PAPER 1

Analysis of the water flow requirements, expected environmental benefits and generation reductions required to achieve Good Ecological Potential in HMWBs affected by hydro-electric abstraction in Scotland.

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Introduction

This analysis has been produced to support the Tay DSFB's response to the SEPA / Scottish Government consultation on water storage schemes for hydropower generation.

It is apparent that, in order to answer some of the questions posed by the consultation, it is essential to quantify the amount by which generation would need to be reduced to reach GEP. Only then can a view be given regarding the various thresholds etc proposed in the consultation.

This document presents the results of an initial broad analysis of flows and implications for generation across Scottish HMWBs affected by hydro generation.

Methods

The following analyses are limited to those waterbodies which have already been defined by SEPA in the first RBMPs as Heavily Modified Waterbodies (HMWBs) that have failed to reach Good Ecological Potential because of hydropower abstractions.

There may be instances where classification results are subject to debate but, for the present purposes, only those that have been defined by SEPA to fail the current standards are considered.

The relevant HMWBs were identified from SEPA's web based interactive map. For each HMWB, an appropriate base flow was estimated. This was taken to be the Q95 flow according to the SEPA / Scottish Government accepted flow standards, leaving aside, for the present, issues such as the 85% rule etc. The Q95 flow appropriate for each HMWB was assumed to be the sum of the Q95 flows at all significant abstraction points within each HMWB catchment area.

Q95 flows were estimated using Low Flows 2 software (Wallingford Hydrosolutions). The Low Flows range of software is a simpler, less costly, form of the flow estimation software used by SEPA and SSE (e.g Low Flows 2000 or Low Flows Enterprise). The original Low Flows software produced the same central estimates of Q95 as Low Flows 2000 but without confidence limits. However, in 2011, Wallingford Hydrosolutions issued an updated version of Low Flows called Low Flows 2. In the River Garry catchment, at least, Low Flows 2 generally produces higher flow estimates than Low Flows or Low Flows 2000 did and provides a more accurate estimate of gauged flows in the River Tilt compared to Low Flows and Low Flows 2000. Low Flows 2 is assumed therefore to produce the most up to date flow estimates.

Q95 flow estimates for each waterbody were used to produce estimates of reduced electricity generation. These were based on published head data for the affected power stations. For SSE schemes, gross head data were obtained from the publication *Power from the Glens.* For the purposes of the estimates, headloss was assumed to be 10%. For the Scottish Power Galloway schemes, "net head" data were obtained from the *Galloway Hydros Technical Factsheet* on the Scottish Power website. As "net head" data were used, no correction for headloss was made in this case. Such detailed information have not yet been obtained for the Alcan power stations, but approximate heads are referred to in Payne's book *The Hydro* and these have been used (assumed to be gross head).

The only form of quantification of environmental gain attempted was to estimate the approximate area of wetted river habitat that would be restored in each waterbody. This had, of necessity, to be a very rough process in this first instance.

For the purposes of at least producing consistent relative measures between waterbodies, the length of watercourse downstream of an abstraction point that was assumed to benefit from flow restoration was to that point where the area of unabstracted catchment below an abstraction point equalled the abstracted catchment area. That is, unless a major confluence with an unabstracted waterbody occurred first. Beyond this point, it is assumed for present purposes that sufficient flow will exist to maintain the wetted area for most of the time.

Approximate expected wetted widths for each waterbody were estimated from aerial photographs on Google Maps. For example, where a watercourse upstream of an abstraction point is clearly visible, the expected downstream wetted width was taken to be the same as the average wetted width immediately upstream of the abstraction point. It was not always possible to do this because of the presence of vegetation or because a waterbody might be impacted by numerous small abstraction points. In such instances, widths had to be inferred from the dry or almost dry stream beds. In some cases it was appropriate to take the width at the point where the abstracted flow discharged from a pipe or aqueduct into another waterbody.

While there is clearly potential for significant error in this approach, it is likely to be good enough to produce approximate "ball park" figures in the first instance. No attempt was made to take account of physical habitat quality, which might vary greatly between streams.

Having estimated Q95 flows, wetted areas and reduced generation, it was possible to put a value on the wetted habitat created in terms of electrical energy per unit area. This was expressed as the number of standard units (kilowatt hours) per square metre.

For the purposes of presentation, in some instances where one or more smaller abstracted HMWBs feed into a larger abstracted HMWB (e.g. the middle Garry), the results were amalgamated and treated as one single unit.

Results

The estimated flows, restored areas and required generation reductions are presented in Table 1 for all the waterbodies considered.

Table 1. Estimated Q95 flows, restored wetted areas and generation reductions for Scottish Heavily Modified Water bodies identified as impacted by hydro abstraction.

Main catchment	Waterbody	Estimated Q95 flow (cumecs)	Restored wetted area (Sq. m)	Generation reduction (GWh per annum)
Scottish and Southern Energy Schemes				
Awe	Abhainn Fionain	0.05	37980	0.665
Awe	Cladich River	0.034	38080	0.848
Awe	Allt Kinglas	0.051	25152	0.828
Conon	Allt Goibhre	0.042	46016	0.773
Conon	River Grudie	1.613	169026	20.958
Conon	Allt Coire Mhuilidh	0.039	14868	0.486
Conon	Glascarnoch River	0.617	63000	11.119
Eachaig	Little Eachaig River	0.025	11840	0.238

Earn	Lednock Water and Invergeldie Burn	0.236	26700	5.147[1]
Earn	Glen Tarken Burn	0.021	24123	0.411
Earn	Beich Burn	0.03	15238	0.188[2]
Fyne	Allt na Lairige	0.07	13384	1.348
Fyne	Kinglas Water	0.028	20682	0.600
Loch Lomond	Inveruglas Water	0.23	51914	4.927
Loch Lomond	Dubh Eas	0.089	57062	1.907
Loch Tay	Lawers Burn	0.03	22050	0.963
Loch Tay	Morenish Burn	0.08	15296	2.568
Loch Tay	River Lochay	0.18	27400	2.924[3]
Loch Tay	Duncroisk Burn	0.079	14400	1.100[4]
Loch Tay	Auchlyne West Burn	0.049	20410	0.557[5]
Loch Tay	Auchmore Burn	0.02	16880	0.577
Loch Tay	Allt Breaclaich	0.075	20435	2.164
Loch Tay	Ardeonaig Burn	0.021	12720	0.606
LochRiddon	Auchenbrek Burn	0.029	14801	0.276
Loch Striven	Bailliemore Burn	0.023	14100	0.219
LochStriven	Glen Tarsan Burn	0.126	8772	1.199
Lussa	River Lussa	0.201	49824	1.803
Lyon	Allt Conait	0.471	27783	11.730
Lyon	Allt Baile a Mhuilin	0.017	11765	0.469[6]

[1] The Lednock has an existing mitigation flow regime whereby a flow is released from the dam in dry weather but none at other times. The figure quoted assumes a constant Q95 flow, but in reality, the amount of generation reduction will be less than this. Time has precluded making this correction.
[2] The Beich Burn has an existing arrangement whereby at flows under a *ca*. Q60 no abstraction takes place. Partial abstraction is allowed at increasing flows leading to total abstraction at a *ca.* Q26. It has been estimated that a Q95 or greater flow will be in place for approximately 68% of the time, therefore the figure quoted here assumes a new Q95 flow is only required for 32% of the time.
[3] At three of the Lochay offtakes there is an existing arrangement whereby below certain thresholds abstraction reduces and ceases completely at another threshold. It has been estimated that the discharge reaches the Q95 level when the natural flow is *circa* Q56. Therefore, the estimate provided assumes that a Q95 flow will only be required at these three offtakes for 56% of the time. As there is always flow in the Lochay the impact of this measure will be to widen the existing channel. For illustrative purposes it is conservatively assumed here that the width will increase by two metres.
[4] The Duncroisk Burn is abstracted at two locations. The estimates provided are based only on the lower, main, abstraction point. In practice it may not be possible to discharge a full Q95 for 95% of the time unless a flow is also released from the upper intake, but for the purposes of this estimate it is assumed it would.
[5] As in the case of the Lochay abstractions referred to in 3 above, there is an arrangement on the Auchlyne West Burn whereby during the period 15 March – 15 September only, abstraction reduces and eventually ceases at a certain threshold. The effect of this has again been taken into account in the estimate.

Lyon	Allt Gleann Da-Eig	0.017	18410	0.475[7]
Lyon	Allt a Chobhair	0.031	17616	0.915[8]
Naver	River Vagastie	0.035	40500	0.246
Ness	River Foyers (Fechlin and Mohr)	1.427	177260	19.756
Ness	Gearr Garry	3.416	18000	26.684[9]
Ness	Allt Bhlaraidh and Allt Loch a Chrathaich	0.155	46395	4.220
Ness	River Doe and Allt Bhuruisgidh	0.225	41115	1.566
Ness	River Loyne	0.881	53200	6.132
Ruel	Garvie Burn	0.07	16254	0.400[10]
Shira	Brannie Burn	0.045	26726	1.023[11]
Shira	Kilblaan Burn	0.017	11065	0.387
Spey	Allt Cuaich	0.16	31220	3.762
Tummel	Allt Chaldar	0.07	5548	0.162
Tummel	River Ericht	2.295	94500	27.690
Tummel	Killichonan Burn	0.05	32430	0.603
Tummel	Aulich Burn	0.008	11100	0.097
Tummel	Allt Cregain Odhair	0.011	17713	0.113
Tummel	River Garry (upper waterbody)	0.353	130320	2.130
Tummel	Bruar Water	0.352	79588	6.507
Tummel	River Garry (middle W.B.)	0.921	304844	17.024[12]

[6] As with the Beich, Lochay etc there is also an arrangement in the Allt Baile a Mhuilin where no abstraction takes place below a threshold. The effect of this has also be taken into account in the estimate.

[7] A similar arrangement described in 6 also occurs on the Allt Gleann Da-Eig.

[8] A similar arrangement to 6 and 7 also occurs on the Allt a Chobhair.

[9] There is an existing compensation agreement on the Gearr Garry whereby a flow of at least 1.044 cumecs must be released. That flow is estimated to be < Q99 (that is with the Low Flows 2 "lake effect" correction on). The estimated flow shown is the additional amount of flow that would be required to meet Q95. However, from images on google maps it appears that the existing flow does almost cover the entire river bed. Therefore the flow increase will largely result in an increase in depth rather than width. The increase in width was therefore assumed to only be 5 metres in this case.

[10] Again, on the Garvie Burn, there is an agreement to cease abstraction at lower flows and this has been corrected for.

[11] The main stem of the River Shira was also identified by SEPA as being at less than GEP. However, there is an existing agreement whereby a flow of at least 0.263 cumecs should be maintained at the highest point to which salmon can access, which is just downstream of the confluence with the Brannie Burn. The Q95 at that point is estimated to be 0.314 cumecs. The provision of a Q95 flow on the Brannie Burn would effectively ensure that the Q95 flow would be achieved in that part of the Shira as well as in the Brannie Burn itself. It is assumed here that this action would add 2 metres wetted width to the Shira down to the confluence with the Kilblaan Burn.

[12] The middle Garry waterbody (Struan Weir to Garry Offtake) is fed by another failing HMWB, the Allt Anndeir. Its Q95 flow and surface area are included in this figure. While not failing in its own right, the flow of another tributary, the Edendon Water, is also included as part of the total flow. Note also, in practice, it would not be

SSE Total				**197.49 GWh**
SSE total annual hydro production (2009 – 2011 average[13])				**2963.33 GWH**
% of SSE total production				**6.7%**
Alcan Schemes				
Leven	Allt na h Eilde	0.154	23856	3.395
Lochy	Allt a Mhuillin	0.052	15776	0.981
Lochy	Allt na Caillich	0.044	24090	0.830
Lochy	Allt Leachdach	0.041	15939	0.774
Lochy	Allt Laire	0.061	23287	1.151
Lochy	River Cour	0.247	113276	4.661
Spey	River Mashie	0.122	28676	2.302
Alcan Total				**14.09 GWh[14]**
Scottish Power Galloway Scheme				
Dee	Earlstoun Power Station	0.963	26100	1.655[15]
Dee	Carsfad Power Station	0.646	17500	1.110[16]
Dee	Kendoon Power Station	0.869	23760	3.435
Dee	Black Water of Dee & Pullaugh Burn	0.598	113276	5.961[17]
Dee	Water of Deugh[18]	0.202	13020	0.226
SP Total				**12.387 GWh**
SP total Galloway hydro production				**245 GWh[19]**
% of SP Galloway production				**5%**

possible to maintain a Q95 flow all of the time in the middle Garry unless either a flow is also released in the upper Garry or if water diverted to Garry Offtake from the Bruar Water is used.

[13] Data from SSE Annual Report 2011

[14] Annual production data have yet to obtained from Alcan's Fort William site

[15] At Earlstoun Dam there is an existing compensation flow which is less than Q95. The flow estimate shown is that required to make up the difference.

[16] Carsfad Dam - ditto

[17] There is a compensation requirement in the lower reaches of the Blackwater of Dee, but the threshold is less than the Q95 for that point and that flow is partially made up of natural flow from the lower catchment. Therefore, there is no consistent flow from Clatteringshaw Reservoir and no flow from a tributary called the Pullaugh Burn. The flow estimate shown is based on a full Q95 from the Pullaugh Burn and on the arbitrary assumption that the additional flow that will need to be released from Clatteringshaws over and above present releases to maintain a Q95 will be equivalent to 60% of the Q95 at Clatteringshaws.

[18] There are existing HoFs on the Water of Deugh and the Bow Burn. The Bow Burn HoF already exceeds Q95. The flow estimate provided for the Deugh is that required to make up the difference between the existing HoF and the estimated Q95.

[19] Estimated using installed capacity and average load factor data presented in the *Galloway Hydros Technical Factsheet*

It is clear from Table 1 that, notwithstanding errors and uncertainties, to provide Q95 flows in all the HMWBs identified will require a total reduction in generation of more than twice the 100 GWh envisaged by SEPA. And that is only to cover the base flow. Any provision of freshets will be additional.

The flows required and estimated areas of habitat restored vary considerably between waterbodies, reflecting differences in the size of rivers that are subject to abstraction, presence of major confluences etc. There are considerable differences in the amount of electrical energy that would have to be reduced in different waterbodies.

To provide a clearer picture of the differences in wetted areas between waterbodies, they are displayed in ranked order according to size in Figure 1. This shows that the most significant river affected by hydro abstraction is the River Garry (Perthshire), but in comparison to the most significant rivers, many of the abstracted water bodies are, in fact, quite small.

In Table 2, each waterbody is ranked in descending order according to percentage of the total area of restored habitat (column 2) (all companies combined). Column 3 of Table 2 shows the required energy reduction for each waterbody as a percentage of the total reduction required. While the trends in the 2nd and 3rd columns do parallel each other, the two percentages are not identical for each waterbody. In some cases the percentage reduction in energy is less than the percentage of the habitat gained and in others the reduction in energy gain is greater, meaning that the restored habitat varies in terms of energy reduction. This is more clearly demonstrated in the 4th column of Table 2 which presents the required energy reduction in each waterbody in terms of standard units of electricity (kilowatt hours) per square metre of habitat. That varies from less than 10 to hundreds.

Figure 1. Estimated surface area of new wetted habitat which will be restored in each HMWB under a Q95 flow.

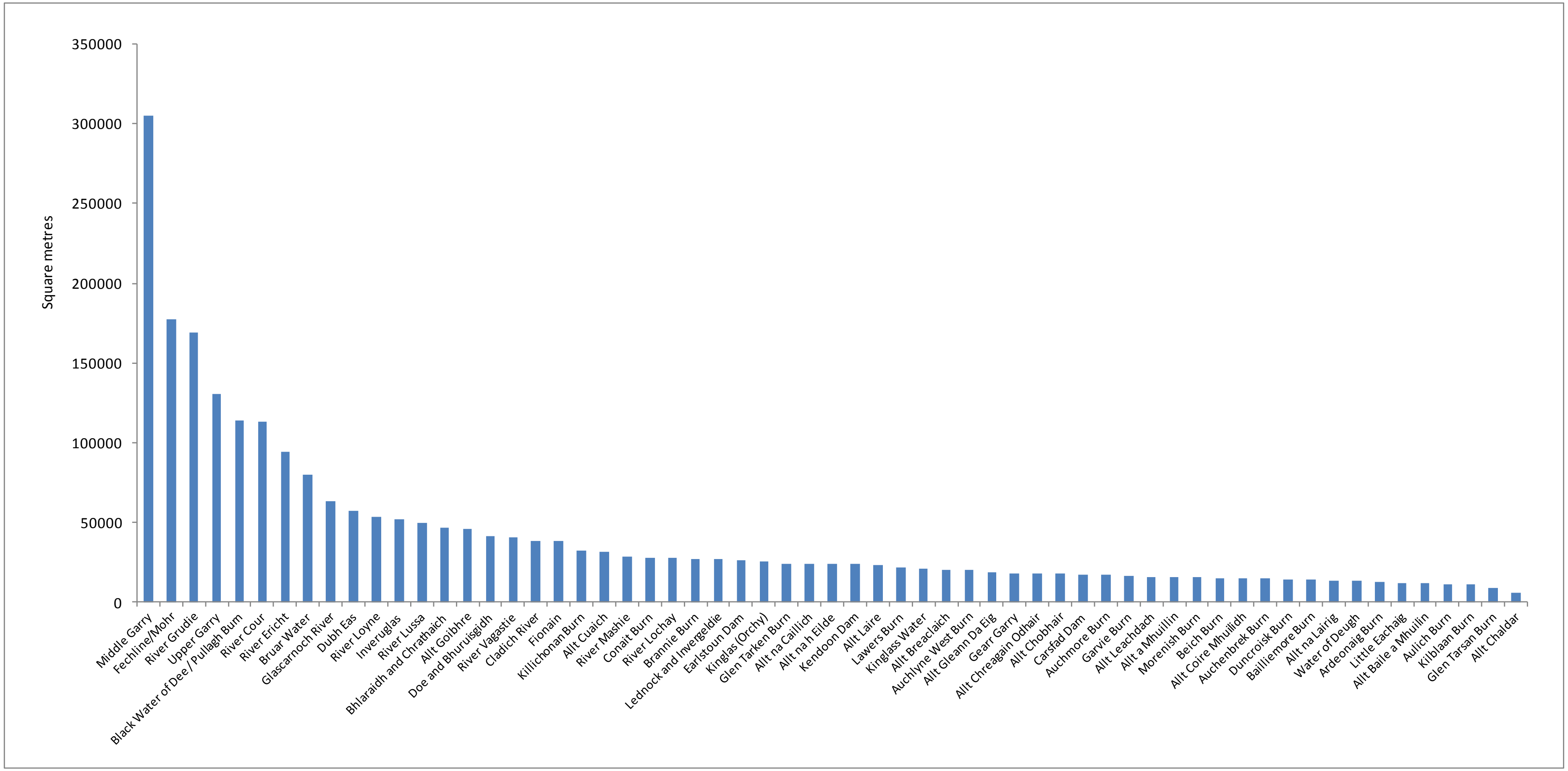


Table 2: Estimated area of restored habitat in each water body expressed as a percentage of the total area of habitat restored, reduction of generation required for each waterbody expressed as a percentage of the total reduction in generation required (all schemes / companies combined) and the energy reduction required in each waterbody in terms of kilowatt hours per square metre.

Waterbody	**% of overall wetted area**	**% of overall reduction in generation**	**Reduction in generation / wetted area (KWh/sq.m)**
River Garry (middle WB)	12.17	7.6	55.8
River Foyers (Fechlin and Mohr)	7.08	8.82	111.5
River Grudie	6.75	9.36	124
River Garry (upper WB)	5.2	0.95	16.3
River Cour	4.52	2.08	41.1
Black Water of Dee & Pullaugh Burn	4.52	2.66	52.6
River Ericht	3.77	12.36	293
Bruar Water	3.18	2.91	81.8
Glascarnoch River	2.52	4.96	176.5
Dubh Eas	2.28	0.85	33.4
River Loyne	2.12	2.74	115.3
Inveruglas Water	2.07	2.2	94.9
River Lussa	1.99	0.81	36.2
Allt Bhlaraidh and Allt Loch a Chrathaich	1.85	1.88	91
Allt Goibhre	1.84	0.35	16.8
River Doe and Allt Bhuruisgidh	1.64	0.7	38.1
River Vagastie	1.62	0.11	6.1
Allt Cuaich	1.6	1.68	93.7
Abhainn Fionain	1.52	0.3	17.5
Cladich River	1.52	0.38	22.3
Killichonan Burn	1.29	0.27	18.6
River Mashie	1.14	1.03	80.3

Allt Conait	1.11	5.24	422.2
River Lochay	1.09	1.31	106.7
Brannie Burn	1.07	0.46	32.3
Lednock Water and Invergeldie Burn	1.07	2.3	192.8
Earlstoun Dam	1.04	0.74	63.4
Allt Kinglas	1	0.37	32.9
Glen Tarken Burn	0.96	0.18	17
Allt na Caillich	0.96	0.37	34.5
Allt na h Eilde	0.95	1.52	142.3
Kendoon Dam	0.95	1.53	144.6
Allt Laire	0.93	0.51	49.4
Lawers Burn	0.88	0.43	43.7
Kinglas Water	0.83	0.27	29
Allt Breaclaich	0.82	0.97	105.9
Auchlyne West Burn	0.81	0.25	27.3
Allt Gleann Da-Eig	0.73	0.21	25.8
Gearr Garry	0.72	11.91	1482.4[20]
Allt Cregain Odhair	0.71	0.05	6.4
Allt Chobhair	0.7	0.41	51.9
Carsfad Dam	0.7	0.5	63.4
Auchmore Burn	0.67	0.26	34.2
Garvie Burn	0.65	0.18	24.6
Allt Leachdach	0.64	0.35	48.6
Allt a Mhuillin	0.63	0.44	62.2
Beich Burn	0.61	0.08	12.3
Morenish Burn	0.61	1.15	167.9
Allt Coire Mhuilidh	0.59	0.22	32.7
Auchenbrek Burn	0.59	0.12	18.6
Duncroisk Burn	0.57	0.49	76.4
Bailliemore Burn	0.56	0.1	15.5
Allt na Lairige	0.53	0.6	100.7
Water of Deugh	0.52	0.1	17.4
Ardeonaig Burn	0.51	0.27	47.6
Little Eachaig River	0.47	0.11	20.1
Allt Baile a Mhuilin	0.47	0.21	39.9
Kilblaan Burn	0.44	0.17	35

[20] For explanation of this very high figure see footnote no. 9.

Aulich Burn	0.44	0.04	8.7
Glen Tarsan Burn	0.35	0.54	136.7
Allt Chaldar	0.22	0.07	29.2

Prioritisation

While we may wish to see all these waterbodies restored, if in the event that cannot be justified, then some method(s) of prioritisation will be required or there will have to be reductions in the flows provided to all or certain waterbodies.

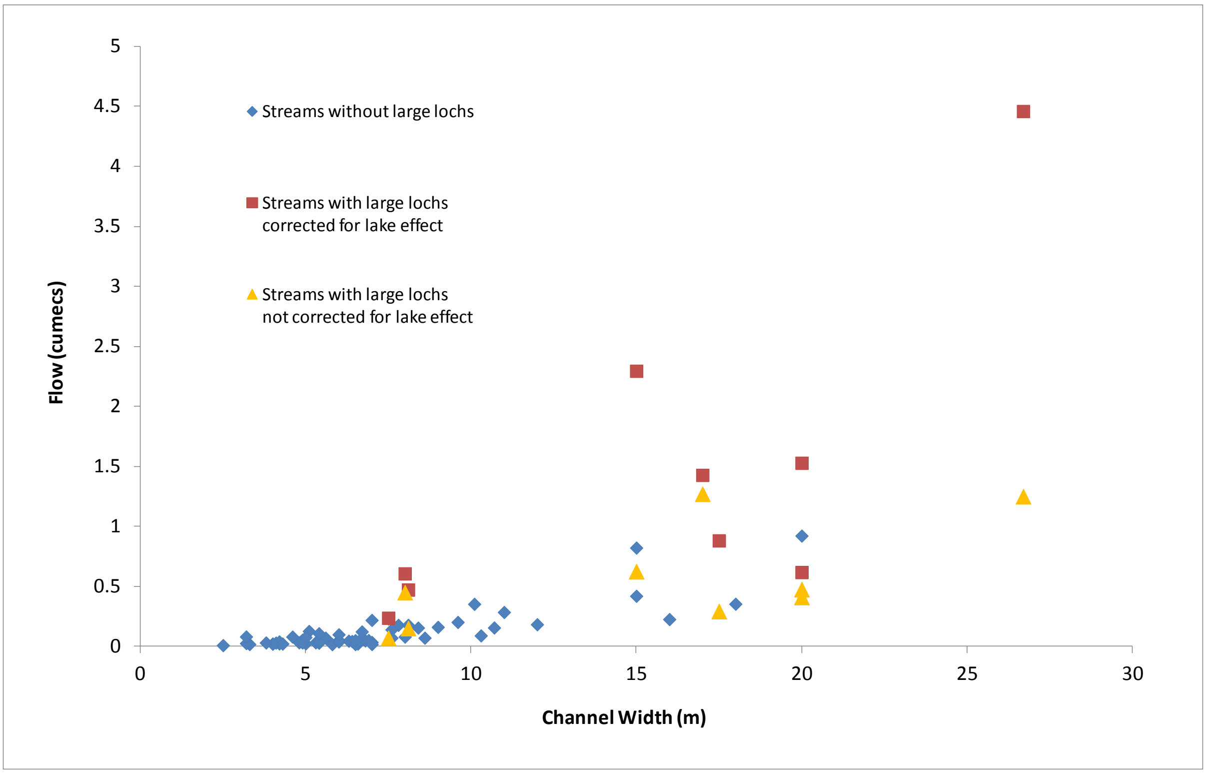
Therefore some ideas on prioritisation are now considered.

<u>The influence of "lake effect" corrections</u>

It is the case that there is one type of waterbody which does not appear to make such an efficient use of water as others. That is waterbodies with large lochs upstream. Low Flows 2 contains a feature which incorporates the buffering effects of lochs in flow estimation. This means that, for a given catchment area, rivers flowing out of large lochs have more flow in dry weather but less flow in wet weather than rivers which do not. A consequence of this is now demonstrated.

Figure 2 presents a scatter plot of the estimated average stream widths of each waterbody in this study versus the estimated Q95 flow. Those waterbodies downstream of large lochs are specifically identified and their Q95 estimates are shown both with and without the Low Flows 2 "lake effect" correction. This indicates that, where the lake effect correction is used in rivers downstream of large lochs, the wetted stream width will not be as great as it would be in a stream without a loch which had the same flow. Thus, this may represent a less efficient use of water.

Figure 2. Scatterplot of the estimated wetted channel width of each water body in this study versus the estimated Q95 flow. For those waterbodies which flow out of large natural lochs, the estimated Q95 flows are shown both with and without the Low Flows 2 “lake effect” correction.



Therefore, in instances where there are large natural lochs in the catchment (or rather there were prior to damming), if the Low Flows 2 Q95 estimates used are not corrected for lake effects, or somewhere between the two, then a saving of flow and generation can be made.

To illustrate the saving which may be made, the effects of using both the corrected and the uncorrected Q95 flow is shown in Table 3 for the major loch fed waterbodies under consideration. The effect of that change would be to save a total of 78 GWh per annum. Its effect on the SSE total (5th Column, Table 1) would be to reduce the 197.4 GWh per annum to 119.49 GWh per annum which equates to 4% of their overall average annual hydro production in the last three years.

Table 3. The effects of not applying the Low Flows 2 "lake effects" correction on Q95 estimates for rivers flowing out of large natural lochs and corresponding effects on generation reduction.

Waterbody	**Estimated Q95 flow with "lake effects" correction (cumecs)**	**Estimated Q95 flow without "lake effects" correction**	**Amount of generation reduction required with lake effects correction (GWh per annum)**	**Amount of generation reduction required without lake effects correction (GWh per annum)**
River Grudie	1.613	0.559	20.96	7.26
Glascarnoch River	0.617	0.426	11.12	7.68
Lednock Water and Invergeldie Burn	0.236	0.131	5.15	2.86
Allt Conait	0.471	0.184	11.73	4.58
River Foyers (Fechlin and Mohr)	1.427	1.27	19.76	17.58
Gearr Garry	3.416	0.205[21]	26.68	1.60
River Loyne	0.881	0.306[22]	6.13	2.13
River Ericht	2.295	0.624	27.69	7.53
Totals			**129.22 GWh**	**51.22 GWh**

<u>Benefits to migratory fish</u>

While it is clearly understood that flow restoration is being considered for the benefit of all aspects of the ecology, one issue which could be used if prioritisation has to take place is the level of benefit to migratory fish, particularly salmon.

Therefore, in order to investigate the effect of this, the limits of salmon migration were identified for each of the waterbodies concerned, as far as possible. Where necessary, information was sought from the relevant district salmon fishery boards or fisheries trusts. In a number of instances the exact locations of natural barriers or whether known barriers

[21] As explained in note 9, this flow represents the additional flow required in addition to the present compensation flow of 1.044 cumecs on the Gearr Garry.

[22] Note, on the River Loyne, in the SSE/APEM proposal to rewater this river, the proposed flow from the dam of 0.25 cumecs is described as being just under Q95. In addition a flow of 0.035 cumecs was proposed from a tributary. The 0.306 cumecs estimated here also represents the Q95 at the dam plus the Q95 from the stream as estimated by LF2. Therefore, the SSE/APEM estimate would not appear to have been corrected for lake effects.

would be passable under natural flows was not exactly known. Therefore the following results are approximate and subject to numerous caveats.

The area of new accessible salmon habitat which could potentially be created in each waterbody is presented in Table 4. However, this takes no account of the quality of the habitat present and merely reflects accessibility. In some instances accessible habitat may be poor, for example on account of steepness.

That said, Table 4 again shows there is considerable variation in the area of salmon habitat that might potentially be created, with the Perthshire Garry having the greatest potential.

If those waterbodies which have been identified as offering no potential for salmon are eliminated, then the total reduction in generation (for all companies) falls to under 107 GWh per annum. If, by some criteria, a proportion of the waterbodies with very limited benefit to salmon were also to be eliminated, the total falls even further. For example, if those waterbodies with less than 10,000 square metres of salmon habitat were eliminated, a further 15.51 GWh would be saved, bringing the total reduction in generation down to around 90 GWh. For SSE in particular this would bring the reduction down to 71 GWh (2.4% or output).

Table 4. Estimated full wetted area of new habitat which might be created in each tributary and the estimated wetted area of new habitat which is expected to be accessible to salmon (assuming lake effect corrections not used in waterbodies with large lochs).

Waterbody	Full area of channel rewatered	Area available to salmon	Estimated reduction in generation (GWh p.a.)	KWh/sq. m of accessible area
River Garry (Option 1 - middle and upper waterbodies combined)	435164	493794[23]	19.15	38.8
River Garry (Option 2 - middle waterbody only)	304844	300000	19.15[24]	56.8
Black Water of Dee & Pullaugh Burn	113987	113987	5.96	52.3
River Cour	113276	113276	4.66	41.1
Glascarnoch River	63000	63000	7.68	121.9
River Loyne	53200	53200	2.13	40.0
Inveruglas Water	51914	51914	4.93	94.9
River Lussa	49824	49824	1.80	36.2
River Vagastie	40500	40500	0.25	6.1
River Grudie	169026	40000[25]	7.26	181.2
River Ericht	94500	37500[26]	7.53	200.8
Allt Cuaich	31220	31220	3.76	120.5

[23] The area of the Garry accessible to salmon would be greater than that rewatered, because salmon would be able to access upper tributaries which have a natural flow.
[24] Note, irrespective of whether salmon are allowed to access the upper Garry or not, the reduction in generation would be the same as it would still be necessary to restore flow to the upper Garry in order to provide flow for the middle Garry.
[25] A large waterfall limits salmon access to the lower reaches of the Grudie.
[26] It is believed there is an impassable waterfall on the Ericht, but this has to be confirmed.

River Mashie	28676	28676[27]	2.30	80.3
River Lochay	27400	27400	2.92	106.7
Earlstoun Dam	26100	26100	1.66	63.4
Kendoon Dam	23760	23760	3.44	144.6
Allt Kinglas	25152	21792	0.83	38.0
Kinglas Water	20682	20682	0.600	29.0
Allt Conait	27783	18630	4.58	246.0
Gearr Garry	18000	18000	1.60	89.0
Allt na Caillich	24090	17545	0.83	47.3
Carsfad Dam	17500	17500	1.11	63.4
Allt Chaldar	5548	12920[28]	0.16	12.6
Little Eachaig River	11840	11840	0.24	20.1
Bailliemore Burn	14100	11450	0.22	19.1
Abhainn Fionain	37980	11280	0.67	59.0
Auchlyne West Burn	20410	11193	0.58	49.8
Allt Bhlaraidh and Allt Loch a Chrathaich	46395	10000	4.22	422.0
Allt a Mhuillin	15776	9802	0.98	100.1
Dubh Eas	57062	9064	1.91	210.4
Glen Tarsan Burn	8772	8772	1.20	136.6

[27] The abstraction point on the Mashie is built on the top of a waterfall. It is not clear whether this was historically passable or not. The estimate shown assumes it was not, but if it was, then the accessible area could be much larger.

[28] The Allt Chaldar is another example of where flow restoration could allow salmon access to formerly accessible habitat upstream of the hydro intake, hence the area of salmon habitat is greater than the area of rewatered habitat.

Killichonan Burn	32430	8763	0.60	68.8
River Shira (Brannie Burn)	26726	7700	1.02	132.9
Duncroisk Burn	14400	5600	1.10	196.4
River Doe and Allt Bhuruisgidh	41115.2	5056	1.57	309.8
Garvie Burn	16254	4300	0.40	92.9
Allt Leachdach	15939	3351.6	0.77	230.9
Auchenbrek Burn	14801	3280	0.28	84.1
Glen Tarken Burn	24123	3139	0.41	130.9
Lawers Burn	22050	2450	0.96	393.0
Kilblaan Burn	11064.9	2323.2	0.39	166.4
Morenish Burn	15296	1600	2.57	1604.8
Allt na Lairige	13384	1439.2	1.35	936.7
Allt Coire Mhuilidh	14868	0	0.49	
Allt Goibhre	46016	0	0.77	
Allt Laire	23287	0	1.15	
Allt na h Eilde	23856	0	3.39	
Ardeonaig Burn	12720	0	0.61	
Auchmore Burn	16880	0	0.58	
Aulich Burn	11100	0	0.10	
Beich Burn	15238	0	0.19	
Allt Breaclaich	20435	0	2.16	

Bruar Water	79588	0	6.51	
Allt Chobhair	17616	0	0.92	
Cladich River	38080	0	0.85	
Allt Cregain Odhair	17712.5	0	0.11	
Allt Gleann Da-Eig	18410	0	0.47	
Water of Deugh	13020	0	0.23	
River Foyers (Fechlin and Mohr)	177260	0	17.58	
Lednock Water and Invergeldie Burn	26700	0	2.86	
Allt Baile a Mhuilin	11765	0	0.47	
Total generation reduction, excluding those waterbodies with no salmon access (i.e those shaded grey) (all companies combined)			**106.58**	
SSE only			**84.87**	
Alcan only			**9.54**	
Scottish Power only			**12.17**	

It is also clear from Table 4 that the restoration of salmon habitat again comes at a different cost in different waterbodies. Thus, in any attempts at prioritising waterbodies, it may also be appropriate to take account of the amount of energy involved.

As an example of how this might be done, an attempt was made to weight the accessible wetted area according to the KWh/sq. metre ratio for each waterbody. This was done by firstly identifying the waterbody with the lowest KWh/sq. metre ratio. This was the River Vagastie. The Vagastie's KWh/sq. metre ratio was then assigned a value of 1. A weighting factor was then calculated for each other waterbody by dividing the KWh/sq m for the Vagastie by the KWh/sq m for the waterbody in question. The resulting weighting factors were multiplied by the accessible area. The results of the exercise are shown in Table 5.

This shows that, if salmon were allowed access to the entire Perthshire Garry, it would come out on top. However, there is some rearrangement in the rankings with the Vagastie rising to second place. If salmon were only allowed access to the middle Garry section (i.e. no fish passage arrangements made at Garry Offtake), the Garry would come second to the Vagastie. Again, a clear feature is of a few more significant waterbodies and a long tail of waterbodies with low scores.

A further refinement to this process would be to apply a weighting factor for habitat quality. That would clearly involve a significant amount of work to obtain the necessary data.

Table 5. Accessible salmon habitat in each water body adjusted by a weighting factor to take account of differences in the KWh/sq. metre ratio between waterbodies.

	Weighted accessible area
River Garry (middle and upper WBs combined)	77429
River Vagastie	40500
River Garry (middle WB only)	32153
River Cour	16743
Black Water of Dee and Pullaugh Burn	13257
River Lussa	8373
River Loyne	8082
Allt Chaldar	6251
Kinglas Water	4337
Bailliemore Burn	3644
Little Eachaig River	3585
Allt Kinglas	3487
Inveruglas Water	3327
Glascarnoch River	3145
Earlstoun Dam	2503
Allt na Caillich	2255
River Mashie	2172
Carsfad Dam	1678
Allt Cuaich	1576
River Lochay	1562
Auchlyne West Burn	1368
River Grudie	1340
Gearr Garry	1231
Abhainn Fionain	1164
River Ericht	1136
Kendoon Dam	1000

Killichonan Burn	774
Allt a Mhuillin	596
Allt Conait	461
Glen Tarsan Burn	390
River Shira (Brannie Burn)	352
Garvie Burn	281
Dubh Eas	262
Auchenbrek Burn	237
Duncroisk Burn	173
Glen Tarken Burn	146
Allt Bhlaraidh and Allt Loch a Chrathaich	144
River Doe and Allt Bhuruisgidh	99
Allt Leachdach	88
Kilblaan Burn	85
Lawers Burn	38
Allt na Lairige	9
Morenish Burn	6

Other ways of offsetting generation reductions

The results presented in the Tables above are based on a maximum scenario of electricity reductions needed to produce Q95 flows.

However, in some instances, the amount of water required might prove to be less than that estimated, and, in some instances, there may genuinely be ways of gaining water for generation in other ways.

<u>Effects of "spillage"</u>

For example, there may be instances where surplus water spills over dams and offtakes. In such cases, diversion of flows for ecological benefit might be offset by reduced spillage. Such opportunities need to be identified.

One instance where this might be an issue is the Vagastie. Water abstracted from the Vagastie is diverted to Loch Shin and from there through Shin Power Station. The River Shin downstream of Loch Shin is subject to a controlled compensation flow regime but, on occasion, this is augmented by spillage over the dam. SEPA have a gauging station in this reach, upstream of Shin Power Station, which provides a valuable record of spillage events.

In order to qualify for ROCs on the refurbishment of the power station, the installed capacity of Shin Power Station, and some others, was reduced some years ago. It has been argued that one consequence of this action could be to increase spillage[29]. In order to investigate this possibility, daily flow data for the Shin gauging station were obtained from the National Riverflow Archive. The NRFA website also provides data for direct download for some gauging stations. While this facility is not provided for the Shin gauging station, it is for the Oykel, the closest unregulated gauged river. This has allowed comparisons to be made between Oykel flows and Shin flows from 1982 to 2009 (the most recent Oykel data on the website is for 2009).

The months in which high flows are most common in the River Shin tend to be February and March, presumably the months when the spare capacity of Loch Shin tends to be lowest. Since 2002, the year in which the change in installed capacity is assumed to have taken effect (in order to qualify for ROCs, the capacity had to be reduced before 1 April 2002), higher average flows have occurred in the majority of Februarys and Marches, while they were relatively rare between 1982 (the first year for which data are available) and 2001 (Figs. 3 and 4). Prior to 2001, high average flows in February and March in the Shin only occurred when average Oykel flows were also very high. However, the threshold Oykel flow at which high flows now occur in the Shin appears to have reduced.

Thus, if it is the case that wet winters / springs result in more water being “wasted” from Loch Shin, then, in some years at least, the provision of a hands off flow in the Vagastie would only serve to reduce the amount of spillage from Loch Shin and impact less on generation. For example, if from Figs 3 and 4 it is assumed that any flow over 5 cumecs in February represents spillage and 7.5 cumecs in March, then the average spillage flow in February over the period 2002 - 2009 is 6.6 cumecs and in March 8.1 cumecs. In terms of the total volume of water released, that is equivalent to a flow of 1.225 cumecs over the course of the whole year. On that basis, not only would a Q95 flow in the Vagastie be justified, but perhaps a relevant question would be whether any abstraction from the Vagastie is needed at all.

Spillage must also occur at many river intakes in high flows, and this must be taken into account when considering generation reductions. For example, at Garry Offtake, APEM stated that spillage occurred for 7% of the time. If this is a general finding, then the overall total loss in generation will be reduced accordingly.

[29] One account of this event is provided in the document *Subsidies and Subterfuge* available at http://www.spanglefish.com/HydroROCs/Documents/SubsidiesandSubterfuge.pdf

Figure 3. Average gauged flow in the River Oykel versus the average gauged flow in the River Shin upstream of Shin Power Station for the month of February, 1982 – 2009. Data courtesy of the National River Flow Archive.

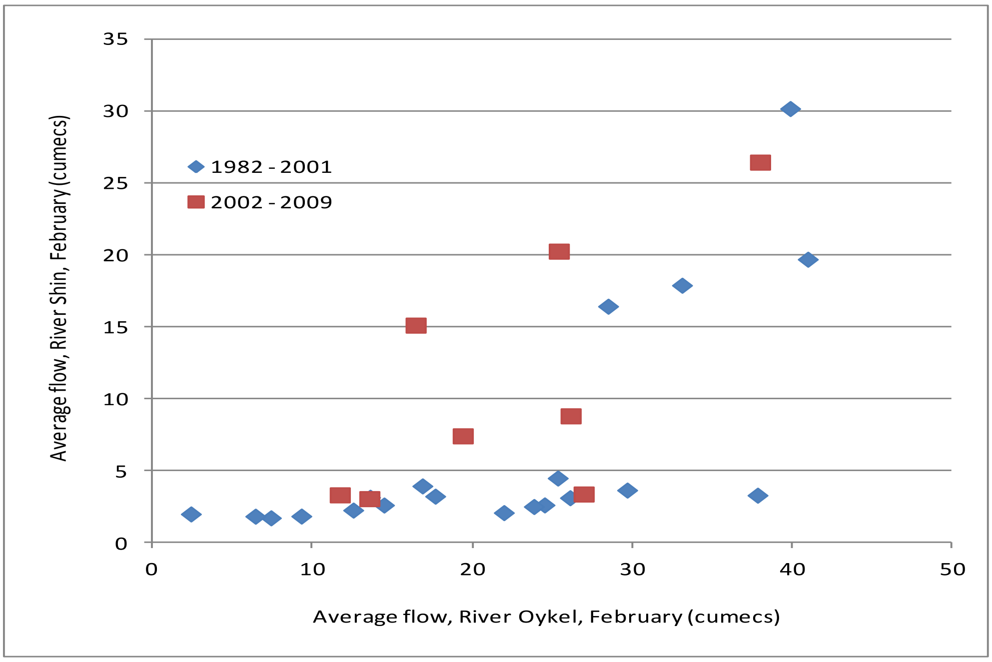
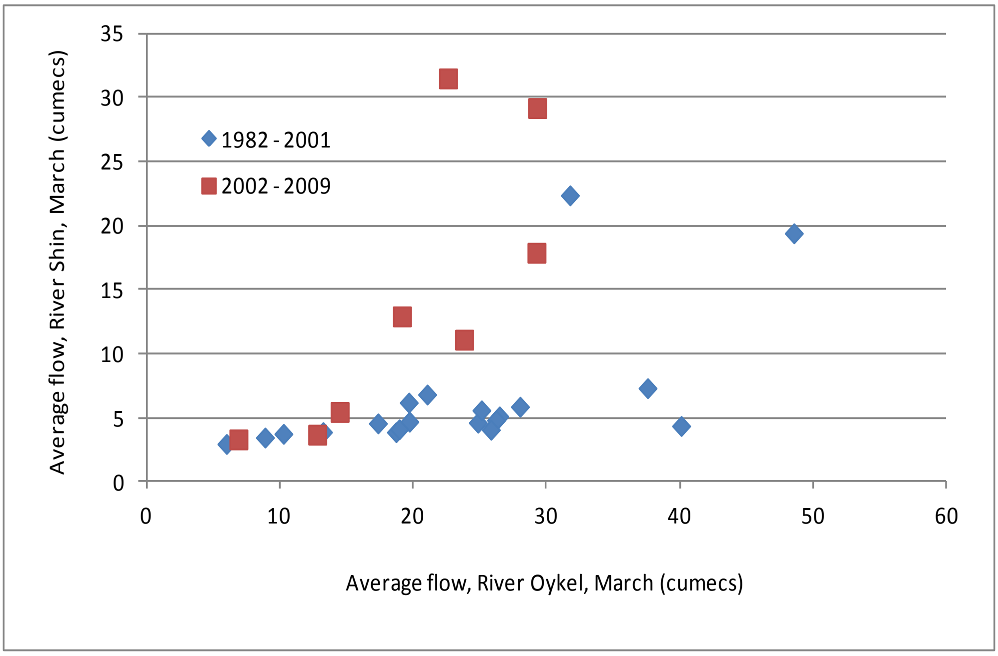


Figure 4. Average gauged flow in the River Oykel versus the average gauged flow in the River Shin upstream of Shin Power Station for the month of March, 1982 – 2009. Data courtesy of the National River Flow Archive.



Intermittent flows instead of constant flows

In practice, there could also be instances where it is not necessary to provide a Q95 discharge from abstraction points all of the time.

For example, in the River Lochay, there is not a single abstraction point which completely dries out the main channel. The furthest headwaters are not in fact abstracted, but a succession of tributary offtakes reduces the accretion of flow moving downstream. In wet weather, flow from the headwaters is sufficient to maintain a flow of more than Q95 throughout the main channel. Thus, in this instance, the flow in the main channel could be prevented from falling below Q95 by only curtailing abstraction at lower flows. In fact, this concept is already partially in place on the Lochay. On three upper tributaries there is a licence condition whereby no abstraction can take place when flows are less than *ca*. Q75 – Q85 and a progressively higher proportion of the flow may be abstracted at higher flows, leading to total abstraction at flows above a *ca*. Q 50. If, at the other abstraction points, a Q95 flow was discharged when the natural flow fell below *ca*. Q80 (which is what is estimated to be required to ensure Q95 flows are maintained throughout the main channel), then the reduction in generation would fall from 2.924 GWh to 0.484 GWh per annum. If the same wetted area is used this would represent a fall from 106.7 GWh / sq. m to 17.7 GWh / sq. m. The weighted score would then rise to 9434 putting it near the top of that list. Perhaps this concept has wider application and needs investigating.

Effects of freshet provision

The previous analyses have given no consideration to the provision of freshets.

Therefore, in order to provide some ball park figures for the likely effect of providing freshets, at least on the more significant waterbodies that would require them (i.e. accessible to migratory fish), the following exercise was conducted.

The top 12 waterbodies in Table 5 were selected for analysis (all rivers were not included due to time constraints). For each, it was assumed that over the salmon spawning season, the hands-off flow is increased to a Q70 flow for one month of the year. In addition to this, Q20 flows are released (assuming they are released when such flows are naturally available) on 7 days in the year. (This is not necessarily the ideal freshet prescription but is indicative of the minimum types of flows that might need to be provided.)

The resulting flows and energy requirements are presented in Table 6 with a total requirement of around 16 GWh per annum. This might indicate that a block of say 20 to 25

GWh might be needed in total to be allocated to freshets – i.e. up to 25% of the total generation reduction proposed by SEPA.

Table 6. Generation reductions required to provide freshets for the twelve most significant waterbodies identified in Table 5, assuming one month of Q70 hands off flow and 7 days of Q20 flows.

	Q70 flow (cumecs)	**GWh for one month of Q70 flow**	**Q20 flow(cumecs)**	**GWh for seven days of Q20 flow**
River Garry (middle waterbody)	2.422	2.31	12.013	3.93
River Vagastie	0.089	0.03	0.463	0.06
River Cour	0.68	0.68	3.944	1.34
Black Water of Dee	1.973	1.14	9.953	1.79
River Lussa	0.438	0.8	1.899	0.29
River Loyne	0.977	0.39	6.961	0.89
Allt Chaldar	0.189	0.02	0.956	0.04
Kinglas Water	0.093	0.112	0.649	0.26
Bailliemore Burn	0.073	0.04	0.514	0.09
Little Eachaig River	0.082	0.05	0.536	0.09
Allt Kinglas	0.143	0.12	0.827	0.24
Inveruglas Water	0.556	0.58	3.167	1.21
Total		**6.272**		**10.23**

Discussion

This admittedly rough overview has shown that to provide Q95 flows in all the failing HMWBs more than two times the overall cut in generation proposed by SEPA will be required.

The options available to SEPA will therefore include:

1) Accept a higher reduction in generation
2) Recommend even lower base flows.
3) Prioritise on the most significant / least energy demanding HMWBs
4) Find innovative ways of flow release to reduce the need to cut generation

In reality, unless 1) is accepted, or ineffectual token flows, some form of prioritisation would seem to be essential. This paper has provided some suggestions as to how that might be done.

However, there are other more general observations which arise.

For example, although there are a surprising number of failing abstracted HMWBs, most are modest streams. Most offer relatively little benefit for migratory fish, apart from a few exceptions. In the context of all hydro / migratory fish issues, abstraction may not be the overwhelmingly dominant issue. The benefits of restoring abstracted streams should perhaps also be considered alongside issues such as fish passage at problem dams and offtakes, for example. It may be that mitigation to improve fish passage through or around possible problem locations (e.g. Shin Dam, Glen Beg, Clunie Dam, Tongland Dam etc) might generate more migratory fish production than the majority of abstracted streams could but, crucially, perhaps at a lower long term cost.

This argument is relevant also to the situation in the upper Garry waterbody. There, SSE have proposed restoring a flow but not fish passage on the grounds of difficulty in providing smolt passage at Garry Offtake. However, the area that could be made accessible to salmon in the upper Garry is equivalent to about 20% of the total area of all abstracted waterbodies that could be accessible to salmon outwith the Garry. If habitat quality was taken into consideration, this percentage might be even higher. Would it not be more cost effective in the long run, given the upper Garry is to be re-watered anyway, to screen smolts from Garry Offtake rather than undertake costly abstraction reductions on very small waterbodies?

In addition to issues regarding physical barriers, another issue that has not really been considered in this paper is abstraction itself as a fish barrier. Again, there may be examples where a lot more benefit might accrue to migratory fish by changing abstraction at some key abstraction bottlenecks rather than trying to generate new juvenile habitat upstream.

An example of this might be Tongland on the Galloway Dee. The compensation flow between the dam and the power station is at times much lower than Q95, but because the length of river affected is small, this section is considered to be at GEP. While the area of new habitat that might be created in that reach may admittedly be small, if it is the case that the low compensation flow does deter adult salmon from moving upstream through the dam – which does appear to be a matter of concern – then the benefit of this action might be much greater than some of the actions that are proposed on this river, e.g. increasing compensation flows at Carsfad and Earlstoun dams.

Yet another example is the River Lochay. This study has shown that maintaining a Q95 flow might make a relatively modest increase in wetted surface area. However, it is the case that significant areas of the Lochay have been underpopulated by salmon and this may in part at least be an adult migration issue. It has been a concern of the Tay DSFB that flows may be an issue and this could operate in several ways. For example, there is an SSE fish counter on the lower Lochay and this shows that adult salmon start to enter from May/June onwards. However, there can be significant downstream movements of adult salmon in the late summer and early autumn. We are concerned that fish drop downstream during low flow periods because of the limited availability of deep secure water for adult salmon to lie in and then do not return. If this is the case, addressing autumn flows may have a much greater benefit and be much more cost effective than maintaining Q95 flows all year round.[30]

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[30] For example, if during the period mid September to mid November the river was augmented by a flow of 0.5 cumecs introduced above the most upstream fishpass on the river (this could perhaps be done by releasing flow from the main diversion pipe crossing the Lochay and some of the offtakes further upstream) and this proved successful, it could secure salmon production over an area of at least 80000 sq metres. This would be achieved by a loss of 1.35 GWh per annum, equating to 16.9 KWh / sq metre. That would give the Lochay a score of 28880 in terms of Table 5 which would then make it one of the most significant priorities in terms of benefits to salmon.