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Mapping Hydropower Opportunities and Sensitivities in England and Wales

Technical Report

Final Report
February 2010

ea/br/e/std/v1

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1 Introduction

The following final report (dated 8thth Febuary 2010) has been prepared by Entec UK as the main output of the Mapping Hydropower Opportunities project (commissioned January 2009). The commission was managed by Harry Huyton of the Environment Agency and was undertaken under the terms and conditions of the Environment Agency's Environmental Policy Consultancy Framework.

1.1 Background to Study

The Environment Agency has to balance the relative pressures of the Water Framework Directive, River Basin Planning and other legislative drivers alongside those of climate change mitigation or adaptation. The UK has committed to an ambitious target of generating 15 per cent of its energy from renewables by 2020, and, whilst small-scale hydropower is not expected to play a major role in this, the ambition is such that all sources of renewable energy are expected to deliver their maximum sustainable potential. The Environment Agency supports these targets, and has committed to working constructively with the hydropower industry to balance the benefits and impacts of hydropower.

The key aim of this project is to provide a comprehensive national assessment of the potential for small-scale hydropower alongside the key environmental sensitivities that need to be addressed to unlock this potential. This report gives a national overview, and does not replace the need for a site by site assessment.

1.2 Structure of Report

This remainder of this report is subdivided into six main sections:

Section 2 Height estimation

This Section provides a critique of the different height data sources available to the project and the methods used in their extraction. It also provides a summary of the barriers and outlines the head data calculated as part of the automated process.

Section 3 Flow estimation

This Section provides a critique of different flow data sources available to the project team and assesses their suitability for deriving flow estimates for the barriers considered in this study. This provides the background to the ground truthing and estimation methodologies and the application to the national data described in the reminder of the Section.

Section 4 Power potential

Section 4 presents the estimated power potential of the barriers is analysed at a national and regional scale.

Section 5 Sensitivity categorisation

This Section outlines the data (including Fish Classification Scheme and protected area datasets) and the methods that have been used quantify the sensitivity of barrier sites. This classification has been designed to use nationally available datasets to provide an indication of the sensitivity of water bodies across England and Wales.

Section 6 Hydropower opportunities

This Section presents the results from bringing together the power potential and the sensitivity categorisation. The opportunity matrix is outlined and the results from the previous sections are combined to categorise the opportunity at each barrier. The “Win-win” situations where a barrier has good power potential and is located in a Heavily Modified Water Body are shown.

Section 7 Future improvements

This report outlines the application of the described methods to the national dataset. The findings presented have their limitations as outlined in the previous sections. Section 7 suggests possible improvements in the input data sets to allow the calculation of hydropower opportunities at a local/regional scale or possibly on a site-by-site basis.

2 Height Estimation

2.1 Section Summary

The hydropower opportunity at a potential site is a function of the head (i.e. the height), the flow available, the efficiency of a turbine and a constant for gravity. The approach used in this study gives a simple measure of the hydropower opportunity by integrating gradient data with flow information. This Section outlines the method used for calculating the power generation and the source and error checking of the height data:

- The height data was extracted from the Environment Agency's Geomatics Group data holdings;
- A number of height extraction methods were trialled to ensure positive head (height of the barrier) values were extracted for the barriers, these were:
- Point height extraction;
- Extraction of maximum/minimum values within 5m of the barrier;
- Extraction of maximum/minimum values within 5m of the upstream/downstream points;
- Extraction of maximum/minimum values within 25m of the upstream/downstream points;
- The head values were compared to a number of other datasets to provide ground truth to the automatically extracted data;
- No conclusive results were found from the comparisons, the greatest head value from the above methods was used as the head value for the barrier.

2.2 Barrier Locations

The core dataset of potential hydropower barrier locations and additional information was developed at the start of the project by a project undertaken by the Environment Agency Fisheries Group[1]. The list of potential hydropower structures is based on in-river features, derived from OS MasterMap, that cross the Environment Agency's Detailed River Network and include waterfalls, weirs, dams, barrages and locks. This was commissioned at the start of the project and termed the River Barriers dataset as it represents the most definitive list of barriers to fish movement in England and Wales. The dataset comprises of 25,935 barriers, each of which was attributed with information describing the type of feature that comprises the barrier. This field was inferred from the site name, description or text string of the Ordnance Survey Mastermap feature used to

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[1] Many of these barriers are used to minimise flood risk, the impact on these barriers is not considered in this report

generate the barrier points. However some of the Environment Agency obstructions could not be matched to text, so this field is blank in some cases, (610 out of 25935 barriers, of these 264 have other information which allows the feature to be classified)). The summary of the type of features present is shown in Table 2.1.

Table 2.1 Summary of Feature Types Present in the Barriers Data

Feature Type	Count
Barrage	6
Dam	564
Lock	1,730
Mill	274
Unknown	538
Waterfall	6,098
Weir	16,725
Total	**25,935**

➔

Description	Count
Natural Falls	14
Weirs	36

2.3 Source of Height Data for Head Calculations

The main elevation datasets (LiDAR and SAR), the methodology used to extract the head values, and the ground-truthing methodologies are detailed in the following sections. The distribution of the source of the head values are shown in Figure 2.1

2.3.1 LiDAR

The Environment Agency's Geomatics Group describe LiDAR as:

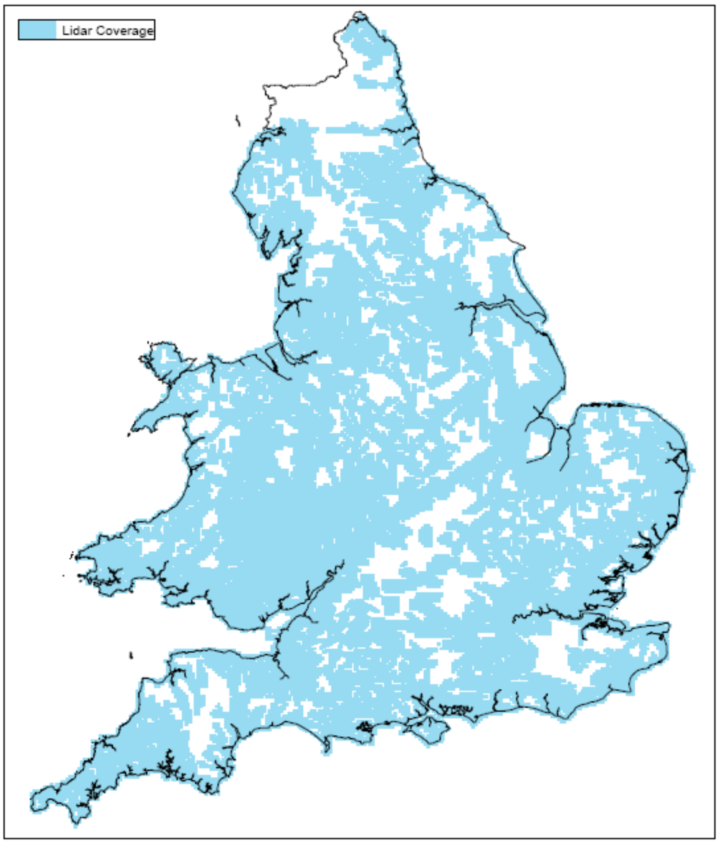
Light Detection and Ranging (LIDAR) is an airborne laser mapping technique which produces accurate elevation data. The technique is a cost-effective and rapid solution for the production of high quality terrain mapping. The Geomatics Group have also developed processes that allow surface objects such as vehicles, buildings and vegetation to be identified and removed, producing 'bare earth' Digital Terrain Models (DTM).

LiDAR data provided by the Environment Agency has many uses in flood modelling and in studies where widespread accurate height data is required. The current LiDAR coverage held by the Geomatics group is outlined in Figure 2.2. The LiDAR data is primarily flown for flood risk purposes. For this reason it largely covers the flood plain. In areas where there is no LiDAR coverage the SAR data is used, see Section 2.2.2.

2.3.2 SAR

The other main elevation data source held by the Environment Agency Geomatics Group is Intermap's NEXTMap Synthetic Aperture Radar (SAR) dataset. The Environment Agency purchased this national elevation model from Intermap to provide a nationally consistent data set for the generation of the first phase of National Flood Maps. The data was flown over the winter of 2002/2003 and underwent a similar filtering process to the LiDAR data, although the methodology and criteria applied differ and limitations are well understood[2]. The use of this data and a comparison to LiDAR data is provided in Duncan et al (2004)[3].

Figure 2.2 April 2009 Geomatics Group LiDAR Coverage



- [2] Independent Verification And Validation Of Elevation Data Using ArcGIS 9.0, Stephen Cliffen 2005, http://proceedings.esri.com/library/userconf/proc05/papers/pap1135.pdf (Last accessed 22/09/2009)

- [3] The National Flood Mapping Program: Using IFSAR for Flood Modelling in England and Wales, Alastair Duncan, Bruce Kerridge, John Michael, Alistair Strachan, 2004, http://www.intermap.com/uploads/1170362540.pdf (Last accessed 09/09/2009)

2.4 Calculating Barrier Head Values

At the commencement of the study, the Environment Agency Geomatics Group calculated upstream and downstream elevation values using either the LiDAR or SAR datasets for each of the 25,935 barriers detailed in Section 2.2. In total, 16,531 of the barriers were located in areas where LiDAR data is held, whilst for the remaining 9,404 barriers the SAR National Elevation model was used. Four different methods have been used to extract the height data from the Geomatics Group Data holdings, these are:

- Point height extraction;
- Extraction of maximum/minimum values within 5m of the barrier;
- Extraction of maximum/minimum values within 5m of the upstream/downstream points;
- Extraction of maximum/minimum values within 25m of the upstream/downstream points.
- An outline of the extraction methodologies described below is shown in Figure 2.3. The only variation being the distance upstream/downstream used in the 5m/25m methods, as outlined in Section 2.4.4.

2.4.1 Point Height Extraction

The specification for the original height extraction of barrier head (i.e. the difference between upstream and downstream values) information was outlined as, “the nearest elevation data to a distance upstream and downstream of five metre radius of each barrier, together with the date the elevation was measured”. This method of extraction led to 4,883 barriers being assigned a negative head value (i.e. the downstream height value above upstream height value). A number of these points (16) are due to the upstream point falling on the boundary between two cells within the elevation models and the upstream value being assigned zero, these have been corrected manually.

The quoted vertical accuracy of the LiDAR system is ±25cm and the SAR data has a quoted vertical accuracy of ±1m. This accuracy applies to the Digital Surface Model, which is then filtered to remove vegetation, buildings and other features to produce the ‘bare earth’ Digital Terrain Model from which these heights are generated. The conversion can potentially create errors in the generated data, which will cause a deviation from the quoted value. Because of this a negative head (where the down stream height is greater than the upstream height) of 50cm is acceptable within the constraints of the LiDAR data and a 2m within the SAR data.

Using the data supplied by the Environment Agency Geomatics Group, Entec identified that 1,908 of the barriers with negative head values derived from LiDAR data were within the quoted accuracy, and 1,875 barriers with negative head values derived from SAR data were within the quoted accuracy. This left 902 obstructions with negative values that cannot be explained by the accuracies of the data used, representing 3.42 per cent of the total number of barriers being assessed.

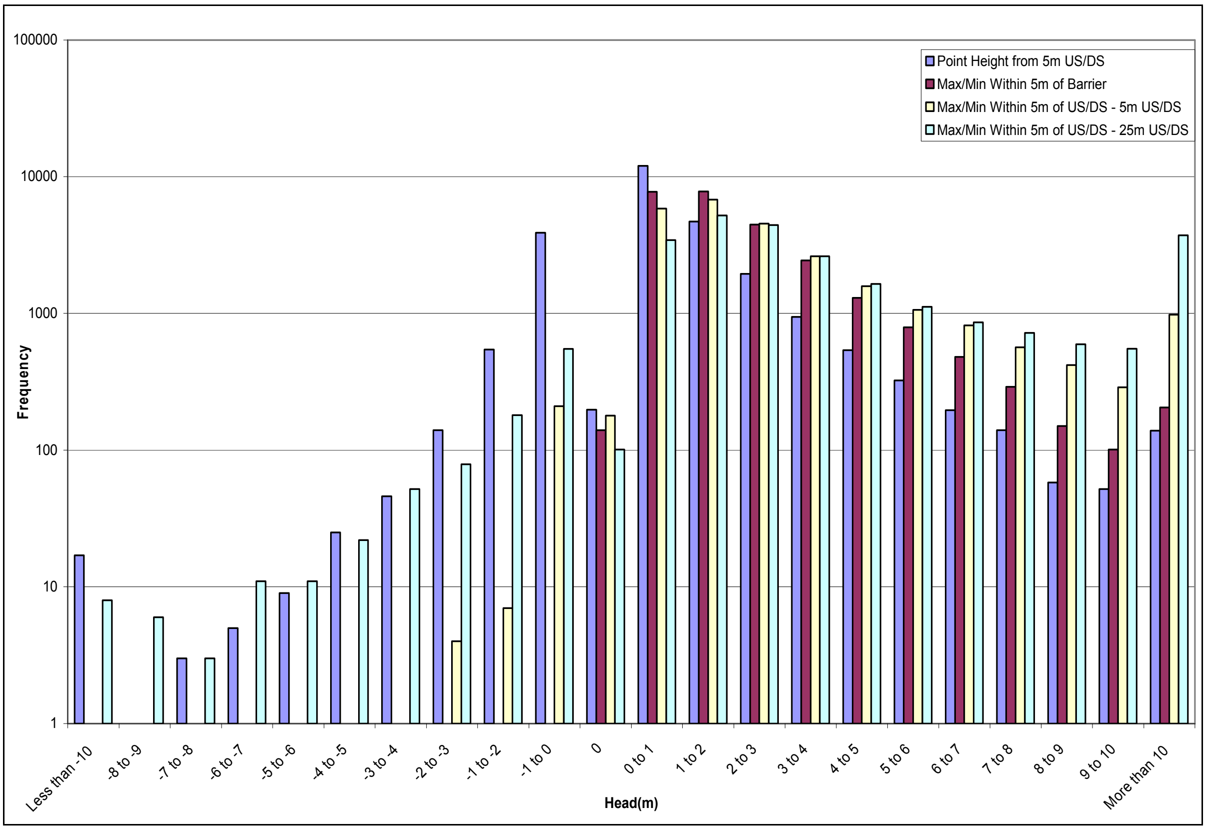
In addition to the vertical accuracies outlined above, consideration was also given to the positional accuracy of the height data. From information provided by the Environment Agency Geomatics group, the LiDAR data used in the study has a horizontal accuracy of ±45cm, while the horizontal accuracy for the SAR data is ±2m. These horizontal accuracy threshold means that in some cases the height values recorded could actually be the height of the barrier itself, rather the surface upstream/downstream of the barrier. This is an important issue which must be considered carefully when viewing the results of this study and any future studies which attempt to evaluate the suitability of small-scale hydropower opportunities at a more detailed level.

2.4.2 Extraction of Maximum/Minimum Values Within 5m of the Barrier

Due to the issues outlined above with the original methodology, the specification was revisited and two alternative methods were trialled. The first was the extraction of the minimum and maximum height values within a 5m radius of the barrier. This method applies a buffer to the barrier point and extracts the maximum and minimum values within the radius. This method provides a range of values rather than being reliant on one height value from an elevation model and has led to the creation of data without any negative head values.

Whilst this method greatly improves the accuracy of the data, it is possible the bank height or other features could be selected and therefore give a spurious head value for the barrier with downstream elevation higher than upstream. The distribution outlined in Figure 2.4 illustrates that no negative head values have been calculated by using this method and the modal class (the class having the greatest frequency) using this method is 0 to 1m.

Figure 2.4 Distributions of Head Values



2.4.3 Extraction of Maximum/Minimum Values Within 5m of the Upstream/Downstream Points

In the third method trialled, the upstream and downstream points were used and the maximum and minimum height values within a 5m radius of the point were selected. This method derived four different values which can be used for the head calculation: Upstream maximum, upstream minimum, downstream maximum and downstream minimum. From reviewing a number of specific locations, it was considered that the use of upstream maximum and the downstream minimum values was the most effective in minimising negative height values.

However the key drawback of this approach was that elevation values were being taken from a greater distance away from the barrier, increasing the possibility of creating negative head values. This is reflected in the distribution shown in Figure 2.4, where 221 barriers still have negative head values, many in the range of -1 to -2m.

2.4.4 Extraction of Maximum/Minimum Values Within 25m of the Upstream/Downstream Points

As described in the previous sections, there is a danger that the upstream or downstream elevation values extracted for some barriers is the height of the structure itself rather than the upstream or downstream level of the river either side of the structure. This would lead to a misrepresentation of the heights and possibly still cause negative head values. To assess this issue, Entec trialled on a limited number of obstructions the impact of using an increased upstream/downstream distance. To perform the test, height values were manually extracted for ten obstructions from SAR data using the point extraction method, but increasing the distance of the upstream and downstream sampling areas to 50m.

Table 2.2 contains the results from this test. If the height values were originally generated by the LiDAR data then values were extracted from SAR data to provide a direct comparison.

Table 2.2 Comparison of Head Values Generated Using 5m and 50m Upstream/Downstream.

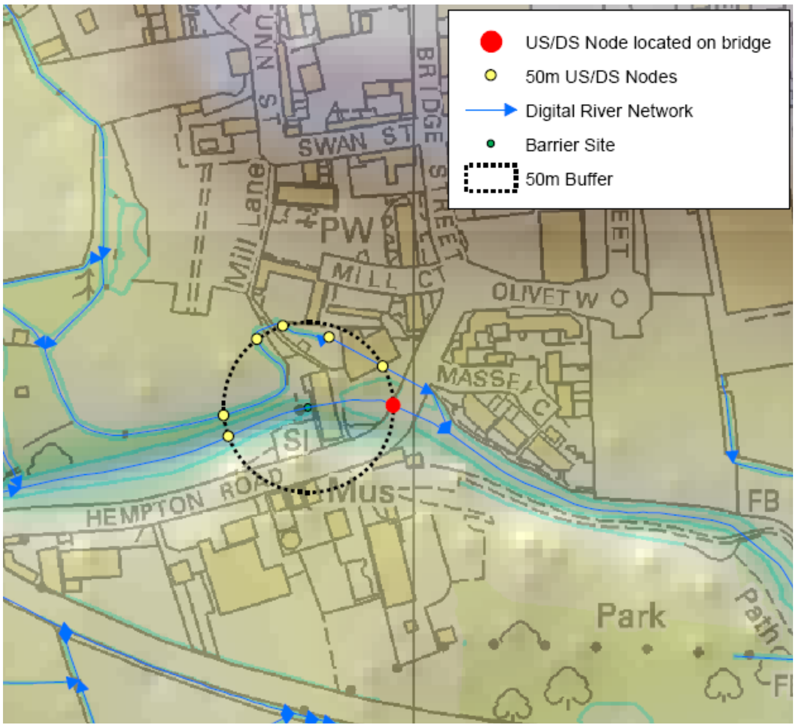
Obstruction ID	Head Value	Height Source	SAR 5m Head	SAR 50m Head
10105	-0.896	NextMap DTM		**-0.658**
10105	-0.896	NextMap DTM		-1.530
10987	-0.411	LIDAR 2m	**0.039**	-0.845
10987	-0.411	LIDAR 2m	**0.039**	**1.329**
10998	-0.012	NextMap DTM		**0.162**
10999	-0.347	LIDAR 2m	**-0.112**	-1.146
11005	-0.044	LIDAR 2m	**0.191**	**0.634**
11018	-0.522	LIDAR 2m	**0.114**	**0.376**
11029	-0.112	LIDAR 2m	**0.128**	-0.333
11030	-0.045	NextMap DTM		-0.093
11035	-0.379	LIDAR 2m	**0.022**	**0.492**
11083	-0.458	LIDAR 2m	**-0.053**	**0.118**

The values in red show an improvement (positive head or increase in head) and the figures in blue show a decline (negative head or decrease in head).

As shown in Table 2.2, barrier 10105 has two upstream nodes (both giving negative values), as does 10987 (one giving a positive value and the other, a negative). It is possible that some of the negative values result from the presence of other obstructions in the area, such as bridges. Figure 2.5 illustrates the context of the points and the location for the downstream node which would result in an error in the values as it is located on the bridge over the water course. Figure 2.5 also illustrates problems with increasing the distance analysed due to tributaries in the surrounding area. In the above example there are 5 points that could be selected in place of the upstream node. These observations indicate that rigorous decision rules would be needed need to be included to ensure that the upstream/downstream height extraction nodes are located on the same main channel/primary flow route as the barrier being assessed.

Following this test, it was decided by the project team that 50m was too large a distance and the final up stream and downstream distance was reduced to 25m to minimise the potential problems, with the identification of the points upstream and downstream being based upon the primary flow path and the length of the river segment. Using this process, it was possible to assign elevation values for 25,767 of the 25,936 barriers, the other 169 barriers were located too close to the upper limit of river sections an it was not possible to use the 25m distance. In these cases the up stream point was located at the furthest possible point.

Figure 2.5 Example of Down Stream Node Identifying an Obstruction.



The Figure shows the errors that can be introduced in the data by using a greater distance upstream/downstream. The downstream node (red point) is located on a bridge over the water body and would result in a higher downstream value.

2.5 Ground Truthing of Barrier Elevation Values

The project team evaluated the accuracy of the extracted head values from the LiDAR/SAR data using two additional data sources. These were: barrier data held within a Humber eel management issues; barriers and stocking report4 and flood management structure data stored in the Environment Agency NFCDD database.

2.5.1 University of Hull International Fisheries Institute (HIFI): Humber Eel Management Issues, Barriers and Stocking Report[5]

This report was written to assess and prioritise the removal of key barriers to eel migration in the Humber catchment with a view to improve bottlenecks to recruitment, and to identify potential stocking sites for elvers. As part of the work undertaken by the project a number of barriers were identified as obstructions to the migration of eels, and the height was assessed. The barrier heights were measured to the nearest 0.5m, suggesting visual assessment and not detailed measurement of the barriers. This means that direct comparison with our data is not possible but it gives an indication of the accuracy of the LiDAR/SAR extracted values.

The distribution of the points is shown in Figure 2.7. The error bars represent the possible range of values for the barrier heights assuming the values have been rounded to 1 decimal place. There are large discrepancies between the two datasets. This prompted the consideration of other sources of ground truthing information.

The height comparison of the LiDAR heights to the obstruction heights in the University of Hull report are only considered in relation to the original point extraction methods described in Section 2.3.1. The comparison was made before the height extraction methods were revised by the Geomatics Group. Once the height data was revised the quality of the comparison did not give a conclusive answer so were not undertaken again.

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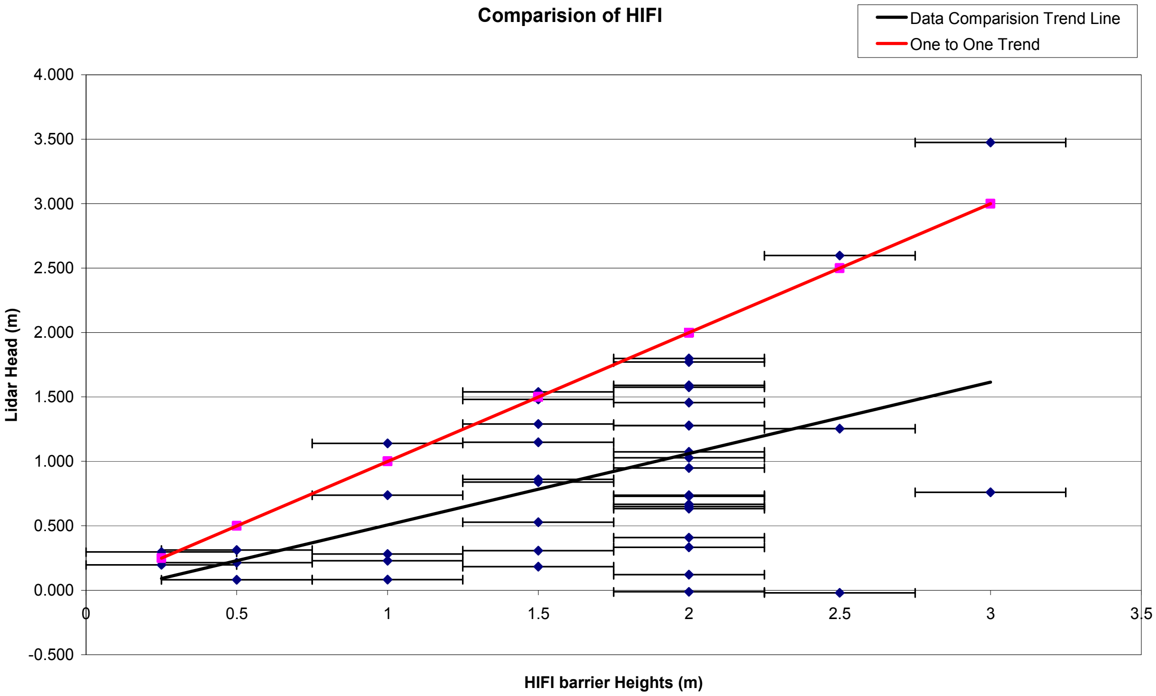
[4] Humber eel management issues: barriers and stocking, A. D. Nunn, J. P. Harvey, R. A. A. oble & I. G. Cowx, 2007

Figure 2.7 Comparison of Hull International Fisheries Institute Barrier Heights and LiDAR/SAR Head Values



One to one trend line represents the desired trend and the data comparison trend line is the correlation for the data comparison

2.6 Flood Risk Management Structure Data

As a second ground truthing comparison , the project team reviewed the height information for flood defence structures stored in the Environment Agency's National Flood and Coastal Defence Database (NFCDD). This dataset contains a total of 152,869 features, of which 58,688 features have height information associated with them. However a majority of the features stored in the database relate to structures not relevant to this study, such as foot bridges and outfalls. For the purposes of this study, 4,551 weirs where associated height information was extracted from the NFCDD database and compared to the LiDAR/SAR extracted values.

The obstructions data was linked to the information from the NFCDD database to enable comparisions to be made. Differences existed in the locations of the barriers; this is due to differences between the structure the Flood Risk Management NFCDD data identifies and the structure within the MasterMap barriers data. An assumption was made that features within 1m were co-located. An example obstruction is shown in Figure 2.7. Two points exist within the NFCDD, these are represented as blue points and have different heights, of 4m and 2m. The LiDAR point is shown in red and has a height of 0.6m. The structure appears to be a constant height so it is possible that the NFCDD misrepresents the Figure, see Figure 2.8 for an aerial view of this site.

Figure 2.8 Differences in Feature Representation Between MasterMap Barriers and NFCDD Features

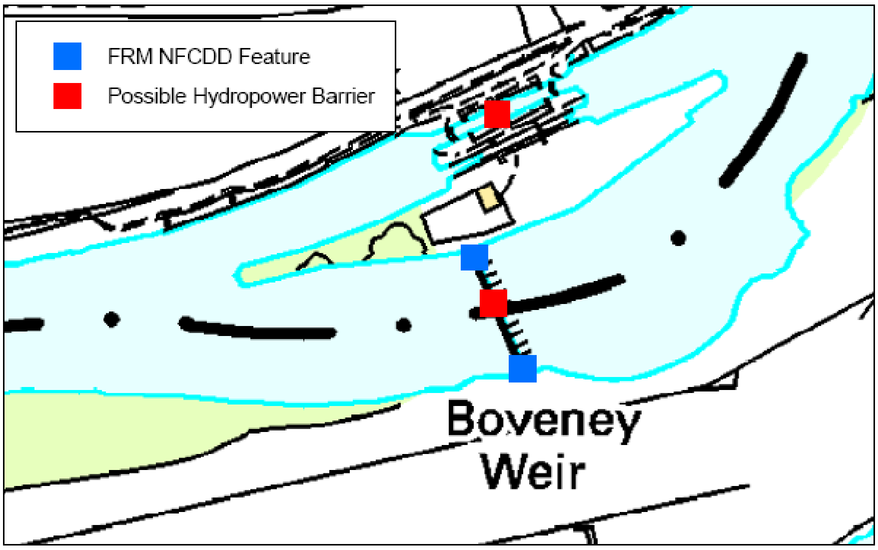


Figure 2.9 Aerial View of Features Shown in Figure 2.8

2.6.1 Results from Comparison

Table 2.3 shows the results from the comparison of the NFCDD features and the barrier sites within a set distance.

As might be expected, the results show a decline in the correlation as the distance between the points increases. There is a low degree of correlation between the points that are one meter or under, this is not unexpected as the features that are less than 1m apart should be identifying the same structure. There is also a decrease in the correlation between the point extraction method and the two methods using an area based method. Of these methods using the maximum/minimum values within 5m of the upstream/downstream points, 25m from the barrier, yields the best correlation with the NFCDD height data.

Table 2.3 Results from Comparison of NFCDD Feature Height Against LiDAR/SAR Head Values

		Point Height from 5m US/DS		Max/Min Within 5m of Barrier		Max/Min Within 5m of US/DS Point		Max/Min Within 5m of US/DS Point - 25m Method	
Distance Between Features (m)	**Number of Features**	**Average Height Difference (m)**	**R^2 correlation**	**Average Height Difference (m)**	**R^2 correlation**	**Average Height Difference (m)**	**R^2 correlation**	**Average Height Difference (m)**	**R^2 correlation**
0 to 1	310	0.328	0.0732	-0.564	0.0119	-0.896	0.0325	-0.016	0.3857
0 to 2.5	722	0.586	0.0369	-0.218	0.0133	-0.541	0.0262	-0.030	0.2516
0 to 5	1076	0.498	0.0035	-0.183	0.0251	-0.515	0.0525	-0.044	0.3006
0 to 10	1355	0.586	0.0026	-0.119	0.0124	-0.443	0.0297	-0.053	0.2601
0 to 15	1448	0.599	0.0027	-0.109	0.0119	-0.431	0.0282	-0.056	0.2571
0 to 20	1502	0.608	0.003	-0.108	0.0131	-0.429	0.0298	-0.059	0.2611
0 to 100	1873	0.662	0.0006	-0.035	0.0098	-0.335	0.0235	-0.068	0.2508

Note: R^2 is a statistic that will give some information about the goodness of fit of a model. An R^2 of 1.0 indicates that the regression line perfectly fits the data.

2.7 Height Conclusions

The comparisons undertaken in the previous sections have not drawn a conclusive answer on the suitability of the head values extracted for use in this project. This is due to the variability and inaccuracies with the data being compared to the LiDAR/SAR. There is inevitably an inherent error in these figures, and should therefore be taken as representative. The quoted vertical accuracy of the LiDAR Digital Surface Model is ±25cm and the SAR data has a quoted vertical accuracy of ±1m.

Accurate height figures for individual barriers would require measurement on site. We were able to improve the accuracy by following a number of methodologies, but further recommendations to improve the availability and accuracy of height data for future studies are provided in Section 7.

It was agreed (with the project steering board) that a representative head value for each of the barriers would be derived by using the maximum estimate of the methods outlined in the previous Section. The resulting height sources used for the barriers are shown in Table 2.4 and the distribution shown in Figure 2.9.

Table 2.4 Source of Height Data

Height Source	Number of Barriers
Max/Min Within 5m of US/DS - 25m US/DS	19558
Max/Min Within 5m of US/DS - 5m US/DS	3494
Point Height from 5m US/DS	2883

3 Flow Estimation

3.1 Section Summary

The other required factor to calculate power potential is the flow value. This Section outlines the data sources and methods employed to generate a flow value for each of the barriers being assessed.

The key issues covered are:

- A number of flow data sets were used as there was not a readily available nationally consistent flow dataset;
- The Environment Agency's Water Resources GIS (WRGIS) was chosen to provide the background flow data and the values were proportioned using a number of methods. These included:
- Stream ordering;
- Upstream river length;
- Hi-Flows Qmed values;
- The WRGIS values were ground truthed against gauging stations to check on the suitability of the values;
- The flow information at the barriers was selected based on the most accurate data available.

3.2 Sources of Flow Information

Four flow datasets were been reviewed and used in this project task. These were the Concise Register of Gauging Stations; Low Flows Enterprise; flows values held in the WRGIS and the HI-FLOWS dataset.

The characteristics of these four datasets are discussed in detail below.

3.2.1 Concise Register of Gauging Stations

The Concise Register of Gauging Stations (http://www.nwl.ac.uk/ih/nrfa/station_summaries/crg.html) provides reference information relating to the river flow gauging stations for which flow data are held on the National River Flow Archive. For the majority of gauging stations, values have been derived for the Q_{mean} (mean flow)and Q_{95} (the flow rate that is exceeded for 95 per cent of the time) based on historic flow records. For this project, flow values required were extracted from the individual web pages and attributed to the location points in the GIS. The use of this dataset to enable the benchmark of values within the WRGIS (see below) and estimates of flow values is considered in Sections 3 and 4.

3.2.2 Low Flows Enterprise

The potential extraction of the required flow values (Q_{mean} and Q_{95}) from Low Flows Enterprise (formerly Low Flows 2000) was considered at an early stage of this project. However the Low Flows tool is not designed to enable the evaluation of the many thousands of points required within a short timescale for this national-level study.

3.2.3 Water Resources GIS

Summary flow duration statistics (Q30, 50, 70 and 95) are held within the Environment Agency's Water Resources GIS (WRGIS) for the outflow points of around 11,000 'Integrated Water body' sub-catchments across England and Wales. These include Water Framework Directive River and lake water bodies and CAMS Assessment Points which are usually located at gauging stations. The upstream sub-catchments and total catchments delineated for these points, and the routing between them has been reviewed by Agency staff and is now considered fairly robust, although local errors may still exist.

For each point, the summary flow per centiles are estimated for four artificial influence scenarios (natural, recent actual, future predicted, and fully licensed) of which two are most relevant for this project are described in the box below.

The Natural Scenario

This is the scenario in which there are no abstractions or discharge influences. The QN30, QN50, QN70 and QN95 per centile flow estimates are derived, where possible, from the natural flow duration curves entered by Environment Agency staff into CAMS Ledgers at CAMS Assessment Points, or by interpolation between and upstream of these points based on catchment area. The source of these statistics will vary according to the tools applied locally (e.g. Low Flows 2000, gauged flow naturalisation, groundwater or other models etc), with checks carried out to ensure credible patterns of accretion before they are uploaded to the WRGIS. The period of record represented by these statistics is currently variable down to a minimum of 10 years – migration towards a standard 18 year period (i.e. 1990 to 2007) is underway but has not been completed. The hydropower project could use the QN95 value as an indication of natural low flows free from any influence (and potential error) associated with abstractions and discharges.

The Recent Actual Scenario

The Recent Actual Scenario which is a prediction based on the impact of current 'live' abstractions and discharges at their recent actual rates over the last 6 years on the natural flows previously defined): The hydropower project has used the ScenRAQ95 to indicate low flows as modified by 'typical' artificial influences. This should be a more credible prediction of the actual flow regime but is also potentially subject to errors in the artificial influences held within the WRGIS. The abstraction and discharge influences are undergoing an ongoing process of quality assurance and improvement through CAMS but this is not yet complete. Estimates of ScenRAQ30 have also been used as a substitute for a Recent Actual mean flow estimate which is not calculated within the WRGIS (Q30 flow estimates are often a reasonable first pass approximation for mean flows although this is only a 'rule of thumb')

In addition to the WRGIS based flow duration statistics, the project team evaluated the natural mean flow values for the water body outflow points, as derived from their WRGIS delineated catchments, from the raster based Continuous Estimation of River Flow dataset. This was developed by the Environment Agency and the Centre for Ecology and Hydrology to address the need for a cheaper method to derive natural flows within un-gauged catchments. It provides an independent indication of mean natural flow for each water body outflow point.
The use of information contained in the WRGIS database to derive estimated flow values for the barrier dataset is discussed in the remainder of this Section.

3.2.4 Hi-Flows

The Environment Agency's Hi-flows dataset (produced by CEH) was considered. This has primarily been used in the generation of the Environment Agency's Flood Map and has the advantage of comprehensive national coverage (over 400,000 points) across England and Wales. However the key limitations of this dataset are that it only contains Qmed (annual median flood flow) information and other parameters associated with the flood hydrograph, it is only derived for catchments larger than 5km^2. The direct use of Qmed from this data would lead to the calculation of an exaggerated hydropower potential at the assessed barrier sites. To address this problem, the project team investigated the use the Hi-flow Qmed values on the 1:50,000 Ordnance Survey (OS) river network as a means to estimate lower flow estimates in the Water Resources GIS (WRGIS) from water body outflow points to the location of each of the weirs.

The use of this dataset to aid the estimation of flow values at hydropower opportunity sites is described later in Section 3.3.

3.3 Ground Truthing of the WRGIS Water Body Flow Estimates

We assessed the reliability of the flow estimates held for the WRGIS outflow points using readily available gauging station datasets. This was necessary to enable the use of this dataset for estimating flow values for hydropower opportunity locations not located at the gauging station site.

Flow values for gauging stations located at, or very close to, the outflow points of the WRGIS water bodies (typically CAMS Assessment Points) were derived and compared. This provided a dataset against which methods for transposing flow estimates to other locations could be tested.

Gauged flows may not be equivalent to either the natural or recent actual scenario assumptions within the WRGIS, and no attempt has been made to check the consistency between either set of statistics. The checks are intended to indicate whether the WRGIS flow estimates appear to be in 'the right ball park' where they are co-located with a gauging station for which data are available.

Using the 1131 individual points contained in the Gauging Station Register (see Section 3.2.1), 1071 points were selected which contained information on the Q_{mean} and Q_{95} flow values. The gauging station values were compared with WRGIS flow estimates and the correlation analysed. To ensure that the two values represent the same point on the river network, the stream order on which the river Section of the gauging station is located and that of the water body outflow point have been compared. This reduced the number of sites available for comparison to 210.

The values compared were:

- Gauged Qmean vs WRGIS QMeanUps;
- Gauged Q95 vs WRGIS QN95ups;
- Gauged QMean vs WRGIS ScenRAQ30;
- Gauged Q95 vs WRGIS ScenRAQ95.

To test the statistical correlation between the gauged values and the WRGIS estimates, we calculated an R^2 value, which indicates the extent to which the WRGIS correlates with the gauging station values. Table 3.1 shows the correlations for the comparisons listed above. The highest confidence in the correlations is seen with the comparison of the gauged Q_{mean} against WRGIS QMeanUps and WRGIS ScenRAQ30 and the comparison of the Gauged Q_{95} vs WRGIS ScenRAQ95. The comparision and correlation of the filtered points are outlined in Figures 3.1 and 3.2.

This suggests that the WRGIS provides reliable estimates of flows in comparison with gauging station values from the same locations. This is unsurprising because WRGIS flows should be based on Catchment Abstraction Management Strategies Assessment Points (CAMS APs) which should themselves have been checked against gauging records where available. We therefore carried forward all four WRGIS flow estimates into further development of a method to transpose to points within the water body sub-catchment. However, use of the natural flow estimates (i.e. QN95Ups and QmeanUps) is the most credible approach, unless it is possible to identify and remove artificial influences that lie in between the weir being assessed and the sub-catchment outflow point.

Table 3.1 Correlation Between Gauged Flow Values and WRGIS Estimates

Gauging station values	**Gauged Qmean**	**Gauged Q95**	**Gauged Qmean**	**Gauged Q95**
WRGIS estimates tested	**QmeanUps**	**QN95Ups**	**ScenRAQ30**	**ScenRAQ95**
R² for Full data set of 1071 gauging stations:	0.958	0.815	0.965	0.820
R² using filtered stream order to leave only co-located points (210):	0.986	0.925	0.986	0.966

Note: R^2 is a statistic that will give some information about the goodness of fit of a model. An R^2 of 1.0 indicates that the regression line perfectly fits the data.

Figure 3.1 Correlation Between the Gauged Q_{mean} Values and the Equivalent WRGIS Estimates for Co-located Points

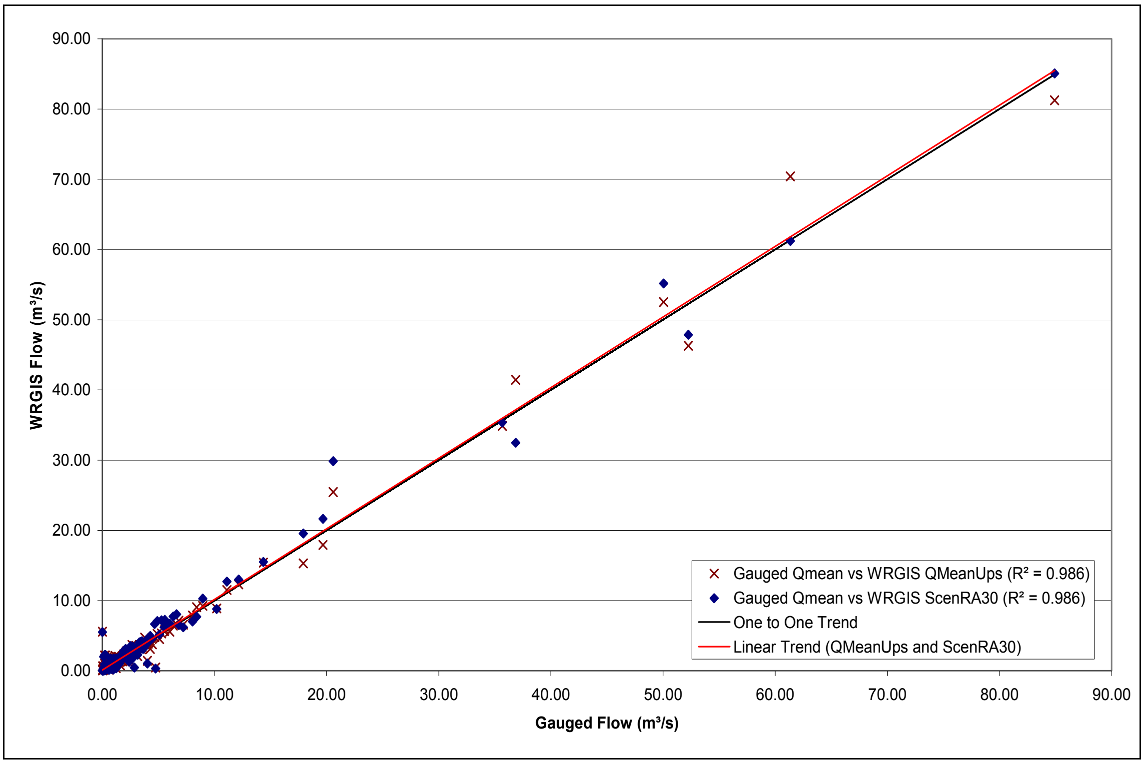
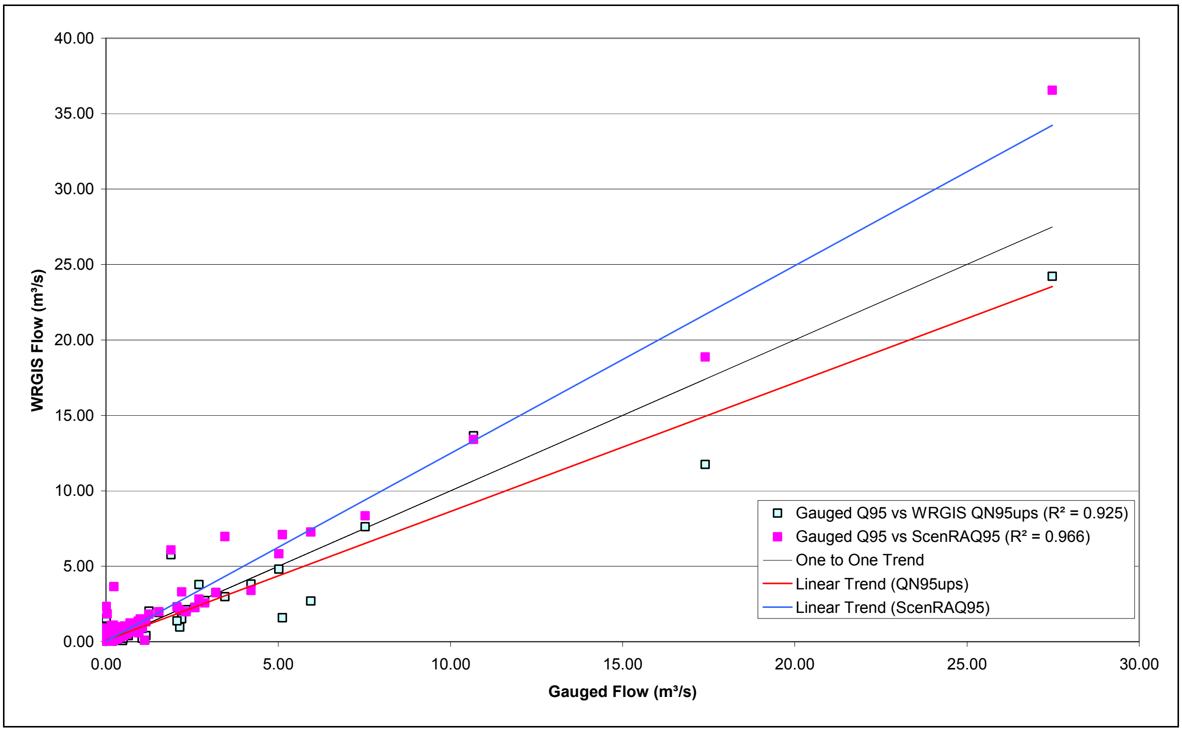


Figure 3.2 Correlation Between the Gauged Q_{95} Values and the Equivalent WRGIS Estimates for Co-located Points



3.4 Methods to Estimate Flows for Hydropower Opportunity Sites

The analysis presented in Section 3.2 demonstrated a high level of confidence in the flow estimates held within the WRGIS. However, for the purposes of this project, it is necessary to develop a method to derive a first-pass estimate of river flows at barrier points, which are mostly not located at a WRGIS water body outflow point. This Section explains the methodology we developed to achieve this.

The starting point is to identify the WRGIS water body sub-catchment within which the weir is located, and the flow estimates for the outflow point of this water body. A number of alternative techniques and datasets could then be used to transpose these estimates to the location of the weir itself which may, for example, be on a small tributary to the main river, and therefore be poorly represented by the water body outflow point.

These alternatives include:

- Identify the 1:50,000 OS river network Shreve order (the method for defining structure/location of river Section within network) at the water body outflow point and the barrier, and use the relationship between these to adjust the flow estimates;
- Use a calculated 'total length of upstream river lines' for both points in a similar fashion, although. this would require pre-processing to assign values to all river reaches in the river network; or

- Use Hi-Flows Qmed values at the barrier location and WRGIS outflow point to derive a reasonable flow estimate.

If an estimate of the total upstream catchment area were available for each of the weirs, this would provide the most reliable basis for transposing flows, but such catchment area estimates are not readily available.
The following sub-sections present four examples where these alternative approaches were trialled ‘manually’ to determine the most effective and accurate methodology. In these examples, river Shreve order estimates have been taken from the closest segment of the 1:50,000 OS river network, the ‘total length of upstream river lines’ has been manually calculated from the closest point on this segment to include all the upstream segments, and the Qmed estimates have been taken from the closest CEH Hi-Flows points (disregarding whether this is located on the closest 1:50,000 OS river segment). In all cases the WRGIS outflow point estimates to be transposed are based on the natural QmeanUps, and QN95ups estimates.

3.4.1 Example 1 – WRGIS Water Body “AP15, River Lyd”

Figure 3.3 shows the location of two gauging stations within the AP15, River Lyd WRGIS water body sub-catchment (Example 1). The dots shown in the Figure represent locations recorded in the HI-FLOWS dataset which have recorded Qmed values.

The presence of the gauging stations within the water body allows the alternative flow transposition methods to be checked against the recorded values.

Table 3.2 shows the flow values and the flow values amended by using the pro rata methods discussed above. The Shreve order ratio is calculated based on a ratio of the Shreve order at the gauging station to the Shreve order at the outflow point, for example in the case of the southern gauging station the ratio is 32/42. The upstream river length is based on a similar ratio but for length of the river network upstream.

Table 3.2 Example 1: Comparison of Flow Estimates with Gauged Values

		Southern Gauging Station		Northerly Gauging Station	
	WRGIS Outflow Point	**Values**	**Difference (Estimate – Gauge)**	**Values**	**Difference (Estimate – Gauge)**
Qmean (m^3/s)	0.630	0.340	0.290	0.130	0.500
Q95 (m^3/s)	0.280	0.056	0.224	0.019	0.261
Shreve Order	42	32	10	21	21
Shreve Order Ratio		0.762 (32/42)		0.500 (21/42)	
Qmean (Shreve Order Proportioning)		0.480 (0.63*0.762)	0.140	0.315 (0.63*0.5)	0.185
Q95 (Stream Order Proportioning)		0.213 (0.28*0.762)	0.157	0.140 (0.28*0.5)	0.121
Upstream river Length (m)	55138	36,221		18,916	
Upstream River Length Ratio		0.657 (36222 / 55138)		0.343 (18916 / 55138)	
Qmean (River Length Proportioning) (m^3/s)		0.414 (0.63*0.657)	0.074	0.216 (0.63*0.343)	0.086
Q95 (River Length Proportioning) (m^3/s)		0.184 (0.28*0.657)	0.128	0.096 (0.63*0.343)	0.077
CEH Qmed (m^3/s)	11.23	7.86		3.34	
CEH Qmed (Proportion) (m^3/s)		0.700 (7.86/11.23)		0.297 (3,34/11.23)	
Qmean (CEH Qmed Proportioning) (m^3/s)		0.441 (0.63*0.7)	0.101	0.187 (0.63*0.297)	0.057
Q95 (CEH Qmed Proportioning) (m^3/s)		0.196 (0.28*0.7)	0.140	0.083 (0.28*0.297)	0.064

Note: Calculation method shown in brackets in the Table

The differences from this example show the use of Qmed for proportioning, the WRGIS flow values, provides slightly better results than using the upstream river length for the northerly gauging station, with the opposite being the case for the southerly gauging station. Both of these methods provide better flow estimates than the use of the Shreve order, and both represent a considerable improvement over the direct use of the WRGIS outflow point estimates.

3.4.2 Example 2 – WRGIS Water Body “GB106039022980”

Figure 3.4 shows the location of two gauging stations for the GB106039022980 WRGIS Water body (Example 2). Table 3.3 shows the flow values for the gauging stations and outflow point for this water body.

Table 3.3 Example 2: Comparison of Flow Estimates with Gauged Values

		Southern Gauging Station		Northerly Gauging Station	
	WRGIS Outflow Point	**Values**	**Difference (Estimate – Gauge)**	**Values**	**Difference (Estimate – Gauge)**
Qmean (m^3/s)	0.410	0.360	0.050	0.220	0.190
Q95 (m^3/s)	0.053	0.074	-0.021	0.031	0.022
Shreve Order	15	14	1	11	4
Shreve Order Ratio		0.933		0.733	
Qmean (Shreve Order Proportioning)		0.383	0.023	0.301	0.081
Q95 (Stream Order Proportioning)		0.049	-0.025	0.039	0.008
Upstream river Length (m)	33,104	30,150		20,228	
Upstream River Length Ratio		0.911		0.611	
Qmean (River Length Proportioning) (m^3/s)		0.373	0.013	0.251	0.031
Q95 (River Length Proportioning) (m^3/s)		0.048	-0.026	0.032	0.001
CEH Qmed (m^3/s)	12.06	10.47		7.48	
CEH Qmed (Proportion) (m^3/s)		0.868		0.620	

Qmean (CEH Qmed Proportioning) (m^3/s)		0.356	-0.004	0.254	0.034
Q95 (CEH Qmed Proportioning) (m^3/s)		0.046	-0.028	0.033	0.002

As with the previous example, the use of either Q_{med} or upstream river length proportioning provides better estimates than using the Shreve order, although the Q_{95} low flow estimate from the WRGIS outflow point is already lower than the value from the southern gauging station so all transposition approaches make this difference larger.

3.4.3 Example 3 – WRGIS Water Body "GB104027068250"

Figure 3.5 shows the location of two gauging stations for the GB104027068250 WRGIS Water body (Example 3). Table 3.4 shows the flow values for the gauging stations and outflow point for this water body.

Table 3.4 Example 3: Comparison of Flow Estimates with Gauged Values

		Southern Gauging Station		Northerly Gauging Station	
	WRGIS Outflow Point	**Values**	**Difference (Estimate – Gauge)**	**Values**	**Difference (Estimate – Gauge)**
Qmean (m³/s)	1.010	0.650	0.360	0.340	0.670
Q95 (m³/s)	0.178	0.132	0.046	0.059	0.119
Shreve Order	48	46	2	30	18
Shreve Order Ratio		0.958		0.625	
Qmean (Shreve Order Proportioning)		0.968	0.318	0.631	0.291
Q95 (Stream Order Proportioning)		0.171	0.039	0.112	0.053
Upstream river Length (m)	67,891	52,059		26,761	
Upstream River Length Ratio		0.767		0.394	
Qmean (River Length Proportioning) (m³/s)		0.774	0.124	0.398	0.058
Q95 (River Length Proportioning) (m³/s)		0.137	0.005	0.070	0.011
CEH Qmed (m³/s)	11.73	12.43		9.35	
CEH Qmed (Proportion) (m³/s)		1.060		0.797	
Qmean (CEH Qmed Proportioning) (m³/s)		1.070	0.420	0.805	0.465
Q95 (CEH Qmed Proportioning) (m³/s)		0.189	0.057	0.142	0.083

Unlike the previous example, the calculations using the river length method produce a better result than the methods using the stream ordering or Qmed. This is because the CEH flow point values decrease rather than increase downstream along the river within the water body sub-catchment.

3.4.4 Example 4 – WRGIS Water Body "GB105031050480"

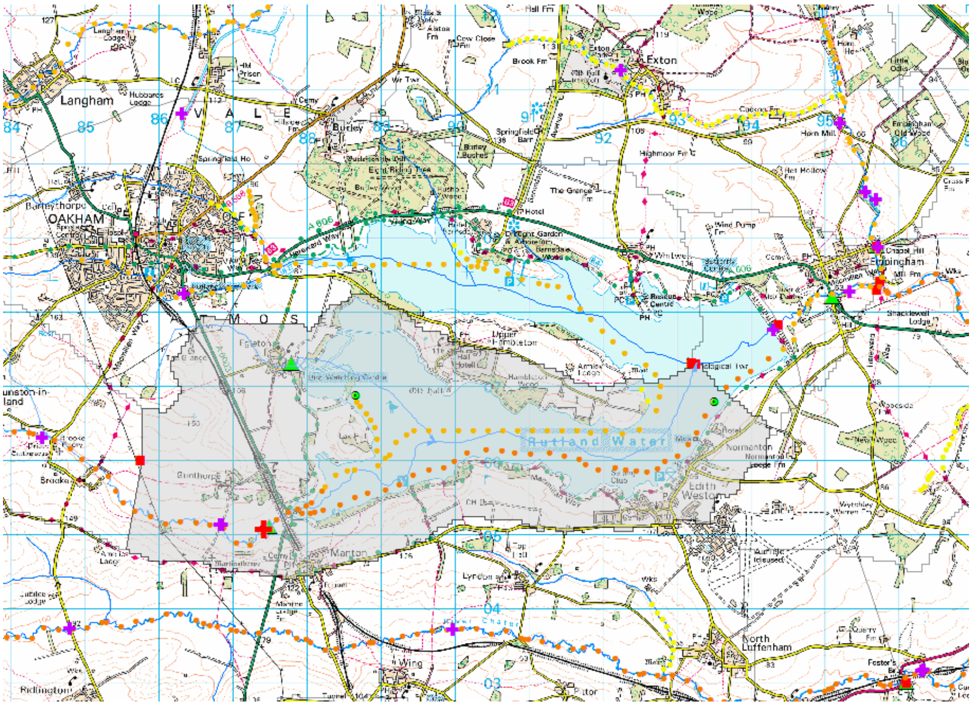
Examples 1 -3 suggest that the WRGIS values recorded at the Water Body outflow points can be proportioned to create a reasonable estimated flow value for hydropower opportunity locations located on main river network

However, it is important to note that the examples given do not account for unique situations that are likely to be encountered in the structure of the river network, and potential limitations of the Flood map flow points.

One such example is given here. Figure 3.6 shows the location of two gauging stations upstream of the GB105031050480 WRGIS water body outflow point Table 3.5 shows the flow values for the gauging stations and outflow point for this water body. Figure 3.7 shows the context of this water body, as the surrounding area is a lake, making it different to the other examples.

This example suggests that any additional processing for the national calculations may require additional screening criteria to reduce errors that arise from such situations.

Figure 3.7 Overview Location of Example 4 (Figure 3.6)



The key to the symbols is the same as in Figure 3.6

In this example the northerly gauging station is located on a tributary and has a very small upstream catchment. The tributary joins the main river from the southerly gauging station. Because the Flood Map flow points are only calculated for catchments greater than 5km^2, the closest point is taken. If this distance was greater it could lead to inaccuracies in the values used.

Table 3.5 Example 4: Comparison of Flow Estimates with Gauged Values

		Southern Gauging Station		Northerly Gauging Station	
	WRGIS Outflow Point	Values	Difference (Estimate – Gauge)	Values	Difference (Estimate – Gauge)
Qmean (m^3/s)	0.281	0.190	0.091	0.020	0.261
Q95 (m^3/s)	0.043	0.001	0.042	0.000	0.043
Shreve Order	12	11	1	1	11
Shreve Order Ratio		0.917		0.083	
Qmean (Shreve Order Proportioning)		0.258	0.068	0.023	0.003
Q95 (Stream Order Proportioning)		0.039	0.038	0.004	0.004
Upstream river Length (m)	67891.196	52059.928		26761.106	
Upstream River Length Ratio		0.767		0.394	
Qmean (River Length Proportioning) (m^3/s)		0.216	0.026	0.111	0.091
Q95 (River Length Proportioning) (m^3/s)		0.033	0.032	0.017	0.017
CEH Qmed (m^3/s)	16.83	10.24		0.67	
CEH Qmed (Proportion) (m^3/s)		0.608		0.040	
Qmean (CEH Qmed Proportioning) (m^3/s)		0.171	-0.019	0.011	-0.009
Q95 (CEH Qmed Proportioning) (m^3/s)		0.026	0.025	0.002	0.002

This example shows a variation between the suitability of the methods for the Q_{mean} or Q_{95} methods. The Qmed method generally provides the best flow estimates, but not in all cases. To identify these cases, criteria were developed, including the distance from the weir location to the Qmed point used for flow transposition, and a reducing Qmed estimate from the weir to the water body outflow point. These criteria were built into the flow calculation process to flag those sites where flow estimates needed greater caution.

3.4.5 Power Potential of Example Water Bodies

The power potential is a function of the flow and the weir height ('the head'). Entec investigated the impact of the different flow methodologies, outlined in the previous sections; have on the power output calculation. Due to the nature of calculating the power, errors at each stage of the calculation can create errors in the final power. This Section shows the differences in calculated power at the gauging stations and the test points in the previous examples

Table 3.6 shows the calculated power for each of the examples in sections 3.4.1 to 3.4.4. The power potential was calculated using the gauged flow values and then compared to the values for the flows based on:

- The Outflow Point;
- The estimation of flow using the stream order proportioning;
- The estimation of flow using the upstream river length proportioning, and
- The estimation of flow using the CEH Qmed proportioning.

The results show a range of differences between the hydropower power potential calculated using the gauging station flow values and the values from the proportioning methods. As expected, the use of the outflow points to estimate the hydropower potential result in an overestimation of the power for all but one of example sites. This is due to the outflow points being at the lower regions of the catchment and having additional inflows between the site in question and the outflow point. For four of the seven test sites, the best approximation of the power generated using the gauged results, comes from the use of the river length proportioning method. For two sites, the Qmed proportioning method is most successful. The stream order proportioning was the most successful for only one site. The total differences are shown in Table 3.7. If the river length method were to be utilised as the final method in this study, the power potential would be over estimated by approximately 5 kW (13 per cent) for these particular examples. This is in comparison to the use of the outflow points, which would over estimate the potential by 57 kW (112 per cent).

It is worth noting that the reliability of using the Qmed values for transposition can readily be checked by including simple screening criteria, such as the distance from the weir to the Qmed point, and by checking that the Qmed values close to the weir are less than those close to the outflow point. In this manner a two step screening process has been devised in which Qmed proportioning was applied first to the majority of sites, followed by the calculation of upstream river lengths for the fewer sites where the Qmed approach is associated with greater uncertainty.

Table 3.6 Estimates of Hydropower Potential Based on the Flow Estimates in Section 4.1-4.4

		Southern Gauging Station		**Northerly Gauging Station**	
		Values	**Difference (Estimate – Gauge)**	**Values**	**Difference (Estimate – Gauge)**
Example 1	Barrier Height	1.405		1.794	
	Hydropower Potential (Gauged Flow Values) (kW)	**2.793**		**1.394**	
	Hydropower Potential (Outflow Point Values) (kW)	3.442	***0.649***	4.395	**3.001**
	Hydropower Potential (Stream Order Proportioning) (kW)	2.623	**-0.170**	2.198	0.804
	Hydropower Potential (River Length Proportioning) (kW)	2.261	-0.532	1.508	0.114
	Hydropower Potential (CEH Qmed Proportioning) (kW)	2.409	-0.384	1.307	**-0.087**
Example 2	Barrier Height	2.897		3.800	
	Hydropower Potential (Gauged Flow Values) (kW)	**5.800**		**5.027**	
	Hydropower Potential (Outflow Point Values) (kW)	7.240	**4.446**	9.496	**8.102**
	Hydropower Potential (Stream Order Proportioning) (kW)	6.757	0.957	6.964	1.936
	Hydropower Potential (River Length Proportioning) (kW)	6.594	0.794	5.803	**0.775**
	Hydropower Potential (CEH Qmed Proportioning) (kW)	6.285	**0.485**	5.890	0.862

Example 3	Barrier Height	1.792		6.527	
	Hydropower Potential (Gauged Flow Values) (kW)	**6.498**		**12.839**	
	Hydropower Potential (Outflow Point Values) (kW)	10.429	**7.636**	37.985	**36.591**
	Hydropower Potential (Stream Order Proportioning) (kW)	9.994	3.497	23.741	10.902
	Hydropower Potential (River Length Proportioning) (kW)	7.997	**1.499**	14.973	**2.134**
	Hydropower Potential (CEH Qmed Proportioning) (kW)	11.051	4.553	30.278	17.439
Example 4	Barrier Height	0.102			
	Hydropower Potential (Gauged Flow Values) (kW)	**0.135**			
	Hydropower Potential (Outflow Point Values) (kW)	0.170	**-2.623**		
	Hydropower Potential (Stream Order Proportioning) (kW)	0.156	0.021		
	Hydropower Potential (River Length Proportioning) (kW)	0.130	**-0.005**		
	Hydropower Potential (CEH Qmed Proportioning) (kW)	0.104	-0.032		

The values in red show the smallest difference and the values in blue show the greatest difference

Table 3.7 Sum of Potential Power Differences for Examples 1-4 from Table 4.5

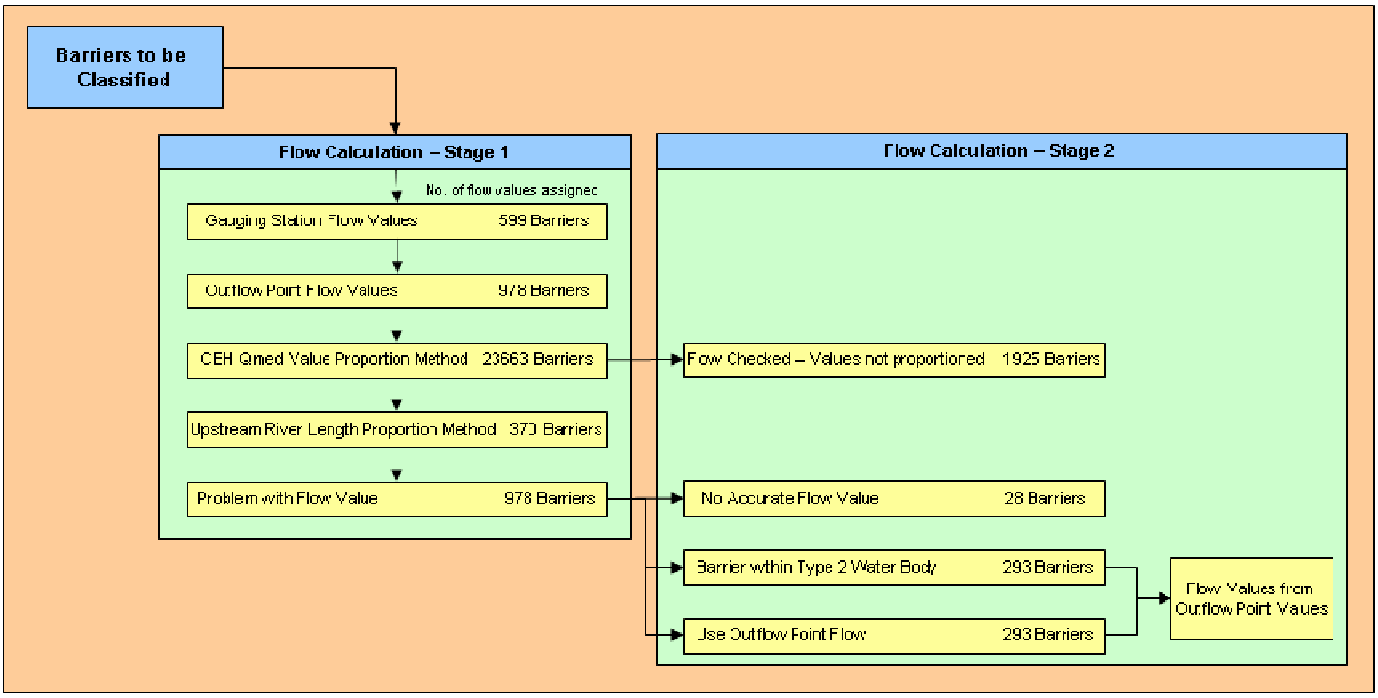
Flow Estimation Method	Total Power	Sum of Power Potential Differences (kW)	Per centage over/under estimation (%)
Gauged Flow Values	34.49	-	-
Outflow Point Values	73.16	57.80	112.14
Stream Order Proportioning	52.43	17.95	52.04
River Length Proportioning	39.27	4.78	13.86
CEH Qmed Proportioning	57.32	22.84	66.22

3.5 Application to the National Data

The methods that described in Section 3.4 were applied to the national barrier dataset. This Section describes the data sources and methods that were used to give a flow estimate for each barrier.

The four methodologies trialled in Section 3.4 each have their strengths and weaknesses, and it is not possible to apply one to all of the points being assessed in this study. Instead, a hybrid method was used based on the best available information at the barrier. Figure 3.8 shows the methods used and the number of barriers that were categorised by each method.

Figure 3.8 Method and Numbers of Barriers Categorised by Each Flow Method.



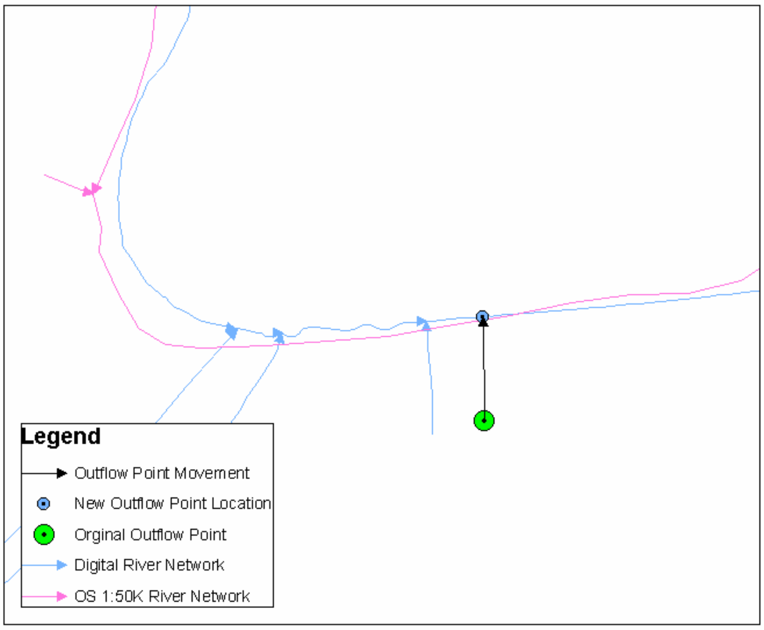
3.5.1 Gauging Stations

In the 599 instances where a barrier was located on the same river stretch as a gauging station the flow values were taken direct from this station. The same river stretch was chosen to ensure that no tributaries affected the flow values recorded at these points.

3.5.2 Outflow Point

If the barrier was located on the same stretch as a Water Resources Outflow point then the flow values were taken direct from the Water Resources GIS. This was the case for 978 barriers. Pre-processing was carried out at this stage to ensure that the river network and the outflow points mapped on to each other and that the outflow points were co-located. This involved an automated movement and a manual check of the water bodies that contained a barrier or had a barrier located close to the boundary. Figure 3.9 shows an example of the movement that occurred.

Figure 3.9 Example of WRGIS Outflow Movement from Ordnance Survey Network to Digital River Network



3.5.3 CEH QMED Points

The next method applied to the remaining barriers was the attribution of the barriers and the associated water body outflow with the CEH Qmed value. Once the attribution had taken place, manual checks were performed to ensure the correct points were associated and to ensure that the flow values at the outflow points were less than those at the barriers. In the latter case the values were either classified as “Problem with Outflow”, “Use the Upstream River Proportion Method” or the raw outflow point flow value was used. The methods to correct these values were based on manual editing and assessment of the best data available at those points.

3.5.4 Upstream River Proportion

Section 3.4 showed that there was very little difference between the CEH Qmed point proportioning and the Upstream River Length Proportioning. For this reason 370 of the barriers were categorised using this method. A database query was developed to calculate the upstream length based on the network topology inherent within the Digital River Network data. It was only possible to use this query on certain sections of the network due to the scale of the query involved. Once the upstream river length was generated it was used to proportion the outflow point flows as per Section 3.4.

3.5.5Outflow Difficulties

In situations where the previous methods are not applicable the following methods were employed.

No Accurate Flow

The barriers that are located in Transitional Water bodies[6] do not have an accurate flow value due to the flow estimation methods used within the Water Resources GIS. The barriers located within the transitional water bodies are therefore categorised as “No accurate flow”.

Type 2 Water Bodies

In some circumstances there are water bodies that only contain streams that flow direct into the sea. These are classed as Type 2 Water bodies. In these situations it is unclear where the primary flow is located and thus the outflow point is unknown. The water body flow was therefore taken as the flow value in the absence of a better flow estimate.

Outflow Point Used

This final category of flow value categorisation was used where there were difficulties using the other methods. In these situations the outflow value was used and no proportioning was undertaken.

3.6 Flow Conclusions

The summary points from this Section are:

- The QMeanUps (mean) and QN95Ups (low flow) data from the WRGIS provide a reliable indication of flows at the outflow points of water bodies;
- Three methods were been investigated to derive flow estimates for each of the hydropower opportunity sites using the WRGIS water body flow values. These estimates were derived using river Shreve, upstream river length, and hi-flow Qmed values;
- The upstream river length method and the use of the Qmed values were the best methods for deriving estimates of recorded actual flow values. This conclusion is based upon the four case study examples (including seven sites) used in this study;
- When the Hydropower potential is calculated using a proportion derived from the upstream river length it provides the best estimate, but based on the examples chosen it over estimates the power at the sites by 14 per cent (in the four examples considered).

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[6] Transitional Water bodies are defined by The Water Framework Directive as ‘‘bodies of surface water in the vicinity of river mouths which are partially saline in character as a result of their

4 Power Potential

4.1 Section Summary

Sections 2 and 3 have presented the methodology used to generate estimates of head and flow for each barrier point. This Section uses this information to calculate the power potential at each of the barrier sites and the distribution of the maximum power potential and power potential by region is calculated

4.2 Power Potential

As per the guidance given by the British Hydropower Association[7], the opportunity is calculated by using the following formula:

$$\mathbf{P = \eta \, \rho \, g \, Q \, H}$$

Where:

- **P** is the mechanical power produced at the turbine shaft (Watts);
- η is the hydraulic efficiency of the turbine, ρ is the density of water (1000 kg/m3);
- **g** is the acceleration due to gravity (9.81 m/s2);
- **Q** is the volume flow rate passing through the turbine (m3/s);
- **H** is the Head (height from top to bottom of the barrier).

Assuming per cent as a typical water-to-wire efficiency for the whole system, the above equation simplifies to:

$$\mathbf{P\ (kW) = 7 \times Q\ (m^3/s) \times H\ (m)}$$

This formula multiplies the flow and the head at a site, which will exaggerate any errors that may already exist in the head and flow data.

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proximity to coastal waters but which are substantially influenced by freshwater flows''

[7] A Guide To UK Mini-Hydro Developments, British Hydropower Association, http://www.british-hydro.co.uk/download.pdf (last accessed 09/09/2009)

The power potential is split into a number of categories based on the categorisation that is used for types of turbines, as shown below.

- 0-10kW
- 10-20kW
- 20-50kW
- 50-100kW
- 100-500kW
- 500-1500kW
- >1500kW

4.3 National Summary of Power Potential

The frequency and total power potential for each of the categories is shown in Table 4.1. The modal class for the number of barriers is the 0-10kW category, this reflects the distribution of the barriers that have a smaller head value and this category represents over 60% of the number of barriers but only 4% of the total power. The modal class for the categories total power potential is 100-500kW, this class represents 27.5% of the total power. The spatial distribution of the barriers and the maximum power potential is shown in Figure 4.1.

Table 4.1 Distribution of Power Potential

	Maximum Power Potential	
	Frequency	**Total Power (kW)**
0 - 10 kW	15,653	48,090
10 - 20 kW	3,418	48,680
20 - 50 kW	3,384	107,127
50 - 100 kW	1,497	104,903
100 - 500 kW	1,548	324,678
500 - 1500 kW	360	294,128
> 1500 kW	75	250,219

The power potential can further analysed by the type of barrier. Table 4.2 shows the power potential distribution alongside the type of barrier. The greatest total power potential is in the artificial barriers

Table 4.2 Maximum Power Potential by Barrier Type

	Maximum Power Potential			
	Maximum Power (kW)	Average Power (kW)	Total Power (kW)	Number of Barriers
National Data	10254	45	1177826	25935
Natural Barriers	10254	102	622692	6098
Artificial Barriers	2772	28	538329	19299
Weirs	2078	23	382647	16725
Waterfalls	10254	102	622692	6098

4.4 Regional Summary of Power Distribution

Figures 4.3 to 4.11 show the power potential at barriers for each Government region and Wales. The distribution by power category and total power is shown in Table 4.3 and Table 4.4. The modal class for every region is the 0 – 10kW category. The distribution of the barriers across the power bands and regions are given in Table 4.5.

Table 4.3 Frequency of Maximum Power Potential by Region

	Distribution of maximum power potential								
	East of England	**East Midlands**	**North East**	**North West**	**South East**	**South West**	**Wales**	**West Midlands**	**Yorkshire and the Humber**
0 - 10 kW	947	1404	1,066	2,437	2,276	2,232	1,590	1,776	1,925
10 - 20 kW	124	260	175	686	264	391	720	185	613
20 - 50 kW	121	220	169	696	239	353	928	186	472
50 - 100 kW	29	110	77	359	128	130	373	74	217
100 - 500 kW	18	112	94	350	111	109	381	75	298
500 - 1500 kW	0	17	54	60	49	17	77	15	71
> 1500 kW	0	3	7	5	0	3	43	9	5

Table 4.4 Maximum Total Power Potential by Region

	Total Power by Region (kW)								
	East of England	East Midlands	North East	North West	South East	South West	Wales	West Midlands	Yorkshire and the Humber
0 - 10 kW	2,467	3,996	3,190	9,752	4,919	6,668	6,711	3,514	6,873
10 - 20 kW	1,754	3,558	2,479	9,687	3,715	5,650	10,483	2,655	8,699
20 - 50 kW	3,716	7,037	5,425	22,403	7,382	10,973	29,704	5,941	14,547
50 - 100 kW	2,035	7,874	5,446	25,032	9,354	9,015	25,350	5,085	15,711
100 - 500 kW	2,632	20,927	20,202	74,001	21,281	22,013	83,914	14,005	65,703
500 - 1500 kW	0	15,656	41,966	44,683	41,954	10,903	65,279	16,427	57,259
> 1500 kW	0	5,339	14,881	10,895	0	9,125	174,512	25,125	10,342

Table 4.5 Regional Maximum Power Potential Statistics

	Maximum Power Potential								
	East of England	East Midlands	North East	North West	South East	South West	Wales	West Midlands	Yorkshire and the Humber
Maximum Power Potential (kW)	266	2,025	2,765	3,316	1,435	4,286	10,042	10,254	2,772
Average Power Potential (kW)	10	30	57	43	29	23	96	31	50
Total Power Potential (kW)	12,604	64,388	93,590	196,453	88,605	74,348	395,951	72,753	179,135
Number of Barriers	1,239	2,126	1,642	4,593	3,067	3,235	4,112	2,320	3,601

5 Sensitivity Categorisation

5.1 Section Summary

The following Section outlines the methodology adopted to evaluate the sensitivity in developing future small-scale hydropower opportunities within England and Wales. The sensitivity is based upon modelled fish population data and Special Areas of Conservation (SAC).

It should be noted that this is a coarse national overview aimed at illustrating the environmental challenges of exploiting the energy resource that is identified in this study. A detailed classification of all the barriers on a site by site basis is not feasible, and is an absolute imperative for the development of all individual schemes. The environmental sensitivity classification is indicative only and does not consider a number of environmental variables that need to be considered in individual schemes due to the complexity of doing this at the national scale for over 20,000 barriers. These include water quality, flood risk and wider biodiversity issues.

5.2 Input Data

The following Section considers the Fish Classification Scheme 2 and Special Areas of Conservation (SAC) data sources which have been used to develop the national sensitivity categorisation.

5.2.1 Fish Classification Scheme 2 (FCS2)

The key fisheries data that was used is the Environment Agency's Fish classification Scheme data. The dataset provides a national overview of a range of species based on a number of sites where fish are observed as well as their expected locations. The Environment Agency briefing note that accompanies the FCS2 describes the data:

The Fisheries Classification Scheme (FCS2) assesses the ecological quality of rivers entirely on the basis of the abundance of fish species, as determined by survey data. FCS2 uses fish to classify ecological quality based on the Ecological Quality Ratio (EQR), a measure of the observed population in relation to the population expected in a similar river type under reference conditions. It is therefore very different to a classification of fish abundance that may be required for fisheries management purposes.

The expectation for the number of fish at a site cannot be expressed as a single number, but is expressed as a probability distribution of possible values. This distribution is described in terms of the prevalence (the probability that the species will be present) and average abundance (at sites where the species is present).

FCS2 predicts reference conditions using a non-parametric (smooth) geostatistical model relating the prevalence and abundance of each of the 23 species of fish to: a) *environmental variables (e.g. altitude), b) pressure variables (e.g. un-ionized ammonia) and c) geographic location. The inclusion of a geostatistical component adjusts for large-scale variation in fish populations caused by factors such as geology, climate and species dispersal, that are not otherwise explicitly included in the model. The model is then used to predict what fish community would be expected for a given river type (defined by the environmental variables and geographic location) under reference conditions (i.e. with the pressure variables set to zero).*

The models are calibrated from quantitative and semi-quantitative data from over 6,000 sites across England and Wales that were surveyed between 2001 and 2005.

The species accounted for in the FCS2 model are shown in Table 5.1.

Table 5.1 Species in FCS2 Classification

Bream	Spined Loach	Gudgeon	Perch	Rudd
Bleak	Bullhead	Ruffe	Minnow	Grayling
Eel	Carp	Lamprey	Roach	Tench
Stoneloach	Pike	Chub	Salmon	
Barbel	Stickleback	Dace	Trout	

To enable a national level assessment, the project team worked with fisheries experts in the Environment Agency to categorise the 23 species according to their mobility, which is one of the principle criteria that will determine a hydropower scheme’s impact on a particular fish population. The categories are shown in Table 5.2. The categories are generalised groupings; the overall sensitivity to a reduction in longitudinal connectivity for each species depends on the habitat in the impounded river reaches, which is an element that cannot be considered at a national scale.

Table 5.2 Fish Species Groupings

Diadromous Species	Migratory Species	Mobile Species	Non-Migratory Species
Salmon	Barbel	Bleak	Bream (silver)
Shad (Allis and Twaite)	Dace	Bream (common)	Loach (Spined and Stone)
Lamprey	Grayling	Carp	Stickleback (3 and 9 Spined)
Eel	Chub		Carp (Crucian)
Smelt	Pike		Gudgeon
	Trout		Perch
			Roach
			Rudd
			Bullhead
			Tench
			Minnow

Included in FCS2	🟦
Not considered in this study	🟧
Only included in SAC Data	⬜

5.2.1 Probability of Presence

The Fish Classification Scheme data was analysed to provide three bandings that reflect the likelihood of a fish species being present at a FCS2 sample site. It was trialled generating the bandings by analysing the abundance of the species against the prevalence of the species for the available data, however the anomalies and the range of values meant the bandings would have changed depending on the species. The bandings are outlined in Table 5.3.

Table 5.3 Definition of the Prevalence Bands

Prevalence Banding	
1.0 to 0.666	High probability of presence – it is highly likely that the particular species is present at the sample site
0.666 to 0.333	Medium probability of presence – it is likely that the particular species is present at the sample site
0 to 0.333	Low probability of presence – it is unlikely that the particular species is present at the sample site

5.2.2 Environmental Designations - Special Areas of Conservation

A Special Area of Conservation (SAC) is a designation under Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora. Data supplied has the status of "Candidate". They are part of the Natura 2000 network of protected sites created by the Habitat and Birds European Directives. Areas designated as SACs are those which make a significant contribution to the conservation of the habitats and species identified by the Directive.

Sites that are specific to fish were identified and the features selected from the national data. Table 5.4 shows the number of sites relevant to each species, there are multiple species and habitats present at each site and the distinction is given by the population of the species present in the SAC area

Table 5.4 Freshwater Habitats and Species Relevant to Diadromous Analysis in this Study (Bold)

Freshwater habitats	**Number of Areas**
Acid peat-stained lakes and ponds.	6
Allis shad.	**15**
Atlantic salmon.	**31**
Brook lamprey.	**29**
Bullhead.	34
Calcium-rich nutrient-poor lakes, lochs and pools.	10
Clear-water lakes or lochs with aquatic vegetation and poor to moderate nutrient levels.	12
Freshwater pearl mussel.	13
Mediterranean temporary ponds.	1
Naturally nutrient-rich lakes or lochs which are often dominated by pondweed.	6
Nutrient-poor shallow waters with aquatic vegetation on sandy plains.	3
Otter.	56
River lamprey.	**27**
Rivers with floating vegetation often dominated by water-crowfoot.	22

Sea lamprey.	**27**
Spined loach.	5
Turloughs.	1
Twaite shad.	**18**
White-clawed (or Atlantic stream) crayfish.	15

5.2.3 Other Supporting Data

Integrated Water Bodies

The risk categorisation also uses the WRGIS integrated water bodies to provide catchment hierarchy. As part of the generation of the Water Resources GIS, simple hydrological functionality has been incorporated for the water bodies by identifying the next water body downstream for all the sub-catchments. This allows artificial influences to be accumulated downstream, rates of flow accretion to be checked, and dependencies and controls - both down and up the catchment - to be represented. This hierarchy can be used to identify sites and features up or downstream of the barriers to be assessed

5.2.4 Data Coverage

The input data used in the sensitivity classification has a limited coverage this is due to the discontinuous nature of the input data sets. This will be reflected in the final sensitivity banding. There is not enough information to draw the conclusion regarding whether these sites are “low-risk”. The FCS2 data is 7,415 sample locations, these are located in 2,962 water bodies and there are 102 relevant SAC locations.

5.3 Methodology

This Section describes the methodology used to assign environmental sensitivity classes to each of the barriers. The outputs of this classification are combined with the estimates of hydropower potential in Section 6. The methodology is outlined in Figure 5.1.

5.3.1 Stage One - Diadromous Species

The first stage of the sensitivity classification process determines if a diadromous species is highly likely to be present (a FCS2 site has a prevalence score for the diadromous species greater than 0.666) and/or if a relevant Special Area of Conservation intersects the water body. If either or both of these criteria are met, the water body and any water bodies immediately downstream of it are classified as high sensitivity.

The species and habitats identified by SACs are shown in Table 5.3. The water bodies within or downstream of any SAC designated for species shown in bold are classified as high sensitivity.

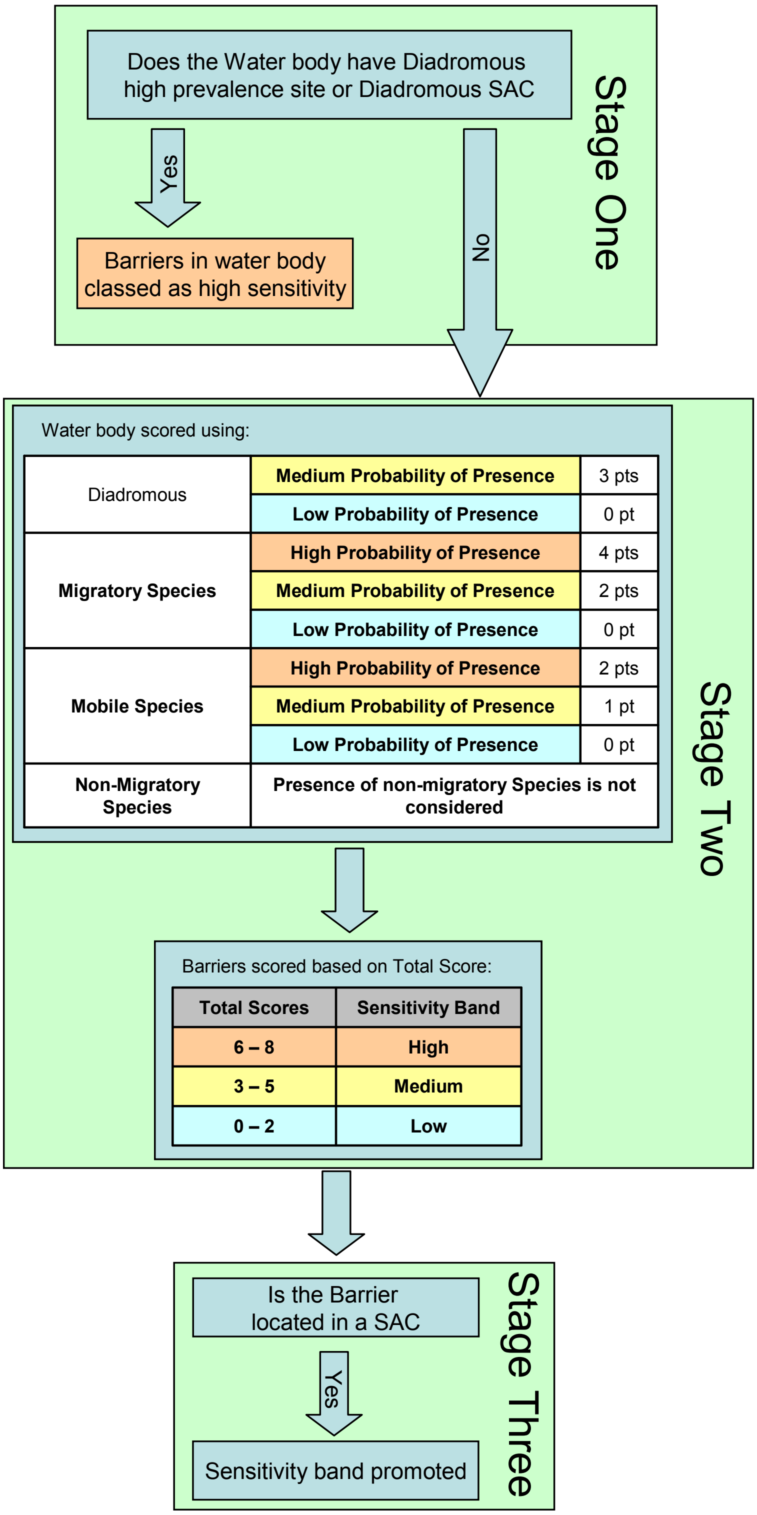
If neither of the criteria is met in stage one then the tests in stages two and three are undertaken.

5.3.2 Stage Two – Other Species and Water Bodies

All remaining water bodies were categorised according to the probability of presence of the fish species shown in Section 5.2.1, with the water body being given a score which is totalled to give a final classification. Because there can be more than one FCS2 site in a water body a conservative approach is used, where the highest category present for the water body is used. The scores assigned to the water bodies are shown in Table 5.5

Once the water bodies are scored for each species, a total score was generated based on the sum of the values. For example, a water body with a low probability of presence for all three categories has a final score of 2. The final scores were then categorised into a series of sensitivity bands to derive the final sensitivity band, as shown in Table 5.6.

Figure 5.1 Sensitivity Classification Process



Water body scored using:

Diadromous	**Medium Probability of Presence**	3 pts
	Low Probability of Presence	0 pt
Migratory Species	**High Probability of Presence**	4 pts
	Medium Probability of Presence	2 pts
	Low Probability of Presence	0 pt
Mobile Species	**High Probability of Presence**	2 pts
	Medium Probability of Presence	1 pt
	Low Probability of Presence	0 pt
Non-Migratory Species	**Presence of non-migratory Species is not considered**	

Barriers scored based on Total Score:

Total Scores	Sensitivity Band
6 – 8	High
3 – 5	Medium
0 – 2	Low

Table 5.5 Scores Given to Each Water Body Based on the FCS2 Probability of Presence

Diadromous Species	**High Probability of Presence**	Accounted for in Stage one assessment
	Medium Probability of Presence	3 pts
	Low Probability of Presence	0 pt
Migratory Species	**High Probability of Presence**	4 pts
	Medium Probability of Presence	2 pts
	Low Probability of Presence	0 pt
Mobile Species	**High Probability of Presence**	2 pts
	Medium Probability of Presence	1 pt
	Low Probability of Presence	0 pt
Non-Migratory Species	**Presence of non-migratory Species is not considered**	

Table 5.6 Mapping of Probability of Presence Scores to Sensitivity Bands

Total Scores	Sensitivity Band
6 – 9	**High**
3 – 5	**Medium**
0 – 2	**Low**

5.3.3 Stage One and Two Combined

Once the water bodies have been categorised into the sensitivity bands the scores are applied to the barriers that are located within the boundary and the barriers are taken forward to the stage three assessment.

5.3.4 Stage Three – Special Areas of Conservation

Following the stage one and two assessments the barriers are analysed for their relationship with the Special Areas of Conservation that are designated for freshwater. If the barrier falls with the boundary of an SAC then the sensitivity category for that barrier is promoted, for example if following the stage one and two assessments the barrier is medium and it falls with an SAC then the final category will be high. This reflects the fact that any development within a SAC will inevitably have more environmental considerations than one outside it, but it by no means precludes development, and the impact it has on a development will also be linked to the reason for which the SAC is designated.

5.4 Sensitivity Categorisation Results

5.4.1 Stage One

Table 5.7 shows the number of water bodies and the categorised barriers that result from this first stage of sensitivity analysis. Whilst only 32 per cent of water bodies are affected, a high number of barriers (40.2 per cent) are automatically classified as high sensitivity as a result of stage one.

Table 5.7 Results from the Stage One Assessment

Data Source	Diadromous species	Number of Water bodies	Barriers Affected	Total Barriers Affected
FCS2 Sites	3,533 Sampling locations from 7,415	2,559 from 10,147	9,427	10,421
SAC	51 of the 102 freshwater SACs are relevant to diadromous species	1,193 from 10,147	2,793	

5.4.2 Stage Two

Table 5.8 shows the results from the application of the stage two assessment methods.

Table 5.8 Results from Categorising Water Bodies Using the Stage Two Methods

Species Category	Total Number of affected Water Bodies	Number of Water bodies in each sensitivity category		Barriers Affected
Diadromous	766	Medium	213	5,671
		Low	553	
Migratory	2,963	High	2,577	16,933
		Medium	361	
		Low	25	
Mobile	2,963	High	4	16,933
		Medium	266	
		Low	2,693	

The scores for the water bodies in Table 5.8 are generated from the scoring in Table 5.5. The summary of the total scores for the water bodies are displayed in Table 5.9. The combination of the stage two results alongside the stage one results is also shown.

Table 5.9 Scoring Results from Stage Two and the Results from Stage One and Two.

Final Score	Stage two total	Stage two Sensitivity Band Total	Total for stage one and two combined	Number of barriers affected
0	19	354	212	1,043
1	2			
2	279			
3	54			
4	2211	2,431	832	5,650
5	214			
6	6			
7	154	178	4,001	12,021
8	23			
9	1			

The affect of overriding the stage two results with the stage one results increases the number of water bodies, and hence the number of barriers, in the high sensitivity band.

5.4.3 Stage Three

The results for the individual barriers from stage one and two are used as input in conjunction with the SAC boundaries to provide the final sensitivity bandings. Any barriers that fall within a freshwater SAC have their sensitivity band promoted. Table 5.10 shows the results from this assessment.

Table 5.10 Results from Stage 3 Assessment

Sensitivity Band	Stage One and Two Total	Barriers within SAC	Total Following SAC assessment	Per centage of Barriers Categorised
No Sensitivity	7,221	49	7,172	27.65%
Low	1,043	0	1,092	4.21%
Medium	5,650	19	5,631	21.71%
High	12,021	N/A	12,040	46.42%

As per the previous steps there are a higher number of barriers categorised as high sensitivity than other bands. As outlined in Section 5.2.4 over one quarter of the barriers are not categorised due to the absence of data for those locations.

5.5 National and Regional Results Summary

The national sensitivity categorisation results are shown in Figure 5.2 and the regional maps are shown in figures 5.3 to Figure 5.11. The regional summary count is shown in Table 5.11. The modal classes are highlighted in bold. There are a high number of water bodies within Wales that are categorised as high sensitivity (80.4 per cent), combined with the high number of water bodies that are categorised as high sensitivity following the stage one classification, approximately 73 per cent the water bodies.

Table 5.11 Summary of Regional Sensitivity Categorisation

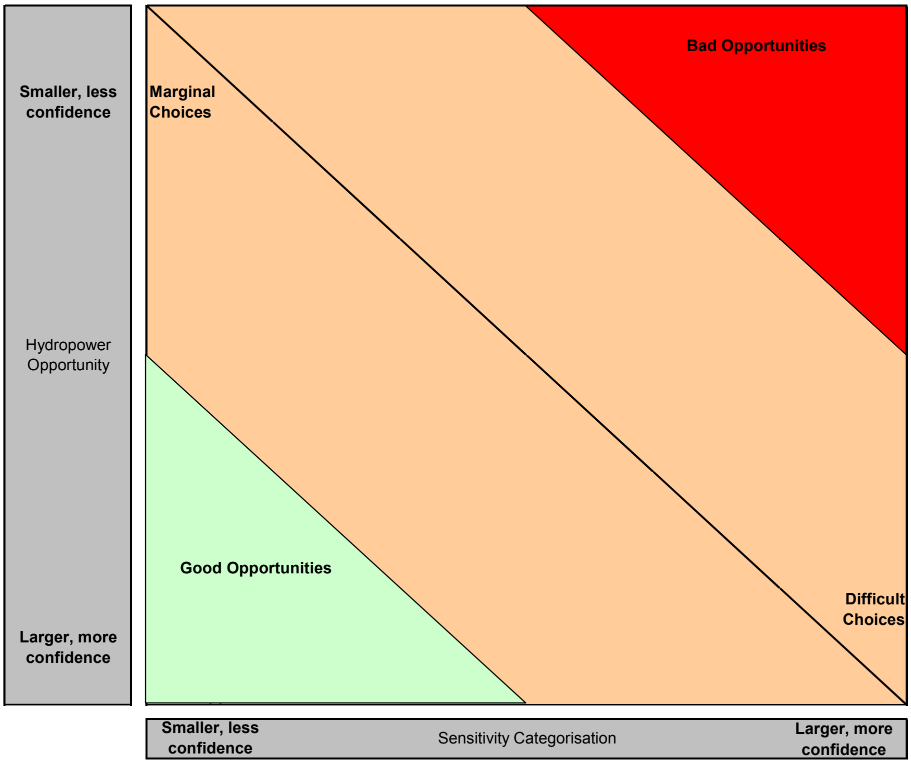
	Region									
	East Anglia	East Midlands	North East	North West	South East	South West	Wales	West Midlands	Yorkshire & Humber	Total
Unclassified	285	729	301	1460	832	888	645	1106	926	7172
Low	278	128	1	145	358	75	20	81	6	1092
Medium	265	695	180	791	794	412	142	421	1931	5631
High	411	574	1160	2197	1083	1860	3305	712	738	12040
Total	285	729	301	1460	832	888	645	1106	926	25935

Modal Class Shown in Bold

6 Hydropower Opportunities

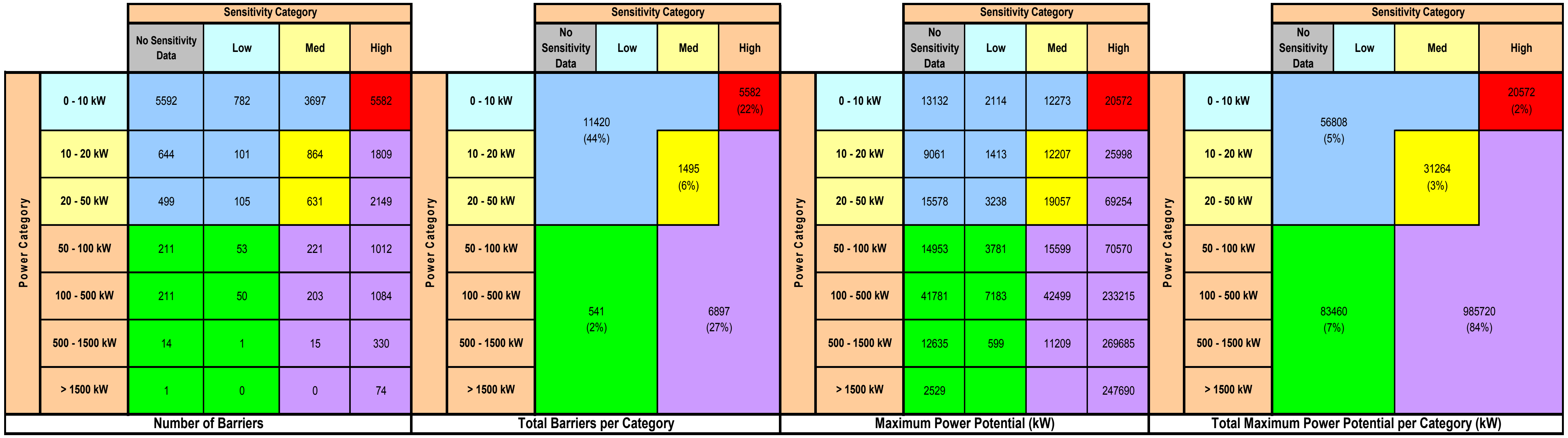
The opportunity to generate hydropower from an existing barrier depends on two factors, the physical potential and the sensitivity of the barrier being converted to a hydropower scheme. This Section considers these two elements together to give an overview of the overall national hydropower opportunities in England and Wales.
The power potential and the sensitivity categorisation of a barrier allow the generation of an overall "opportunity" matrix. The best opportunities exist at locations where there is a high hydropower potential and a low sensitivity categorisation, whilst the least attractive opportunities are those with low hydropower potential and high sensitivity. This is represented schematically in Figure 6.1.

Figure 6.3 Opportunity Categorisation Matrix



The discrete nature of the bandings created in Section 4 and Section 5 maps on the matrix as outlined in Table 6.1, with each of the barriers located into twenty eight matrix locations that can be further summarised into five final generalised categories.

Table 6.1 Hydropower Opportunity Categorisation Matrix



		Sensitivity Category			
		No Sensitivity Data	Low	Med	High
Power Category	0 - 10 kW	5592	782	3697	5582
	10 - 20 kW	644	101	864	1809
	20 - 50 kW	499	105	631	2149
	50 - 100 kW	211	53	221	1012
	100 - 500 kW	211	50	203	1084
	500 - 1500 kW	14	1	15	330
	> 1500 kW	1	0	0	74

Number of Barriers

		Sensitivity Category			
		No Sensitivity Data	Low	Med	High
Power Category	0 - 10 kW	11420 (44%)			5582 (22%)
	10 - 20 kW			1495 (6%)	6897 (27%)
	20 - 50 kW				
	50 - 100 kW	541 (2%)			
	100 - 500 kW				
	500 - 1500 kW				
	> 1500 kW				

Total Barriers per Category

		Sensitivity Category			
		No Sensitivity Data	Low	Med	High
Power Category	0 - 10 kW	13132	2114	12273	20572
	10 - 20 kW	9061	1413	12207	25998
	20 - 50 kW	15578	3238	19057	69254
	50 - 100 kW	14953	3781	15599	70570
	100 - 500 kW	41781	7183	42499	233215
	500 - 1500 kW	12635	599	11209	269685
	> 1500 kW	2529			247690

Maximum Power Potential (kW)

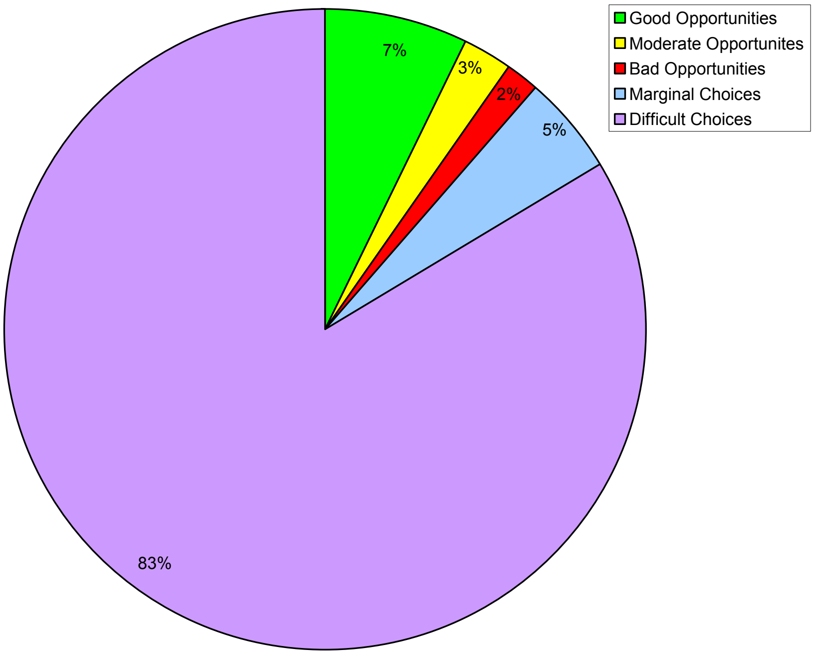
		Sensitivity Category			
		No Sensitivity Data	Low	Med	High
Power Category	0 - 10 kW	56808 (5%)			20572 (2%)
	10 - 20 kW			31264 (3%)	985720 (84%)
	20 - 50 kW				
	50 - 100 kW	83460 (7%)			
	100 - 500 kW				
	500 - 1500 kW				
	> 1500 kW				

Total Maximum Power Potential per Category (kW)

🟩	Good Opportunities
🟨	Moderate Opportunites
🟥	Bad Opportunities
🟦	Marginal Choices
🟪	Difficult Choices

Within the final categories the majority of the barriers fall within the 'marginal opportunities' category. The small percentage of barriers that fall within the good and moderate opportunity categories represent approximately 83 per cent of the total maximum power potential for all the barriers assessed in the project. The proportion of the power is shown in Figure 6.2.

Figure 6.4 Per centage of Total Maximum Power Potential per Category



The national distribution of the opportunities is shown in Figure 6.3, the barriers that have a high potential (>50kW) and low/medium risk are shown in Figure 6.4 and the barriers that have a high/medium potential (>10kW) and low/medium risk are shown in Figure 6.5.

6.1 Heavily Modified Water Bodies

Within the Water Framework Directive, Heavily Modified water bodies are those water bodies which have been identified as being at significant risk of failing to achieve good ecological status because of modifications to their hydromorphological characteristics resulting from past engineering works, including impounding works. The designation criteria are:

- Making the hydromorphological improvements necessary to achieve good status would have a significant adverse effect on the wider environment or on a specified water use;

AND

- For reasons of technical feasibility or disproportionate cost, there is no significantly better environmental option to reasonably achieve the benefits provided by the modifications.

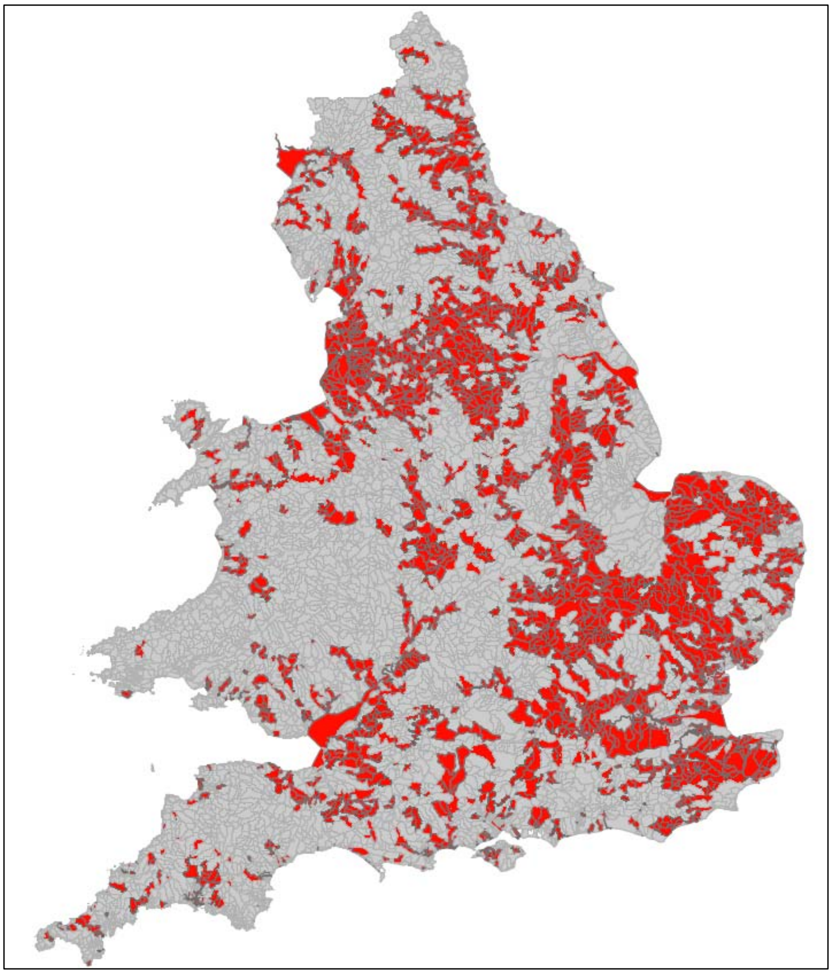
Due to these characteristics, there is potential for the creation of a hydropower barrier to be beneficial to the passage of fish upstream. These locations are therefore considered “Win-win” opportunities which could result in the delivery of a good hydropower potential and improve the ecological status of a river. Win-win opportunities will not only exist in heavily modified water bodies, and the EA plans further work to identify such opportunities at the individual level through linking this work with work on prioritisation of fish passes for removal. The representation of win-win opportunities based on river status here is therefore used as a demonstration of the potential scale of win-wins available.

We defined win-wins as an opportunity of medium to high power potential that is within one of the 2708 heavily modified water bodies in England and Wales (see Figure 6.6). The location of these barriers is shown in Figure 6.7, with a summary outlining the number of barriers and the power potential detailed in Table 6.2. The highlight of these figures is that these potential “Win-win” opportunities account for nearly half (49%) of the national maximum total potential power.

Table 6.2 Summary of “Win-Win” Hydropower Opportunities

	10 - 20 kW	**20 - 50 kW**	**50 - 100 kW**	**100 - 500 kW**	**500 - 1500 kW**	**> 1500 kW**	**Total**
Number of Barriers	1,292	1313	618	712	223	32	**4,190**
Total "Win-win" Power Potential Per Catgory (kW)	18,433	41,421	44,196	151,911	180,032	90,378	**526,371**
Percentage of "Win-win" Total Power Potential	3.50%	7.87%	8.40%	28.86%	34.20%	17.17%	
Percentage of Total Power Potential (1,177,826(kW))	1.56%	3.52%	3.75%	12.90%	15.29%	7.67%	**44.7%**

Figure 6.5 Locations of Heavily Modified Water bodies



Heavily Modified Water bodies shown in Red

7 Future Improvements

This report has outlined a methodology that we developed to calculate the hydropower potential and environmental sensitivities for England and Wales. This has provided a national overview of the opportunity and some constraints to that opportunity. A detailed classification of all the barriers on a site by site basis is not feasible at this scale. This Section outlines work that could be undertaken to improve the accuracy and availability of datasets used in this study, and ultimately improves the future assessment of hydropower potential.

7.1 Scale of Project

The key objective of this study was to develop a national level assessment of hydropower potential across England and Wales. As a consequence, the data and processes used have been nationally orientated, with the complete barrier dataset being compared and analysed against other national datasets such the CEH flow Qmed flow values, the Geomatics Group height data catalogue, and the Fish Classification Scheme data.

This methodology allows a national picture to be created, but improvements can be made by applying local knowledge, improvement in the methodology used and the data of enhanced revolution. Future efforts need to identify detailed data that can improve the power potential estimation and develop a methodology framework that can be applied by local area staff and other interested parties to determine the best locations to target resources towards. The targeting of resources should either be based on the number of barriers or the maximum power potential of the barriers, the ranking of these values are outlined in Table 7.1. The regions are ranked by the number of barriers and the maximum power potential in the region.

Table 7.5 Number of Barriers and Power Potential by Environment Agency Region

		Number of Barriers in each Power Category							
		0 - 10 kW	**10 - 20 kW**	**20 - 50 kW**	**50 - 100 kW**	**100 - 500 kW**	**500 - 1500 kW**	**> 1500 kW**	**Total**
EA Region	**Southern Region**	1,225	117	108	35	10	0	0	**1495**
	Anglian Region	1,126	145	150	51	46	0	0	**1518**
	Thames Region	1,390	188	159	100	94	49	0	**1980**
	South West Region	1,968	339	324	132	116	15	1	**2895**
	Midlands Region	2,720	409	353	151	158	38	14	**3843**
	EA Wales	1,639	713	923	360	363	74	43	**4115**
	North West Region	2,510	698	729	385	385	60	5	**4772**
	North East Region	3,075	809	638	283	376	124	12	**5317**
	Total	**15,653**	**3418**	**3384**	**1497**	**1548**	**360**	**75**	**25935**

		Total Power in Each Power Category (kW)							
EA Region	**Southern Region**	2,473	1640	3436	2447	1109	0	0	**11106**
	Anglian Region	2,711	2000	4817	3627	6346	0	0	**19502**
	South West Region	5,918	4914	10089	9245	22859	9326	4286	**66637**
	Thames Region	3,396	2685	4864	7328	19117	41954	0	**79343**
	Midlands Region	6,377	5758	11261	10593	32857	36163	27796	**130804**
	North West Region	9,953	9888	23457	26930	80000	44818	10895	**205939**
	North East Region	10,496	11440	19789	20350	83314	98459	25224	**269072**
	EA Wales	6,767	10354	29415	24383	79077	63408	182019	**395423**
	Total	**48,090**	**48680**	**107127**	**104903**	**324678**	**294128**	**250219**	**1177826**

7.2 Improved/Consistent Input Data

7.2.1 Flow Values

Section 3 outlined the methods used to generate estimates of flow at each of the barriers being studied. The sources of flow information are outlined in Section 3.1 and the final methods used to estimate the flows were outlined in Figure 3.8. Although the methods adopted (including Qmed and river length proportioning) have allowed the estimation of a representative flow value for the complete barrier dataset, alternative methods could be considered to derive more accurate estimates of flow for the national dataset.

One possible approach which is the automated assignment of flow values for each barrier location using the HR Wallingford Low Flow Enterprise database. At a general level, the Low Flows database has been developed by HR Wallingford and allows for the selection of a point on the river network and automatically defines the catchment above that point to generate the required flow statistics. The Environment Agency has access to this software but the current version only allows processing of features on an individual basis. The ability to calculate flow values in a batch format would be particularly helpful for this study. This would allow the use of a nationally consistent flow data set for all 25935 barriers.

Investigations and calculations could also be performed using the recent actual scenario flows (ScenRAQ30 and ScenRAQ95) in place of the Qmean and Qn95UPS values used in this study. These flow values could be considered in further analysis as they indicate the extent of existing influences in the upstream catchments.

7.2.2 Elevation and Head Values

As shown in Section 2.4, one of the main problems encountered in this study was the calculation of representative elevation values upstream and downstream of each of the barrier locations investigated. Based on the work conducted in this study, the project team have identified a number of recommendations for future work to improve the generation of elevation values and/or use of this information. These are:

- Development of an automated GIS procedure to calculate multiple upstream/downstream elevations at increasing distances. The selection of the final head value would be based on an average of the values derived and hence reduce the possibility using single spurious elevation values at the barrier or adjacent bank feature;

- Development of an automated GIS procedure to identify at a set distance upstream/downstream of the barrier an offset point perpendicular point to the Digital river network. This offset location could be used to extract the upstream and downstream elevation values for bank and hence reduce errors generated by the selection of water heights in the LiDAR/SAR data;

- The use of 3D information stored in future versions of the Digital River Network. It is expected that this type of information for each of the nodes between the river segments will become available from early 2010. This version of the River Network is being used as a Quality Assurance technique for the flow paths within the main DRN dataset and has checks to ensure the flow is enforced downwards. This should ensure that negative head values will be eliminated;

- The estimation of height values for all barriers using only the more detailed LiDAR data rather than the less detailed SAR data. This is reliant on the Geomatics Group data collection program which is focussed primarily on flood plain area. Unfortunately many of the barriers in this study are located outside of the main floodplain areas;
- Future population of the Environment Agency NFCDD database with the calculated head values for all weirs/flood defence structures. This would help improve the quality of data held in this database and benefit other areas of Environment Agency work, including notably flood risk management.

7.3 Improved Sensitivity Categorisation

The categorisation method outlined in Section 5 allowed 19,217 (74 per cent) barriers within the national dataset to be classified, with the remaining 6718 (26 per cent) of the barriers being unclassified. The remainder of this Section outlines potential methods of addressing these gaps and issues associated with the data used in this project.

7.3.1 Fish Population Information

The Fish Classification Scheme data used in this project has a number of limitations in the species observed and the distribution of the sampling sites.

Distribution of Sites

It is important to note that the FCS2 dataset contains 7415 sampling points, which are distributed across only 2963 of the water bodies stored in the current version of the Environment Agency WRGIS Integrated Water bodies dataset. Within these water bodies there are 16932 barriers, the other barriers were not classified in the stage two classifications (however, others were classified in the stage three classifications). There is a data gap regarding whether these sites are “low-risk” or whether there is not enough data to draw this conclusion.

The distribution of the information used relates to the Environment Agency’s monitoring network and the improvements might not be possible of the scales required.

Species Studied

The species studied by this project have been driven by the content of the available data. The two sets of data have a number of key limitations that have been made aware by Technical Fisheries staff. The Fish Classification Scheme excludes key species such as Shad and has additional limitations in the observations of young fish in certain species. The SAC designated areas identify a limited number habitats related to the species being studied.

The improvements to this data would have to focus on the collection of consistent additional data at the local level and possibly include a greater emphasis on the observation of fish population numbers.

Connectivity of Rivers

As mentioned previously the sporadic nature of the FCS2 data has been avoided by the generalisation of the information to water body level. This method does not account for the longitudinal connectivity of the system and reaches that are potentially “cut-off” from a species. Further complex processing could be undertaken by using the stream ordering and network topology of the Digital River Network to identify areas that would affect the connectivity and movement of river stretches to a particular species.

The position of the barrier in relation to the whole system is also not considered as part of this project. A barrier across the mouth of the river will have a much greater impact on migration than one on a small tributary because far more fish will have to migrate through that point. The impact of a barrier could be related to stream order. This could potentially be a complex calculation on larger river networks.

7.3.2 Environmental Categorisations

The environmental sensitivity categorisation could be extended to include a variety of other opportunity and constraint factors. These include:

- Sites of Special Scientific Interest (SSSI);
- Special Protected Areas (SPA);
- National Nature Reserves;
- Local Nature Reserves;
- Areas of Outstanding Natural Beauty (AONB);
- National Parks;
- Impact on other conservation areas;
- Flood Risk Management Defence Structures;
- Other Landscape/Cultural Designations

The above factors do not prevent the development of a site as a hydropower scheme however if there is an equally good opportunity that is not constrained by the above then this should be promoted and encouraged instead. These factors although important, fall largely into the impact of a hydropower scheme, and impact assessment needs to be performed on a detailed site by site basis to fully account for local sensitivities.

7.4 Integration with Other Environment Agency Programmes

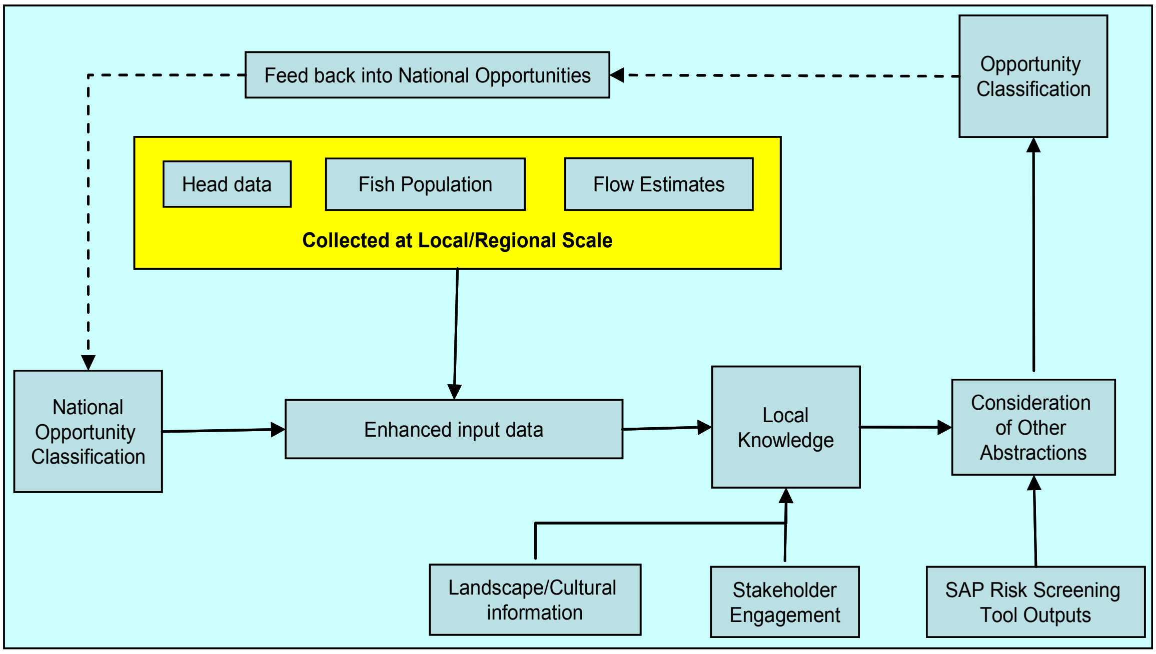
Over recent years, Entec has worked closely with the Environment Agency Water Resources team to develop enhanced methods to store, manipulate and report water resource related information. As part of these developments, Entec has developed a GIS based abstraction risk screening tool has been developed to enable risk based assessments of new or revised abstraction licences submitted to the Agency. The GIS assessments use the underlying Environment Agency's WRGIS database and a set of nationally developed rules to conduct various operations including spatial searches, river network tracing, and downstream searches. The end output is an Excel formatted risk report which is now being actively used to support new/amended application determinations.

One potential development would be to adapt the current abstraction risk screening tool and use it as the basis for assessing the local and downstream conservation and hydrological risks associated with hydropower opportunities. It is therefore recommended that a scoping exercise could be undertaken to compare the outputs from the current version of the Abstraction Risk Screening tool and the outputs of this project.

7.5 Suggested Regional Scale Process

The improvements in the data and data at a greater resolution would allow the opportunities to be calculated at the regional and possibly the local scale. The latter would be useful in engaging local authorities and other stakeholders to the potential of converting barriers to hydropower schemes. The process outlined below should be taking as a starting point and revised accordingly based on resources, availability to the data and the wider pressures relating to hydropower.

Figure 7.5 Suggested Regional Process



Glossary of terms

LiDAR	An airborne laser mapping technique which produces accurate elevation data. The technique is a cost-effective and rapid solution for the production of high quality terrain mapping. The Geomatics Group have also developed processes that allow surface objects such as vehicles, buildings and vegetation to be identified and removed, producing 'bare earth' Digital Terrain Models (DTM).
SAR	Synthetic Aperture Radar. A form of radar in which multiple radar images are processed to yield higher-resolution images than would be possible by conventional means.
Digital Surface Model	A terrain model that contains the surface objects, buildings and vegetation etc.
Digital Terrain Model	A Digital Surface model with the surface features removed to leave the terrain.
NFCDD	The Environment Agency's National Flood and Coastal Defence Database (NFCDD). This centralised database provides the definitive repository for all data on flood and coastal defence assets in England and Wales
Qmean	The Mean flow
Q95	The flow rate that is exceeded for 95 per cent of the time
The Natural Scenario	This is the scenario in which there are no abstractions or discharge influences. The QN30, QN50, QN70 and QN95 per centile flow estimates are derived, where possible, from the natural flow duration curves entered by Environment Agency staff into CAMS Ledgers at CAMS Assessment Points, or by interpolation between and upstream of these points based on catchment area
The Recent Actual Scenario	The Recent Actual Scenario which is a prediction based on the impact of current 'live' abstractions and discharges at their recent actual rates over the last 6 years on the natural flows previously defined):
WRGIS	A collection of water resources data
CAMS APs	Catchment Abstraction Management Scheme Assessment Point
Qmed	The Median Flood Flow Value

SAC	Special Area Conversation. The sites are strictly protected sites designated under the EC Habitats Directive
FCS2	Fish Classification Scheme 2 data which assesses the ecological quality of rivers entirely on the basis of the abundance of fish species, as determined by survey data

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