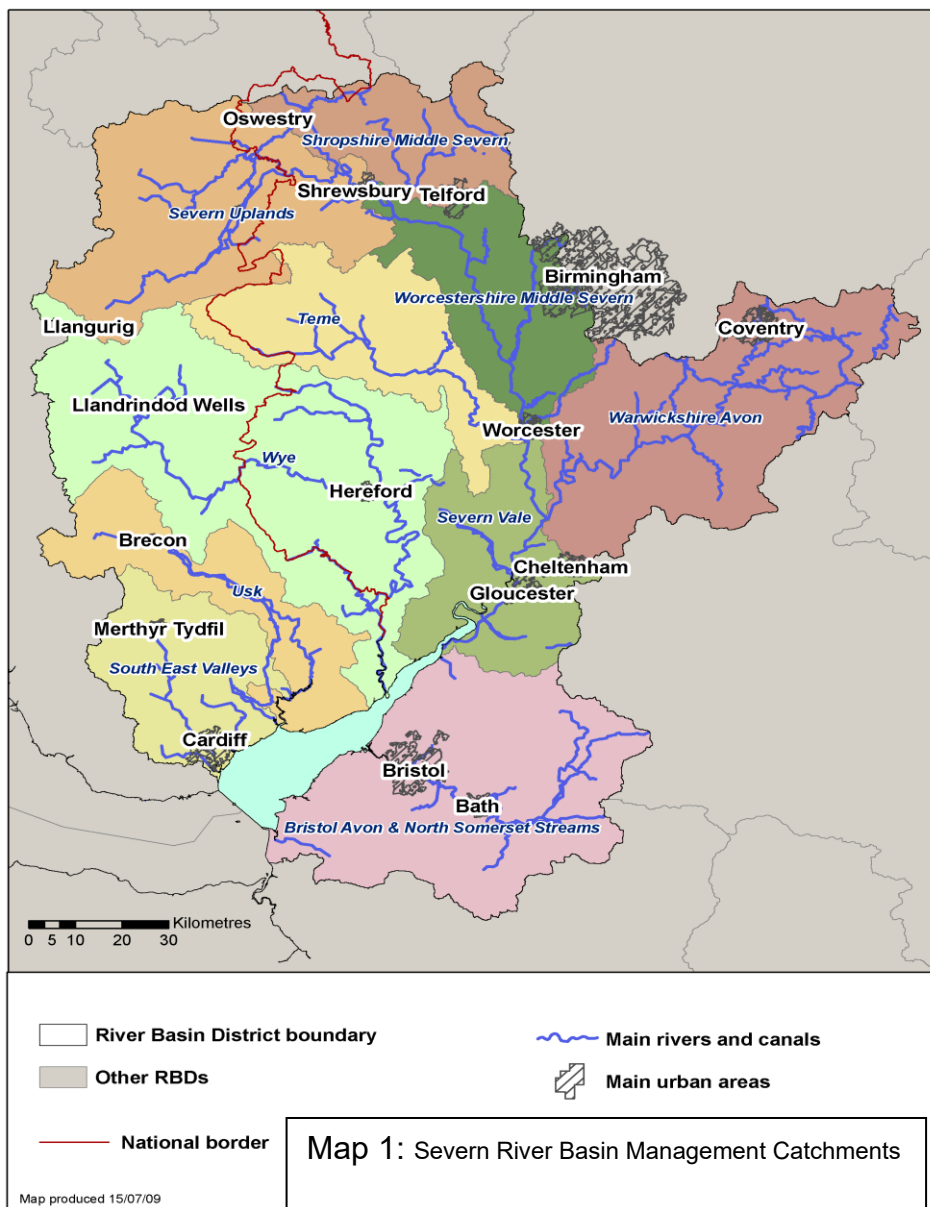
All River Severn water bodies In England (GB109054049142 - Severn – conf Bele Bk to conf Sundorne Bk onwards on Table 8) are classified as failing chemical status due to Mercury (and Its Compounds) and Polybrominated diphenyl ethers (PBDE).

Five water bodies (GB109054049142 - GB109054049144 - GB109054039760 - GB109054044404 - GB109054032750) are failing for Perfluorooctane sulphonate (PFOS)

One Waterbody (GB109054044404) is failing for Benzo(g-h-i)perylene.

River Basin Management Plans

The WFD requires EU member states to formulate RBMPs to deliver the objectives of the Directive. The River Basin Management Plan (RBMP) for the River Severn divides the catchment up into 10 'Management Catchments'



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1. Severn Uplands
2. Shropshire Middle Severn
3. Worcestershire Middle Severn
4. Teme
5. Severn Vale
6. Warwickshire Avon
7. Wye
8. Usk
9. South East Valleys
10. Bristol Avon and North Somerset Streams

The river basin management plan is updated every six years, cycle 1 ran from 2009, cycle 2 from 2015 and cycle 3 from 2019 and cycle 4 from 2025.

The water quality of management catchments 1 through 6, the River Severn from source to the tidal influence at Gloucester, is discussed in more detail in this appendix.

Each management catchment is discussed below starting with upper most catchment down to the lower estuarine reaches of the Severn river basin.

Severn Uplands catchment

A mostly rural catchment, the Severn Uplands includes the towns of Oswestry, Llanidloes, Newtown and Welshpool. The catchment spans the England and Wales border but lies mainly in Wales.

There are 99 water bodies (2019 Cycle 3) including Clywedog and Vyrnwy reservoirs, the River Severn and River Vyrnwy.

For England, The Catchment Data Explorer (updated 17th March 2025) reports 29 of the 99 river and lake water bodies, with only 1 currently achieving good ecological status or potential. 28 water bodies are reported as moderate or poor ecological status. 0 water bodies are classified as good chemical status.

For Wales, 33 of the river and lake waterbodies are reported as achieving good ecological status or potential. 37 waterbodies are reported as moderate, poor or and ecological status. 65 waterbodies are classified at good or high chemical status.

There are many designated conservation sites in this catchment, and tributaries support a diverse range of ecology associated with good water quality. Phosphate, TON and ammonia are seen in lower concentrations indicating better quality in these upper reaches of the River Severn where there are less anthropogenic influences. However, the headwaters of many streams along the western uplands are impacted by acid runoff or drainage from abandoned metal mines. Agricultural chemical and sediment run-off are thought to have some impact on ecology in several rivers such as the Tanat, Vyrnwy and Cain. Cycle 3 data for the sample points in Wales in this catchment are presented in Tables 9 and 10 are analysed from raw data provided by NRW.

Shropshire Middle Severn catchment

The Shropshire Middle Severn catchment is a largely rural area incorporating the towns of Shrewsbury, Newport, Market Drayton and part of Telford. It contains River Seven tributaries, the River Roden, River Perry and the River Tern & Meese. The area is ecologically rich and includes a large number of designated conservation sites, most of which come under the Midlands Meres and Mosses Ramsar Site. There are also several water related Sites of Special Scientific Interest (SSSIs) in this area).

Abstraction for public supply and irrigation for agriculture can have a major impact on water resources. Several rivers have been over abstracted or over licensed at low flows, for example the Coley Brook and Rivers Perry and Tern.

The Environment Agency's Restoring Sustainable Abstraction (RSA) programme and subsequent WFD objectives have resulted in several water company asset management plan (AMP) improvement programmes, investigations and schemes in the catchment to reduce the impact of abstraction on the environment.

The Catchment Data Explorer for the Shropshire Middle Severn reports that only 1 of the 41 river and lake water bodies currently achieve good ecological status or potential; the remainder being below good status. All 41 waterbodies fail for chemical status.

There are no main River Severn water bodies within this management catchment.

The Rivers Tern and Roden have suffered from excessive plant and algal growth due to high levels of nutrients from STWs effluent, other industries and agriculture. Subsequently, the River Tern, The Strine/Strine Brook and Aqualate Mere have all been designated sensitive areas eutrophic (SA(E)) under the Urban Waste Water Treatment Directive (UWWTD). As a result, phosphate treatment commenced at Barnhurst STW in August 2008, Market Drayton STW and Newport STW in March 2012 and Telford Rushmoor STW in 2014. This has resulted in an overall reduction in phosphate concentrations in the catchment. Further STW improvements are planned to move towards WFD good status for phosphate under the water company asset management plan (AMP) improvement programme (see Tables 12 to 16 of AMP improvements below).

Worcestershire Middle Severn catchment

The Severn and its tributaries are highly valued for their landscape and potable drinking water supply. The catchment extends from the southern end of Telford, through rural areas of East Shropshire, the urban conurbations of Bridgnorth, Kidderminster, Stourport, Bromsgrove and Droitwich into the city of Worcester. It is a highly diverse catchment with both urban and rural pressures. The main River Severn tributaries are the Rivers Stour, Salwarpe and Worfe. These have all suffered from unsustainable levels of abstraction at low flows, again relevant consequences of water company impacts are addressed via the AMP improvement programme.

The area contains a wide diversity of habitats and a number of designated wetland sites. Notable sites include Wilden Marsh, Puxton and Stourvale Marshes, Upton Warren, Hurcott and Podmore, Hartlebury Common and Hillditch Coppice.

The River Salwarpe and the River Stour with Smestow Brook, have suffered from excessive plant and algal growth due to high levels of nutrients from STW effluent, other industries and agriculture. Subsequently, they were designated SA(E)s under the UWWTD. As a result, phosphate treatment commenced at Roundhill STW in 2008, Kidderminster STW in March 2012. Trescott STW and Lower Gornal STW in 2013 and Bromsgrove STW and Droitwich STW in 2014.

Following designation of the main River Severn from GB109054049143 (confluence of Much Wenlock/Farley Brook near Ironbridge in Worcestershire Middle Severn catchment) down to GB109054044404 (at Upper Parting near Gloucester in Severn vale catchment) as an SA(E) in 2019 further phosphate treatment will be delivered as qualifying STW discharges in this and downstream management catchments.

0 of the 51 river, canal and lake water bodies are achieving good ecological status/potential and all 51 of the water bodies fail for chemical status.

The four main River Severn water bodies in this management catchment are:

GB109054049141 R Severn (Sundorne Bk to conf M Wenlock-Farley Bk). As previously said, this waterbody is influenced by high levels of phosphate in the Tern. Phosphate levels in the Tern have reduced significantly since 1996 (see Figure 1 below) and will reduce further when all WFD driven improvements are implemented.

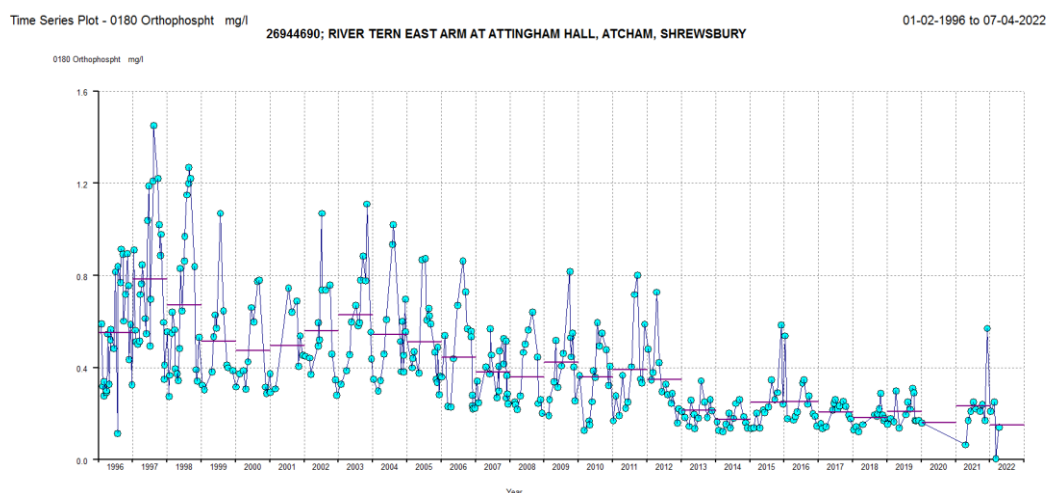


Figure 1: Long term Phosphate, River Tern at Attingham Hall 1996 to 2022.

GB109054049143 R Severn (conf Much Wenlock-Farley Bk to conf R Worfe). The two monitoring points on this waterbody are at Coalport and Apley Forge. Both are moderate status for phosphate. This waterbody receives inputs of phosphate from Coalport STW and the Much Wenlock-Farley Brook improvements under UWWTD and WFD will reduce the impact of these inputs.

Figure 2 shows nitrogen (total oxidised as N – TON) levels whilst variable, shows a slight downward trend over time. Figure 3a plots the phosphate against the WFD cycle 1 and cycle 2 target for good status (the environmental quality standard or EQS). Cycle 2 2015 mean phosphate levels were lower than cycle 1 means (see Table 9 above). Overall phosphate levels have reduced, although with some higher variability in later samples, coinciding with reduced sample frequency. In the Severn the phosphate data does show a seasonal trend as shown in Figure 3b.

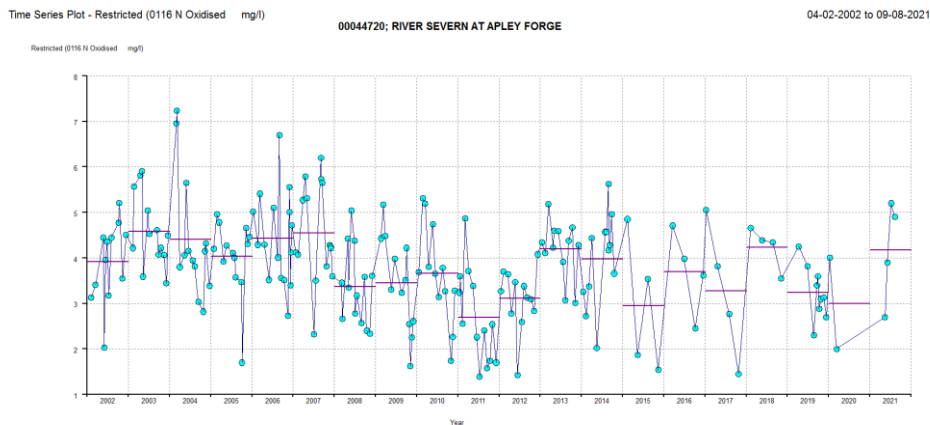


Figure 2: TON River Severn at Apley Forge 2002-2022

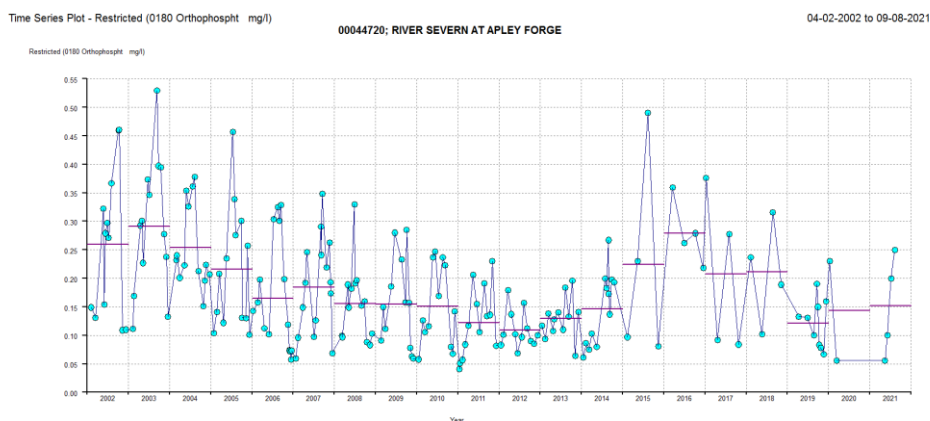


Figure 3a: Phosphate, River Severn at Apley Forge 2002-2022

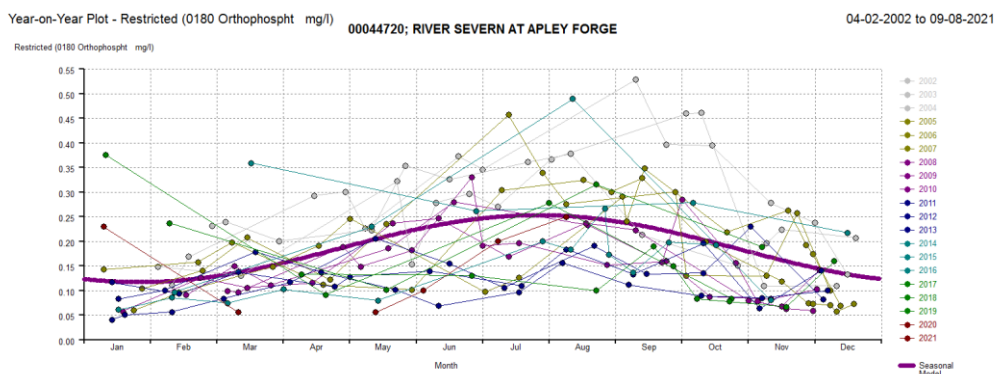


Figure 3L: Phosphate, Apley Forge (2002-2022) Year on Year with seasonal trend overlain.

GB109054049145 R Severn (conf R Worfe to conf R Stour). In this waterbody the monitoring points at Bewdley and Hampton Loade are both moderate status for phosphate. All other physico-chemical elements are at good or high status.

Figure 4 shows a similar TON pattern at Bewdley to that at the upstream Apley Forge point levels are variable but with a slightly decreasing trend. In Figure 5a phosphate is plotted and shows a clear reduction over time. We still see some higher levels and increased variability in the last 2 years of data but this is less pronounced than at Apley Forge and Figure 5b shows no statistically significant step change in the data since 2007.

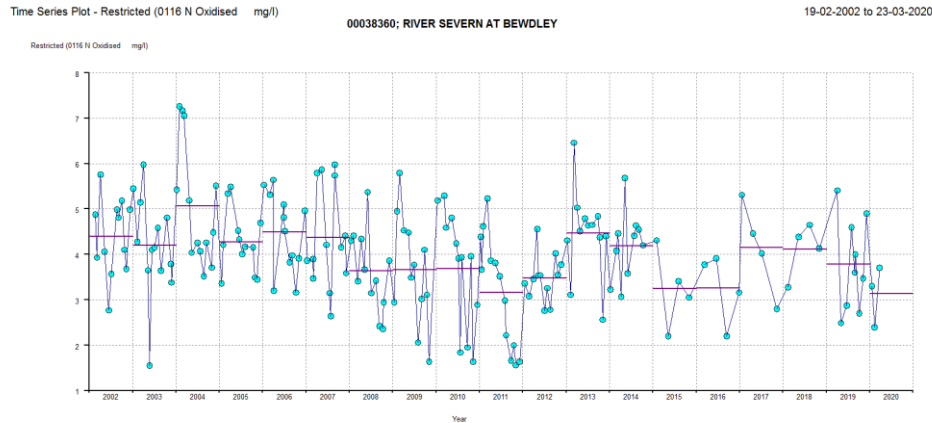


Figure 4: TON, River Severn at Bewdley 2002 to 2020.

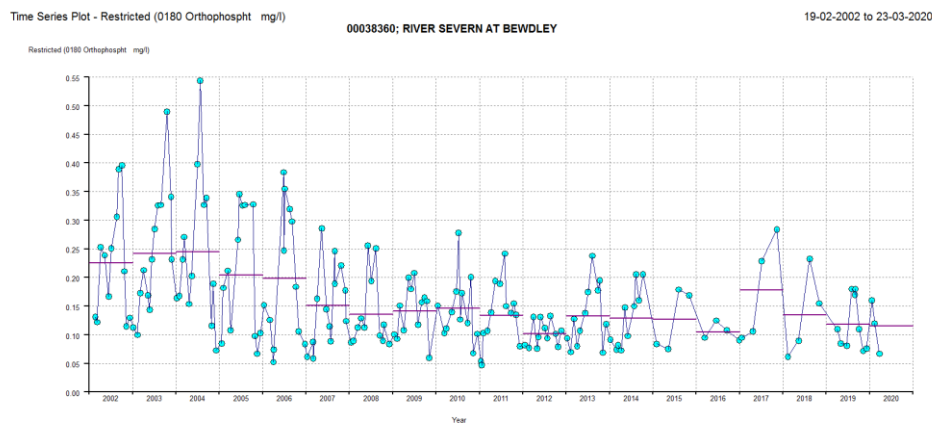


Figure 5a: Phosphate, River Severn at Bewdley 2002 to 2020.

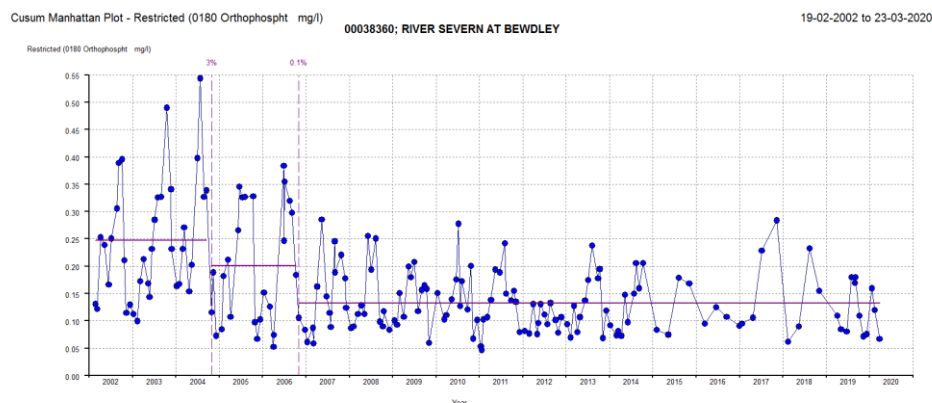


Figure 5b: Phosphate, Bewdley. Step changes 2002-2020

GB109054049144 R Severn (conf R Stour to conf R Teme). The physico-chemical elements are all classified as good or high except phosphate which is again moderate status.

Holt Fleet monitoring point within this waterbody is located downstream of the River Stour confluence, TON is again variable but reveals slightly higher levels at this point (see Figure 6) compared to upstream.

In cycle 1 data analysis, a significant increase in phosphate was observed at this point, by cycle 2 the phosphate quality has improved with a much less noticeable increase between Bewdley and Holt Fleet. This is likely to be due to improvements to inputs in the Stour catchment. Figure 7a and 7b show this significant improvement in phosphate at Holt Fleet over time with no uplift in recent years.

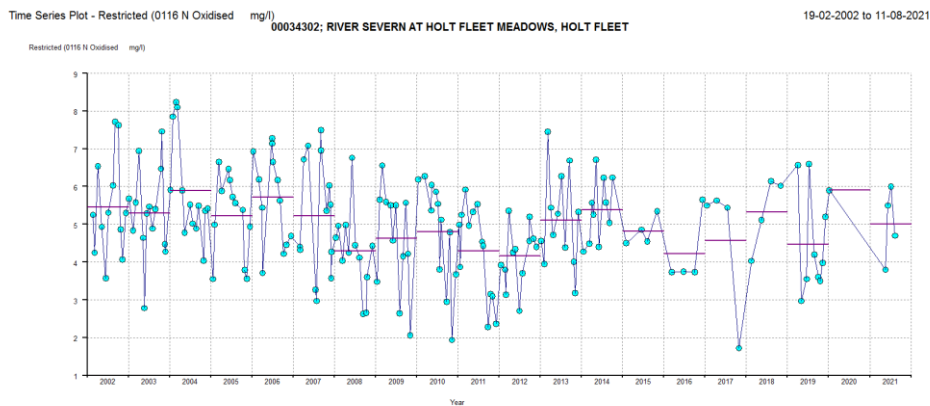


Figure 6: TON, River Severn at Holt Fleet 2002 to 2021.

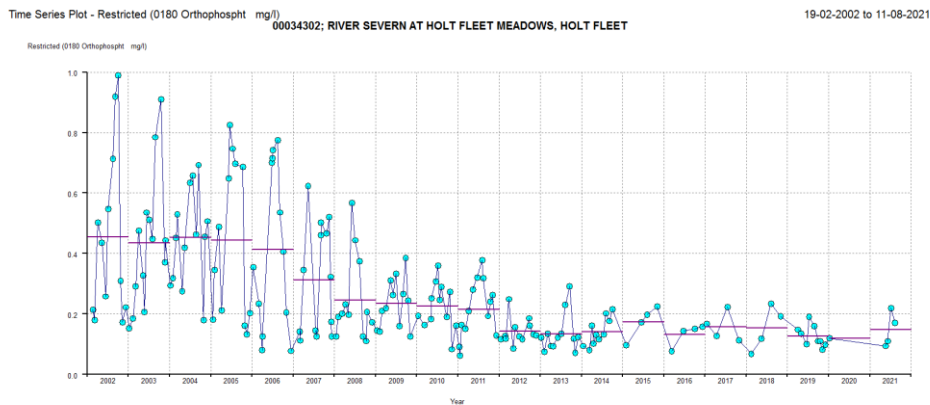


Figure 7a: Phosphate, River Severn at Holt Fleet 2002 to 2021.

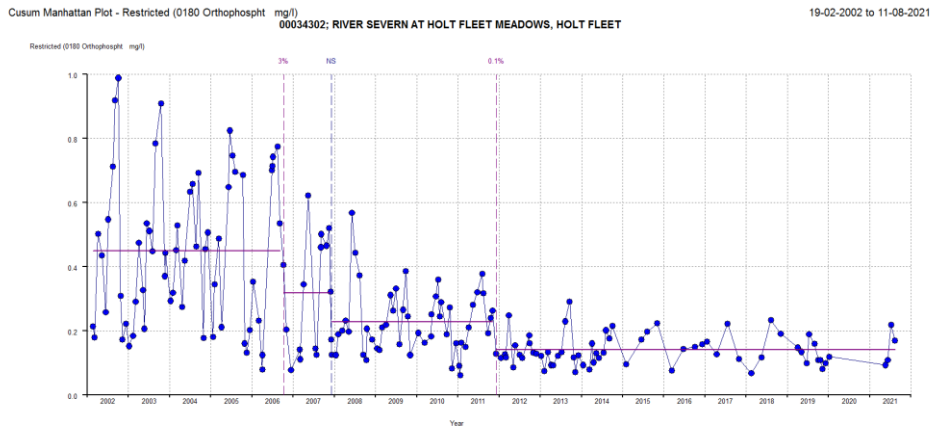


Figure 7b: Phosphate, Holt Fleet. Step changes 2002-2021

River Stour

Looking further at the quality of the River Stour which conflues with the River Severn upstream of Holt Fleet, Figure 8 shows TON levels are much higher in the Stour, influencing the elevation in levels in the Severn at Holt Fleet. Phosphate levels in the Stour were also very elevated prior to 2008 as shown in Figure 9a, however concentrations have fallen significantly over the last decade with downward step changes in quality demonstrated in Figure 9b, consequently the Stour has a much reduced impact on the phosphate quality of the Severn.

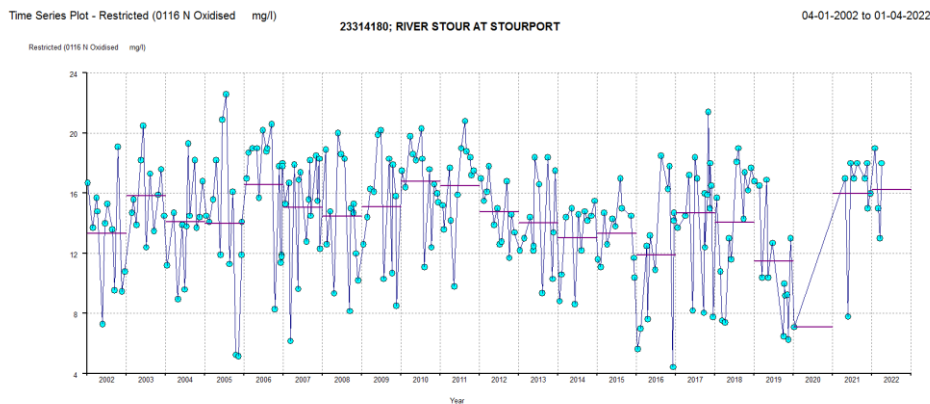


Figure 8: TON River Stour at Stourport 2002 to 2022.

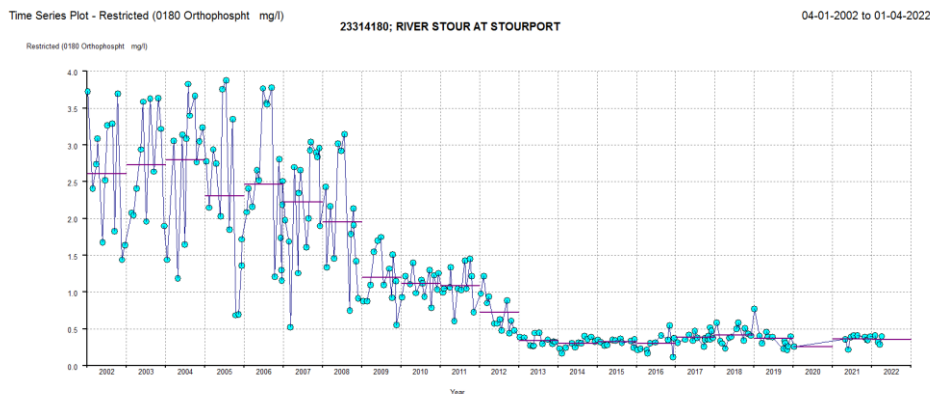


Figure 9a: Phosphate, River Stour at Stourport 2002 to 2022.

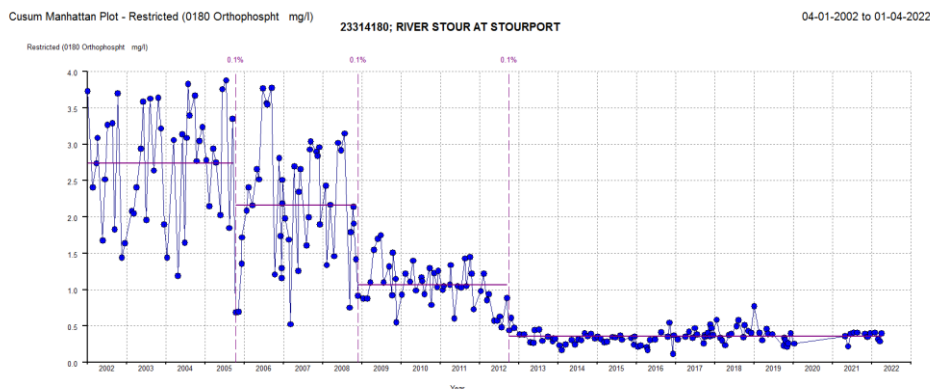


Figure 9b: Phosphate, River Stour at Stourport - Step changes 2002-2022.

River Salwarpe

Downstream of Holt Fleet the River Salwarpe joins the Severn, similar to the Stour this river also has urban influences.

Figure 10 shows TON levels are high in the Salwarpe, but not quite as high as seen in the Stour. Similarly, phosphate was historically elevated but not to the extent of the Stour, again levels have declined as demonstrated in Figure 11a, with downward step changes evident in 2007 and 2014 shown in Figure 11b.

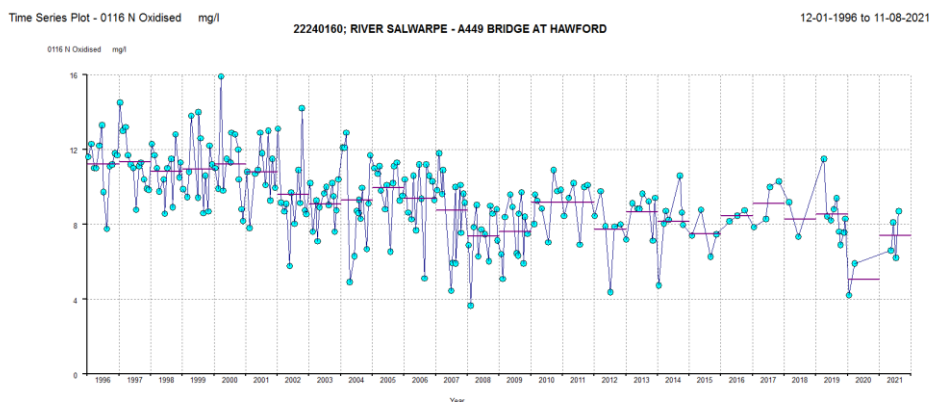


Figure 10: TON, River Salwarpe at Hawford, 2002 to 2021.

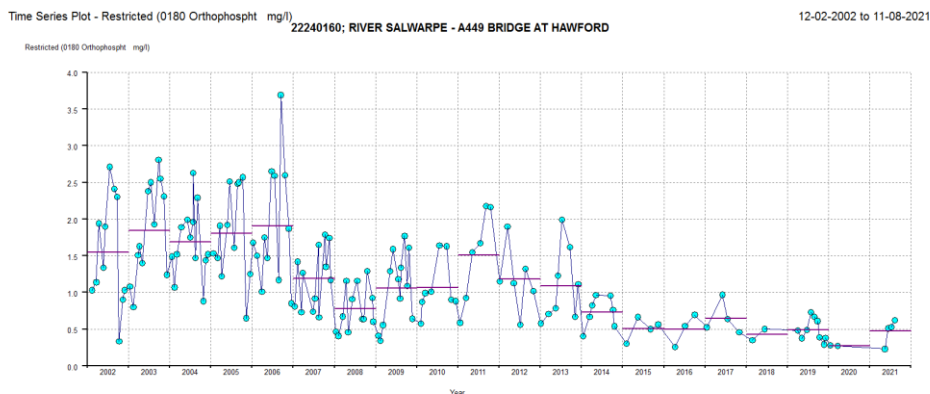


Figure 11a: Phosphate, River Severn at Hawford, 2002 to 2021.

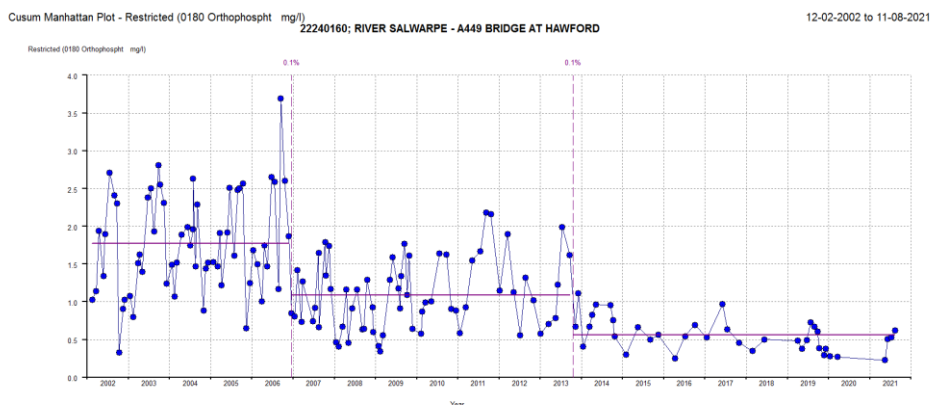


Figure 11b: Phosphate, Hawford. Step changes 2002-2021.

Downstream of the River Salwarpe confluence but still within waterbody GB109054049144 is the Worcester Bridge monitoring point, this location shows similar patterns to Holt Fleet for both TON (Figure 12) and phosphate (Figure 13a and 13b)

WFD status for phosphate in this waterbody overall has improved from poor in cycle 1 to moderate in cycle 2, despite the cycle 2 site specific class targets being more stringent.

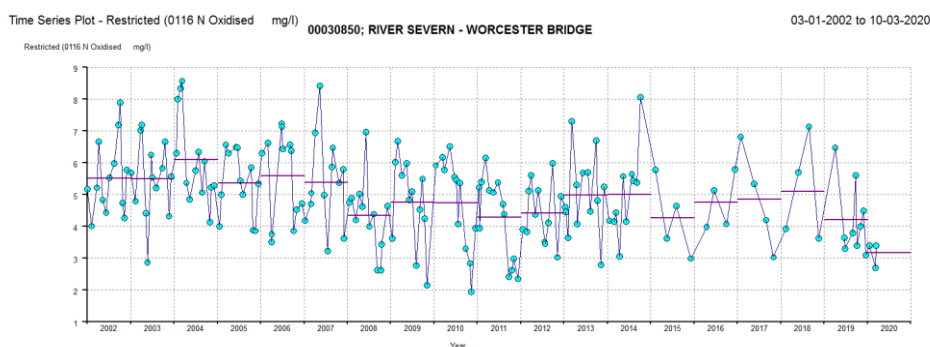


Figure 12: TON, River Severn at Worcester Bridge 2002 to 2020.

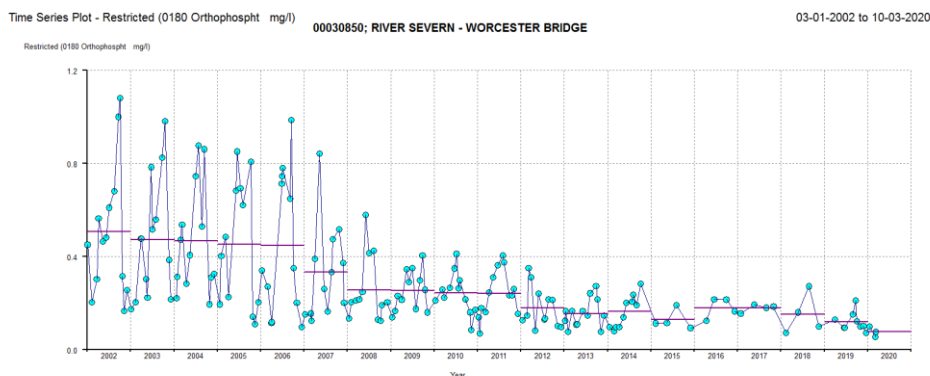


Figure 13a: Phosphate, River Severn at Worcester Bridge 2002 to 2020.

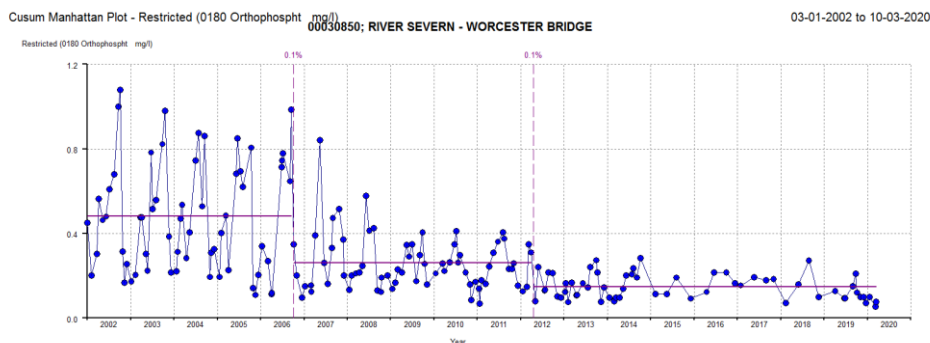


Figure 13b: Phosphate, Worcester Bridge Step changes 2002-2020.

Teme catchment

The second largest tributary of the River Severn, the Teme is a predominately rural catchment incorporating the market towns of Knighton, Ludlow and Tenbury Wells. Major tributaries include the River Clun, Rea, Onny and Corve. The catchment includes some special areas of conservation (SACs): The Stiperstones and Hollies in the upper reaches of the catchment, and the Downton Gorge on the River Teme between Leintwardine and Ludlow. The lower part of the River Clun to the confluence with the River Teme is also a SAC on the basis of its freshwater pearl mussel population, currently in unfavourable condition, partly due to water quality and sediment. The whole of the River Teme is classed as a SSSI, and Brown trout and migratory Atlantic salmon are found throughout the majority of the Teme catchment and its tributaries provide extensive spawning grounds for both species. The presence of obstacles, such as weirs, limits the distribution of salmon within the catchment, although WFD is driving improvements in fish passage. Water quality in the lower reaches of the catchment is affected by diffuse pollution, mainly by nutrients and sediment; however, overall the river is good quality. Whilst there is adequate supply of surface water in the catchment during the winter months, in the summer the Teme often experiences low flows. Abstraction mainly provides water for irrigation for agriculture, with increased use for trickle irrigation.

There are 46 waterbodies in total in the Teme catchment across both England and Wales (41 in England and 5 in Wales). In England, 3 of the 41 river water bodies are at good ecological status or potential. 38 water bodies are at less than good status. 0 water bodies are at good chemical status.

Phosphate removal was initially installed at Tenbury and Ludlow STWs in 1994. The Teme was designated a SA(E) under the UWWTD in 1998. More recently, AMP Habitats Directive and Crow Act sewage works improvement schemes have delivered further phosphate reductions from STWs in the catchment, including significant reductions in phosphate loading in 2018 from STWs in continuity with the Clun SAC. In the final River Teme waterbody in 2015 ammonia classification is high and phosphate is at good status reflecting the overall good quality of this tributary.

Severn Vale catchment

Land use in the Severn Vale is a combination of urban, agricultural and forested areas. The main River Severn tributaries are the River Leadon, the River Chelt, and the River Frome. Downstream of Gloucester the catchment features numerous small brooks and drainage channels that drain directly to the River Severn. The main urban areas are Gloucester, Cheltenham, Ledbury and Stroud. Arable land dominates the Leadon catchment, which suffers from poor water quality due to excessive quantities of silt and high levels of phosphate and nitrate. Extensive woodlands are present in the Forest of Dean, where there are also water quality problems associated with former mine workings. These are often acidic and contain metals and other harmful substances. Abstraction within the catchment is mainly for public water supply and agriculture. Significant quantities are also used for power generation. The Cinderford and Glynch brooks have been over abstracted and groundwater is used to enhance low flows in the Glynch Brook during summer months.

The Rivers Cam, Frome, Chelt and Leadon all suffered from excessive plant and algal growth due to high levels of nutrients from sewage works effluent, other industries and agriculture. Subsequently, they have been designated SA(E) under the UWWTD and phosphate removal was introduced at Coaley, Stroud, Cheltenham (Hayden) and Ledbury STWs by 2005.

Of the 48 surface water bodies in this catchment, 4 are currently at good ecological status or potential. 44 are less than good. All 48 water bodies are failing for chemical status.

There are two main River Severn water bodies within this management catchment:

GB109054039760 R Severn - conf R Teme to conf R Avon. The overall waterbody phosphate classification remains moderate status in this stretch of the Severn, although the most downstream sample point (River Severn Upper at Tewkesbury) only achieves poor. All other physico-chemical elements are high.

GB109054044404 R Severn - conf R Avon to conf Upper Parting. This stretch takes in the largest tributary, the River Avon. All physico-chemical elements except phosphate and Biochemical Oxygen Demand (BOD) are high, with BOD being at good status. Again, phosphate levels remain moderate status in this stretch of the Severn. Currently the input of the River Avon doesn't noticeably change the phosphate level in the Severn. However, in the past phosphate levels in the Avon itself were extremely high.

Warwickshire Avon

The Warwickshire Avon catchment extends from the source of the River Avon near Coventry to its confluence with the River Severn near Tewkesbury and includes tributaries such as the River Arrow, Swift, Leam and Stour. It is a largely rural catchment with some urban conurbations, notably Coventry, Warwick, Stratford-upon-Avon, Evesham, and Redditch. Agriculture accounts for a high proportion of the land use including arable, livestock, horticulture,

and market gardening around Evesham. Whilst this catchment does not contain any main River Severn water bodies it is a major tributary.

There are 75 river water bodies and 3 lakes in the catchment. 1 of the water bodies achieves good ecological status/potential. 77 are at less than good. All water bodies fail chemical status.

The River Avon is navigable and a major resource for recreational activities such as boating, canoeing, fishing and walking. Water is abstracted primarily for public water supply, agriculture and industry. Water quality in the headwaters of the main tributaries is generally good. Elsewhere water quality problems are due to a mixture of the impact of sewage discharges, diffuse (urban and agricultural) run off leading to nutrient enrichment and other pollution.

TON levels are noticeably higher in the Avon than the Severn (see Figure 13).

As shown in Figure 14 and mentioned above, historically phosphate levels in the Avon were very high, since its designation as a SA(E) in 1994 and subsequent phosphate stripping at a number of sewage works in the catchment, levels have reduced significantly but currently do not achieve the WFD good target. However various WFD driven improvements are being delivered via the AMP programme to tackle the fair share of phosphate resulting from STW discharges.

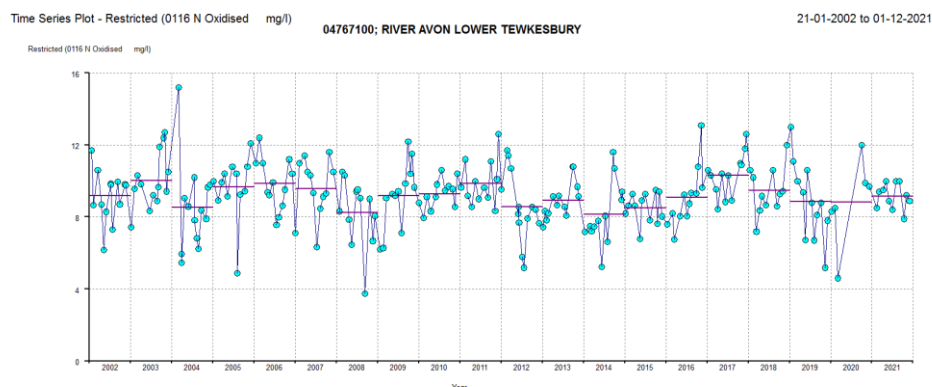


Figure 13: TON River Avon at Tewkesbury 2002 to 2021.

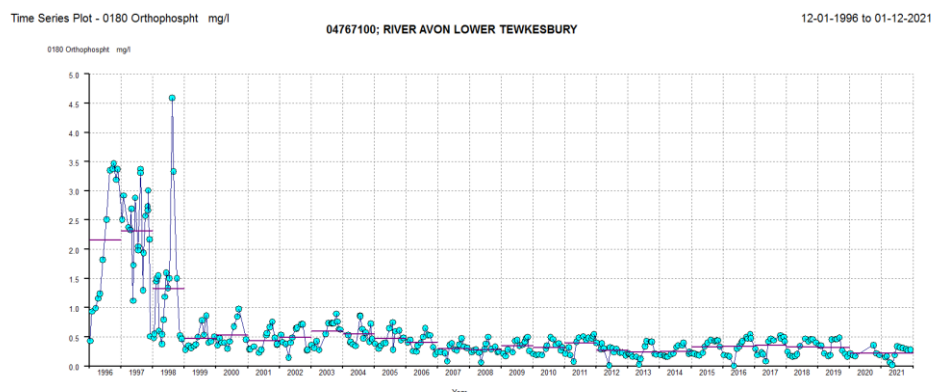


Figure 14: Long term Phosphate, River Avon at Tewkesbury 1996 to 2021.

This is not a WFD sample point however for reference the WFD targets for good status in cycle 1 was 0.12 mg/l and for cycle 2 is 0.091mg/l.

GB109054032750 Severn (E Channel) - Horsebore Bk to Severn Est, covers an arm of the Severn that runs parallel to main channel through northern Gloucester before re-joining the main channel. This waterbody contains one sample point (but this isn't included in the tables above) the quality is reported as moderate overall potential, with ammonia being high, but phosphate classification is moderate in this waterbody.

The Severn Vale management catchment goes down to and surrounds the Severn as it transitions into a more estuarine state.

The River Severn downstream of Gloucester (Maisemore Weir)

The River Severn from the weir at Maisemore to Hock Cliff near Fretherne is not with the Severn Vale management catchment, although water bodies within the Severn Vale catchment drain into it. This stretch of the Severn is named the Severn Upper, GB530905415403 and is a transitional waterbody type. The only physico-chemical elements used in this waterbody's classification are dissolved oxygen which is reported as high status and dissolved inorganic nitrogen, which is moderate status (uncertain) in 2015.

The River Severn from Hock Cliff near Fretherne to just above the Wye confluence again is not within the Severn Vale management catchment, although water bodies within the Severn Vale catchment drain into it. This stretch of the Severn is named the Severn Middle, GB530905415402 and is a transitional waterbody type. The only physico-chemical elements used in this waterbody's classification are dissolved oxygen (reported as high status) and dissolved inorganic nitrogen which is good status in 2022, showing an improvement from moderate status in cycle 1.

Below the Wye confluence is the Severn Lower waterbody, GB530905415401. The only physico-chemical elements used in this waterbody's classification is dissolved oxygen, reported as high status, and dissolved inorganic nitrogen, which is good status (again improved from moderate in cycle 2)

Water Discharges

There are numerous sewage and other trade effluent discharges into the River Severn. Discharges of sewage and trade effluent require a discharge permit from the Environment Agency. The permit limits are set on both the quantity and quality of the discharge according to the amount of water available to dilute the effluent at the point of discharge without causing significant deterioration in the quality of the watercourse. Also, the limits aim to ensure that the discharge does not compromise downstream uses of the river and that the resulting downstream water quality conforms to the relevant environmental quality standards.

STWs that serve a population in excess of 2000 people (or population equivalent) must also comply with the minimum standards required by the UWWTD.

The majority of industrial discharges that directly enter the Severn are not of sufficient size to present any threat to the receiving watercourse. One of the largest discharges was clean cooling water from the Ironbridge Power Station, where a volume of 16 MI/d was consented for discharge. The power station used to be closed down for a six week period during the summer. This had to be taken into consideration by the Environment Agency during the development of the various drought order management scenarios. However the power station ceased operating in 2015 and has since been decommissioned.

The major STWs that discharge to the River Severn are presented in Table 11 below. The Environment Agency reports that compliance with discharge permit conditions is generally good and the most recent Abstraction Licensing Strategy (ALS) / Catchment Abstraction Management Strategy (CAMS) for the River Severn does not identify any water quality issues directly associated with failure of discharge conditions at STWs. However, STWs can have a significant impact during periods of low flow.

Table 11: Major STWs Discharges to the River Severn (direct and indirect)

Name of discharge	Direct / Indirect	NGR	Consented Volume (M ³ /d)
Gloucester (Netheridge) STW	Direct	SO 80961594	42800
Worcester STW	Direct	SO 8449 5340	33000
Shrewsbury Monkmoor STW	Direct	SJ 5240 1357	20838
Coalport STW	Direct	SJ 7094 0134	17700
Malvern Barnards Green STW	Direct	SO 8009 4475	13400
Newtown Powys STW	Direct	SO 1380 9245	3700
Bridgnorth (Slads) STW	Direct	SO 7341 9104	2954
Welshpool STW	Direct	SJ2352007260	2021
Coventry Finham STW	Indirect (via R Avon)	SP 3361 7379	115000
Roundhill STW	Indirect (via R Stour)	SO 8698 8365	59836
Barnhurst STW	Indirect (via Staff/Worcs)	SJ 9020 0176	47500
Warwick STW	Indirect (via R Avon)	SP 2777 6290	36000
Cheltenham Hayden STW	Indirect (via R Chelt)	SO 9060 2310	35000
Redditch Spermal STW	Indirect (via R Arrow)	SP 0846 6263	27500
Kidderminster STW	Indirect (via R Stour)	SO 8256 7375	26504
Stanley Downton (Stroud) STW	Indirect (via R Frome)	SO 7910 0480	24300
Telford Rushmoor STW	Indirect (via R Tern)	SJ 6130 1354	23523
Rugby Newbold STW	Indirect (via R Avon)	SP 4942 7635	21600
Stratford Milcote STW	Indirect (via R Avon)	SP 1805 5297	13110
Bromsgrove Fringe Green	Indirect (via R Salwarpe)	SO 9596 6834	11500
Lower Gornal STW	Indirect (via Bobs Bk)	SO 9030 9075	8500

Droitwich STW	Indirect (via R Salwarpe)	SO 8626 6166	7183
Coaley STW	Indirect (via R Cam)	SO 7562 0217	6680
Trescott STW	Indirect (via Smestow Bk)	SO 8549 9763	6460
Evesham STW	Indirect (via R Avon)	SP 0318 4467	5797
Tewkesbury STW	Indirect (via Mill Avon)	SO 8812 3186	5192
Oswestry Mile Oak STW	Indirect (via R Morda)	SJ 3024 2713	4890
Redditch Priest Bridge STW	Indirect (via Bow Bk)	SO 9926 5983	3576
Ludlow STW	Indirect (via R Teme)	SO 5163 7310	3500
Market Drayton STW	Indirect (via R Tern)	SJ 6685 3320	3400
Brockhampton STW	Indirect (via Hyde Bk)	SO 9462 2593	4420
Itchen Bank STW	Indirect (via R Itchen)	SP 4069 6281	2881
Blackminster STW	Indirect (via Badsey Bk)	SP 0661 4464	2756
Newport STW	Indirect (via Strine Bk)	SJ 7358 1924	2500
Tenbury Wells STW	Indirect (via R Teme)	SO 6044 6848	1247

Summer storms following periods of dry weather have potential to cause serious pollution and associated fish kills, either through STWs, storm water overflows or through the flushing-out of urban pollution. Most of the large public sewerage systems have intermittent storm overflows that operate within the system or at the STWs at times of heavy rainfall. The majority of the overflows operate without causing nuisance, although it is reported that those situated in areas of high public amenity do give rise to some complaint. Pollution incidents associated with storm overflows are generally of short duration, but have potential to cause long term effects on the biological and aesthetic quality of the river.

The water industry AMP improvement programme runs in five year blocks and includes both water quality and water resource improvements. As part of the AMP, improvements have been delivered at a number of continuous and intermittent discharges since 2000, to improve substandard discharges or meet updated environmental standards. The STWs and receiving watercourses which have benefited from this programme for water quality are summarised in Tables 12 to 16 (one table per five year programme). These improvements, which include tightening of discharge permits to reduce discharges of ammonia, phosphate and organic matter, have been driven by non-compliance with RQOs and by a number of Directives (i.e. Freshwater Fish Directive, Habitats Directive, and UWWTD) and more recently the WFD.

TABLE 12: SUMMARY OF IMPROVEMENT WORKS CARRIED OUT UNDER THE WATER INDUSTRY ASSET MANAGEMENT PLAN (AMP) IMPROVEMENT PROGRAMME (2000-2005)

WFD Management Catchment	Discharge Name	Discharge Type	Receiving Watercourse	Completion date
Worcestershire Middle Severn	Albrighton	Continuous	Albrighton Brook	31.03.05
	Ombersley	Continuous	Hadley Brook	31.03.05
	Droitwich	Continuous	River Salwarpe	31.03.01
	Bromsgrove	Continuous	Sugar Brook	31.03.03
	Coven Heath	Continuous	Staff/Worcester Canal	31.03.05
	Bagley Street	Intermittent	River Stour	31.03.03
	Wellmeadow	Intermittent	River Severn	31.03.02
	Hayes Lane	Intermittent	River Stour	31.03.04
	Hagley Road	Intermittent	River Stour	31.03.03
	The Kingsway P/S	Intermittent	River Stour	31.03.03
	Stourville Road	Intermittent	River Stour	31.03.04
	Enville Street	Intermittent	River Stour	31.03.04
Severn Vale	Ledbury STW	Continuous	River Leadon	31.12.04
	Little Marcle Road PS	Intermittent	River Leadon	31.03.05
	Staunton STW (Pitsmill)	Intermittent	River Leadon	31.03.03
	Malvern (Barnards Green) STW	Intermittent	River Severn	31.03.03
	Ashleworth Quay	Continuous	River Severn	31.03.05
	Stanley Downton STW	Continuous	River Frome	31.12.04
	Coaley STW	Continuous	River Cam	31.06.03
	Cheltenham STW	Continuous	River Chelt	31.12.04
	Dunkirk Mills	Intermittent	Nailsworth Stream	31.03.03
	Malakoff Inn	Intermittent	River Frome	31.03.03
	Wallbridge PS	Intermittent	River Frome	31.03.04
	Lodgemoor Mills	Intermittent	River Frome	31.03.03
	King Stanley East	Intermittent	River Frome	31.03.03
	Ocean Bridge	Intermittent	River Frome	31.03.05
	Stanley Downton STW	Intermittent	River Frome	31.03.05
	Coaley STW	Intermittent	River Cam	31.03.05
	Listers Car Park	Intermittent	River Cam	31.03.04

TABLE 13: SUMMARY OF IMPROVEMENT WORKS CARRIED OUT UNDER THE WATER INDUSTRY AMP (2005-2010)

WFD Management Catchment	Discharge Name / location	Effluent type	Receiving water name	Delivery Date
Severn Uplands	Coleham SPS	Intermittent	River Severn	31.03.09
	Hanwood SPS	Intermittent	Rea Brook	31.03.08
	The Flash CSO, Shrewsbury	Intermittent	River Severn	Not required
Severn Vale	Cheltenham Hayden STW	Continuous	River Chelt	31.03.09
	Ellwood SPS	Intermittent	Trib Cannop Bk	31.03.07
	Shuttlefast Farm CSO, Malvern	Intermittent	Merebrook Pool	31.03.08
Shropshire Middle Severn	Betton Byeways STW	Continuous	River Tern	31.03.07
	Maer Village Drain	Continuous	River Tern	31.03.12
	Newport STW	Continuous	Strine Brook	31.03.08
	High Ercall CSO (Shop lane)	Intermittent	Shirlowe Brook	31.03.09
	Bishops Castle STW	Continuous	Snakes Croft Brook	31.03.07
	Blundell Hall Bishops Castle STW	Continuous	Trib River Kemp	31.03.07
	Bucknell STW	Continuous	River Redlake	31.03.08
	Church Stretton STW	Continuous	Quinny Bk	31.03.11
	Church Stretton STW Storm Tanks	Intermittent	Quinny Brook	31.03.10
	Clun STW	Continuous	River Clun	Not required
	Craven Arms STW	Continuous	River Onny	31.03.11
	Knighton STW	Continuous	River Teme	01.03.10
	Lydbury North STW	Continuous	River Kemp	Not required
	Wichenford Queens SPS	Emergency Overflow	Trib of Laughern Brook	31.03.08
Warwickshire Avon	Astwood Bank STW	Continuous	Doe Bank Brook	31.03.10
Worcestershire Middle Severn	Bath Rd./ Stanley St. CSO Worcester	Intermittent	Duck Brook (trib of River Severn)	31.03.09
	Batten Hall Rd/St. Dunstons Cres. CSO, Worcester	Intermittent	Duck Brook (trib of River Severn)	31.03.06
	Belle Vue Storm Tanks	Storm Tank	River Stour	31.03.07
	Blakedown STW	Continuous	Blakedown Brook,	31.03.09
	Bridge Road CSO	Intermittent	Benthall Brook, trib River Severn	31.03.09
	Bromsgrove STW	Continuous	Sugar Brook (River Salwarpe)	31.03.10
	Diglis Syphon, Worcester	Intermittent	River Severn	31.03.09
	Grandstand Road, Worcester	Intermittent	River Severn	31.03.07
	Ladywood SPS on B4377 Ironbridge	Intermittent	River Severn	31.03.07
	Much Wenlock STW Storm Tanks	Intermittent	Much Wenlock Brook	31.03.07
	Newport Road CSO, Albrighton	Intermittent	Albrighton Brook	31.03.08
	Pine Grove SPS	Intermittent	Sugar/Spadesbourne Brook	31.03.07
	Roundhill STW - Outlet B	Continuous	Gallows Brook	31.03.10
	Roundhill STW - OutletA	Continuous	River Stour	31.12.08
	Springfield SPS, Worcester	Intermittent	Duck Brook	31.03.07
	Worcester STW Storm Tanks	Intermittent	River Severn	31.03.10

TABLE 14: SUMMARY OF IMPROVEMENT WORKS UNDER THE WATER INDUSTRY AMP (2010-2015)

WFD Management Catchment	Scheme Name/Name of Discharge/Investigation	Effluent type	Name of Waterbody	Completion date
Severn Uplands	Llanfyllin STW	Continuous	A. Cain	31.03.15
	West Felton STW	Continuous	Weir Brook	31.03.15
Severn Vale	Longhope STW	Continuous	Longhope Bk	31.03.15
	Coaley STW	Continuous	R Cam	31.03.15
Shropshire Middle Severn	Newport STW	Continuous	Strine Bk	31.03.12
	Rushmoor STW	Continuous	R Tern	31.03.13
	Market Drayton STW	Continuous	R Tern	31.03.12
	Oswestry (Drenowydd) STW	Continuous	Common Bk	22.12.12
	Edgmond	Continuous	Strine Bk	22.12.12
Teme	Hallow STW	Continuous	Laughern Brook	31.03.15
Warwickshire Avon	Kimcote STW	Continuous	R Swift	31.03.15
	Swinford STW	Continuous	River Avon	31.03.15
	Brinklow STW	Continuous	Smite Bk	Not required
	Kineton-STW	Continuous	R Dene	31.03.14
	Gaydon STW	Continuous	R Dene	31.03.13
	Norton Lindsey STW	Continuous	Sherbourne Bk	31.03.15
	Whichford STW	Continuous	R Stour	31.03.15
	Cherington STW	Continuous	R Stour	31.03.15
	Broadway STW	Continuous	Badsey Bk	Not required
	Lutterworth STW	Continuous	R Swift	31.03.14
	Itchen Bank STW	Continuous	R Itchen	31.03.12
	Blackminster STW	Continuous	Badsey Brook	31.03.14
Worcestershire Middle Severn	Cutnall Green STW	Continuous	Hadley Brook	31.03.15
	Chaddesley Corbett-STW	Continuous	Hadley Brook	31.03.15
	Trescott STW	Continuous	Smestow Brook	31.03.13
	Kidderminster STW	Continuous	R Stour	31.03.12
	Wombourne STW	Continuous	Smestow Brook	31.03.13
	Droitwich STW	Continuous	R Salwarpe	30.06.14
	Bromsgrove Fringe Green STW	Continuous	Sugar Brook	30.09.14
	Lower Gornal STW	Continuous	Bobs/Holbeche Brook	30.03.13
	Lower Penn STW	Continuous	Merryhill Brook	22.12.12

TABLE 15: SUMMARY OF IMPROVEMENT WORKS UNDER THE WATER INDUSTRY AMP (2015-2020)

WFD Management Catchment	Discharge Name	Discharge Type	Receiving Watercourse	Planned Completion Date
Shropshire Middle Severn	Duddleston Heath STW	Continuous	R Perry	31/03/20
	Edgmond STW	Continuous	R Tern	31/03/20
	Ellesmere Wharf Meadow STW	Continuous	R Perry	31/03/20
	Ellesmere Wharf Meadow STW	Continuous	R Perry	31/03/18
	Much Wenlock STW	Continuous	Farley Bk	31/03/20
	Newport STW	Continuous	R Tern	31/03/20
	Oswestry Drenwydd STW	Continuous	R Perry	31/03/20
Worcestershire Middle Severn (Stour)	Gospel End STW	Continuous	Smestow Bk	31/03/20
	Trescott STW	Continuous	Smestow Bk	31/03/20
Teme	Clun Catchment Schemes (Changes at Bucknell STW, Clun STW, Lydbury North STW, Newcastle on Clun STW)	Continuous	River Clun	31/03/18
Warwickshire Avon	Brockhampton	Continuous	R Swilgate	14/11/18
	Alderton STW	Continuous	R Avon	31/03/20
	Ashton Under Hill STW	Continuous	R Avon	31/03/20
	Bearley STW	Continuous	R Alne	31/03/20
	Blockley STW	Continuous	R Stour	31/03/20
	Braunston STW	Continuous	R Leam	31/03/20
	Brinklow STW	Continuous	R Sowe	31/03/20
	Brockhampton STW	Continuous	R Swilgate	31/03/20
	Chipping Campden STW	Continuous	R Stour	31/03/20
	Claverdon STW	Continuous	R Alne	31/03/20
	Corley STW	Continuous	R Sowe	31/03/20
	Coventry (Finham) STW	Continuous	R Sowe	31/03/20
	Dunchurch STW	Continuous	R Leam	31/03/20
	Fenny Compton STW	Continuous	R Itchen	31/03/20
	Frankton STW	Continuous	R Leam	31/03/20
	Itchen Bank STW	Continuous	R Itchen	31/03/20
	Kilsby STW	Continuous	R Leam	31/03/20
	Kimcote STW	Continuous	R Swift	31/03/20
	Lutterworth STW	Continuous	R Swift	31/03/20
	Monks Kirby	Continuous	R Sowe	31/03/20
	Napton STW	Continuous	R Stowe	31/03/20
	Rowington STW	Continuous	R Alne	31/03/20
	Rugby STW	Continuous	R Avon	31/03/20
	Shipston STW	Continuous	Stour	31/03/20
	Staverton STW	Continuous	R Leam	31/03/20
	Winchcombe STW	Continuous	Isbourne	31/03/20
	Wolston STW	Continuous	R Avon	31/03/20
	Woolstone STW	Continuous	R Swilgate	31/03/20
	Wootton Wawen STW	Continuous	R Alne	31/03/20
	Yelvertoft STW	Continuous	R Avon	31/03/20
Severn Vale	Bosbury STW	Continuous	R Leadon	31/03/20
	Ledbury STW	Continuous	R Leadon	31/03/20
	Newent STW	Continuous	R Leadon	31/03/20
	Staunton Pitts Mill STW	Continuous	R Leadon	31/03/20
	Tibberton STW	Continuous	R Leadon	31/03/20

TABLE 16: SUMMARY OF PROPOSED IMPROVEMENT WORKS UNDER THE WATER INDUSTRY AMP (2020-2025/6) *

*TBC following OFWAT final determination and EA publication of Severn River Basin Management Plan 3.

WFD Management Catchment	Discharge Name	Type	Receiving Watercourse	Planned Completion Date
Severn Uplands - Morda and Severn	BOMERE HEATH STW	Continuous	R Severn	22/12/22
	MILE OAK OSWESTRY STW	Continuous	R Morda	22/12/24
	WEST FELTON STW	Continuous	Weir Bk	22/12/24
Severn Uplands - Rea Brook	MINSTERLEY STW	Continuous	Rea Bk	22/12/24
	PONTESBURY STW	Continuous	Rea Bk	22/12/24
	WORTHEN STW	Continuous	Rea Bk	22/12/24
	YOCKLETON STW	Continuous	Rea Bk	22/12/24
Shropshire Middle Severn - Perry Roden and Tern	ADBASTON STW	Continuous	R Meese	22/12/24
	BLYMILL STW	Continuous	R Meese	22/12/24
	CHESWARDINE STW	Continuous	R Meese	22/12/24
	CLIVE STW	Continuous	R Severn	22/12/24
	HIGHER HEATH-PREES STW	Continuous	R Tern	22/12/24
	HINSTOCK STW	Continuous	R Meese	31/03/25
	HODNET STW	Continuous	R Tern	31/03/25
	LOGGERHEADS SANATORIUM STW	Continuous	R Tern	22/12/24
	LOGGERHEADS VILLAGE STW	Continuous	R Tern	22/12/24
	MARKET DRAYTON STW	Continuous	R Tern	22/12/24
	PREES - GOLFHOUSE LANE STW	Continuous	R Roden	22/12/24
	RUSHMOOR STW	Continuous	R Tern	22/12/24
	SHAWBURY STW	Continuous	R Roden	22/12/24
	STOKE HEATH STW	Continuous	R Tern	22/12/24
	WEM STW	Continuous	R Roden	22/12/24
	WOODSEAVES STW	Continuous	R Meese	22/12/24
	WOORE STW	Continuous	R Tern	22/12/24
Shropshire Middle Severn - Telford	NEWPORT STW	Continuous	R Tern	22/12/21
	WELLINGTON CSOs	Intermittent	Various	31/03/25
Worcestershire Middle Severn - Shropshire West	MONKMOOR SHREWSBURY STW	Continuous	R Severn	12/05/26
	HOMER STW	Continuous	R Severn	22/12/24
Worcestershire Middle Severn - Worfe	ALBRIGHTON STW	Continuous	R Worfe	22/12/24
	CLAVERLEY STW	Continuous	R Worfe	22/12/24
	PATTINGHAM STW	Continuous	R Worfe	22/12/24
	SHIFNAL STW	Continuous	R Worfe	22/12/24
Worcestershire Middle Severn - Severn Worcs	COALPORT STW	Continuous	R Severn	12/05/26
	BRIDGNORTH STW	Continuous	R Severn	12/05/26
	WORCESTER STW	Continuous	R Severn	12/05/26
Worcestershire Middle Severn - Stour	BELBROUGHTON STW	Continuous	R Stour (Worcs)	22/12/24
	KIDDERMINSTER STW	Continuous	R Stour (Worcs)	22/12/22
	ROUNDHILL STW	Continuous	R Stour (Worcs)	31/03/25
	GOSPEL END STW	Continuous	Smestow Bk	31/03/25
	HIMLEY STW	Continuous	Smestow Bk	31/03/25
	LOWER GORNAL STW	Continuous	Smestow Bk	22/12/24
	LOWER PENN STW	Continuous	Smestow Bk	31/03/25
Worcestershire Middle Severn - Salwarpe River	BROMSGROVE STW	Continuous	R Salwarpe	22/12/21
	OMBERSLEY STW	Continuous	R Salwarpe	22/12/24
	STOKE PRIOR STW	Continuous	R Salwarpe	22/12/24

WFD Management Catchment	Discharge Name	Type	Receiving Watercourse	Planned Completion Date
Teme	BISHOPS CASTLE STW	Continuous	R Clun	31/03/25
	COLWALL STW	Continuous	R Teme	22/12/24
	HALLOW STW	Continuous	R Teme	22/12/24
	MARTLEY DUCTONS COPPICE STW	Continuous	R Teme	22/12/24
	WEST MALVERN STW	Continuous	R Teme	22/12/24
	BRAMPTON STW	Continuous	R Teme	31/03/25
	CLEOBURY MORTIMER STW	Continuous	R Teme	22/12/24
	LEINTWARDINE STW	Continuous	R Teme	22/12/24
	WIGMORE STW	Continuous	R Teme	22/12/24
Warwickshire Avon - Urban	ALCESTER STW	Continuous	R Arrow	22/12/21
	ALVECHURCH STW	Intermittent	R Arrow	22/12/24
	REDDITCH - SPERNAL STW	Continuous	R Arrow	22/12/24
	ROWINGTON STW	Continuous	R Alne	31/03/25
Warwickshire Avon - Rural	ASHORNE STW	Continuous	R Avon	22/12/24
	BIDFORD-ON-AVON STW	Intermittent	R Avon	31/03/24
	BLOCKLEY STW	Intermittent	R Stour (Warks)	31/03/23
	CHERINGTON STW	Intermittent	R Stour (Warks)	31/03/23
	CHURCH LAWFORD STW	Intermittent	R Avon	31/03/23
	ITCHEN BANK STW	Continuous	R Itchen	22/12/21
	KILSBY STW	Continuous	R Leam	31/03/25
	KINETON STW	Continuous	R Dene	22/12/21
	LIGHTHORNE STW	Continuous	R Avon	22/12/24
	LIGHTHORNE HEATH STW	Continuous	R Avon	22/12/24
	LONG COMPTON STW	Continuous	R Stour (Warks)	22/12/21
	LONG MARSTON STW	Intermittent	R Avon	31/03/23
	NETHERCOTE STW	Continuous	R Stour (Warks)	22/12/21
	NORTHEND STW	Continuous	R Dene	22/12/24
	NORTON LINDSEY STW	Continuous	R Avon	22/12/24
	OXHILL STW	Continuous	R Stour (Warks)	22/12/24
	RUGBY NEWBOLD STW	Continuous	R Avon	31/03/25
	SNITTERFIELD STW	Continuous	R Avon	22/12/24
	TYSOE STW	Continuous	R Stour (Warks)	22/12/24
	WARWICK LONGBRIDGE STW	Continuous	R Avon	22/12/22
	WELLESBOURNE STW	Continuous	R Dene	22/12/21
	WESTON-UNDER-WETHERLEY STW	Intermittent	R Leam	31/03/23
Warwickshire Avon - West	ASTWOOD BANK STW	Continuous	Bow Bk	22/12/24
	BISHAMPTON STW	Continuous	Piddle Bk	22/12/24
	BLACKMINSTER STW	Continuous	Broadway-Badsey Bk	22/12/24
	BROADWAY STW	Continuous	Broadway-Badsey Bk	31/03/25
	CHURCH LENCH STW	Continuous	Piddle Bk	22/12/24
	CROWLE - WORCS STW	Intermittent	Bow Bk	31/03/23
	HARVINGTON STW	Continuous	Harvington Bk	31/03/25
	HONEYBOURNE STW	Continuous	Bretforton Bk	31/03/25
	INKBERROW STW	Continuous	Piddle Bk	31/03/25
	PRIEST BRIDGE - REDDITCH STW	Continuous	Bow Bk	22/12/24
	WOOLSTONE STW	Continuous	R Swilgate	22/12/22
Severn Vale - Leadon	KEMPLEY STW	Continuous	R Leadon	22/12/24
	NEWENT STW	Intermittent	R Leadon	31/03/24
	PITTS MILL STW	Intermittent	R Leadon	31/03/24
Severn Vale	CHELTENHAM STW	Continuous	R Chelt	22/12/22

WFD Management Catchment	Discharge Name	Type	Receiving Watercourse	Planned Completion Date
	CINDERFORD - CRUMPMEADOW STW	Intermittent	Cinderford Bk	31/03/25
	GUARLFORD STW	Continuous	R Severn	22/12/24
	WELLAND STW	Continuous	R Severn	22/12/24
	HUNTLEY STW	Continuous	R Severn	22/12/24
	MALVERN STW	Continuous	R Severn	12/05/26
	POWICK STW	Continuous	R Severn	12/05/26
	RIPPLE STW	Continuous	R Severn	22/12/24
	UPTON-ON-SEVERN STW	Intermittent	R Severn	31/03/24
Severn Vale - Trac	FRAMPTON STW	Intermittent	SEVERN MIDDLE	31/03/24
	LITTLEDEAN STW	Intermittent	SEVERN UPPER	31/03/23

Appendix H

Physico-Chemical Water Quality

Physico-Chemical Water Quality

GQA – Chemistry and Nutrients

The Environment Agency (EA) has a duty to monitor and report on the quality of the water environment for a range of statutory (e.g. EC directives, statutory regulations, international conventions etc) and non-statutory (e.g. historic General Quality Assessment (GQA)) drivers. For over twenty years (up until 2009) the EA used the GQA scheme to assess river quality. The GQA scheme was designed to provide an accurate and consistent assessment of the state of water quality and changes over time. This assessment was described in terms of chemical, nutrient, aesthetic and biological quality. This section provides an overview of chemical and nutrient quality only².

Sites were sampled a minimum of 12 times a year. The data collected over three years were used to determine average concentrations to reduce any non-seasonal variation due to unusual weather conditions. All the results collected over the three years were included. No extreme data values were excluded.

The Chemical GQA described quality in terms of chemical measurements which detect the most common types of pollution (i.e. dissolved oxygen, biochemical oxygen demand and ammonia). It allocated one of six grades (A to F) to each stretch of river, using the same, strictly defined procedures, throughout England and Wales (Table C.1.). The overall GQA grade assigned to a reach was determined by the worst of the three grades for the individual determinants.

Table C.1 GQA chemical standards

GQA grade	DO (% saturation) 10-percentile	BOD (mg/l) 90-percentile	Ammonia (MgN/l) 90-percentile
A (Very Good)	80	2.5	0.25
B (Good)	70	4	0.6
C (Fairly Good)	60	6	1.3
D (Fair)	50	8	2.5
E (Poor)	20	15	9.0
F (Bad)	<20	-	-

The GQA for nutrients described quality in terms of phosphate and nitrate. A grade from 1 to 6 was allocated for both phosphate and nitrate (Table C.2). These are not combined into a single nutrient grade. In this respect it differs from the chemical classifications which combine factors into a single grade.

There are no formally prescribed 'good' or 'bad' concentrations for nutrients in rivers comparable to those used to describe chemical and biological quality. Rivers in different parts of the country have naturally different concentrations of nutrients. However, by considering man made nutrient sources and influences against ideal targets for the river environment present, or aspired to, it was possible to determine whether the nutrient status is appropriate.

² Aesthetic quality was not considered in this study

Table C.2 GQA standards for Nitrate and Phosphate

Grade	Nitrate		Phosphate	
	Grade Limit (mg NO ₃ /l) average	Description	Grade Limit (mg P/l) average	Description
1	<5	Very low	<0.02	Very low
2	>5 to 10	Low	>0.02 to 0.06	Low
3	>10 to 20	Moderately low	>0.06 to 0.1	Moderate
4	>20 to 30	Moderate	>0.1 to 0.2	High
5	>30 to 40	High	>0.2 to 1.0	Very high
6	>40	Very High	>1.0	Excessively high

WFD Surface Waters

Water Framework Directive (WFD) introduced a new approach to assessing the whole water environment. EA have reported using the WFD classification of waters since 2009. For surface waters, good status is a statement of 'overall status', and has an ecological and a chemical component. Good ecological status is measured on the scale high, good, moderate, poor and bad. Physico-chemical elements are a supporting element in the classification of ecological status. Chemical status is measured as good or fail. Good ecological status applies to natural water bodies, and is defined as a slight variation from undisturbed natural conditions.

An Environment Agency document explaining the classification process in more detail can be found at: http://www.environment-agency.gov.uk/static/documents/Research/Classification_Method_Statement_FINAL.pdf

Further details regarding the Physico-Chemical water quality and the WFD classification of the River Severn can be found in Appendix G.

UK Technical Advisory Group (UKTAG)

UKTAG is a partnership of the UK environment and conservation agencies which was set up by the UK-wide WFD policy group consisting of UK government administrations. It was created to provide coordinated advice on the science and technical aspects of the European Union's Water Framework Directive (2000/60/EC) including environmental standards and classification.

For more information see the UKTAG website: <http://www.wfduk.org/>

Appendix I

SIMCAT Water Quality Modelling Technical Report – River Severn Drought Order

River Severn Drought Order – WQ Modelling Summary

Environment Agency

As the only current water quality modelling tool available that includes the River Severn corridor from source to estuary, including the ability to model the inputs from all tributaries and the flow control measures at Vyrnwy and Clywedog reservoirs, the 2009 River Severn River Basin District SIMCAT model represented the best option for assessing the Severn Drought Order options.

SIMCAT is a proven modelling tool for water quality planning and has been used by the Environment Agency for over two decades. It has been developed as a software package that can represent point and diffuse source inputs as well as in-river decay. SIMCAT is and can be used for the calculation of water quality statistics (usually mean and 90th percentiles) and for the determination of discharge consent conditions.

The model, rebuilt in 2009 using the most up to date data available at that time, was deemed fit for purpose in terms of both quality and quantity calibration at the time of its completion. SIMCAT models are constructed using mean and standard deviation quality data and mean and 95% low flow data for flow. A more recent model has been built (2015) but, for reasons discussed below, it wasn't deemed necessary to rerun the modelling for this update report.

The model operates on the relatively simple principles of mass balance calculations in which upstream loads and discharge loads are mixed to provide a downstream estimate of load. Although it is possibly not best suited to the representation of extreme low flows as experienced during drought conditions, it is the best suited water quality modelling tool available for a whole catchment assessment. As such it was agreed that the model represents the best available tool for the Severn Drought Order water quality assessment.

In terms of flow data, the model has been built on data provided from 57 flow gauges throughout the catchment and daily mean flow data provided by Severn Trent Water where available for the discharges included in the model. Where actual data was not available, the permitted discharge volumes were used.

Major abstractions are also included in the SIMCAT model where it was felt they had a significant impact upon the flows in the environment (29 sites in total). Where applicable, the appropriate hands-off flows can be incorporated in order to limit how much water can be taken from the environment at times of very low flow. The model, however, does not incorporate drought permit requirements at any features.

The quality data used to build the final SIMCAT model came from a variety of sources including a total of 499 river quality sites, 334 sewage treatment works and 50 industrial discharge sites.

A series of correlation exercises were completed to determine the degree of relationship between certain model parameters. These included investigating the relationship between river flow and river quality, effluent flow and quality and effluent flow and river flow. How each parameter relates to each other was then incorporated into the final model.

In terms of flow calibration, all sites satisfied the primary goal of predicting mean and 95%ile river flows within one standard deviation of the measured data provided during the model build. Calibration against the secondary, and more stringent, test of remaining within 10% of the observed data was less successful, however, only seven of the 57 flow gauge locations failed to achieve this criteria. Many of these sites were in areas of low flow meaning that any small error is often exaggerated in terms of percentage error but that the actual difference between calculated and observed values are often quite small.

Locations of poorer calibration of most interest with regards to the output of this assessment are as follows:

1. River Severn, Buildwas – -13.2% difference in 95%ile (predicted = 779.3MI/d, Observed = 897.3MI/d)
2. River Severn, Bewdley – 16.4% difference in Mean (predicted = 6054.5MI/d, Observed = 5202.0MI/d)
3. River Severn, Saxons Lode – -16.2% difference in 95%ile (predicted = 1324.1MI/d, Observed = 1580.0MI/d)

Table 1 – Percentage of water quality points calibrated to within one standard deviation

Parameter	Statistic	No. of Water Quality Points	% of Water Quality Points within Criteria
BOD	Mean	483	92
BOD	95%ile	483	60
Ammonia	Mean	486	72
Ammonia	95%ile	486	43
Dissolved Oxygen	Mean	486	95
Dissolved Oxygen	95%ile	486	80
Phosphate	Mean	485	78
Phosphate	95%ile	485	41
Nitrogen	Mean	486	81
Nitrogen	95%ile	486	54

These figures represent the results from manual calibration and, in terms of theoretical water quality modelling, can be regarded as having achieved a 'good match'. The performance of the model was further improved, however, through the use of auto-calibration where the model automatically adds or removes load from the model in order to improve the match between predicted and observed data.

In terms of the use of the model for the assessment of the Severn Drought Order, however, the manually calibrated model was used to assess the relative performances of the different scenarios to be tested. Although this may appear strange given the improved nature of the model following auto-calibration, there were two key reasons for this decision:

1. When running what-if scenarios in an auto-calibrated model, it is very difficult to eliminate the effects of the 'adjusted' loads from all locations in the model. It is often unknown why this should occur and so, as a safeguard, it was decided to use the manually calibrated model in this assessment.
2. As the assessment of the Severn Drought Order options was a straight forward comparison of river quality as opposed to an assessment of compliance or an exercise to set permit limits, it was felt that perfect calibration was not required, especially given the potential errors that could occur as detailed in 1 above.

The original modelling brief involved a two stage process:

Stage 1: Representation of drought conditions in the model under an acute and chronic scenario

Stage 2: Modelling the impact of invoking the Environment Agency's Severn Drought Order for both stage 1 scenarios

Stage 1 – Representation of drought conditions in SIMCAT

From a starting point of the original model representation of mean and Q95 low flows, the original aim was to reduce flows to match those modelled in Aquator, simulating two theoretical drought events of greater magnitude than the 1976 drought.

This was to be achieved through a catchment-wide reduction in flows in line with prescribed ratios derived from the Aquator flow modelling scenarios. A full table of the adjustment factors can be found in Table 2 below:

Table 2 – Drought condition adjustment factors

Headwater reference location			Flow headwater adjustments			
			Acute		Chronic	
			mean	95%	mean	95%
2001	Bewdley	R. Severn 13	8.39	8.43	1.64	1.68
2003	Vyrnwy Weir	R. Vyrnwy	see below			
2032	Saxons Lode	R. Severn	8.39	8.43	1.64	1.68
2057	Haw Bridge	R. Severn	8.07	6.36	1.46	1.97
2109	Bryntail	R. Clywedog	see below			
2134	Buildwas H	R Severn	18.13	6.77	3.12	2.36
2134	Buildwas S	R. Severn	6.48	5.23	1.77	1.79
2606	Deerhurst	R. Severn	8.07	6.36	1.46	1.97
n/a	Hook Cliffe	R. Severn	8.07	6.36	1.46	1.97

Having assigned all headwater flows included in the SIMCAT model to the relevant flow gauge included in Table 2, the appropriate flow was reduced by the corresponding factor in the same table, depending upon the severity of drought condition being modelled (acute or chronic).

The same process was applied to diffuse flows entering the model and also tributary flows included in the model but not specifically modelled for water quality.

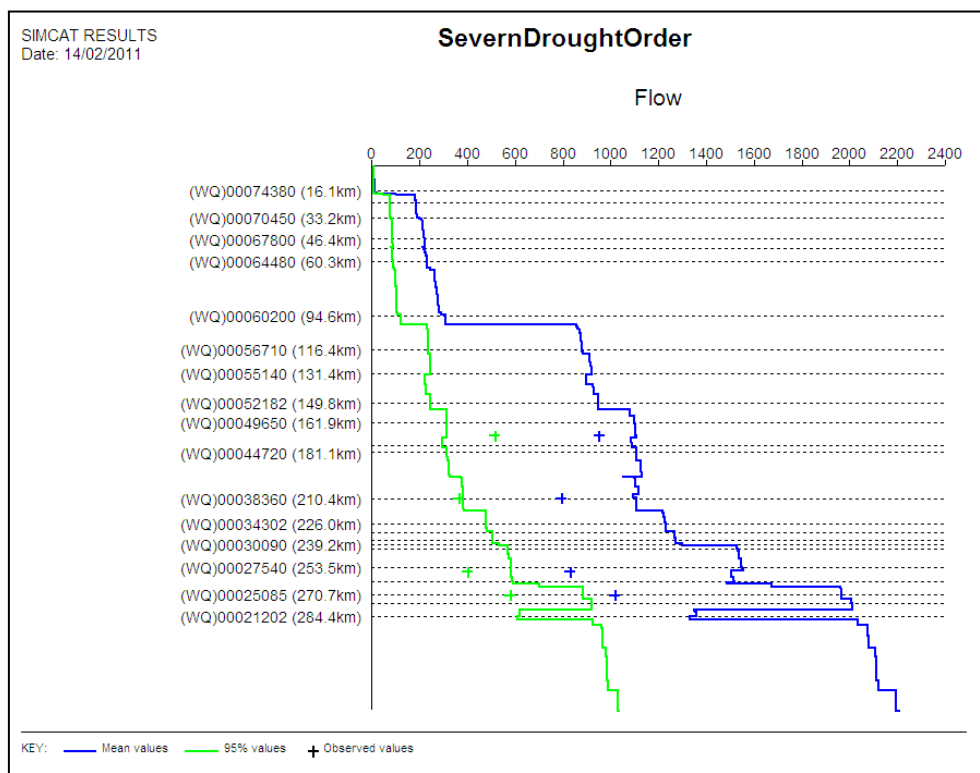
In order to further represent the drought conditions, all discharge inputs to the model were reduced to represent just their dry weather flow as opposed to the inclusion of storm water runoff. This was further enhanced by the reduction of the standard deviation of this data to zero in order to represent a prolonged dry period.

The intention of these initial reductions was to match the prescribed flows detailed in Table 3 below:

River Flows	Acute				Chronic (2nd summer)			
	With DO		Do Nothing scenario		With DO		Do Nothing scenario	
	mean	95%	mean	95%	mean	95%	mean	95%
Clywedog Reservoir	142.03	75.88	222.83	8.87	253.32	18.20	108.07	12.39
Vyrnwy Reservoir	145.03	45.00	145.03	45.00	82.55	25.00	58.16	25.00
Buildwas C Flow	869.87	605.93	950.07	512.69	1020.02	911.19	1610.17	638.01
Bewdley C Flow	727.42	456.77	791.23	363.30	834.82	711.14	1441.64	443.60
Saxon Loade CF	774.46	513.60	828.93	400.10	956.04	765.21	1719.37	581.90
Haw Bridge C Flow	962.64	692.35	1014.77	577.05	1173.54	915.96	2057.80	794.55
Lower Part CF	746.99	499.15	789.42	371.34	997.70	693.29	1870.58	532.95

Table 3 – Prescribed Flow Gauge flows based on Modelled drought scenarios

Figure 1 below represents the results of this initial adjustment under acute, non-drought order conditions with the coloured crosses representing the target flows listed in Table 2.

Figure 1 – SIMCAT output following initial flow adjustments

It is clear from the SIMCAT output in Figure 1 that the initial adjustments made failed to achieve the required flow reduction throughout the model. Although flow representation in the upper Severn corridor matched prescribed flows accurately enough, an ever increasing margin of error was evident with distance downstream.

Consultation with the originators of the forecasted flows suggested that the model may be wrongly estimating the many abstractions that occur between Buildwas and Bewdley and that these should be checked to ensure the abstracted volumes were correct.

Completion of this exercise showed that the model represented the full licensed volumes and, therefore, the worst possible impact in terms of flow reduction. Removal of the hands-off flows associated with these abstractions was trialled although this further complicated the results with a practical 'bottoming-out' of the Q95 flow and a persistent over-estimation of the mean flow. Specific drought permit parameters cannot be integrated into the SIMCAT model and as such, will not be a factor in the calibration of the drought condition model.

Further investigation into the input flow data showed up obvious areas of error that could be approached to try to improve the match between predicted and observed data. These are included in Table 4 below:

Table 4 – SIMCAT/AQUATOR Prediction errors

Tributary Name	SIMCAT Predicted Flow (MI/d)	AQUATOR Predicted Flow (MI/d)
Afon Vyrnwy	547.0MI/d	145.0MI/d
River Stour	111.5MI/d	85.1MI/d
River Teme	233.3MI/d	6.11MI/d
River Avon	439.8MI/d	239.9MI/d

Further investigation into the four key tributaries showed no immediate errors so an exercise to further reduce the headwater and diffuse flows was undertaken to try to create a better match between predicted and observed data.

Problems were immediately encountered on the River Stour where it became apparent that population growth in the catchment since the mid 1970s had been considerable and that discharge flows under dry weather conditions alone exceeded the target flow suggested by AQUATOR.

Assuming this would be the case throughout the model, it became further apparent that trying to achieve the target flows in the River Severn corridor would entail making adjustments in flow that would not represent reality and would no longer be defensible in terms of the Severn Drought Order justification.

Consequently, it was decided to just make logical adjustments to the Severn River Basin District SIMCAT model flow parameters which could be backed up and fully justified. These can be summarised as:

1. Adjustment of headwater, diffuse and tributary flow inputs in line with the Table 2 adjustment factors
2. Reduction in licensed discharge volumes to the measured dry weather flows
3. Reduction of the discharge standard deviations to zero.

Figure 2 below illustrates the final acute, non-drought order representation of flows whilst Figures 3 (mean flow) and 4 (Q95 flow) compares this final situation with the flow conditions represented in SIMCAT during non-drought periods.

Figure 2 – Final acute drought condition representation

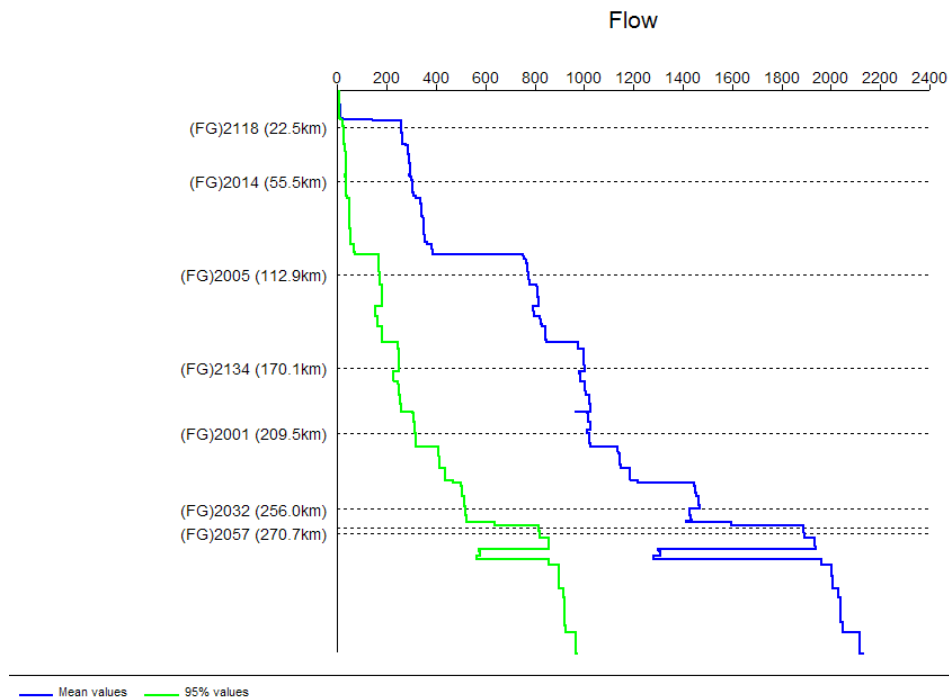


Figure 3 – Acute drought / Non-drought mean flow condition comparison

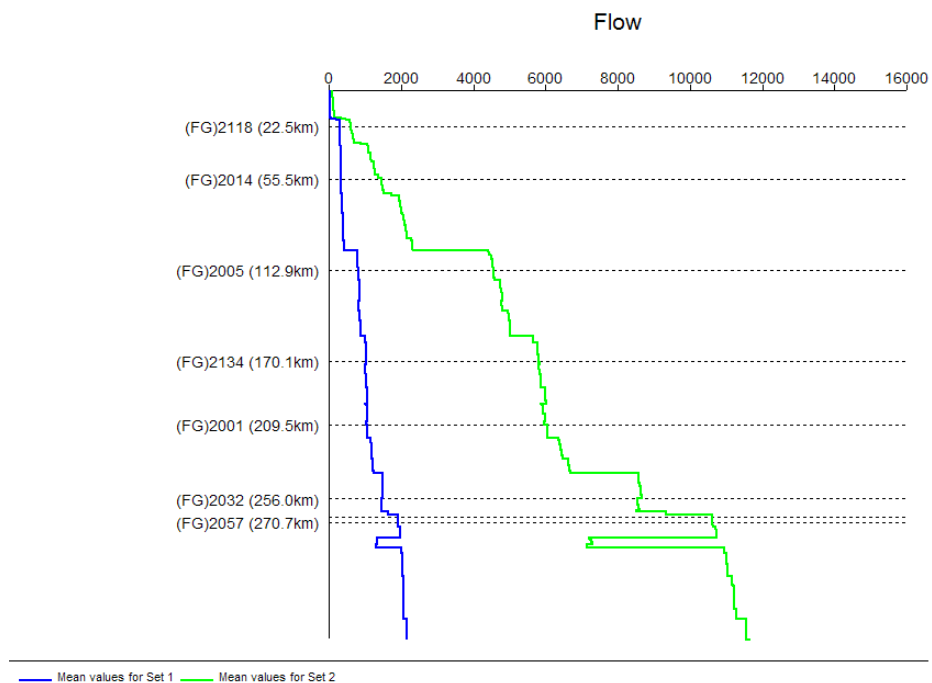
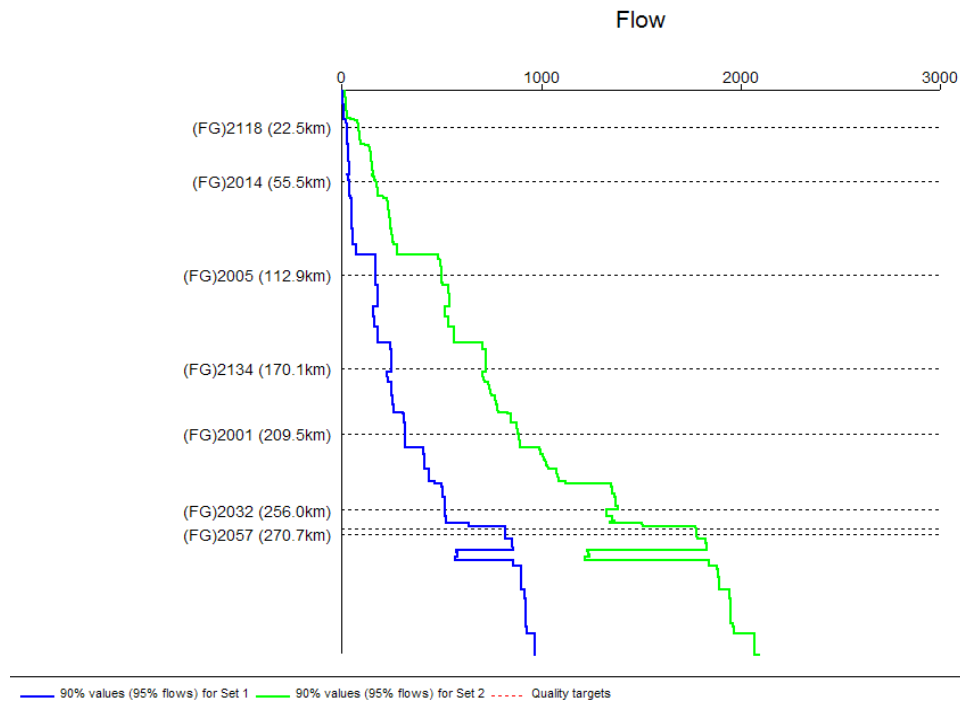
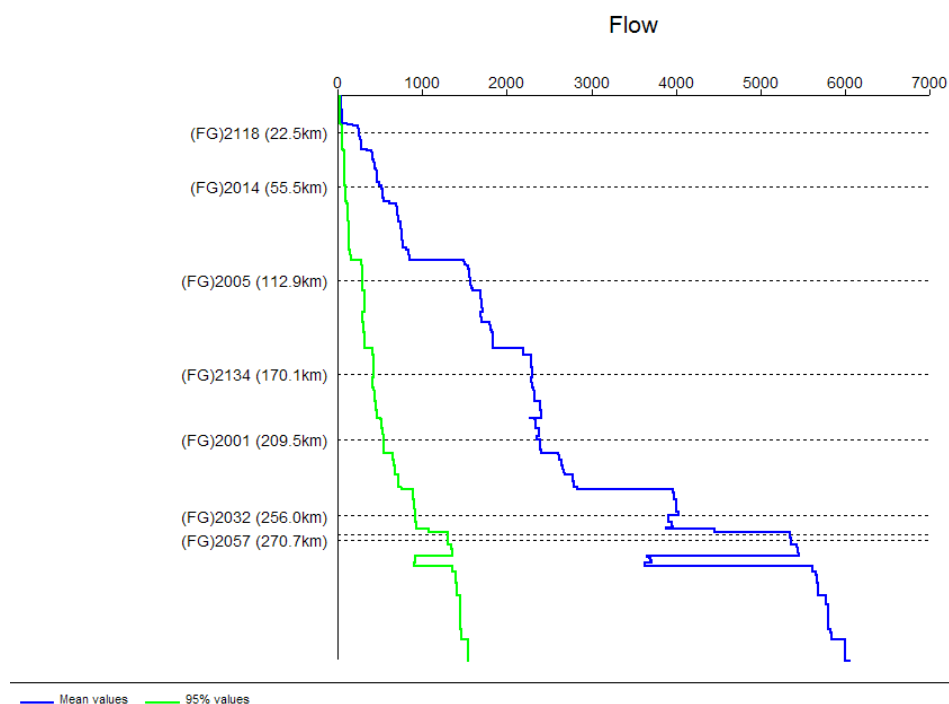


Figure 4 – Acute drought / Non-drought Q95 flow condition comparison

Having established that further refinement of the model was unrealistic and undefendable, work could also progress on the chronic drought condition representation in SIMCAT. The same process was followed to establish the non-drought order scenario, using the chronic mean and Q95 adjustment factors from Table 2 in place of the corresponding acute scenario figures.

Figure 5 below represents the final, adjusted SIMCAT flows for chronic drought conditions.

Figure 5 – Final chronic drought condition representation

Similar to the graphs produced for the acute drought situation, Figures 6 (mean flow) and 7(Q95 flow) compares the final acute situation with the flow conditions represented in SIMCAT during non-drought periods.

Figure 6 – Chronic drought / Non-drought Mean flow condition comparison

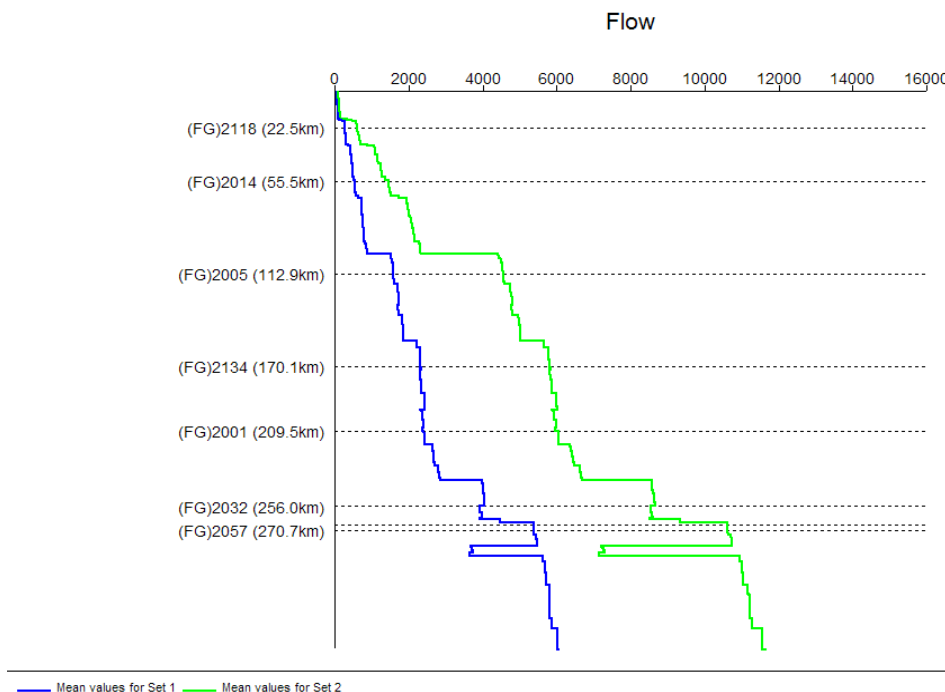
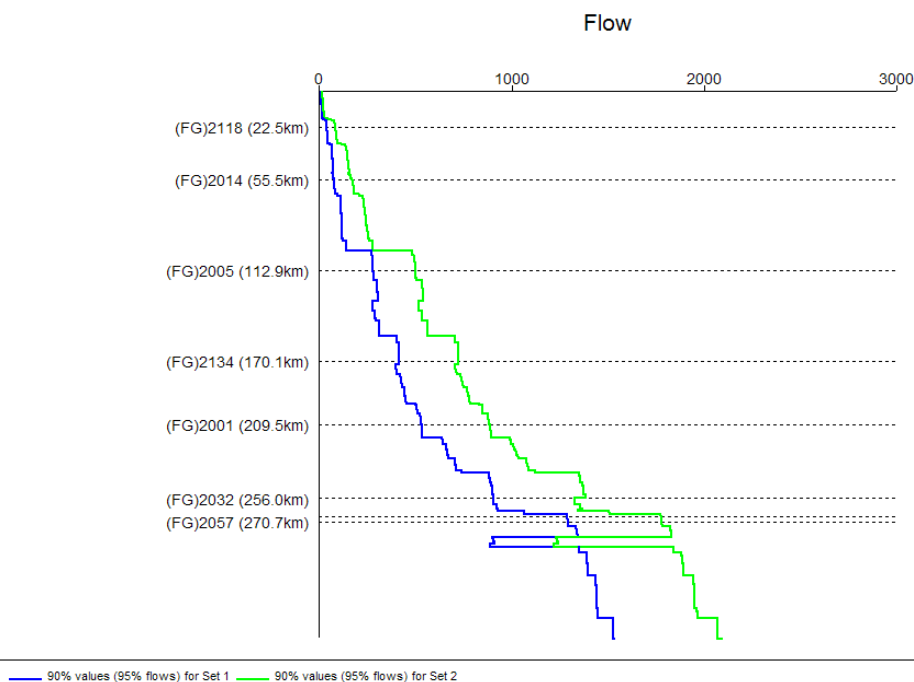


Figure 7 – Chronic drought / Non-drought Q95 flow condition comparison



Despite the assumption that the adjustments made to the model to reduce flows to represent drought conditions have been accepted as the best possible attempt whilst remaining within realistic bounds, it was also decided to simulate a worst possible flow scenario in SIMCAT by reducing all natural flows to zero.

By reducing all headwater flows and all diffuse inflows to the Severn catchment to zero, the modelling exercise effectively simulated a situation where flows comprised of just treated effluent discharges and the releases from Vyrnwy and Clywedog reservoirs.

Figures 8 and 9 below illustrate how these changes are reflected in the model for both acute and chronic flow scenarios compared with the predicted Aquator flows.

Figure 8 - Acute Drought Scenario, Zero Natural Flow

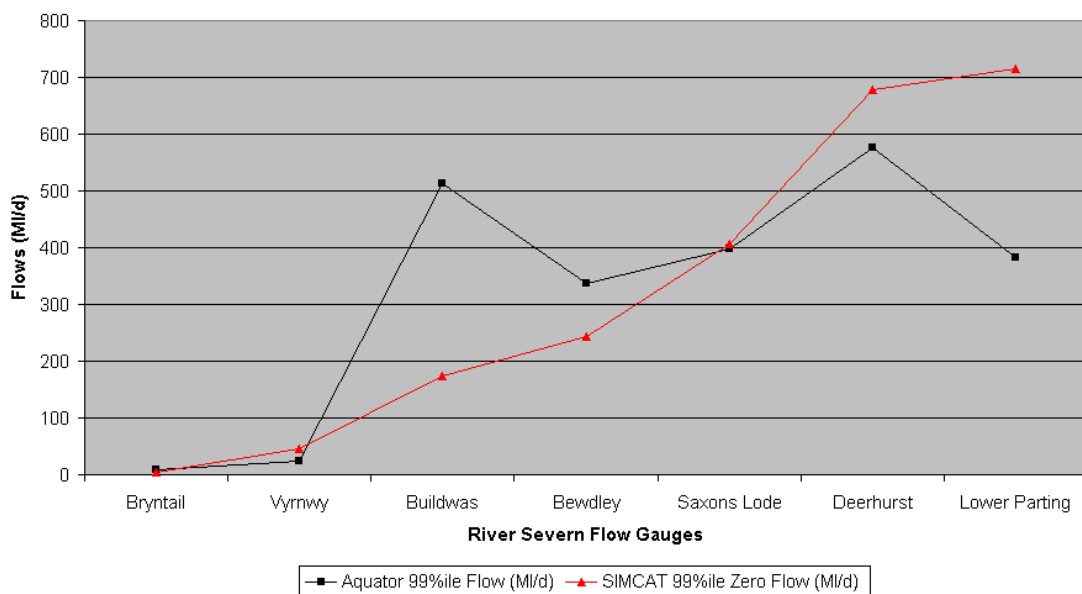
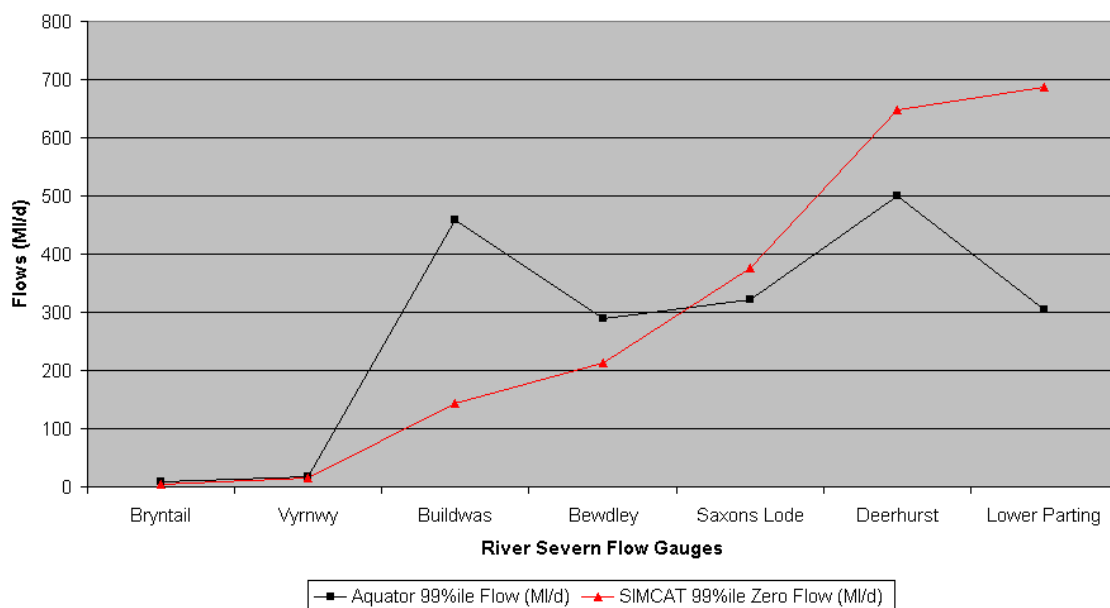


Figure 9 - Chronic Drought Scenario, Zero Natural Flow



Despite remaining in excess of the predicted Aquator flows beyond Saxons Lode in both cases, the overall difference is much reduced and flows predicted by SIMCAT at the head of the Severn Estuary are much lower compared with the previous calibration attempts.

This would appear to better represent the required flows throughout the model but it should be recognised that the adjustments made are unrealistic and should only be applied for the purpose of portraying a worst case water quality scenario.

Stage 2 – Water Quality Assessment following application of the Environment Agency’s Drought Order

Having previously established the SIMCAT data files to represent both acute and chronic drought conditions throughout the River Severn catchment, the only alterations required to the data files in order to simulate the impact of the drought order were changes to the key control locations at Vyrnwy and Clywedog reservoirs.

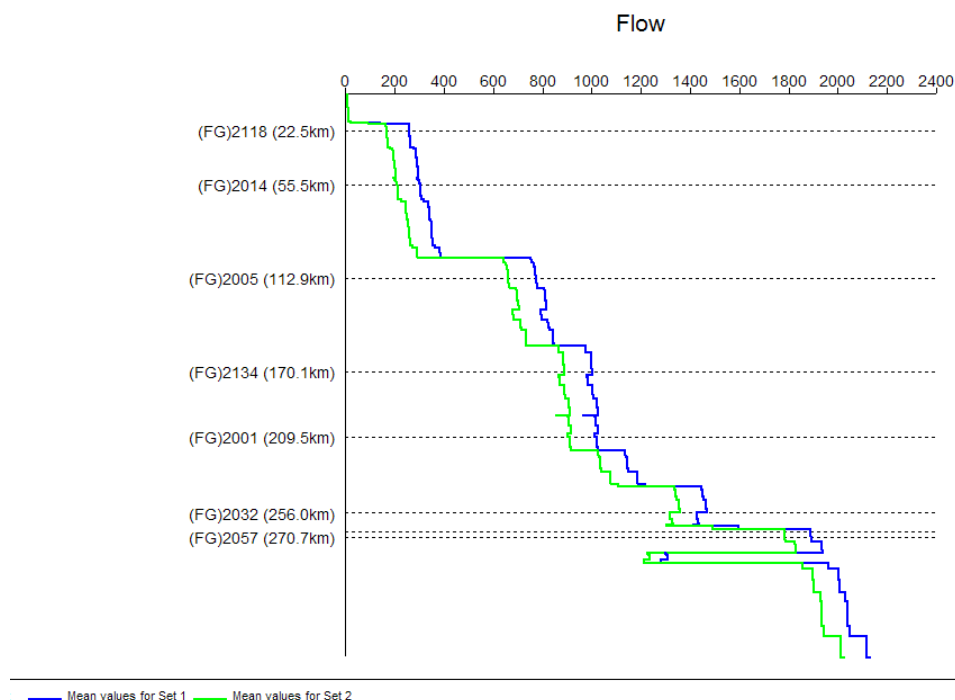
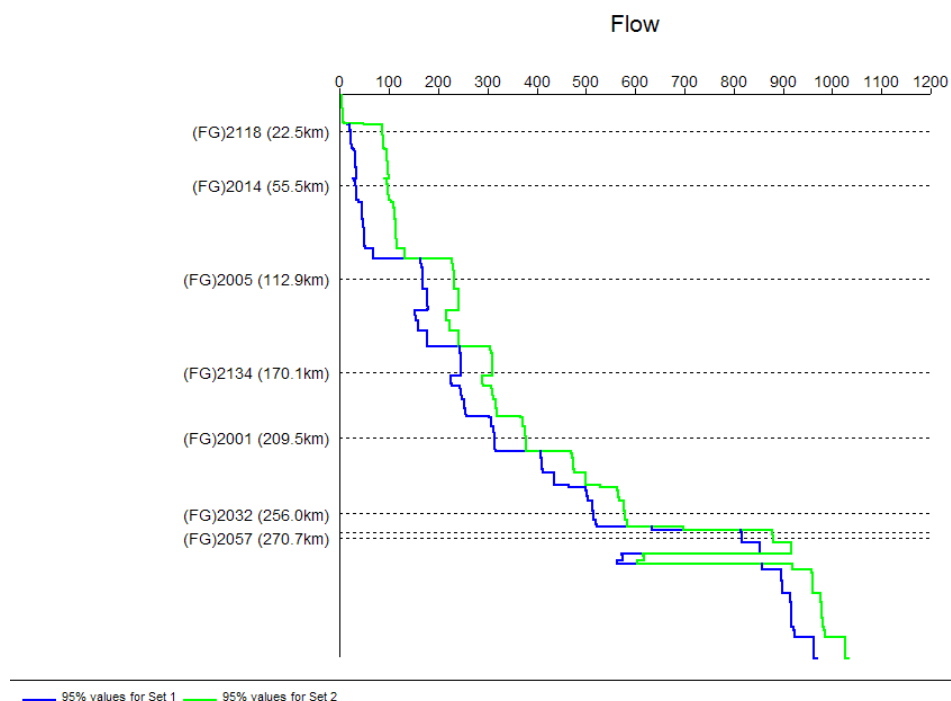
Table 5 below summarises in bold the key changes required in order to represent the varying control measures in the catchment. In both reservoir cases, the required flows were represented by making factored changes to the headwater and diffuse flow inputs in order to match the Table 5 flow figures at Bryntail (for Clywedog) and Vyrnwy Reservoir flow gauges.

Table 5 – Drought Order Flow Gauge Measurements

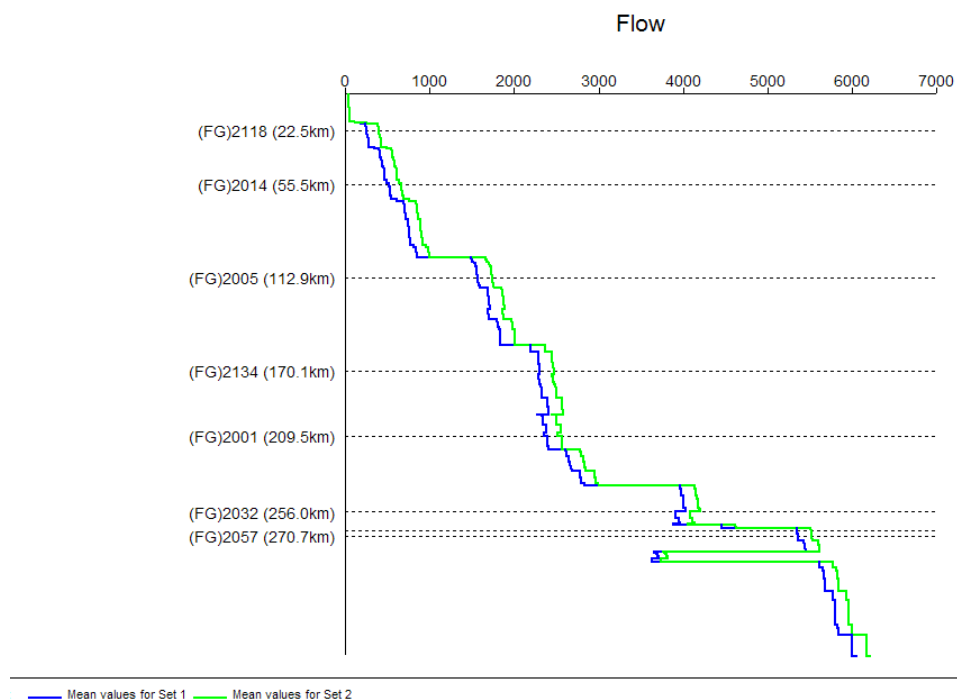
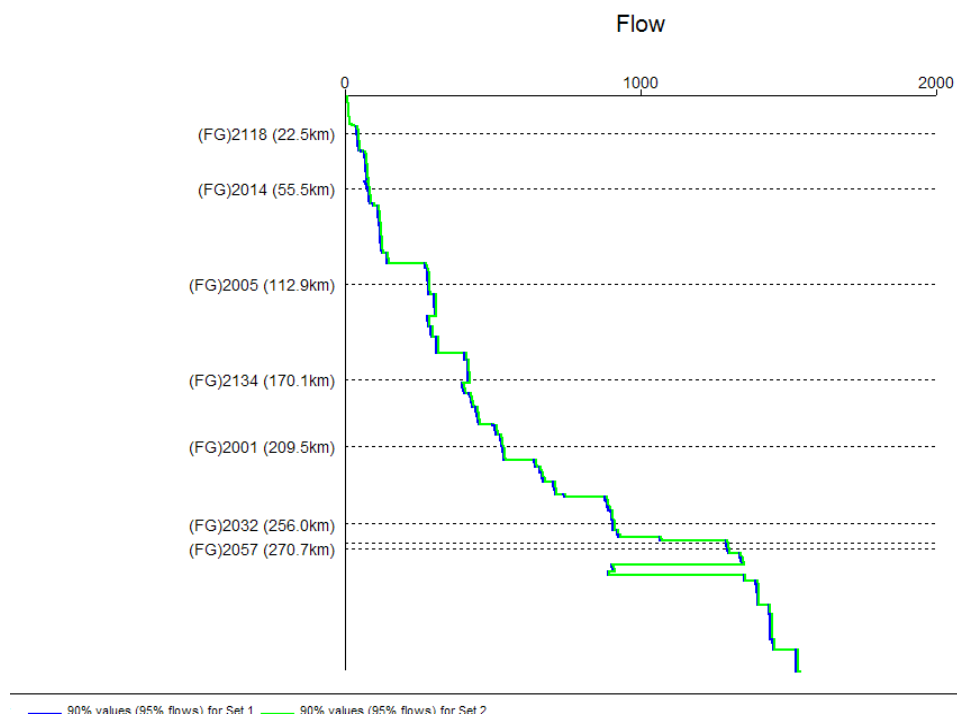
River Flows	Acute				Chronic (2nd summer)			
	With DO		Without DO		With DO		Without DO	
	mean	95%	mean	95%	mean	95%	mean	95%
Clywedog Reservoir	142.03	75.88	222.83	8.87	253.32	18.20	108.07	12.39
Vyrnwy Reservoir	145.03	45.00	145.03	45.00	82.55	25.00	58.16	25.00

Representation of the revised releases and their impact on flows throughout the River Severn corridor can be seen in Figures 8 to 11 below.

With regards to the acute drought scenario in figures 10 and 11, the managed and reduced mean reservoir release from Clywedog results in a reduction in the mean flow throughout the river corridor (no drought order in blue, drought order in green) whilst the increase in the released Q95 flow sees an improved situation along the same length of river.

Figure 10 – Acute drought comparison including drought order operation (mean flow)**Figure 11 – Acute drought comparison including drought order operation (Q95 flow)**

Applying the same logic to the changes required for the chronic drought scenario (Figures 12 & 13 – no drought order, blue, drought order, green), the comparison shows barely any difference in the Q95 flows (the managed scenario effectively tracks the drought conditions) whereas the chronic mean flows show significant benefit from the increased releases from both reservoirs.

Figure 12 – Chronic drought comparison including drought order operation (mean flow)**Figure 13 – Chronic drought comparison including drought order operation (Q95 flow)**

In order to fully assess the impact of the operation of the drought order on water quality, an assessment of compliance against both Water Framework Directive (WFD) targets and Fundamental Intermittent

Standards was carried out for phosphates, ammonia and biochemical oxygen demand (BOD). A comparative assessment of Total Oxidised Nitrogen is also included for reference.

From the same graphs, it is possible to determine the relative impact in terms of water quality concentration as a result of the operation of the drought order.

The relative standards for the various sections of the River Severn corridor can be found in Table 6 below.

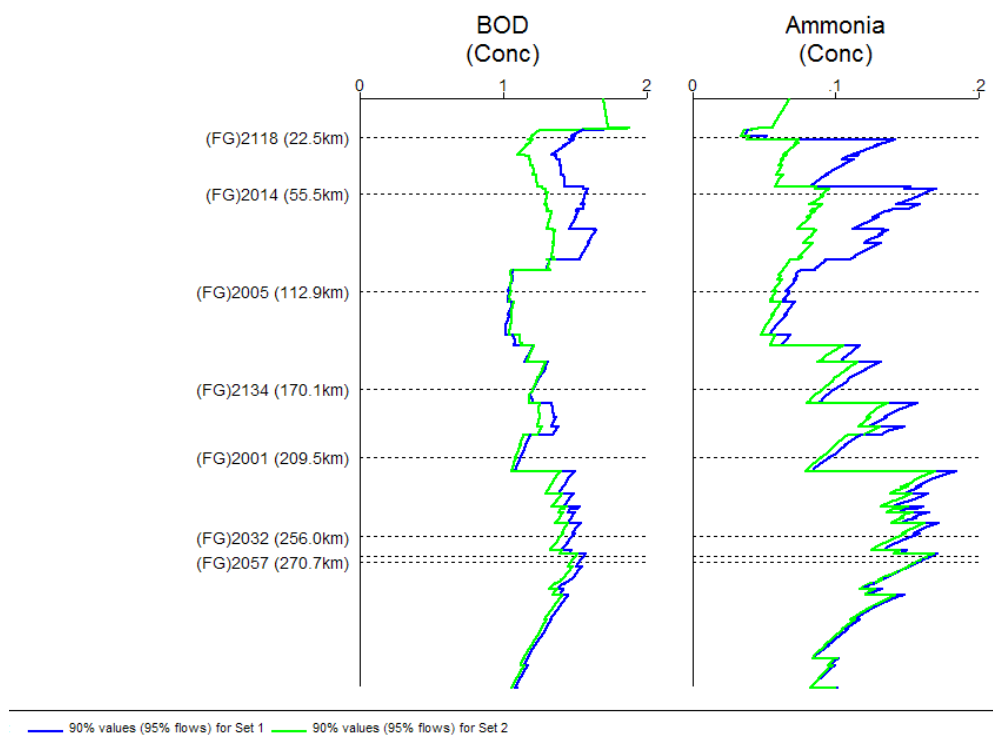
Table 6 – Water Framework Directive Targets and Fundamental Intermittent Standards

Waterbody ID	Waterbody Name	Ammonia		BOD		Phosphate	
		WFD Good (mg/l)	FIS 99%ile (mg/l)	WFD Good (mg/l)	FIS 99%ile (mg/l)	WFD Good (mg/l)	FIS 99%ile (mg/l)
GB109054044790	R Severn - source to conf Afon Dulas	0.3	0.6	4	5	0.028	n/a
GB109054049310	R Severn - conf Afon Dulas to conf R Camlad	0.3	0.6	4	5	0.028 – 0.038	n/a
GB109054049700	R Severn - conf R Camlad to conf Bele Bk	0.6	1.5	4	5	0.049	n/a
GB109054049142	Severn - conf Bele Bk to conf Sundorne Bk	0.6	1.5	4	5	0.052	n/a
GB109054049141	Severn - Sundorne Bk to conf M Wenlock-Farley Bk	0.6	1.5	4	5	0.054 – 0.061	n/a
GB109054049143	Severn conf M Wenlock-Farley Bk to conf R Worfe	0.6	1.5	4	5	0.062 – 0.064	n/a
GB109054049145	Severn - conf R Worfe to conf R Stour	0.6	1.5	4	5	0.065 – 0.068	n/a
GB109054049144	Severn - conf R Stour to conf River Teme	0.6	1.5	4	5	0.071 – 0.072	n/a
GB109054039760	Severn - conf R Teme to conf R Avon	0.6	1.5	5	9	0.075 – 0.076	n/a
GB109054044404	Severn - conf R Avon to conf Upper Parting	0.6	1.5	5	9	0.077 – 0.079	n/a
GB109054032750	Severn (E Channel) - Horsebere Bk to Severn Est	0.6	1.5	5	9	0.078	n/a

Figure 14 below displays both BOD and ammonia concentrations throughout the River Severn corridor for the Acute scenario and compares the relative water quality under the 'Do Nothing' (blue line) and EA Drought Order (green line) scenarios. The first obvious observation is that there are only very limited areas

of deterioration as a result of the drought order operation and that, generally, water quality in the drought order scenario (green line) is improved compared with the unmanaged situation.

Figure 14 - 90%ile assessment for BOD and Ammonia in acute drought conditions



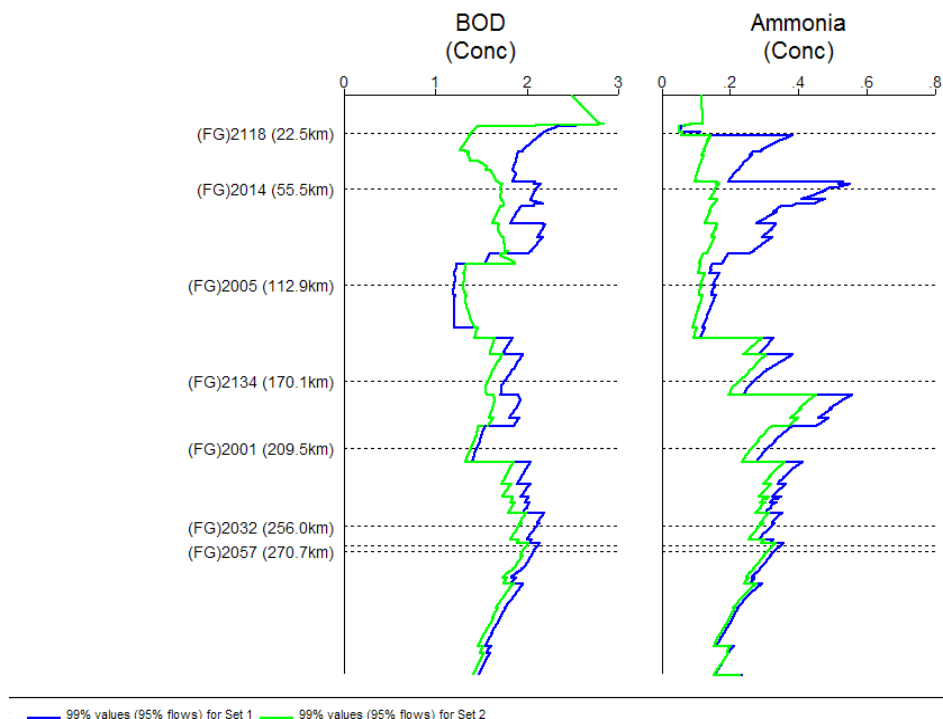
The only areas of minor deterioration in either determinand can be summarised as follows:

- BOD - Maximum 5% deterioration between Montford Bridge and Cross Houses on the River Severn
- BOD - Minor deterioration at Caerhowell on River Severn (1.5%)
- Ammonia – 25% increase in concentrations on the Afon Vyrnwy d/s of Llansantffraid

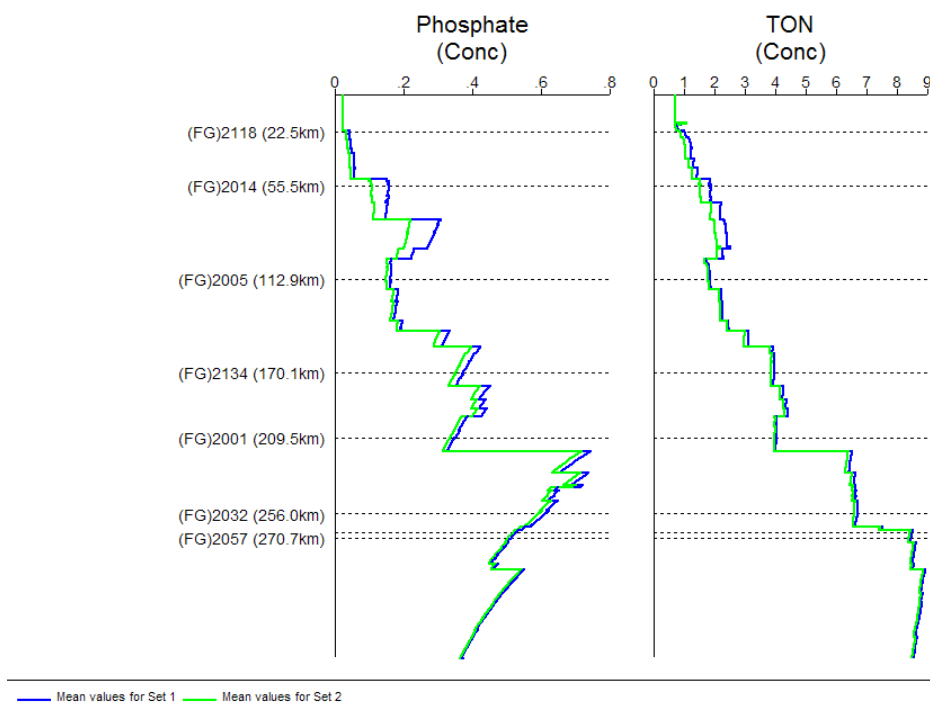
In none of the above locations, however, was the deterioration great enough to cause any failure of WFD targets. In fact, Figure 14 above illustrates that no failures of the respective WFD target would be recorded in either the managed or un-managed drought scenario.

Figure 15 below displays the same two determinands (BOD and ammonia) as 99 percentiles. Use of such high percentiles allows a direct application of the results to extreme conditions. For example, Figure 15 effectively represents the concentrations which are exceeded for just 1% of the time or, the equivalent of just 3.65 days/year.

Use of such standards allows assessment of potential worst case scenarios when, one could assume, river flows are at their lowest and dilution conditions for discharges to the river are at their worst.

Figure 15 – 99%ile assessment for BOD and Ammonia in acute drought conditions

Comparison of the results portrayed in Figure 15 with the required standards in Table 6 shows that at no point on the River Severn are concentrations predicted to exceed the 99th percentile regarded as representing a threat to the aquatic environment.

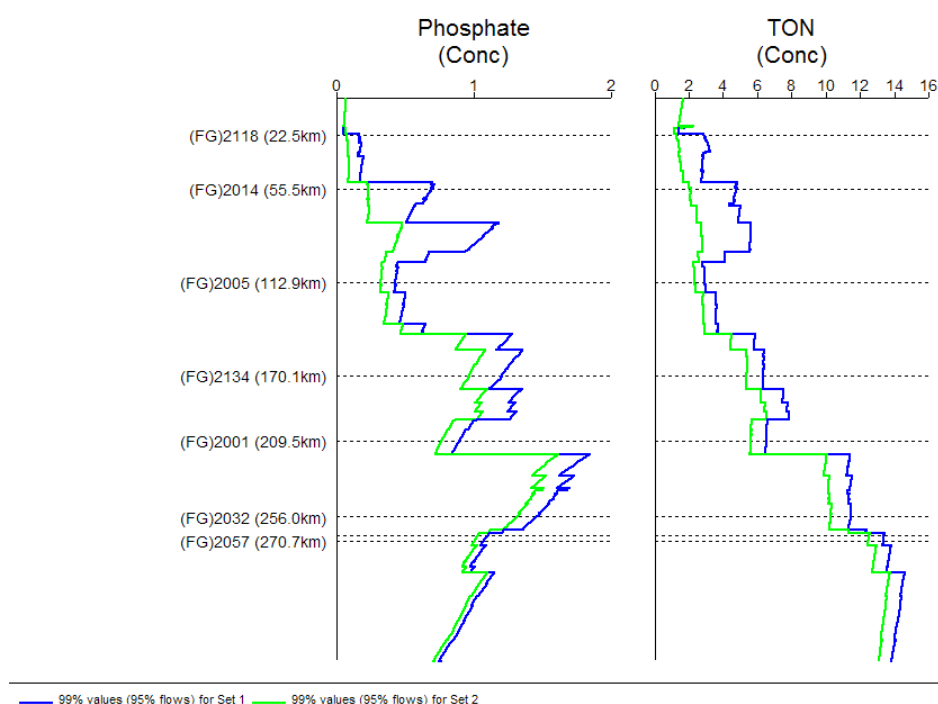
Figure 16 – Mean assessment for Phosphate and TON in acute drought conditions

Although it is immediately evident that phosphate concentrations exceed WFD standards in both acute drought scenarios, this is of lesser concern considering WFD compliance for phosphate along the River Severn corridor is currently less than good at all locations downstream of Cressage.

Consequently, there would appear to be a significant length of new WFD standard failure for phosphate in the River Severn during drought conditions but crucially, operation of the drought order generally improves concentrations throughout the Severn corridor compared with the unmanaged scenario.

The same can be said for Total Oxidised Nitrogen (TON) concentrations in that they do not appear to deteriorate following commencement of the drought order operations.

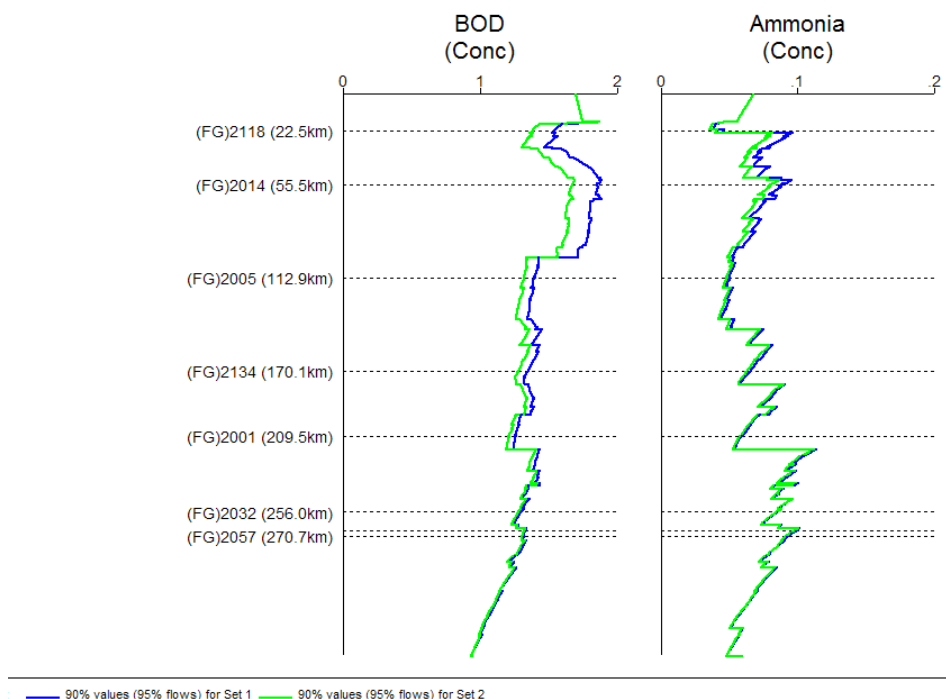
Figure 17 – 99%ile assessment for Phosphate and TON in acute drought conditions



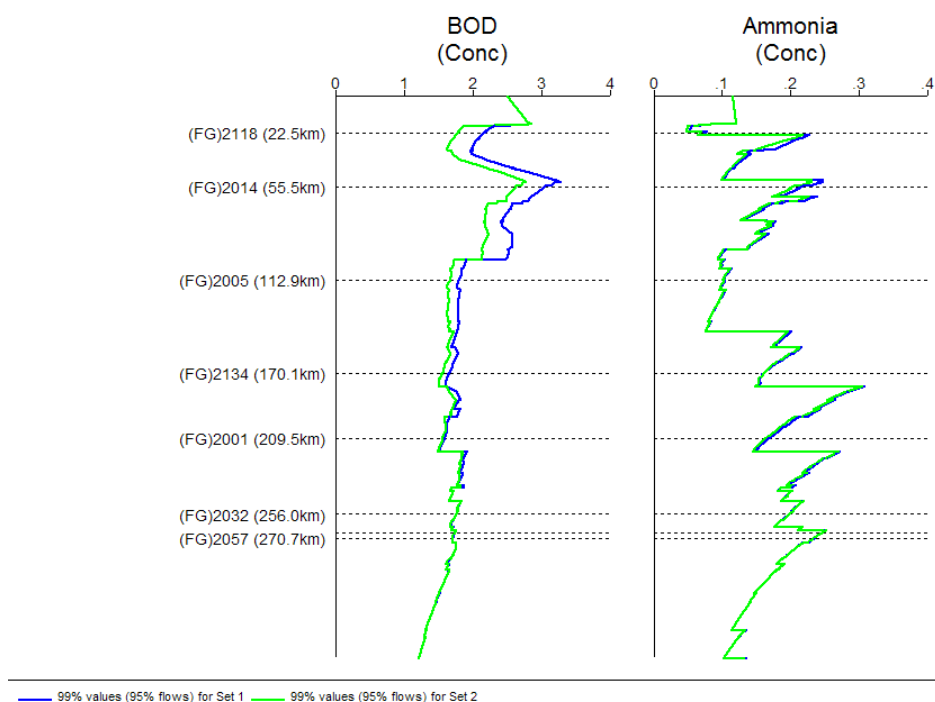
In terms of an almost worst case scenario, Figure 17 demonstrates that concentrations of both nutrients will reach quite high levels during the lowest flow situations. This is inevitable given the lack of dilution in these cases but, once again, it is noticeable that the Severn drought order operation will only help to improve the situation and reduce the potential impact on the aquatic ecosystems.

Consideration of the chronic drought scenario shows a very similar situation. Figures 18 to 20 below demonstrate no significant deterioration in any determinand at any point in the Severn or Vyrnwy catchments as a result of the revised releases from Vyrnwy and Clywedog Reservoirs under operation of the drought order.

This is of no real surprise given the increased flows assessed throughout the catchment as part of this drought scenario and the fact that operation of the drought order would result in greater mean and Q95 flows released from Clywedog and mean flows from Vyrnwy.

Figure 18 - 90%ile assessment for BOD and Ammonia in chronic drought conditions

As with the acute drought scenario, no new WFD failures are recorded in either BOD or ammonia as a result of the environment experiencing drought conditions. The same is true of the 99 percentile standard applicable to River Severn corridor as demonstrated in Figure 19 below where the maximum concentrations predicted in the worst case scenario both largely remain below 3mg/l and 0.3mg/l for BOD and ammonia respectively (tightest applicable targets = 5mg/l and 0.6mg/l)

Figure 19 – 99%ile assessment for BOD and Ammonia in chronic drought conditions

Not unexpectedly, achievement of WFD Good Status for phosphates is made harder during the modelled periods of drought with a general increase in nutrient concentrations across the board (Figure 20). As with the acute conditions, however, the biggest comfort remains that application of the drought order marginally improves the situation with increased dilution reducing both phosphate and TON concentrations (Figures 20 & 21).

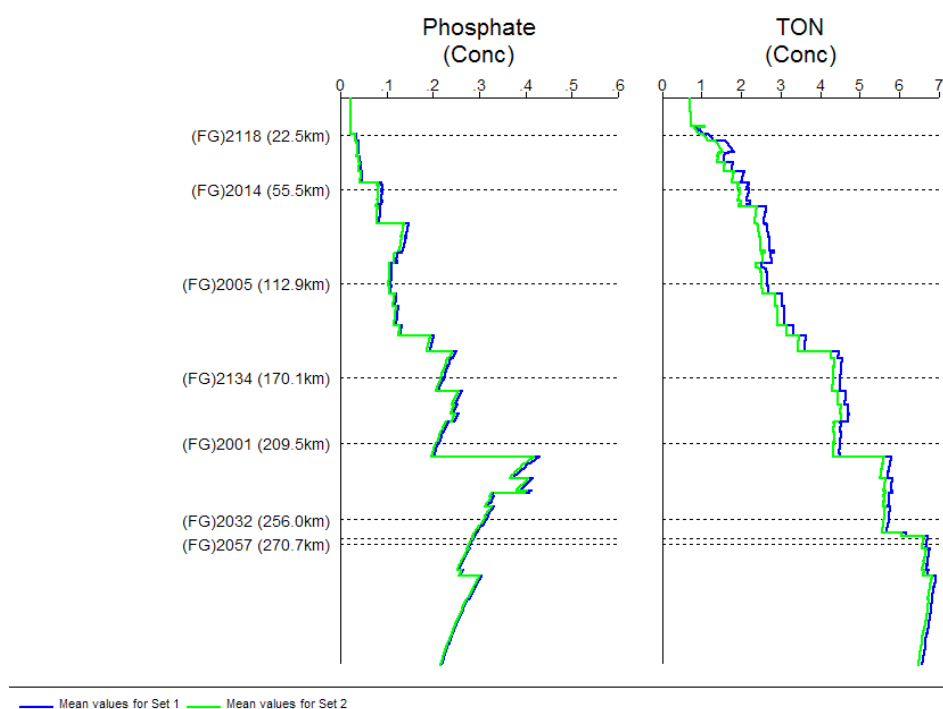
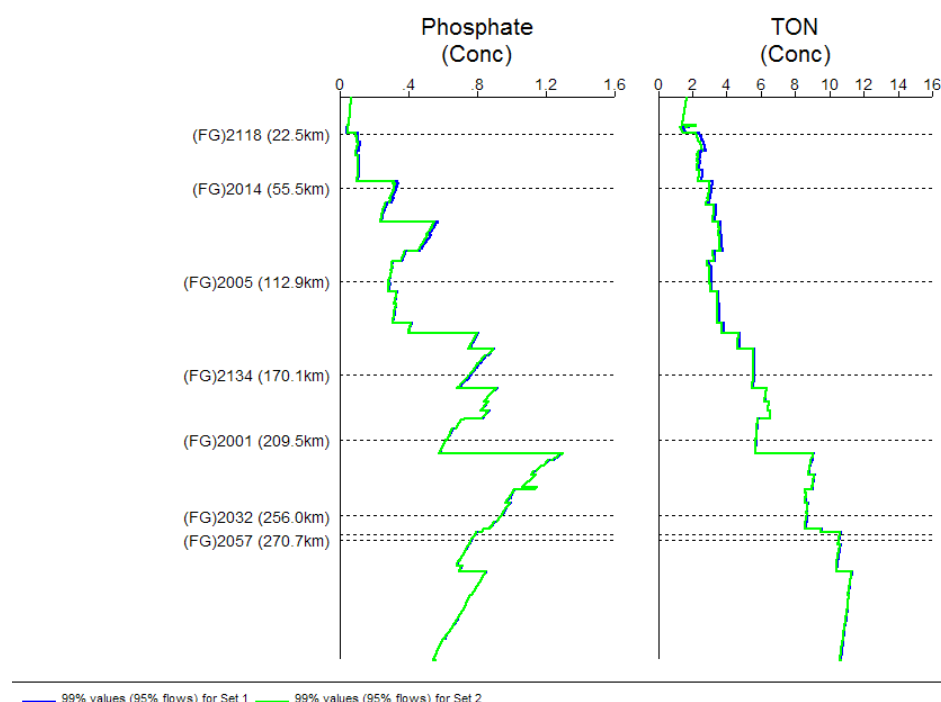
Figure 20 – Mean assessment for Phosphate and TON in chronic drought conditions

Figure 21 – 99%ile assessment for Phosphate and TON in chronic drought conditions

Consideration of the zero natural flow scenario shows a similar situation for both ammonia and BOD in both acute and chronic drought conditions. Comparison with the previous work (Figures 15 & 19) suggests that predicted concentrations for both determinands in this scenario are not particularly elevated and, as such, do not record failures of the required Water Framework Directive Standards. This is reassuring considering the lack of natural dilution, even when measured at the 99%ile (Tables 7 & 8) and additional comfort is offered by the prediction that application of the drought order only improves the predicted water quality.

Table 7 – BOD and Ammonia predicted concentrations in acute drought conditions with no natural flows

Flow Gauge Location	FG Ref	No Drought Order		Drought Order	
		BOD 99%ile (mg/l)	Ammonia 99%ile (mg/l)	BOD 99%ile (mg/l)	Ammonia 99%ile (mg/l)
Bryntail	2109	1.6	0.05	1.6	0.05
Vyrnwy	2003	1.67	0.03	1.67	0.03
Buildwas	2134	2.13	0.36	1.84	0.31
Bewdley	2001	1.61	0.47	1.36	0.36
Saxons Lode	2032	2.32	0.45	2.1	0.38
Deerhurst	2057	2.28	0.39	2.17	0.36
Lower Parting		2.08	0.35	1.96	0.33

Table 8 – BOD and Ammonia predicted concentrations in chronic drought conditions with no natural flows

Flow Gauge Location	FG Ref	No Drought Order		Drought Order	
		BOD 99%ile (mg/l)	Ammonia 99%ile (mg/l)	BOD 99%ile (mg/l)	Ammonia 99%ile (mg/l)
Bryntail	2109	1.6	0.05	1.6	0.05
Vyrnwy	2003	1.67	0.03	1.67	0.03
Buildwas	2134	2.42	0.43	1.88	0.35
Bewdley	2001	1.73	0.48	1.42	0.37
Saxons Lode	2032	2.44	0.46	2.18	0.4
Deerhurst	2057	2.35	0.41	2.23	0.37
Lower Parting		2.12	0.36	2	0.33

The application of the drought order can also be seen to improve water quality in terms of nutrient concentrations in the zero natural flow scenarios. Although maximum concentrations are predictably higher in this situation compared with the more realistic scenarios discussed earlier (Figures 17 & 21), it is noticeable in Tables 9 and 10 below that concentrations are reduced once revised regulation of the flows from Clywedog and Vyrnwy are employed. **Table 9 – Predicted nutrient concentrations in acute drought conditions with no natural flows**

Flow Gauge Location	FG Ref	No Drought Order		Drought Order	
		Phosphate 99%ile (mg/l)	TON 99%ile (mg/l)	Phosphate 99%ile (mg/l)	TON 99%ile (mg/l)
Bryntail	2109	0.06	1.07	0.06	1.07
Vyrnwy	2003	0.06	0.58	0.06	0.58
Buildwas	2134	1.39	7.14	1.27	5.93
Bewdley	2001	1.07	6.69	0.97	6.1
Saxons Lode	2032	1.69	12.95	1.6	11.73
Deerhurst	2057	1.21	15.73	1.17	15.01
Lower Parting		1.11	15.56	1.07	15.04

Table 10 – Predicted nutrient concentrations in chronic drought conditions with no natural flows

Flow Gauge Location	FG Ref	No Drought Order		Drought Order	
		Phosphate 99%ile (mg/l)	TON 99%ile (mg/l)	Phosphate 99%ile (mg/l)	TON 99%ile (mg/l)
Bryntail	2109	0.06	1.07	0.06	1.07
Vyrnwy	2003	0.06	0.58	0.06	0.58
Buildwas	2134	1.61	8.18	1.4	6.52
Bewdley	2001	1.21	7.4	1.05	6.6
Saxons Lode	2032	1.79	13.49	1.66	12.34
Deerhurst	2057	1.24	16.02	1.19	15.16
Lower Parting		1.14	16.06	1.09	15.28

Summary

Acute Flow Scenario

- Application of the drought order generally results in an improvement in the water quality. There are some local areas of deterioration, notably
 - Phosphate - Afon Vyrnwy d/s of Llansantffraid - 33% increase in concentrations.
 - BOD - Maximum of 5% deterioration between Montford Bridge and Cross Houses. Minor deterioration at Caerhowell on River Severn (1.5%) - no new WFD failures.
 - Ammonia - Afon Vyrnwy d/s of Llansantffraid - 25% increase in concentrations - no resultant failure of WFD targets.
 - Nitrogen - General deterioration in concentrations throughout the Vyrnwy catchment.
- No new failures to achieve Water Framework Directive good ecological status for ammonia or BOD although widespread phosphate failures persist.
- No failures of the 99% targets associated with the river reach classes imposed under the River Ecosystem Classification and representative of extreme events
- Even under zero natural flow scenarios, maximum ammonia concentrations are predicted to equal 0.47mg/l with BOD pollution topping out at 2.32mg/l, both well within the WFD 90%ile standards.
- Nutrient concentrations continue to breach the required standards and are, indeed, elevated further without the benefit of any natural dilution flow for the treated effluent discharges.
- In all four cases, however, application of the drought order improves concentrations throughout the Severn catchment.

Chronic Flow Scenario

- No significant deterioration for any determinands at any point in the Severn or Vyrnwy catchments as a result of the drought order.
- No new failures to achieve Water Framework Directive good ecological status for ammonia or BOD although widespread phosphate failures persist.
- No failures of the 99% targets associated with the river reach classes imposed under the River Ecosystem Classification and representative of extreme events even under the worst-case scenario of zero natural flow.

Severn Estuary – Water Quality and Flow assessment

It has proved impossible to accurately calibrate the flows in the SIMCAT model to match the prescribed flows from the freshwater River Severn system to the Severn Estuary. The original attempt to adjust the model flows in accordance with ratio'd headwater flows and diffuse flows resulted in an over-estimation of almost 1250MI/d in the mean flow at Lower Parting at the head of the estuary and bottom of the SIMCAT model. This modelling error manifested itself as an error of almost 350MI/d at low flows, giving a predicted SIMCAT flow at almost twice the value suggested by AQUATOR.

The margin of error was duplicated in the second calibration exercise when all natural flows were removed from the SIMCAT model. This would suggest that treated effluent discharges into the catchment alone would contribute more flow to the head of the estuary than is expected by the AQUATOR modelling.

Given that the discharge flow figures were based on actual measured volumes during dry weather, it would appear that the SIMCAT model is incapable of achieving the prescribed freshwater flows to the estuary without forcing a fit through use of unrealistic abstraction and discharge data.

In terms of water quality impact on the estuary, however, given that the drought flows represent an 82% reduction in mean flows and a 56% reduction in low flows compared with the baseline model output, the deterioration in water quality at the 95%ile concentration is relatively slight. Phosphate concentrations increase from a non-compliant 0.58mg/l to 0.78mg/l whilst the deterioration in ammonia is just 0.04mg/l compared with a baseline of 0.14mg/l. Both concentrations being compliant with WFD Good Ecological Status requirements. Changes in BOD concentration actually see a predicted 40% improvement.

Extrapolating this data forward to the much lower flows predicted by AQUATOR, it could be suggested that any further deterioration in quality would be equally slight and would be unlikely to cause any new failures of desired water quality standards. It is possible, however, that the increasing nutrient

concentrations could result in eutrophic conditions given the right physical conditions in which macrophyte and algal growth could establish.

The worst case, zero natural flow scenario would tend to support this assumption. Considering this scenario represented almost zero dilution for treated sewage effluent discharges, the concentrations predicted at Lower Parting in tables 7 and 8 represent little concern with regards to the sanitary determinands, BOD and ammonia. As discussed above, the elevated nutrient concentrations could be of concern if appropriate growing conditions allow excessive plant growth to occur.

Referring the findings of this modelling to an actual historic situation, the 1976/77 drought, it is reassuring to read that the quality of the River Severn during the drought event caused very few concerns, despite the increased percentage of flow originating from sewage effluents. It should be noted, however, that temperatures recorded during the 1976/77 event were very high which aided the biological treatment of polluting loads in terms of both in-river purification and at treatment facilities. It is possible that should a drought period be experienced without these high temperatures then water quality deterioration could be more pronounced.

Of greater concern in terms of water quality is the possibility of conditions of high saline intrusion, elevated suspended solids and, as a result, reduced dissolved oxygen levels that could occur if residual freshwater flow to the estuary were severely reduced. Such conditions could prevail where residual flows are insufficient to prevent the landward movement of the area of maximum turbidity which is responsible for the drop in dissolved oxygen.

Mitigation options

Judging by the fact that water quality is not predicted to significantly deteriorate under the perceived worst case scenario of zero natural flows and that, under the same conditions, the predicted 99thile quality remains within WFD concentration criteria for ammonia and BOD, there appears to be little benefit in employing mitigation measures for water quality in drought conditions.

With regards to phosphate and nitrogen, the drought is likely to cause a further increase in concentrations. As water quality standards are already breached and environmental damage is already likely to be occurring in non-drought conditions, continuation of the current regime of work to reduce nutrient enrichment is seen to be the best way forward with no further mitigation measures required.

Modelling Limitations

Throughout the exercise to determine the impact of drought conditions on the water quality of the River Severn corridor and also the impact of managing the flows through implementation of the Severn Drought Order, it became obvious that the SIMCAT models at our disposal were not necessarily the right tools for the job.

The verification exercise initially attempted to match predicted and observed drought flows at the various assessment points proved to be fraught with difficulty and was eventually abandoned in favour of a number of logical assumptions. This was predominantly due to the fact that the current SIMCAT models are based on current day populations rather than those present at the time of the drought situations attempting to be matched (1976/77).

Being a spatial rather than a temporal model, it also proved impossible to provide the data for ecological appraisal in the form that was required. Whereas the ecological impact would be best assessed using an indication of the varying ammonia and BOD concentrations at one location with time and flow (temporal model), SIMCAT was only able to provide a worst case scenario for the entire length of river with no immediate link to the flows at the corresponding time. In other words, an assumption had to be made that the 99th percentile value for each determinand represented the worst case scenario when, in fact, higher concentrations would be present for a maximum of 4 days in a year.

SIMCAT is also a tool more suited to representing more stable conditions and can struggle to represent prolonged, extreme events such as droughts. By its nature of representing mean and standard deviation

statistical input, it is not inherently designed to predict environmental conditions in extreme, worst case scenarios.

Although a specific modelling tool cannot be recommended, any tool which is better suited at representing a temporal link between flow and pollutant concentration would probably be better suited to the tasks required in this water quality assessment.

The SIMCAT model itself could be improved by more sophisticated and numerous water quality and flow monitoring. Currently, the model is based upon the known input data, in other words measured data from flow gauges, water quality monitoring points, measured discharge volumes and quality. From this data, the model must make assumptions on the source of any errors that may occur following mixing of all the known data.

Without enhanced monitoring, much larger data sets encompassing all possible sources of pollution and diffuse flow inputs and highly detailed knowledge of the catchment, this calibration process can be fraught with problems. The SIMCAT models employed in this assessment have been signed off and accepted as the best possible representation of the environment given the data available but it also has to be recognised that the model contains numerous locations where accurate representation of the environment was not possible. Calibration errors such as this can only successfully be rectified through the use of greater amounts of top quality monitoring of all potential sources of pollution and flow.

Future Recommendations & Monitoring Requirements

The underlying SIMCAT model used to predict the baseline water quality can always be improved through a thorough investigation of all polluting or diluting sources and subsequent data collection exercise of the entire catchment, focussing predominantly on the areas highlighted as being of poor calibration.

Such an exercise is likely to improve the model calibration but it would not be a foregone conclusion given the complicated nature of environmental interactions and the fact that it is notoriously difficult to balance a large catchment model. Quite often, what would appear to be an improvement in data quality in one location can deteriorate calibration in other locations in the catchment.

In terms of the Severn Drought Order, the report earlier highlighted the limitations of the SIMCAT model in terms of flow and water quality at strategic locations on the River Severn. Improvement of this calibration is, unfortunately, not as easy as improving data quality at the same locations as, quite often, it is a lack of data from feeding tributaries that impose a greater influence on the model. As discussed above, the model needs to be seen as a holistic tool where data quality and catchment knowledge would need to be improved at all locations in order to achieve a better calibration.

With regards to the improved representation of drought conditions, SIMCAT would need to be fundamentally changed to be able to better represent the intricate operation of the major abstractions in terms of hands of flows and drought orders. In most cases, the model is already built based on measured abstracted flows although the representation of this data could probably be improved.

In short, it is not felt that SIMCAT is the best modelling tool for the job given the limitations discussed earlier in the report. In order to fully understand and better replicate the impacts of drought flows, a specifically developed water resource model capable of accurately representing current and drought conditions would be the recommended way forward. Perhaps a water quality function could be incorporated within AQUATOR?

All SIMCAT models are initially calibrated for flow followed by a water quality calibration exercise based upon the accurate representation of the flow characteristics. Any work beyond this point tends to be in the form of 'what-if' scenarios. In other words, what will happen to the quality if we halve the flow?

Providing the initial calibration is as accurate as possible, any change in the model with regards to flow should give a suitably accurate prediction of the impact on quality. What is lacking in SIMCAT is the functionality to represent the complicated flow controls in the River Severn. If this could be rectified in SIMCAT (or any other model for that matter) then an accurate water quality prediction in drought conditions should be possible.

In an ideal modelling world, a tool capable of predicting both temporal and spatial changes in water quality and flow would be available with the capability to represent any number of different flow situations. Providing it was then fully calibrated in terms of water quality in 'normal' conditions, reactive predictions in water quality at any location or time could be possible.

Appendix J

Ecological Technical report - River Severn Drought Order

ECOLOGICAL TECHNICAL REPORT - RIVER SEVERN DROUGHT ORDER

Environment Agency

ECOLOGICAL MODELLING AND ASSESSMENT

A number of ecological assessment tools and methodologies were used to both assess the current environment, and possible impacts of the River Severn Drought Order alone:

- **Water Framework Directive (WFD) classification³** - classifies each surface water body in terms of ecological and chemical quality.
- **River Habitat Surveys (RHS)** - provide an assessment of the morphology of a 500m reach of river, recording both modifications, natural features and giving an idea of habitat quality and diversity.
- **Biological Monitoring Working Party (BMWP)** - score classifies families of invertebrates according to their tolerance of organic pollution.
- **Average Score Per Taxon (ASPT)** – derived from the BMWP, this gives a more precise reflection of the pollution tolerance of the invertebrates found and therefore of water quality.
- **River InVertebrate Prediction And Classification System (RIVPACS)** – the programme predicts the probability of capture of taxa from the sites physiochemical characteristics. Now superseded by RICT River Invertebrate Classification Tool
- **Lotic-invertebrate Index for Flow Evaluation (LIFE)** method - recognised flow associations of different macro-invertebrate species and families allow the measurement of ecological effects from low flows.
 - **LIFE O:E** - Observed LIFE (O) scores are divided by Expected (E (calculated by RIVPACS)) life scores to get a ratio and assess potential flow stress.
- **Proportion of Sediment-sensitive Invertebrates (PSI)** biotic index - used for assessing sediment pressures.
- **Hydroecological Validation (HEV)** tool - uses ecological and hydrological data to assess the ecological response of a site to river flow.

Of all the biological elements, the macroinvertebrates are the most sensitive to changes in flow and therefore have been considered in the greatest depth for the River Severn Drought Order impact assessment.

The tools and methodologies listed above were the best-practice methodologies at the time of modelling. BMWP has since been replaced with Whalley Hawkes Paisley Trigg (WHPT) which is now used in WFD classification and for deriving ASPT.

³ At the time of modelling (2014) cycle 1 methodology for WFD classification was used.

Water Framework Directive classification

The Water Framework Directive (WFD) requires all surface water bodies to be classified in terms of ecological and chemical quality. For those water bodies not designated as heavily modified or artificial, this ecological quality is described in terms of 'ecological status'. This is an expression of the quality of the structure and functioning of surface water ecosystems as indicated by the condition of a number of 'quality elements'. The WFD uses the term 'quality elements' to refer to the different indicators of ecological quality making up its ecological status classification schemes.

There are five classes of ecological status, defined in terms of how much the ecological quality deviates from natural conditions. These are high, good, moderate, poor or bad. High status means that the water body is unaffected or virtually unaffected by human activity. A good status water body shows some signs of damage, such as slight alterations in the balance of aquatic species (biological quality elements) that would be expected in a water body unaffected by human activity. The quality elements used to assess ecological status are:

- biological quality elements (diatoms, macrophytes, invertebrate and fish);
- chemical and physicochemical elements; and
- hydromorphological quality elements

The ecological status of a water body is determined by combining assessment results for biological, chemical and physicochemical quality elements; with the quality element most severely affected by human activity determining the overall ecological status. This is called the '*one out - all out principle*'.

For a water body to achieve good ecological status, the biological quality elements must show only slight signs of disturbance caused by human activity. Among other things, this requires the chemical, physicochemical and hydromorphological quality of the water body to achieve the standards and conditions necessary to support the biological quality elements at good status.

Chemical status is either 'good' or 'failing to achieve good'. 'Good' means that none of the environmental quality standards established for priority substances and other dangerous substances identified at EU-level is being exceeded.

Artificial and heavily modified waters

Some surface water bodies are designated as 'artificial' or 'heavily modified'. This is because they may have been created or modified for a particular use such as water supply, flood protection, navigation or urban infrastructure. By definition, artificial and heavily modified water bodies are not able to achieve natural conditions. Instead the classification and objectives for these water bodies, and the biology they represent, are measured against 'ecological potential', with the same five categories of high, good, moderate, poor and bad, rather than status. For an artificial or heavily modified water body to achieve good ecological potential, the chemistry of the water body must be good. In addition, there must be no structural or physical changes that could impact upon biology other than those that are essential to maintain the valid uses of the water body. All non-essential modifications have had to be removed or changed so that there is potential for biology to be as close as possible to that of a similar natural water body. Often though, the biology will still be impacted and biological status of the water body may be less than good. The chemical status of these water bodies is measured in the same way as natural water bodies.

The overall status for heavily modified water bodies are not calculated in quite the same way as for normal surface water status. Firstly an assessment is made of whether the flow condition for supporting good status has failed. If this is the case, ecological potential is determined by the worst of the mitigation measures assessment or status as shown by fish, invertebrates, macrophytes diatoms or supporting physico chemistry. All the biological quality elements are used because they are all sensitive to flow pressure.

If the flow condition for supporting good ecological status has passed, ecological potential is based on mitigation measures and the status result from non-sensitive (to morphological pressure) quality elements e.g. diatoms and supporting physchem. Otherwise, heavily modified and artificial water bodies that are polluted from other pressures would be incorrectly labelled as being of good ecological potential because morphological mitigation is in place.

Table 1: Baseline Water Framework Directive (WFD) status of RBMP3 for water bodies on the Severn.

Waterbody		Water Framework Directive Quality Elements						
Id number and Name	Overall Status/Potential	Mitigation measures	Chemical	Physico-chemistry	Diatoms	Macrophytes	Invertebrates	Fish
GB109054049880 R Vyrnwy – Lake Vyrnwy to conf Afon Cownwy	MODERATE POTENTIAL	MODERATE	GOOD	GOOD			GOOD	HIGH
GB109054049720 Afon Vyrnwy – conf Afon Cownwy to Afon Banwy	MODERATE POTENTIAL	MODERATE	GOOD	GOOD	GOOD	HIGH (NRW 2024 classification)	HIGH	HIGH
GB109054049851 Afon Banwy*	GOOD STATUS	NYA	FAIL	HIGH			HIGH	POOR
GB109054049852 Afon Vyrnwy – DS of Banwy confluence	GOOD STATUS		GOOD	GOOD	GOOD		HIGH	

GB109054044760 Afon Clywedog – Clywedog dam to R Severn	MODERATE POTENTIAL	MODERATE	GOOD	GOOD		HIGH (NRW 2024 classification)	GOOD	POOR
GB109054044790 R Severn – source to conf Afon Dulas	MODERATE STATUS	NYA	GOOD	HIGH	HIGH	GOOD	HIGH	MODERATE STATUS
GB109054049310 R Severn – conf Afon Dulas to conf R Camlad	MODERATE POTENTIAL	MODERATE	GOOD	GOOD	GOOD		HIGH	HIGH
GB109054049700 R Severn – conf R Camlad to conf Bele Bk	MODERATE POTENTIAL	MODERATE	GOOD	GOOD	MODERATE	MODERATE	HIGH	
GB109054049142 R Severn - conf Bele Bk to conf Sundorne Bk	MODERATE STATUS	N/A	FAIL	MODERATE	GOOD	MODERATE	HIGH	
GB109054049141	MODERATE STATUS	N/A	FAIL	MODERATE	GOOD	MODERATE	GOOD	

R Severn - Sundorne Bk to conf M Wenlock-Farley Bk								
GB109054049143 R Severn – M Wenlock-Farley BK to conf R Worfe	MODERATE STATUS	N/A	FAIL	MODERATE	MODERATE	MODERATE	HIGH	
GB109054049145 R Severn - conf R Worfe to conf R Stour	MODERATE STATUS	N/A	FAIL	NOT ASSESSED	MODERATE	HIGH	HIGH	
GB109054049144 R Severn – conf R Stour to conf R Teme	MODERATE POTENTIAL	MOD/LESS	FAIL	MODERATE	GOOD	HIGH	GOOD	
GB109054039760 R Severn - conf R Teme to conf R Avon	POOR POTENTIAL	MOD/LESS	FAIL	MODERATE	MODERATE	GOOD	POOR	
GB109054044404 R Severn - conf R Avon to conf Upper Parting	MODERATE POTENTIAL	MOD/LESS	FAIL	MODERATE		GOOD	POOR	

GB109054032750 R Severn (E Channel) - Horsebere Bk to Severn Est	MODERATE POTENTIAL	MOD/LESS	FAIL	MODERATE		BAD

* Water body ID GB109054049850 Afon Vyrnwy – conf Afon Gam to conf Afon Tanat was split into two in cycle two and now comprises of waterbodies GB109054049851 and GB109054049852. Please note there is a difference in methodologies between how EA and NRW calculate chemical status.

Table 1 shows the baseline WFD status for River Basin Management Plan 3 for each of the water bodies involved in the Severn Drought Order. Some of the water bodies on the Severn, Vyrnwy and Clywedog have been designated as heavily modified water bodies (HMWB) due to the regulation of flows, navigation use and flood protection and therefore the 'one out, all out' principle is not used. As HMWB they produce a 'Potential' class rather than 'Status'.

The Severn is a large and deep river, where monitoring fish effectively by means of electric fishing for classification purposes is not possible. The fish data used for these water bodies in the first River Basin Management Plans (RBMP) was therefore not suitable to give a truly representative picture for the fish quality element. Further monitoring methods are being developed in order to improve this information in the future.

Physical Habitat

River habitat surveys (RHS) provide an assessment of the morphology of a 500m reach of river, recording both modifications and natural features, and giving an indication of habitat quality and diversity.

Hydromorphology forms part of the overall ecology of a water body by underpinning and supporting the biology. Most aquatic species have certain physical habitat requirements, in addition to those of water quality and hydrology.

RHS data can be summarised using two summary indices.

The *habitat modification score (HM)* is a scoring system used to assess the degree of modification associated with a river. The scores can then be used to place the water body in a habitat modification class. The HM score is independent of water body type and so can be used to describe artificial modification to physical structure across the board.

Table 2: Habitat Modification Scores

HMC	HMC description	HM score
1	Pristine/near-natural	0-16
2	Predominantly unmodified	17-199
3	Obviously modified	200-499
4	Significantly modified	500-1399
5	Severely modified	1400+

These classes differ from those describing ecological status under the WFD and also the category of 'heavily modified' which classifies an entire water body, and is derived from morphological and socio-economic criteria.

The *habitat quality assessment (HQA)* scoring system offers a broad measure of the diversity and 'naturalness' of the physical habitat structure of a site, including both the channel and river corridor. A survey will accumulate points under 9 different sub-score categories. These sub-scores are totalled to give the overall HQA Score.

HM and HQA indices are designed to give only a summary of the habitat over the 500m river length surveyed. For more targeted investigations (such as looking at siltation), using the raw data is recommended.

RHS cover 500m lengths of river. Current work shows that this is likely to be representative of 1 km of river either side of the mid-point. For assessments at the water body scale, it is likely that a number of RHS will be required to allow meaningful conclusions to be drawn.

RHS surveys have been conducted throughout the Severn catchment, but for the purposes of this report only RHS surveys that are centred on the individual macroinvertebrate sites have been included.

Table 3: River Habitat Survey (RHS) scores

NGR of Site (Survey ID)	River	Survey Year	Ecology Monitoring/ RSDO comparison sites	HMS Score	HMS Class	HQA
SN9280086100	CLYWEDOG	2019	49774 Caravan Park SN94000 85700	895	4	45
SJ0430014400	VYRNWY	2024	50350 Dolanog SJ06780 12860	705	4	61
SJ4619816554 40463	SEVERN	2021	173804 Lower Isle of Bicton	80	2	44
SJ6790003400 40425	SEVERN	2021	52526 Cressage SJ 70200 02100	540	4	40
SJ6880002900 40423	SEVERN	2021	Buildwas	599	4	40
SJ7012702083 40437	SEVERN	2021	52795 Coalport SJ 70200 02100	400	3	41
SO7892575192 (40462)	SEVERN	2021	52393 D/S Dowles Brook SO78000 76400	520	4	43
SO8613840508 (40780)	SEVERN	2022	172484 Upper Ham SO8617740354	360	3	49
SO8453127958 (40793)	SEVERN	2022	51327 Hawbridge SO84500 27720	596	4	49
SJ2330023400 (40474)	TANAT	2021	50766 Llanyblodwel SJ 24200 22900	989	4	57
SO6020068500 (40486)	TEME	2021	48210 Tenbury SO 59942 68511	20	2	46

There is no consistent pattern to the Heavily Modified Scores (HMS) the Habitat Quality Assessment (HQA) scores travelling downstream through the catchment (Table 3). The level of modification on a river is important for the ecology as the more modified a river is the fewer habitats and refugia are available for macroinvertebrates and fish. The Habitat Quality Assessment (HQA) score provides evidence of this as it decreases as the river goes downstream.

Macrophytes

Macrophytes have traditionally been used to monitor the impacts of eutrophication in rivers. However like invertebrates they respond to a wide range of pressures. Different pressures can often have similar effects and it can therefore be difficult to apportion cause. Flows can have a significant impact on macrophyte communities within the

reach of a river. The principal mode of impact is via physical stress caused by flows damaging the plants or causing uprooting. Some macrophyte types, such as marginal herbs and floating leaved plants, can only exist in areas of reduced flows, whereas submerged linear and fine leaved plants are morphologically adapted to thrive in areas of higher flows. If flows change then the plant community will often change in response. Where flows are reduced within a stretch of river it may cause plant taxa with a preference for high flows to either decrease in dominance or be lost altogether as more marginal taxa and broad leaf taxa are able to out-compete them and can expand into the middle of the river changing the balance in the plant communities. In lowland systems however, flow pressures can often be masked by nutrient pressures

River macrophyte nutrient index (RMNI). The RMNI is designed to categorise a macrophyte community's preferences to nutrient levels. Scores range from 1 to 10 with scores of 1 representing plant communities with preference for very low levels of nutrients and 10 representing communities with a preference for very enriched conditions.

River macrophyte hydraulic index (RMHI). The RMHI describe a plant community's preferences for flow conditions on a scale of 1 to 10. Scores of 10 indicates a plant community has a preference for very slow or non-existent flows, while scores of 1 are found in plant communities with a preference for very rapid powerful flows.

There is a close relationship between RMNI and RMHI as species of fertile environments tend to be associated with low energy systems. Impacts such as sedimentation, channel widening, flow abstraction and the introduction of physical modifications are all likely to result in a shift to an essentially lower energy depositional environment. Note – this index is no longer calculated by the NRW system so is unavailable for NRW sites.

Number of aquatic plant functional groups (N FG). The N FG index is a richness or diversity index and describes the number of functional macrophyte groups existing within a surveyed plant community. There are 23 different functional groups defined. The higher the value, the more diverse and rich the plant community is considered to be.

Number of aquatic taxa (N TAXA). The N TAXA index is another richness index but simply describes the number of truly aquatic taxa. Higher values represent a more diverse and rich aquatic plant community.

Both the N FG and N TAXA indices are very useful indicators of habitat quality. High quality habitats with good flow regime, habitat heterogeneity, upstream connectivity and low sedimentation pressures will have higher values for both these indices in areas where channel modifications exist both these indices will often be reduced.

Macrophyte monitoring has been undertaken on the Severn, Vyrnwy and Clywedog specifically for the purpose of the Severn Drought Order since 2012. Table 4a shows the results of the plant data available in England, Table 4b shows the results in Wales.

Table 4a: EA Macrophyte Monitoring Results

Site/Station name	Site ID	Sample Date	RMHI	RMNI	N a taxa	N f g	% Filamentous Algae	Class
LOWER ISLE OF BICTON	173804	25-Jun-2014	6.87	6.82	13	7	7.55	<i>Good</i>
LOWER ISLE OF BICTON	173804	03-Jul-2015	7.00	6.9	13	10	0.1	<i>Good</i>
LOWER ISLE OF BICTON	173804	02-Aug-2016	7.08	7.21	8	6	3.85	<i>Good</i>
LOWER ISLE OF BICTON	173804	26-Jun-2017	7.31	7.13	7	6	0.05	<i>Good</i>
LOWER ISLE OF BICTON	173804	03-Jul-2018	7.32	7.44	6	6	37.5	<i>Poor</i>
LOWER ISLE OF BICTON	173804	07-Aug-2019	7.66	7.77	8	5	0.55	<i>Moderate</i>
LOWER ISLE OF BICTON	173804	19-Jul-2021	6.96	6.93	9	7	0.05	<i>Good</i>
LOWER ISLE OF BICTON	173804	12-Jul-2022	7.21	7.36	14	10	7.5	<i>Moderate</i>
LOWER ISLE OF BICTON	173804	21-Jun-2023	7.28	7.35	9	9	0.55	<i>Moderate</i>
CRESSAGE	52526	23-Aug-2004	7.82	7.98	17	11	1.75	<i>Moderate</i>
CRESSAGE	52526	18-Jul-2006	7.54	7.59	14	11	0.55	<i>Moderate</i>
CRESSAGE	52526	19-Jul-2013	7.41	7.46	16	13	0.5	<i>Good</i>
CRESSAGE	52526	03-Sep-2014	7.28	7.52	12	8	2.25	<i>Moderate</i>
CRESSAGE	52526	01-Jul-2015	7.42	7.99	14	10	18	<i>Moderate</i>
CRESSAGE	52526	09-Aug-2016	7.38	7.6	13	9	0.6	<i>Moderate</i>
CRESSAGE	52526	26-Jun-2017	7.29	7.47	13	9	5.5	<i>Good</i>
CRESSAGE	52526	08-Aug-2019	7.64	7.9	16	11	3.85	<i>Moderate</i>
CRESSAGE	52526	18-Jul-2022	7.57	7.68	13	8	0.55	<i>Moderate</i>
CRESSAGE	52526	13-Jul-2023	7.46	7.77	14	10	9.7	<i>Moderate</i>
CRESSGAE	52526	24-Jun-2025	7.5	7.92	14	10	17.6	<i>Moderate</i>
BUILDWAS	158364	13-Aug-2012	7.54	7.91	8	7	0.05	<i>Moderate</i>
BUILDWAS	158364	25-Sep-2013	7.37	7.64	17	11	38.05	<i>Poor</i>
BUILDWAS	158364	17-Sep-2014	6.96	6.95	12	7	17.6	<i>Good</i>
BUILDWAS	158364	01-Jul-2015	7.39	7.79	11	8	7.6	<i>Moderate</i>
BUILDWAS	158364	09-Aug-2016	7.16	7.16	7	7	3.8	<i>Good</i>
BUILDWAS	158364	26-Jun-2017	7.33	7.4	12	9	1	<i>Good</i>

BUILDWAS	158364	27-Jun-2018	7.14	7.26	13	10	37.5	Moderate
BUILDWAS	158364	08-Aug-2019	7.31	7.62	11	9	3.8	Moderate
BUILDWAS	158364	19-Jul-2021	7.41	7.59	10	8	0.55	Moderate
BUILDWAS	158364	18-Jul-2022	7.65	7.93	13	10	1.7	Moderate
BUILDWAS	158364	13-Jul-2023	7.31	7.54	16	10	3.85	Moderate
BEDLAM FURNACES	167605	23-Sep-2013	6.58	7.01	13	6	0.6	Good
BEDLAM FURNACES	167605	17-Sep-2014	6.76	6.73	11	6	37.5 5	Moderate
BEDLAM FURNACES	167605	23-Jul-2015	7.28	7.74	14	10	38.0 5	Poor
BEDLAM FURNACES	167605	10-Aug-2016	7.03	7.12	12	7	17.5 5	Moderate
BEDLAM FURNACES	167605	27-Jun-2017	6.94	7	13	7	7.65	Good
BEDLAM FURNACES	167605	21-Jun-2018	6.67	6.99	11	6	37.5 5	Moderate
BEDLAM FURNACES	167605	08-Aug-2019	7.14	7.46	14	6	17.6	Moderate
BEDLAM FURNACES	167605	12-Aug-2022	6.67	6.83	15	10	7.55	Moderate
BEDLAM FURNACES	167605	13-Jul-2023	7.31	7.78	19	11	62.6	Poor
D/S DOWLES BROOK	52393	23-Sep-2013	6.95	7.27	11	7	9.2	Good
D/S DOWLES BROOK	52393	16-Sep-2014	6.99	7.42	8	5	9.25	Good
D/S DOWLES BROOK	52393	19-Aug-2015	7.29	7.58	14	9	11.3 5	Moderate
D/S DOWLES BROOK	52393	10-Aug-2016	6.97	7.06	9	6	17.5	Good
D/S DOWLES BROOK	52393	27-Jun-2017	6.82	6.93	11	6	7.6	Good
D/S DOWLES BROOK	52393	21-Jun-2018	6.97	7.06	8	6	1.7	High
D/S DOWLES BROOK	52393	04-Sep-2019	6.83	7.31	10	6	37.5 5	Moderate
D/S DOWLES BROOK	52393	07-Sep-2021	6.59	7.42	11	5	37.5 5	Moderate
D/S DOWLES BROOK	52393	25-Aug-2022	6.55	7.05	10	6	1	High
D/S DOWLES BROOK	52393	24-Jun-2025	7.08	7.69	11	6	17.5 5	Moderate
D/S DOWLES BROOK	52393	23-Jun-2026	6.93	7.36	13	8	4.3	Good
OPPOSITE UPTON UPON SEVERN MARINA	172485	24-Jun-2014	7.44	8.41	3	3	0.05	Good

OPPOSITE UPTON UPON SEVERN MARINA	172485	08-Jul-2015	7.47	7.98	3	3	0.05	Poor
OPPOSITE UPTON UPON SEVERN MARINA	172485	19-Sep-2016	7.46	7.79	5	4	0.05	Moderate
OPPOSITE UPTON UPON SEVERN MARINA	172485	03-Aug-2017	7.09	7.39	2	2	0.05	Moderate
OPPOSITE UPTON UPON SEVERN MARINA	172485	09-Jul-2018	7.40	7.84	1	1	0.05	Moderate
OPPOSITE UPTON UPON SEVERN MARINA	172485	11-Jul-2019	7.71	7.71	8	5	0.05	Poor
UPPER HAM	172484	13-Sep-2022	7.47	7.56	5	5	0.5	Good
OPPOSITE UPTON UPON SEVERN MARINA	172485	20-Jul-2023	6.93	6.78	4	4	0.05	Good
HAW BRIDGE	51327	24-Jun-2014	6.46	6.96	4	3	0.05	High
HAW BRIDGE	51327	08-Jul-2015	7.42	7.73	1	1	0.05	Moderate
HAW BRIDGE	51327	20-Sep-2016	7.47	7.94	3	3	0.05	Moderate
HAW BRIDGE	51327	05-Jul-2017	6.88	7.05	7	5	0.1	High
HAW BRIDGE	51327	09-Jul-2018	6.91	7.19	5	3	0.55	Good
HAW BRIDGE	51327	11-Jul-2019	6.80	6.74	5	3	0.05	High
HAW BRIDGE	51327	20-Sep-2022	7.47	7.47	6	5	0.05	Good
HAW BRIDGE	51327	19-Jul-2023	7.43	7.57	8	7	0.05	Good
LLANYBLODWEL	50766	30-Aug-2002	6.02	5.97	16	7	1	Good
LLANYBLODWEL	50766	01-Sep-2006	6.01	5.52	10	4	0.55	High
LLANYBLODWEL	50766	30-Sep-2013	6.34	6.16	18	9	17.5 5	Good
LLANYBLODWEL	50766	30-Jul-2014	6.17	5.97	20	10	7.55	Good
LLANYBLODWEL	50766	21-Jul-2015	6.44	6.46	16	9	4.85	Moderate
LLANYBLODWEL	50766	08-Aug-2016	6.05	5.9	15	8	1.75	Good
LLANYBLODWEL	50766	03-Jul-2017	6.15	6	17	8	0.25	Good
LLANYBLODWEL	50766	03-Jul-2018	6.17	5.99	15	8	0.6	Good
LLANYBLODWEL	50766	07-Jul-2019	6.48	6.37	14	9	0.55	Moderate
LLANYBLODWEL	50766	27-Jul-2021	6.20	6.06	15	8	0.6	Good
LLANYBLODWEL	50766	13-Sep-2023	6.48	6.57	16	9	3.45	Moderate
LLANYBLODWEL	50766	02-Jun-2026	6.37	6.23	13	8	0.55	Good

TENBURY	48210	30-Sep-2013	6.62	6.94	10	6	7.6	Good
TENBURY	48210	18-Sep-2014	6.75	6.92	11	5	37.6	Moderate
TENBURY	48210	30-Jul-2015	6.12	6.49	10	4	1.8	High
TENBURY	48210	13-Sep-2016	6.53	6.86	15	7	25.1	Moderate
TENBURY	48210	09-Aug-2017	6.47	6.52	14	6	37.6	Moderate
TENBURY	48210	19-Jul-2018	6.33	6.66	15	6	11.3 5	Good
TENBURY	48210	02-Aug-2019	6.24	6.35	13	5	9.25	Good
TENBURY	48210	25-Aug-2021	6.50	7.09	12	5	38.0 5	Moderate
TENBURY	48210	07-Sep-2022	7.15	7.38	14	8	26.7	Moderate
TENBURY	48210	09-Aug-2023	7.13	7.46	14	9	5.55	Moderate
TENBURY	48210	25-Jun-2024	6.52	7.09	10	6	4.3	Good
TENBURY	48210	17-Jul-2025	6.78	6.76	13	7	0.6	High

Table 4b: NRW Macrophyte Monitoring Results

Site/Station name	Site ID	Sample Date	RMHI	RMNI	N a taxa	N f g	% Filamentous Alg	Class
PARK (BIO SP PT)	49874	10-September-2013	N/A	4.4346	13	5	0.05	High
PARK (BIO SP PT)	49874	23-September-2015	N/A	4.3185	12	5	0.05	High
PARK (BIO SP PT)	49874	31-August-2016	N/A	3.9596	12	3	0	High
PARK (BIO SP PT)	49874	6-July-2017	N/A	4.3195	11	4	0.05	High
PARK (BIO SP PT)	49874	21-June-2018	N/A	4.0972	10	4	0	High
PARK (BIO SP PT)	49874	29-July-2019	N/A	4.1700	11	3	0	High
PARK (BIO SP PT)	49874	5-June-2024	N/A	4.1831	9	5	0.05	High
MILL BRIDGE DOLANOG	50350	23-July-2013	N/A	4.8408	12	6	0.05	High
MILL BRIDGE DOLANOG	50350	19-August-2015	N/A	5.2208	16	8	0.1	Good
MILL BRIDGE DOLANOG	50350	5-July-2016	N/A	4.7319	14	6	0.05	High
MILL BRIDGE DOLANOG	50350	6-July-2017	N/A	4.7367	13	6	0	High

MILL BRIDGE DOLANOG	50350	21-June-2018	N/A	4.8436	16	6	0.05	<i>High</i>
MILL BRIDGE DOLANOG	50350	30-July-2019	N/A	4.6072	16	5	0.05	<i>High</i>
MILL BRIDGE DOLANOG	50350	17-July-2024	N/A	4.7841	15	7	0	<i>High</i>
DOLWEN	52148	4-August-2004	N/A	5.1050	11	6	0	<i>High</i>
DOLWEN	52148	26-September-2013	N/A	5.6182	11	6	0.05	<i>Good</i>
DOLWEN	52148	19-August-2015	N/A	6.0312	15	9	0.05	<i>Good</i>
DOLWEN	52148	31-August-2016	N/A	5.8538	15	8	0.1	<i>Good</i>
DOLWEN	52148	5-July-2017	N/A	5.7656	12	7	0.05	<i>Good</i>
DOLWEN	52148	22-June-2018	N/A	5.5727	15	7	0.1	<i>Good</i>
DOLWEN	52148	29-July-2019	N/A	5.5725	13	6	0.05	<i>Good</i>
DOLWEN	52148	5-June-2024	N/A	5.3919	10	4	0.1	<i>Good</i>

Data now exists for the Afon Clywedog, the Afon Vyrnwy and the River Severn including the heavily modified navigable stretches of the Severn. In general there is an increase in both the RHMI and RNMI with distance downstream. In the headwaters, the macrophyte community is associated with faster and more powerful flows and lower nutrient status such and consists mainly of bryophytes (mosses and liverworts). The communities change as the sites move downstream to include a more marginal and submerged macrophytes (including Water Crowfoot, Water Milfoil and Starwort) and filamentous algae. The sites furthest downstream also include the presence of floating leaved plants (duckweeds). These communities indicate slower flows and a more nutrient enriched system.

Following the commencement of a baseline macrophyte monitoring programme specifically for the Severn Drought Order, further work is now required to understand the impacts that flow is having on the macrophyte communities of the rivers Clywedog, Vyrnwy and the Severn and to determine whether the application of the drought order would have beneficial or detrimental effect on the ecology.

Macroinvertebrates

The majority of the macroinvertebrate samples were collected using the standard Environment Agency three-minute kick sample and 1 minute manual search method. The exceptions to this were the samples taken from the lower reaches of the Severn where it is not possible to collect samples in this way due to the depth of the water. Airlifting is now used as the standard deep water methodology for macroinvertebrate sampling⁴. The samples were then analysed in the laboratory, macroinvertebrates identified to mixed taxon level and their abundance estimated. A number of different scoring methods were used to interpret the data.

Macroinvertebrate taxa are able to tolerate different degrees of water quality. The **Biological Monitoring Working Party (BMWP)** score classifies families of invertebrates according to their tolerance of organic pollution. Using a scale from 1 to 10, invertebrates that are able to tolerate low oxygen levels associated with gross organic pollution, such as oligochaete worms, are given low BMWP scores, while invertebrates that require high water quality, such as stonefly larvae, are given high

⁴ Airlifting is now used (2019) to take deep water samples.

BMWP scores. A BMWP score for a standard stream invertebrate sample is calculated by adding together the individual BMWP scores of the taxa found. BMWP scores and the corresponding water quality can be compared between sites and scores can be compared over time to determine if the water quality has changed at a site.

The Average Score Per Taxon (ASPT) is derived by dividing the total BMWP score of the sample by the number of taxa found. This gives a better reflection of water 'quality' because it is not influenced by the number of taxa recorded.

[https://wfduk.org/sites/default/files/River Invertebrates WHPT UKTAG Method Statement - updated July 2023.pdf](https://wfduk.org/sites/default/files/River%20Invertebrates%20WHPT%20UKTAG%20Method%20Statement%20-%20updated%20July%202023.pdf).

The **River Invertebrate Classification Tool (RICT)** programme predicts the probability of presence of taxa, based on a site's physicochemical characteristics. A comparison of the observed taxa with those predicted can indicate changes in environmental quality. The system has been tested in a variety of studies to assess the effects upon the benthic communities of heavily abstracted watercourses.

The **Lotic-invertebrate Index for Flow Evaluation (LIFE)** method is primarily based on recognised flow associations of different macro-invertebrate taxa (species and families) and thus can measure the ecological effects of low flows. Flow categories are ascribed to families or species of invertebrate taxa, based on their sensitivity to and tolerance of low flows. These LIFE scores are cross-indexed with logarithmic abundance to give a flow score taxon (family or species group). A mean score is then calculated from each taxon list for each invertebrate sample. High LIFE scores indicate invertebrate assemblages that are sensitive to low flow, such as small, fast upland streams, while low LIFE scores indicate sites that are less sensitive to low flows such as wide deep rivers.

In order to determine if the invertebrate community at a particular site has been impacted by any periods of low flows, historic LIFE scores can be compared to flow data. However, there is usually a small time lag before the effects of the low flows are seen in macroinvertebrates. Different flow parameters show greater correlation to LIFE scores than others. For example monthly flow figures or minimum monthly flow figures may show a greater correlation with LIFE than daily flows. This is because the impact of flow on different life stages of macroinvertebrates will vary according to the macroinvertebrate communities that the watercourse can support and the impact of flows will vary at different sites depending upon the structure of the site.

Historic LIFE scores can also be compared over time with each other to determine if artificial changes to the flow regime, such as augmentation in the catchment, have affected the invertebrate LIFE scores.

Predicted LIFE scores can also be calculated to determine if a site is stressed by flows. This is the LIFE score that would be expected at a site under pristine conditions, i.e. no water quality, habitat, or flow stresses. Expected LIFE (E) scores are calculated by generating a list of predicted macroinvertebrates, using RIVPACS. Observed LIFE (O) scores are then divided by expected life scores to get a ratio (LIFE O:E).

Hydroecological Validation (HEV) uses ecological and hydrological data to help us assess the ecological response of a site to river flow (As per operational instruction 318_10 – Hydroecological validation using macroinvertebrate data). It compares

expected and observed river ecology to see if there is a relationship between ecological condition and river flow. HEV can also be used to infer the effect of other pressures, such as water quality, sediment and morphology. This tool was specifically developed for unregulated rivers but has been used in this case to see how LIFE and the other variables change over time.

For this process RICT is used. Some of the physical variables used to make RICT predictions (width, depth, substrate type) can be modified by regulation. This may lead to an under prediction for the expected scores and thereby the O:E ratios may be higher than they should be. In order to overcome this problem, the observed LIFE scores have also been compared to long term average and the lower quartiles for the site and displayed alongside hydrological data to see whether any declines in the LIFE scores appear to be related to river flow.

Increased siltation within a river reach is often associated with morphological change or a reduction in flows. However, it can also arise from sediment runoff from poor land management. Siltation often reduces the quality of the habitat available, reducing interstitial spaces, oxygen availability, and light penetration. It can also have a physical impact, smothering macroinvertebrates and damaging sensitive gills. Macroinvertebrate communities impacted by siltation will often be missing the more sensitive taxa and can have reduced diversities, having one or two very dominant taxon.

The **Proportion of Sediment-sensitive Invertebrates (PSI)** index is a methodology used for assessing sediment pressures. PSI is a biotic index designed to describe a macroinvertebrate community's sensitivity to sedimentation. The score decreases with increased impact of fine sediments covering the riverbed (Table 5).

Table 5: Proportion of Sediment-sensitive Invertebrates (PSI) Biotic index

PSI score	River bed condition
81- 100	Minimally sedimented/unsedimented
61-80	Slightly sedimented
41-60	Moderately sedimented
21-40	Sedimented
0-20	Heavily sedimented

Limitations of the Ecological modelling

Limited data, inconsistent coverage of historical data and a lack of tools specifically designed for predicting the impact of low flows/drought on the ecology of regulated rivers made true assessment difficult.

The use of the new hydroecology toolkit is being developed for use in the River Severn, but is not yet available.

Therefore, the best available data was used and professional expertise was applied to the assessment process.

For the purposes of this report, the Severn (including its two main source tributaries, the Afon Clywedog and the Afon Vyrnwy) has been split into sections with seven assessment points. A macroinvertebrate sampling site with a robust historical dataset has been assigned to each of these sections. There was no macroinvertebrate data available for the Lower Parting assessment point, due to the methodology being unsuitable for this size of river and impacts of saline intrusion (freshwater invertebrates only). In addition to, two reference sites have also been included: the Afon Tanat (a tributary of the Vyrnwy) at Llanyblodwel and the River Teme (a tributary of the middle Severn) at Tenbury. Both reference sites are on rivers that are non-regulated and give an indication of the reaction of macroinvertebrates to natural periods of lower flows in the Severn catchment.

Table 6: Severn Drought Order Invertebrate Assessment points

Assessment Point	Watercourse	Invertebrate Site	Biosys ID	Grid reference
Afon Clywedog, Bryntail	Clywedog	Park (BIO SP PT)	49874	SN94000 85700
Afon Vyrnwy, Vyrnwy weir	Vyrnwy	Mill Bridge Dolanog	50350	SJ06780 12860
	Severn	Dolwen	52148	SN9970085200
-	Severn	Lower Isle of Bicton	173804	SJ46198 16554
-	Severn	Cressage	52526	SJ59472 04613
River Severn, Buildwas	Severn	Buildwas	158364	SJ64620 04425
River Severn, Coalport	Severn	Coalport	52795	SJ 70200 02100
River Severn, Bewdley	Severn	D/S Dowles Brook	52393	SO78000 76400
River Severn, Saxons Loade	Severn	Upton on Severn	47463	SO85050 40890
River Severn, Hawbridge	Severn	Hawbridge	51327	SO84500 27720
River Severn, Lower Parting	n/a	n/a	n/a	n/a
Control site	Tanat	Llanyblodwel	50766	SJ 24200 22900
Control site	Teme	Tenbury	48210	SO 59942 68511

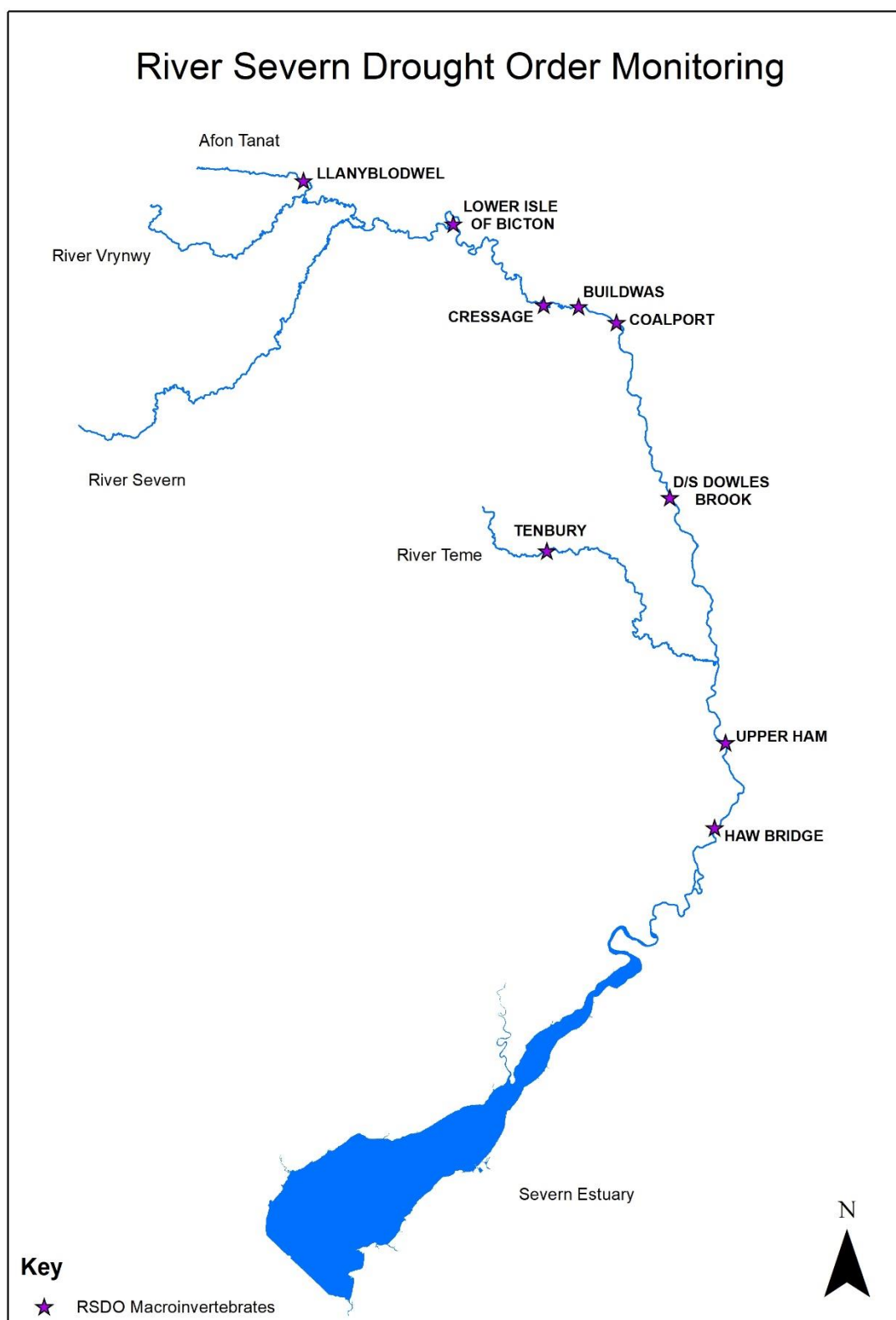


Figure 21 - Map showing macroinvertebrate sampling sites in England

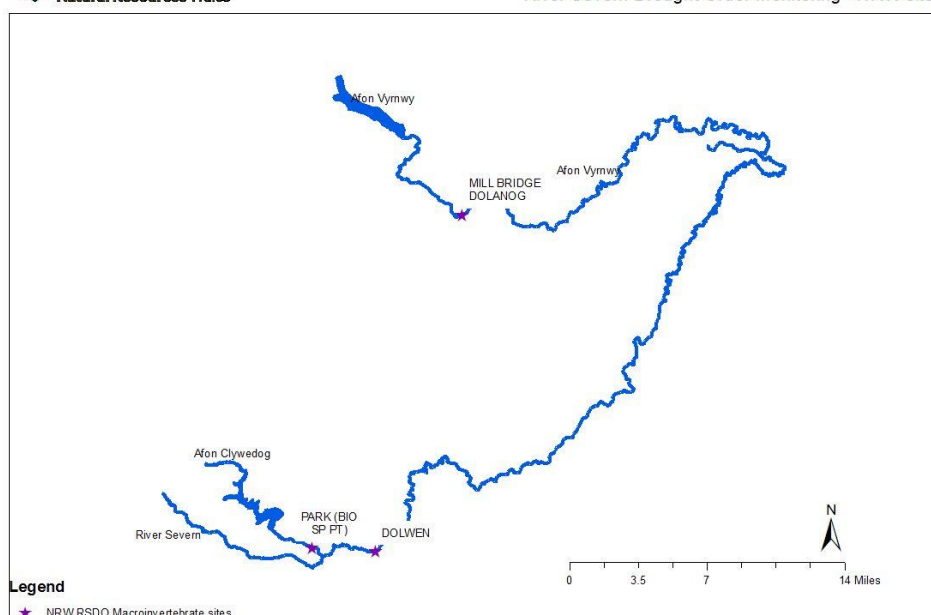


Figure 3 - Map showing macroinvertebrate sampling sites in Wales

The LIFE index is a proven technique for assessing the impact of variable flows on benthic macroinvertebrate populations (Extence *et al*, 1999). Summer flow variables are highlighted by Extence *et al*. (1999) as being a key factor in determining community structure in most chalk and limestone streams, whereas macroinvertebrate communities in rivers draining impermeable catchments are much more influenced by short-term hydrological events. In addition, macroinvertebrates in rivers with regulated or augmented flows tend to be most strongly affected by non-seasonal, inter-annual flow variation. As a result, the correlation of LIFE scores with flow can vary considerably between sites.

Figures in Appendix J.1 show the HEV plots and drought response plots for the six macroinvertebrate sites selected for this study and the two control sites. Generally historical macroinvertebrate data was available from the 1990s onwards.

Afon Clywedog – Park (Site ID 49874)

As part of the River Severn Regulation system, during periods of low flow releases are made from Clywedog reservoir in order to maintain flows at Bewdley. As a consequence flows increase at the Park site in times of regulation. The HEV LIFE plot for Clywedog, Park shows that generally after periods of regulation in the low flow years of 1989/90, 1995/96, 2003, 2005, 2006 and 2010/11 the LIFE O:E does increase slightly in the autumn sample. The observed LIFE scores also follow the same pattern. Exceptions to this was a decrease in LIFE and LIFE O:E in autumn 1996, 2024 and 2025. In 1996 this was just after the low flows encountered in 1996 and therefore an increase in regulation flow. This was likely the same case for 2024 and 2025. Number of taxa (O:E) has traditionally been low at this site and is most likely to be due to the unstable nature and the compacted substrate of the Afon Clywedog because of releases from Clywedog reservoir. However there appears to have been a general increase in taxon richness over time with a corresponding decrease in ASPT. ASPT O:E is generally good and therefore water quality should not be an issue at this site. The observed PSI scores range between 53 and 100 and

can therefore the site can be described as ranging from minimally silted/ unsilted to moderately silted. The lowest PSI O:E scores appear to occur in the spring preceding regulation, possibly indicating a build-up of fine sediment before the increased flows of regulation remove the sediment from the system. The autumn samples generally have a higher PSI O:E ratio than the ones taken in spring. There appears to have been a slight downward trend in both PSI O:E and observed PSI over time, suggesting a general increase in sediment at this site, however this has improved slightly since 2024.

Afon Vyrnwy – Dolanog (Site ID 50350)

The lowest LIFE scores for the Vyrnwy at Dolanog occur in the autumns of 1996 and 2003. This may be reflecting the low flow years 1995/6 and 2003 but there is a lack of data collected for this site in the years proceeding these dates and this makes interpretation of the data unreliable. The lowest PSI scores (appear to occur following lower flow years, suggesting a build-up of fine sediment that may be a result of the low flows experienced during this time. As on the Clywedog, there appears to be a slight downward trend in PSI O:E over time. The N TAXA O:E ratio is variable but the site, although very stable, can be difficult to sample especially in less than ideal conditions due to its substrate and fast flow.

River Severn – Dolwen (Site ID 52148)

All samples taken since 1995 have exceeded the 0.94 guidance threshold for LIFE O:E suggesting no low flow impacts but as the river is highly regulated this is not a reliable statement. PSI scores for this site are steady and show no impact from sedimentation as all above the guidance threshold. ASPT O:E scores are steady and above the G/M boundary in WFD classification. WHPT NTaxa is less stable and does fail the G/M boundary but has increased over time.

River Severn – Isle of Bicton

While this site does not have a long historic data set going back to 1995 it does have lots of recent data. All samples have exceeded the 0.94 guidance threshold for LIFE O:E suggesting no low flow impacts. All other indices are also above the guidance threshold for the majority of the time

River Severn – Cressage

All samples taken at this site since 2000 have exceeded the 0.94 guidance threshold for LIFE O:E suggesting no low flow impacts. All other indices are also above the guidance threshold for the majority of the time, although more variability with N Taxa which could be due to difficulty in sampling during or just after higher flows.

River Severn – Buildwas

All samples taken at this site have exceeded the 0.94 guidance threshold for LIFE O:E suggesting no low flow impacts. All other indices are also above the guidance threshold for the majority of the time, although more variability with N Taxa which could be due to difficulty in sampling during or just after higher flows

River Severn - Coalport

This site can be difficult to sample, particularly during slightly higher flows and this has resulted in data gaps making interpretation difficult. The ASPT and N TAXA plots (actual and O:E) indicate that there has been a general improvement in water quality since 2001.

There appears to be a delayed decline in observed LIFE scores and LIFE O:E following the low flows of 95/96 but lack of data during and immediately after these periods makes it difficult to draw any firm conclusions with regards to response to flow and the length of time taken for the macroinvertebrate community to recover. There also appears to be a decline following the low flows of 2010/11, followed by a recovery in LIFE by autumn 2012. The PSI scores are at their lowest when the LIFE reduces and follows the same pattern, indicating an increase in fine sediment build up as a consequence of the reduced flows.

River Severn – D/S Dowles Brook

For the purposes of long term monitoring invertebrates are usually sampled once in a season, but raw invertebrate data taken monthly from this site was found in report by Craig Goch Research Team, Severn Trent Water Authority covering the 1975 drought and subsequent recovery period. The data from this time was not sampled using the exact methods used today but it was felt that for the purposes of this report the data should not be excluded due the critical time period the data covered. Any data collected prior to 1995 was not subject to the same procedures and high analytical quality control standards that have been in place since but are thought to still be reliable and can be used to examine long term patterns. LIFE scores (O:E ratios and actual) were compared with flow data. The lowest LIFE scores occur in the 1975 and 1989/90 drought period when flows were low, suggesting that the invertebrate fauna is responding to the low flows in these periods. The LIFE scores begin to recover by the following summers of 1978 and 1991 respectively. This also corresponds with the lowest actual PSI values. There is also a dip in LIFE after the 1995/96 low flow period. There were no samples taken in the autumn 1996 or spring 1997, making the interpretation of this data difficult for this period, but LIFE scores had recovered by spring 1998. There was a decline in LIFE (both actual and O:E) autumn 2011 following the low flows in 2010/11. Unfortunately there are no samples in 2010 and high flows prevented the sample being taken in autumn 2012. The PSI results suggest that during periods of low flow there is an increase in fine sediment and the macroinvertebrate community is changing and responding to this.

The HEV LIFE plot from River Severn, d/s Dowles Brook shows that this site appears responsive to changes in flow and that the invertebrate life has been impacted in the 1976/77, 1989/90, 1995/96 and more recently 2010/11 drought.

The lowest LIFE O:E scores do occur following the low flows in 1989/90. The low LIFE O:E scores in 1989/90 also have corresponding low PSI O:E scores.

River Severn - Upper Ham

The LIFE and LIFE O:E scores do not appear to be corresponding to variations in flow. The low PSI results suggesting the site is heavily sedimented are due to the modified nature of the site in this navigable reach and fine sediment dropping out in the lower reaches of the Severn. The data from the lower reaches of the Severn are not directly comparable with the other sites due to the methodology used to collect data from the deep sections of the river.

River Severn - Hawbridge

Similar conclusions can be made with regards to The Severn at Hawbridge. LIFE and LIFE O:E scores from this site appear not to be responding to changes in flow. The PSI results are suggesting fine sediment pressure. This would be expected for a modified site on the lower navigable reaches of a large river.

Afon Tanat - Llanyblodwel and the **River Teme –Tenbury (control sites)**. Both sites appear to be responding to variation in flow but have not been stressed by lack of flow. The greatest impact on the macroinvertebrates appears to occur following a second year of low flows and the time taken to recover is lengthened. It would be expected that in the case of an area wide drought, these sites would respond and LIFE scores would reduce.

Historic Macroinvertebrate Data

Historic macroinvertebrate data for previous periods of low flow and proceeding recovery time were classified using the cycle one techniques for WFD classification and is therefore not directly comparable with Table 1. The results are shown in Table 7.

Table 7: Historic Macroinvertebrate WFD Classification Calculation

Site ID	Site Name	1975	1978	1989	1990	1991	1992	1995	1996	1997
49874	Clywedog - Caravan Park			Good	Moderate		Good	Good	High	Good
50350	Vrynwy - Dolanog							Good		
52795	Severn - Coalport							Good		
52393	Severn - D/S Dowles Brook	Moderate*	High*	Good	Good	Good	Good	Good		
47463	Severn – Upton on Severn							Poor	Moderate	
51327	Severn - Hawbridge							Bad	Bad	
50766	Tanat- Llanyblodwel			High	High	Good	High	High	High	
50350	Teme - Tenbury				High	Good	High	High		

* The 1975 and 1978 data from Severn - D/S Dowles Brook was not sampled using the WFD standard sampling technique but a 3 minute kick sample on the riffle was used and therefore it is considered consistent with the later methodology for the purposes of this report.

Samples from both spring and autumn are required in order to undertake a WFD classification. Unfortunately this data is not available for all sites and all years, hence the gaps in Table 7. The classification results indicate that although the invertebrate life was undoubtedly affected by the drought of 1975 the macroinvertebrates had recovered by 1978. In the case of the 1989/90 drought, the WFD classification would have remained at good although again the invertebrate fauna were showing signs of stress and were affected by the low flows.

General Impact of Low Flows

The general consequence of low flows is a reduction in the wetted width of the river, thereby reducing the availability of habitat for the invertebrates and the alteration of flow patterns and water velocity within the watercourse. The composition of the invertebrate assemblage alters, with the loss of invertebrates that require high velocity, high oxygen conditions and an increase in invertebrates that can tolerate these reduced flow conditions. As the flow declines further, stream margins become

exposed and invertebrates that rely heavily on hydrological linkages to the macrophytes at the edge of the channel for food, shelter and emergence are impacted as water recedes from these habitats. Even the taxa that live on the surface may become more prone to predation when the marginal vegetation is isolated from the stream/river edge.

The reduction in flow will often promote the settlement of fine sediment. Siltation stresses many aquatic insects by clogging their respiratory systems or smothering their food sources. This can slow post drought recovery in some watercourses. The low flows may also lead to a decrease in water quality due to the lack of dilution of effluents.

The most dramatic changes occur when flow ceases and pools form with possible decreases in dissolved oxygen and higher temperatures. Associated with this could be an increase in algal blooms, which can cause large fluctuations in dissolved oxygen as they produce oxygen in the day and then use it up overnight. Algal blooms can also block out light causing the death of submerged macrophytes and can smother the substrate, therefore reducing the interstitial oxygen. Many invertebrates rely on flow to provide feeding currents, enhance respiration, enable passive movement, import detritus or aerate the water through physical turbulence. These rheophilous groups will disappear as they are unlikely to find suitable refuges except in nearby flowing habitats within reach. The break in longitudinal connectivity also stops invertebrate drift, preventing recolonisation in remnant flowing sections.

Recovery after a drought will depend on a number of variables including the drought length, the time of year when the drought occurred and the availability of recolonisers. Usually early colonists with short life cycles (e.g. chironomids and simuliids) are then joined by longer lived invertebrates (e.g. mayflies and caddisflies). Taxon richness then rises steadily as flows establish. However, previously common drought-intolerant taxa may be reduced and new habitat created for taxa that were rare before the drought. The response of individual invertebrate species very much depends on their individual life cycles and environmental preferences. Ecological resilience to flow stress is greater in more natural channels, due to the greater habitat diversity and substrate stability that provide more refugia for the invertebrates at extreme high and low flows.

Actual Impacts of the 1975/76 drought

Research was undertaken by Craig Goch Research Team of Severn Trent Water Authority during and after the 1975/76 drought to determine the impact of the drought.

Afon Clywedog

Afon Clywedog has low density and diversity of invertebrate fauna. A small change in discharge when the river is at low flows may have a much greater ecological consequence than a large change at higher flows simply because of the relative change in wetted area. Under normal circumstances many organisms are capable of moving down into interstitial spaces and remaining there for 6-8 weeks before recolonising the surface. In the Clywedog, the substrate is bedrock or heavily compacted and during the drought period of 1975/6 it was covered with silt from the scour valves.

Due to the increased use of the Clywedog for regulation in 1975 and 1976, the level of Llyn Clywedog was greatly reduced by the end of both summers. In order to

conserve water and quicken refilling, outflows from Clywedog were greatly reduced (to 20MI/d) for considerable periods. This led to large areas of the river bed being left exposed as the water flowed along a narrow channel. The lowered water level in the lake and high winds in late summer resulted in greater silt erosion by the wave action from the exposed banks.

Compensation water was taken from the bottom in order to remove silt from the reservoir and this was deposited in the Afon Clywedog, exacerbating the ecological problems. From early 1975, flows were often higher and temperatures lower than normal during periods critical for the emergence, development and oviposition for many species of invertebrates e.g. *Serratella ignita* normally occur in large numbers over a short (3 month) period. It is present in very low numbers and is spread out over a 6 month period in the Afon Clywedog. This will result in a very sparse and sporadic emergence of adults and hence cause a lowered egg production for the following year. The effects of drought and spate will depend on the time of the occurrence in relation to an organism's life history – this is probably an important factor in the Afon Clywedog as the normal winter/summer flow regime is reversed.

Afon Vyrnwy

An investigation was undertaken between 1975 and 1978 order to determine the effect of proposed changes to the pattern of compensation releases from Lake Vyrnwy in order to achieve a more flexible approach to compensation flows and to balance differing interests of water supply, fisheries management and general ecology and minimising the frequency of spillage from the reservoir. These are the control rules that are still used today.

The Vyrnwy has two distinct reaches, the upper reach from the dam to the confluence with the Banwy, which is fast flowing with typical pool and riffle sequence; and the lower reach, that is deep and more slow flowing. The effects of changing the flow regime on the Vyrnwy and the likelihood that this would induce ecological change were dependent on the width, depth and flow at individual sites. The velocity over the bedrock was higher and less variable than over the stones. The most direct changes in flow in the Vyrnwy was to alter the wetted width of the river in the upper reach.

Quantitative samples were taken using Surber samples, but a direct comparison of the numbers of invertebrates collected cannot be made with kick samples. The kick samples did not include the bedrock areas. Higher densities and more taxa were recorded from the stony substrate than from the bedrock (the bedrock contains pockets of sand and silt in the crevices and hollows particularly at times of low or stable flow). During the summer months, the bedrock was covered by epilithic and filamentous algae. Many of the invertebrate species that were found on the bedrock were algal feeders.

At Pont Robert, which was 5km downstream from the site at Dolanog, the whole of the river bed was covered at flows of 100mld. 2/3 of the bed is stones and boulders and 1/3 bedrock shelves. At times of low flow, <100 MI/d, almost ½ of the wetted area was bedrock. At about 50 MI/d, 1/3 of the bed was exposed. During the summer of 1976, flows were generally very low and much of the stony substrate was dry. However during the monthly freshet, dry areas were rewetted and this instability is thought to have contributed to lower numbers found on the stones. The lowest number of animals was recorded during the summer and autumn of 1976.

At times of low rainfall when natural run off to the river is minimal, almost all the flow in the Vyrnwy was reservoir water. Under these conditions, the flow at Pont Robert falls well below the desirable 100 MI/d, causing a drought reaction in the invertebrates as they move in to the smaller wetted areas. It is significant that the changes in flow resulted in fluctuations in the area of submerged gravels and stones, which are important habitats for the invertebrate fauna.

Severn - Bewdley

Invertebrate samples were taken to study the effect of a reduction in flow during the period of 1975/76 drought. During this period flow at Bewdley was maintained at 730 MI/d but this presented some difficulties and the minimum flow was approximately 450 MI/d.

Flow reductions due to abstractions occurred mainly during the night. This coincided with the period of greatest invertebrate activity, possibly leading to increased drift rates. The sampling site used for this study is the same site that is used today and is the riffle located downstream of the confluence with Dowles Brook. During low flows the area of the wetted riffle was reduced by up to 50% and confined to the eastern bank. The western edge of the river dried up completely and the central area became largely stagnant water 5-10cm deep. During 1977, the drying of the riffle and narrowing of the wetted area was further exacerbated by the building of a boulder dam about half a metre high above the riffle to increase the water depth in the upstream pool, probably for angling purposes.

In general the River Severn at Bewdley supported a rich and varied fauna and was characterised by the dominance of Crustacea, Ephemeroptera and Trichoptera. The drought conditions of 1976 and the artificial drought of 1977 had pronounced effects and the riffle fauna suffered from the low flows experienced. Crustacea, Trichoptera and Oligochaeta all declined in abundance whereas Chironomidae, Simuliidae and some Ephemeroptera increased in abundance.

Lower River Severn

During and immediately after the 1976 drought, there were some problems with water quality in the lower River Severn with an increase in nitrate and ammonia and a decrease in DO to 50-60% saturation. Increased use of Clywedog resulted in a noticeable reduction in turbidity and in the numbers of algal blooms. Dredge samples were taken from a boat. There was an exceptionally low abundance and species diversity of invertebrates, the lowest levels being recorded in autumn 1976. Low densities of invertebrates are thought to be mainly due to unsuitable substrate (ranges from thick glutinous mud to extremely dense clay which effectively forms a bedrock layer). The bedrock substrate would not provide a refuge from predators or adverse physical factors, while the large amount of shifting materials, such as mud and leaves would contribute not only to the lack of invertebrates but also prevent the establishment of plants and algae. It was noticeable that the substrate did not remain constant throughout the period of the study. Most of the invertebrates were found in piles of debris which offered more stability and protection than the natural substrates.

Assessment of Impact on the Current Environment: Severn Corridor Ecology

Limitations of the Ecological modelling

Limited data, inconsistent coverage of historical data and a lack of tools specifically designed for predicting the impact of low flows/drought on the ecology of regulated rivers made true assessment difficult.

A new hydroecology toolkit has been developed building on the DRIED UP (Distinguishing the Relative Importance of Environmental Data Underpinning flow Pressure). A hydroecology model for use on the River Severn is under development but not available for this assessment.

Therefore, the best available data was used and professional expertise was applied to the assessment process.

Discussion of possible impacts from the River Severn Drought Order in isolation

The main aim of this report is to separate the impacts the River Severn Drought Order would have on the ecology of the River Severn as opposed to the 'Do Nothing' scenario of allowing the natural drought event to take its course, resulting in a potential complete loss of flows in the upper reaches of the Severn. The challenge is to try to differentiate and evaluate the pros and cons of applying the River Severn Drought Order or leaving nature to run its course.

Macrophytes

It has not been possible to accurately determine what extent periods of very low flow would impact on the macrophyte communities along the River Severn, Clywedog and Vyrnwy. Surveys have been undertaken annually (with data gaps due to Covid pandemic) as part of the updated monitoring programme, although further work needs to be undertaken to understand the impact of flow on macrophytes as opposed to current indices which relate to nutrient pressure.

Diatoms

Diatoms are generally not considered to be appropriate for use in drought monitoring and assessment and therefore have not been specifically used in this case other than as part of the general WFD classification process. Further work needs to be undertaken to understand the impact of flow on diatoms as opposed to current indices which relate to nutrient pressure. Current analysis methods also differ between EA and NRW and this would need to be factored into any future data analysis.

Macroinvertebrates

This section will assess whether applying the Drought Order would have detrimental effect on the macroinvertebrate assemblages within the Severn, when compared to not applying the Drought Order. It must be remembered that any severe natural drought is likely to have a detrimental effect on the macroinvertebrate life within a river system. The exact response will depend on a number of variables and will differ according to the severity of the drought, the time of year and temperature i.e. there are likely to be more detrimental effects if the weather is hot.

Looking at the historical invertebrate data available it is possible to suggest what may happen to the invertebrate life under the different scenarios.

Bryntail AP(Site id 49874 Clywedog – Park)

Acute

Do Nothing

Historic data suggests that this site does respond to changes in flow conditions and that LIFE scores will decline if the compensation flows are reduced. If the drought is allowed to follow the natural course of events, the compensation flows would fail in late September and for 35 days there would be flows of less than 10MI/d. This failure is likely to have a detrimental effect on the invertebrate life in the Clywedog. The compensation flows are restored at the beginning of November in the model but flow variation does not happen until 306 days later when the reservoir refills while regulation is not required. Even with flows of 18.2 MI/d for compensation, much of the river substrate will be exposed as the flow is reduced to a narrow channel (as recorded in 1977 at a site less than 1km upstream of the site) and therefore there will be continued longer term implications for the macroinvertebrate population. The amount of river bed exposed will be dependent on the site and the profile of the river bed at that point. The reaches closest to the dam will be the more adversely affected as there will be less run off from the reduced catchment size when it does eventually start to rain.

EA Drought Order

If the Drought Order is applied, there will be a reduction in flows from late August as opposed to late September but there is no complete failure of the compensation flows, therefore allowing flows to continue for a greater length of time. The macroinvertebrates will be compromised by the change in regime, but it will be to a lesser extent than if the compensation flows were allowed to fail by doing nothing and causing greater harm in the longer term. In this model, flow variation is lost for 224 days, an improvement of 82 days when compared to the 'Do Nothing' scenario. The improvement in the flow regime will mean that the invertebrate population would be expected to recover more quickly. The flows in the river are still artificially elevated above what would naturally be present in a period of drought in a non-regulated river and the system is likely to be better off than many of the other watercourses in the locality.

Chronic

Although there are still a number of issues to be resolved with regards to the accuracy of the modelling of the chronic flows, the general pattern is considered correct.

Do Nothing

As discussed earlier, there would have been a dramatic decline in the invertebrate life following a failure in the compensation flows in the previous autumn in the acute scenario. In the chronic scenario where there is a long term drought, it is unlikely that the invertebrate life would have recovered from the previous years lack of flow particularly as the flow variation is lost until late May 1977. There would be another failure of compensation water in October 1977, which will cause a further impact on the already stressed invertebrate population. The length of time taken for the macroinvertebrate population to return to a pre drought/normal level would increase particularly as the amount of drift is restricted due to the dam, the low population densities within the Clywedog system and the nature of the substrate.

EA Drought Order

There would be an improvement to the situation as compared to the 'Do Nothing' scenario as there would be no compensation flow failure and an improvement in the length of time without flow variation. This can only help to reduce the severity of the effects of the drought on the invertebrate population reduce the length of time that the macroinvertebrate community will take to recover from the drought after the flows have recovered.

Vyrnwy Weir AP (Site ID 50350 , Afon Vyrnwy – Dolanog)

Acute

Do Nothing

This site appears to be responding to changes in flow and the declines in LIFE may be reflecting the low flow years 1995/6 and 2003 but there is a lack of data collected for this site in the years proceeding these dates and this makes interpretation of the data unreliable and estimating the recovery period difficult. The 'Do Nothing' scenario does not cause a compensation flow failure but there are 174 days of no flow variation as the reservoir fills. The effects of changing the flow regime on the Vyrnwy and the likelihood that this would induce ecological change were dependant on the width, depth and flow at individual sites. Samples taken 5km downstream of the Dolanog site showed that flows fell well below the desirable 100mld, causing a drought reaction in the invertebrates as they move into the smaller wetted areas. The changes in flow resulted in fluctuations in the area of submerged gravels and stones, which are important habitats for the invertebrate fauna. In order to determine the response of this site, future monitoring should include the use of cross sections of the river to look at the effect of the altering levels on wetted area and the exposure of substrate and sediments.

EA Drought Order

There are no improvements or deteriorations in flows when compared to the 'Do Nothing' scenario.

Chronic

Do Nothing

There appear to be 20 days of irregular failures of the compensation flows with a minimum of 17.46mld at the beginning of October 1977. The compensation failure, the extended period of reduced compensation flows (until April 1978) and lack of flow variation while the reservoir refills, will further exacerbate any detrimental response of the macroinvertebrate community following the previous years drought and extend the period of recovery for the fauna to return to pre-drought levels. The exact response will depend on the extent wetted area and the exposure of the substrate and sediments at specific sites.

EA Drought Order

There will be a reduction in the number of days of irregular failures of the compensation flow predicted with the application of the drought order. This is an improvement on the 'Do Nothing' scenario, but there will still be an adverse effect on the macroinvertebrate life. The improvements can only help to reduce the severity of the effects of the drought on the invertebrate population reduce the length of time that the macroinvertebrate community will take to recover from the drought after the flows have recovered.

Buildwas AP (Site ID 52795, Severn – Coalport)

Acute

Do Nothing

Historic data suggests that this site responds to flow and on occasions has suffered from flow stress. However, the nature of the site and the lack of data during and immediately after periods of low flow makes it difficult to draw any firm conclusions. The geomorphology of the River Severn as it flows through the Ironbridge Gorge may explain why this site may be more sensitive to changes in levels than other locations on the main Severn and has suffered from periods of flow stress in the past. When the flow is reduced through the rocky narrow channel, much of the river bed will be left exposed. In order to determine the precise effect of reducing the flows within this short section of the Severn, cross sections and levels would need to be taken. Other sites within this stretch of river are likely to be slightly less sensitive to the reductions in flow.

The 'Do Nothing' scenario will maintain the flow at 1100 MI/d for nearly 2 months but then flow will be reduced to below 600MI/d towards the end of October

EA Drought Order

The flows would drop by approximately 200MI/d for August and September. Although the flows are lowered, they are still higher than what would naturally be present without the regulation. The EA Drought Order would provide a flow benefit for approx. 20 days in the latter half of October.

Chronic

Do Nothing

There is no significant flow failure but flows would be reduced to a lower level later in the season as the flows are not maintained by regulation. The invertebrate community in the Gorge has been shown to be stressed in periods of lower flows and therefore recovery time when flows do eventually improve is likely to be extended especially following a second year of low flows.

EA Drought Order

In this scenario there are no significant flow failures expected and there is a flow benefit in the latter part of autumn. Greater benefit is seen as regulation is continued, albeit at a lower level for a greater length of time in a critically flow stressed period.

Bewdley AP (Site ID 52393, Severn - D/S Dowles Brook).

Acute

Do Nothing

There is a 20 day flow crash from mid October to beginning of November following the complete failure of compensation flows from Clywedog with a minimum flow of 336MI/d.

There was a pronounced deleterious effect on the invertebrate life in the latter part of 1975 and 1976. In 1975, the flow was maintained at the 730 MI/d but this did present problems and the minimum flow was 450MI/d. This is 100MI/d higher than predicted in the 'Do Nothing' scenario. Observations made at the time likely to be exacerbated with even lower flows that are modelled in the 'Do Nothing' scenario but the true extent of reduction cannot be predicted accurately until cross sections of the river bed are taken and related to river levels. It is highly probable that the invertebrate

life will be greater than has been seen before and the recovery time will be increased.

EA Drought Order.

If the Drought Order is applied and flows are maintained at 730MI/d, there is no significant deterioration (within 10% of EFI) and flows are maintained at a higher level than if the natural course of events were allowed to continue, until it begins to rain at the beginning of November.

In the 1976 drought, the overall water quality at Bewdley was reported to have deteriorated during the summer months, especially in the periods of low flow. There has been a general upward trend in the ASPT at this site, indicating a general improvement in water quality at this site.

In 1989, over the summer period to the end of September, Bewdley was maintained to 850MI/d but there were a number of days when flows fell below this level with the lowest mean daily flow recorded at 706MI/d. Flows also fell overnight to less than 650MI/d on a number of occasions over a six hour period due to the overnight abstractions. A Drought Order was applied in late September 1989 and flows were maintained at 730MI/d. There was a decline in the LIFE score during this period and it is probable that if the EA Drought Order was applied to the modelled scenario, the macroinvertebrate population would be adversely affected. However, historically the invertebrate community does appear to recover relatively quickly after these events. This will be further aided by the improvements that have been seen in water quality since the mid 1970s and late 1980s.

Chronic

Do Nothing

There is a flow crash in mid October with flows falling significantly from the EFI (to the high risk band). The minimum flow is modelled to be 289MI/d. This supports the conclusion of a significant flow impact and there is likely to be a severe detrimental impact on the invertebrate community.

During 1977, the drying of the riffle and narrowing of the wetted area was further exacerbated by the building of a boulder dam about half a metre high above the riffle to increase the water depth in the upstream pool. The effect of this was to mirror the drought of the previous year. This gives us an insight into the likely effect of a two year drought and the length of time taken for the invertebrates to recover. In this case life had recovered to pre-drought conditions by spring 1978. However the modelled scenario flows are much lower than experienced in the actual drought of 1976 and therefore it must be concluded that there will be a much greater deterioration in the invertebrate community and the length of time taken to recover would be increased.

EA Drought Order

Due to modelling issues it is difficult to assess the flow impacts with certainty. However it is expected that there would be no further adverse impacts, while more significant flow gains could be achieved if the drought continued for long enough.

Saxons Lode AP (Site ID 47463, River Severn – Upper Ham)

Hawbridge/Deerhurst AP (Site ID 51327, River Severn – Hawbridge)

The invertebrate community appears not to be responding to variations in flow. The use of LIFE and PSI scores are unreliable as these indexes were not designed to be used with sampling technique used at these sites. Airlifting has been trialled in the

lower Severn and has proved very effective in sampling the macroinvertebrate community. It has been suggested that the sparse and variable nature of the invertebrates in these reaches is mainly due to the lack of suitable and stable habitat available in the lower reaches of the river. Airlifting does sample across the whole width of the river and results have proved variable.

It has not been possible to predict the impacts of the modelled scenarios on the invertebrate life in the lower part of the Severn. Future monitoring should include the use of cross sections of the river to look at the effect of the altering levels on wetted area and the exposure of substrate and sediments. This may help give further insight into predicting the response of the macroinvertebrate community.

ECOLOGY CONCLUSIONS

Any severe natural drought is likely to have a detrimental effect on the macroinvertebrate life within a river system. The exact response will depend on a number of variables and will differ according to the severity of the drought, the time of year and temperature i.e. it is likely to be more detrimental if the weather is hot. The response of individual macroinvertebrate species very much depends on their individual life cycles and environmental preferences.

The biological data assessed within this report suggests that the upper and middle reaches of the River Severn macroinvertebrate assemblages are responding to changes in flow. The sites have shown that flow sensitive ecology has been affected by low flows/drought events in the past. Reductions in LIFE scores in relation to the 1975/76, 1989/90 and 1995/96 and 2010/11 droughts were detected. It is probable that in the scenarios given for the Severn Drought Order and consequently the reduction in the amount of water that is being used for regulation, would have a negative impact on the macroinvertebrate community. Evidence from historical data suggests that the invertebrate life will recover relatively quickly though. However it must be remembered the Drought Order is being used to prolong the length of time water is available for regulation of the River Severn. If the Drought Order was not applied i.e. the 'Do Nothing' scenario, there would be a much greater deterioration in the macroinvertebrate community and the length of time taken for the ecology to fully recover from the effects of a drought would be greatly increased.

Monitoring

To gain baseline data it is proposed that the sites listed in Table 8 are monitored annually in spring and early autumn. All monitoring would be analysed to mixed taxon level.

Table 8: Ecological Monitoring requirements

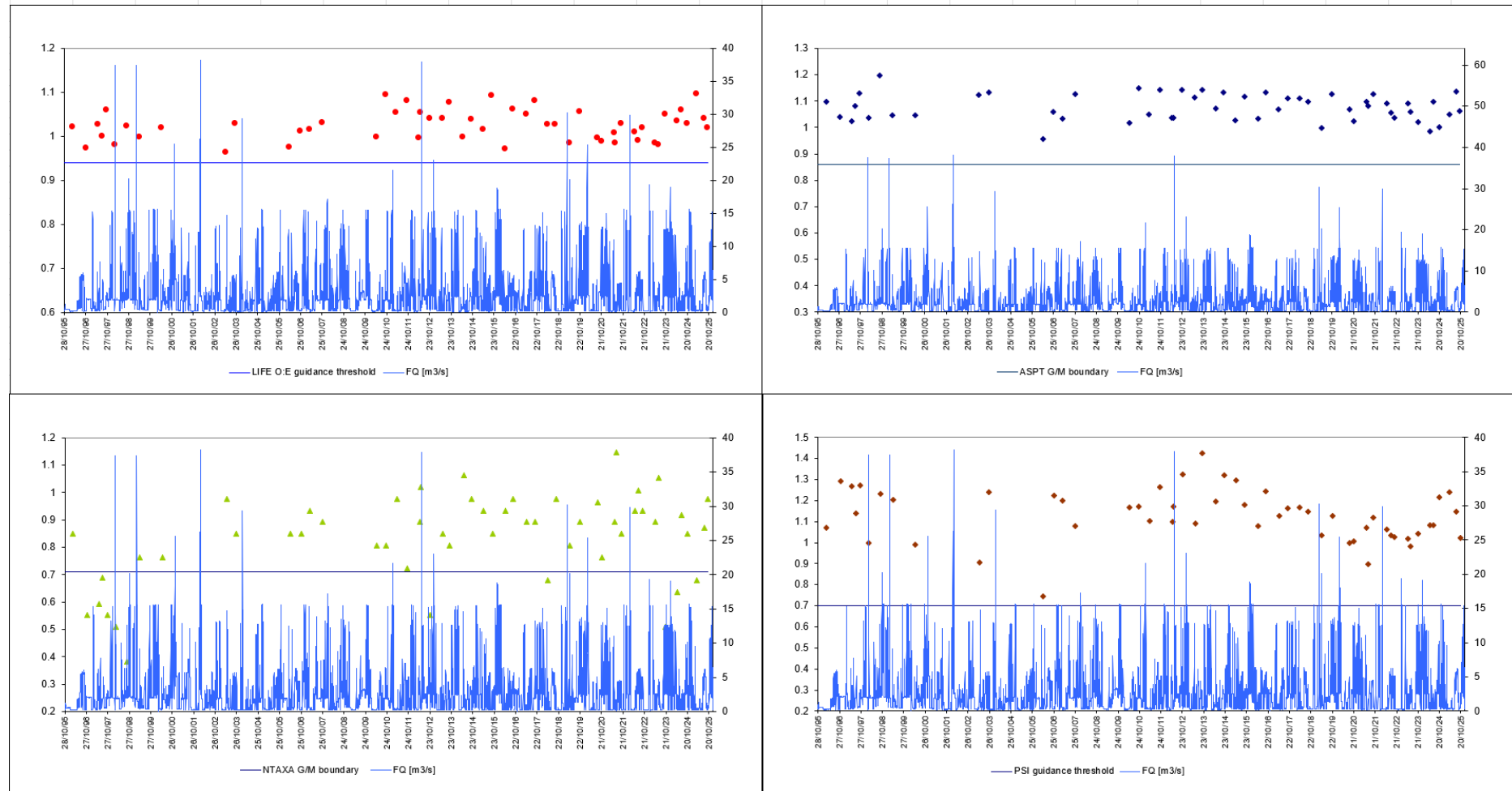
Watercourse	Site	Biosys ID	Grid reference
Clywedog	Caravan Park	49874	SN94000 85700
Vyrnwy	Dolanog	50350	SJ06780 12860
Severn	Dolwen	52148	SN 99700 85200
Severn	Isle of Bicton	51052	SJ 46773 16460
Severn	Cressage	52526	SJ 59380 04550
Severn	Buildwas	158364	SJ 64620 04425
Severn	Coalport	52795	SJ 70200 02100
Severn	d/s Dowles Brook	52393	SO78000 76400
Severn	Upton on Severn	47463	SO85050 40890
Severn	Hawbridge	51327	SO84500 27720
Tanat	Llanyblodwel	50766	SJ 24200 22900
Teme	Tenbury	48210	SO 59942 68511

It is also proposed that a RHS is undertaken at each invertebrate site (1 in 6 years), as it is suggested that LIFE scores and LIFE flow relationships are influenced by physical habitat.

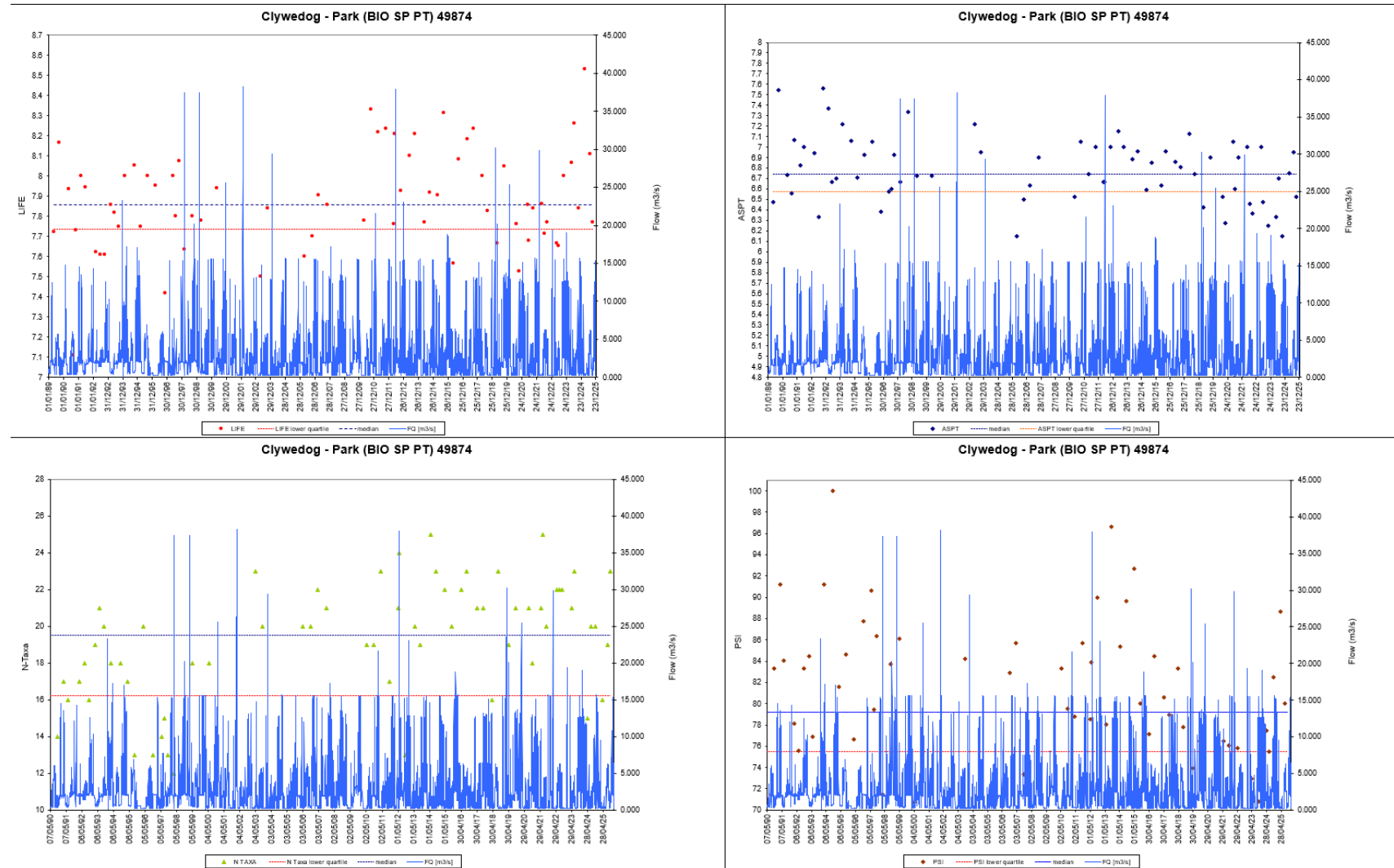
Appendix J.1

Macroinvertebrate HEV and drought response graphs

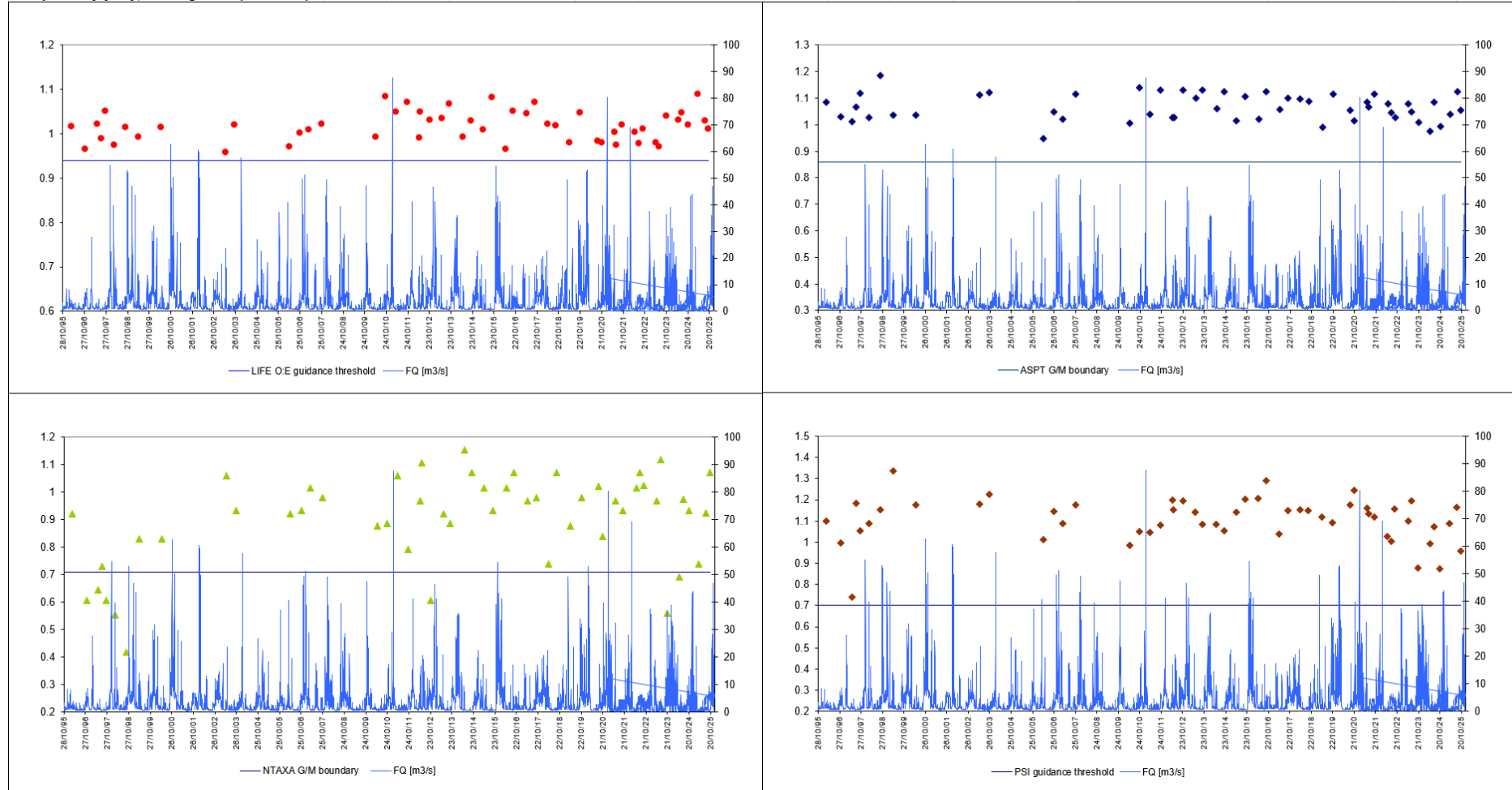
HEV Plot at Clywedog, Park (BIO SP PT) - 49874 (1995-2025)



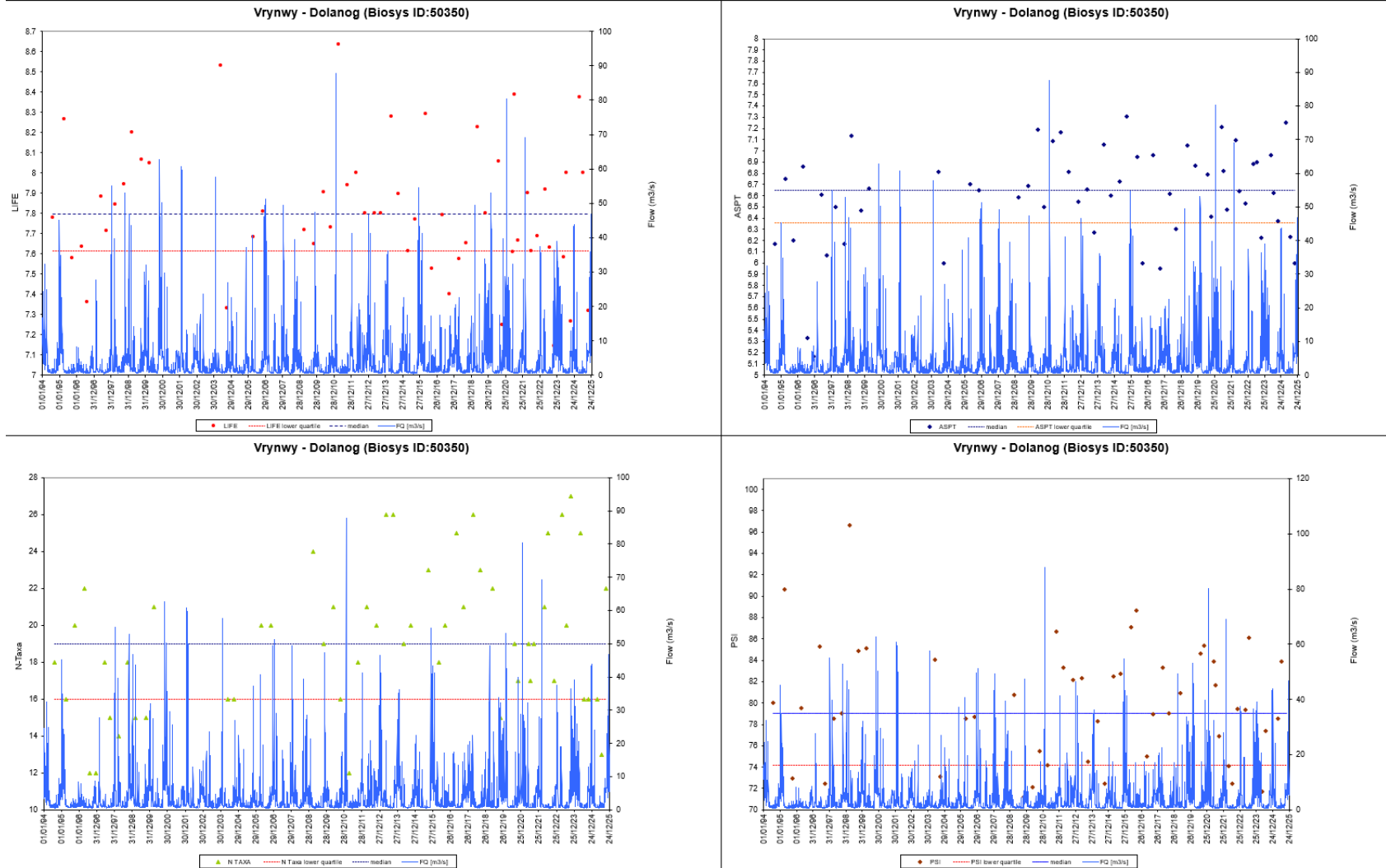
Drought response Ita plot at Clywedog, Park (BIOSP PT) - 49874 (1989-2025)



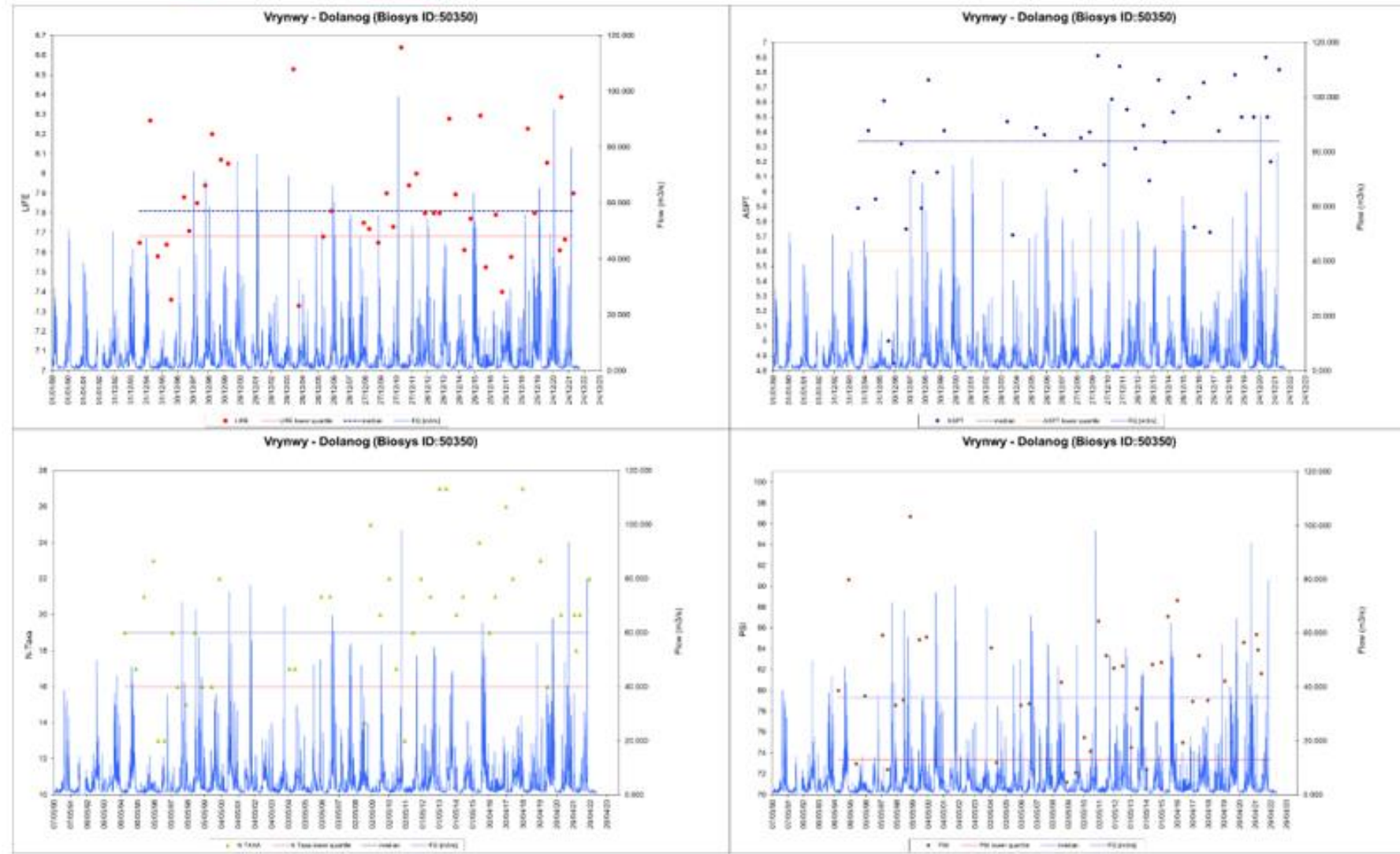
HEV plot at Vyrinwy, Dolanog 50350 (1995-2025)



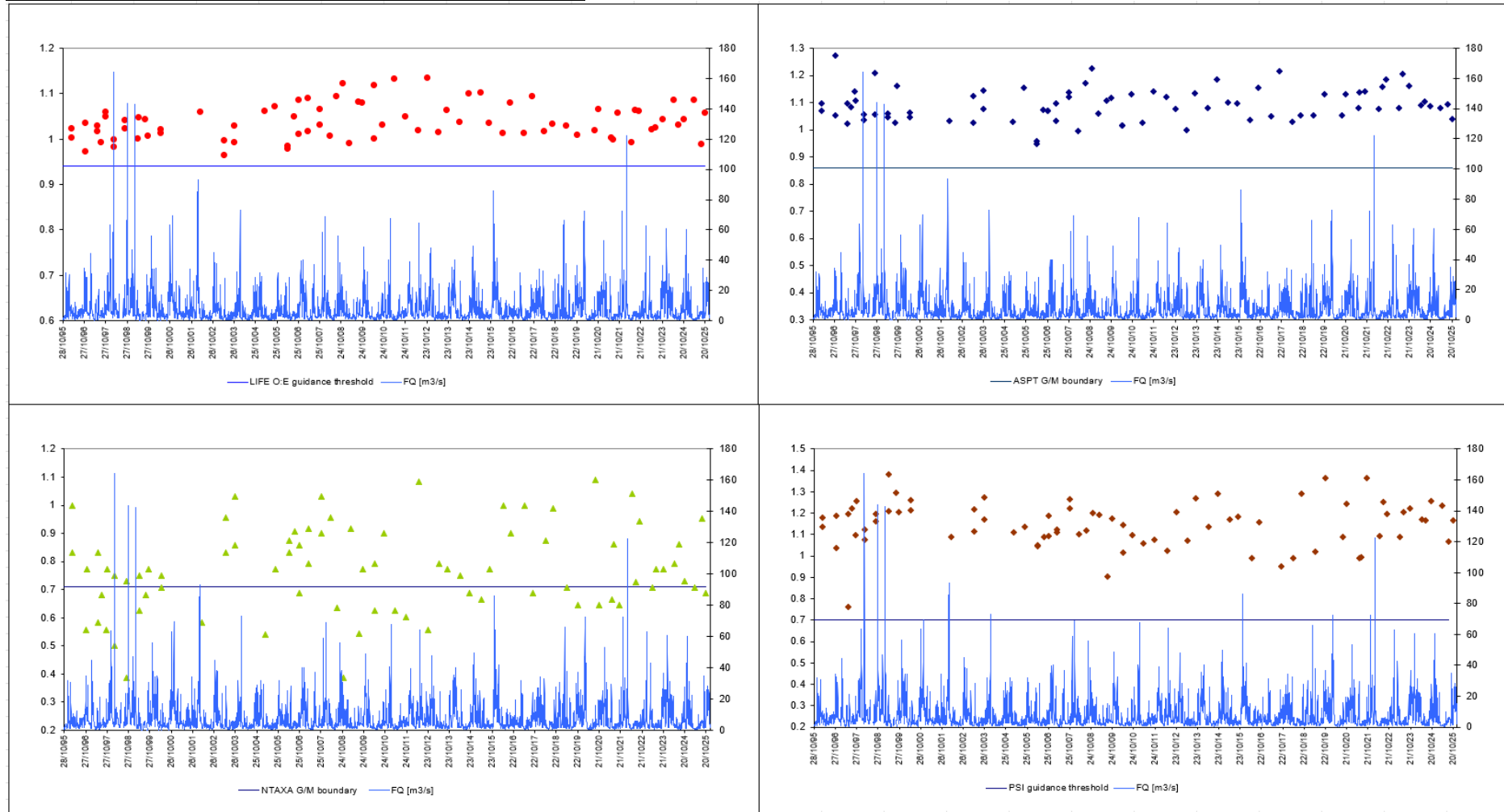
Drought response Ita plot at Vrynwy, Dolanog - 50350 (1994-2025)



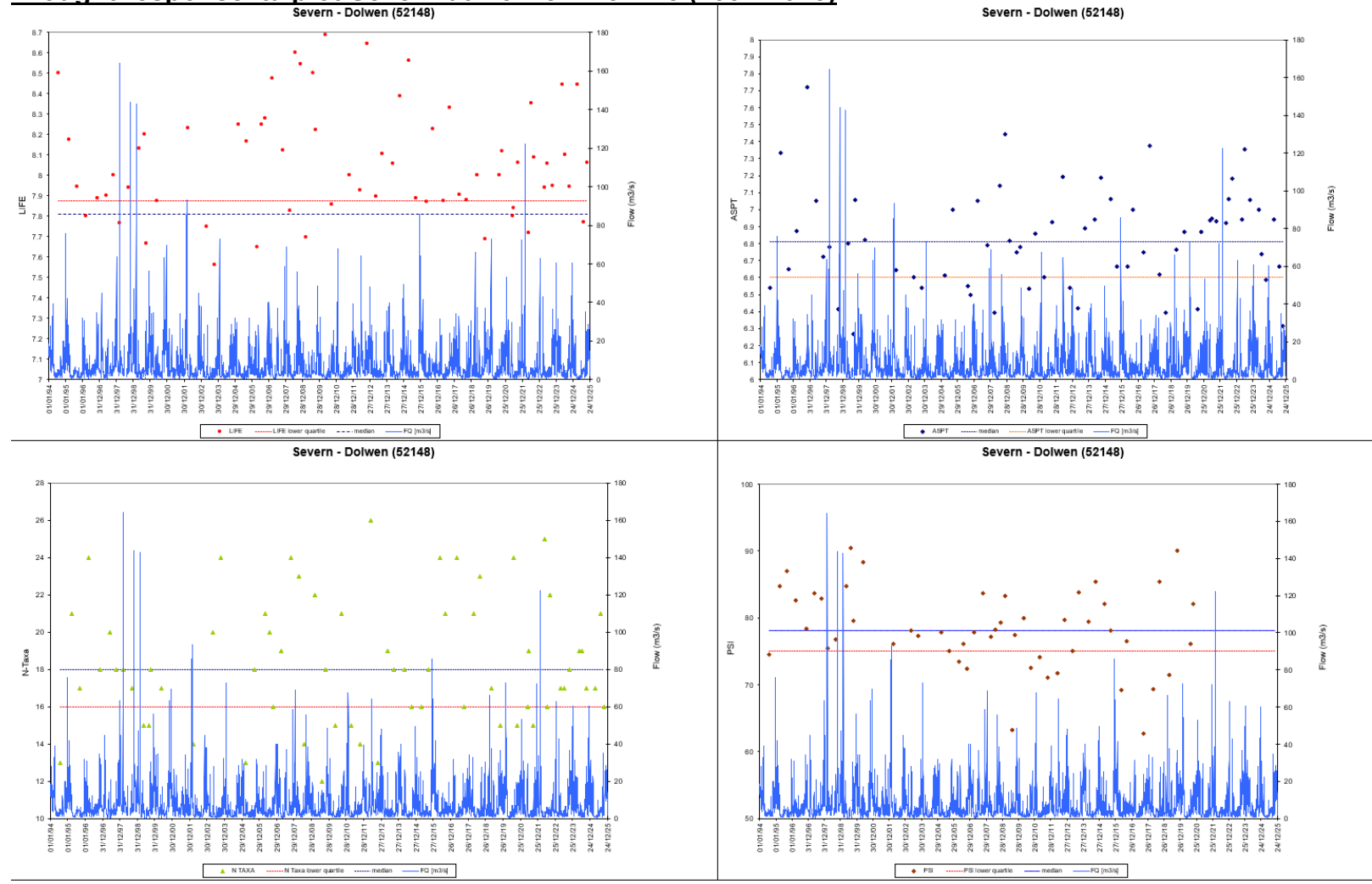
Drought response Ita plot at Vyrnwy, Dolanog



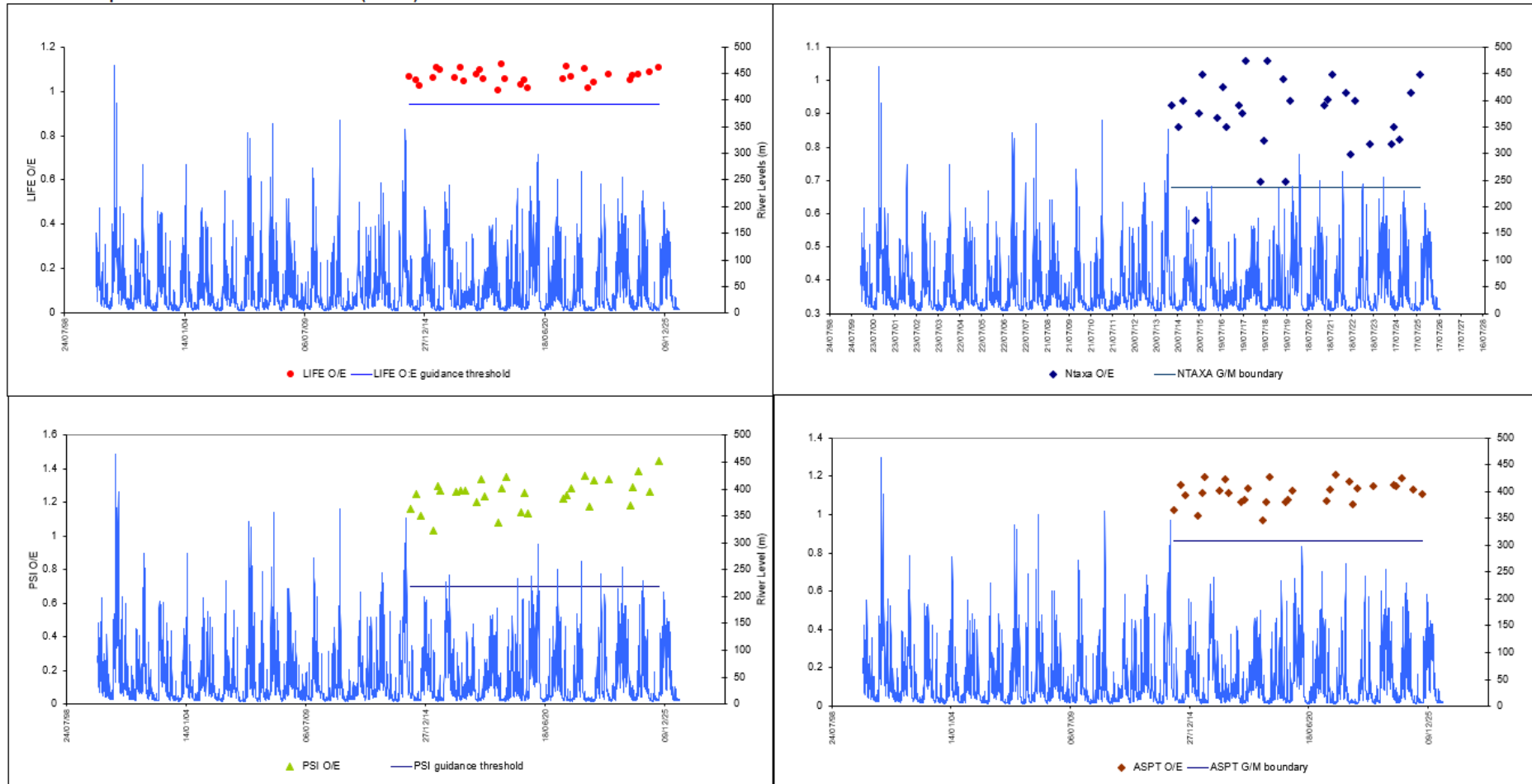
HEV plot Severn at Dolwen – 52148 (1995-2025)



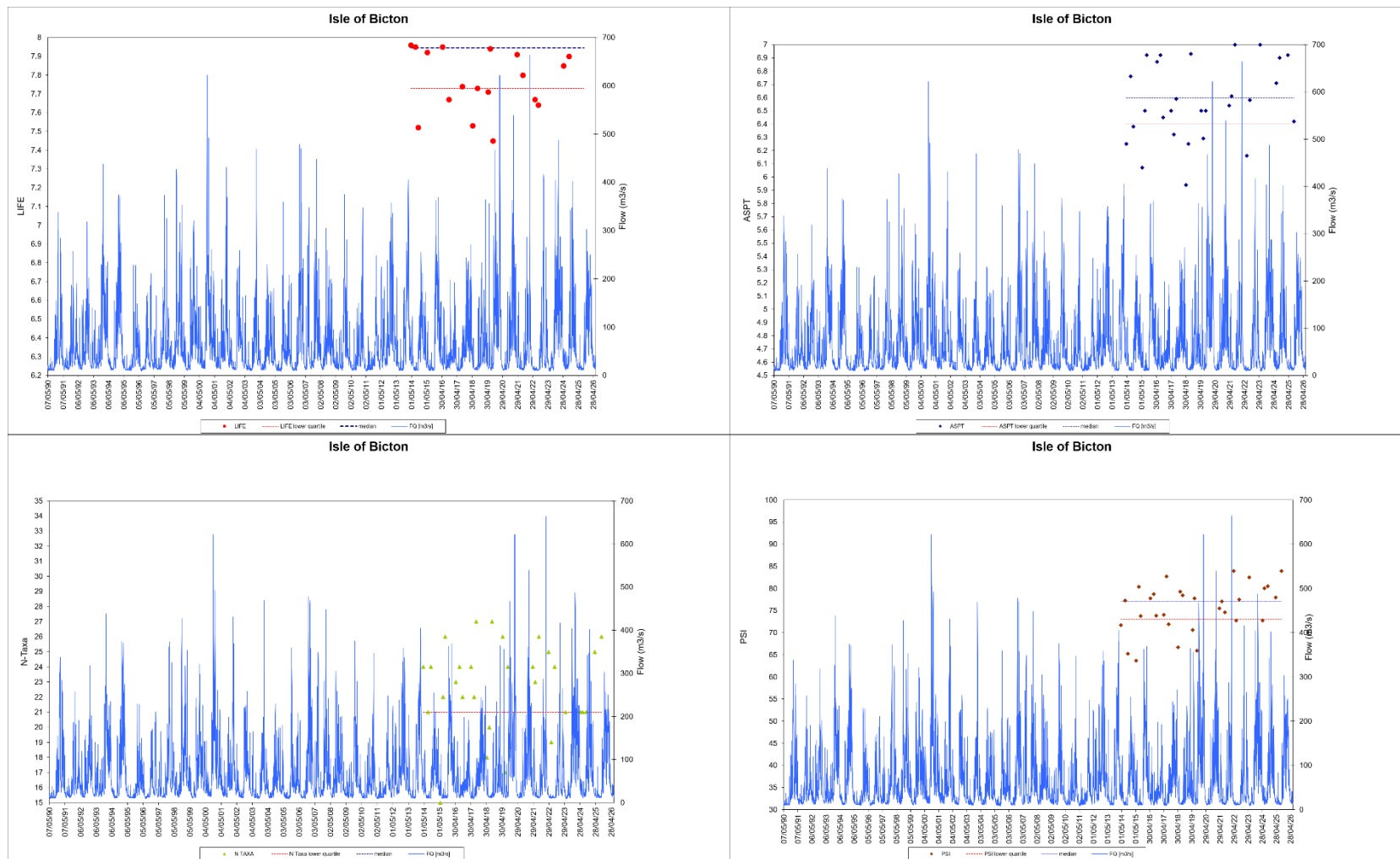
Drought response Ita plot Severn at Dolwen – 52148 (1994-2025)



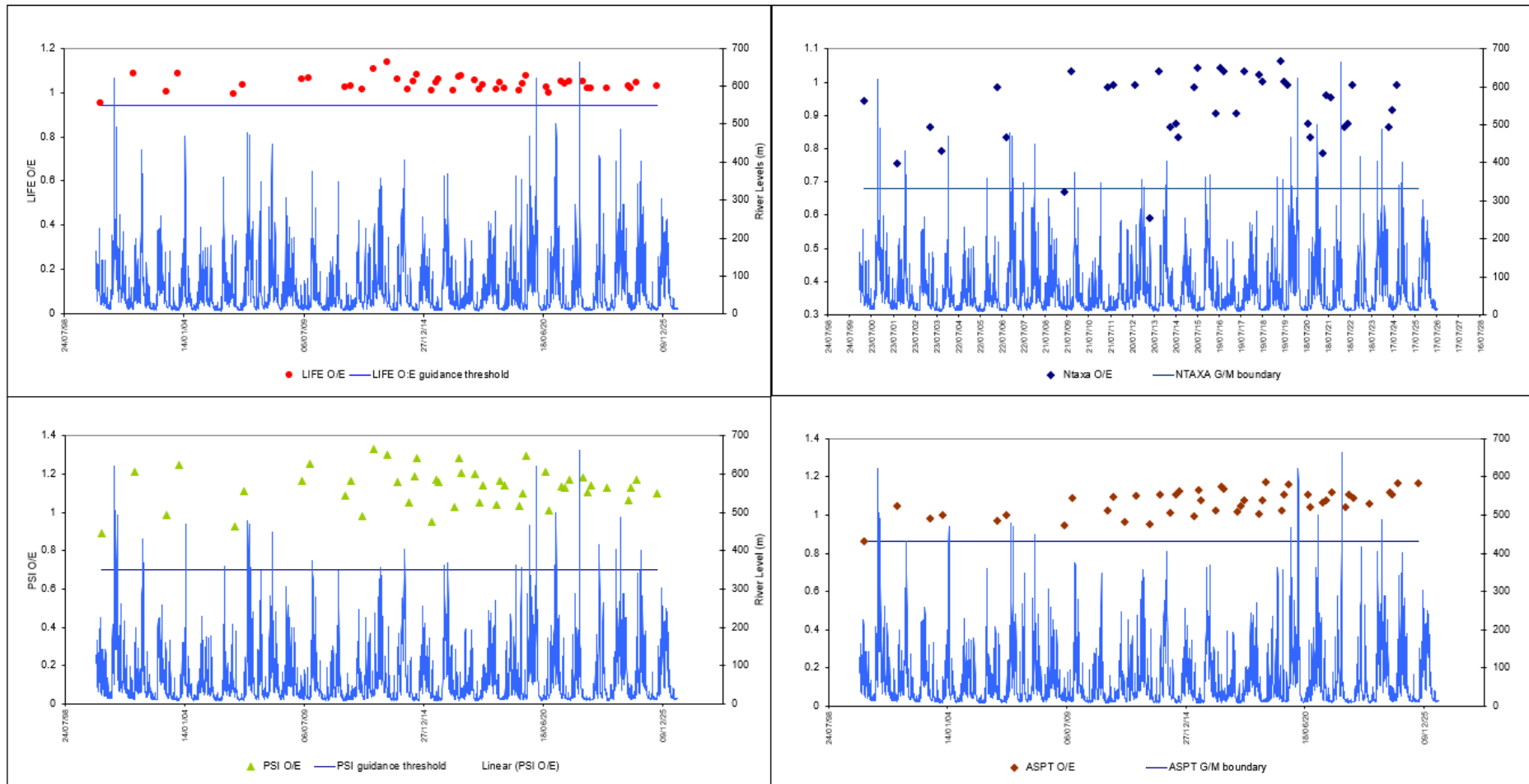
HEV plot for River Severn Isle of Bicton (173804)



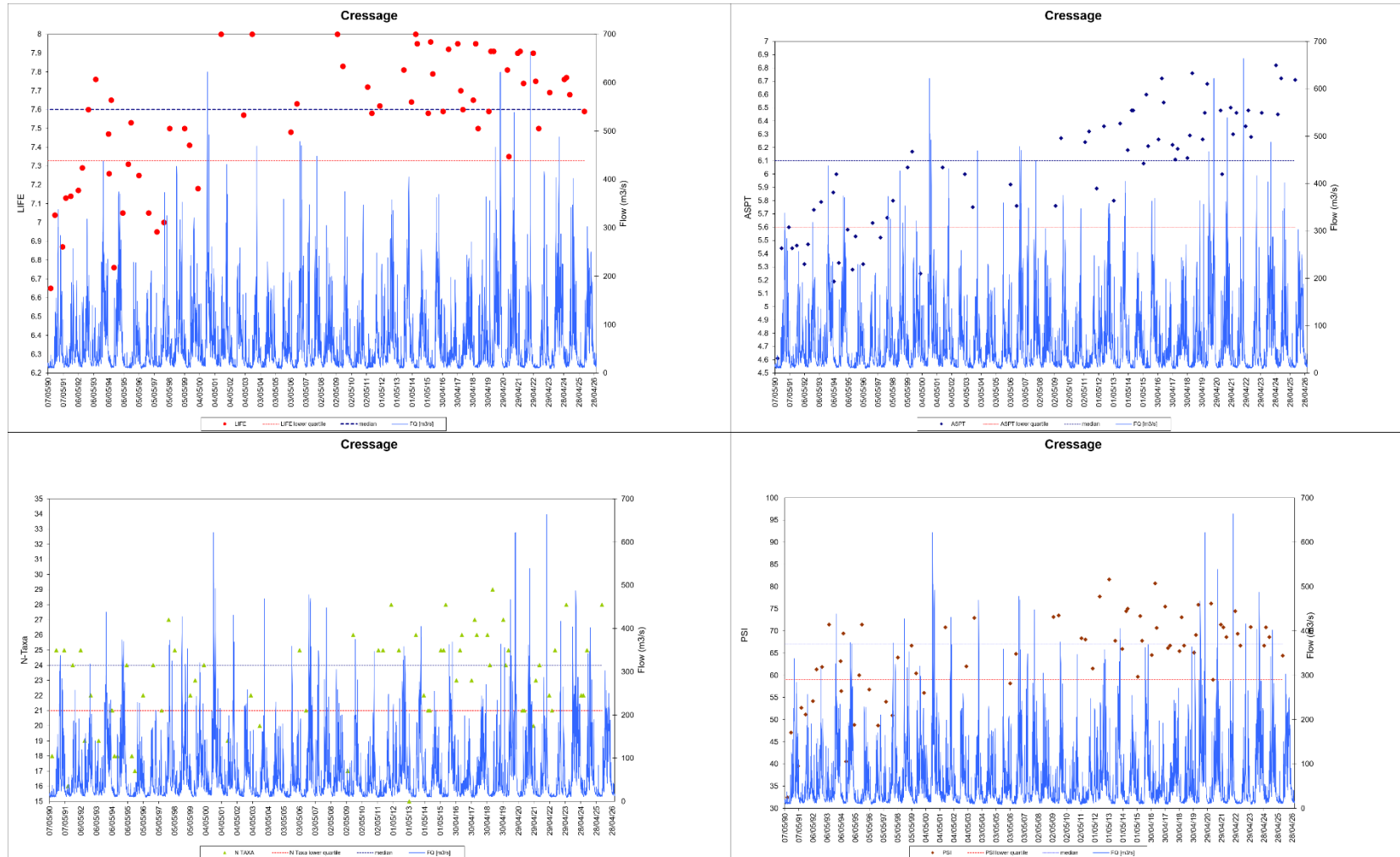
Drought LTA plot for isle of Bicton



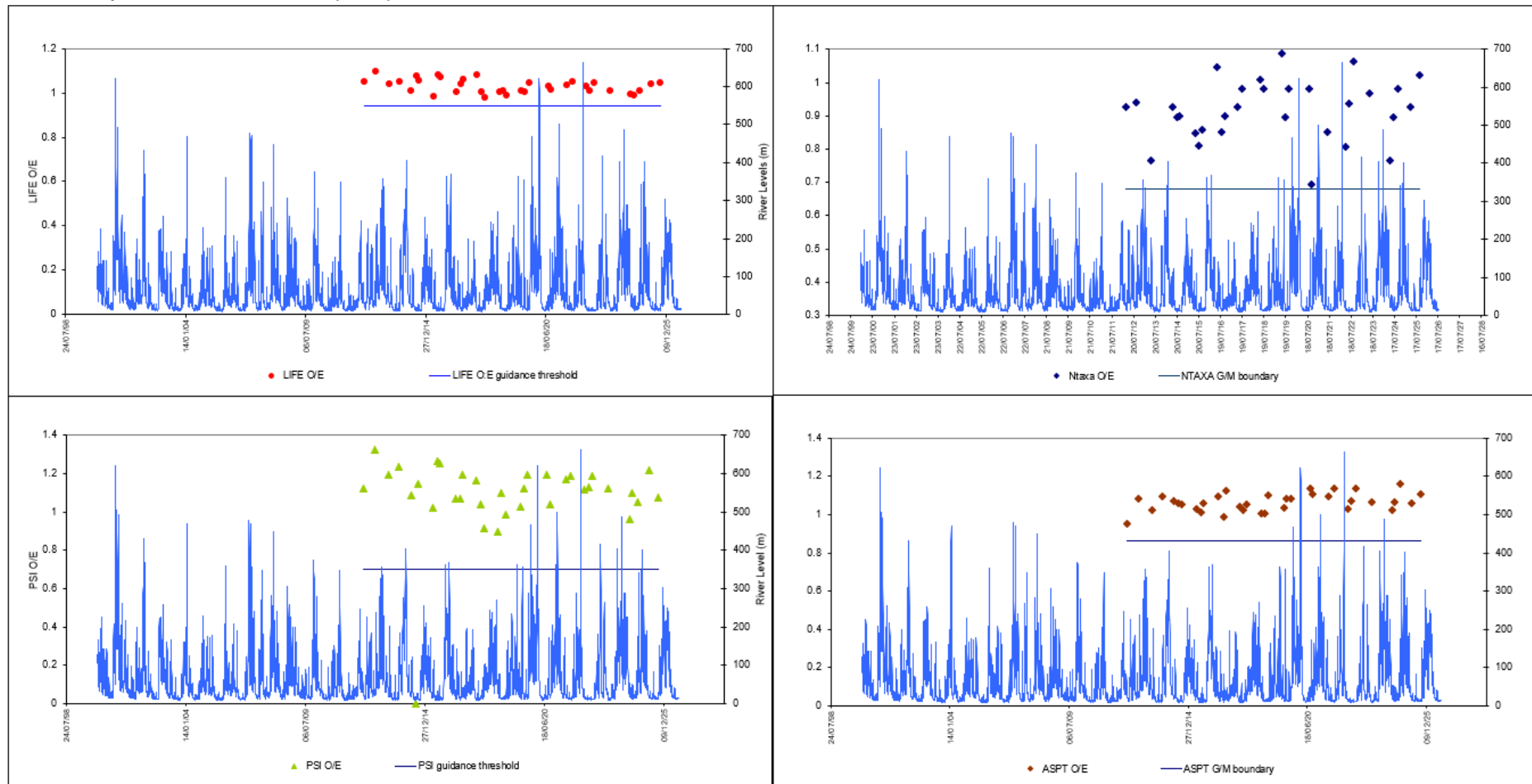
HEV plot for River Severn Cressage (52526)



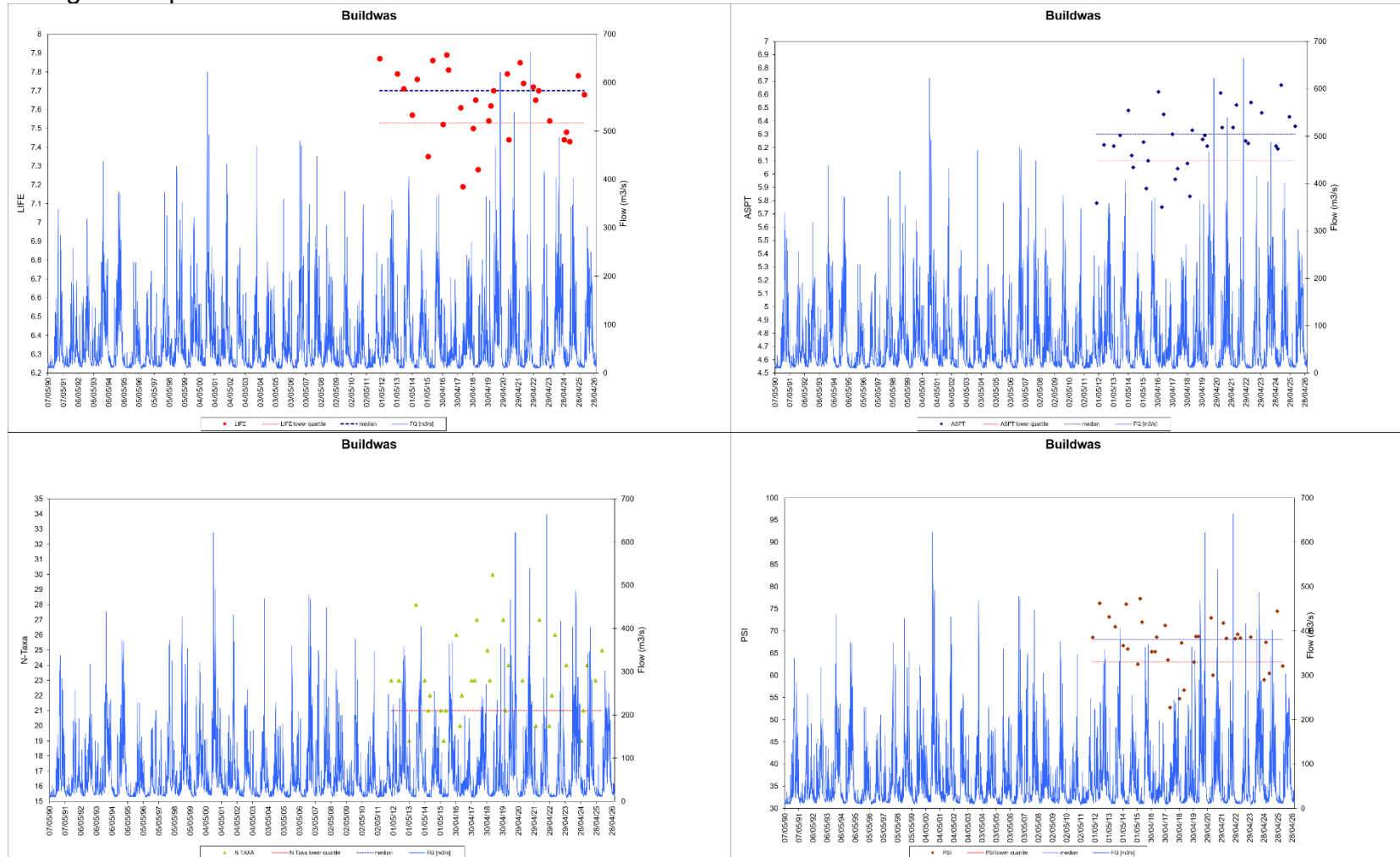
Drought LTA plot for Cressage



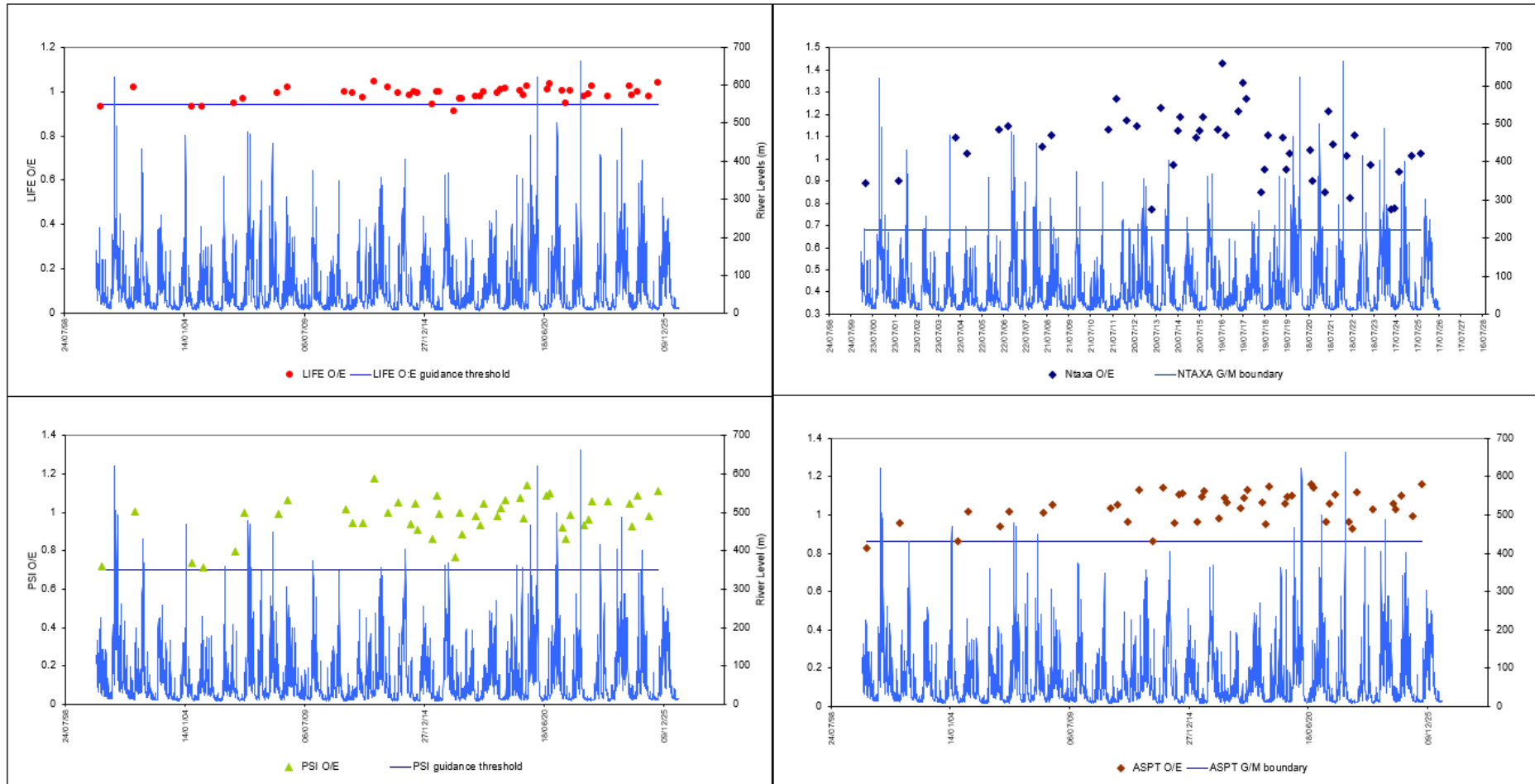
HEV plot for River Severn Buildwas (158364)



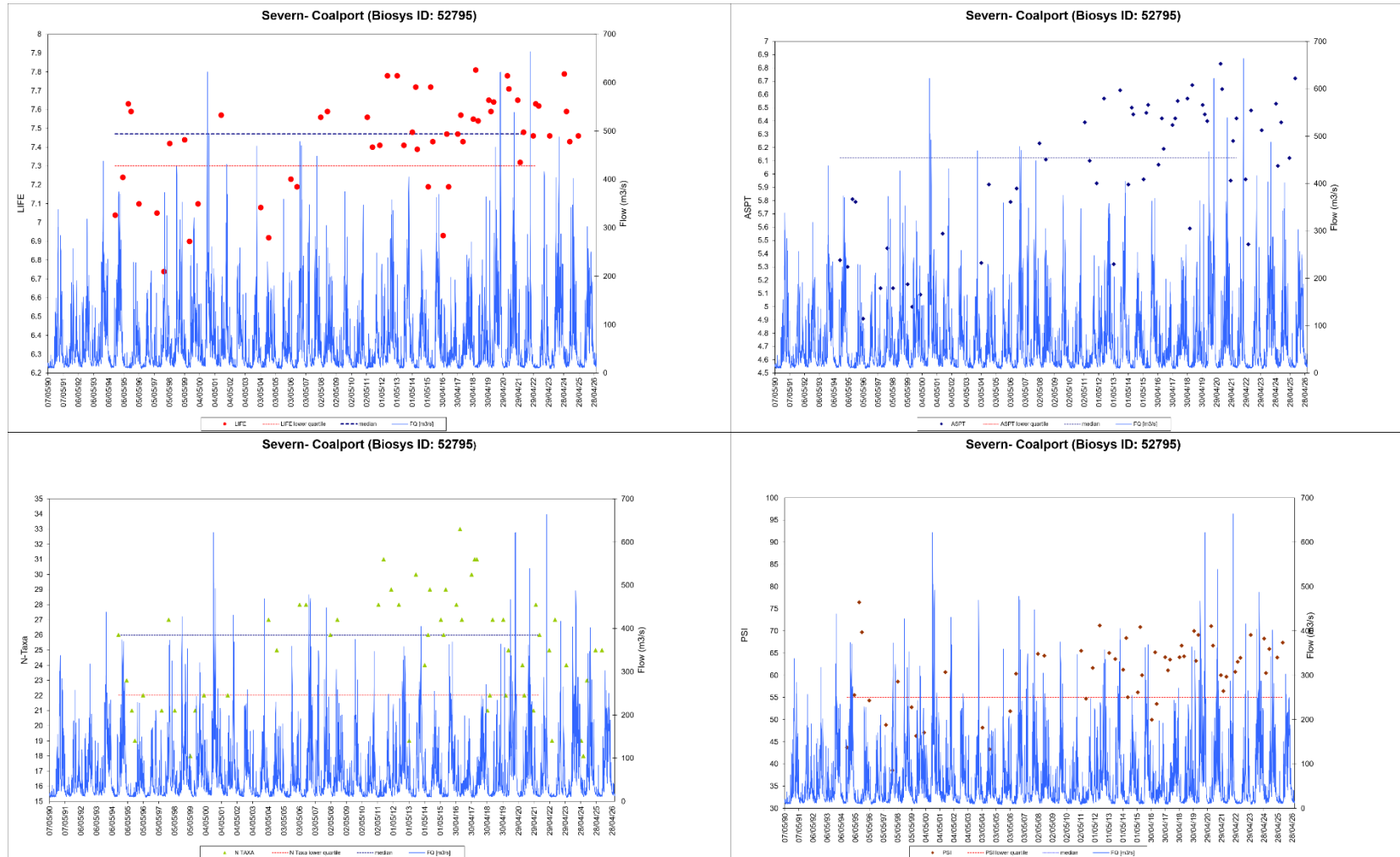
Drought LTA plot for Buildwas



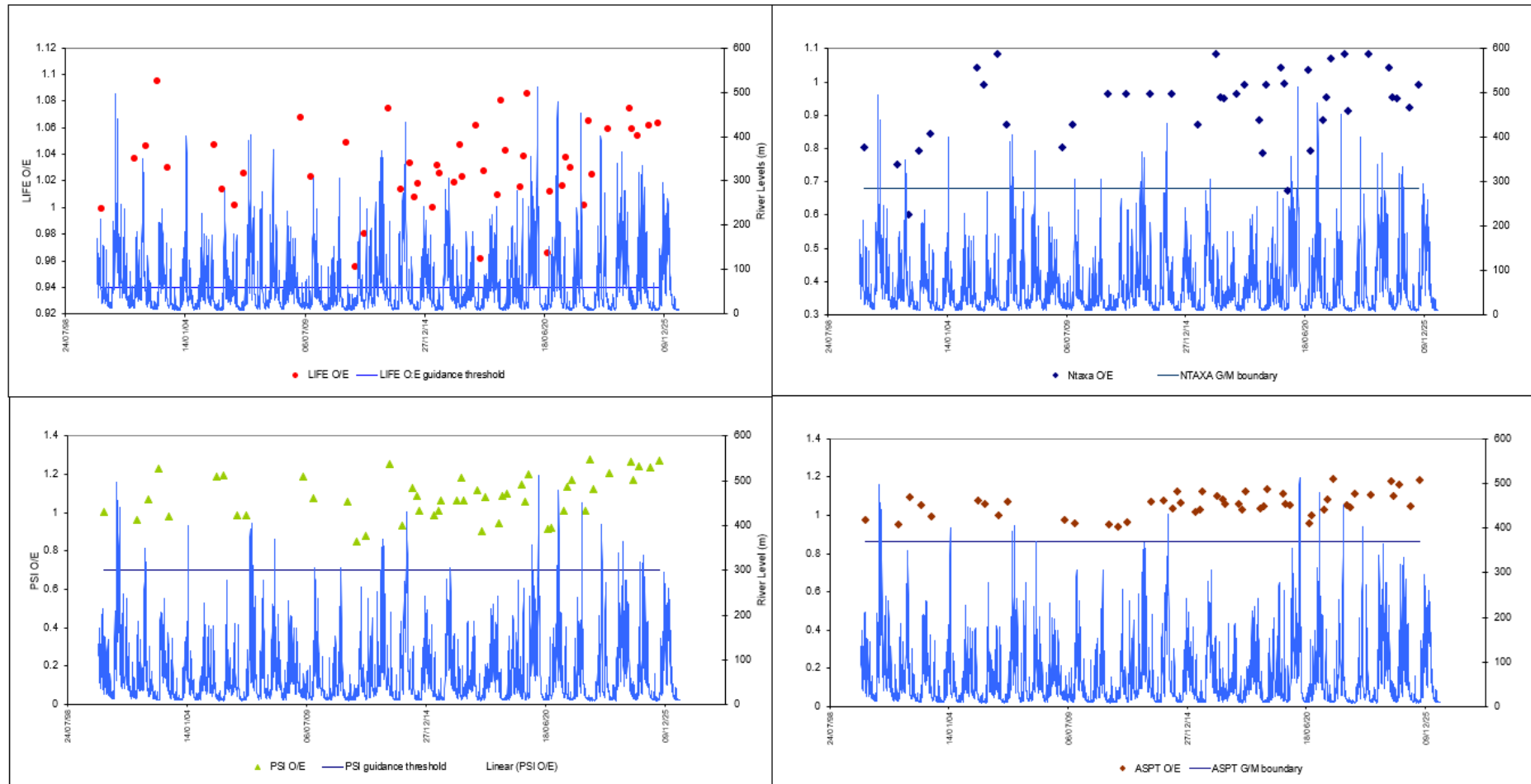
HEV plot for River Severn Coalport (52795)



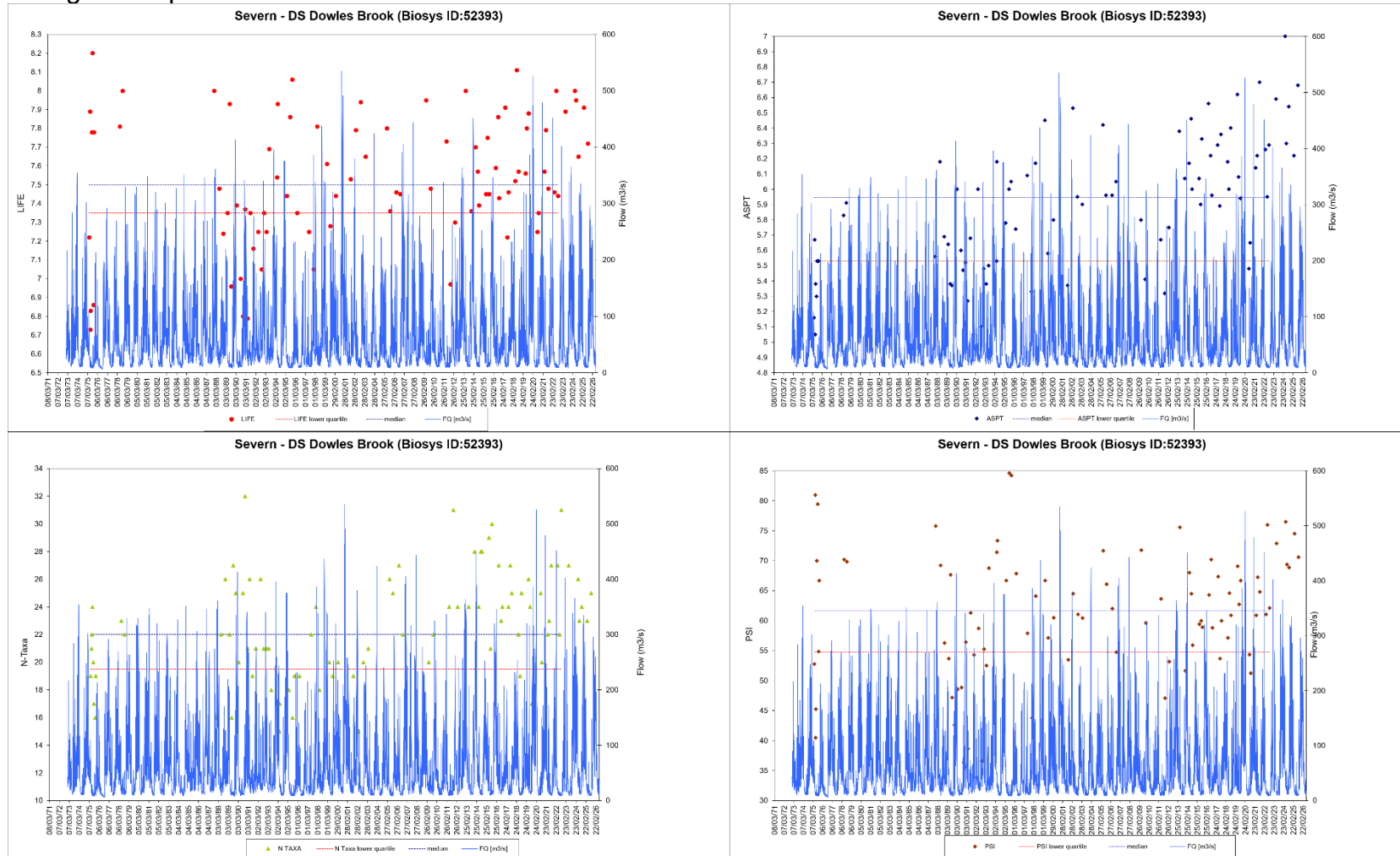
Drought LTA plot for Coalport



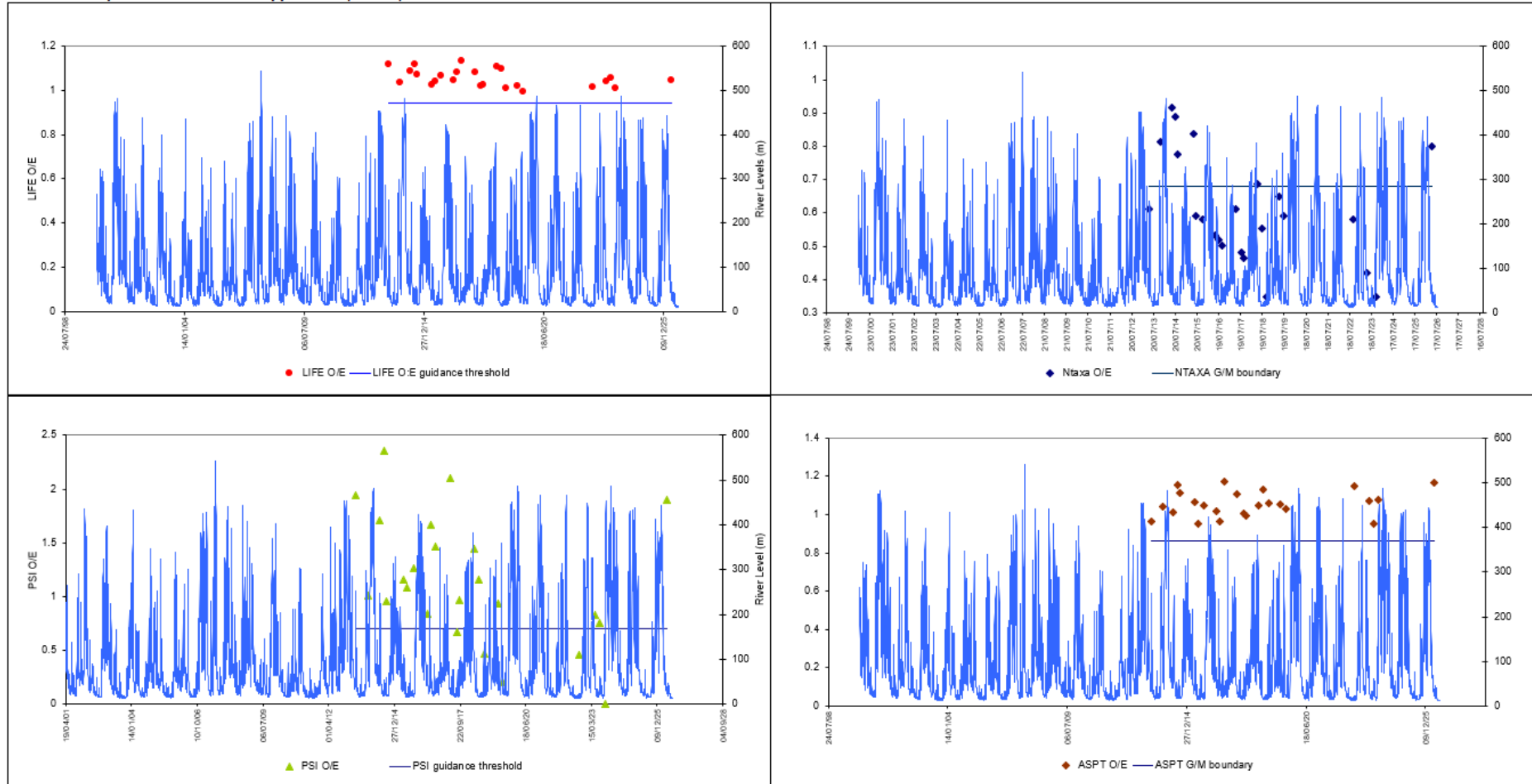
HEV plot for River Severn D/S Dowles Brook (52393)



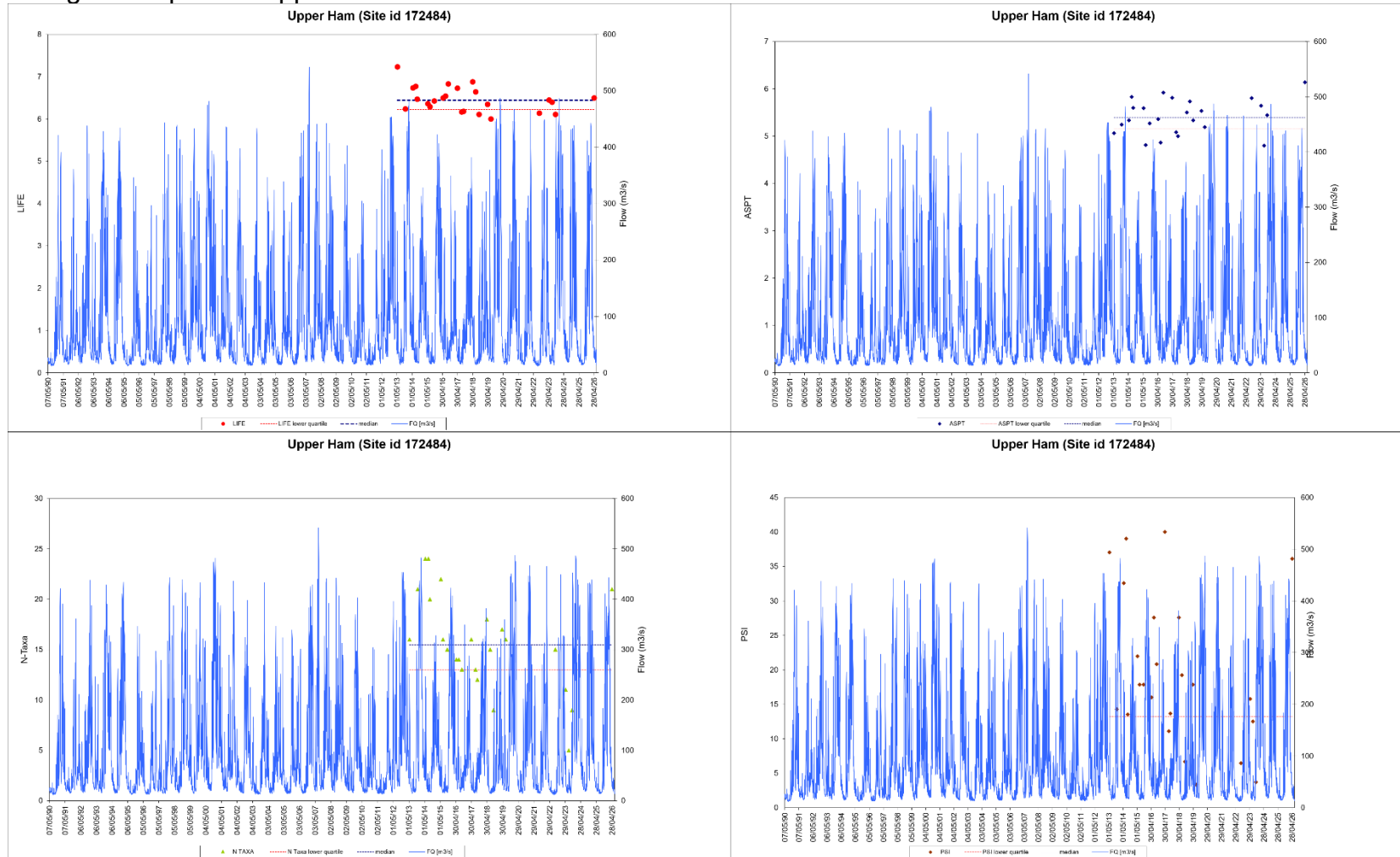
Drought LTA plot for D/S Dowles Brook



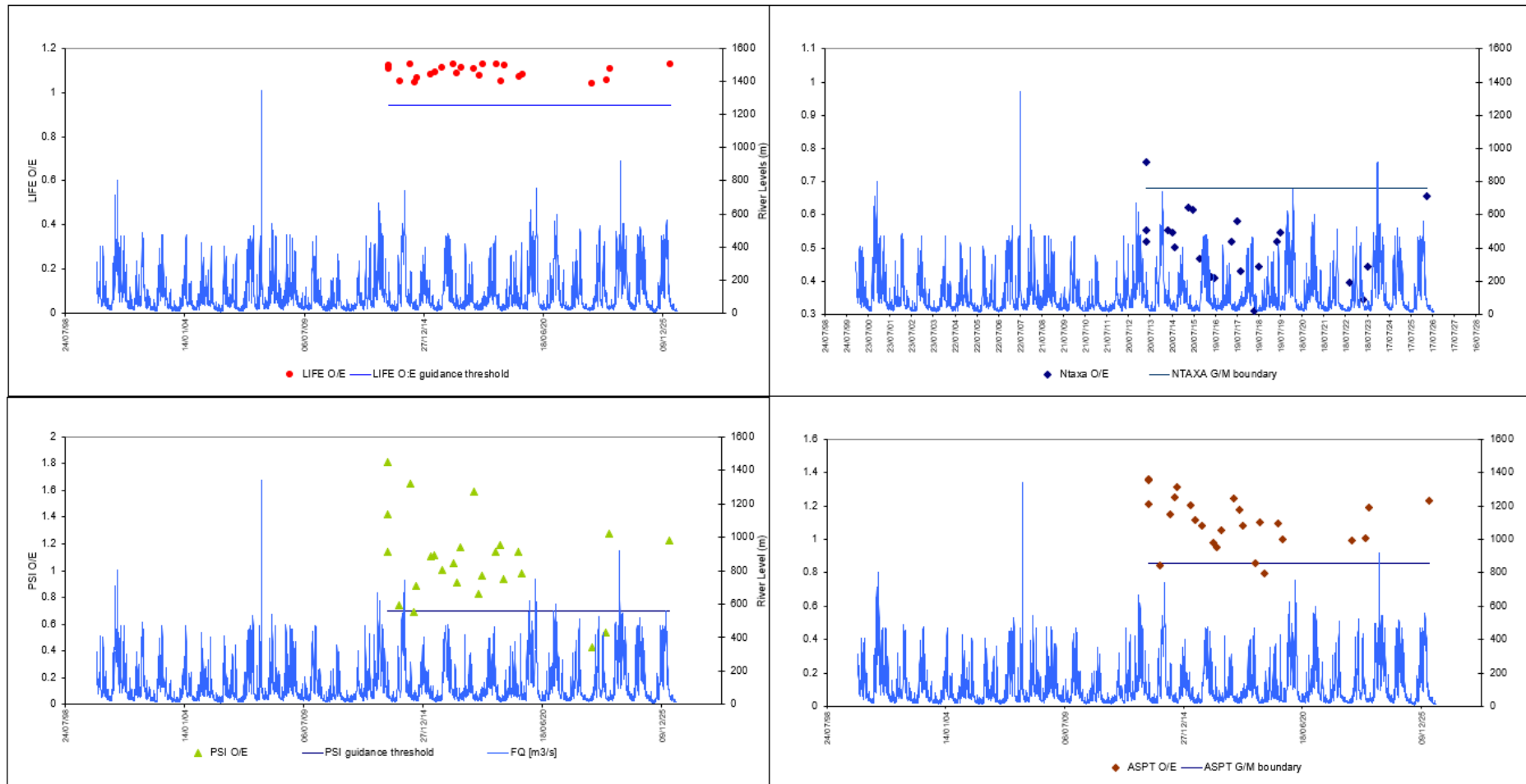
HEV plot for River Severn Upper Ham (172484)



Drought LTA plot for Upper Ham



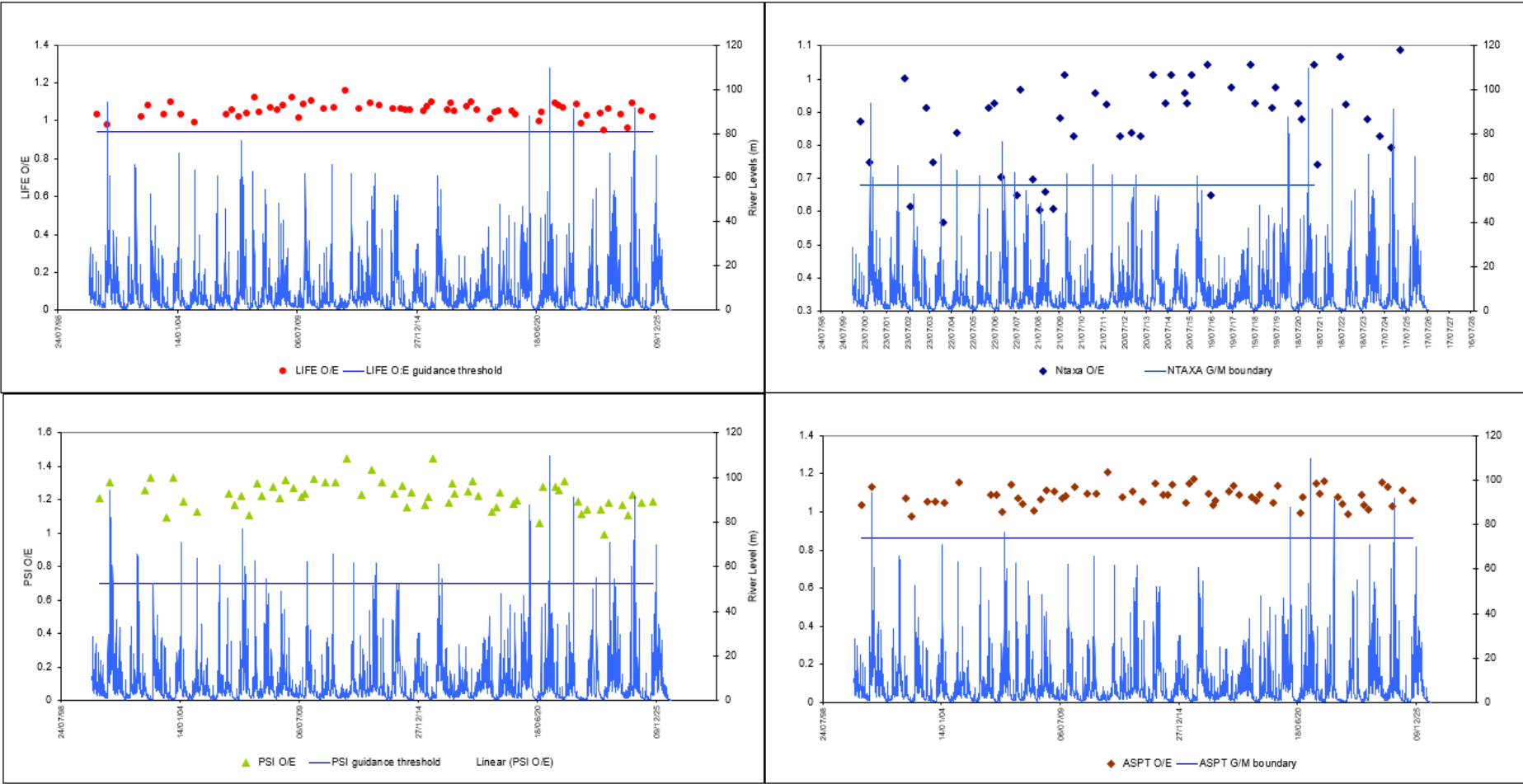
HEV plot for River Severn Haw Bridge (51327)



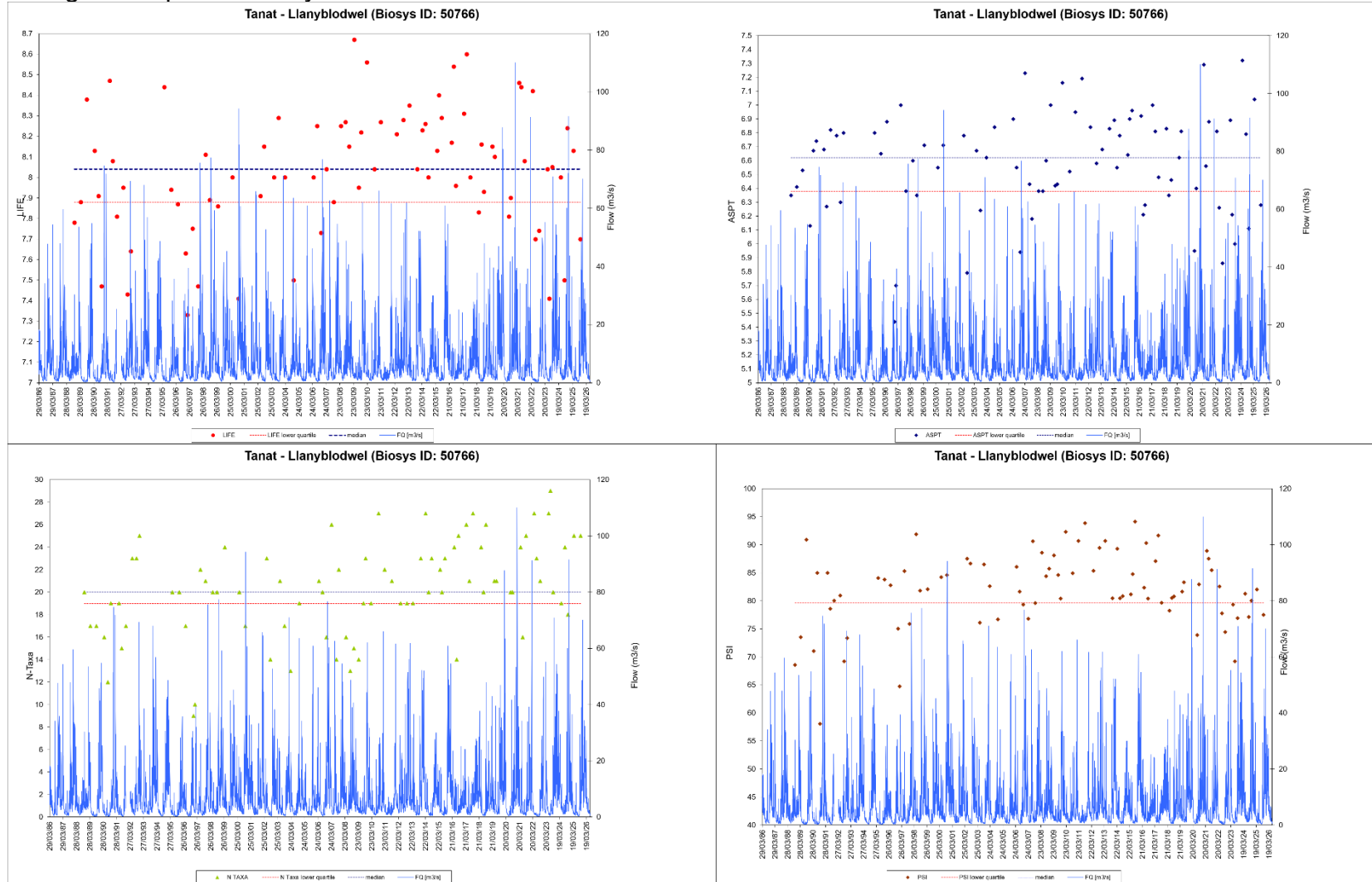
Drought LTA plot for Hawbridge



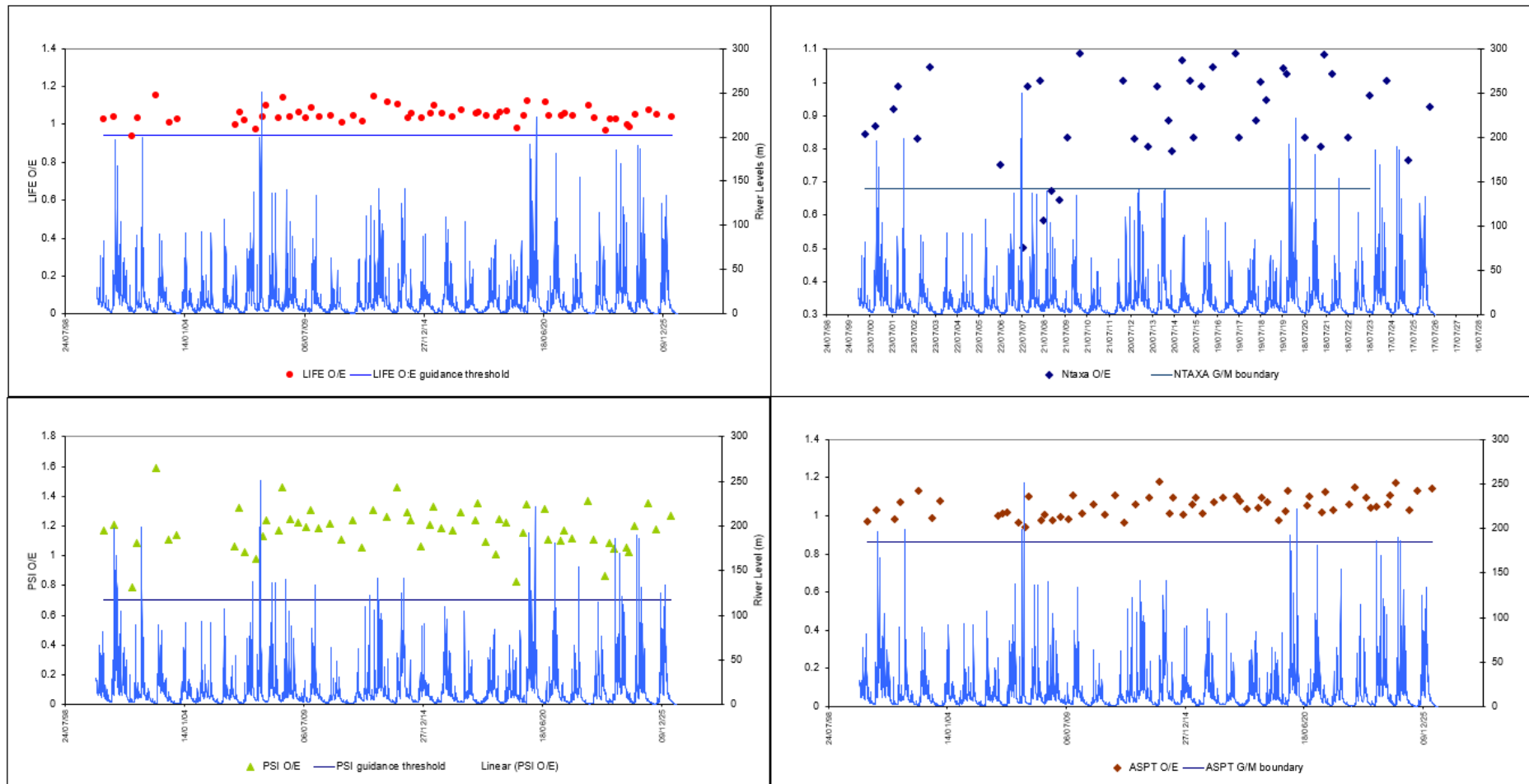
HEV plot for River Tanat Llanyblodwell (50766)



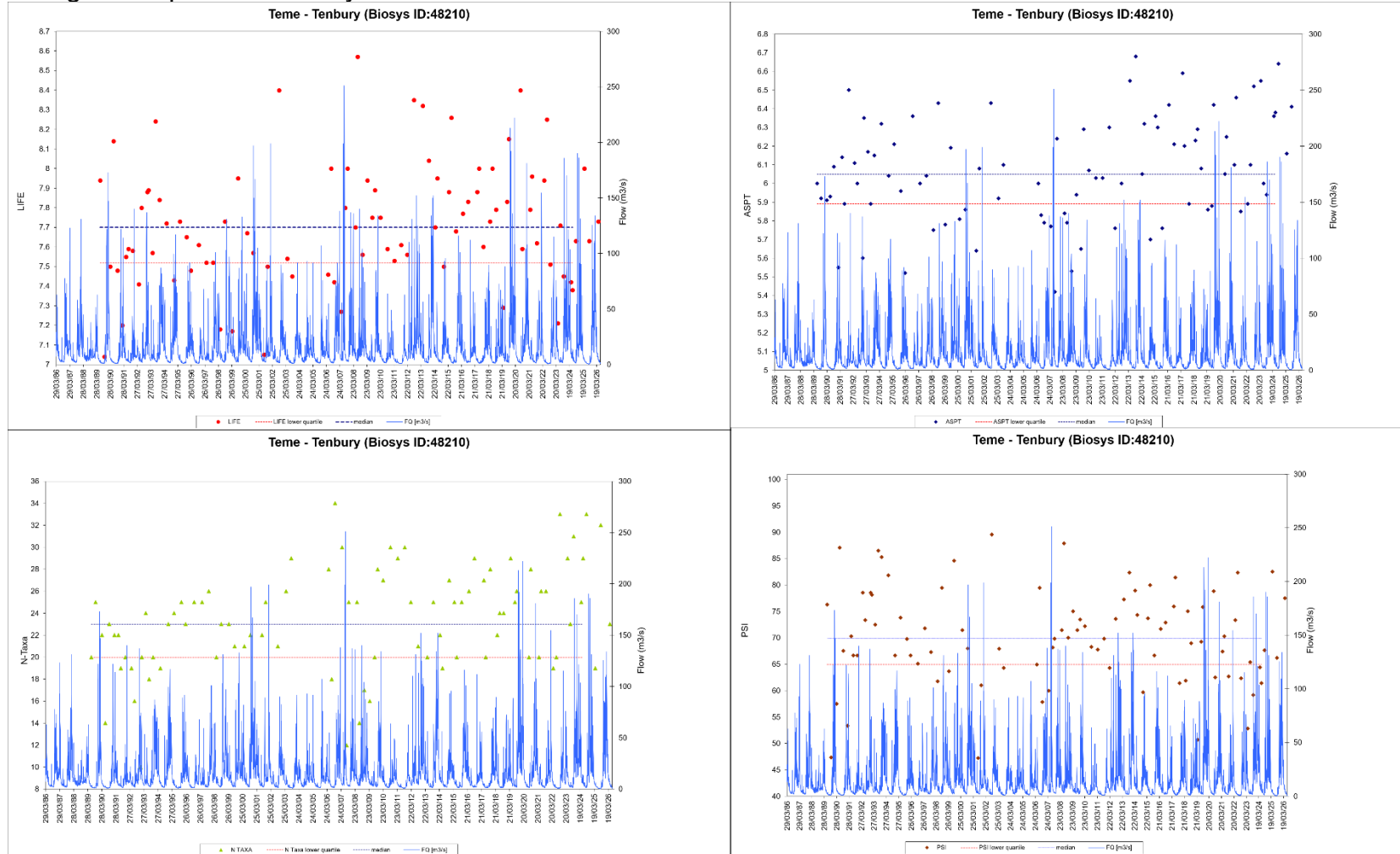
Drought LTA plot for Llanyblodwel



HEV plots for River Teme Tenbury (48210)



Drought LTA plot for Tenbury



Appendix K

Fish Technical report – River Severn Drought Order

FISH OF THE SEVERN CORRIDOR

Environment Agency and Natural Resources Wales

Fisheries data availability and assessment

The River Severn supports a mixed coarse and salmonid fishery. Important fish in this fishery include barbel (*Barbus barbus*), brown trout (*Salmo trutta morpha fario*), chub (*Leuciscus cephalus*), dace (*Leuciscus leuciscus*), perch (*Perca fluviatilis*), pike (*Esox lucius*) and roach (*Rutilus rutilus*). The Severn also has the following notable migratory species: Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta morpha trutta*) and European eel (*Anguila anguila*) and the Annex II species that the Severn Estuary has been given SAC status for Twaite shad (*Alosa fallax*), river lamprey (*Lampetra fluviatilis*) and sea lamprey (*Petromyzon marinus*). Fishing within the Severn is conducted for recreational and commercial purposes.

The main River Severn is a designated fishery under the EC directive on the quality of freshwaters needing protection or improvement in order to support fish life. The Salmonid fishery extends from the weir at Shrewsbury upstream, encompassing the Afon Vyrnwy. Below this the Severn is designated a cyprinid fishery (coarse fish) down to Saxons Lode near Tewkesbury.

Routine surveys are carried out by Natural Resources Wales in the Welsh part of the Severn catchment and the Environment Agency in the English section to evaluate the fish numbers and to determine whether or not populations are stable, improving or declining. The most widely used technique is electric fishing, but the effectiveness of this method generally reduces as the size of the river increases. Consequently, the middle and lower reaches of the river present specific challenges when trying to assess the fish population present so all electric fishing in the section can only be qualitative. Therefore other methodologies are utilised. Mobile boat-based hydro-acoustic surveys have been used to survey these parts of the river, which provides a useful tool for estimating fish biomass and density. Surveys are conducted at night when coarse fish stop shoaling and are not hiding. The one downside of this method is it is unable to distinguish between species.

Rod catch data provides additional information on the fish stocks, with salmon and sea trout anglers obliged to submit records of catches made during a season. The Environment Agency also has a match catch database where data from fishing competitions provides information on the coarse fishery. However this is a voluntary scheme and it should be noted that all angling data are subject to bias in some form. Angling matches are judged on the biomass of fish caught, therefore anglers will fish selectively for those species that are most likely to be caught. This is likely to vary depending on the specific location on the river, the prevailing weather and the flow conditions being experienced at the time. Seine net surveys for coarse fish fry can also be used to get an approximate idea of species composition and an indication of that year's spawning success.

Migratory fish movements can be monitored by fish counters. Historically, three different types of fish counter have been installed to monitor the upstream movements of Atlantic salmon at three locations within the River Severn

catchment (see Figure 2). At Carreghofa on the Afon Tanat there is a resistivity counter that measures changes in conductivity within the water column and can tell whether movement of fish is upstream or downstream. Carreghofa weir is an impassable barrier to upstream salmon migration even at high flows so all fish moving upstream have to move through the fish pass and hence the counter. At Ashford on the River Teme there was previously a Vaki counter. This records fish movement through the counter as silhouettes through infra-red beams (see Figure 1). A debris screen has been added to reduce blockage of the pass. Salmon are able to jump Ashford weir during high flows this means this counter can only give a partial count of salmon moving up the River Teme. The Severn Rivers Trust are at present reinstating the Vaki counter at Ashford.



Figure 1: Salmon moving through Vaki counter at Ashford, River Teme

On the River Severn at Shrewsbury there was a video camera system, which used four cameras at the edge of the pass. Special motion detection software can be used to detect fish movement through the pass. These counters have shown that the salmon tend to move upstream through the fish passes as flows are starting to recede after high flows, especially in the autumn (Fenn, 2009).

Monitoring has been an important component of the Unlocking The Severn project. Citizen science, hydroacoustics, fish tagging, eDNA and cameras at Diglis fish pass have all been used by the project and have given us a better understanding of the twaite shad population within the River Severn.

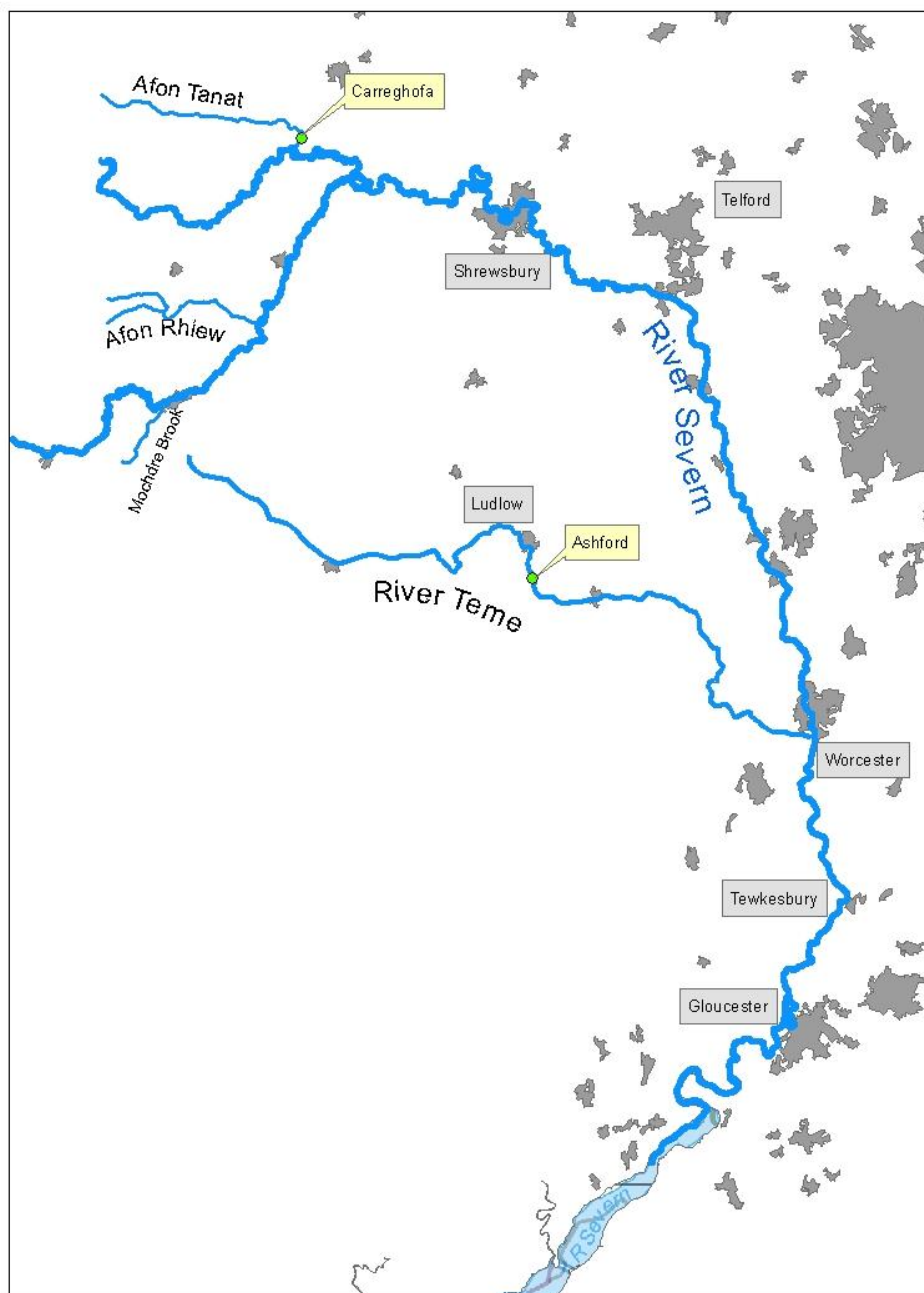


Figure 2: Map showing location of fish counters within Severn catchment

The Severn Estuary is an important fishery but is difficult to monitor. Fyke netting, seine netting and beam trawling have been used to monitor fish populations as part of the TraC monitoring programme, but are only qualitative and not quantitative.

7.2 Fish Species Present

Before it is possible to make judgments on whether there is sufficient water for the fish in the River Severn it is imperative that the ecology of the fish is understood.

Resident (non-diadromous) fish

The resident fish population of the River Severn is very diverse. Different sections of the river support different fish species. The upper section of the River Severn (above Welshpool) are the principal salmonid (brown trout and grayling) spawning and nursery areas, although some spawning does take place in the middle reaches, in the shallow gravel areas downstream of Shrewsbury and between Bridgnorth and Kidderminster. Many of the tributaries also are utilised by salmonids for spawning e.g. River Teme. Brown trout will spawn around late autumn/early winter (similar to the sea trout), while grayling spawn earlier from March to May. Both species lay their eggs in nests in gravels.

Brown trout are included in the Section 7 List of species of principal importance to Biodiversity in Wales, under the Environment (Wales) Act 2016.

From Shrewsbury downstream coarse fish dominate with barbel being a very popular fish with anglers in the middle section of the Severn. These coarse fish tend to spawn in spring and summer when the water temperatures start to rise sometimes shoaling up in large groups.

Another fish found mainly in the upper sections of the River Severn is the bullhead (*Cottus gobio*), which in England is a BAP species. These are a bottom dwelling species that spawn between February and June. This species is impacted by low flows mainly due to deposition of fine sediment over their preferred hard substrate and so reducing available habitat.

Migratory fish

Atlantic salmon, sea trout, twaite shad and both migratory lamprey species are 'anadromous' which means they migrate up rivers from the sea to breed. While the European eel are 'catadromous' spending most of its life in freshwater and travels to the Sargasso Sea to spawn. Figure 3 shows movements of these fish through the year within the Severn catchment.

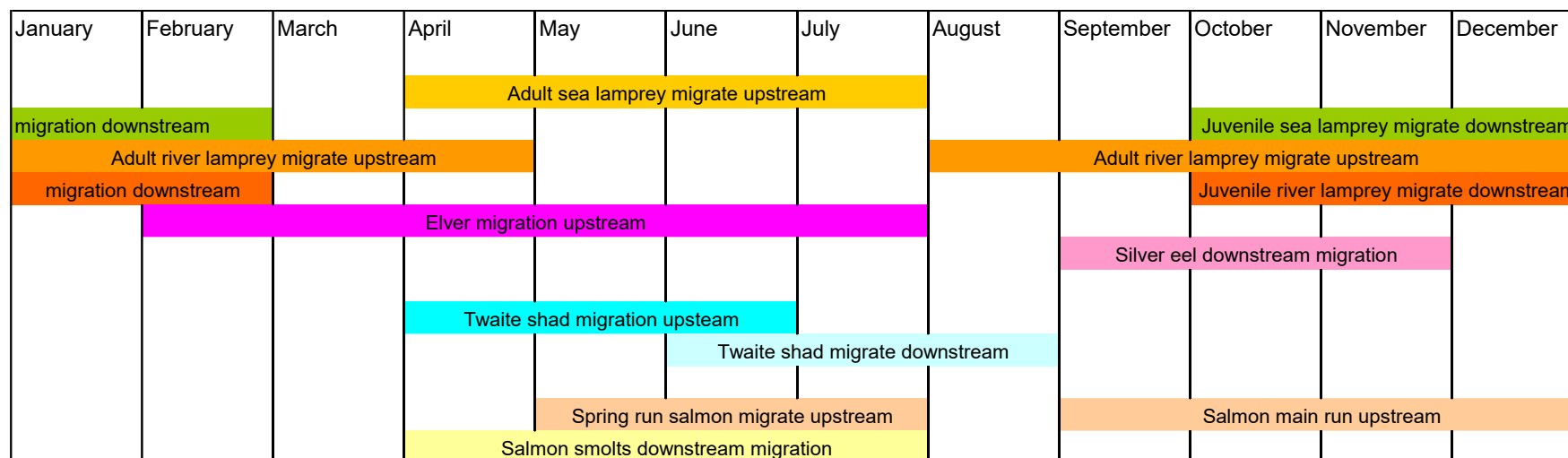


Figure 3: Graphical representation showing the movements of the migratory fish within the River Severn catchment

Annex II species

Shad

Historically both twaite and allis shad spawned within the River Severn catchment. A recent study (Antognazza, 2022) using genetics found no pure allis shad within their study, only twaite shad and hybrids (45.5%). Hybrids were found to share more of the characteristics from twaite shad than allis shad suggesting the Severn has been more of a stronghold for the twaite shad than the allis shad. The Unlocking The Severn project has recorded a small number of allis shad entering the Severn, although there is no evidence of a breeding population. The twaite shad generally migrate out of the estuary early in the year (April to June) to spawn in freshwater between mid-May to mid-July. The main trigger for movement upstream is thought to be water temperature (10.6 to 12.3°C) and movement has been observed entering rivers between 05:00 and 20:00. Eggs are released into the water over gravel beds and hatch within 5 to 8 days (Maitland, 2004). Adult shad are repeat spawners and spent adult fish return to the estuary around June and July. The juveniles require slow flowing nursery areas before they move down to the estuary (August and September). Juvenile twaite shad tend to migrate down to the estuary earlier in the River Severn than in the River Wye and this is thought to be due to channelisation of the lower Severn, hence less useable habitat (Maitland & Hatton-Ellis, 2003).

The navigation weirs on the River Severn between Diglis and Lincomb have prevented twaite shad reaching prime spawning habitat which caused the population to crash in the 1850's. The Unlocking The Severn project has now (2022) created fish passage for shad past all four navigation weirs. In 2022 over 750 shad were recorded passing through the Diglis fish pass from reviewing camera footage. Of the 100 acoustically tagged shad, undertaken at Upper Lode, shad were shown to pass upstream all the way to Lincomb fish pass. Acoustic sound recorders positioned through the now opened reach confirmed spawning throughout the river up to Lincomb. eDNA monitoring confirmed this distribution and confirmed that shad eDNA was found upstream of Lincomb from samples taken at Stourport bridge. In 2026, 632 shad were counted passing through the fish pass at Diglis which is second highest number recorded.

Lamprey

River lamprey *Lampetra fluviatilis* and sea lamprey *Petromyzon marinus* are features for which the Severn Estuary is a SAC. The general lifecycle of lamprey involves the migration of adults upstream to reach spawning areas, normally stony or gravelly stretches of running water. Upstream migration of sea lamprey is usually between April to June, while river lamprey migrate upstream later in the year (August to December) and tend to migrate later during low flow autumns. Migrating adult lamprey (sea and river) have been shown to positively respond to pheromones released by ammocoetes within river systems. Hence allowing the adults to assess the suitability of rivers for spawning (Severn Tidal barrage scoping document, 2008). Sea lamprey often travel up the Severn as far as Shrewsbury and have been known to get to Newtown and Llanymynech. Monitoring associated with the Severn Thames Transfer has recorded sea lamprey eDNA within the River Vyrnwy and sightings have been made around Llanymynech and Meifod. They spawn in pairs or groups using features such as displaced stones, logs or clumps of vegetation to form crude nests, with adults dying after spawning. After hatching, the young elongate larvae, known as ammocoetes which are only a few centimetres in length, swim or are washed downstream by the current to areas of sandy silt in still water where they burrow and spend the next few years in tunnels. After several years, the number of years varying with the species and habitat, the larvae metamorphose into the adult form.

Notable species for SAC

Atlantic salmon

The Atlantic salmon is a species of great importance for the River Severn. Although numbers have dropped through over exploitation, blockages to migration and pollution. Adult Atlantic salmon return to the River Severn throughout the year, but the two main runs of fish are the spring run and the autumn run. The spring run fish enter the Severn around May to July and stay in the river system until spawning in late autumn early winter. The River Severn has long been known for its spring run of large salmon (multi sea winter fish). Once salmon have entered the estuary they do not eat and rely on fat reserves to survive until spawning. The autumn run fish start entering the Severn around late September until early December on the first high flows of the autumn but do not spawn until the first frosts of autumn. Salmon can now migrate up the Severn to 'Severn break it neck' in the Hafren Forest, which encompasses the

regulated section of the River Severn. The cock fish generally get to the spawning grounds first where they will compete with other males for territories. Then the hens move in and excavate their redds (nests) in the gravels. When the redd is ready she will settle into it and start shedding her eggs. At this point the male moves in beside the female and then he fertilises the eggs as she ejects them. Straight after spawning is over the hen buries the eggs by shifting the stones from upstream back into the hollow. The majority of Atlantic salmon die after spawning with the males suffering the most fatalities due to the stresses involved, (normally fewer than ten percent of the adult salmon will survive). The eggs hatch, and the young salmon (initially referred to as fry, and later as parr) remain in fresh water for up to three years; they then enter the smolt stage and migrate downstream to begin the marine phase of their lifecycle. Most will remain in the North Atlantic for between one and three years before returning to freshwaters again to spawn.

The current (2024) Atlantic salmon stock has been assessed as “At Risk” of failing to meet its management objectives.

European eel

The River Severn is an internationally renowned eel fishery (elvers) and has an eel management plan in place. The eel differs from the other migratory species found in the River Severn in the fact that it spawns out at sea and after one or more years the young elvers then migrate into freshwater. Large numbers of glass eels enter the Severn estuary between February and April and migration upstream into the rivers occurs at night. All available evidence indicates that elvers and eels migrate upstream either without regard to river flow, or migrate to a greater extent at low flows than at high flows (Soloman and Beach 2004) and likely to be linked to water temperature. Two factors combine in the lower section of Severn to limit migration of elvers. Firstly the majority of the rivers entering the Severn have had flood defence works in the lower and tidal reaches including flood control tidal flaps and secondly the building of weirs. During the upstream migration small eels can climb vertical damp surfaces at times as long as there is sufficient grip, but this activity appears to be restricted to eels of less than 100mm. They then stay in freshwater as yellow eels for 8-18 years (Maitland, 2004) before they migrate back to the Sargasso Sea, where they spawn, as silver eels usually from the beginning of September to the end of December. After spawning, the resultant larvae are then transported by oceanic currents back to Europe where they change into glass eels.

Eel populations throughout the United Kingdom are declining and further research is being undertaken to improve our understanding of the marine phase of their life cycle.

Sea Trout

The sea trout tend to migrate back into the rivers after feeding in the sea for 12 to 14 months and start moving upstream around late summer/autumn time to spawn in gravels in rivers and streams generally in the lower Severn catchment, although occasionally anglers claim to have caught sea trout as far up as Shrewsbury. While sea trout do respond to increases in flow, they will move upstream without such a stimulus and are thought to require smaller discharges than salmon. Eggs hatch in approximately 150 days and the fry spend a year or more in the nursery streams before migrating back to sea.

Sea trout numbers in the Severn are low compared to the size of river, which could be due to distances needed to travel to reach spawning gravels.

Fisheries Current Environment

The present situation on the River Severn is quite complex and our understanding is impeded by the difficulty in monitoring such large rivers. Recent monitoring (2020 and 2021) has also been seriously impacted due to constraints caused by COVID19.

The numbers of adult salmon returning to spawn in a river each year, and hence the number of eggs deposited, are estimated and compared against the Conservation Limit (CL). The CL is the lowest desirable spawning stock level of spawning salmon (described as the number of salmon eggs deposited) for each river. The size of a stock should not be allowed to fall below the CL, otherwise the risk of that river’s salmon stock suffering serious decline greatly increases.

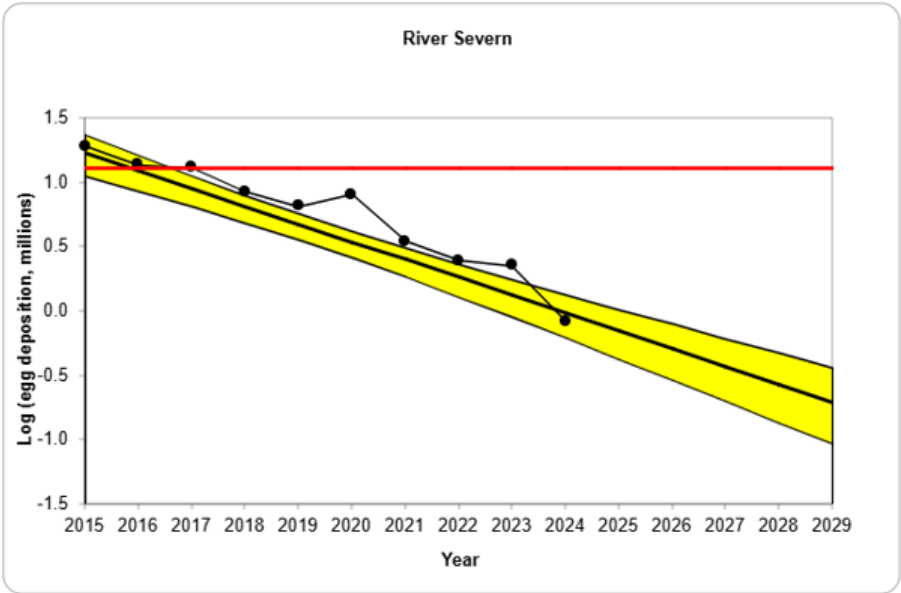


Figure 4 River Severn compliance against the CL from the 2024 assessment

Key to graph	
	20 th percentile trend line (in a 10 year period around 2 annual egg deposition values would be expected to fall below this line)
	Annual egg deposition estimates
	Conservation Limit
	Upper and lower boundaries of the Bayesian Credible Interval.

The River Severn has not achieved its salmon Management Objective (MO) for several years. The current (2024) provisional compliance of Severn stock is judged to be “At Risk”, failing its MO with a declining trend illustrated in Figure 4. The predicted status remains “At Risk” with a likelihood of failure of meeting the management objective in 5 years’ time.

Because salmon stocks naturally vary from year to year, the Environment Agency aims to ensure that a stock meets its CL in at least four out of five years on average (i.e. >80% of the time); this is the Management Objective (MO). To meet this MO, the average level of a stock typically needs to be approximately 40% above the CL. This higher target level is referred to as the Management Target (MT). Stocks are therefore classified according to whether, on the basis of the trend over the past 10 years, they are likely to meet the MO in five years’ time.

The annual egg deposition, CL and MT for the Severn salmon stock for the last ten years are presented in Figure 5 below. The stock assessment indicates that the Severn salmon stock has only exceeded its CL in two of the last ten years, declining since 2015.

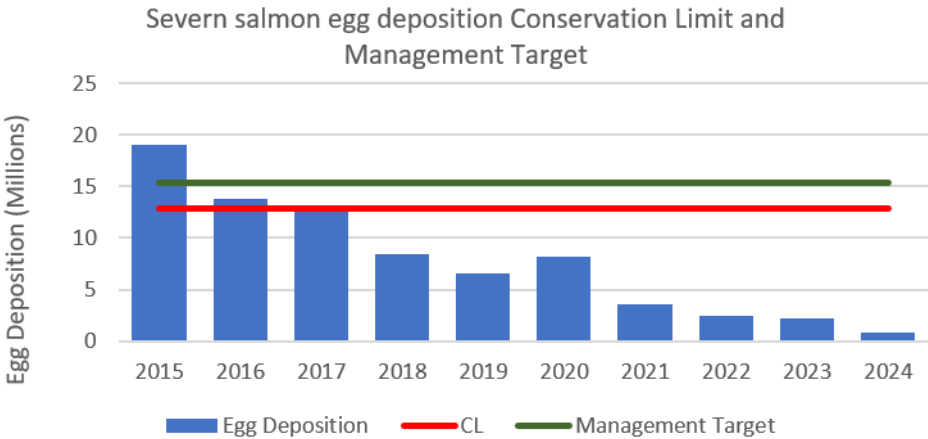


Figure 5 Egg deposition estimates relative to the conservation limit and management target for the River Severn between 2015 and 2024

The 2024 egg deposition equates to only 124 spawning adult females. The number of spawning females equivalent to the CL is 1857, indicating a shortfall of 1733 spawning females in 2024.

On the Upper Severn catchment Natural Resources Wales have 16 temporal sites to monitor juvenile salmonid densities. Figure 8 below highlights the distribution of the sites.

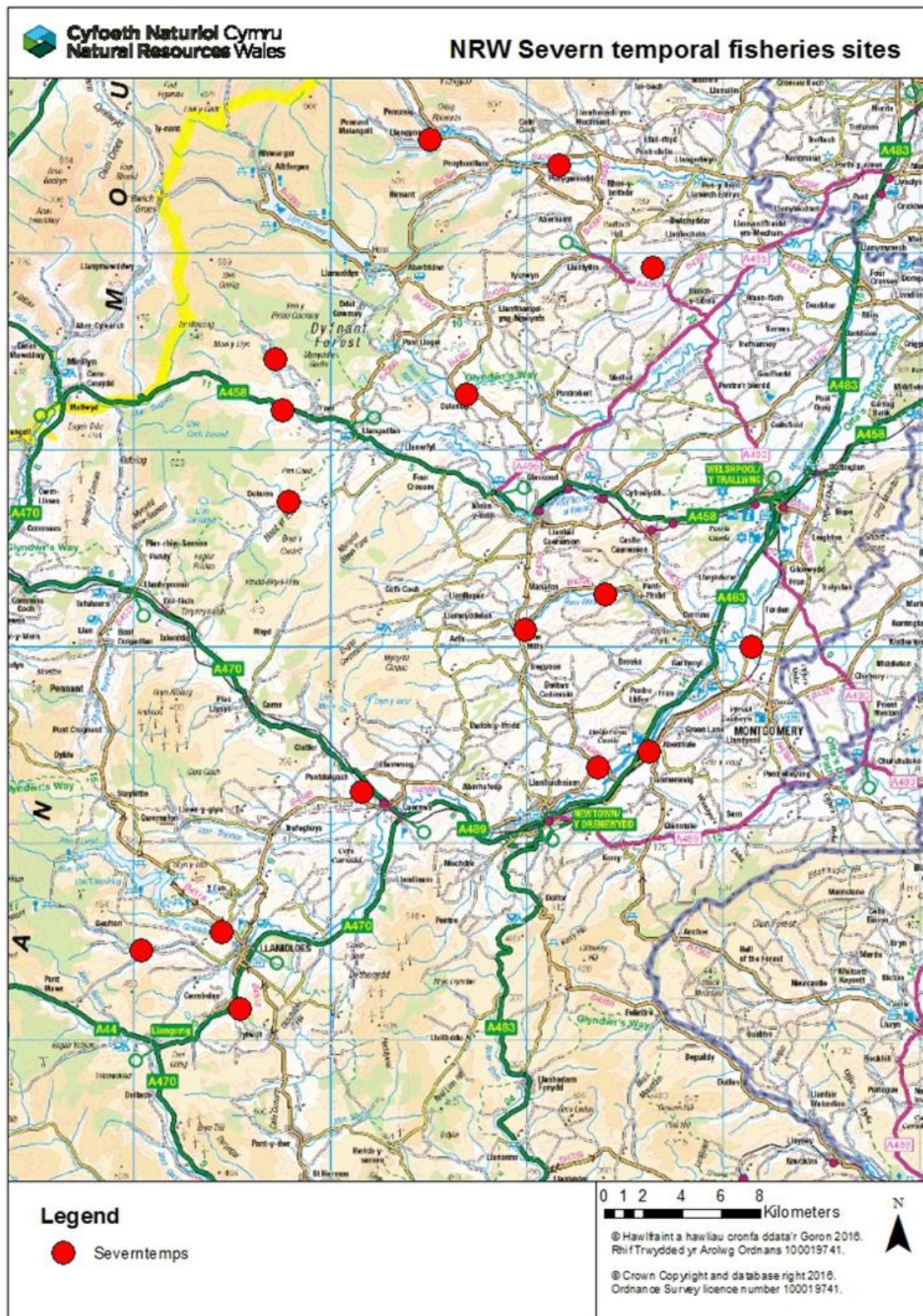


Figure 8 Map of Welsh salmon temporal surveys

Since 2013 most sites have been completed annually, however there have been certain instances where sites have not been completed due to the river levels being too high throughout the survey season. The 2019 data set has been left out of figure 9 as the majority of the sites on the Vyrnwy catchment, which is the most productive area, were not fished due to high flows. No surveys were completed in 2020 due to Covid19.

Results remained relatively consistent up to 2018 in comparison to some catchments in Wales. The decline in 2016 was seen across the whole of the UK and was named the 'salmon crisis'. The weather during the spawning season was particularly warm and there was also significant flooding during this period. There is a notable decline in 2021.

The juvenile data does not follow the trend of the egg deposition rates, however the decline in 2021 is starting to follow the egg deposition trend.

In the past few years the majority of the spawning appears to have been occurring on the Vyrnwy catchment, and the graphs below show the difference in the density between the Vyrnwy and Severn tributaries.

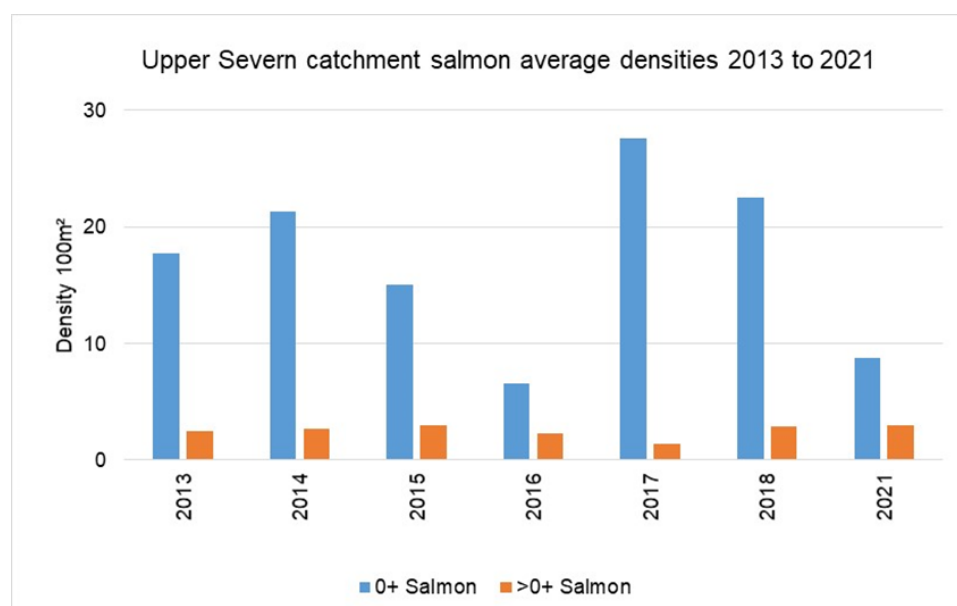


Figure 9 Salmon densities from Welsh surveys in the Upper Severn 2013 to 2021

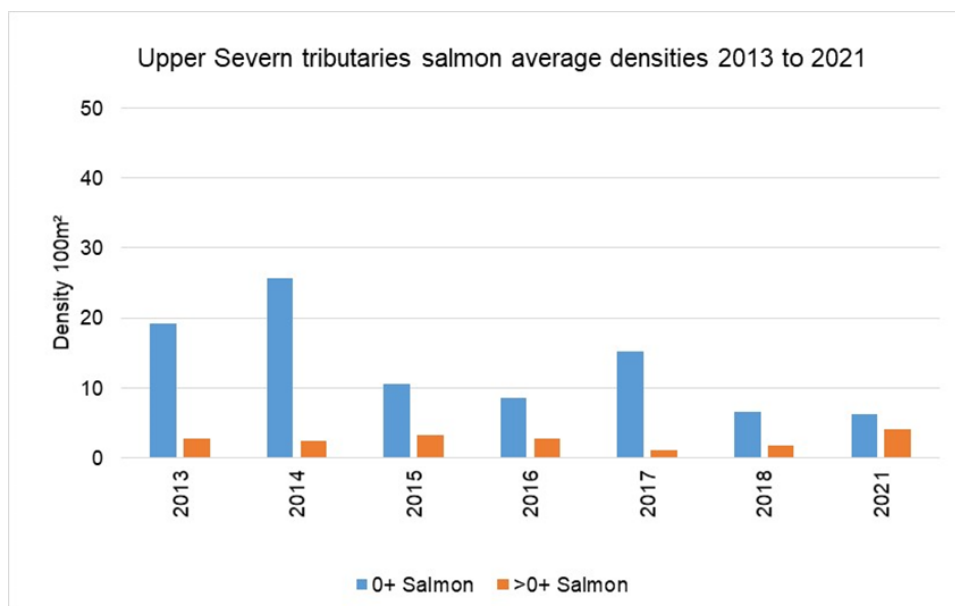


Figure 10 Salmon densities from Welsh surveys in the Upper Severn tributaries 2013 to 2021

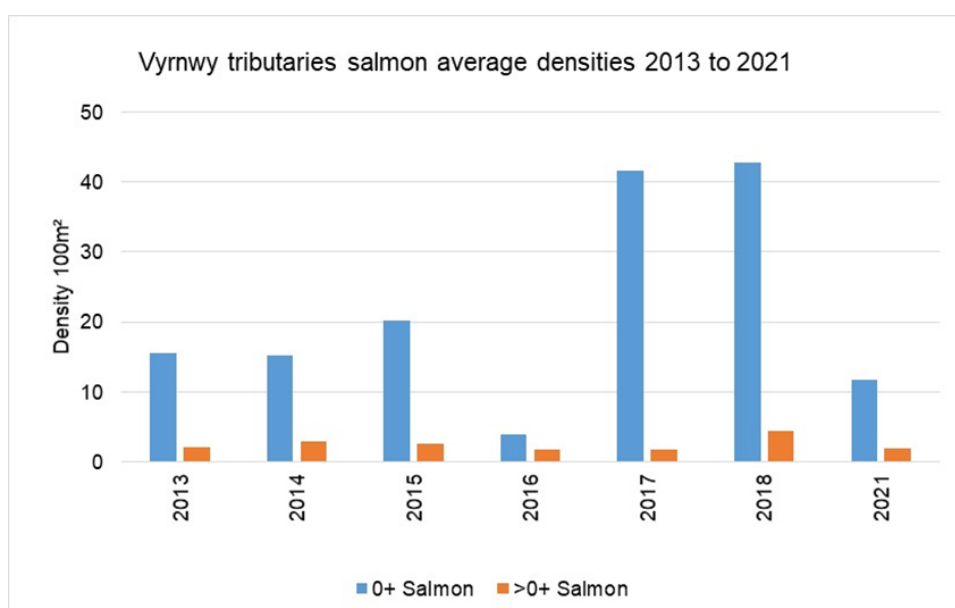


Figure 11 Salmon densities from Welsh surveys in the Vyrnwy tributaries 2013 to 2021

Of the three fish counters running in the Severn catchment the only long term dataset available is that on the Afon Tanat at Carreghofa. Figure 12 shows salmon movements from the last ten years through the Carreghofa fish pass. Power failures in 2008, 2016 and 2018 caused a lower count. The counter has shown a continued decrease in salmon numbers since 2006. The majority of salmon pass through the counter during October and November.

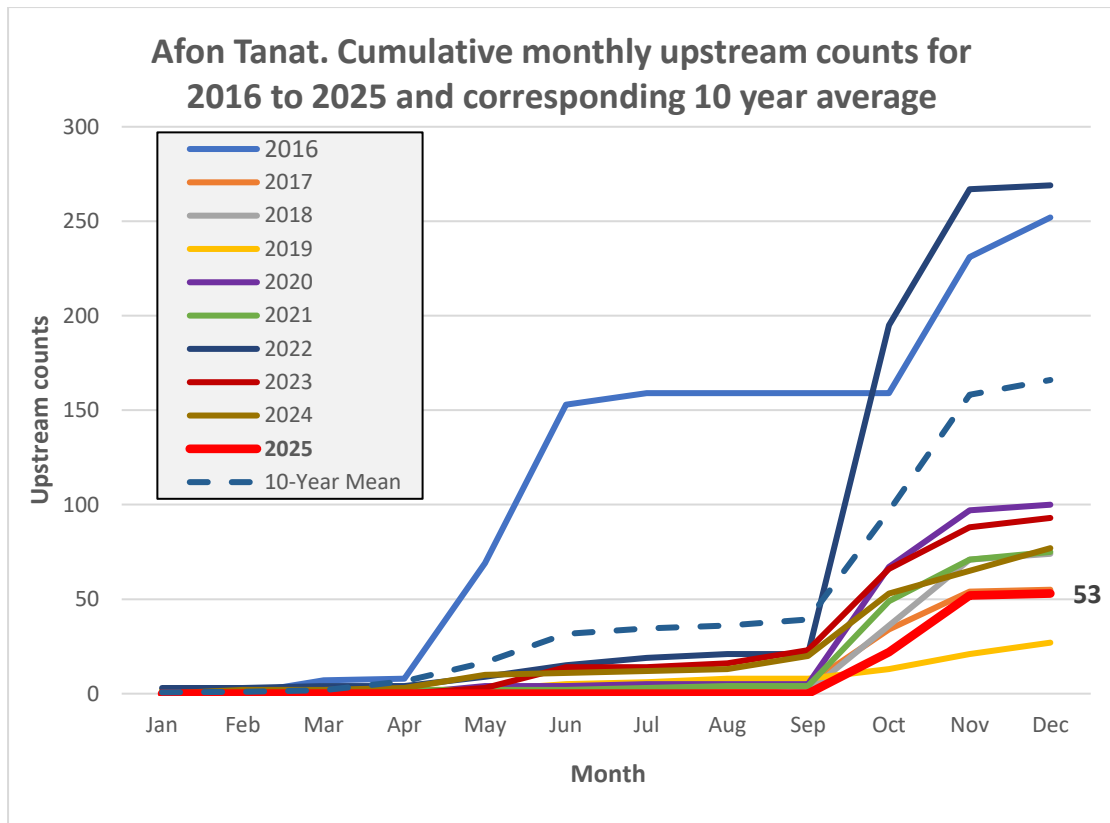


Figure 12 Year on year plot of salmon upcounts through Carreghofa fish counter 2016 to 2025

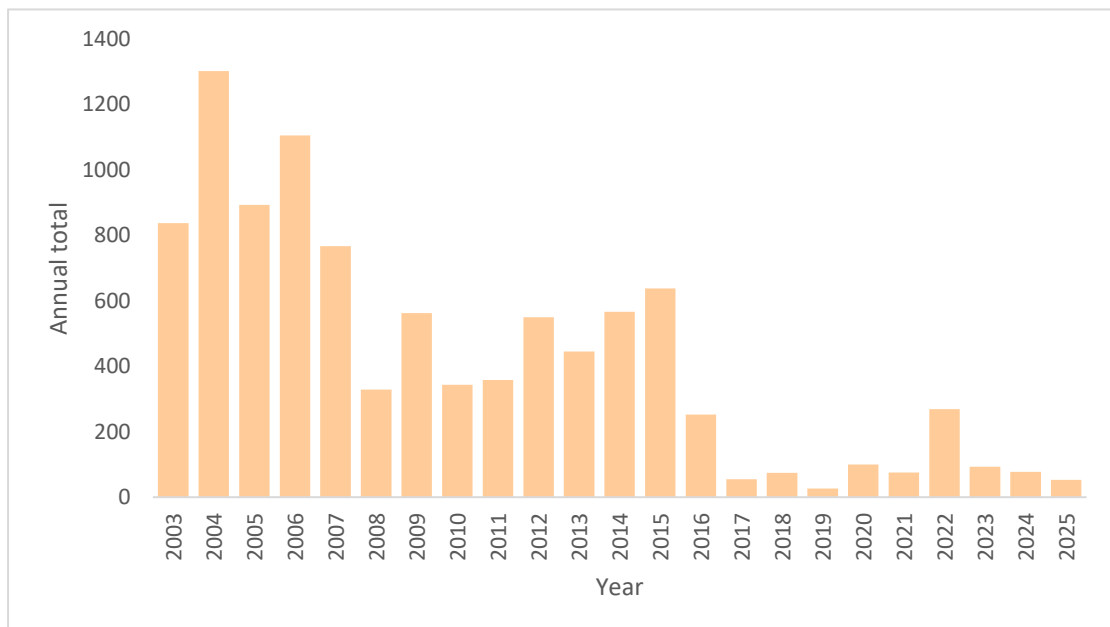


Figure 13 Annual salmon upcounts for Carreghofa, Afon Tanat 2003 to 2025

Principal salmon catch per unit effort timed electric fishing surveys on riffles within England show that Atlantic salmon spawn in the main river from the Welsh border down as far as Bewdley. Coarse fry netting surveys in 2023 and 2022 between

Shrewsbury and Upton upon Severn show that barbel fry were caught from Shrewsbury downstream to Bridgnorth, while gudgeon was the only species caught at all eight sites. Holt fleet was the most productive site with over 1,700 fish caught with Upton on Severn being the second. Numbers were particularly low at Pengwern with changes in habitat and dog walkers being main reason..

The Environmental Quality Standards (EQS) Directive is a daughter directive of the Water Framework Directive (WFD) and focuses on limiting the input of certain hazardous substances to the water environment. For this, fish are caught and then tested for bioaccumulation of certain hazardous substances. The target species for these surveys in the River Severn are roach. Fish were caught using electric fishing from a boat. All fish caught by this method were identified, counted and measured. The site used for this is in and around the marina at Upton upon Severn.

Roach were the most numerous species caught which is to be expected as they were the target species. However, there were also a large number of the invasive non-native fish zander caught as well.

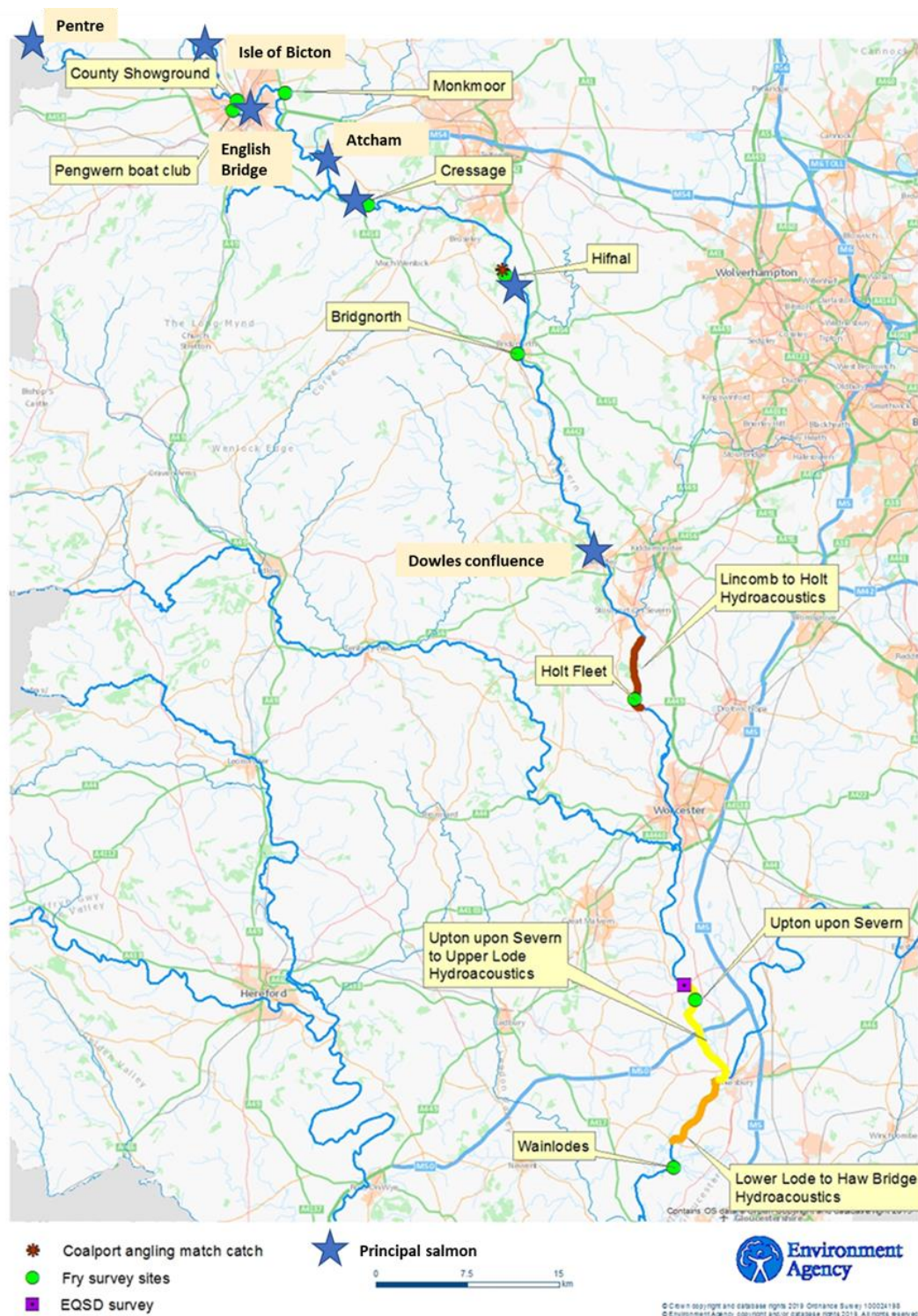


Figure 14 Location of main fish surveys on River Sever in England

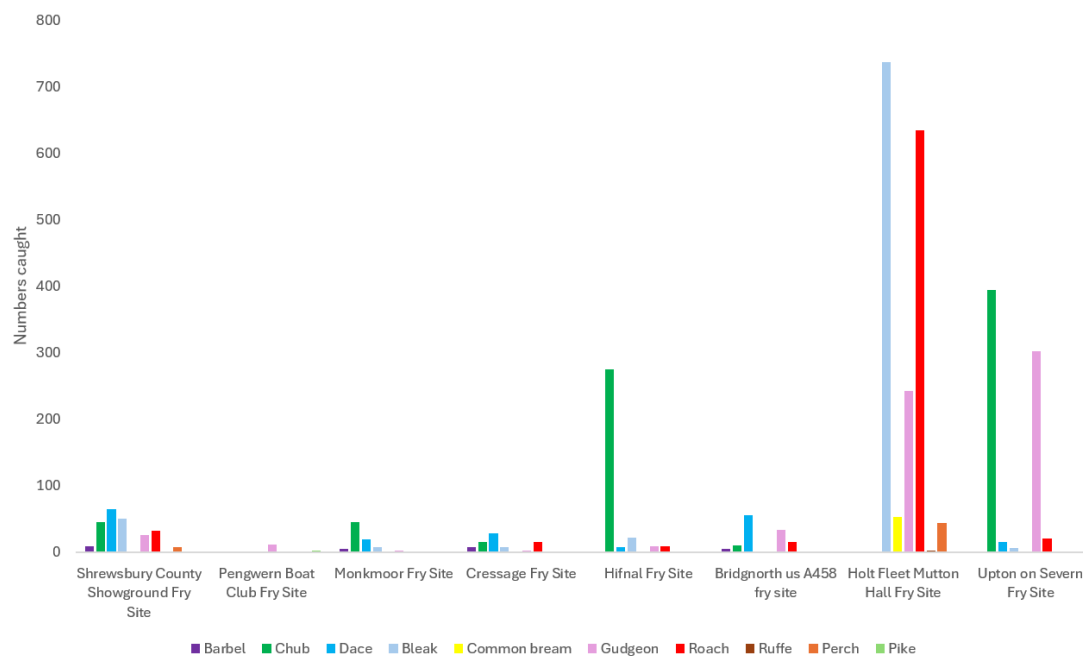


Figure 15 Results from latest fry surveys of coarse fish of angling interest on River Severn (mainly 2023 other than Pengwern and Holt Fleet 2022 and Upton on Severn 2019)

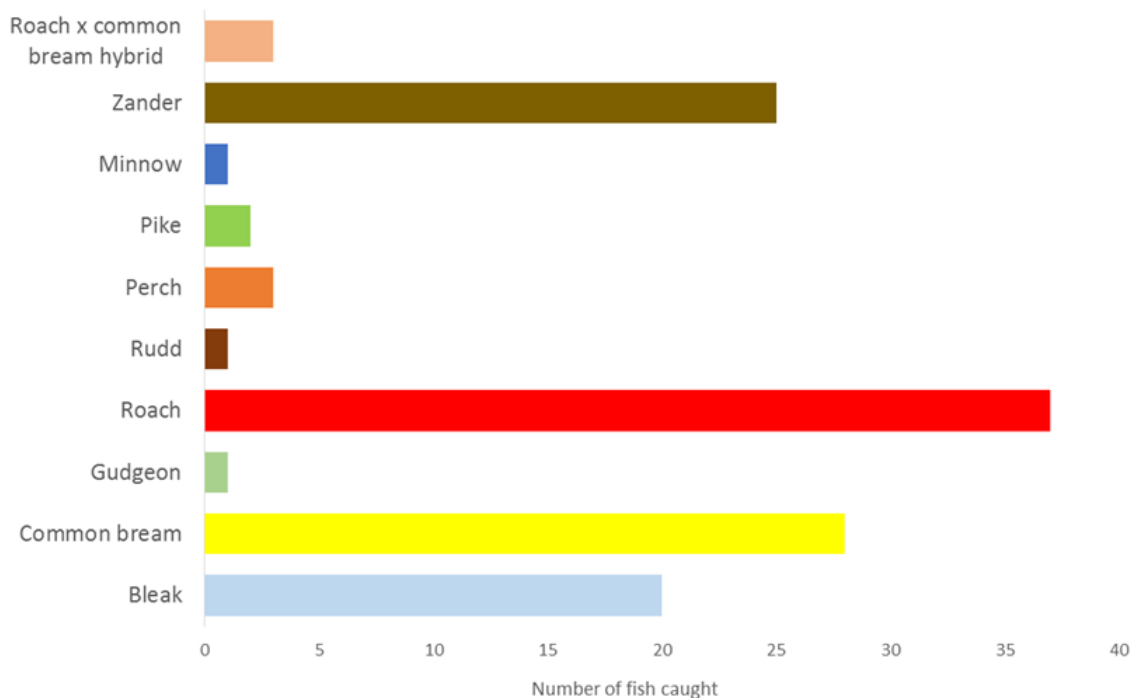


Figure 16 Number of fish caught from Upton upon Severn during 2019 EQSD survey (roach were target species)

The River Onny has been set up as a local salmon index river to help improve the general understanding of Atlantic salmon populations in the Severn catchment. Five sites are surveyed annually to capture yearly trends. Juvenile Atlantic salmon were found at all sites, except Craven Arms in 2025. The majority of salmon caught on these surveys are 0+ fish, although a smaller number of 1+ and 2+ salmon were also recorded. 2025 was a below average year for salmon numbers on these surveys although the sites further up the catchment have seen a slight increase in salmon numbers in 2024 and 2025.

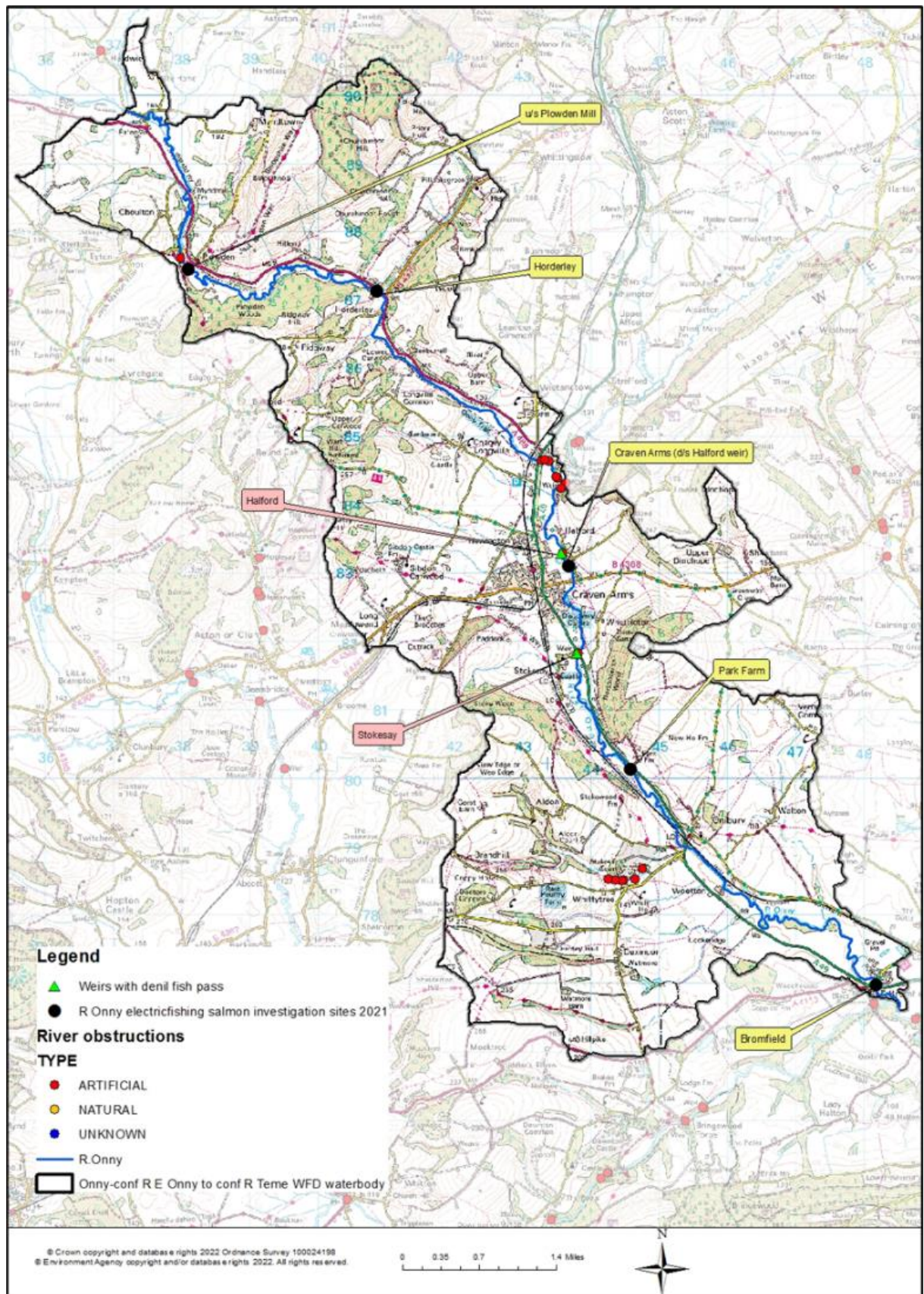


Figure 17 Locations of River Onny Salmon Index fish surveys

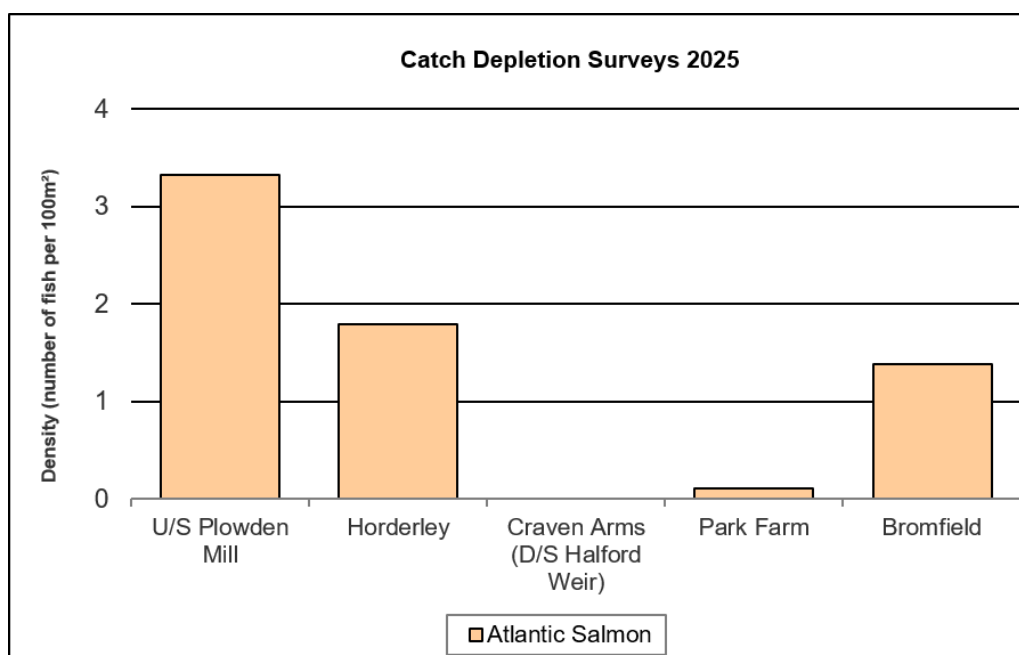


Figure 18 Density of Atlantic salmon caught during 2025 surveys on River Onny Salmon Index surveys

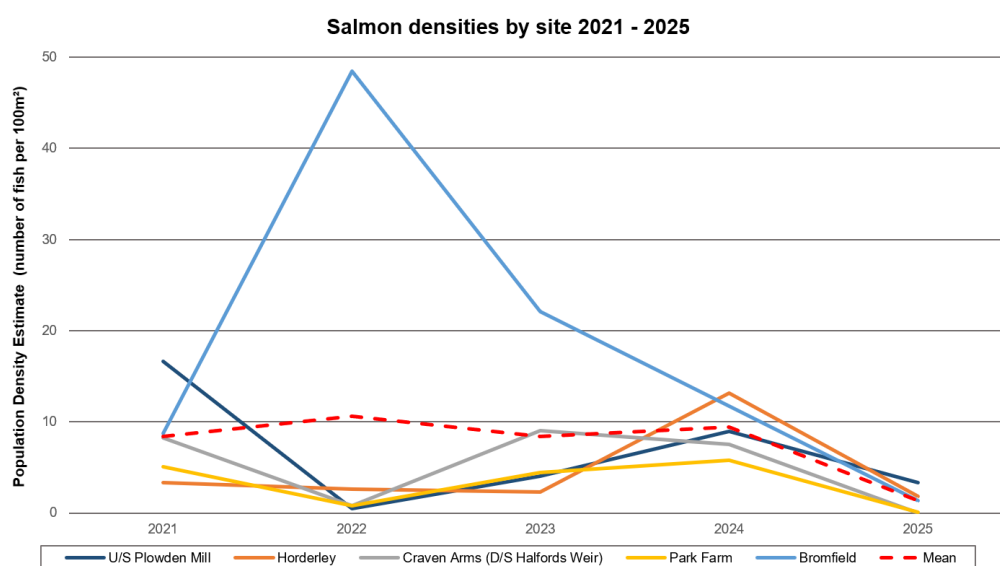


Figure 19 Long term dataset for River Onny Salmon index surveys 2021 to 2025

The hydroacoustic data for the River Severn is collected annually when possible. Unfortunately 2025 and 2026 data is not yet available for this assessment. Fish densities between Lincomb and Holt in 2019 were lower than previous years, while densities between Upton upon Severn and Upper Lode were higher and comparable to previous years. Unfortunately due to high tides Lower Lode to Haw bridge had to be cancelled in 2019, but this section tends to have the lowest fish densities of the three sections surveyed. Observations during 2026 hydroacoustic surveys noted very high

densities of fish between Upton upon Severn and Upper Lode (Caroline Cook pers comms).

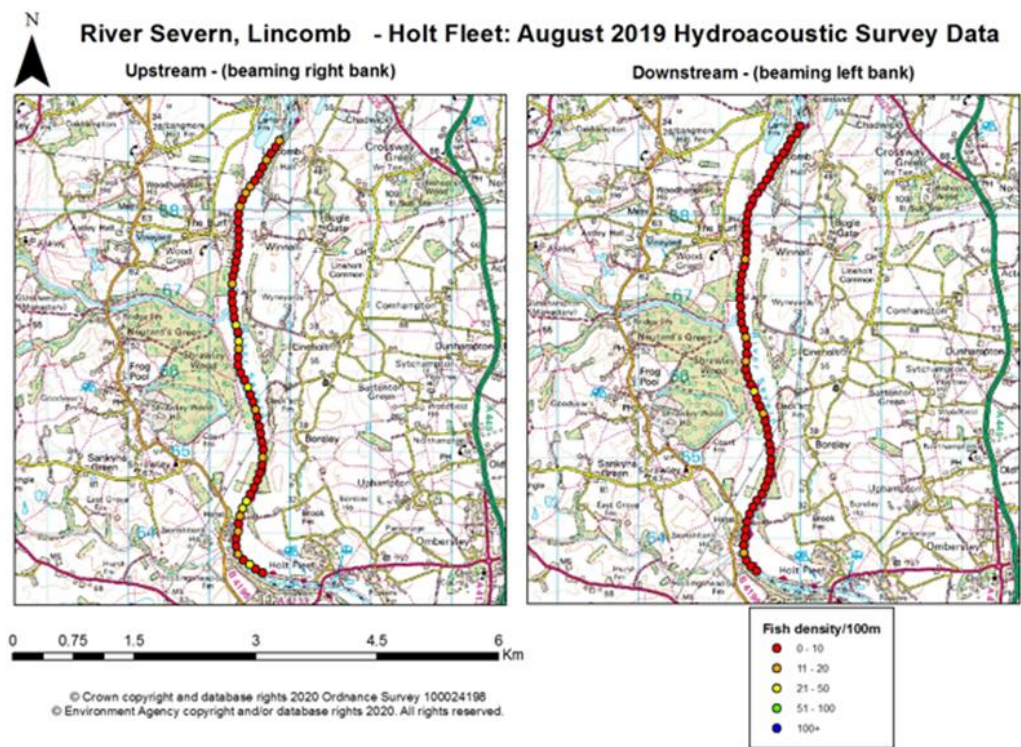


Figure 20 Fish densities recorded during hydroacoustic surveys on River Severn between Lincomb and Holt 2019

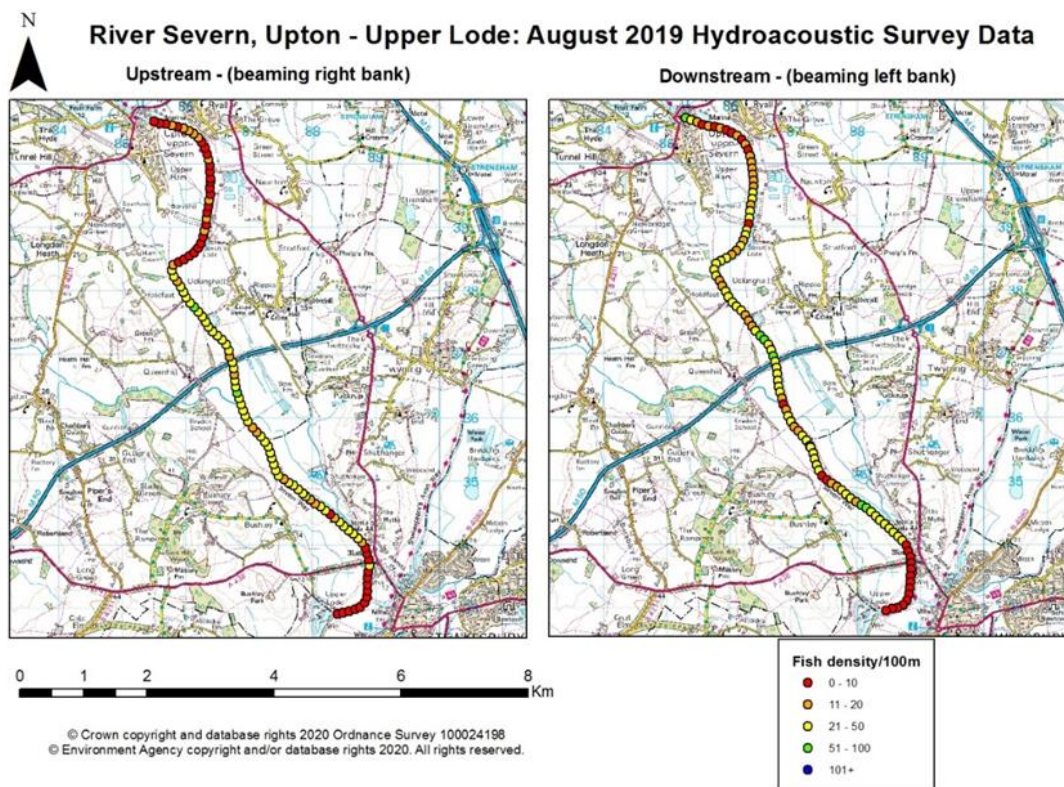


Figure 21 Fish densities recorded during hydroacoustic surveys on River Severn between Upton upon Severn and Upper Lode 2019

Some angling clubs have match catch data going back further than our monitoring results. For example the Leighton Anglers (Cressage to Buildwas) have provided match catch data from 1964 showing weight of fish caught (Figure 22). As can be seen since the early 1970's barbel have been the main fish that anglers have caught in competitions. This is not surprising due to anglers targeting species like barbel to maximise their match weight. Up to 2003 weights of fish caught have stayed relatively constant or even improved. In the drought period of 1975/6 numbers of barbel caught were lower, while chub increased. However, this is not repeated in 1989 or 1995.

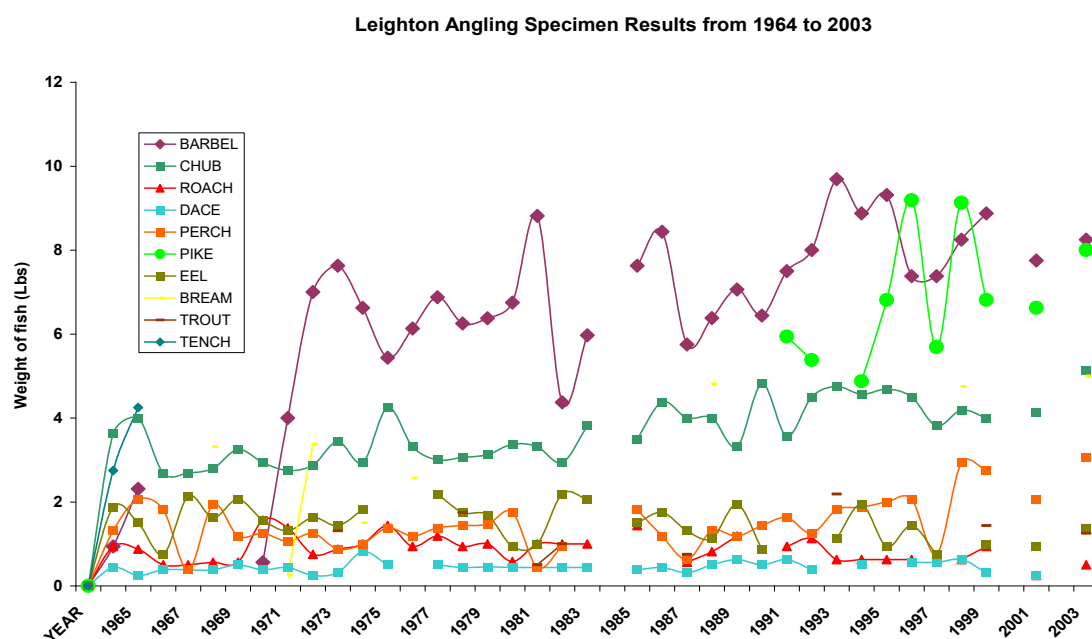


Figure 22 Match catch data from Leighton Anglers 1964 to 2003

**no new data available from Leighton anglers (other angling clubs data available for future work).*

Recent match catch data from Rowley District Angling Club (Coalport) shows dace, bleak, chub and barbel were the most common fish caught. Numbers of the 'silver' fish (dace, chub, roach and bleak) have increased in the Severn over the 10 years of data we have as can be seen in the match catch data (Figure 24).

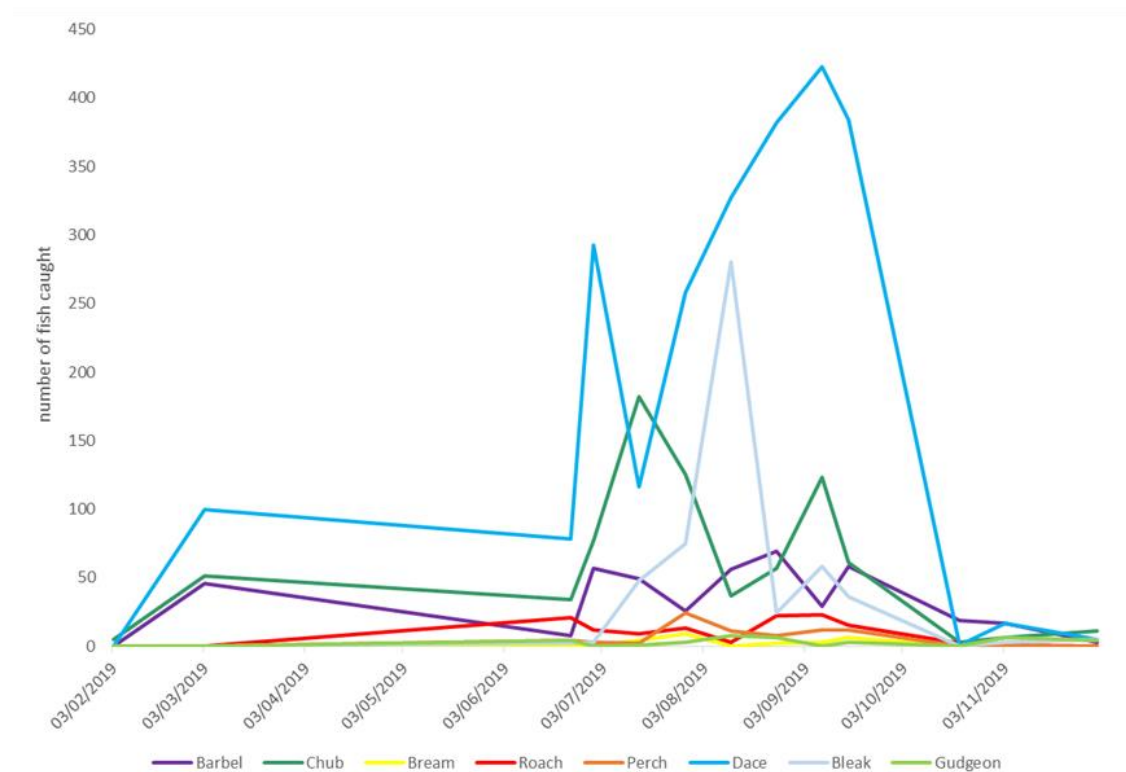


Figure 23 Match catch data from Rowley District Angling Club for 2019

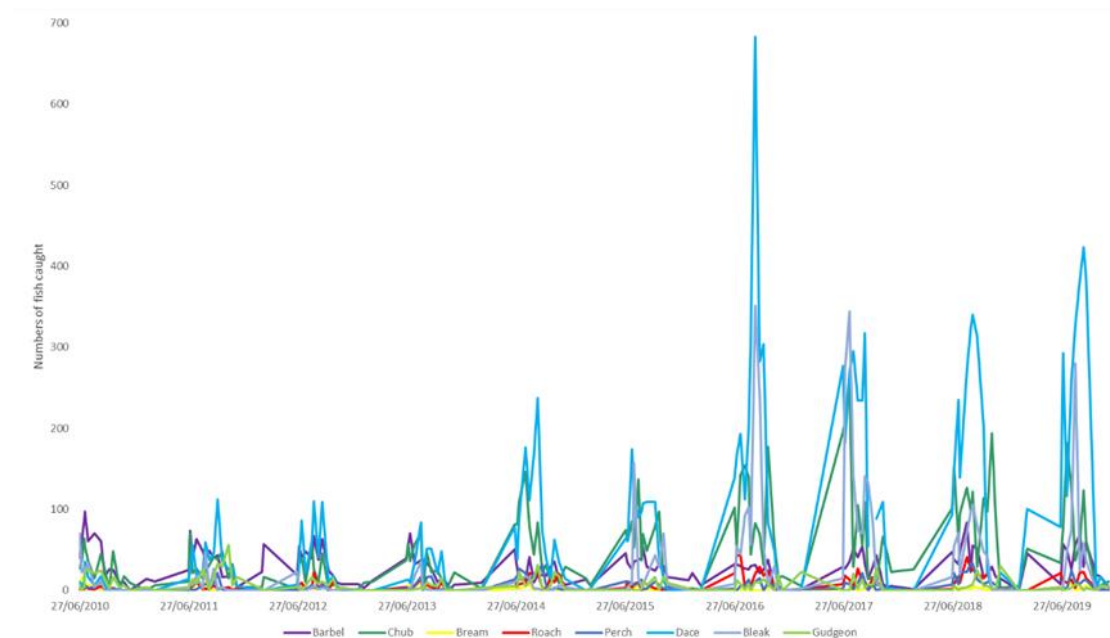


Figure 24 Match catch data from Rowley District Angling Club 2010 to 2019

Monitoring in 2017 for Unlocking the Severn estimated a run of approximately 15,000 shad, while 2020 monitoring suggested a run of approximately 11,678. Based only on citizen science observations at Upper Lode weir the 2022 run of shad was only estimated to be a much smaller run of 3,500 shad. However,

over 632 shad were recorded as passing through Diglis fish pass from reviewing camera footage taken at the viewing window in 2026 which is the second highest total recorded. As mentioned previously the main breeding population of shad in the River Severn are twaite shad. Twenty eight different fish species have so far been recorded using the fish pass at Diglis highlighting the large species diversity of this section of the river including allis shad, twaite shad, Atlantic salmon, European eel, barbel, bleak, bream, brown/sea trout, carp, chub, dace, grayling, gudgeon, river lamprey, sea lamprey, minnow, perch, pike, roach, ruffe, stone loach, tench, three spined stickleback, rainbow trout and zander.

7.4 Assessment of Impact on the Current Environment from the Severn Drought Order

The main aim of this report is to assess the impacts of the River Severn drought order on the fish within the River Severn catchment, in comparison to the 'do nothing' approach.

From monitoring results within the River Severn and its tributaries there is little evidence on which to assess the impact of normal dry and wet periods on fish populations. A Drought Order was put in place on the River Severn in the droughts of 1976 and 1989. Reports from these periods suggest that generally the dry summers were good for coarse fish on the Severn and bad for salmonids and where serious problems were experienced they were either in the sub-catchments or estuary and so beyond any influence of regulation (NRA,1990 and Severn Trent Water,1977).

For the migratory fish the first question has to be whether having a flow less than 850 Ml/d at Bewdley will reduce the distance up the river they can access. The Atlantic salmon and sea trout will require freshets to cause upstream migration so those 'spring' run salmon were able to move up into the freshwater part of the Severn while flows were still good in May. Camera footage in 2026 from Diglis showed a larger spring run of salmon than previous years . These fish then stay within the river until the first frosts of autumn before they spawn. This means they are susceptible to low flows and hot temperatures during the summer as they stay in pools and can become trapped. Solomon and Sambrook (2004) concluded that low flows during the summer caused fish to remain in the tidal water and then not make it into the river, which could possibly be linked to high temperatures and low dissolved oxygen. However, now a large proportion of salmon in the Severn catchment move upstream in the autumn. These fish would be waiting until higher flows later in the year and so might be at risk to low flows in the estuary, especially at times of spring tides. Redd counts within the Upper Severn area suggested that in 1995 low flows did not have a detrimental impact on salmon creating redds in fact this was the best count on record, although conversely 1975 and 1976 were lower counts. Weather and river conditions on the day of survey will impact surveys for redds potentially giving an inaccurate count

The fish counter on the Afon Tanat gives a good count of salmon using the Afon Tanat catchment as it is on a weir that would be impassable for salmon if not for the fish pass and is not far from its confluence with the River Vyrnwy. This has shown that the majority of salmon moving through the fish pass will wait until flows increase in the winter to travel upstream. While dry years have not shown there to be an impact on autumn run salmon the spring runs are

generally lower. Flows on the Afon Tanat are not impacted by regulation, but salmon reaching the Tanat have to travel up the River Severn and Vyrnwy. It is a similar story on the River Teme, which has some key habitats for salmon but flows are not impacted by regulation. It is likely that both the Tanat and Teme would be impacted far greater by a drought than the River Severn as flows would not be supplemented.

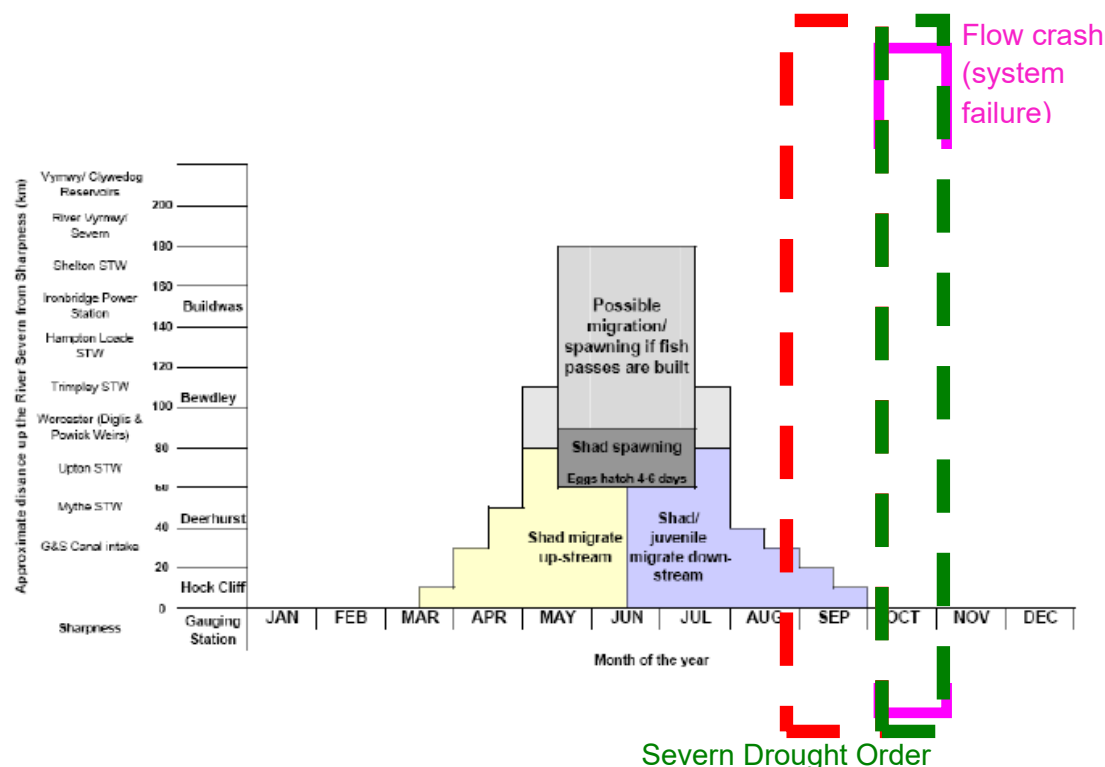


Figure 25: Twaite shad movements within the Severn catchment (red hatched box is section where flows lower with Severn Drought Order and green hatched box flow better, pink hatching where flow crashes in do nothing approach)

Previous studies (Severn Estuary SPA & SAC Review of Consents Stage 3) have shown it unlikely that low flows would have an impact on twaite shad and sea lamprey migration. In fact twaite shad on the River Severn had a very successful year in 1975, which was accredited to lower flow and higher water temperatures increasing the growth and survival of the juveniles before moving down to the estuary (Maitland, 2003). The lowest flows that have been measured and appear to be suitable for twaite shad at Saxons Loade have been summarised in Table 2 (taken from Review of Consents). There is a proviso that these were seen as 'acceptable' flows where the shad year class did not appear to be affected.

Table 2 Acceptable low flows for twaite shad at Saxons Loade

	cumecs	MI/d
May	16.5	1426
June	12.2	1054
July	12.2	1054
Aug	9.8	847
Sept	12.2	1054
Oct	12.2	1054

However, it could have a limited impact on river lamprey migration, although peak migration upstream is generally October to March when flows are higher (see Figure 26). It is not envisaged that the elvers (young of European eels) migration would be impacted hugely by these low flows for they migrate upstream early in the year. Elvers migrating upstream later in the year would have difficulty with some obstructions.

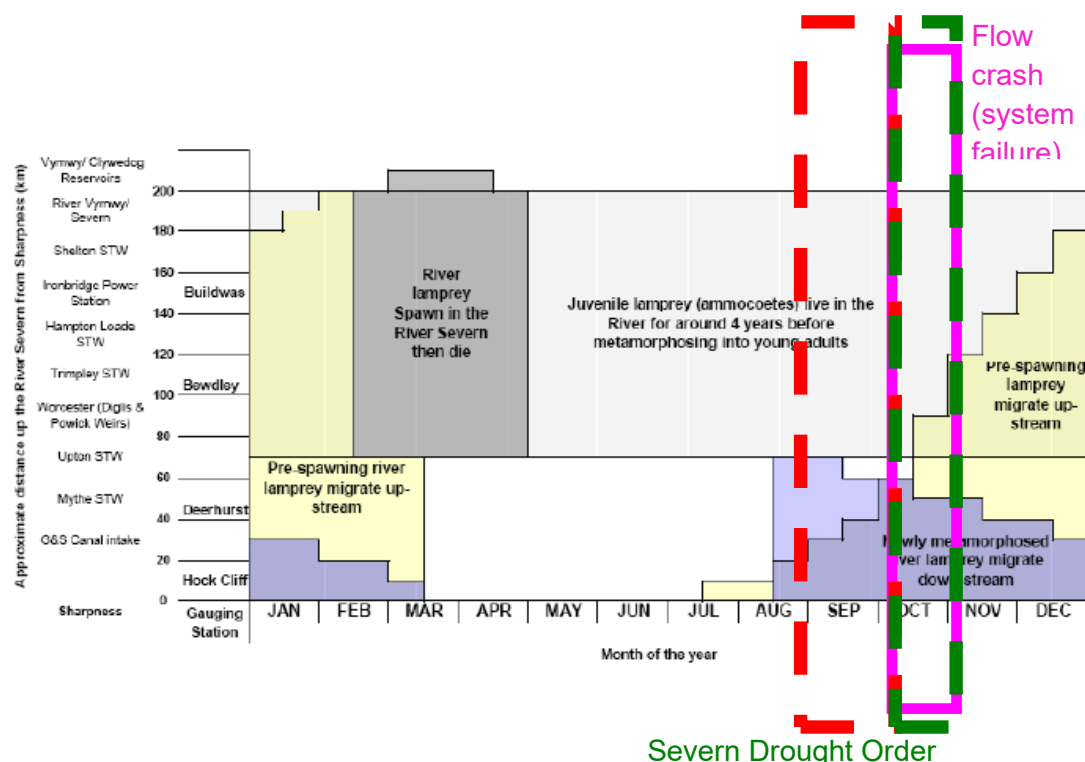


Figure 27: River lamprey movements within the Severn catchment (red hatched box is section where flows lower with Severn Drought Order and green hatched box flow better, pink hatching where flow crashes in do nothing approach)

As far as the resident species are concerned barriers to movement caused by low flows will cause a reduction in spawning and feeding areas they will be able to utilise. The movement of coarse fish is sometimes overlooked but they can move long distances without obstructions. Blonska, et al 2025 showed barbel in the River Severn can migrate over 100km in one season. The main obstacles to movement would be the weirs along the River Severn (often barriers in normal flows) and very shallow riffles exposed in low flows, which increase in frequency higher up the catchment.

Low flows can cause a decrease in water quality due to lack of dilution of effluents, with possible decreases in dissolved oxygen and higher temperatures. This is remediated slightly by the fact that sewage treatment works are believed to work more efficiently in warm temperatures. Each species has different tolerances to drops in water quality with salmonids, especially juveniles, the most susceptible (see Table 3). To coincide with this the higher the water temperature the more toxic certain compounds such as ammonia become to fish. It has been reported that oxygen sags in the upper estuary have been linked to several episodes of fish mortality. The majority of reported fish killed have been salmon, but mortalities of twaite shad and lamprey have also been reported (Hutchinson and Wade, 1992). These oxygen sags are linked to spring-neap tidal cycles. Fish within the upper section of the Severn Estuary will have to deal with these water quality issues and lower flows will lead to increased saline intrusion on spring tides.

Table 3 Tolerances of certain fish to dissolved oxygen levels and temperature

	Dissolved Oxygen	Temperature (°C)
Salmonids	40 - >100%	1 to 20
Roach	20 - >100%	1 to 25
Carp	10 - >100%	1 to 28

Associated with a drought is an increase in algal blooms. These can cause large fluctuations in dissolved oxygen as they produce oxygen during daytime and then use it up during nighttime. This can cause fish kills and quite often during hydroacoustic surveys on the middle section of the River Severn fish densities are higher at the base of weirs where the water has become oxygenated. During 2011 reports came in from lock keepers on the River Severn that algae was building up during low flows. In the upper reaches gravels can become smothered by filamentous algae leading to reduced water percolation through redds and potentially impacting macroinvertebrates which are the main food source of juvenile salmonids. The use of a drought order is unlikely to enhance algal growth during natural low flow conditions.

Another associated problem with low flows is they will cause a decrease in the wetted area available to fish. This then leads to trapped fish and also reduces the availability of cover from predators. Many anglers perceive predation to be one of the greatest problems for fish stocks in the River Severn and the increases in numbers of cormorants and goosander have been mainly blamed for this. The decreased wetted perimeter also increases competition for food and spawning areas. Spawning areas become limited and if water levels drop suddenly this can impact fish that have spawned in late spring and early summer leaving eggs out of the water e.g. roach spawn on aquatic macrophytes in late spring which makes them prone to water level fluctuations. However, this is unlikely to occur in sections of the River Severn where coarse fish are known to spawn. Under low flow conditions Atlantic salmon parr can exhibit a preference for shallow riffles rather than migrating to pools (Armstrong, Braithwaite and Fox, 1995). This is thought to be due to brown trout being more common in pools (competition) and that salmon in pools are more vulnerable to predation.

Indirectly coarse fish will be impacted in rivers that receive large volumes of groundwater as part of the river regulation system (River Tern and River

Perry). The groundwater will be a lot cooler than river water and therefore will be detrimental to spawning and juvenile fish growth for coarse fish, although this only likely to be localised to the area of discharge as river water quickly returns to normal temperature as shown in test trials. However, in the main River Severn coarse fish may well have a good year during drought conditions as water temperatures will be higher meaning earlier spawning and faster growing juveniles.

Assessment of Impact from the River Severn Drought Order

Flows have been modelled for each assessment point for an acute (one year) and chronic (two years) drought scenario based on the 1976 drought. Hydrographs have been produced to show differences between various management options:

- Do nothing
- EA Drought Order only

Each assessment point will be looked at separately with respect to the expected impact the different flow regimes would have on the fish population. It must be noted that this is only a modelled scenario and timings of low flows in real life would most likely differ and hence cause different problems.

Acute Scenario

Clywedog

This section is likely to be impacted by the introduction of the Drought Order as it relies heavily on flow from Clywedog Reservoir. Previous studies (Cowx and Gould, 1989) have shown that large releases from the reservoir have left the Afon Clywedog with an impoverished salmonid population and NRW surveys confirm that salmon densities are low. When the drought order is first introduced a decrease in flow occurs as releases from Clywedog decrease. It is envisaged that this is a high proportion of the total flow of this section especially in the Afon Clywedog, as there is virtually no groundwater to add to surface water flows. The fish population is salmonid which require high dissolved oxygen (especially juveniles). If water levels drop very rapidly (if dead water reached) this could leave fish stranded on riffles or in pools that might dry up leaving them vulnerable to predation and decreasing dissolved oxygen. The acute scenario shows that while flows do drop off sharply initially with the drought order they then keep some flow within this section and at least dead water at Clywedog is not reached. Without the drought order dead water is reached at Clywedog and this could have a large detrimental impact on the fish population. This occurs for 35 days in the do nothing management option, which would have large repercussions on the fish population. Back in the 1990s the Environment Agency requested a PHABSIM for the upper River Severn. This involved habitat assessment for Atlantic salmon under different flow conditions in the upper Severn based on flows at Dolwen (SN 996 581). It was concluded that not letting flow drop below 70MI/d at Dolwen would be beneficial for adult spawning (141.4% in Wetted Usable Area) and juvenile (16.4% WUA) salmonids. In the acute scenario the do nothing approach causes the flow to fall below 70MI/d for 397 days (1975-79), while the EA Drought Order causes the flow to fall below 70MI/d for 305 (23% change). This can be seen to be a significant improvement for salmon at Dolwen.

Vyrnwy

The majority of the Afon Vyrnwy is dominated by salmonids, with increasing coarse fish numbers near its confluence with the River Severn. The flow graphs for the Vyrnwy assessment point show that having a drought order in place would have a negligible difference to flows in the acute scenario. Even in the do nothing approach the flow never crashes, just that there is very little flow variation over the winter (November to April). This might limit the migration of Atlantic salmon to the top of the Vyrnwy; however an impassable barrier at Dolanog (13kms downstream reservoir) prevents salmon progressing to the reservoir even in high flows.

Buildwas

This section of the River Severn is dominated by coarse fish, but is still used by migratory Atlantic salmon, eels and lamprey. The acute scenario shows negligible differences between having the drought order or not and in the flow duration curves all management options are above the EFI (Environmental Flow Indicator) line used within the water resources national CAMS process. The Ironbridge Gorge would be an area of concern as the river changes character considerably as it changes from a slow meandering river (Buildwas) to a more enclosed riffle/run system as it passes through the gorge. Here it would be expected that the available habitat for fish would reduce. Cross sectional information of the wetted perimeter would be required to assess the impact on this section.

Bewdley

The Severn at Bewdley again is a coarse fish dominated system and is in the vicinity of some large scale abstractions for public water supply. There are still a number of important riffles in this section of the River Severn, which are used by salmonids for spawning. The acute drought scenario shows flows reduce to an average 368Ml/d for 22 days (from 12th October), which is below the High Risk EFI line (i.e. >30% lower than EFI), for the do nothing approach. For the drought order the flow reduces slightly later and does not drop to such a low level showing some form of mitigating effect from these management options.

This is where the first of the navigation weirs start impacting the nature of the River Severn. Salmon below weirs that cannot get through the rudimentary fish passes would have been prone to predation and angling pressure. In 2011 with low flows in the main Severn through the summer the main catch of salmon was below Diglis weir on the River Severn. This gives evidence that salmon were unable to pass through Diglis weir fish pass. However, with the Unlocking the Severn project improved fish passage has been created for all four of the navigation weirs, with evidence that multiple species are benefitting from this (28 fish species recorded using Diglis fish pass). A review of how well these passes operate at low flows would be useful for our understanding of impacts of a Severn Drought Order.

Saxons Lode

The river is now becoming increasingly engineered and less like a natural watercourse. In the acute drought scenarios a slight difference is seen through September where flows are slightly higher with do nothing than with the drought order. With the drought order flows would be around the 'acceptable' level for shad at Saxons Loade for August flows (847Ml/d), but lower than

September (1054MI/d). It is unlikely that the flow with the drought order in September (around 800MI/d) would have a negative impact on shad. However, the crash in flow in October is worse with no drought order and could impact any shad that have not migrated down to the estuary. The drought order management options drop below the High Risk EFI line for longer than the do nothing approach in the flow duration curves, but this is a broad environmental indicator, while knowing more about the ecology of the shad it is more likely to be beneficial to the juvenile fish to have low flows in this section of the River Severn at this time. Research by Aprahamian & Aprahamian (2003) looking at year class strength of twaite shad within the River Severn found flows from June to August to be inversely correlated to year class strength with no significant correlation to flows in May, September and October. It is also anticipated that the coarse fish fry within this section would also benefit from enhanced growth due to the low flows especially as water quality has been shown not to deteriorate.

Haw Bridge/Deerhurst

In the do nothing management option at Haw Bridge/Deerhurst the flow crashes on the 13th October for 19 days and drops below the High Risk EFI (average flow 608MI/d), while the drought order tends to be around the Medium Risk EFI. However, the do nothing approach has higher flows than the drought order for around 45 days, average flows of 1100MI/d. The flow crashes should not be at a critical time for most fish species in this section as water quality is not thought to deteriorate enough to impact coarse fish species and salmonids will mainly be waiting in deeper water or the estuary for the autumn rains before migrating up the river.

Lower Parting

This section is very different as it is within the tidal range of the estuary. Any high tides combined with the low flows of a drought could have a very negative impact on the fish population. This will be due to saline intrusion and increased suspended solids causing low dissolved oxygen levels. All management options within the acute drought are equally susceptible to high tides suggesting that the effect of drought on dissolved oxygen is unavoidable. Work completed by Hutchinson and Wade (1992) recommended that a flow of 1800MI/d at Haw Bridge would be required to maintain dissolved oxygen levels above 3mg/l (critical concentration for survival of migratory salmon), prevent suspended solid concentrations of greater than 6000mg/l and prevent saline intrusion for 94% of predicted tides. During the acute drought model this flow is not attained for 19% of the year. This suggests potential for fish kills (mainly salmon). However, water quality within the estuary has been improved dramatically since this study. Timings of high tides and low flows would be critical on the magnitude of this problem. As regards the timings of flow declines in the do nothing management option the crash in October could be the most detrimental to salmon and river lamprey waiting to migrate upstream and any shad that are still in the upper estuary. Any high tides within this time period could cause large fish losses and the Severn estuary usually has a spring tide once every two weeks.

2011 was a very dry year with low flows on the River Severn through the summer, however no dead salmon were recorded by the Severn netsmen. At present it is not certain where within the estuary salmon wait as monitoring

movements is very problematical, but they tend to respond rapidly to increases in flow in lower Severn.

Chronic

Clywedog

Flows over the winter months between first and second year would be lower (as reservoir filling up) and this could limit the dispersal of salmon spawning in the upper Severn as insufficient flows to stimulate movement up the catchment. It is anticipated this would be worse in the do nothing management option.

In the second year of the chronic drought scenario the do nothing approach has an extensive period of flow failure (again), which would cause substantial fish kills. This would be the second consecutive year and so would create long term issues for the fish community and lengthen the recovery time considerably. The drought order prevents total flow failure, which would be beneficial.

At Dolwen the flow falls below 70MI/d (1975-79) for 469 days, while the EA Drought Order causes the flow to fall below 70MI/d for 413 days. Although this is a less significant difference than in the acute scenario, the difference is still greater than 10% and so can be assumed to be beneficial for salmon.

Vyrnwy

In the do nothing management option again low flows during the winter months while the reservoir fills up will limit the dispersal of salmon spawning. Also in the second year near the end of the drought there are 20 days of irregular flows which could impact the fish population. Not only could the change in flow be an issue so could the fluctuating temperatures (reservoir water generally colder). Salmonids may benefit from the cooler water, but at the detriment to the coarse fish in the lower Vyrnwy.

Buildwas

Even in a chronic drought Buildwas flows stay above the EFI for both management options. As with the acute scenario it would be anticipated that the available habitat for fish within the gorge would reduce. Cross sectional information of the wetted perimeter would be required to assess the impact on this section.

Bewdley

In the do nothing management option the flow crashes below the High Risk EFI for 24 days from 10th October to a minimum level of 289MI/d, which has not been seen in recent history. This would cause large problems for riffle sections that would dry out, with juvenile salmonids being impacted most.

Salmon should now be able to pass through the fish passes at the navigation weirs, although more research is needed to understand how well they operate under very low flow conditions.

Saxons Lode

For short periods with no drought order the flows will be reduced substantially within this section (average flow of 428MI/d for 22 days from 10th October). No

information is available on the impacts this could have on the fish population, but low flows in 1976 and 1989 did not cause significant fish kills.

This section is important for migratory fish such as shad and eel and the low flows in the chronic scenario might actually be beneficial to the juvenile shad (Aprahamian & Aprahamian, 2003).

Hawbridge/Deerhurst

It is anticipated that the impacts within this section are most likely to be the same as at Saxons Loade. The only exception being that on very high spring tides when freshwater flows are so low in October (with the do nothing management option) a certain amount of saline intrusion might occur which could impact dissolved oxygen levels.

Lower Parting

The flow crash in October with the do nothing option could cause serious problems for fish in the upper estuary, especially migratory salmon waiting for the autumn high flows. Any spring tides at this time would cause serious problems with average freshwater flow of only 350ML/d modelled.

Fish kills within the upper estuary were largest in the late 1980s, early 1990s and mainly in June and July. Again if the drought order comes on too early this could cause freshwater flows entering the estuary to be too low to prevent saline intrusion and dissolved oxygen sags. Although water quality has been improved sediment oxygen demand can still cause significant dissolved oxygen sags and could lead to deaths of fish (especially salmonids) within the upper estuary.

Conclusions

The closest events in recent history to these scenarios were the droughts of 1976 and 1989. Conclusions from these events on fisheries were that most impact from regulation was found in the upper Severn and that even when higher flow levels in early June were adhered to it had little positive impact on the lower river and estuary. Serious problems were encountered in the sub catchments and the estuary rather than the main River Severn, where flows were kept higher by regulation releases. These releases would have been beneficial for the salmonids within the upper Severn and scale readings from fish caught during 1989 electric fishing surveys gave the general impression that the summer had been beneficial for coarse fish.

Twaite shad

Research by Aprahamian & Aprahamian (2003) showed that both 1976 and 1989 were good spawning years on the River Severn for Twaite shad. Therefore a drought of similar magnitude and of similar timings would not be expected to be detrimental to twaite shad; in fact it might lead to a good spawning year. The main concern would be for those shad that are still within the upper estuary in the late autumn with the do nothing scenario. With freshwater flows so low saline intrusion and sediment oxygen demand could cause distress, especially if we have hot weather in early October as was the case in 2011. Lower flows earlier in the summer due to a drought order might limit upstream migration of adult shad. Water temperature was positively correlated and flow negatively correlated to year class strength for shad (Aprahamian and Aprahamian 2001). Multiple regression analysis indicated that water temperature was the only significant variable for year class strength.

Lamprey

It has been concluded that both sea and river lamprey would not be impacted significantly through the various management option. River lamprey migration might be slightly delayed, but they have such a long season for migration (over winter) it is unlikely to be too detrimental.

Atlantic salmon

The impact on salmon is not so straight forward. Fish kills in the upper estuary were a problem in the 1976 and 1989 droughts for adult salmon waiting to migrate. Water quality has improved significantly since those events, but the large flow crashes of the do nothing scenarios would cause serious issues, especially if linked to a spring tide.

The juvenile salmon parr would also be impacted in the upper Severn when the flow crashes in the do nothing scenario. Regulation releases will be generally beneficial to salmonids (cooler water) and so keeping releases going for longer with the drought order would be beneficial. Cowx, et al. (1984) reviewed the impacts of the drought of 1976 on an un-regulated river in upland Wales and discovered that the only measurable impact on the fish population was the loss of the 1976 year class of young salmon.

European eel

Although the drought might impact the movement of elvers upstream it is not thought that any of the management options would be significantly different to have a demonstrable impact on the eel population.

Sea trout

The sea trout population in the Severn is not as well understood. It is unlikely that many sea trout use the main river for spawning and so it will be adult sea trout in the upper estuary waiting to migrate upstream that would be impacted. Juvenile sea trout tend to be in the smaller streams and not the main River Severn and therefore not impacted by river regulation on the Severn.

Overall

In the event of an acute and especially a chronic drought the fish population of the River Severn would be significantly impacted. These impacts would be envisaged to be worst at the top of the catchment where salmonids dominate and at the very bottom in the estuary. Although a better understanding of the impacts on the upper estuary are required. Previous low flow investigations have shown that low flows increase mortality especially in 0+ salmon, trout and grayling (Riley, et al 2009) and that maintenance of a river flow over a longer period is beneficial to the fish population. With the drought order in place river levels do not drop to the catastrophic levels of the 'do nothing' approach in the upper reaches. Hence the drought order is beneficial to the fish population in the upper River Severn. Further downstream the beneficial impact of the drought order diminishes for the Severn, especially in the acute scenario.

It is important to note that low flows with both the acute and chronic drought scenarios are still higher with river regulation than they would be naturally at Bewdley.

Summary impacts

Table 3 Impacts of drought order on acute and chronic drought scenarios

		Do nothing		Severn Drought Order	
Assessment Point	Fish population	Acute scenario effect	Chronic scenario effect	Acute scenario effect	Chronic scenario effect
Clywedog	Salmonid	Moderate	Major	Minor	Moderate
Vyrnwy	Salmonid	Minor	Minor	Minor	Minor
Buildwas	Coarse (migration corridor)	No impact	No impact	No impact	No impact
Bewdley	Coarse (migration corridor)	Moderate	Moderate	Minor	Minor
Saxons Loade	Coarse (migration corridor)	Minor	Minor	Minor	Minor
Haw Bridge	Coarse (migration corridor)	Minor	Moderate (depends on tides)	Minor	Minor
Lower Partington	Coarse (migration corridor)	Moderate	Major	Moderate	Moderate

Mitigation Options

Possible mitigation ideas to support fish during drought and increase our understanding of impacts;

- Better understanding of how the fish passes on the main barriers on the River Severn perform at very low flows (Q99)
- Deploy sonde at Upper Lode on River Severn to monitor water quality in lower section
- Using the 70MI/d at Dolwen to protect top section
- Research other sources of water to supplement flows or public water supplies in exceptionally dry years
- Gradual ramping down of regulation releases when the Drought Order is actioned

Appendix L

Water Quality Improvements at Netheridge

Brief Note on Changes in the Ammonia, BOD and COD Levels discharged by Gloucester (Netheridge) STW from 1974 to Present

Environment Agency

The oxygen demand on the receiving waters of the Severn Estuary due to the discharge from Gloucester (Netheridge) Sewage Treatment Works (STW) is characterised by the levels of ammonia, biochemical oxygen demand (BOD) and Chemical Oxygen Demand (COD) in the final effluent. This brief note assesses the changes which have occurred in the levels of these determinands in the final effluent from Gloucester (Netheridge) STW from 1974.

The earliest monitoring data for Gloucester (Netheridge) STW is in January 1974. There was apparently no consent for the STW until 1992, although it is assumed that there was a Deemed Consent issued under COPA. It would be useful to check what Deemed Consent was in force prior to 1992.

Prior to 1992, the only treatment given to the discharge was apparently primary settlement. In 1992, the consent had limits for BOD and Suspended Solids (SS): these were 95%iles of 120 mg/l BOD and 180 mg/l SS. In 1993, these limits were tightened to 60 mg/l BOD and 90 mg/l SS. These limits indicate that some secondary treatment was in place. However, the limits only applied to a maximum flow of 20,000 m³/d, so that not all the normal flows arriving at the STW were being treated.

In 1996, the limits for BOD and SS were tightened further, and a limit was also put on the discharge for ammonia. The 95%ile values were 25 mg/l BOD, 45 mg/l SS, and 15 mg/l ammonia. These 95%ile limits have remained in force since 1996, although there have been some minor changes to the maximum values allowed in the consent. The discharge from 1996 has therefore received secondary treatment, and this treatment has been applied to all normal flows arriving at the STW. The consented Dry Weather Flow since 1996 has been 42,800 m³/d, with a maximum flow of 105,000 m³/d.

It is apparent that the major change in treatment level at Gloucester (Netheridge) STW was in 1995 to 1996, although some improvements were made in the period 1992 to 1995. These changes are evidenced by the changes in concentrations of ammonia, BOD and COD in the final effluent over the period 1974 to 2019, as shown in Figures 1 to 6. It should be noted that the change in concentrations which are apparent in 1992 relate to the difference between the settled final effluent and the treated final effluent, although until 1996 not all the flows received the higher level of treatment.

The mean concentrations of ammonia, BOD, and COD for the 3 different final effluent streams are summarised in Table 1 below.

Table 1

	Settled Final Effluent	Treated Final Effluent	Secondary Treated Effluent	Secondary Treated Effluent	Secondary Treated Effluent
Mean Values	1974 to 1995	1992 to 1995	1995 to 2000	2004 to 2007	2007 to date
Ammonia as N mg/l	42.77	25.32	0.39	0.75	0.81
BOD mg/l	326.21	20.49	3.62	2.47	2.74
COD as O₂ mg/l	594.90	131.89	62.20	48.55	46.99

These mean values indicate that the overall reductions in ammonia and BOD are about 100 fold between the settled final effluent and the secondary treated effluent, and about 10 fold for COD.

Based on these changes in concentrations, it is clear that there have been significant reductions in the oxygen demand on the receiving waters of the Severn Estuary arising from the discharge of effluent from Gloucester (Netheridge) STW since the last major drought in 1976. In any future drought, the impact of the discharge from Gloucester (Netheridge) STW will therefore be considerably less than it was in 1976, notwithstanding that there has been some increase in effluent flows over the same period.

Figure 1 – Gloucester (Netheridge) STW – Ammonia – 1974 to 2000

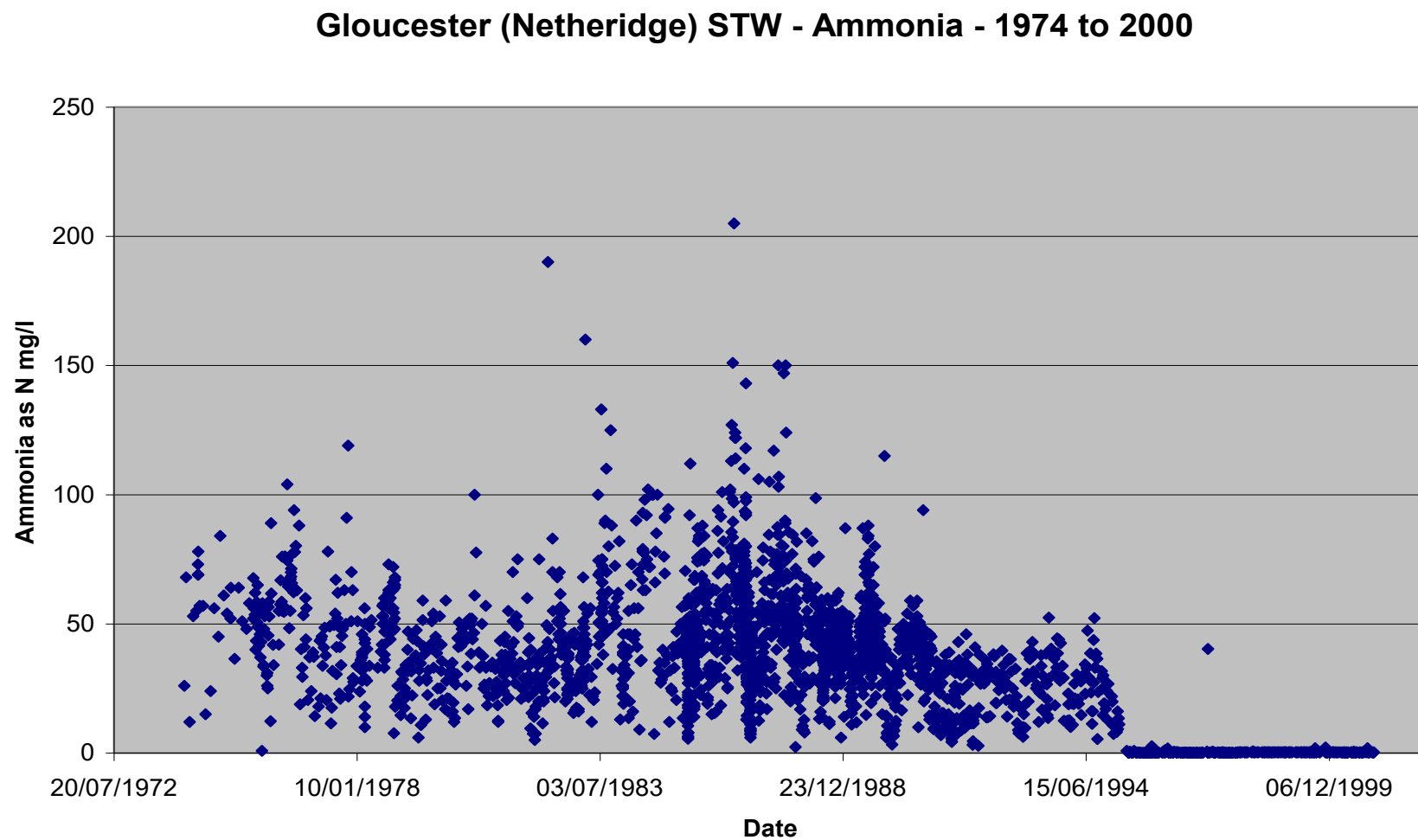


Figure 2 – Gloucester (Netheridge) STW – Ammonia – 2002 to 2019

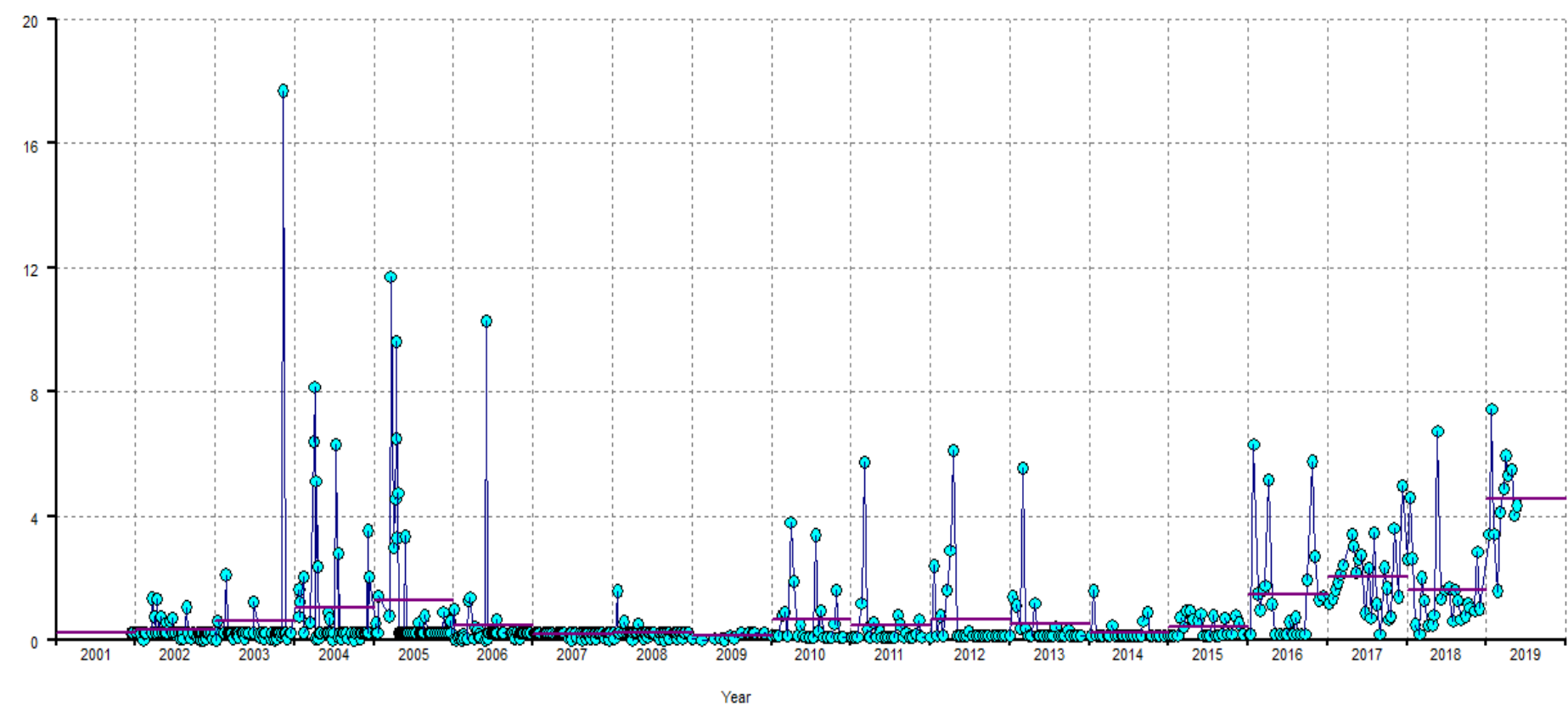


Figure 3 – Gloucester (Netheridge) STW – BOD – 1974 to 2000

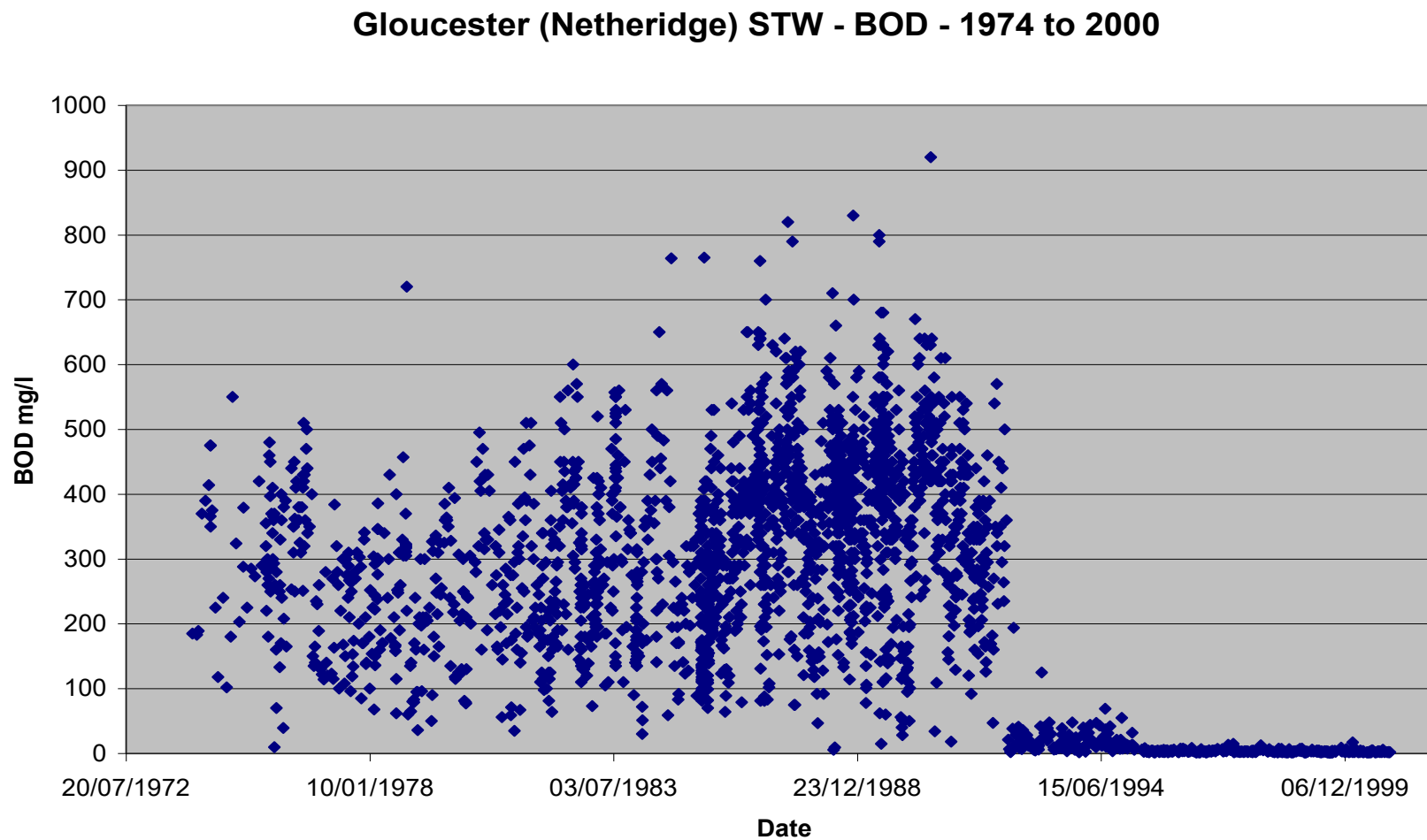


Figure 4 – Gloucester (Netheridge) STW – BOD – 2002 to 2019

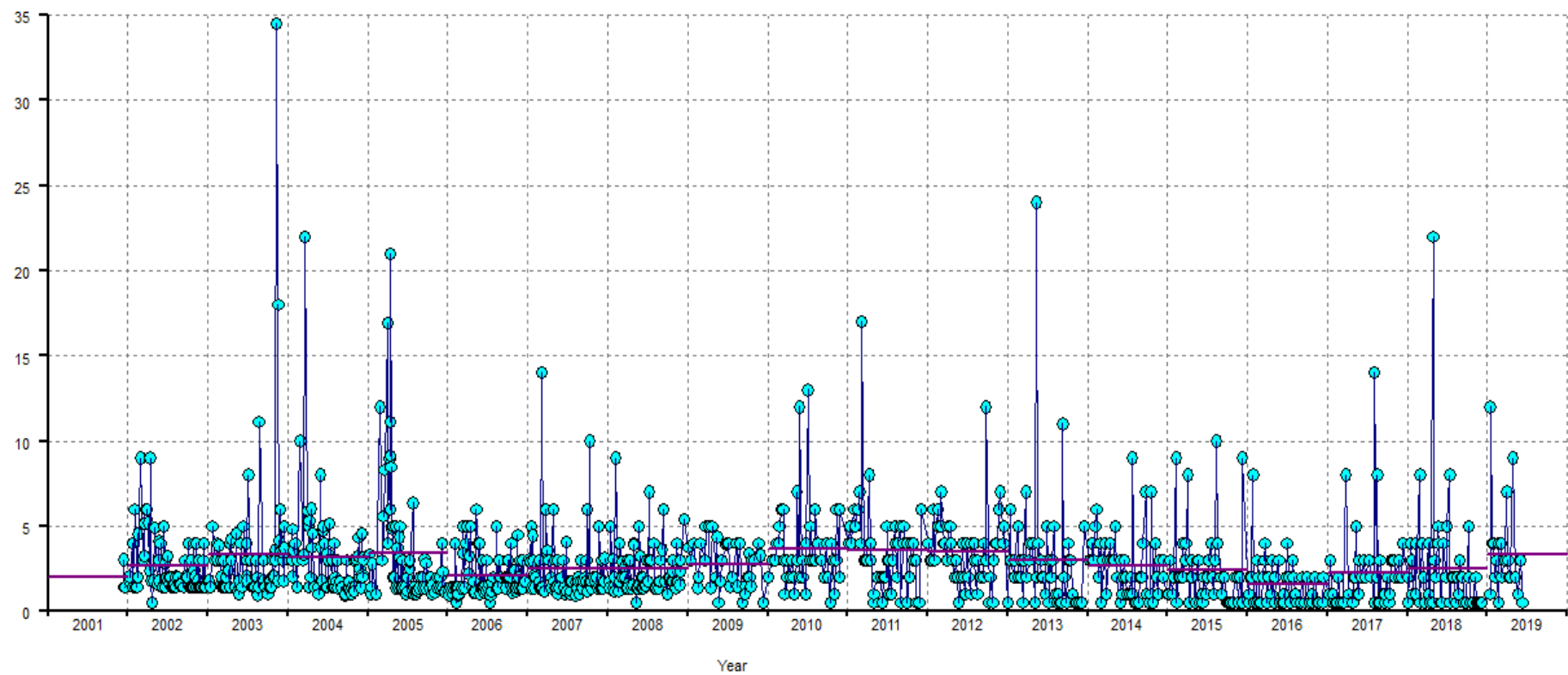


Figure 5 – Gloucester (Netheridge) STW – COD – 1974 to 2000

Gloucester (Netheridge) STW - COD - 1974 to 2000

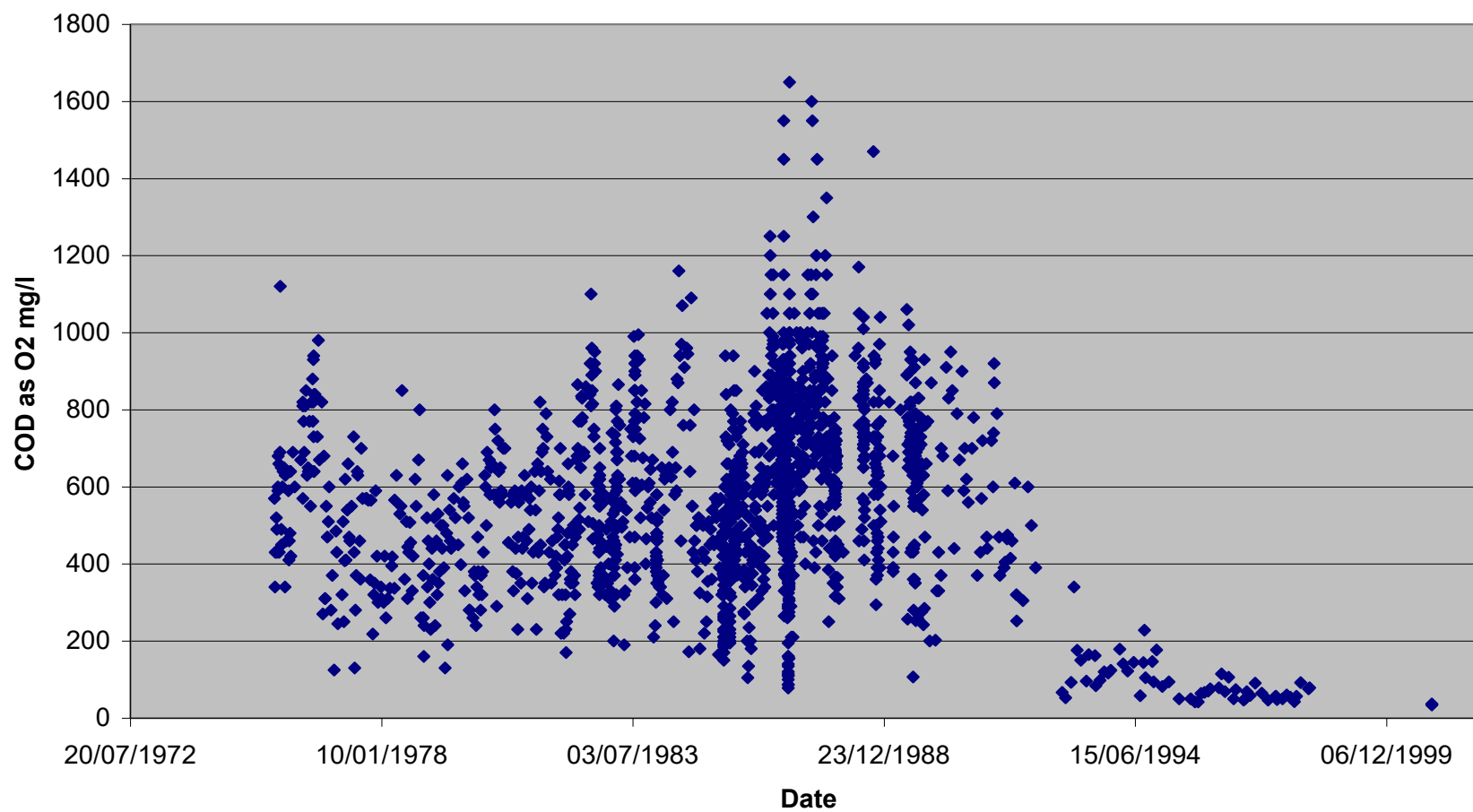
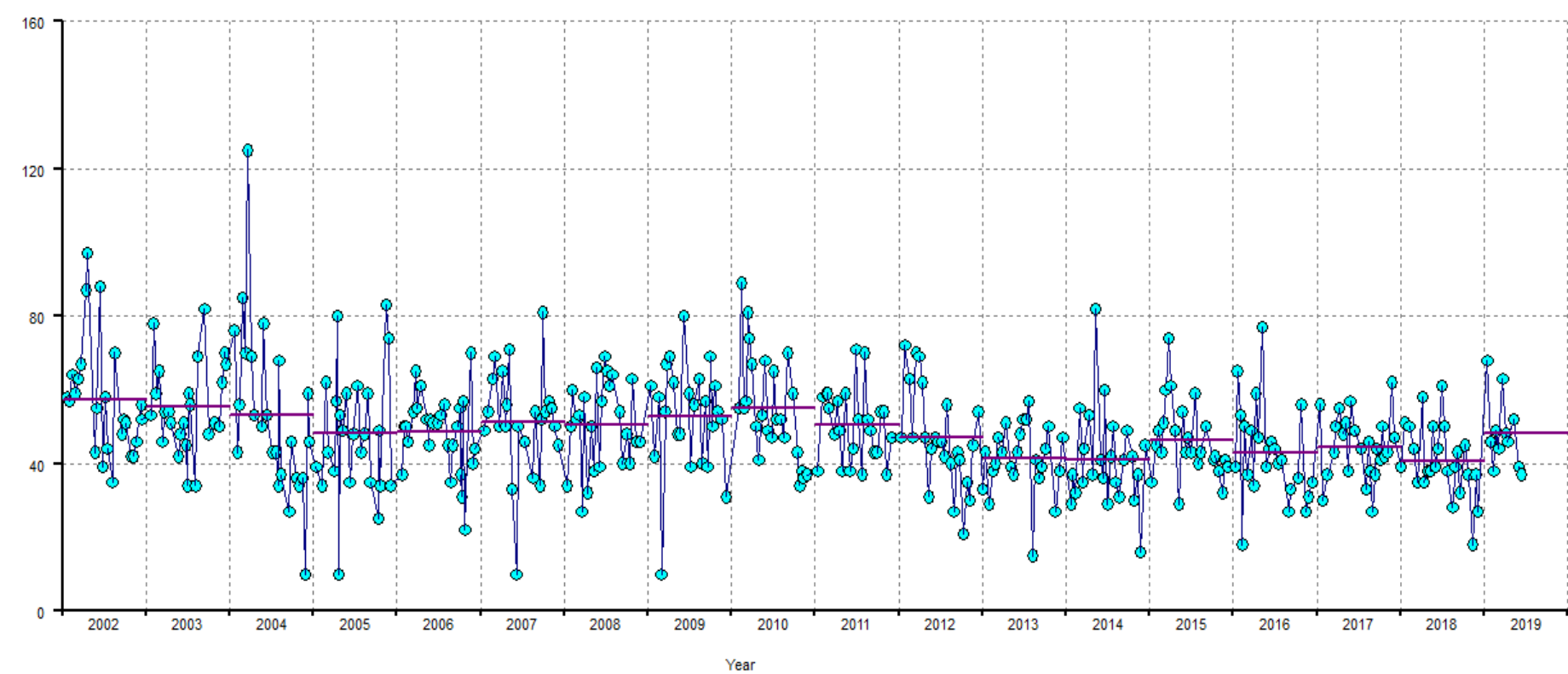


Figure 6 – Gloucester (Netheridge) STW – COD – 2002 to 2019



Appendix M

Water Quality Assessment of the Upper Severn Estuary (RoC)

Water Quality Assessment of the Upper Severn Estuary Related to Performance at Gloucester STW

Environment Agency

The Upper Severn Estuary has historically suffered with significant sags in the dissolved oxygen concentrations. These sags have been most noticeable in the stretch of water downstream of the discharge of treated sewage from Gloucester Netheridge Sewage Treatment Works (STW) although, there are several explanations as to why they occur.

The historic discharge from Netheridge STW, especially large quantities of untreated sewage during storm events, has offered one explanation although an alternative train of thought suggests that the impact of salinity and suspended solids may be responsible. The latter theory suggests that the area of maximum turbidity (and greatest suspended solid concentrations), often related to the fresh-salt water interface, can be associated with the location of the oxygen sag. Consequently, the degree of the oxygen sag is directly linked to the amount of freshwater entering the estuary with a greater flow restricting the area of maximum turbidity to the wider parts of the channel where the biochemical oxygen demand (BOD) is less concentrated.

Netheridge is the main sewage treatment facility serving the population of Gloucester (a current population equivalent of nearly 195,000) and has a consented flow of 42.8 Ml/d. The treatment on site was improved during the AMP2 investment period with an improved quality and tightened discharge consent coming into effect on 1st January 1996. Further consent revisions have since followed. See Appendix Q for further details.

Unfortunately, these major improvements show no major corresponding reduction in BOD concentration within the Severn Estuary immediately downstream of the discharge point. This is probably a consequence of the estuarial nature of the receiving watercourse and the naturally turbid conditions associated with such watercourses. What is evident, however, is an increase in the lower range of dissolved oxygen concentrations (Circled in Figures 1, 2 and 3):

00015203 R SEVERN (TIDAL) LOWER REA (136 Sa Restricted (O Diss %sat %))

Number of Observations (LT)	64
Date Range	17-01-1995 to 06-01-2000
Minimum	49.00
Mean	89.63
Maximum	127.00
Standard deviation	14.539
SDD	11.464
Non-Parametric estimate (Weibull) of:	
5 Percentile	56.25
10 Percentile	64.50
20 Percentile	81.00
Median	92.00
80 Percentile	100.00
90 Percentile	103.00
95 Percentile	111.25

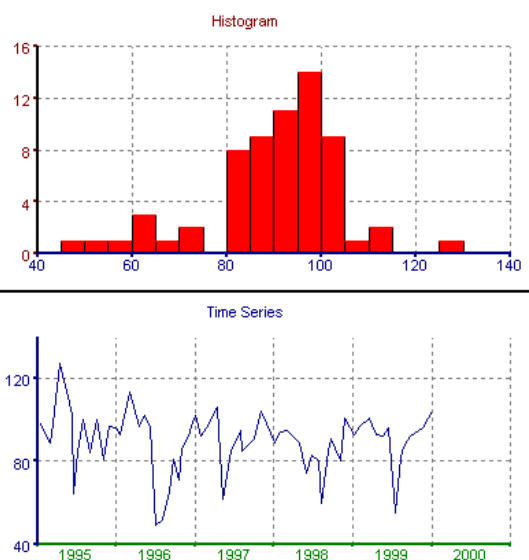


Figure 1 – Dissolved Oxygen distribution data for Severn Estuary at Lower Rea, downstream Gloucester Netheridge STW – January 1995 to January 2000

00015203 R SEVERN (TIDAL) LOWER REA (136 Sa
Restricted (O Diss %sat %)

Number of Observations (LT)	67
Date Range	08-02-2000 to 11-08-2006
Minimum	55.00
Mean	89.40
Maximum	138.00
Standard deviation	14.639
SDD	12.104
Non-Parametric estimate (Weibull) of:	
5 Percentile	64.40
10 Percentile	69.80
20 Percentile	78.60
Median	91.00
80 Percentile	99.40
90 Percentile	105.00
95 Percentile	113.40

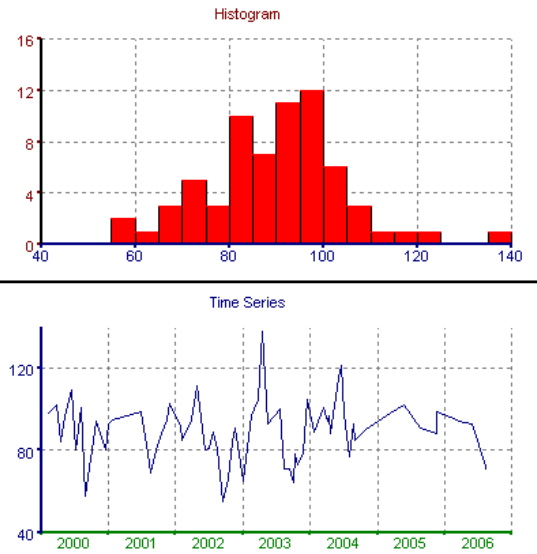


Figure 2 – Dissolved Oxygen distribution data for Severn Estuary at Lower Rea, downstream Gloucester Netheridge STW – January 2000 to August 2006

00015405; LOWER REA HEMPSTEAD - SETF9
Determinand Summary - 9901 O Diss %sat %

Number of Observations (LT)	18
Date Range	26-06-2008 to 16-10-2018
Minimum	80.60
Mean	105.59
Maximum	172.60
Standard deviation	22.396
SDD	21.743
Non-Parametric estimate (Weibull) of:	
5 Percentile	86.27
10 Percentile	87.80
20 Percentile	101.10
Median	118.24
80 Percentile	146.86
90 Percentile	
95 Percentile	

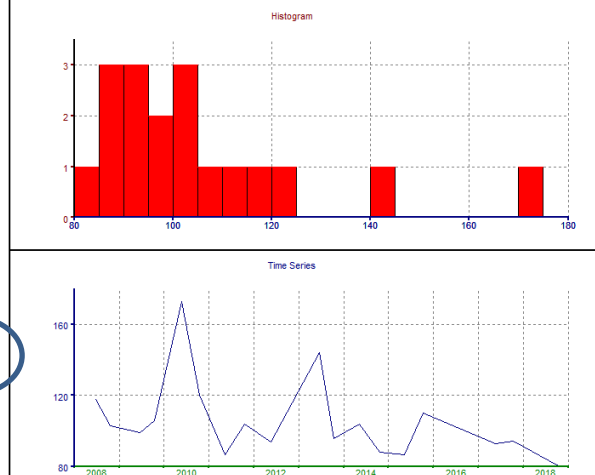


Figure 3 – Dissolved Oxygen distribution data for Severn Estuary at Lower Rea, downstream Gloucester Netheridge STW – January 2008 to August 2019

In practice, this improvement could be linked to the reduced BOD and solids concentrations being discharged from the sewage treatment works during both normal and storm operation although, it must also be considered that a range of possible explanations exist.

The estuarial effect is further demonstrated by the fact that the collected data shows little deterioration in water quality across the point of discharge from Gloucester Netheridge STW, both before and after the AMP investment. All of the sanitary determinands demonstrate similar concentrations at both Upper and Lower Rea on the Severn Estuary, a situation which would be regarded as unlikely should the discharge be made to an inland watercourse with predominantly downstream flow as opposed to the tidal flow experienced at Gloucester.

It should also be noted that as data is only collected on a monthly basis at best. Such a sampling frequency is prohibitive when it comes to assessing the impact of improvements in the treatment of sewage effluent from Netheridge STW. Not only will it fail to assess the changing conditions of the tidal system but it is also inadequate for assessing the impact of storm sewage discharges from the treatment works which occur on an intermittent, weather dependent basis and are more often than not, missed by the current sampling frequency.

Appendix N

Recommended Monitoring Programme

Introduction

The jointly produced 'Drought permits and drought orders' guidance identifies the need for a robust monitoring programme to support any drought order application. The monitoring programme ensures evidence will be collected to identify and enable the mitigation of drought impacts.

The recommended monitoring programme only contains sites specific to assessing the River Severn Drought Order, however the EA (and other bodies/organisations) have an extensive monitoring network, in addition to the sites listed, and all available data will be used during a real event. For example, WFD monitoring data and reports, Severn Estuary monitoring (6 yearly Habitat's Directive programme) programme etc.

Data monitoring limitations

Due to the significant size of the River Severn catchment, and area of potential impact from the River Severn Drought Order, it is challenging to design a specific monitoring programme that is not too large to be feasible, or too sparse to be useful. The proposed monitoring programme represents a range of monitoring at the key assessment locations (conditions will vary locally between these targeted sites), however the programme application may need to be flexible, and discussions will need to be held between organisations.

Due to the large area and tidal variations within the Severn Estuary, monitoring baseline conditions in the Estuary is very challenging. For example, surveying fish at specific locations only provides a snapshot picture of what species were caught on that day according to the environmental conditions at that time. Various fish species may avoid the monitoring nets or simply be located elsewhere within the Severn Estuary and therefore be excluded.

Various Severn Estuary monitoring options and techniques were considered for this project. For transitional fish no monitoring at present is taking place due to relatively limited usefulness of the data. Macrophyte surveys were considered inappropriate for the Estuary due to the absence of significant vegetation. Diatom surveys were also considered for the Upper Estuary (already conducted in the middle and lower section), however due to the dynamic nature of the system along this section the results are unlikely to be conclusive or helpful in understanding the ecosystems response to low flows/drought. Macroinvertebrate surveys were also considered unfeasible for the lower Severn, some deep-water surveys have been undertaken at Haw Bridge, but the size and dynamic nature of the upper Severn Estuary make it unlikely results would be conclusive for this project.

RSDO Monitoring programme

All **‘baseline’** monitoring specific to the River Severn Drought Order is required to collect a benchmark of the aquatic environment and ecology in the River Severn over a normal range of flow conditions. This data can then be used alongside low flow/drought evidence to determine the impact of natural drought, any additional impacts from operating the River Severn Drought Order, and help assess what the minimum flow requirements are for the River Severn. The baseline monitoring will be included in the Environment Agency and Natural Resources Wales annual work programme, highlighting the River Severn Drought Order as a key driver⁵.

The **‘low flow’** specific monitoring is required to collect data for naturally developing drought conditions prior to a River Severn Drought Order application, building a representative benchmark for comparison. The data will inform decisions on when an application may be required and provide evidence to help separate natural drought impacts from those caused solely by the River Severn Drought Order. The low flow specific monitoring will be included within the Midlands Drought Plan, linked to appropriate triggers.

The **‘Severn Drought Order’** monitoring will be triggered by the activation of the River Severn Drought Order conditions. The data collected will allow the state of the environment to be regularly monitored and compared against both the baseline and low flow data, to help assess the true impacts from the drought orders operation. Monitoring can also be used to help target any mitigation options available at the time. The Severn Drought Order specific monitoring will be identified in the Midlands Drought Plan.

‘Post low flow/natural drought and/or Severn Drought Order’ specific monitoring is required to monitor the recovery time following both a natural low flow/drought event, and the use of the River Severn Drought Order. Monitoring after a natural event will provide the baseline evidence crucial for then comparing data from a Severn Drought Order operational event against, distinguishing between what would have occurred even if the drought order were not operated and helping to isolate the drought order specific impacts which then need managing appropriately. Both sets of monitoring will also provide evidence on the long-term implications of drought events. The Post low flow/natural drought and/or Severn Drought Order specific monitoring will also be identified in the Midlands Drought Plan.

All the proposed River Severn Drought Order monitoring sites and requirements are listed in Table 1, starting in the upper most catchment and working downstream towards the Severn Estuary. It is recommended that gap analysis and collaborative work be carried out with organisations, and the Environmental Report be updated periodically to ensure it is kept up to date. The monitoring programme should retain a degree of flexibility to cope with the dynamic nature of droughts, additional routine or one-off monitoring could be warranted according to each event.

⁵ Drivers describe the justification for monitoring and support the financial investment.

Table1: River Severn Drought Order Monitoring Sites

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
1	Bryntail (2109)	SN 9134 8679	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
2	Clywedog at Park (BIO SP PT) (49874)	SN 94505 85470						
			Ecology - Invertebrate	3/year – Spring, Summer & early Autumn	Baseline	Monthly	Baseline	
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
3	Afon Clywedog,	SN9447285487	Electric fishing	1 every 3 years	Baseline frequency	Baseline frequency	Year after the event	Should not increase during low flows to

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
	Below Dieldre Brook							avoid further stress to fish.
4	River Severn at Llanidloes Felindre bridge (00074380)	SN 94397 83902	Water Quality	Quarterly	Baseline frequency	Monthly	Monthly	Monitor for Ammonia, Phosphate, Total Oxidised Nitrogen, Dissolved Oxygen, Alkalinity, pH, Temperature
5	Dolwen (2118)	SN 9897 8520	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
6	Severn at Dolwen (52148)	SN 99700 85200	Ecology - Invertebrate	3/year – Spring, Summer & early Autumn	Baseline	Monthly	Baseline	
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
								frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
11	River Severn, Abermule	SO1580095000	Electric fishing	1 every 3 years	Baseline frequency	Baseline frequency	Year after the event	Should not increase during low flows to avoid further stress to fish.
12	River Severn at Caerhowel bridge (00064480)	SO 19685 98132	Water Quality	Quarterly	Baseline frequency	Monthly	Monthly	Monitor for Ammonia, Phosphate, Total Oxidised Nitrogen, Dissolved Oxygen, Alkalinity, pH, Temperature
13	Vyrnwy Weir (2003)	SJ 0188 1904	Hydrology -Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
14	Vyrynwy at Dolanog (50350)	SJ 06837 12739	Ecology - Invertebrate	3/year – Spring, Summer & early Autumn	Baseline	Monthly	Baseline	
			Ecology - macrophyte	1/year – summer	Baseline frequency	Baseline frequency		Awaiting further guidance from

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
							Baseline frequency	WRTS that may alter this part of the programme
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
15	Afon Vyrnwy, New Bridge	SJ 14200 11500	Electric fishing	1 every 3 years	Baseline frequency	Baseline frequency	Year after the event	Should not increase during low flows to avoid further stress to fish.
16	Llanyblodwel (50766) (R. Tanat)	SJ 24200 22900	Ecology - Invertebrate	2/year - Spring & early Autumn	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - diatom	2/year - Spring & Autumn	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
17	Llanymynech (2028)	SJ 2529 1963	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
18	River Severn at Maginnis Bridge (00061340)	SJ 25890 11510	Water Quality	Quarterly	Baseline frequency	Monthly	Monthly	Monitor for Ammonia, Phosphate, Total Oxidised Nitrogen, Dissolved Oxygen, Alkalinity, pH, Temperature
19	Montford (2005)	SJ 4119 1446	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
20	River Severn at Montford Bridge (00056710)	SJ 43192 15316	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for , Ammonia, Phosphate, Nitrate & dissolved Oxygen.
21	Lower Isle of Bicton (173804)	SJ4619816554	Ecology - Invertebrate	2/year - Spring & early Autumn	Baseline frequency	Baseline frequency	Baseline frequency	
22	as above	SJ4619816554	Ecology – macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Ecology - diatom	2/year - Spring & Autumn	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
23	River Severn Shelton intake (00055140)	SJ 46850 13605	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for , Ammonia, Phosphate, Nitrate & dissolved Oxygen.
24	Shrewsbury Showground	SJ4876913212	Fry Sampling, netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme
25	Pengwern Boat Club	SJ4844012390	Fry sampling netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme
26	Monkmoor	SJ5271413811	Fry sampling netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme
27	River Severn at Atcham (00052182)	SJ 540550 9299	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for , Ammonia, Phosphate, Nitrate &

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
								dissolved Oxygen.
28	Cressage (ecology 52526, WQ 00049650)	SJ 59380 04550	Ecology – Invertebrate (52526)	2/year - Spring & early Autumn	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - diatom	2/year - Spring & Autumn	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Fry Sampling, netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme
			Water Quality (00049650)	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
29	Buildwas (2134)	SJ 6455 0440	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
30	Buildwas (158364)	SJ 64620 04425	Ecology - Invertebrate	2/year - Spring &	Baseline frequency	Baseline frequency	Baseline frequency	

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
				early Autumn				
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - diatom	2/year - Spring & Autumn	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
31	Coalport (52795)	SJ 702 021	Ecology - Invertebrate	2/year - Spring & early Autumn	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - diatom	2/year - Spring & Autumn	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
32	Bedlam Furnaces (167605)	SJ6780003291	Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
33	River Severn at Coalport (00045702)	SJ 701900 2060	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for , Ammonia, Phosphate, Nitrate & dissolved Oxygen.
34	Hifnal	SO7075398912	Fry sampling netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme
35	Bridgnorth us A458	SO7181992421	Fry sampling, netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme
36	River Severn at Apley Forge (00044720)	SO 70686 98298	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate & dissolved Oxygen.
37	D/S Dowles Brook (52393)	SO7800676374	Ecology - Invertebrate	2/year - Spring & early Autumn	Baseline frequency	Baseline frequency	Baseline frequency	May need to investigate a new site but would still sample in parallel with d/s Dowles Brook to ensure sites are comparable

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - diatom	2/year - Spring & Autumn	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
38	Bewdley (2001)	SO 7823 7616	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
39	River Severn at Bewdley (00038360)	SO 78707 75407	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate & dissolved Oxygen.
40	Holt Fleet	SO8269363338	Fry sampling, netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme
41								

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
	River Severn at Holt Fleet meadows, Holt Fleet (00034302)	SO 82454 63350	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate & dissolved Oxygen.
42	River Severn – D/S Bevere weir (mid) (00032360)	SO 83566 59116	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate & dissolved Oxygen.
43	River Severn - Worcester bridge (00030850)	SO 84663 54769	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate & dissolved Oxygen.
44	River Severn - rear of oil depot bath rd Worcester (00030090)	SO 85101 52319	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate & dissolved Oxygen.
45	Tenbury (48210) (R. Teme)	SO 59942 68511	Ecology - Invertebrate	2/year - Spring & early Autumn	Baseline frequency	Baseline frequency	Baseline frequency	

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Baseline frequency	Baseline frequency	
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
46	River Teme at Powick (13598380) (R. Teme)	SO 836 525	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate & dissolved Oxygen.
47	River Severn (upper) Kempsey (mid) (00029500)	SO 84685 49500	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate & dissolved Oxygen.
48	Upper Ham 172484	SO8617740354	Ecology - Invertebrate	2/year - Spring & early Autumn	Baseline frequency	Baseline frequency	Baseline frequency	Airlift methodology used
			Ecology – diatom	2/year - Spring & Autumn	Baseline frequency	Baseline frequency	Baseline frequency	

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Ecology – RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Fry Sampling, netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme
49	OPPOSITE UPTON UPON SEVERN MARINA (172485)	SO8561640621	Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	
50	River Severn - Upton on Severn (00027540)	SO 85178 40790	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for WFD_R1, chlorophyll, turbidity and SS
51	Saxons Lode (2032)	SO 8634 3904	Hydrology -Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
52	River Severn (upper) Tewkesbury (00026230)	SO 88870 33719	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate & dissolved Oxygen.

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
53	River Severn Upper Lode	SO8808232766	Water quality - sonde	Continuous		Deployed just before application of drought order		Monitoring dissolved oxygen, ammonium, pH, water temperature, turbidity, conductivity and chlorophyll
54	River Avon at Tewkesbury (04767100) (R. Avon)	SO 893 332	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate & dissolved Oxygen.
55	Deerhurst (2606)	SO 8679 3010	Hydrology -Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
56	Hawbridge (51327)	SO 845 277	Ecology - Invertebrate	2/year - Spring & early Autumn	Baseline frequency	Baseline frequency	Baseline frequency	Airlift methodology used
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Baseline frequency	Baseline frequency	Will need to use artificial substrate for diatom sampling

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
57	River Severn (lower) Ashleworth (00024062)	SO 81930 25040	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate & dissolved Oxygen.
58	West channel, River Severn	SO816196	Hydrology -Flow & stage	3/year	See Drought Plan triggers	Weekly	Revert to baseline	Spot Flow Gauging (no flow gauge present).
59	East channel, River Severn	SO 825 191	Hydrology -Flow & stage	3/year	See Drought Plan triggers	Weekly	Revert to baseline	Spot Flow Gauging (no flow gauge present).
60	D/S G&S abstraction	SO 824 183	Hydrology -Flow & stage	3/year	See Drought Plan triggers	Weekly	Revert to baseline	Spot Flow Gauging (no flow gauge present).
61	River Severn (lower) Severn rd	SO 82283 18228	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for Ammonia, Phosphate, Nitrate &

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
	foot bridge (00021202)							dissolved Oxygen.
62	Epney D/S	SO 760 110	Hydrology -Flow & stage	3/year	See Drought Plan triggers	Weekly	Revert to baseline	Spot Flow Gauging (no flow gauge present).
63	D/S Epney	SO 760 110	Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis.
Severn Estuary Monitoring*1								
64	Severn (North bank)	SO 72051 08065	Fucoid Extent	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Continuous salinity tag deployment
65	Gatcombe	SO 68260 05210	Water column	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Phytoplankton, Chlorophyll, Salinity, Temperature, DO, Secchi, Light.
66	Bollow Point (Bullo Pill)	SO 75130 13870	Water column	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Phytoplankton, Chlorophyll, Salinity, Temperature,

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
								DO, Secchi, Light

**1 Reference will be made to useful baseline data collected for other purposes, e.g. the 6 yearly European site reporting programme, carried out by NRW, NE EA and others, WFD baseline data and reporting etc.*

It is suggested that the above recommendations be discussed and updated as required in consultation with STWL, SSW, The Canal & River Trust, Natural England and Natural Resources Wales.

Appendix O

Additional Fisheries Information: Severn Estuary HRA

Additional Fisheries information: Severn Estuary HRA

Environment Agency

Introduction

The Severn Estuary is one of Europe's most important estuarine nursery areas for fish, even with the issues caused by its unique character. The level of primary production in the Severn Estuary is severely impacted by poor light penetration due to high sediment loads. These turbid waters limit the production of both phytoplankton and attached algae (potential food source). Added to this the high bed shear stresses and instability of the estuary bed has a major impact on the sub tidal invertebrates (another potential food source). However, in areas where the substrate is more stable populations of invertebrates flourish ensuring an important food source for the fish of the estuary.

The Severn Estuary is important for its migratory fish, which assisted in its designation as a SAC. The Annex II species found within the estuary include twaite shad (*Alosa fallax*), river lamprey (*Lampetra fluviatilis*) and sea lamprey (*Petromyzon marinus*). The Severn also has the following notable migratory species: Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta morpha trutta*) and European eel (*Anguilla anguilla*).

Also the large fish assemblage within the estuary is one of the important features in the designation of the estuary as a RAMSAR site.

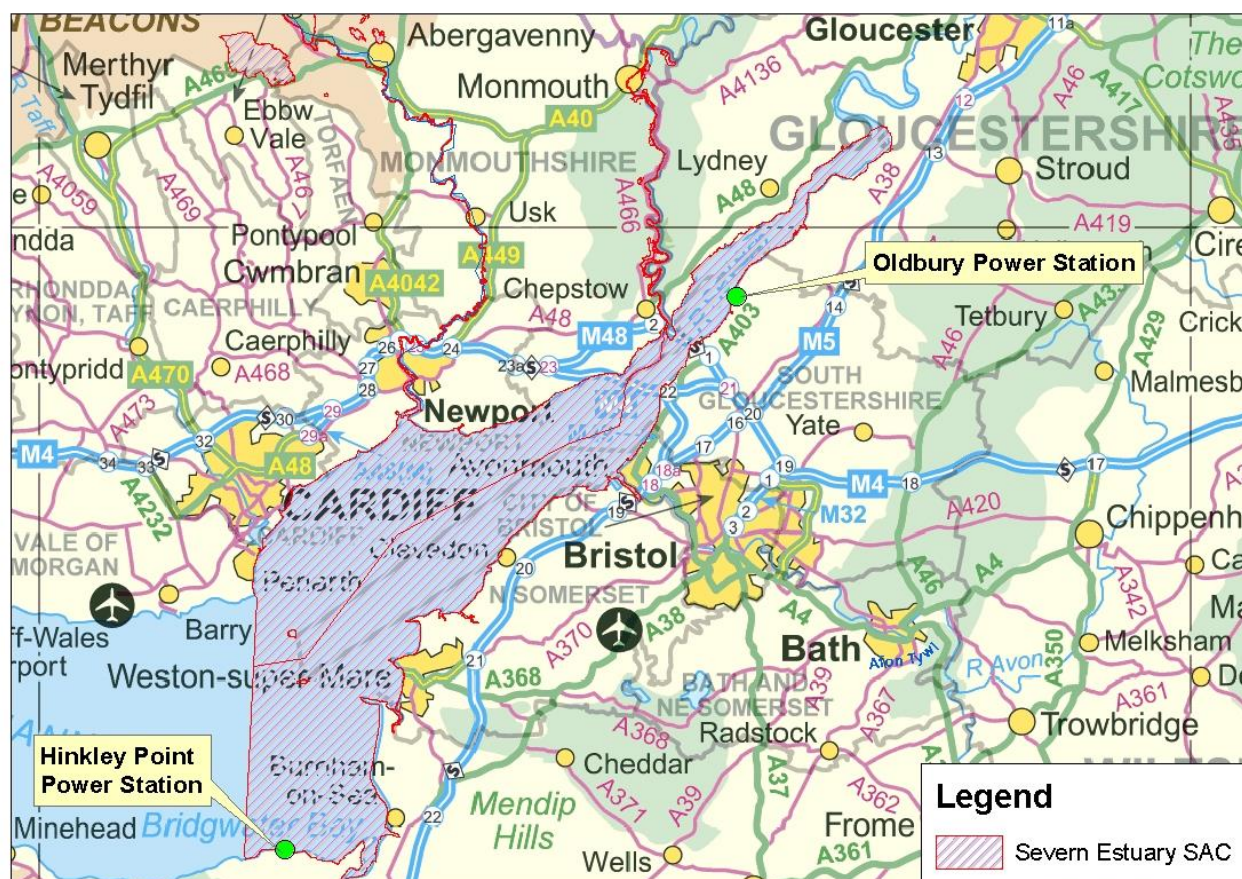


Figure 1. Map of Severn Estuary SAC with power station sampling points

Available Data

Due to the enormous size of the Severn Estuary monitoring of the fish population is extremely difficult. The best fish data collected to date has been from the power station intakes at Oldbury (ST 60633 94448) and Hinkley Point (ST 21155 46107) Power Stations. Individuals become entrained on the cooling water-intake screens used at power stations these are washed off into metal cages and can then be counted. Obviously this form of monitoring has an element of bias as only fish swimming near location of intakes are entrained and pelagic species have a better chance of avoiding the intake. Also juvenile fish are generally slower and weaker swimmers so more likely to be entrained. However, this long term data set (especially at Hinkley Point) is invaluable as an estimate of the fish community of the Severn Estuary.

Another source of information is from the Severn netsmen. These fishermen use traditional methods almost unique to the River Severn to catch Atlantic salmon. The Environment Agency also has a Transitional fish sampling programme for the Severn Estuary mainly using fyke and seine netting.

Table 1. Environment Agency tidal lower Severn transitional monitoring sites

Site Name	Method	NGR	
Arlingham Passage	Fyke Net	SO6937011428	
Lower Rea Hempstead	Fyke Net	SO8033315876	
Water End	Fyke Net	SO7560814407	
Cott Point	Fyke Net	SO8033018051	

There has been limited success in radio tracking fish within the Severn Estuary due to the difficulty in catching large enough numbers. However tracking studies on Atlantic salmon and shad are giving us a better understanding of these species movements within the estuary.

There is unfortunately no fish counter on the lower River Severn either to assess movement of migratory fish, although there is now a video recording system at Diglis weir.

More research papers and Government documents have been produced recently due to the interest in harnessing the tidal power of the estuary for electricity generation. This has increased understanding of this system and provided access to more information, as has the public inquiry regarding Hinkley Point C.

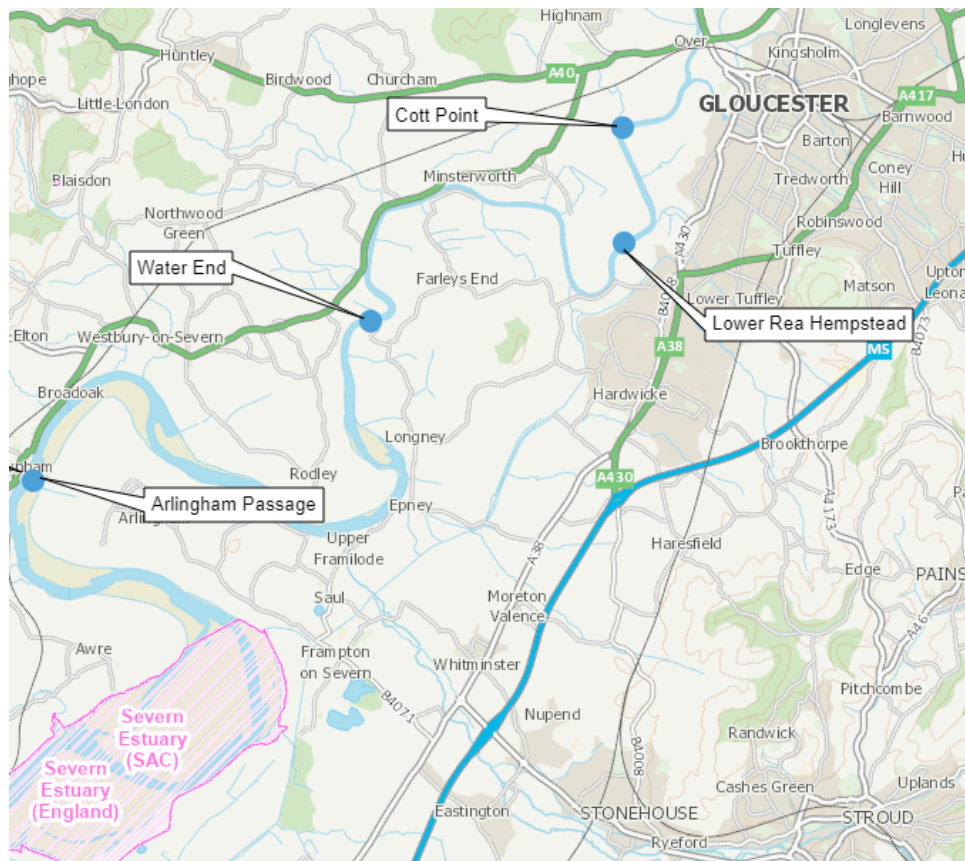


Figure 2. Map showing locations of transitional monitoring sites within the Lower Tidal Severn (EA)

Fish Population Present

A list of fish species recorded in Bridgewater Bay are displayed in Table 2. This shows the wide diversity of fish present in the estuary with their corresponding functional group:

Marine Migrant – species where adults live and breed in marine environments, with juveniles frequently found in estuaries in large numbers. Juveniles can be opportunistic (i.e. can find suitable conditions within or outside estuaries), or dependant (i.e. require estuarine types of habitat).

Marine Straggler – generally marine species abundant in the marine environment but occurring infrequently in the Severn Estuary

Estuarine Species – species that typically occur and breed in estuaries

Freshwater Straggler – species that typically occur and breed in freshwater but are found in low numbers in the Severn Estuary

Anadromous – species that migrate from the sea into freshwater to breed

Catadromous – species migrating from freshwater into the sea to breed

The majority of the fish species in this list are highly mobile and will move up and down the estuary with changing tides and seasons. Results from Oldbury (Table 3) show that the main fish caught at this point of the estuary over a long period tend to be sprat, whiting, sand goby and bass.

Variations overtime have been noted for certain species by Hendersen and Bird (2010) with some changes related to recent warming (water temperature) and the North Atlantic Oscillation. Species such as the European eel have seen a national decline caused possibly by excessive fishing for elvers, freshwater habitat degradation, barriers to migration and the introduction of parasite *Anguillicola crassus* from Asia (Hendersen, Seaby and Somes, 2007). What is interesting is that at Oldbury the European eel was still ranked 9th in the 1972 to 1977 and the 2006 to 2011 catches. This could suggest that numbers in this part of the estuary have not seen as marked a decline. However, reports by Hendersen, et al. (2007) have highlighted major concerns with falling eel numbers at Hinkley Point.

Table 2. List of species recorded within from Hinkley Point and functional group
(taken from Severn Tidal Barrage Scoping Topic Paper, 2008)

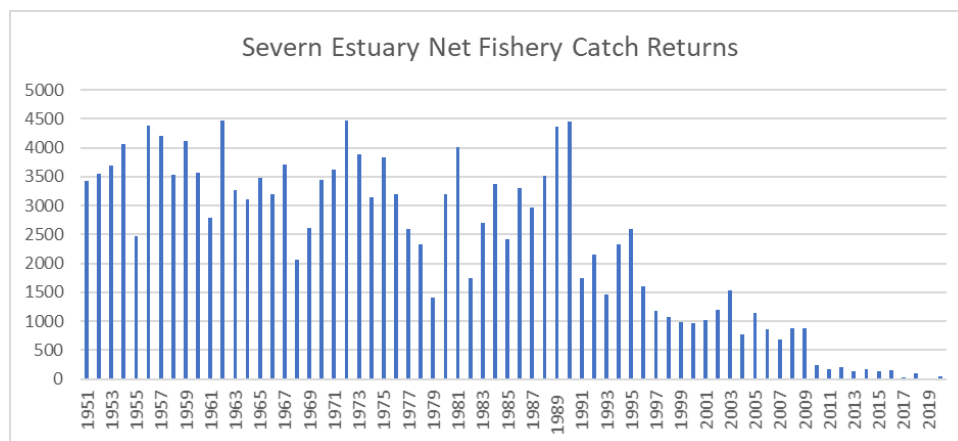
Species	Functional Group	Species	Functional Group
Anchovy <i>Engraulis encrasicolus</i>	MARINE STRAGGLER	Norway pout <i>Trisopterus esmarkii</i>	MARINE STRAGGLER
Angler fish <i>Lophius piscatorius</i>	MARINE STRAGGLER	Painted goby <i>Pomatoschistus pictus</i>	MARINE STRAGGLER
Ballan wrasse <i>Labrus bergylta</i>	MARINE STRAGGLER	Pearlsides <i>Maurolicus muelleri</i>	MARINE STRAGGLER
Bass <i>Dicentrarchus labrax</i>	MARINE MIGRANTS	Perch <i>Perca fluviatilis</i>	FRESHWATER STRAGGLER
Black goby <i>Gobius niger</i>	ESTUARINE SPECIES	Pilchard <i>Sardina pilchardus</i>	MARINE STRAGGLER
Black sea bream <i>Spondyllosoma cantharus</i>	MARINE MIGRANTS	Piper <i>Trigla lyra</i>	MARINE STRAGGLER
Blonde ray <i>Raja brachyura</i>	MARINE STRAGGLER	Plaice <i>Pleuronectes platessa</i>	MARINE MIGRANTS
Blue whiting <i>Micromesistius poutassou</i>	MARINE STRAGGLER	Pollack <i>Pollachius pollachius</i>	MARINE MIGRANTS
Brill <i>Scophthalmus rhombus</i>	MARINE STRAGGLER	Poor cod <i>Trisopterus minutus</i>	MARINE MIGRANTS
Cod <i>Gadus morhua</i>	MARINE MIGRANTS	Pout <i>Trisopterus luscus</i>	MARINE MIGRANTS
Common goby <i>Pomatoschistus microps</i>	ESTUARINE SPECIES	Raitt's sandeel <i>Ammodytes marinus</i>	MARINE STRAGGLER
Common sand eel <i>Ammodytes tobianus</i>	MARINE STRAGGLER	Red mullet <i>Mullus surmuletus</i>	MARINE STRAGGLER
Common sea snail <i>Liparis liparis</i>	MARINE MIGRANTS	River lamprey <i>Lampetra fluviatilis</i>	ANADROMOUS
Conger eel <i>Conger conger</i>	MARINE STRAGGLER	Rock cook <i>Centrolabrus exoletus</i>	MARINE STRAGGLER
Corkwing wrasse <i>Crenilabrus melops</i>	MARINE STRAGGLER	Rock goby <i>Gobius paganellus</i>	MARINE STRAGGLER
Crystal goby <i>Crystallogobius linearis</i>	MARINE STRAGGLER	Saithe <i>Pollachius virens</i>	MARINE STRAGGLER
Cuckoo wrasse <i>Labrus mixtus</i>	MARINE STRAGGLER	Salmon <i>Salmo salar</i>	ANADROMOUS
Dab <i>Limanda limanda</i>	MARINE STRAGGLER	Sand goby <i>Pomatoschistus minutus</i>	ESTUARINE SPECIES
Dover sole <i>Solea solea</i>	MARINE MIGRANTS	Sand smelt <i>Atherina boyeri</i>	ESTUARINE SPECIES
Dragonet <i>Callionymus lyra</i>	MARINE STRAGGLER	Scaldfish <i>Arnoglossus laterna</i>	MARINE STRAGGLER
Eel <i>Anguilla anguilla</i>	CATADROMOUS	Sea lamprey <i>Petromyzon marinus</i>	ANADROMOUS

Species	Functional Group	Species	Functional Group
Fifteen-spined stickleback <i>Spinachia spinachia</i>	MARINE STRAGGLER	Small eyed ray Raja microocellata	MARINE STRAGGLER
Five-bearded rockling <i>Ciliata mustela</i>	MARINE MIGRANTS	Snake pipefish Entelurus aequoreus	MARINE STRAGGLER
Flounder <i>Platichthys flesus</i>	MARINE MIGRANTS	Solenette Buglossidium luteum	MARINE STRAGGLER
Garfish <i>Belone belone</i>	MARINE MIGRANTS	Sprat Sprattus sprattus	MARINE MIGRANTS
Golden mullet <i>Liza aurata</i>	MARINE MIGRANTS	Tadpolefish Raniceps raninus	MARINE STRAGGLER
Goldsinny wrasse <i>Ctenolabrus rupestris</i>	MARINE STRAGGLER	Thicklipped grey-mullet Chelon labrosus	MARINE MIGRANTS
Greater pipefish <i>Syngnathus acus</i>	MARINE STRAGGLER	Thinlipped grey-mullet Liza ramada	MARINE MIGRANTS
Greater sand eel <i>Hyperoplus lanceolatus</i>	MARINE MIGRANTS	Thornback (roker) ray Raja clavata	MARINE STRAGGLER
Grey gurnard <i>Eutrigla gurnardus</i>	MARINE STRAGGLER	Three-bearded rockling Gaidropsarus vulgaris	MARINE STRAGGLER
Hake <i>Merluccius merluccius</i>	MARINE STRAGGLER	Three-spined stickleback Gasterosteus aculeatus	ESTUARINE SPECIES
Herring <i>Clupea harengus</i>	MARINE MIGRANTS	Tompot blenny Parablennius gattorugine	MARINE STRAGGLER
Hooknose (Pogge) <i>Agonus cataphractus</i>	MARINE STRAGGLER	Topknot Zeugopterus punctatus	MARINE STRAGGLERS
Horse mackerel <i>Trachurus trachurus</i>	MARINE STRAGGLER	Transparent goby Aphia minuta	MARINE STRAGGLER
John dory <i>Zeus faber</i>	MARINE STRAGGLER	Trigger Fish Balistes capriscus	MARINE STRAGGLER
Lemon sole <i>Microstomus kitt</i>	MARINE STRAGGLER	Tub gurnard Chelidonichthys lucernus	MARINE MIGRANTS
Lesser spotted dogfish <i>Scyliorhinus caniculus</i>	MARINE STRAGGLER	Turbot Psetta maxima	MARINE STRAGGLER
Lesser weaver <i>Trachinus vipera</i>	MARINE STRAGGLER	Twaite shad Alosa fallax	ANADROMOUS
Ling <i>Molva molva</i>	MARINE STRAGGLER	Whiting Merlangius merlangus	MARINE MIGRANTS
Lumpsucker <i>Cyclopterus lumpus</i>	MARINE STRAGGLER	Witch Glyptocephalus cynoglossus	MARINE STRAGGLER
Nillson's pipefish <i>Syngnathus rostellatus</i>	MARINE MIGRANTS	Worm pipefish Nerophis lumbriciformis	ESTUARINE SPECIES
Northern rockling <i>Ciliata septentrionalis</i>	MARINE MIGRANTS		

Table 3. Top ten ranked fish caught at Oldbury Power Station over different time periods

	1972 to 1977	1998 to 1999	2006 to 2011
Sand Goby	1	2	4
Whiting	2	3	1
Flounder	3	8	6
Bass	4	4	2
Sea snail	5	5	7
Poor cod	6		
Thin lipped grey mullet	7	7	10
Twaite shad	8		
European eel	9		9
Herring	10	6	
Sprat		1	3
5 bearded rockling		9	
Cod			5
Snake pipefish			8
Dab		10	

Salmon catches within the estuary are displayed in Figure 3. A general reduction in numbers of salmon caught was noted through the 1990's, with a slight recovery in the early part of the 2000's. Fishing effort in the salmon net fishery has reduced nationally over the past two decades, partly as a result of the phasing out of fisheries that target mixed stock. Since 2012 the Environment Agency have been applying limits on the number of salmon that can be retained by the salmon net fisheries in the Severn Estuary. Due to the recent deterioration in stock status for the River Severn and River Wye a new net limitation order came in to being in 2021 which prohibits all putcher and draft net fisheries in the estuary. The lave nets are to be allowed to fish for salmon and sea trout, but when caught fish must be returned alive.

**Figure 3. Annual salmon catch return data for Severn Estuary Net Fishery**

The transitional fish monitoring programme for the Severn Estuary involves results from fyke netting. Sites used were in the Upper Estuary (Figure 2) as this is anticipated to be the area most likely to show any impact from low freshwater flows. The most upstream site (Cott Point) is dominated by freshwater species and within the section we call Tidal Lower Severn. The only estuarine or marine species caught at Cott

Point were flounder. The European eel dominates at all these sites with average length of 410mm. At Arlingham Passage there is a more diverse mix of freshwater and estuarine/marine fish species.

Table 4. Fish species occurring in transitional fish surveys by EA from 2017 to 2019 (with top 5 caught fish numbered)

3 spined stickleback	Herring
Atlantic salmon	Perch
Barbel	Plaice
Brill	Sand goby 2
Chub	Sea bass 3
Common goby	Silver bream
Crystal goby	Sprat
Dover sole	Thin lipped grey mullet 4
European eel 1	Twaite shad
Flounder 5	Whiting
Golden grey mullet	Zander

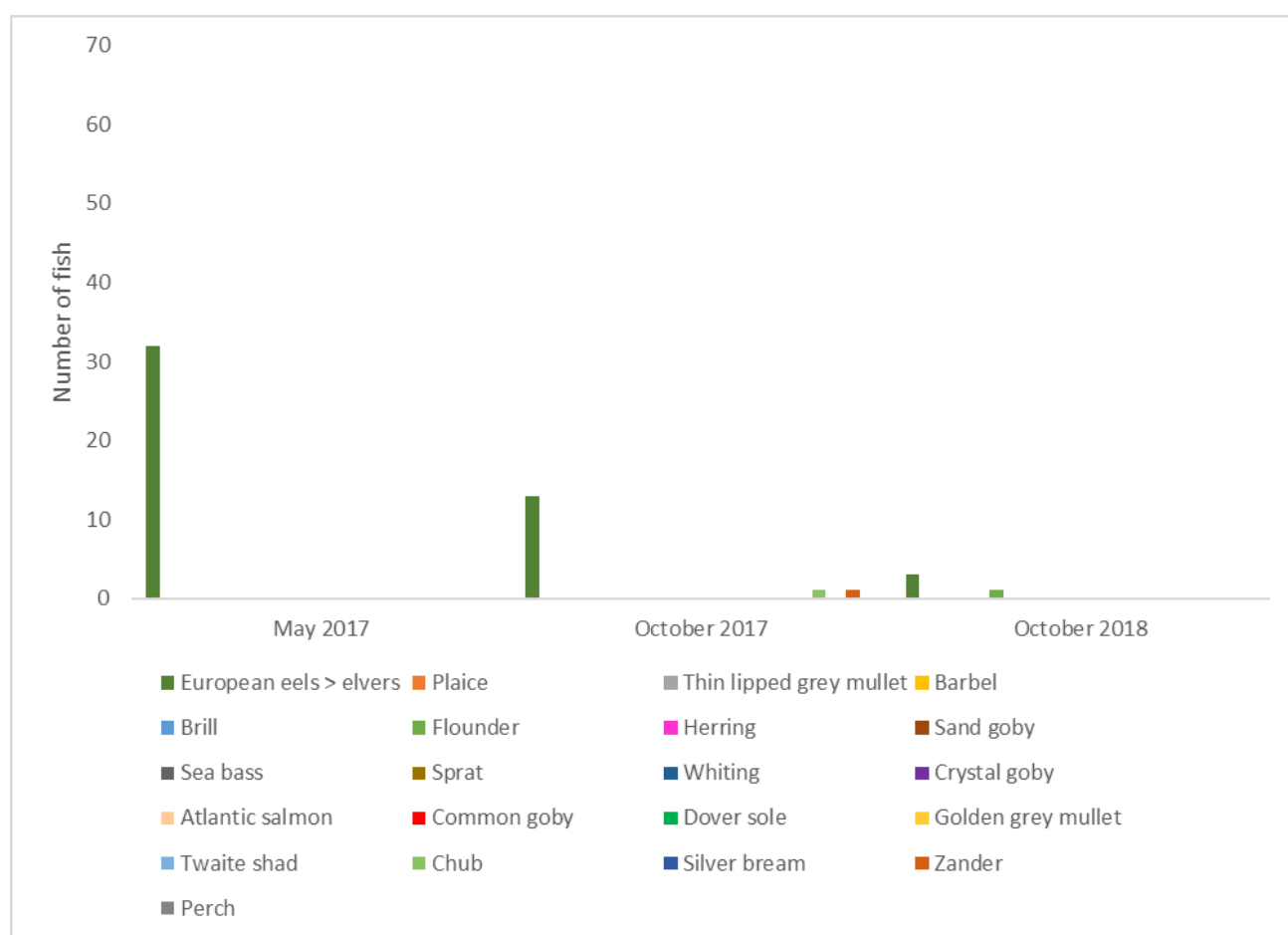


Figure 4. Number of fish caught at Cott Point using fyke nets 2017 to 2018

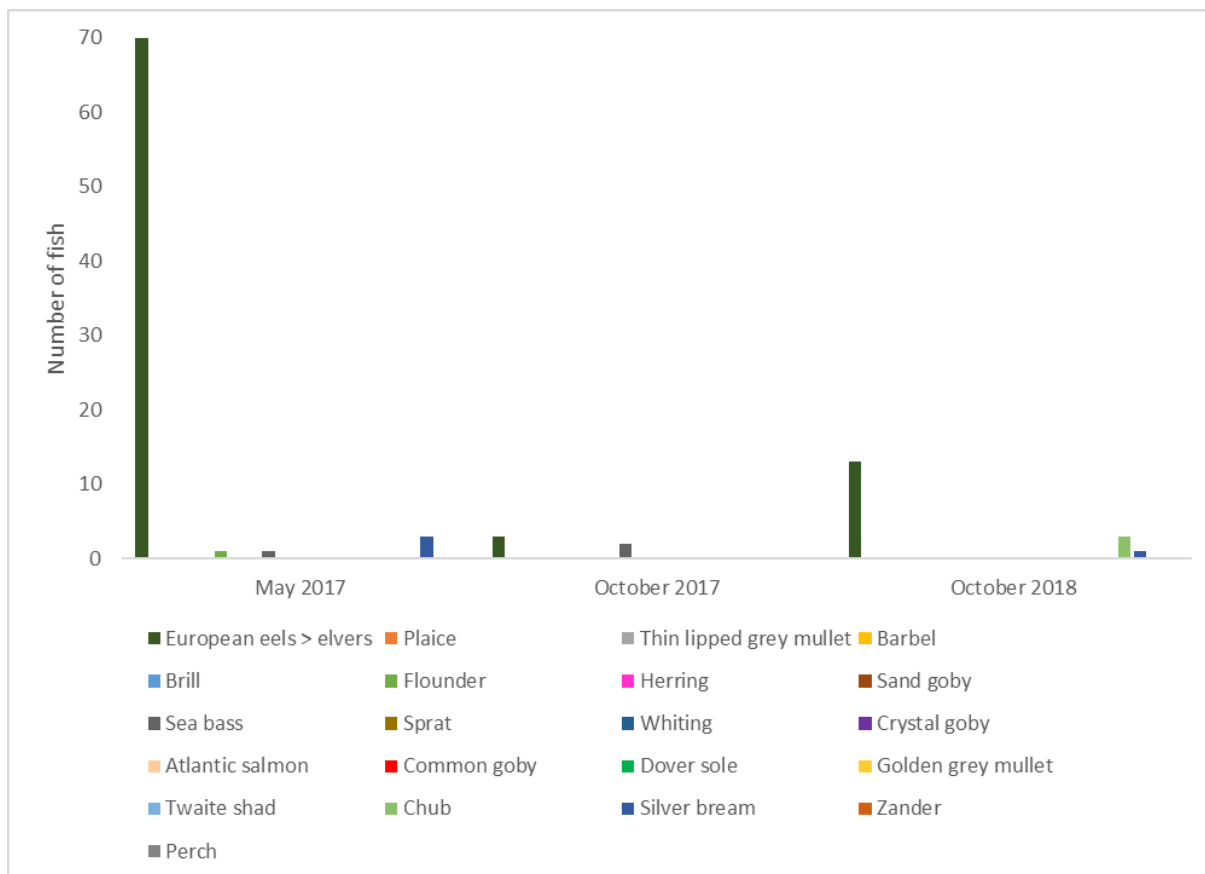


Figure 5. Number of fish caught at Lower Rea Hempstead using fyke nets 2017 to 2018

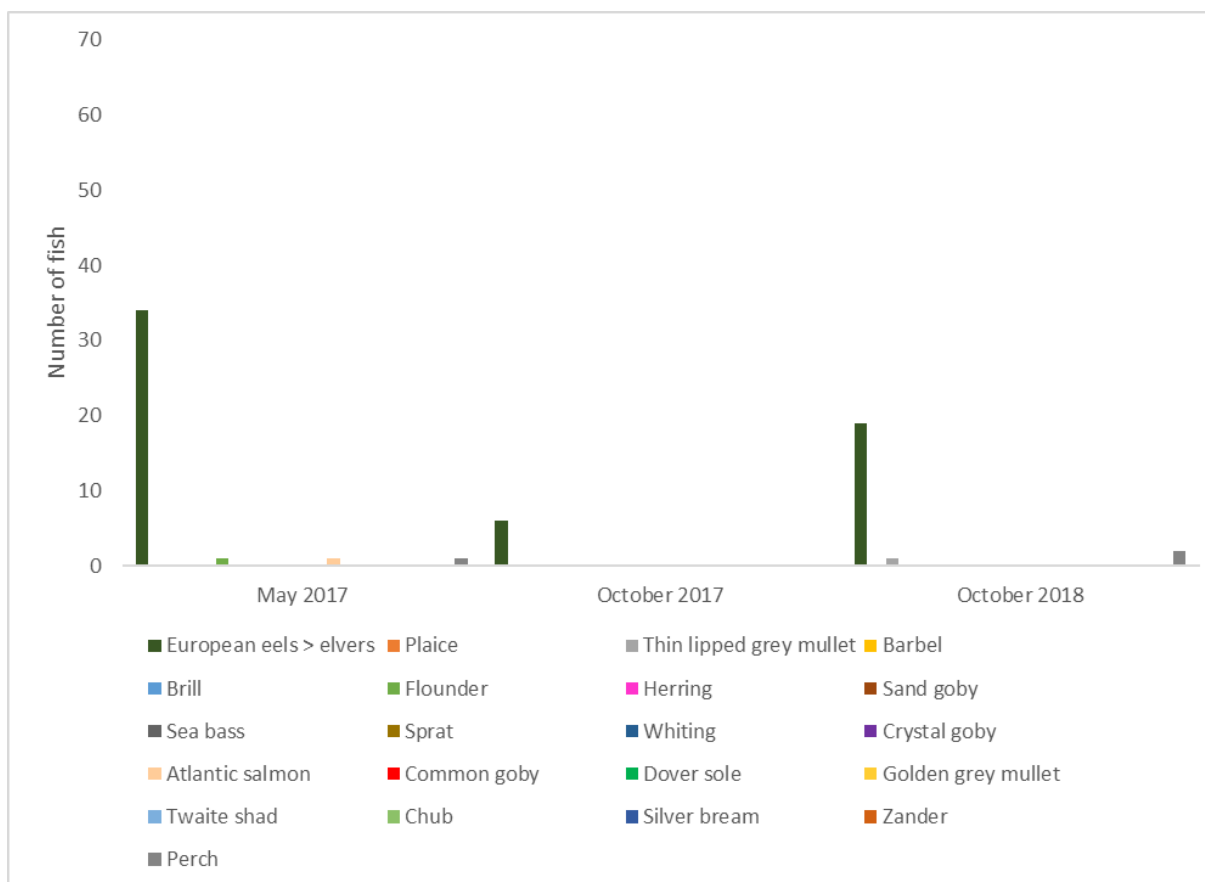


Figure 6. Number of fish caught at Water End using fyke nets 2017 to 2018

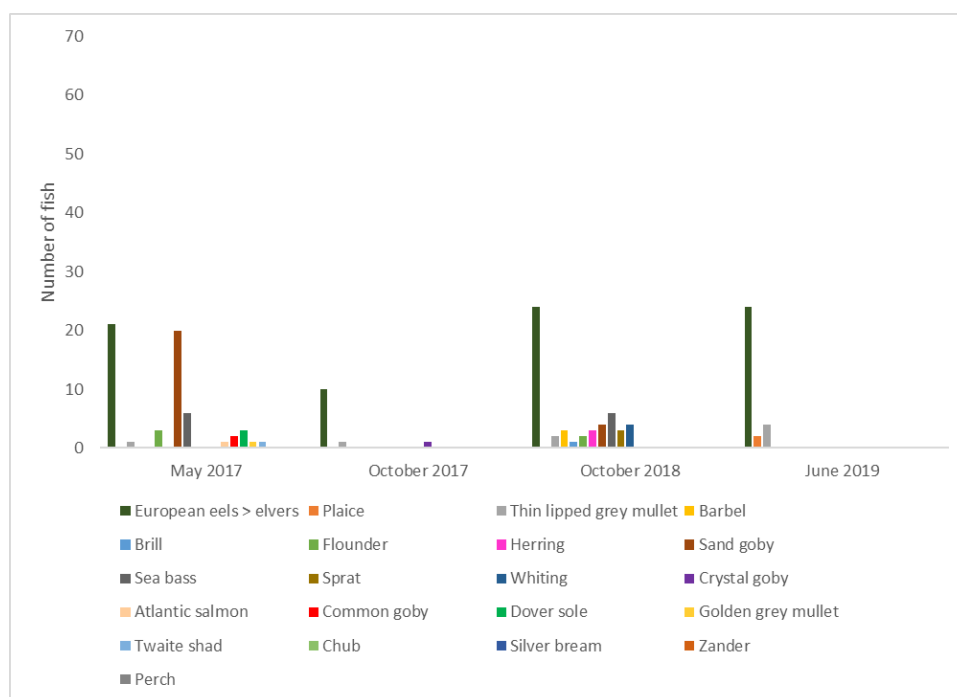


Figure 7. Number of fish caught at Arlingham Pass using fyke nets 2017 to 2019

Impacts of Lowering Flows

Tidal reaches respond to flow in similar ways to lowland freshwater reaches but are also vulnerable to changes in salinity due to the interactions between freshwater flows, winds and tides. Many tidal reaches exhibit long residence times for the water in them, leading to exacerbation of water quality problems. Tidal rivers are hence vulnerable to low freshwater flows during several periods of the year. In summer the impacts are likely to be associated with water quality, typically the development of mobile zones of low oxygen and high ammonia that can be lethal to fish especially in summer when temperatures are also high. This is especially relevant to salmonids attempting to pass through these zones. Low flows allow the ingress of seawater during spring tides, particularly when exacerbated by storm conditions. These can lead to fish kills especially where fish are unable to escape upstream into freshwater due to physical barriers, or where they become trapped in off-channel areas such as marinas or dykes. As with freshwater lowland reaches, tidal river reaches are commonly heavily modified and these modifications interact with the impacts of flow regimes to exacerbate problems for fisheries.

The Severn Estuary is used extensively by juvenile fish and the majority of these move into deeper water in winter (with higher freshwater flows entering the estuary), but sprat and eel appear to do the opposite and move into the estuary. Many of the fish species living in the Severn Estuary are adapted to tolerate high turbidity and a wide range of temperatures, salinity and oxygen concentrations (Bird, 2008). Therefore these are unlikely to be impacted by slight changes in freshwater flows. The species most likely to be impacted by the lowering of freshwater flows are those that migrate from sea to freshwater as part of their lifecycle (Twaite shad, sea and river lamprey, Atlantic salmon, sea trout and European eel).

The main impacts in the estuary caused by a lowering of freshwater flows could be an increase in the occurrence of dissolved oxygen sags and increase saline intrusion. The reason for the dissolved oxygen sags in the estuary are as follows.

During neap tides, fine silt accumulates. This silt contains organic material of natural origin and from the effluent discharges upstream in addition to the settled sewage from Netheridge. Bacterial action in this silt rapidly uses up available oxygen. It then produces chemicals able to react rapidly with oxygen which becomes available when the silt is re-suspended during spring tides by high inflowing velocities. This reaction causes a rapid depletion of the dissolved oxygen. The effect is repeated on successively low tides, each of which re-suspends more sediment, until very low dissolved oxygen levels can be reached. These effects combined with high water temperatures caused the death of many salmon, eels and other fish at the end of June 1976. (Severn Trent Water, 1977).

In the late 1980s and early 1990s large fish kills were noted in the Severn Estuary. Wade (1992) listed the following fish kills during this period (see below).

25/6/89 River Severn, Longney 114 salmon, 2 eels, 1 twaite shad, 1 bream and sea lamprey. Cause thought to be low dissolved oxygen (<0.5ppm), fish from Parting to Bollow

10/7/89 River Severn, Epney 45 salmon. Low dissolved oxygen associated with storm water from Netheridge

26/6/90 River Severn, Minsterworth minimum of 30 salmon. High temperatures, low freshwater flows, high spring tides and low dissolved oxygen

7/7/92 River Severn at Kadam Pool, Weir Green and Longney 27 salmon (minimum). Low dissolved oxygen with spring tide influence

He concluded that Netheridge Water Reclamation Works and the abstraction by Canal & River Trust (CRT) for the Gloucester and Sharpness Canal were having a detrimental impact on dissolved oxygen levels and hence the cause of fish kills. The majority of these reported fish kills and those from the 1976 drought tended to occur in June and July, which is before the main impacts of the modelled drought scenarios. Water quality has improved significantly at Netheridge and now salmon deaths are very rarely recorded.

All the evidence discussed so far in hydrology and saline intrusion section of this document suggests that the main area of concern regarding impacts from a drought and the impact of a Severn Drought Order

would be in the Lower Tidal Severn i.e. above the Severn SAC. Therefore the main fish to be impacted are likely to be freshwater and migratory fish.

Specific Fish of Importance to Estuary

Table 5. List of important migratory fish and their key prey species

Prey species Assemblage Species	Key prey species
Twaite shad	Small crustaceans, especially mysids and copepods, small fish, especially sprats and anchovies, and fish eggs (Maitland, P.S. & Hatton-Ellis 2003).
Allis shad	Small crustaceans, especially mysids and copepods, small fish, especially sprats and anchovies, and fish eggs (Maitland, P.S. & Hatton-Ellis 2003).
Sea lamprey	Eel <i>Anguilla anguilla</i> , cod <i>Gadus morhua</i> , and haddock <i>Melanogrammus aeglefinus</i> are all potential prey species for the sea lamprey found within the Severn Estuary (Bird 2008)
River lamprey	Sea trout <i>Salmo trutta</i> , shad <i>Alosa fallax/Alosa alosa</i> , herring <i>Clupea harengus</i> , sprat <i>Sprattus sprattus</i> , flounder <i>Platichthys flesus</i> and small gadoids such as whiting <i>Merlangius merlangus</i> and pout <i>Trisopterus luscus</i> are all potential prey species for the river lamprey found within the Severn Estuary (Bird 2008).
Atlantic salmon	While at sea, salmon feed on a variety of fish (e.g. herring, sprat, sand eel, mackerel, and various gadoids) and crustaceans (e.g. euphausiid shrimps, prawns, gammarid amphipods and various crabs). (Bird, 2008)
Sea trout	The diet of this species at sea has not been much studied but is believed to include a range of fish species including sprat, young herring and sand eels as well as crustaceans such as amphipods (e.g. Corophium), gammarids, decapods such as Crangon and mysid shrimps. Many of these prey items also occur in estuaries where sea trout are known to feed extensively. (Bird, 2008)
European eel	A range of benthic organisms that include crustaceans and small fish. (Bird, 2008)

Twaite Shad

Adult twaite shad enter the Severn Estuary between April and June with males generally migrating upstream first followed by females one or two weeks later (Maitland and Hatton-Ellis, 2003). Adults appear to move up estuaries on spring tides when freshwater flows are not too high (Aprahamian, 1982) and hence this upstream migration is not expected to be impacted by any of the management options.

Juveniles migrate down to the estuary and remain in the upper estuary for their first summer, tending to move seaward over winter. Within the estuary where fresh and saline water meet there is an abundance of prey species (mysids) and these are particularly important to the juvenile twaite shad population. The actual position varies according to the state of the tide and volume of freshwater input to the estuary. Therefore it must be assumed that any activity that affects the salinity regime of the estuary would in turn impact the distribution of these prey species (taken from The Severn Estuary European Marine Site). This might cause the juvenile shad to move further upstream during low freshwater flows as in the Acute or Chronic drought scenarios. With the low freshwater flows intermittent dissolved oxygen sags would occur in the Severn and the juvenile shad would be vulnerable. This would be more of an issue in the 'Do Nothing' management option where flows seriously crash in the late summer. Also if Canal & River Trust (CRT) were to abstract their maximum quantity it is possible that there would be virtually no freshwater flow entering the estuary.

Allis shad are very similar to twaite shad except they tend to be larger and migrate further upstream during migration. Adult fish have occasionally been recorded from samples at Oldbury (Bird, 2008), but this is a rare event. There are no confirmed spawning sites for allis shad in the UK (Maitland, 2003) and so it is unlikely that this species would be impacted by low freshwater flows.

Lamprey

Sea and river lamprey are both anadromous and migrate into freshwater to breed. Through the Review of Consent for the estuary it was decided that there would be no impact on sea lamprey by low flows. The best conditions for high recruitment might be relatively high water from April to June to aid upstream migration and increase the areas of spawning gravel available, followed by lower flows from June onwards, which would help larvae to disperse across suitable habitat downstream, but not wash them away (Maitland 2003). This could mean that the lowering of the flow earlier in the year with the Severn Drought Order for the Chronic scenario might limit spawning distribution.

The life history of river lamprey is different (see Figure 8) with migration through the estuary and up the River Severn taking place primarily in October to March. The fish adjust their migration to respond to the physical conditions in the river. This means that river lamprey are highly adaptable to flow conditions, but would favour higher flows during the upward migration period of October to March when flows are not considered to be an issue. It is suggested that adult river lamprey do not move far from the coast during adult feeding stage as main fish to have been attacked by lamprey being migratory or brackish water species (see Table 5). The adult river lamprey while feeding in the estuary would be vulnerable to the intermittent dissolved oxygen sags that might increase in frequency in drought conditions.

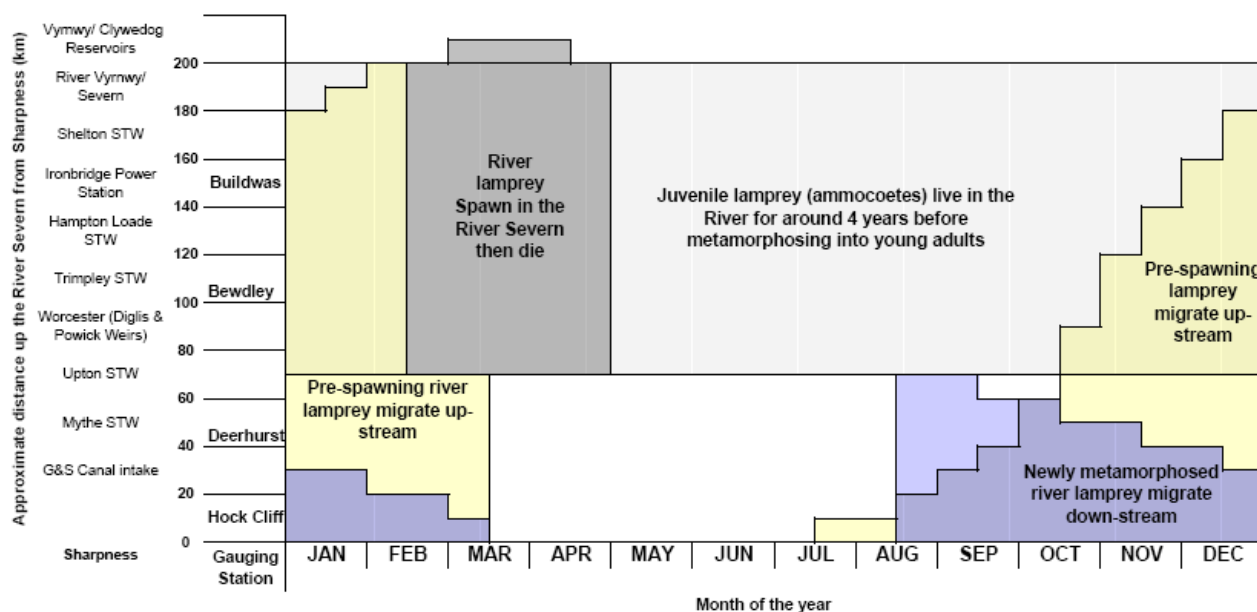


Figure 8. Approximate movements of river lamprey in River Severn (Taken from RoC)

Atlantic Salmon

Atlantic salmon are anadromous and migrate into freshwater to breed. Adult salmon returning to their home rivers arrive in the estuary in most months of the year, although those entering between January - April inclusive - the so-called spring salmon - have become much depleted over the past few decades (pers. comm. Pete Gough 2012). As salmon enter their natal river estuaries their behaviour appears to be very variable. Some fish move up through the estuary into freshwater very quickly (9 hours) while others have been observed to drift passively with the tide (taking up to 130 days). However, the majority of fish appear to take only a few tide cycles (Tidal barrage report, 1989). High freshwater flows are a key mechanism in triggering upstream migration, although temperature and water quality also have an impact. Solomon and Sambrook (2004) describe the uncertainty and interconnection of various influences upon salmon, with flow

being a central factor but not necessarily the strongest influence over successful entry to river. Their study, concluded that high temperatures and at time low dissolved oxygen levels were the major influences for failed river entry during the study period.

Salmon smolts move down into estuary relative to strength of freshwater flows (December to June). Most likely drift passively on tides as acclimatise to saline conditions and then will swim positively seaward (Tidal barrage report 1989).

Adult salmon within the estuary awaiting to migrate upstream are vulnerable to dissolved oxygen sags, caused by low freshwater flows, and large numbers of salmon were killed during the droughts of 1976 and 1989 usually in June and July within the section Tidal Lower Severn. One possible reason for salmon deaths in this section during June and July might be due to weaker spring run fish that did not make it up into main river were then caught out by high tides and as already stressed succumbed to low dissolved oxygen levels. Salmon kills are not as frequent in estuary after 1990s improvements on water quality (Netheridge WRW).

A study by Greest (2009) on the impact of freshwater flows into salmon entry to the Rivers Wye and Usk used a statistical model of salmon migration and flow to demonstrate that any reduction in freshwater flow reduces the number of salmon successfully entering freshwater. Greest (2009) also concluded that water quality is a significant factor at low flows, with flow reductions likely to exacerbate poor water quality.

What needs to be appreciated is that the Bristol Channel and Severn Estuary (SAC) contain populations of salmon derived from a number of salmon-producing rivers. The probability of salmon entering their home river is dependent on freshwater discharge: in high flows this might be prompt however during low flows delay within the estuary or sub-estuary will occur and increased natural loss or mortality then occurs. Prolonged estuary residence is possible in extended low flow periods. The adult fish are a mixed stock of fish from different rivers, ranging from the Severn itself to those along the south coasts of Wales including the Wye, Usk and Tywi National Sites Network sites, to the recovering industrial rivers (Rhymney, Taff, Ogmore, Afan, Neath and Tawe. There is some evidence for fish derived from even further away. The salmon present in the estuary are in the process of identifying their home rivers and a high level of fidelity to those rivers has been widely documented. The fish, whilst resident, will make multiple temporary ascents and descents of the estuary, and may make temporary excursions into sub-estuaries before leaving to locate and enter their own rivers (pers. comm. Pete Gough 2012). Therefore the potential reduction in freshwater flow in the River Severn would reduce attraction of Severn salmon to their home river and hence an extended residence period in the estuary and lower probability of their eventual successful entry to the River Severn. The large scale of the droughts being assessed that would require the implementation of the Severn Drought Order would presumably be impacting the other rivers flowing into the Severn Estuary creating further issues of salmon residing within the estuary for longer. Some salmon waiting to ascend the River Severn tend to wait down below the second Severn crossing (pers. comm. John Powell 2011) while waiting for migratory trigger. This is below the section where impact is to be expected from altering freshwater flows.

Sea Trout

Sea trout are anadromous and a migratory form of the brown trout and breed in rivers from October to February. Very few observations have been made of sea trout within the Severn Estuary with very limited angling interest. Sea trout smolts tend to remain longer in estuarine waters before heading out to sea.

It will be the adults waiting for increased winter flows to begin upstream migration and the smolts feeding in the estuary that are most likely to be impacted by an acute or chronic drought. As salmonids they require good water quality and so would be vulnerable to dissolved oxygen sags.

European Eel

The European eel is catadromous and is believed to breed in the Sargasso Sea. The adult eels migrate out of the rivers and are most abundant in the estuary in September and October. Spawning takes place out at sea in spring and summer. The planktonic larvae (leptocephali) migrate across the Atlantic via ocean currents (two to three years) and metamorphose into transparent glass eels once they reach the continental shelf (White and Knight, 1997). Due to the south westerly orientation and funnel shape of the Severn Estuary the glass eels enter in large numbers in spring. They then metamorphose again within the estuary

to become elvers. While in the estuary they bury themselves in sand or mud and emerge at night to feed. Estuarine migration upstream is slow with some eels staying in the estuary until they migrate back out to sea to breed.

Temperatures of between 14-16°C have been statistically proven to be the best predictor of upstream migration within the Severn Estuary (White and Knight 1997). The elvers move upstream on spring tides from mid-February to mid-May and are caught in large numbers by elver fishermen up to Tewkesbury. During this migration upstream weirs are an obstruction to upstream migration and hence need high tides to get over them. The timing of this migration means that the impacts of the Severn Drought Order would be negligible. Adult eels are more tolerant of low dissolved oxygen than salmonids, but with the exceptionally low freshwater flows (in the 'Do Nothing' management option) to the Lower Tidal Severn there may be small pockets with dissolved oxygen sags that could even cause eel mortality.

Wider Fish Assemblage

The Severn Estuary has been designated as a RAMSAR site due to its fish assemblage. The large diversity of fish (especially for juveniles) within the estuary has been recognised as internationally important and so as a whole needs to be assessed for their response to lowering freshwater flows. A study by Potter et al. (2001) concluded that annual recruitment strengths of the fish assemblage of the Severn Estuary were not correlated to water temperature or changes in salinity. The alteration of freshwater flows impacts the salinity of the estuary and therefore it can be assumed that freshwater flow is not impacting annual recruitment strength.

Hendersen and Bird (2010) highlighted that for fish in the estuary species richness and total abundance reach a maximum in late summer and autumn. This is when any impact of reduced freshwater flows to the estuary from both the drought scenarios (acute and chronic) would be at its peak. However, as shown in results from transitional fish surveys by the Environment Agency (Figures 4 to 10) the fish within the section most likely to be impacted by low freshwater flows and therefore dissolved oxygen sags are freshwater and migratory fish.

All this evidence suggests that the wider fish assemblage of the Severn Estuary will not deteriorate with lowering of freshwater flows as modelled.

Drought Scenarios

It should be noted that these are just modelled flows and timings could vary in a real life situation. Also the model only takes account of a 300MI/d abstraction by Canal & River Trust (CRT) for Gloucester and Sharpness Canal.

Lower Parting

This is the furthest downstream point with modelled flows and is within the tidal range of the estuary (Lower Tidal Severn). Any high tides combined with the low flows of a drought could have a very negative impact on the fish population. This will be due to saline intrusion and increased suspended solids causing low dissolved oxygen levels. Work completed by Hutchinson and Wade (1992) recommended that a flow of 1800MI/d at Haw Bridge would be required to maintain dissolved oxygen levels above 3mg/l (critical concentration for survival of migratory salmon), prevent suspended solid concentrations of greater than 6000mg/l and prevent saline intrusion for 94% of predicted tides. During the acute drought model for example this flow is not attained for 19% of the year. This suggests potential for fish kills (mainly salmonids). However, water quality within the estuary has been improved dramatically since this study and it is anticipated that lower freshwater flows than 18000MI/d at Haw Bridge would now suffice.

Acute

'Do Nothing' – This is the best option for fish up until mid-October. Then the freshwater flow crashes very quickly to very low flows (down to 382MI/d) for a short period. This would impact fish populations in this area, especially salmonids that would be waiting to migrate upstream. As described previously low freshwater flows increase saline intrusion and dissolved oxygen sags.

Severn Drought Order– At the end of August the freshwater flows drop lower than the 'Do Nothing' management option and stays lower for a month and a half. The initial drop is unlikely to have any different impact on the fish community than the 'Do Nothing'. However, freshwater flows fall lower in October four days earlier than the 'Do Nothing' option. This would be a critical period and if it coincided with a high tide could cause increased saline intrusion and dissolved oxygen sags (with consequences discussed previously). After this period this option is above the 'Do Nothing' management option providing extra freshwater flow and hence buffering impacts of saline intrusion and dissolved oxygen sags. Timing of these events would be critical for implications on the fish community.

Chronic

'Do Nothing' – In the second year of the Chronic drought this option is again preferable for the fish population until October. This crash is even lower and longer than the acute scenario (as low as 310MI/d for 3 weeks). These low freshwater flows for that length of time could cause large fish kills in this section of the River Severn (chances of a spring tide falling in this period are high). Again salmonids would be most vulnerable to dissolved oxygen sags, but flows so low other species likely to be impacted e.g. shad and eel.

Severn Drought Order - Flows would be reduced for much of the second year compared to the 'Do Nothing' management option. It would be anticipated that saline intrusion and dissolved oxygen sags would be a greater problem than with the 'Do Nothing' option for two to three months. However, this time there is no flow crash in October (except at very end of month). This is where these management options really assist the ecology of the estuary.

Conclusions

The Water Authority Joint Committee on the River Severn Estuary concluded that, apart from saline intrusion at Gloucester, the drought of 1976 had virtually no immediate effect on the estuary (Severn Trent Water 1977). In fact the evidence from the 1976 drought is that moderate increases and decreases in the regulated flow at Bewdley would have little effect on the river or the estuary (Severn Trent Water 1977). The droughts modelled for this report were based on the 1976 drought, but extended. The impacts on fish caused by the different management options are only within the Lower Tidal Severn and not the Severn SAC. However migratory fish that are part of the designation of the estuary as a SAC that might be impacted are:

Atlantic salmon – during a drought adult salmon migrating upstream are likely to reside for longer in the estuary increasing possibility of them not entering the River Severn to spawn. The main impact likely in the Lower Tidal Severn section will be where dissolved oxygen sags could cause mortalities. In both scenarios the 'Do Nothing' approach is beneficial up until October. However, then in October the 'Do Nothing' approach causes a crash in freshwater flows to the Lower Tidal Severn which could cause mortalities to salmon within this section.

Twaite shad – juvenile twaite shad feed at the saline wedge before migrating to sea at winter. The location of this saline wedge is impacted by tides and quantity of freshwater. Therefore in the Lower Tidal Severn these fish could be vulnerable to dissolved oxygen sags, especially with the very low freshwater flows in the 'Do Nothing' management options.

The fish assemblage of the estuary (qualifying feature of RAMSAR) are generally unlikely to be impacted by the changes in freshwater flows as modelled in the various management options.

There is considerable scope for the abstraction by CRT for the Gloucester Sharpness Canal to cause further damage to the fish population of the Lower Tidal Severn and even the fish within the SAC.

Mitigation

- Any other sources of freshwater for the estuary at times of severe drought.
- If large losses of salmon recorded possibility of restocking salmon.

Future Monitoring

A fish counter down at Upper Lode/Deerhurst would give a better understanding of salmon migration and could be used to produce a statistical model to assess impact of changes in flows.

Radio tracking migratory fish within different sections of the estuary would be very difficult but give a better understanding of movements within the estuary and could be used in conjunction with fish counter data in production of statistical model.