River flow for good ecological potential

Final recommendations

UKTAG
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Version 1.0

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1. Introduction

1.1. The UK Technical Advisory Group on the Water Framework Directive ("UKTAG") makes technical recommendations to the UK government administrations on implementing the Water Framework Directive ("the Directive"[1]). UKTAG is a working group of experts drawn from the UK environment agencies and conservation agencies[2]. It also includes representatives from the Republic of Ireland.

1.2. The physical characteristics of many of our surface waters have been substantially modified for purposes such as flood defence, land drainage, navigation and water storage for public supply or hydroelectricity generation.

1.3. Such uses provide important benefits. Restoring the affected waters to good ecological status can significantly compromise those benefits. Where this would be the case, the waters have been identified as heavily modified water bodies ("HMWBs"). Instead of good ecological status, the aim for HMWBs is to achieve good ecological potential. Good ecological potential is the ecological quality that can be achieved in the affected water bodies without a significant adverse impact on the benefits provided by the uses or a significant adverse impact on the wider environment.

1.4. We first published guidance on the classification of ecological potential in 2008[3]. The guidance provided the basis for classifying heavily modified water bodies for the first cycle of river basin management planning.

1.5. The guidance included lists of mitigation measures relevant to the range of adverse impacts on the water environment that the different water uses can have. Good ecological potential requires all the appropriate listed mitigation to be in place, other than those:

- targeted at adverse impacts not present at the site concerned;
- technically impossible to implement at the site concerned; or
- that would have a significant adverse impact on the use or on the wider environment.

1.6. Achieving good ecological potential can still be challenging and costly. Where the cost would be disproportionate, the deadline for achieving the objective can be extended or a less stringent target can be set. Such objective setting decisions are part of the river basin management planning process.

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[1] Directive 2000/60 /EC of the European Parliament and of the Councilof 23 October 2000 establishing a framework for Community action in the field of water policy

[2] Natural Resources Wales (NRW), Natural England (NE), Environment Agency, Northern Ireland Environment Agency (NIEA), Joint Nature Conservation Committee (JNCC), Scottish Environment Protection Agency (SEPA), Scottish Natural Heritage (SNH), Republic of Ireland's Department of Environment, Community and Local Government (DECLG).

[3] UKTAG 2008

1.7. The recommendations in this document update our guidance on mitigation measures for river water bodies identified as HMWBs because of the impacts of diverting water to, storing water in, or abstracting water from, reservoirs for uses such as drinking water supply or hydroelectricity generation (see box 1).

1.8. The recommendations are based on a review of our existing guidance following:

- requests from the environment agencies for further guidance on ecologically appropriate flow regimes in rivers affected by such uses;
- requests from operators of hydropower schemes; and
- up-dated information on emerging practices in a range of countries across Europe.

1.9. The review led to initial suggestions on how to improve the guidance and better define a river flow regime for good ecological potential. The consultation document was published on the UKTAG website and circulated widely. A stakeholder workshop was held on 16th July 2013 to discuss the proposals with interested parties. The recommendations take account of the consultation responses and other feedback.

Box 1

How this guidance relates to existing UKTAG guidance on the classification of ecological potential for heavily modified and artificial water bodies

UKTAG first published guidance on the classification of ecological potential in 2008[4]. This guidance included lists of mitigation measures relevant to the range of adverse impacts on the water environment that the different water uses can have. For impoundments for the purposes of water storage and supply 12 mitigation measures were identified, the headings of which are listed in Appendix 1 of this document.

This guidance is intended to supersede the existing guidance on assessing whether a measure is in place and adequate for the mitigation measures detailed in the table below.

GEP classification mitigation measures		**Related flow building blocks**
2.	Manage the volume & timing of flow releases to trigger fish migration	Annual minimum flow and autumn and winter flow elevations
5	Establish an appropriate baseline flow regime	All building blocks.
8.	Provide flows to move sediment downstream	Flood flows, late summer, autumn and winter flow elevations

[4] UKTAG 2008

2. Background

2.1. River flows interact with sediments to help shape the physical characteristics of rivers. These characteristics, referred to as "hydromorphological characteristics", comprise the physical form of the channel bed, banks and bank-side habitats and the different depths and velocities of water from place to place and from time to time. The resulting dynamic patchwork of habitats provides the foundation for a river's characteristic ecological diversity and functioning[5].

2.2. The recommendations in this document are intended to help UKTAG's member agencies design appropriate mitigation flow regimes for good ecological potential in heavily modified rivers. They provide guidance on how to:

- identify which of a number of ecologically important components of river flows (referred to in the rest of this document as flow building blocks[6,7]) are likely to be ecologically beneficial at the site concerned; and
- determine the appropriate magnitude, duration and frequency of the relevant flow building blocks, taking account of the ecological characteristics of the site concerned.

2.3. The flow building blocks include low flows to provide an area of continuously wetted habitat to maintain an acceptable level of ecological productivity; medium flows to sort river sediments and stimulate fish migration and spawning; and flood flows to maintain channel structure[8,9]. Figure 1 illustrates the pattern of flows produced by the application of all the building blocks. More detailed illustrations are provided in Annex 4.

[5]Newson et al, 2012
[6]Acreman et al, 2009
[7]Nislow& Armstrong (2012)
[8]Acreman M & Dunbar M.J 2004
[9] King J.M, Tharme R.E & De Villiers M.S, 2008

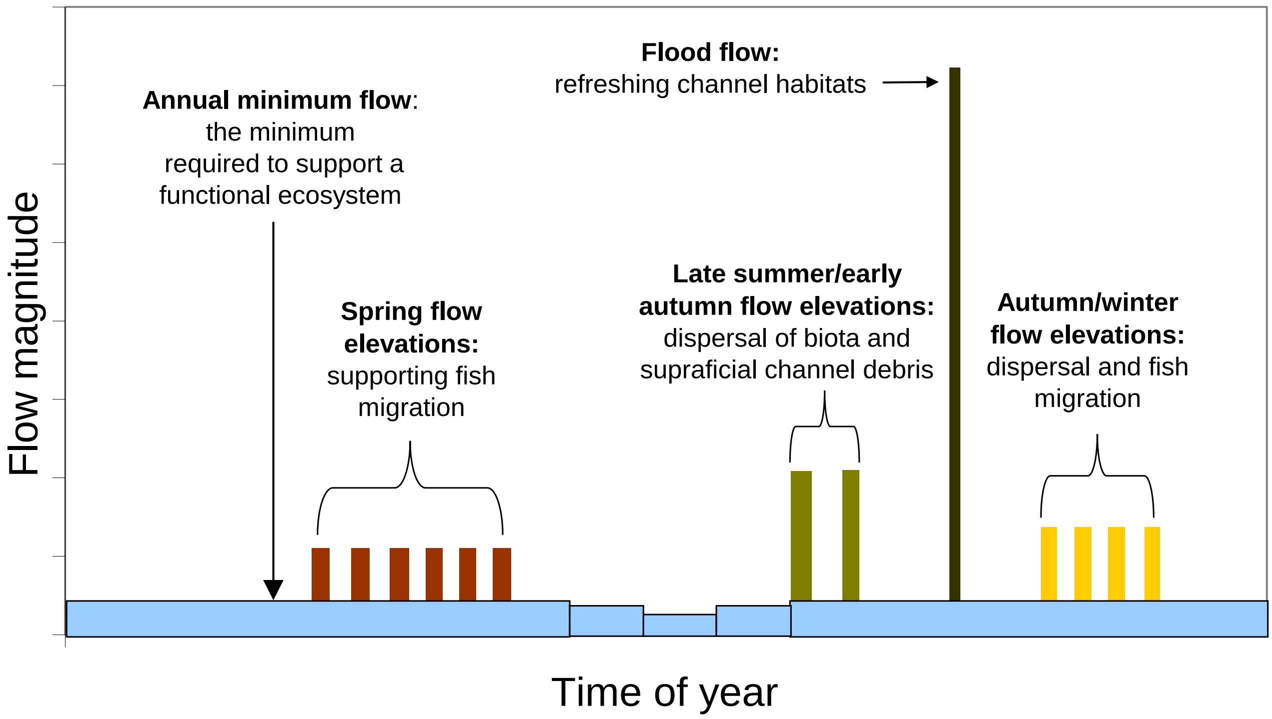

Figure 1: Schematic representation of a mitigation flow regime based on the recommended flow building blocks

2.4. In developing the recommendations, we have taken advice from scientists from our member agencies, reviewed the scientific literature[10], commissioned research[11]; reviewed similar work by other countries[12] and discussed with scientists from other European countries working on the EU Common Implementation Strategy for the Water Framework Directive[13]. In developing guidance on the different flow building blocks, we have considered current scientific knowledge of the flows required:

- by fish species[14], including coarse fish, salmonids and lamprey;
- to help ensure that the rivers contain a balance of different plant and animal species rather than being dominated by species that thrive under stable flow conditions; and
- to refresh and maintain the range of river habitats required by different water plants and animals.

[10] Guidance on environmental flow releases from impoundments to implement the Water Framework Directive, Sniffer Project WFD82, May 2007.
[11] Sniffer 2012
[12] Sintef, 2012
[13] INTECSA-INARSA 2012
[14] Cowx et al. 2004, Noble et al., 2004; Cowx et al., 2012

3. Classification and prioritising water bodies for improvement

3.1. As currently, we recommend that good ecological potential in rivers affected by water storage schemes should represent what can be achieved by way of environmental improvement without significant adverse impacts on the benefits provided by the water use responsible for the modifications or significant adverse impacts on the wider environment.

3.2. In practice, ensuring this requires an iterative approach whereby ecologically-relevant mitigation for the site concerned is identified and then appraised in terms of its implications for the water use and the wider environment.

3.3. For water bodies identified as not at good ecological potential, we recommend that (a) where possible their ecological potential is differentiated into either moderate, poor or bad; and (b) classifications of poor or bad are only assigned where there is ecological evidence of major or severe ecological impacts.

3.4. We have recently recommended a series of ecological indicators capable of, in some cases, detecting major and severe ecological impacts resulting from alterations to river flows[15][16].These can be used for the purposes of (b) above. In addition, some adverse ecological impacts may be picked up using other assessment methods, such as our recommended method for assessing fish populations. However, in general the existing range of assessment methods is not able to adequately measure the ecological effects of alterations to river flows.

3.5. We are currently working to develop ecological assessment methods capable of differentiating a wider spectrum of ecological impact resulting from water abstractions. We expect these methods to become available within the next few years and their results subsequently factored into the river basin planning process.

Box 2.

Recommendations on prioritising rivers for improvement

- In each river basin management planning cycle, we recommend that the setting of priorities for improvement should focus on rivers for which there is ecological evidence of significant adverse impacts.
- Priorities should be reviewed each planning cycle to take account of improved information on ecological impacts.
- When appropriately sensitive ecological assessment methods become available, we will recommend that they are applied to water bodies classed as worse than good ecological potential but for which it has not been possible to obtain data on ecological

[15] UKTAG 2013b
[16] SNIFFER 2013b

impacts using the currently available assessment methods.

- Where the use of appropriately sensitive ecological assessment methods identifies ecological impacts, the water bodies should be considered when setting priorities for improvement for the next river basin management plan. Where significant ecological impacts are found not to be present, and the water bodies' ecology has the potential to reach good ecological status (subject to the criteria in 1.5), we recommend that the designation of the water bodies as heavily modified should be re-considered.
- For some water uses, when determining if there is a significant impact on the benefit provided by the use, it is important to consider the cumulative impact of mitigation at multiple sites (e.g. across a public water supply zone or, for impacts on renewable energy generation, across a country). If further mitigation would result in a significant cumulative impact, we continue to recommend that water bodies still classed as worse than good and for which no further mitigation can be put in place without an impact on use are re-classed as good ecological potential.

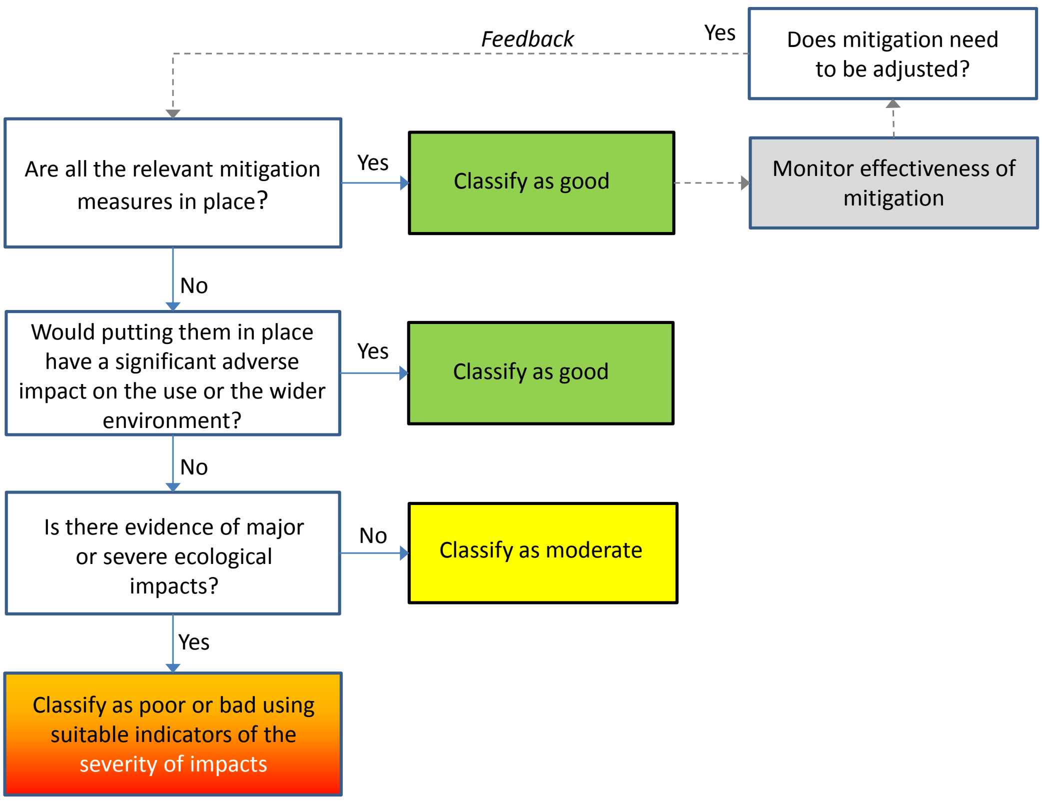

Figure 2: Recommendations on classifying the ecological potential of rivers affected by water storage schemes. Notes: If other pressures (e.g. pollution pressures) are adversely affecting the ecological quality of the river, the overall ecological potential will be determined by the pressure having the greatest impact. Suitable indicators of the severity of impacts may include breaches of relevant ecological standards or relevant river flow standards.

4. Overview of the recommendations

4.1. Our detailed recommendations on each flow building block are set out in Section 6 below. For each flow building block, the recommendations comprise:

- a default flow derived from our review of the latest scientific understanding of ecologically important flows; and
- guidance on when and how to modify each default flow, or even omit a particular flow building block altogether, based on consideration of site-specific and ecologically-relevant characteristics.

4.2. The approach requires local information about the site's characteristics to decide whether or not the default flow is appropriate and, if it is not, to help define an appropriate alternative flow. The information used should be based on reaches representative of those likely to be important with respect to the ecological purpose of the flow building block concerned and sensitive to differences in the mitigation flow. For example, wide, gently shelving reaches may experience greater flow depth and wetted width variations under different flows than narrow, steeply shelving reaches. Reaches closer to abstractions are likely to be more affected by differences in mitigation flows than those that are more distant downstream. More information is provided in Appendix 7.

4.3. Depending on the circumstances and the building block concerned, suitable local information may be obtainable in advance of making any changes to river flows (e.g. by observing trial releases of water from a reservoir or the timing of fish migrations in comparable catchments; using modelling to estimate flow depths, etc). In other cases, it may be necessary to apply the default flow, monitor the effects over a period of time and then use the information obtained to decide if modification of the default flow is appropriate.

4.4. Such adaptive approaches are widely supported by scientists working in this field[17,18] as the best means of taking account of the variability of ecological responses to artificially controlled river flows among and within rivers[19,20].

4.5. The flow making up a flow building block may come from spills from reservoirs and diversion intakes; releases from reservoirs, including via fish passes; intake structures that operates as to pass the flow required for a building block to the river downstream, including as a hands-off-flow[21]; inflows entering from tributary streams; or a combination of the above. Implementation of particular flow building blocks should be synchronised with catchment rainfall events where possible.

[17] See for example King et al, 2010; SINTEF Energy Research, 2012; Sniffer, 2012; Sniffer, 2007.
[18]SNIFFER 2007. Project WFD82
[19]Poff and Zimmerman, 2010; Souchon et al. 2008.
[20] Bradford et al, 2011.
[21] Hands-off-flow means only diverting water to the reservoir when flows upstream of the intake are greater than theannual minimum flow required in the river downstream of the intake.

4.6. In deciding how best to provide the flow building blocks, consideration should be given to options that would ensure river temperatures and oxygen conditions are consistent with the existing guidance for the relevant mitigation measures. For example, it may be possible in some cases to source at least some of the required water from diverted rivers rather than taking it exclusively from depth in the reservoir.

4.7. The degree to which the approach described in this guidance applies to rivers that are designated as Natura 2000 protected areas or SSSI will be determined by each Administration in discussions between relevant agencies and with due consideration to regulatory requirements.

4.8. The operations of some water storage schemes already provide an annual minimum flow significantly higher than the recommended default annual minimum flow. They may also provide more fish migration flows than would the default flows for the relevant building blocks. In such cases, there may be a significant risk of deterioration if, for example, an operator proposes to reduce flows to the default flow. The detailed guidance on the building blocks incorporates recommendations on appropriately modified building block flow criteria for use in identifying reductions in flow that could be made without deterioration of ecological potential.

4.9. In some rivers, floodplains are used by certain fish species for spawning. Periodic flooding can also be important for maintaining some types of floodplain wetlands. Where fish are using floodplains for these purposes or where floodplain wetlands are being maintained by the current operation of a water storage scheme, we recommend that changes to the operation of the scheme should be designed to maintain the role of the floodplain in contributing to the ecological quality of the river system.

5. Implications of the recommendations

5.1. As with our previous guidance, any negative impacts on the economic interests of operators of water storage schemes is limited by, and dependent on:

- decisions on the amount of water that can be provided for mitigation flows without a significant impact on the benefits provided by the water use; and
- the objective setting process, which is designed to ensure that improvement objectives can be achieved without disproportionate cost.

These recommendations do not change this.

5.2. Our previous guidance on mitigation flows for good ecological potential included a comparable set of flow building blocks to those in this updated guidance. The principal difference is that the updated guidance provides much more detail than the previous guidance on how to identify the appropriate flow for each building block. This detail helps ensure a consistent framework for assessing water bodies across the UK. We also expect it to help focus and streamline assessments by the environment agencies and so help reduce regulatory delays.

5.3. On an annual basis, delivering an annual minimum flow requires proportionately by far the largest volume of water compared with the other flow building blocks. Our previous guidance did provide detail of the flow required for the annual minimum flow; this was 75% to 85% of Qn95 in most cases. Our new recommended default flow is virtually the same; Qn96 unless variation is required to support fish throughout their life cycle or particular conditions are present, as outlined in section 6.1.

5.4. The new guidance greatly increases the role of local information on ecologically-relevant characteristics in determining if and how to modify the default flow. For some rivers, consideration of local information may identify modifications to the default flows that require less water to deliver than would delivering the default flows. For others, it may identify modifications that would require more water. This may mean that the appropriate set of building blocks can be implemented without a significant impact on the water use in a different set of water bodies or a different number of water bodies than would have been the case under our previous recommendations.

5.5. The adaptive approach at the heart of our new guidance will ensure that additional water released to rivers affected by water storage schemes is used to best ecological effect.

6. Recommendations for each flow building block

6.1. The tables below describe each of the flow building blocks that together represent the recommendations on the flow regime for good ecological potential in rivers affected by the diversion of water to, storage of water in, and abstraction of water from, reservoirs.

<table>
<tr><th colspan="3">Annual minimum flow</th></tr>
<tr><td>Purposes</td><td colspan="2">To provide a continuously wetted area of habitat capable of maintaining reasonable sized and healthy populations of water plants and animals throughout the year. For fish, this includes sufficient flow and sufficient water depth to facilitate spawning and egg and juvenile growth.
To maintain exchange of oxygen and the removal of metabolites from gravels.
To maintain suitable water temperatures and dissolved oxygen concentrations.
Where possible, by mimicking the timing and magnitude of natural low flow variability (e.g. summer dry episodes), to contribute to ensuring a balance of different plant and animal species and avoiding dominance by species that thrive under stable flow conditions.</td></tr>
<tr><td rowspan="4">Default flow</td><td>Magnitude</td><td>Annual Qn96</td></tr>
<tr><td>Period</td><td>All year</td></tr>
<tr><td>Duration</td><td>Constant</td></tr>
<tr><td>Frequency</td><td>Constant</td></tr>
<tr><td>Variations to default flow</td><td>Increased requirements</td><td>To manage the risk of deterioration where there is an existing, high minimum flow
(i) Where the existing annual minimum flow is greater than Qn96 but less than Qn80, it should be treated as the default flow and should only be reduced where the criteria set out in the reduced requirements section below are met.
(ii) Where the existing minimum flow is greater than Qn80, a flow of Qn80 should be treated as the default flow and should only be reduced where the criteria set out in the reduced requirements section below are met.

Where needed by juvenile fish
(i) Where there is evidence that the default flow is too low to support juvenile salmonid populations at abundances consistent with better than poor status and a flow of Qn90 would significantly increase the area of suitable juvenile habitat that is under a depth of water of between 20 and 40 cm, the default flow should be substituted by a flow of Qn90 throughout the main period of the year for juvenile growth(1st April to 30th September).</td></tr>
</table>

		Where needed to support spawning (i) Where the default flow will not provide a sufficient depth of water over spawning gravels to facilitate spawning, a higher minimum flow should be substituted for the default flow during the spawning period (November to April for salmonids and March to June for coarse fish and lamprey). Guidance on identifying the depth of flow required is given in table A6.1. (ii) Where a significant proportion of the habitat that would have been suitable for fish spawning in the absence of the water storage scheme would be exposed at the default flow, a higher flow sufficient to keep spawning habitats submerged should be provided during the period November to April for salmonids and the period March to June for coarse fish and lamprey. These periods may be refined based on local information on spawning times. **Where needed to aid egg survival** (i) Where there is evidence that egg mortality is resulting from insufficient flow through spawning gravels (e.g. to maintain the exchange of oxygen and the removal of metabolites), a higher flow should be provided. The starting point for this should be the seasonal rather than the annual Qn96 (November to April for salmonids and March to June for coarse fish and lamprey). These periods may be refined based on local information on spawning times and hatching. **Where needed to support fish habitat** Where there is evidence that water becomes ponded over a significant proportion of the affected stretch of river, a higher flow should be provided. **Where needed to support adult resting areas** Where there is evidence that migrating adult fish are compromised by a lack of suitable resting pools, (for example by migrating in significant numbers back downstream following elevated migration flows), higher minimum flows may be needed. These will only be required where there is evidence that a lack of resting pools is caused by abstraction and is not a natural hydromorphological feature.
	Reduced requirements	(i) Where flows upstream of impounding works fall below the default flow or any appropriate increased requirements identified above, the river flow may be matched to the total upstream flow. (ii) Where (i) is not implemented, the river flow may alternatively fall below the default flow or any applicable increased requirements in a manner that matches the natural distribution of frequencies and magnitudes of flows below that flow (e.g. Qn96 for

		up to 15 days per year; below Qn97 for 11 days per year etc). (iii) Where at a lower flow than the default, there would be no significant reduction in useable wetted area, the default flow may be substituted by that lower flow provided that doing so would not (a) significantly reduce the depth of water over any good quality juvenile salmonid habitat to less than 20cm (where currently at least this deep) or (b) trigger any of the increased requirements described above; A significant reduction in useable wetted area means one at which there is likely to be a significant impact on ecological diversity or productivity (e.g. because of reduced habitat space).
For background to suggested flow criteria, go to appendix 6a		

Flood flow		
Purposes	• To maintain and refresh channel habitats by redistributing bed surface and sub-surface gravels and cobbles. This includes refreshing gravels prior to fish spawning. • To prevent riparian vegetation from encroaching into the river channels. • To flush away build-up of fine sediment and/or plant debris lying on the channel bed or at the river margins. • To contribute to ensuring a balance of different plant and animal species and avoiding dominance by species that thrive under stable flow conditions. • To inundate wetlands and marginal areas that act as refuge and nursery habitat for a range of species.	
Default flow	**Magnitude**	Equivalent to a 1 in 2 year return period flood flow
	Periods	Late September to November to optimise spawning gravel flushing although any period in which natural flood flows would have been common.
	Duration	Mimic duration of similar natural events[22]
	Frequency	Once every 3 years
Variations to default flow	**Increased requirements**	(i) Where the default flow is insufficient to break-up armouring or mobilise accumulations of gravels and cobbles (e.g. at tributary junctions), one of the following should be tried: (a) a larger flow; or (b) breaking-up long-standing armouring by a one-off mechanical disturbance and/or artificially refreshing the bed. Where a larger flow is required, its magnitude can be estimated using the methods detailed in Appendix 7.
	Reduced requirements	The default flow may be substituted by a smaller magnitude or lower frequency flow in any of the following circumstances: (i) bed armouring or excessive accumulations of gravels at tributary junctions are absent; (ii) bed armouring is present but is a natural characteristic of the water body(e.g. because the reservoir is a raised loch and, even in the absence of the impounding works, would have acted to restrict sediment supply to the downstream river); or (iii) the default flow is likely to result in adverse consequences for river habitats because insufficient sediments can be supplied (naturally or through managed sediment re-introduction) to replace sediment that would be moved downstream by the flow.
For background to suggested flow criteria, go to appendix 6b		

[22]The typical duration of natural events may be assessed using a flow time series that is representative of the natural, pre-impacted conditions. For example the typical duration of a 1 in 2 year return period flow can be assessed from the average duration of such events in a long term record at an upstream gauging station.

Late summer flow elevations		
Purposes	• To flush away build-up of fine sediment and/or plant debris lying on the channel bed or at the river margins. • Maintenance of substrate and bedforms e.g. riffles, pools and bars. • To contribute to ensuring a balance of different plant and animal species and avoiding dominance by species that thrive under stable flow conditions.	
Default flow	**Magnitude**	0.75 x Qn30 and one event at 60% of a 1 in 2 year return period flood flow.
	Periods	August to September to flush away plant debris.
	Duration	Mimic duration of similar natural events[23]
	Frequency	3 events per year.
Variations to default flow	**Increased requirements**	(i) Where despite provision of the default flow (a) there is evidence of major or severe ecological impacts, such as a juvenile fish classification of poor or bad, and (b) surface accumulations of fine sediment or plant debris are judged likely to be a causal factor, or (c) existing bedforms such as riffles, pools and bar features are not being refreshed and maintained then a greater magnitude flow, equivalent to that which would naturally occur up to three times per year should be provided.
	Reduced requirements	This building block may be omitted where all the following conditions are met: (i) there is evidence that there are no accumulations of fine sediment or old plant growth or, if there are, those accumulations are not causing significant ecological impacts; (ii) the preceding period of stable low flows has not led to dominance by particular species that thrive under stable flow conditions; and (iii) the autumn and winter flow elevations will be provided or, in the year that this block is omitted, there will be an autumn flood flow.
For background to suggested flow criteria, go to appendix 6c		

[23] The typical duration of natural events may be assessed using a flow time series that is representative of the natural, pre-impacted conditions. For example the typical duration of a 1 in 2 year return period flow can be assessed from the average duration of such events in a long term record at an upstream gauging station.

<table>
<tr><th colspan="3">Autumn & Winter flow elevations</th></tr>
<tr><td>Purposes</td><td colspan="2">To support the migration of adult salmon, sea trout, river lamprey and sea lamprey into rivers and the migration of these species and brown trout in rivers to their spawning grounds.
To support the dispersal of juvenile non-salmonid species.
To support the downstream migration of silver eels and salmonid kelts towards the sea.
To flush away build-up of fine sediment and/or plant debris lying on the channel bed or at the river margins.
To contribute to ensuring a balance of different plant and animal species and avoiding dominance by species that thrive under stable flow conditions.</td></tr>
<tr><td rowspan="5">Default flow</td><td rowspan="2">Magnitude</td><td>6x Qn95</td></tr>
<tr><td>Ascending and descending limbs of flow rise to mimic those of comparable natural flow rises.</td></tr>
<tr><td>Period</td><td>October, November, December</td></tr>
<tr><td>Duration</td><td>12 hours if no obstacles to migration are present. If a number of obstacles are present, two to three days.</td></tr>
<tr><td>Frequency</td><td>Once per week at night of 12-hour duration and, where possible, synchronised with catchment rainfall events.</td></tr>
<tr><td>Variations to default flow</td><td>Increased requirements</td><td>(i) To avoid deterioration, where the existing flow regime also supports upstream migration at other times of the year in addition to the autumn/winter period, appropriate migratory flows should be retained in that period.
(ii) Where there is evidence (including from expert knowledge on local timings of fish & eel movements) that migration is being, or would be, curtailed or otherwise compromised by limiting flow rises to the default period, the period should be extended or shifted in time. This should include consideration of the timing of the New Moon as this is when silver eels are most likely to migrate.
(iii) Where there are potential passable natural or man-made obstacles to migration or competing attractant flows from other rivers, the magnitude and timing of flow rises should be designed to support migration over the obstacles/attract migrants.
(iv) Where there is evidence that the default is not sufficient to support upstream fish migration and flow rises are not already synchronised with catchment rainfall events, the potential to do so should be explored. If it is not reasonably possible to synchronise flow rises with catchment rainfall events or flow rises are already so synchronised, the magnitude of the flow should be iteratively increased.
(v) Where there is evidence that, at spawning time, salmon are not entering smaller rivers and streams, the magnitude of flow elevations in those rivers and streams should be increased to that which would naturally have occurred, on average, once a week</td></tr>
</table>

		during the migration period.
	Reduced requirements	(i) Where upstream migration is likely to have been completed over a shorter period, the flow elevations can be limited to that shorter period. The shorter period may be identified based on local expert knowledge or evidence that spawning has occurred. (ii) Where flow elevations (or a high annual flow)already provided by the operation of the water storage scheme represents a lower magnitude flow than the default flow but is not compromising relevant fish migrations and dispersals, application of the default flow is not required. (iii) Where the affected river is a low gradient, un-braided river without extensive rapids and significant man-made or natural obstacles to migration, the default flow may be reduced down to a minimum flow of 2.5 x Qn95. (iv) The building block can be omitted where: (a) the river affected by the water storage scheme is inaccessible to salmon, sea trout, river lamprey and sea lamprey, and would naturally support only very limited migration of brown trout and dispersal of juvenile non-salmonid species; and (b) the late summer flow elevations will be provided or, in the year that this block is omitted, there will be an autumn flood flow.
For background to suggested flow criteria, go to appendix 6d		

Spring flow elevations		
Purposes	• To support downstream migration to sea of salmon and sea trout smolts, including past man-made and natural obstacles. • To support migration of non-salmonid species, including shad and sea lamprey, to spawning areas.	
Default flow	**Magnitude**	Qn90 where annual low flow is Qn96 or lower and Qn80 where the annual low flow is Qn90. Ascending and descending limbs of flow rise to mimic those of comparable natural flow rises.
	Period	March to June
	Duration	12 hours
	Frequency	Once per week, preferably at night
Variations to default flow	**Increased requirements**	(i) Where there is evidence (including from expert knowledge on local timings of fish movements) that migration is being, or would be, curtailed or otherwise compromised under the default period, the period should be extended or shifted in time. (ii) Where there is evidence that a default magnitude flow of Qn90 is limiting migration (including of shad or sea lamprey into freshwater), it should be substituted by a flow magnitude of Qn80. (iii) Where it is likely that smolt migration or non-salmonid fish migration is not adequately provided for by the default duration, the duration should be extended. This includes situations where a longer duration is likely to be necessary to allow smolts time to navigate the length of river affected by the water storage scheme.
	Reduced requirements	(i) Where migration is completed over a shorter period, the flow elevations can be limited to that shorter period. The shorter period may be identified based on local expert knowledge or local observations that spawning has occurred or smolts have migrated downstream. (ii) Where flow elevations (or a high annual flow) already provided by the operation of the water storage scheme represents a lower magnitude flow than the default flow but local information indicates that the lower flow is not compromising relevant fish migrations, application of the default flow is not required. (iii) The building block can be omitted where the affected river is inaccessible to salmon, sea trout, river lamprey and sea lamprey, and would naturally support only very limited migration of brown trout and dispersal of juvenile non-salmonid species.
For background to suggested flow criteria, go to appendix 6e		

Appendix 1. UKTAG mitigation measures for water bodies designated for water supply, storage and power generation.

Driver	Mitigation measure	
Fish migration (in relation to main impoundment)	1	Ensure effectiveness of fish passes
	2	Manage the volume & timing of flow releases to trigger migration
	3	Manage the risk of fish entrainment
	4	Enable access to feeder streams for spawning migration
River flow	5	Establish an appropriate baseline flow regime
	6	River engineering where flow cannot be modified
River sediment	7	Maintain a sediment management regime
	8	Provide flows to move sediment downstream
River water quality	9	Ensure good status of downstream river dissolved oxygen
	10	Ensure good status of downstream river temperature
Lake level	11	Manage the risk caused by lake drawdown
	12	Manage the seasonal pattern of water levels to minimise risk to shore zone communities

Appendix 2: Key life cycle stages of salmon and trout

1. Upstream migration

Salmon

Salmon is a migratory fish species that enters rivers to spawn after feeding and maturing at sea. Spawning migrations can occur throughout the year but on the majority of rivers tend to be between April and November with most in July to October, although it should be recognised that the spring running fish represent an important component of the stock being the multi-sea winter fish. Once in the main river, flow rises generally stimulate and enable upstream migration, including the navigation of barriers otherwise impassable at low flows. Migration is generally thought to proceed in discrete phases, sometimes involving long distance movement, separated by resting periods that can last for several months. The flows needed to initiate movement phases differ depending on preceding flows. A relatively small rise in flow can be sufficient if it follows an extended dry period. The time of year also has an influence, both because of the important role water temperature plays in determining the swimming ability of fish and because the maturity of the fish changes as the year progresses. In large rivers, the need for spates appears to be less critical in lower main stem reaches, possibly because larger, deeper channels can be passed under low flows. In small rivers, a high water discharge appears to be more important for upstream movement.

Trout

After maturing at sea, sea trout tend to enter rivers over narrower seasonal range than salmon, mainly between May and October, peaking June to July. Resident trout can also migrate many kilometres upstream to spawn. Spawning migrations tend to take place in September and October although in chalk steams this may be as late as January. In rivers linked to lakes, trout may feed and mature in the lakes and migrate into rivers to spawn. Resident trout and sea trout are thought to have lower migration flow needs than salmon. Small spates may provide the stimulus and the conditions necessary to pass barriers. In small rivers, a high water discharge appears to be more important than in larger rivers.

2. Spawning

Salmon

Salmon spawn in autumn (typically November to December, with some latitudinal and altitudinal variation and may be later in higher baseflow streams), laying their eggs in stream gravels up to 30 cm deep in redds cut by the female (DeVries 1997). The spawning run into breeding locations (in main stem or tributaries) requires at least moderate flows and is typically initiated by flow increases. Spawning and migration tend to take place particularly on the descending limb of a spate. Relative minimum flows for spawning tend to be higher in smaller streams than in main stem rivers.

After spawning (which incurs high mortality), the surviving post-spawners, termed kelts, drop downstream to the sea. This downstream migration can be impaired by extended or exceptionally low flows, which can impede passage or increase predation risk.

Trout

Resident brown trout and sea trout spawn in autumn, slightly earlier than salmon (e.g. October to November). The spawning run into breeding locations (in main stem or tributaries) requires at least moderate flows and is typically initiated by small flow increases.

Post spawning mortality of sea trout is less than that of salmon, many fish returning to spawn for 2 to 5+ times. Excessive low flows are likely to be detrimental through delays and increased risk of predation.

3. Incubation and hatching

Salmon

Incubation of salmon eggs occurs typically during November to March and can be later in upland tributaries. Egg development is faster in warm water, so the time taken varies between different sites and in different years. Successful incubation requires good intra-gravel flows to ensure sufficient dissolved oxygen and no drying out of gravels, some dewatering of gravels is tolerable providing humidity and temperature are maintained (Malcolm *et al.* 2012). Egg burial is typically at depths below the scour depth associated with typical bank full discharges, although there has been some concern about the amount of redd washout in some spate rivers, and the potential for climate change to increase this risk.

Trout

Incubation of trout eggs occurs typically during October to April.

For both salmon and trout, dewatering of gravels during the period of hatching may result in high mortality (Malcolm *et al.* 2012)

4. Fry emergence

Salmon

Emergence of fry from the gravels occurs in April to May. High flows at this time can cause displacement and mortality. Low flows can restrict food supply (small invertebrates).

Trout

Emergence of fry from the gravels occurs in April to May, normally slightly earlier than salmon. High flows at this time can cause displacement and mortality. Low flows can restrict food supply (small invertebrates).

5. Juvenile growth & maintenance

Salmon

Juveniles (usually termed fry in the first year, and parr in subsequent freshwater years) remain in the river for 1 to 3 years (usually 2), reaching 10 to 20cm in length. The period of time in fresh water is strongly correlated with growth rate, which is correlated with competition and water temperature, and hence altitude and latitude. As they grow, they have increasing space and shelter dimension requirements to allow them to feed, grow and avoid predators. Enhanced, stable flows are thought to be beneficial to salmon production through increased food availability, more stable territory sizes and less variable temperatures. Juveniles are thought to be able to stand physical stress for periods of time. However, exceptional droughts can have major negative effect on numbers.

Trout

Juveniles remain in river for up to three years. In rivers with a sea trout component, their energetic status and growth trajectories either trigger migration to sea as smolts, or early maturation and freshwater resident behaviour. There is a broad spectrum of migration patterns within these extremes, with some trout migrating long distances between tributaries and deep areas of main stem rivers. Where there is a sea trout component to the population, there is usually a strong sexual bias in the adoption of migratory behaviour, with most sea trout usually being female. As they grow, juveniles become less vulnerable to displacement by high flows and have increasing space and shelter requirements. As for salmon, enhanced, stable flows are thought to be beneficial to production through increased food availability, more stable territory sizes and less variable temperatures. Exceptional droughts have major negative effect on numbers of resident juvenile trout.

6. Smolting

Salmon and Trout

Juveniles migrate to sea as smolts in April to May, stimulated by a combination of temperature and flow conditions, and possibly moon phase. Downstream migration requires free passage and moderate flows. If flows are too low, delays and increased predation risk can arise(McCormick *et al* 1998). This is a particular problem at impoundments and through ponded and still water areas.

Appendix 3: Key stages of life cycle of coarse fishes and species of conservation interest

Several fish community types dominated by coarse fishes have been described by Cowx et al, (2004 and 2012) and these are related to physical characteristics of the reach, especially gradient and river width. The main groups identified are
A) Barbel/grayling zone
B) Rheophilic cyprinids (chub, dace and gudgeon)
C) Eurytopic group “a” (roach, pike, perch, bream)
D) Eurytopic group “b” - large lowland rivers (bleak, tench, silver bream).

In general coarse fish are less sensitive to physical habitat conditions than salmonids, and eurytopic fishes adapt better to modified flows, although changes in hydrological regime can have important impacts. For example, water level changes, in response to weed cutting on the River Frome, have been observed to cause mortalities of roach eggs (Ladle, 2002).

While older fish, with well developed swimming abilities are able to actively avoid areas of high velocities, larval fishes (particularly the Cyprinidae) are not morphologically equipped to cope with such events. During the first few weeks of development larvae are able to tolerate velocities of only a few cm per second (Mann & Bass 1997) and are therefore very susceptible to being displaced downstream or totally washed out of the system. They can also be susceptible to mortality through damage by drifting debris or shifting bed material (Erman*et al*., 1988). Eggs may also be lost or damaged through wash-out of vegetation. Flooding is therefore most likely to have a major impact on fish if it occurs during spring or early summer, immediately after spawning has taken place, but see requirements for lowland eurytopic species. In general, species spawning on gravel (lithophils) require higher flow velocities than do phytophils, with phytolithophils occupying an intermediate position demonstrating greater plasticity in their requirements (Mann, 1996).

Lowland floodplain eurytopic species are intrinsically associated with wetland areas and floodplain habitats and may require connectivity between the river channel and floodplain environment for breeding and feeding purposes. For example, pike spawn in February or March in well-vegetated flooded back waters and side channels coinciding with late winter/early spring floods (Fabricius and Gustafson, 1958). Successful breeding and survival is linked to connectivity to these floodplain habitats especially in the spring early summer during higher flow events. This is a high risk strategy which can also lead to stranding of adults and young fish as the water recedes.

Large lowland rivers in particular need sustained marginal habitats, backwater areas and linked wetlands. The absence of large floods and a lack of sediment below a dam may result in this connectivity being lost. When sediment transport is low rivers may down cut, lose connection with their floodplains and drain them of water (Postel and Richter, 2003). Some fish benefit from the cover and food provided by riparian vegetation. In regulated rivers that experience unnaturally large flows, riparian vegetation may be absent. Other fish rely on turbid water for protection from predators.

Finally, cyprinids are known to make large natural longitudinal migrations usually for reproduction to spawn on upstream gravel beds during spring. Female fish then moved downstream quicker than males during summer. In autumn and winter both sexes migrate downstream. Many rheophilic cyprinids need similar conditions to salmonids for migration and spawning, particularly good flows in the spring (March-late June).

Conservation species

Allis shad and twaite shad are anadromous members of the Family Clupeidae, with a distribution that includes most of Western Europe. Both species have been recorded from most areas around the British Isles, but there are only four known spawning populations of twaite shad and none of allis shad (Aprahamian and Aprahamian 1990, Aprahamian et al. 2003, Baglinière et al. 2003, Maitland and Hatton-Ellis 2003). Allis shad is listed in Annexes IIa and Va of the EC Habitats Directive, Appendix III of the Bern Convention, Schedule 5 of the 1981 Wildlife and Countryside Act, and the UK BAP. Twaite shad is listed in Annexes IIa and Va of the EC Habitats Directive, Appendix III of the Bern Convention, and the UK BAP.

Males of allis shad migrate upriver at 3-9 years while females first reproduce 1-3 years later than males. Adults start approaching coasts at the end of February and enter rivers in spring (Whitehead et al. 1989). Twaite shad migrate upriver at 2-4 years with many individuals spawning over several seasons. Onset of migration appears to be linked to water temperature and day length.

River lamprey (*Lampetrafluviatilis*) and sea lamprey (*Petromyzonmarinus*) are anadromous species that spawn in fresh water but complete part of their life cycle in the sea, where they adopt a parasitic lifestyle, feeding on the body tissues and blood of fishes. Adults migrate upstream (late autumn early winter for river lamprey and spring for sea lamprey) to spawn on gravel in clean, fast-flowing rivers in late spring or early summer. The upstream migration takes place almost exclusively at night, with adults being sedentary and resting under rocks and riverbanks during the day (Hardisty 2006). The larvae (ammocoetes) live buried in fine sediments for 3-5 years before metamorphosing and migrating to sea. Both species are widely distributed in the British Isles, but mainly occur south of the Great Glen in Scotland (Maitland 2003a).

Sea and river lamprey are listed under Annex IIa of the European Habitats Directive 92/43/EEC as species whose conservation requires the designation of SACs. River lamprey is also included in Annex Va, as a species whose exploitation and taking in the wild may be subject to management measures (EC 1992). Both species are also listed in Appendix III of the Bern Convention, which requires signatory countries to take “appropriate and necessary legislative and administrative measures” to ensure their protection (COE 1979), are UK BAP species. There is no defined relationship between upstream migration and flows but Cowx et al. (2012) indicated that reduced flows can impede upstream migration past barriers and prevent access to upstream spawning grounds.

The European eel (*Anguilla anguilla*) is a catadromous species that migrates from fresh, estuarine and coastal waters to spawn in the Sargasso Sea in the Caribbean. The larvae (leptocephali) then drift in the Gulf Stream for 2 to 3 years across the Atlantic Ocean to Europe and metamorphose into juveniles (elvers). Eels usually migrate into fresh water as glass eels in the spring as temperatures rise above 4-6^{o}C.They utilise selective tidal stream transport but because of limited energy reserves and the migration is usually associated with spring tides. The adults, commonly referred to as 'silver eels' during the spawning migration, leave river systems to return to the Sargasso Sea. Males mainly mature into 'silver' eels at <45 cm at >4-6+ years, females at 6 to 15+ years, before emigrating back to the sea to breed. Little is known about the potential impact of low flows and over abstraction on eel stocks. The European eel is widely distributed in the British Isles, but is listed in the UK BAP, Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora, and as "critically endangered" on the IUCN red list following a Europe-wide decline in recruitment.

The table below provides key ecologically relevant flow regime elements for coarse fish and other species of conservation importance in UK rivers.

Table A3.1 Ecological relevant flow regime elements

	Timing and related conditions	Flow needs
Coarse fish: migration and spawning	February-June	Rheophilic cyprinids need good flows to migrate and spawn
Coarse fish: pike, stickleback and dace	February – April	No extreme high or low flows. Extreme high flows may wash out/displace or damage eggs and larval fish. Extreme low flows may result in stranding of fish in backwaters/marginal areas or drying out of eggs. Pike and sticklebacks spawn in flooded backwaters during late winter/early spring floods. Sustained and elevated flows are needed to ensure connectivity of backwaters/marginal areas and to avoid fish stranding during flow recessions.
Late spawning coarse fish (e.g. chub, barbel)	May – July	No extreme high or low flows. Extreme high flows may wash out/displace or damage eggs and larval fish. Extreme low flows may result in stranding of fish in backwaters/marginal areas or drying out of eggs.
River Lamprey	September -December	Elevated flows to attract river lamprey species into rivers and support upstream migration
Sea Lamprey	March April	Elevated flows to attract sea\ lamprey species into rivers and support upstream migration
Shad	March April	Elevated flows to attractive shad species into rivers and support upstream migration.

Appendix 4: Summary of building block function in relation to improving ecological potential

Key

Primary function

Secondary function

Function	Annual minimum flow	Autumn flood flow	Late summer flow elevations	Autumn & winter flow elevations	Spring flow elevations	Out of bank flows
Morphological function						
Flushing of fine sediment and organic debris		Primary function	Primary function	Secondary function		Secondary function
Refreshing gravels prior to spawning		Primary function	Secondary function			
Creation and maintenance of bedforms e.g. riffles., pools, bar features		Primary function	Primary function			Primary function
Prevent riparian vegetation from encroaching into channel	Secondary function	Primary function	Secondary function		Secondary function	Secondary function
Maintaining channel plan/cross sectional from and its continuing evolution		Primary function	Secondary function	Secondary function		Primary function
Connection to floodplain habitats/wetlands		Primary function				Primary function
Physico-chemical function						
Maintain nutrient and organic matter exchanges between river and floodplain		Secondary function	Secondary function			Primary function
Maintain exchange of oxygen and removal of metabolites from gravels	Primary function				Primary function	
Maintain suitable water temperatures, dissolved oxygen, and water chemistry	Secondary function				Secondary function	Secondary function
Ecological function						
Provide adequate habitat for aquatic organisms	Primary function	Primary function	Secondary function		Primary function	Primary function
Maintain balance of competitive and stress-tolerant organisms	Primary function	Secondary function	Secondary function	Secondary function	Secondary function	Secondary function
Support the upstream migration of fish	Secondary function		Secondary function	Primary function		
Support successful fish spawning	Primary function			Secondary function	Primary function	
Support the downstream migration of fish	Secondary function				Primary function	
Flows to support egg and larval development in gravels	Primary function				Primary function	

Appendix 5: Applications of the building block method

The recommendations for flow regimes presented within this paper apply to both water bodies immediately downstream of reservoirs and those designated as HMWB from being impacted by reservoir intakes i.e. catchwaters. Figures A5.1 and A5.2 illustrate examples of the flow regimes developed using the default flow building blocks in each of these situations using data from upland Scottish catchments.

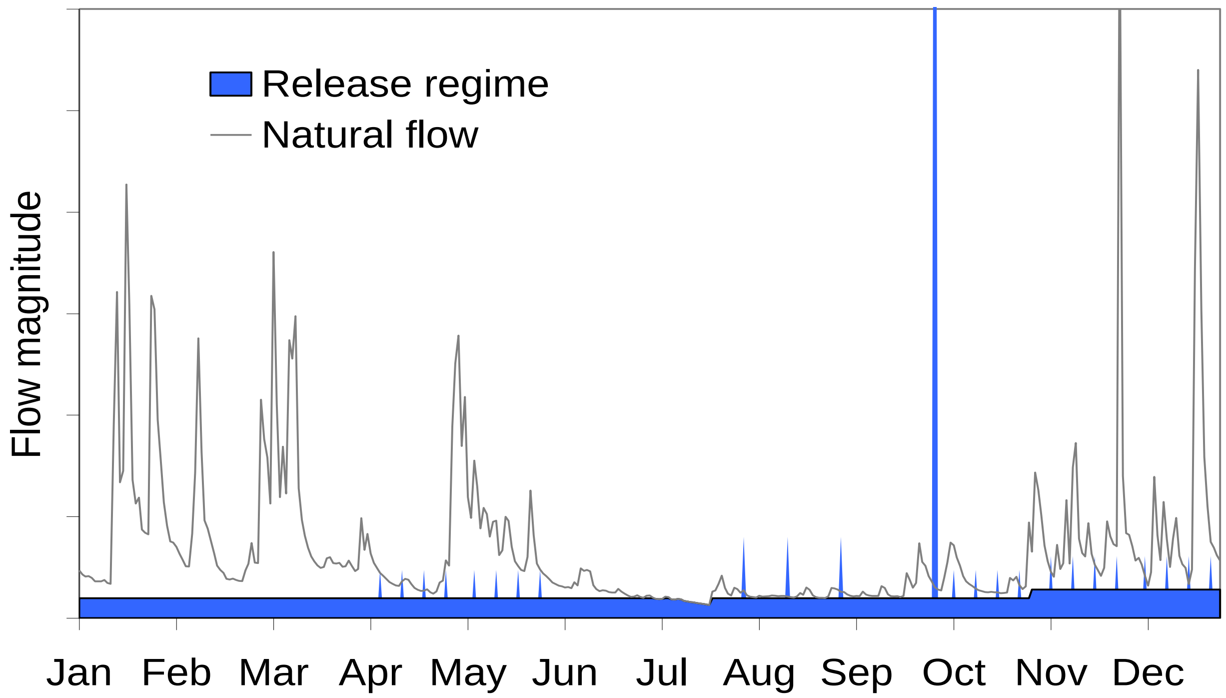

Figure A5.1: An example of a flow release designed using the default building blocks

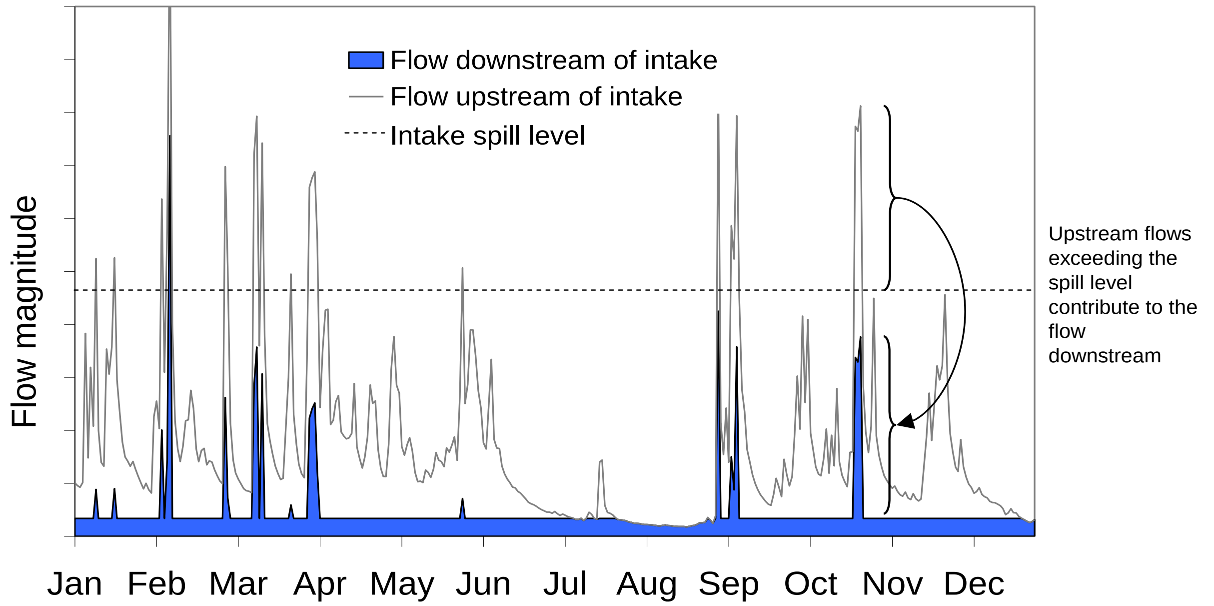

Figure A5.2: An example of a residual flow regime downstream of an intake

Appendix 6: Background to suggested good ecological potential flow criteria

All the flow components described in this appendix refer to the flow in those rivers affected by the water abstractions and impoundments associated with the use. This flow may be made up of water passing the impounding works and intakes (including via fish passes, managed flow releases from the reservoir or reservoir overtopping) and inflows from unregulated tributaries.

(a) Annual minimum flow

Suggested default flow
Key references:

SNIFFER (2006), SNIFFER (2007)
Page 13, Sniffer 2012
Page 101, Sniffer 2012
Page 140, Sniffer 2012
Page 162, Sniffer 2012
Page 163, Sniffer 2012

Some river flow is needed all year to maintain a functioning aquatic ecosystem. If, for good ecological potential, the default magnitude of the flow required for this purpose is set too high, achieving it is unlikely to be possible at many sites lacking such a flow without a significant adverse impact on the use. If the magnitude is set too low, the ecological productivity of sites is likely to be impaired by factors such as limitations on habitat space, and poor habitat conditions. Setting a default flow magnitude requires a judgement about where the right balance lies. This section describes the basis for our suggestions.

The effect on habitat space of reductions in flow depends on the geometry of the channel cross-section. This is illustrated in the figure A6.1 below using a simplified river cross-section, which, although does not represent all river channel shapes, demonstrates the relationship that can occur between flow and wetted area. As flow is reduced from a high flow to a low flow, the initial effect is principally on water depth rather than wetted area (A to A1). As flows reduce further, a point is reached where the rate of decrease in wetted area becomes more marked and flow reduction leads to parts of the river bed being exposed (B to B1).

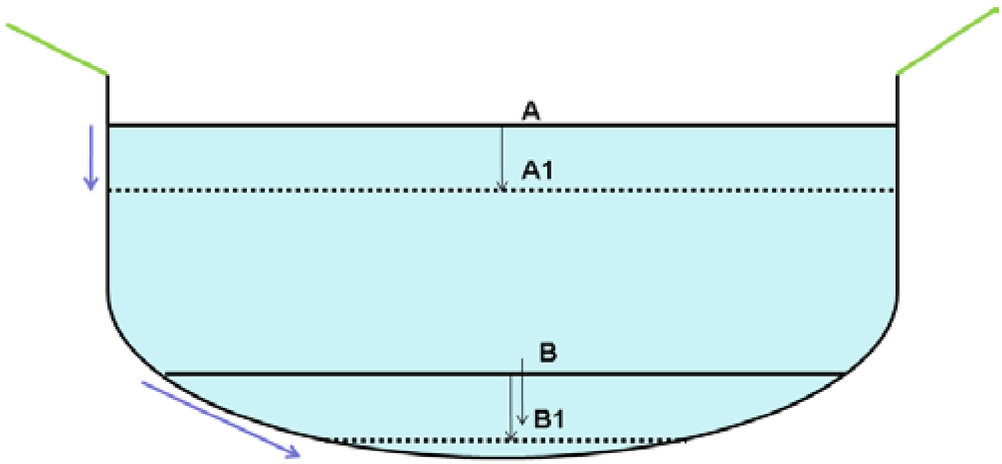

Figure A6.1 An illustration of a simplified cross-section of a river where the levels A and B are natural flow conditions (typically wet and dry periods) where A1 and B1 illustrate the water level after a certain abstraction of water (from SINTEF 2012 p. 21)

The relative importance of the depth and velocity varies between sites; for example, below bankfull, straight channels tend to speed up with increased discharge, whereas braided or meandering channels tend to spread out (i.e. increase their wetted perimeter)[24].

Even regular rectangular or trapezoidal channels have two important breakpoints in hydraulic behaviour; once flow exceeds bankfull, or is insufficient to achieve bed coverage, wetted perimeter and width change rapidly[25]. In some steep channels, velocity changes can be relatively minor as the bed becomes exposed, such that the river is effectively miniaturised, becoming smaller whilst the type of flow is maintained. The effects of low flows are often to miniaturise habitats before their character is ultimately changed as flow over riffles and runs is lost[26].

The geometry of river channels can vary considerably over short distances. As a consequence, the point at which reducing flow starts to make a noticeable impact on wetted area also varies considerably.

Flow thresholds at which further flow reduction has a noticeably greater impact on wetted area than do flow changes above the threshold have been investigated for a number of UK rivers[27]. The results are summarised in Figure A6.2. Of the limited number of rivers assessed, all appeared to have reached a threshold in the rate of reduction in wetted area by around a Qn96 flow. For a proportion, the breakpoint appeared to be at a substantially higher flow.

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[24] Gordon et al. 2004
[25] Gippel and Stewardson, 1998
[26] Mainstone, 2010
[27] Acreman, 2012 reported in Sintef, 2012

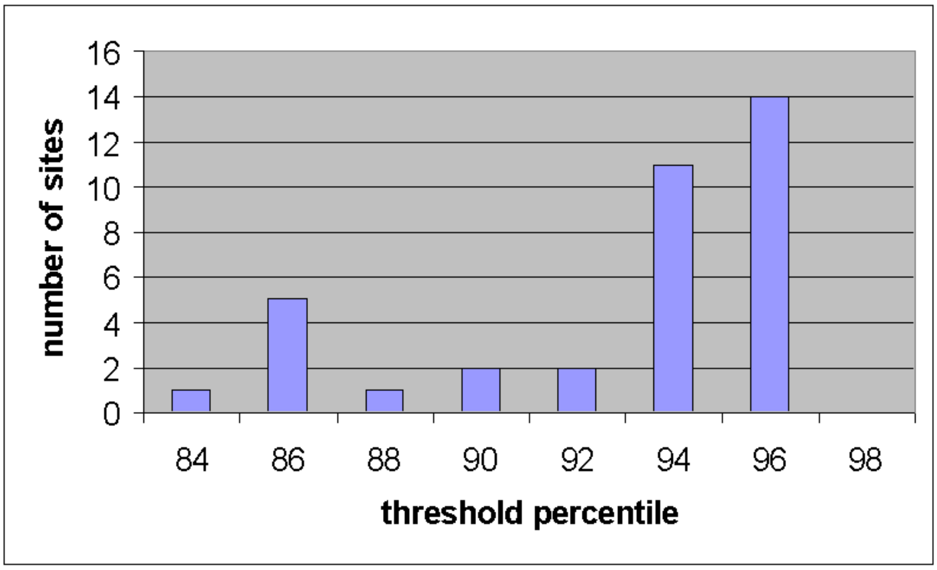

Figure A6.2: Threshold percentiles for a sample of different rivers in the UK

A number of other countries across Europe have defined a minimum maintenance flow in rivers affected by water storage in reservoirs. These are summarised in Table A6.1 and expressed in terms of % of mean flow. As a guide, the low flow statistic Q95 typically falls between 5 and 20% of mean flow in the UK (Gustard et al. 1992)

Table A6.1: Comparison of the maintenance flows identified by a range of European countries

Country	**Maintenance flow value**	**Maintenance flow value as proportion of annual mean flow**
Austria	Must be: • At least 20% of natural daily flow and, when flows are low, not less than: • the lowest daily minimum flow • at least one third of the natural mean annual minimum flow for water bodies where the lowest daily flow is less than a third of the mean annual minimum • at least one half of the natural mean annual minimum flow for water bodies with a mean flow below 1 m³/s and where the lowest daily flow is less than one half of the mean annual minimum	20%
France	5 % to 10 % of mean annual flow	5 to 10%
Norway	Qn95.6	6 to 12%
Romania	In general, Q95% (yearly minimum monthly mean discharge with 95 % probability of occurrence) is recommended as “guaranteed” flow. In the first RBMP (river basin management plans), standing on the available studies done by the research institutes, EF was considered to be the minimum between Q95% (yearly minimum monthly mean discharge with 95% probability of occurrence) and 10% out of the mean discharge averaged on many years. The minimum release is approximately 10 % of mean annual flow or	10%

	Q95.	
Slovenia	Minimum release varies from 8 % to 22 % of mean annual flow	8 to 22%
UK	75 - 85% of Qn95.	6 to 19%

At a flow of around Qn96, in most rivers part of the river bed is likely to be exposed. Unless the breakpoint is at a lower flow, a maintenance flow of Qn96 would mean that average habitat space over the summer months is miniaturised relative to natural conditions. This may limit ecological productivity compared with the river under a natural flow regime. Vulnerability to extremes of temperature may also be higher. However, the available evidence suggests that in many channels, the wetted area at around Qn96 in many cases is likely to be sufficient to maintain a stock of juvenile salmonid fish where channel bed characteristics are suitable.

During winter, natural baseflows are typically higher than during the rest of the year and at this time, egg habitats are vulnerable to dewatering once flows drop back to low baseflows. In addition, low baseflows may compromise water quality, in particular dissolved oxygen levels, within the hyporheic zone (Malcolm et al. 2012). The minimum base flow required to support GEP was addressed within Sniffer project WFD48 (SNIFFER 2006) and the conclusion made was that a higher baseflow during winter is required for adult fish and for spawning.

The international best practice is to introduce a variable annual low flow based on seasonal flow statistics. The variations to the annual low flow are driven by an ecological need to introduce more variability. In some instances, based on local ecological conditions, it may be necessary to introduce more variability than presented in the building block criteria if there is an ecological justification in doing so.

Suggested variations to default flow- key references

Depth criteria

These have been informed by a literature review carried out under SNIFFER project WFD21d, excerpts of which are presented in the table below.

Table A6.2. Relevant depth criteria excerpts

Species	**Life stage**	**Depth criteria**	**Source**
Atlantic salmon and brown trout	Spawning and egg incubation	mean 38cm, range 17-50cm. Fish size (L,cm) specific, thus: Depth(cm) = 0.176L + 0.76	(Crisp and Carling,1989) Armstrong *et al.*, (2003) Klemetsen*et al.*,2003)
Atlantic salmon	0+ rearing (summer/autumn)	5-65cm, prefer 20-30cm	Gibbins*et al* (2001)
Atlantic salmon	1++ rearing (summer/autumn)	20-70cm	Armstrong et al., 2003
Brown trout	0+ rearing	5-35cm	Armstrong et al., 2003

	(summer/autumn)		
Brown trout	1++ rearing (summer/autumn)	5-120cm; mainly opt >50cm.	Armstrong *et al*., (2003); Crisp (2000).

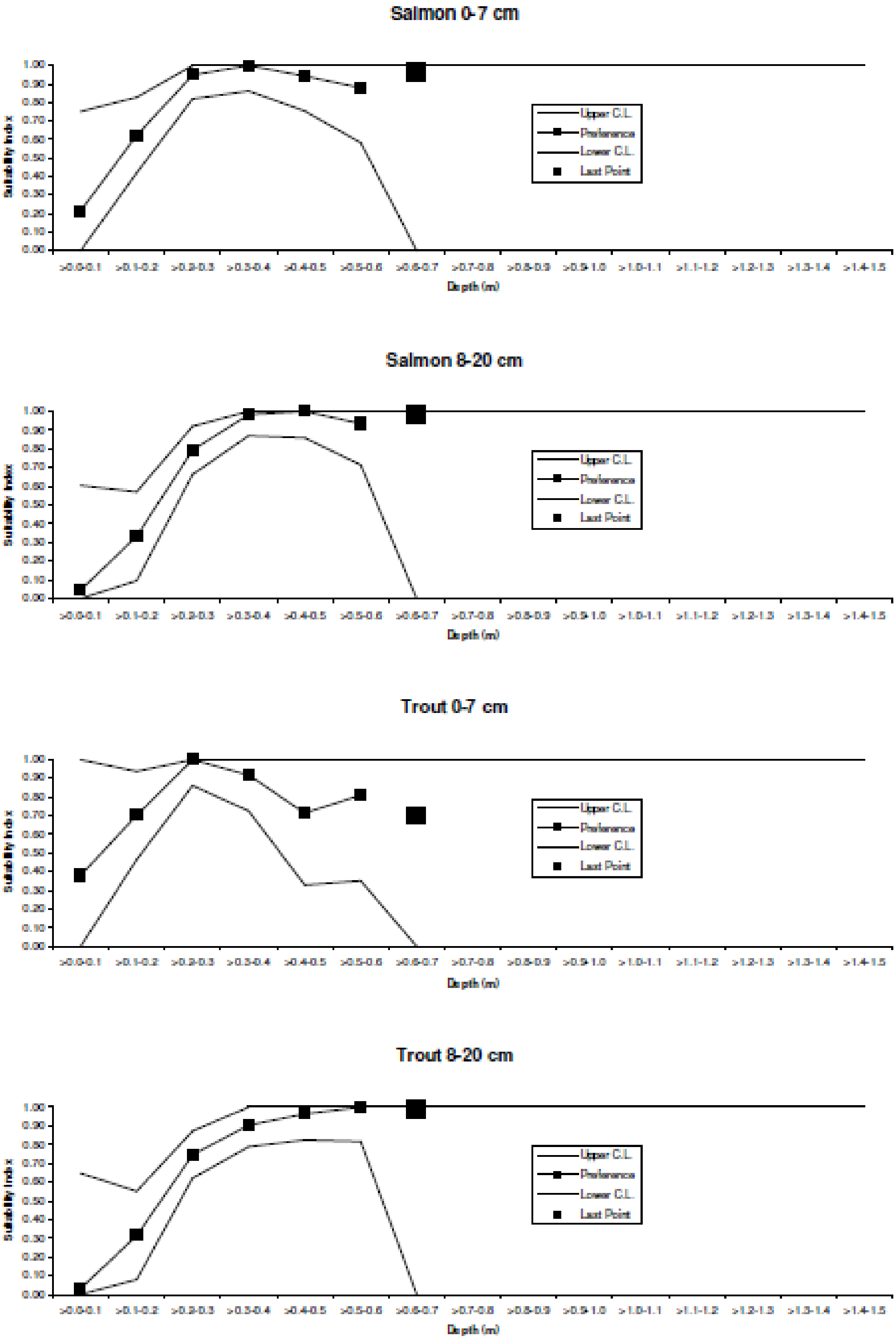

Figure A6.3 Suitability indices derived from preference for depth use by two size groups of salmon and trout. Last point represents combined data for greater depths (from Dunbar et al 2001 p. 67)

(b) Autumn flood flow

Key references
Page 16, Sniffer 2012
Page 147, Sniffer 2012

Small floods, with a return period between one and five years, have the capacity to mobilise coarse sediment on the channel bed, breaking up any coarse surface (armour) layer, releasing finer subsurface sediment and replenishing sediment in bars and on riffles. Through their relative frequency and significant effect on sediment erosion, transport and deposition, small floods of between one and two year return period may be the most important in maintaining channel form[28].

The one to two year return period flood is likely to represent a bankfull flow and this has been found to be sufficient to fully mobilise the bed and break up armouring in typical gravel bed rivers. Armouring occurs where flows are competent enough to transport finer gravels from the bed surface, but are unable to mobilise larger particles (Vericat et al. 2006; 2008). Under a natural flow regime, periodic floods with a high competence would break up the surface armour layer, releasing finer sediment from underneath and replenishing the surface layer with finer particles (Vericat et al. 2006). Where impoundments prevent large floods, break up of the armour layer does not occur and the armouring effect becomes more extreme, creating a more permanent armour, or ‘pavement’. The bed becomes coarser and stable (Sear, 1995) and sediment supply to downstream reaches is reduced. Without active sediment transport, the pool-riffle sequence becomes stagnated, maintaining reasonable flow diversity but not good spawning habitat.

Newson (pers comm.), investigating the break up of armoured and highly structured gravel beds, found random (very minor) movements of bed material at low flows and selective entrainment – (enough to release some fines and be considered a ‘flushing flow’) at half bankfull. ‘Equal mobility’ - i.e. full movement of the bed, was found at bankfull. Carling (1988), however, is reported in King et al. (2008), as showing evidence that in some coarse gravel bed rivers, flows of greater than bankfull are required before substrate is fully mobilised.

(c) Late summer flow elevations

Key references
Page 16, Sniffer 2012
Page 102, Sniffer 2012
Page 146, Sniffer 2012

Geomorphological state defines the response of channel morphology to hydraulic behaviour. The interaction of hydraulics with the channel boundary operates through the erosion of bed and banks, and through the entrainment, transport and deposition of sediment. These

[28] King et al, 2008

processes thereby direct the evolution of channel form, which is constantly adjusting to the prevailing flow and sediment conditions.

Periods of low and average flows tend to cause immobility or, if sediment is available, gradual accretion of finer material.

Pulses of higher flows, during which shear stress (a function of water velocity) and stream power (a function of discharge) are competent to flush the fine material downstream[29] occur seasonally, perhaps two or three times a year[30]. Flows of 0.75*ADF should be adequate to redistribute biological and substrate material in the reach. These will flush surface deposits of fine sediment downstream and may help to prevent clogging of the surface of the coarser matrix. They also support the maintenance of existing bedforms and habitats through the maintenance of features such as channel bars and the refreshing of gravels.

Higher flows may be required to ensure existing channel morphological features such as riffles and bars are refreshed and maintained. Table A6.3 lists some example maintenance flows of particular rivers. The building block default flow can be increased if it is thought that the existing channel morphological features are not being maintained.

Table A6.3 Summary of flows required for channel maintenance

Discharge	River	Source
49% to 57% of bankfull discharge	River Coquet	I.C. Fuller et al (2002)
60% of bankfull discharge	Gravel movement for upland single thread channels	Carling (1988)
60 to 75% of bankfull discharge	AfonTwymyn	Whitfied (unpublished)
55% to 82% of bankfull discharge	River Vyrnwy	Whitfield (unpublished)

[29]Acornley& Sear 1999
[30] King et al 2008

(d) Autumn/winter flow elevations

Key references
Page 101, Sniffer 2012
Page 162, Sniffer 2012

Table A6.4 Recommended river flow thresholds for salmon passage, expressed as proportion of local Q95 and ADFs, adapted from data in Solomon et al. (1999). Based on radio-tracking at specific locations in a chalk river (Hampshire Avon) and five surface water dominated rivers (Exe, Tamar, Taw, Torridge and Tavy) (from SNIFFER 2012 p163.

River type	**Lower river**		**Upper river**	
	Prop (Q95)	Prop (ADF)	Prop (Q95)	Prop (ADF)
Chalk	1.10	0.39	1.30	0.46
Surface water, Min.	1.00	0.11	2.50	0.26
Surface water, Max.	2.50	0.26	6.00	0.63

(min/max refers to range across the five rivers)

(e) Spring flow elevations

Key references
Page 101, Sniffer 2012

Spring flow elevations are primarily designed to support downstream migration to sea of salmon and sea trout smolts and migration of non-salmonid species, including shad and sea lamprey, to spawning areas.

Smolt movement downstream is, in part, triggered by flow elevations and higher flows may lead to more rapid downstream migration, which in turn, may aid successful completion of the migration (McCormick *et al* 1998). Baxter (1961) indicated that freshets of 0.3 x daily mean flow may be required to support salmonid smolt migration.

Appendix 7: Hydraulic modelling

Hydraulic-habitat modelling

Hydraulic information may be used as part of the evidence to refine the default flows for the building blocks to better optimise ecological and geomorphological effectiveness. To apply our suggested hydraulic criteria, it would be necessary to:

(a) carry out a habitat mapping exercise, followed by surveying selected habitats in proportion to their occurrence at the waterbody scale or undertake surveys which work at the waterbody scale. We recommend that the advice of ecologists and geomorphologists should be taken into account in identifying the survey methods;

(b) where a habitat in one or more reaches is critical to overall ecological health, such as a restricted spawning habitat or a barrier to migration which would be passable under natural flow conditions, hydraulic modelling of these reaches would be required to ensure flows are sufficient to overcome these restrictions;

(c) where a sediment mobilisation issue has been identified, identify which sections of river would naturally contain sediments that are periodically reworked by flows, and calculate the flows required to mobilise those sediments. The results should be considered when designing subsequent flow trials or building blocks and

(d) conduct flow trials during which appropriate hydraulic and geomorphological data are collected for comparison with the suggested hydraulic criteria.

There is a requirement that any hydraulic-habitat approach to determining the magnitude of a flow building block in order to improve or maintain ecological quality must work at the water body scale. Microhabitat approaches such as those which use habitat suitability indices may be suitable for determining flows required to meet good ecological potential but only if they are set within a framework that seeks to ensure the evidence is representative of the waterbody through a robust upscaling methodology. For example, Dunbar *et al.* (2001) describe the approach, developed under the Environment Agency's Ecologically Acceptable Flows program, of quantitative habitat mapping in order to define representative reaches in which to employ a microhabitat modelling tool (PHABSIM).

Table A7.1 Range of scale (extent) and granularity of the hydraulic-habitat models covered (from Dunbar *et al.* 2012 p. 503)

Scale (extent) of data collection	Granularity (fundamental modelling unit)	Upscaling to sector or sub-catchment
Representative or critical reaches	Microhabitat	Assumed: because reaches are representative
Cross-sections represent habitat types	Microhabitat	Via mesohabitat mapping
Sector/sub-catchment/catchment	Microhabitat	Not required
Sector/sub-catchment	Mesohabitat	Not required

Table A7.1 illustrates the range of scales of hydraulic-habitat modelling approaches currently used and highlights the methods of up scaling to sector or sub-catchment, which, for the purposes of this guidance includes the water body catchment.

Applying the hydraulic criteria for the building blocks will require evidence that each criterion is met at the water body scale. For example, a criterion that stipulates that no significant reduction in suitable juvenile salmon habitat area with depths of at least 20cm should occur as a result of flow reduction would require a sampling strategy that ensures that depth measurements are representative of the suitable juvenile habitat of the water body as a whole under the specific flow conditions.

Hydraulic modelling for determining sediment movement

In order to ensure that flow are sufficient for sediment movement, their magnitude can be estimated using well established relationships between indicative grain sizes and the boundary shear stresses required to entrain them. Boundary shear stress (τ) varies as a function of flow depth (H) and channel slope (S):

$$\tau = \rho g H S$$

where ρ is the density of water (1,000 kg m^{-3} at 5°C) and g is gravitational acceleration (9.81 m s^{-2}).

The critical boundary shear stress (τ_{cr}) required to entrain a certain size of sediment (D) is given by the Shields entrainment function:

$$\tau_{cr} = 0.045\, g\, (\rho_s - \rho)\, D$$

where ρ_s is the density of sediment (typically 2,650 kg m^3 for silicate sediment).

Established methods (e.g. building a rating curve using observed hydraulic measurements or calibrating a 1-dimensional hydraulic calibrated model such as Conveyance Estimation System (CES) or HEC-RAS) can be used to develop the initial relationship between discharge (flow) and flow depth. The mobilised particle sizes can then be predicted using the model or calculated within a simple spreadsheet using the shear stress equations above

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