Hydro Project Technical Report

Summary of 2008

Sheffield Renewables

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Introduction

In 2008 an enthusiastic group of people from around the Sheffield area set-up Sheffield Community Renewables (SCR) with the aim of identifying and developing small scale renewable schemes, micro-hydro power generation on the River Don was identified as a possibility. Sheffield's industrial history has left it with a number of weirs on the River Don and its tributaries, investigation was required to assess their suitability for the installation of small scale water turbines. This report will summarise the work carried out to January 2009 to forward these goals.

Initial Weir Survey

A number of informal weir surveys were carried out in the summer of 2008. These surveys aimed to identify a number of weirs that might be suitable for further investigation. The main criteria used was based on the position of the weirs, the surrounding areas (whether there would be space for the turbine), access, site visibility. Secondary considerations were whether there was a local community that could benefit, a nearby industry or commercial group that could use the power generated. Based on the information of the initial surveys and the work carried out in the Sheffield City Council Scoping Study (SCC), which makes some ball park calculations as to the available power generation capability of the weirs on the River Don, a short list of weirs was drawn up, working from up to downstream these are:

- **Niagara Forge**; this weir was partially destroyed in the Summer 2007 Floods and it was thought that it was not going to be repaired, however work was under way when the site was visited in Autumn 2008, the condition of the weir is still unknown. Niagara Weir is the largest weir on the section of River Don being considered at 3.1m, it is situated on the Upper Don above the confluence with the River Loxely. The weir backs on to Middlewood park and is very visible from the children's play area in the park, as exemplified by the work currently being carried out access for the heavy works that will be required is possible.
- **Wards End**;Wards End weir is situated in Hillsborough, behind the Owlerton Stadium and Hillsborough College. It benefits from being overlooked by the local electricity substation, and the Cadburys Bassets Allsorts factory is in the near vicinity. Wards End was a weir that was identified as a possible weir for development by h2oPE. The height of the weir was not identified in either the Sheffield Scoping Study or h2oPE's report, SCR carried out a formal survey of the site and measured the height of the weir as 2.1m. There is a Scrap Yard 0.5km further upstream on the eastern bank which is accessed by large goods vehicles so we should be able to use this access route.

- **Ball Street Weir (Kelham Island)**; Ball Street weir is situated just upstream of Kelham Island and controls the water level in the goyt that runs past the Industrial Heritage Museum and into the currently unused but still present wheel pit. The weir itself is 1.5m high and over 100m long (longest weir on the river) and is a listed structure. Installing a screw on the weir itself would need to be done on the southerly end (land owned by the Industrial Museum) and maybe made difficult by the listed status of the weir. However as the goyt and wheel pit are still present and unobstructed, there is a good chance of reinstalling a turbine in position of the old water wheel. The industrial museum would also be a possible on site user of the electricity.
- **Effingham Street**; Effingham Street Weir is situated downstream of Sheffield City Centre and below the confluence of the River Sheaf, it therefore benefits from a considerably higher water flow rate than either Niagara or Wards End. The height weir is 1.3m, from SCC. The weir already has a fish pass installed that will divert some of the flow, reducing that available for power generation. The weir is very visible from Effingham Street on the southern bank, and it also makes up part of the Five Weirs Walk. Recent discussions with the landowner appear promising, as they appear motivated by the green issues.
- **Leveston Street**; this weir like Effingham is very visible and there may be potential users of the power generated in the near vicinity, it is slightly lower than Effingham at 1.2m, from SCC. It appears there would be place to site the screw on the Northern bank however access may be tricky.
- **Sandersons Weir**; This weir like the last two and the next is on the Five Weirs Walk so is a fairly visible site. The weir is 1.7m high, from SCC. Initial observations show that there should be sufficient space to site the screw on either the northern or southern banks of the river, the northern bank is overlooked by the East Coast Railway Mainline, it may be possible to use that for access but that may be expensive, otherwise the southern bank is overlooked by another scrap yard and access may be possible through that.
- **Brightside Weir**; Brightside Weir has been considered by a number of companies and organisations for development, but as of November 2008 it is not certain if any of these are highly advanced proposals or certain of going ahead. The LoadHog Company, who are sited next to the weir, have expressed interest in using the power generated. The weir is 2.15m high, from SCC, so should generate considerable power. It is believed that there was an agreement in principle with the City Council to adjust the route of the Five Weirs Walk to make room for the Turbine. The site itself should be accessible however there is a development proposed next to the site which may make access more tricky.
- **Jordan's Dam**; Situated on the border between Sheffield and Rotherham, Jordan's dam is the furthest downstream weir that we investigated. It's sited well out of town meaning it would not be highly visible to the majority of people. However the river at the weir is navigable at that point and there is a tow path on the opposite bank. It is also near to the museum Magna and where it may be possible to install interpretation boards. The weir is at least 3m high and being further downstream has a higher flow rate than any of the other investigated weirs, as such the energy that would be available is the greatest. The turbine if installed would need to go on the southern bank of the weir as the northern bank is part of the lock island for the Sheffield Canal

Further to the weirs detailed here, 4 weirs upstream of Niagara were also visited as part of the weir survey, but were thought to either not be able to provide sufficient energy to make a viable scheme, or to be too far outside Sheffield. Hadfield's weir located at Meadow Hall was not considered because it is used by the EA as a gauging station.

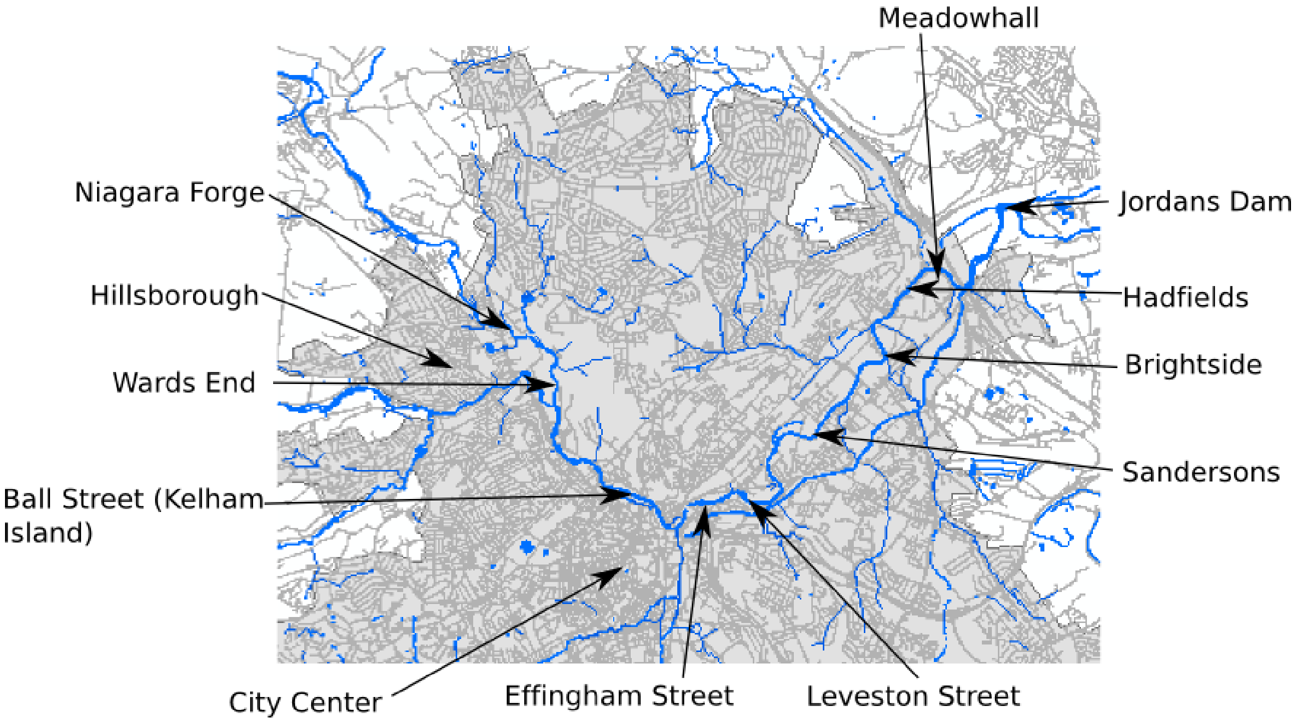

Figure 1: Map Showing the location of the main weirs in and around Sheffield City Centre

River Flow Modelling

To determine whether any of the sites would be suitable it is required to measure the height of the weir and assess the quantity of water flow. With this aim a model of the River Don was created, using historical data, captured from a number of Environment Agency Gauging Stations. Obtained by SCR from the National River Flow Archive in October 2008.

River Don Daily Gauged Flow Data

The river flow data supplied by the National River Flow Archive consisted of the daily gauged flows for 6 stations surrounding Sheffield. Unfortunately it was not possible to get as complete set of data as would have been liked, measurements were stopped at 4 of the sites in 1980 and one of the measuring sites was only initiated in 1981. The data set that was obtained is summarised:

- Scout Dike Stream at Scout Dike Reservoir, from 1st January 1957 → 31st December 1980
- Little Don at Underbank Reservoir,from 1st January 1956 → 31st December 1980
- Ewden Beck at More Hall Reservoir, from 1st January 1954 → 31st December 1980
- Loxley at Damflask Reservoir, from 1st January 1956 → 31st December 1980
- Sheaf at Highfield Road, from 9th January 1981 → 31st December 2007
- Don at Hadfields Weir, from 1st January 1965 → 31st December 2007

There was also a small amount of data missing from within this data range. This data covers the River Don and the major tributaries (with the exception of the Rivelin and the Porter Brook, probably both have fairly low flow rates from inspection) and as such acts as a boundary box for all the weir sites we are investigating (with the exception of Jordan's Dam), with flow entering through the first 5 stations and leaving the system through Hadfield's Weir station. Unfortunately it can be seen that we do not have any data for all of the boundaries at the same instance in time. This will complicate matters when it comes to modelling the flow in the Don.

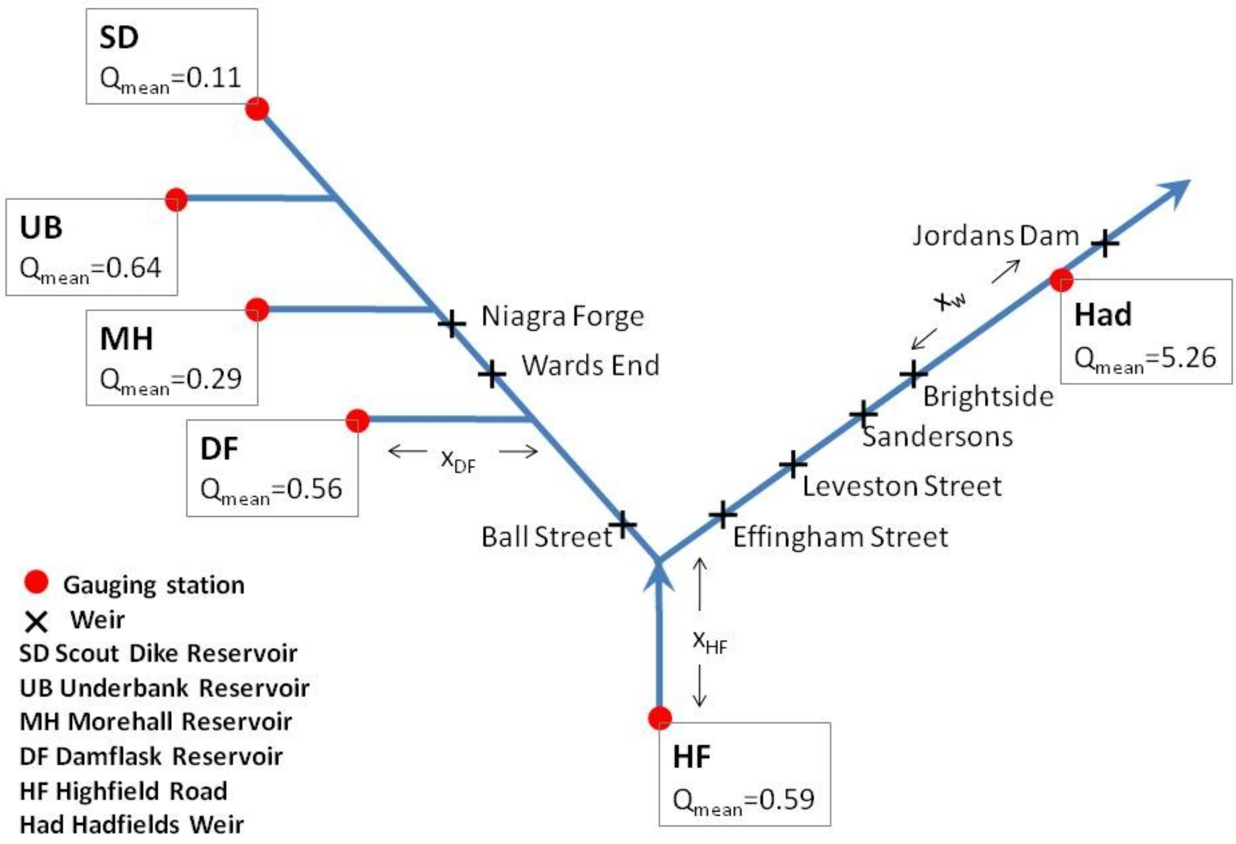

Figure 2: Schematic of the Don river system in and around Sheffield as modelled. Q_{mean} is the mean flow rate at that site.

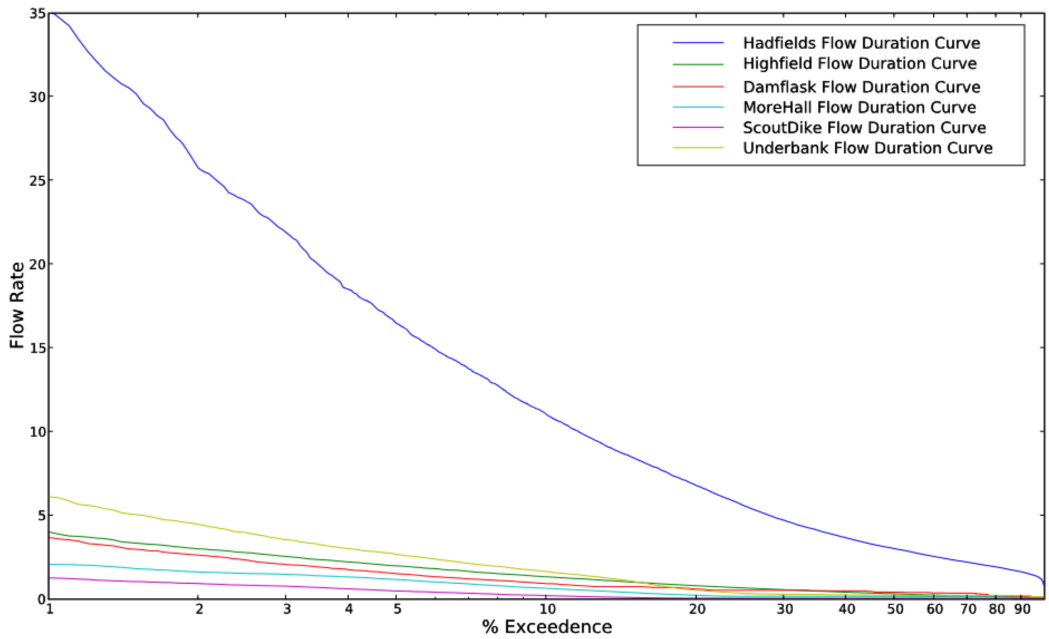

Figure 3: Flow Duration Curves for the 6 gauging stations around Sheffield

The aim of the modelling is to estimate the flow duration curves for the weir sites we identified from the initial weir surveys. Figure 3 shows the flow duration curves for the 6 gauging stations.

Variations Over Time

The variation of the river flows was assessed and found that there existed a slight downward trend in the mean yearly flow rates over the period 1965→2007. It appears from Figure 4b) that there is 20 year cyclic nature to the flow rates in the Don, however there is insufficient data in the set to completely confirm this. Looking at Figure 4d) we can see over the last 40 years there has been a slight downwards trend in the mean flow rate in the river, dropping from 5.45 m^3s^{-1} down to 5.05m^3s^{-1}. If this downward trend continues at the same rate we would expect a mean flow rate of approximately 4.6m^3s^{-1} at the end of the life of the scheme (supposing a 40 year life). This is highly speculative however, due to the changing nature of water use in Sheffield and the uncertainty in the prevailing climatic conditions in the future.

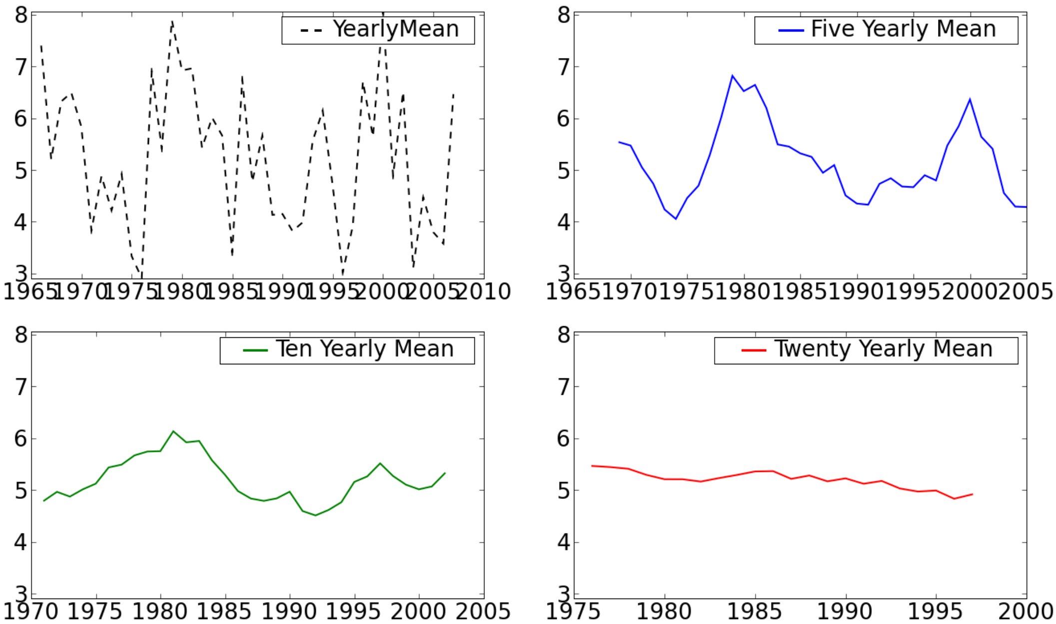

Figure 4: Trends in the yearly mean flow rate for Hadfields Weir from 1965 to 2007. a) (upper left) shows the yearly means, b) (upper right) the mean flow of a 5 year moving average. c) and d) (lower left and right) show a 10 and 20 year moving average respectively. The vertical scales show the flow rate in m^3s^{-1}.

Flow Models

As we don't have any data from all of the measuring sites at the same time we cannot directly model the flow of water from one station through the river system and out at the Hadfields station. A number of options to deal with this issue were investigated (Details can be found in the Document 'Investigating the flow in the River Don in Sheffield').

Direct Modelling of the Flow Duration Curves

We will now describe the method to directly model how the flow duration curve changes in the river system. The flow duration curves were produced for the different measuring sites (Figure 3), these flow duration curves were then uniformly re-sampled so they could be easily compared. The model assumes that we can directly model each percentage of the flow duration curve at one site to the corresponding percentage at the other sites. As such the method below was carried out for each percentage of the flow duration curves.

Model Maths

It is assumed that there is a constant influx or outflow of water to the river per unit length.

First we subtract the flow at each of the 5 rivers inputting flow to the river system (Underbank (UB), Scout Dike (SD), More Hall (MH), Damflask (DF) and Highfield (HF)) from the outlet flow variable at Hadfields Weir (Had).

$$K = Had - (UB + SD + MH + DF + HF)$$

'K' is thus the change in the flow variable needed to be accounted for over the length of the river. Next we divide that by the total length of the river system between our inlets and outlet, this is 48600m.

$$k = K / 48600$$

to give us the variation per unit length of the river. To calculate the value of the variable at a given weir we need the following equations.

$$W = UB + SD + MH + DF + HF + k(48600 - x_w)$$

for weirs below the confluence of the Sheaf and Don (Effingham, Leveston, Sandersons and Brightside)

$$W = UB + SD + MH + DF + k(48600 - x_w - x_{hf})$$

for Ball street weir above the confluence of the Sheaf but below the Loxely

$$W = SD + UB + MH + k(48600 - x_T - x_{df} - x_{hf})$$

for weirs above the confluence of the Loxely and the Don (Wards End and Niagara). Finally the value for Jordan's Dam was calculated by

$$W = Had + k(-x_w)$$

where x_w is the distance from the weir in question to Hadfields weir (in the downstream direction), x_{hf} is the length of the Sheaf between the gauging station and its confluence with the Don, and x_{df} is the length of the Loxely between the gauging station and its confluence with the Don. These are illustrated in figure 2.

Weir	x_w(m)
Niagara	11670
Wards End	9100
Ball Street	6920
Effingham	4900
Leveston	4700
Sandersons	3300
Brightside	1320
Jordan's Dam	2250

Flow Modelling Results

Figure 5 shows the results of the flow modelling, in the average flow duration curves for the sites we are interested in. As expected the further downstream the higher the flow rates. The influence of the Sheaf can be seen in the large difference between the flow duration curve for Ball Street Weir and Sandersons Weir.

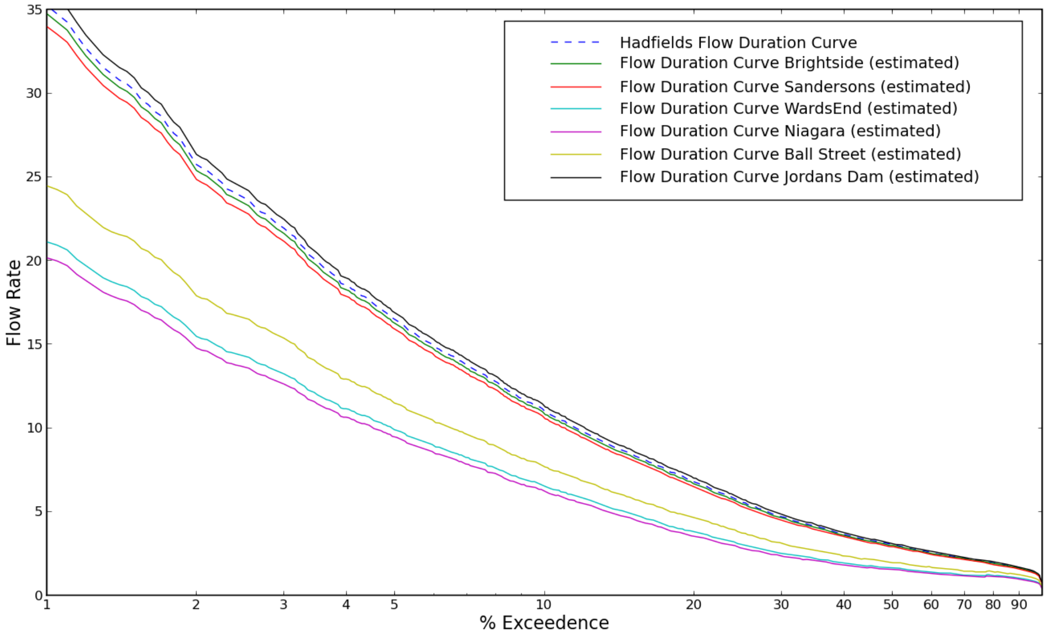

Figure 5: Results of the modelling of the Flow Duration Curves for the surveyed weirs. (log scale x)

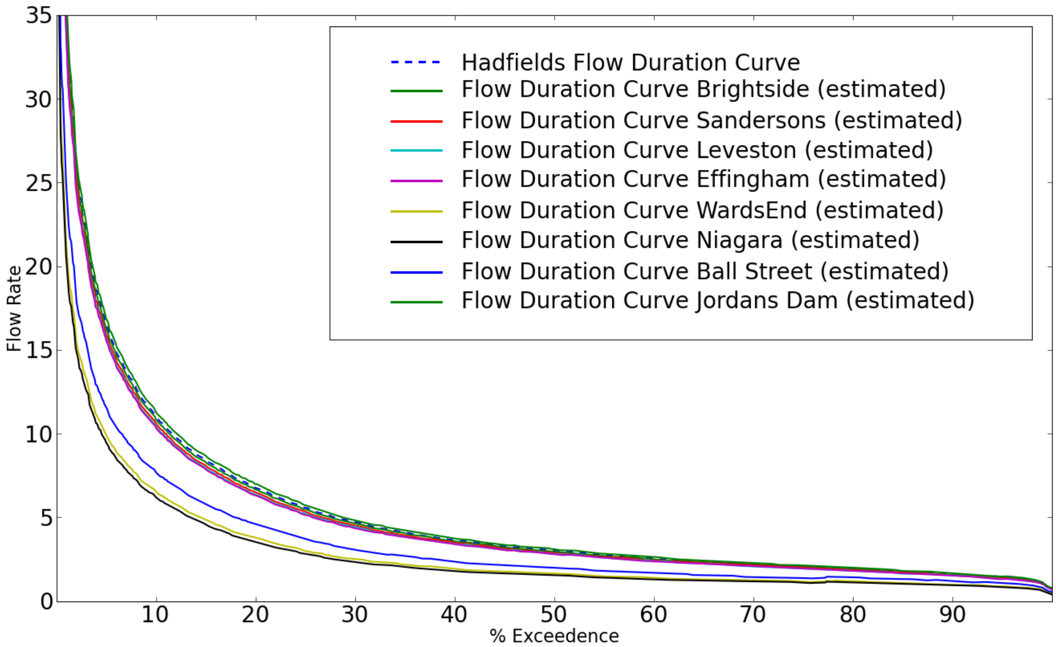

Figure 6: Results of modelling, non log scale

In December SCR received some validation of the flow modelling. Sheffield City Council employed Pico Hydro to work on a Feasibility Study for Kelham Island wheel pit (Ball Street Weir), the results of their study very closely matched the results produced using the above method, as shown in figure 6.

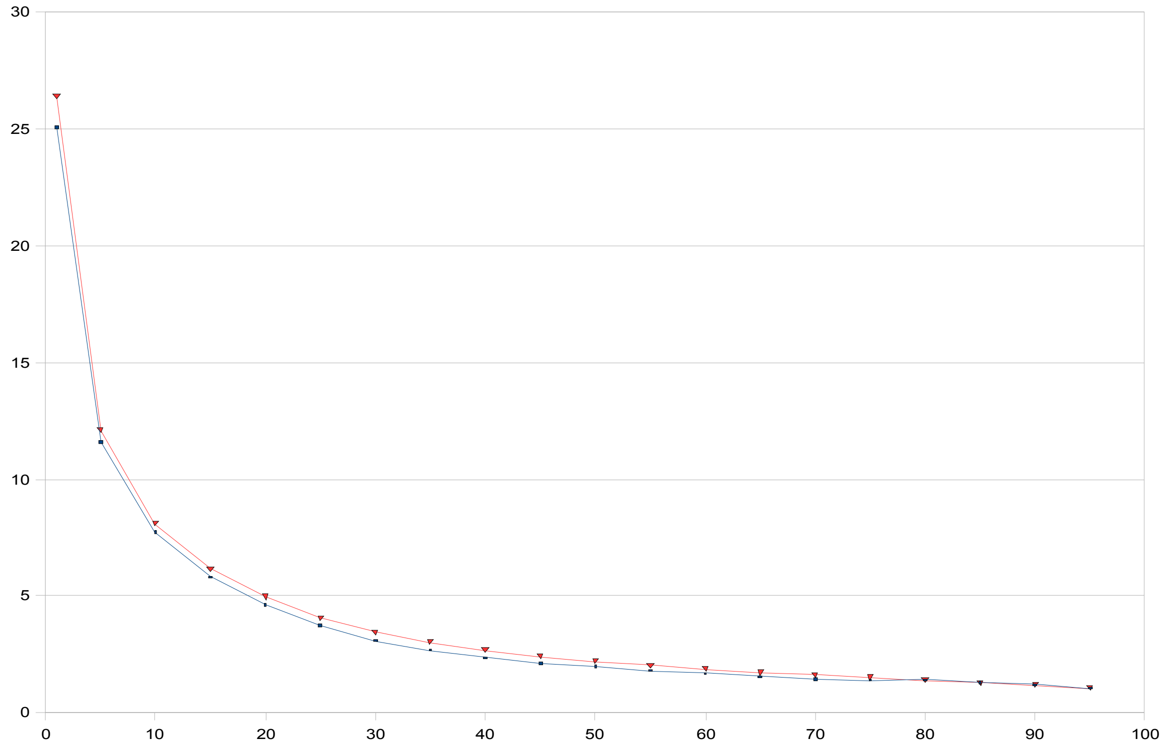

Figure 7: Comparison of SCR Model (blue) and the model produced by Pico Hydro (red)

Energy Capture Modelling

Further to modelling the flow rates in the river, A spreadsheet model was developed for predicting the annual electrical energy output of the scheme

Flow Factor	1		Head Drop Factor		27	Maximum Flow through turbine (m3 s-1)			5		Fish Pass Flow	0	
Weir Name	Brightside	Weir Height		2.15									
% of year	Site Flow Model Est.	Factored Site flow	Minimum residual flow	Available flow	Usable flow	Actual head	Turbine Efficiency	True Turbine Eff.	Power Gen. Eff.	Total eff.	Possible power output (kW)	Energy per year (kWh)	Residual Weir flow
1	35.67	35.67	1.41	34.25	5.00	0.83	89.7	89.7	85	76.25%	31.0	10864	30.67
5	16.34	16.34	1.41	14.93	5.00	1.54	89.7	89.7	85	76.25%	57.8	25302	11.34
10	10.92	10.92	1.41	9.51	5.00	1.75	89.7	89.7	85	76.25%	65.3	28593	5.92
15	8.3	8.30	1.41	6.89	5.00	1.84	89.7	89.7	85	76.25%	68.9	30182	3.30
20	6.67	6.67	1.41	5.26	5.00	1.90	89.7	89.7	85	76.25%	71.2	31170	1.67
25	5.48	5.48	1.41	4.06	4.06	1.95	88.1	88.1	85	74.89%	58.1	25464	1.41
30	4.63	4.63	1.41	3.22	3.22	1.98	85.9	85.9	85	73.02%	45.6	19988	1.41
35	4.05	4.05	1.41	2.64	2.64	2.00	85.6	85.6	85	72.76%	37.7	16518	1.41
40	3.6	3.60	1.41	2.19	2.19	2.02	85.3	85.3	85	72.51%	31.4	13768	1.41
45	3.24	3.24	1.41	1.83	1.83	2.03	83.5	83.5	85	70.98%	25.8	11299	1.41
50	2.96	2.96	1.41	1.55	1.55	2.04	80.2	80.2	85	68.17%	21.2	9268	1.41
55	2.73	2.73	1.41	1.32	1.32	2.05	75.1	75.1	85	63.84%	16.9	7393	1.41
60	2.52	2.52	1.41	1.11	1.11	2.06	68.2	68.2	85	57.97%	12.9	5668	1.41
65	2.32	2.32	1.41	0.91	0.91	2.06	59	59	85	50.15%	9.3	4054	1.41
70	2.18	2.18	1.41	0.77	0.77	2.07	50	50	85	42.50%	6.6	2893	1.41
75	2.03	2.03	1.41	0.62	0.62	2.07	38.7	38.7	85	32.90%	4.1	1813	1.41
80	1.9	1.90	1.41	0.48	0.48	2.08	26.2	26.2	85	22.27%	2.2	962	1.41
85	1.74	1.74	1.41	0.33	0.33	2.09	9.1	9.1	85	7.74%	0.5	229	1.41
90	1.6	1.60	1.41	0.19	0.19	2.09	-10.1	0	85	0.00%	0.0	0	1.41
95	1.41	1.41	1.41	0.00	0.00	2.10	-40.7	0	85	0.00%	0.0	0	1.41
	Mean Flow		5.72				Load Factor	63.91	Avg. Eff.	0.54 Total		245429	
											2% downtime	###	

Table 1: Example of the spreadsheet model for Energy Output Calculations

Explanation of Model

The model is split into 5% sections of the flow duration curve, this is done as the varying conditions in the river greatly effect the amount of energy produced, so doing calculations on small sections then summing the results gives a more accurate result. The first row uses the value at 1% exceedance rather than the maximum 0%. Using the maximum flow (0%) which is usually an extreme outlier, means we do not get an accurate description of the high flow conditions. This means the averages calculated are now taken over 99% of the time which is taken into consideration.

- **Site Flow Model**: this is the flow rate from the river modelling (see figure 5) at the specific weir and that percentage of the flow duration curve
- **Factored Site Flow**: This is the site flow rate multiplied by a factor (**Flow Factor**), this was built in as an easy way to see the effect of a changing river flow rate on the output. For example if the river were to loose 10% of it's flow over the next 20 years what would our expected energy outputs be.
- **Minimum Residual Flow**: The environment agency requires that we do not abstract all the flow from the river and that some water is left going over the weir. Typically the amount required to remain in the river is the Q95 value, the value that occurs 95% percent of the time or greater.
- **Available Flow**: This is the Factored Site Flow minus the Minimum Residual Flow minus any flow required for a fish pass. The Environment Agency may require the installation of a fish pass which would further reduce the available flow.
- **Usable Flow**: An installed turbine only has capacity for a certain flow rate (**Maximum Flow through Turbine**), if the river is running at a higher flow rate water is sent over the weir. Changing the **Maximum Flow through Turbine** provides a way to compare different turbine sizes.
- **Actual Head**: As the flow rate in the river increases the height of water in the river increases also, however the height of water may not increase at the same rate or the same amount above and below a weir (due to many factors including weir position, river geometry, gradient, etc.). This effects the available head (height of dropping water). As the amount the head changes is affected by a great number of factors it is very hard to model here. Other feasibility studies have typically used an empirical equation of the form:

  $$Head_{actual} = Head_{max} – FlowRate/HeadFactor$$

  where the HeadFactor ranges anywhere from 13 to 27. This is probably the greatest source of error in the model at the moment as the value of HeadFactor is only a rough estimation. Studies measuring the flow rate and head in the river would be required to improve the accuracy of the value.
- **Turbine Efficiency** and **True Turbine Efficiency:** Regardless of the type of trbine installed the efficiency that it is able to generate power is a factor of the flow rate passing through the turbine. The values used in the current spreadsheet are taken from Ritz-Hydros published literature for an Archimedes type screw turbine. The True Turbine Efficiency is the Turbine Efficiency setting negative numbers to zero.
- **Power Generation Efficiency:** The electricity generator also has an efficiency associated with converting the mechanical power generated from the turbine to electrical power. This is usually relatively constant over a range of operating conditions
- **Total Efficiency:** The total efficiency is the True Turbine Efficiency multiplied by the Power Generation Efficiency. This corresponds to the total water to wire efficiency of the scheme.
- **Possible Power Output:** The possible power output in kilowatts is:
  Usable Flow * Actual Head * Acc^{n} due to Gravity * Total Efficiency
- **Energy Per Year:** The energy per year in kilowatt hours is:

  Possible Power Output * 8760 * 0.05

Where 8760 is the number of hours in a year and 0.05 the size of each of the sections of the flow duration curve (5% of the flow duration curve)

- **Residual Weir Flow:** This the remaining flow that goes over the weir when the turbine is running.

We have tried to as accurately as possible model the flow and energy, however at this stage we still have a rather large number of variables we are uncertain about, for instance, the best size of turbine, the size of any possible fish passes, turbine and generator efficiencies, and head factor.

Modelling Results

There are a large number of possible variations to the inputs for the energy calculation modelling but here we will illustrate typical results for the weirs considered.

	Mean Flow Rate (m3 s-1)	Height	Total Energy Generated (kWh)	Rated Shaft Power (kW)	C02 Saving per year (kg)	Revenue per year at 10p / kWh
Jordans	5.96	3	383,447	99.5	153,379	£38,345
Brightside	5.72	2.15	231,709	61.05	92,684	£23,171
Sandersons	5.58	1.7	165,889	43.58	66,355	£16,589
Leveston	5.48	1.2	102,335	26.83	40,934	£10,233
Effingham	5.44	1.3	114,179	29.9	45,672	£11,418
Ball Street	3.97	1.5	104,954	28.84	41,982	£10,495
Wards End	3.35	2.1	140,069	38.68	56,028	£14,007
Niagara	3.17	3.1	206,096	56.65	82,438	£20,610

Table 2: Results of the energy capture modelling, figures shown are for turbines sized at the respective mean flow rates, no fish pass and a head factor of 20

As can be seen from the above table Jordans Dam has the potential to provide the greatest energy production, over 1.5 times the next highest contender (Brightside Weir). It is pleasing to see that all the weirs considered appear to have the potential to raise at least £10,000 a year (schemes with a lower than 50kW power rating will be eligible for double ROCS, which will further their finacial viability).

Note:

There are many different ways of considering the power of a system, in the table above we have listed the rated shaft power of the schemes, this is the mechanical power generated by the turbine itself. Other possible terms to consider are: the rated electrical power, this is the electrical power outputted by the scheme, it differs from the mechanical power due to the efficiency of the generating equipment; the equivalent constant output is a further description of power, this is the power required to generate the stated kWh/yr if the turbine was running at a constant rate.

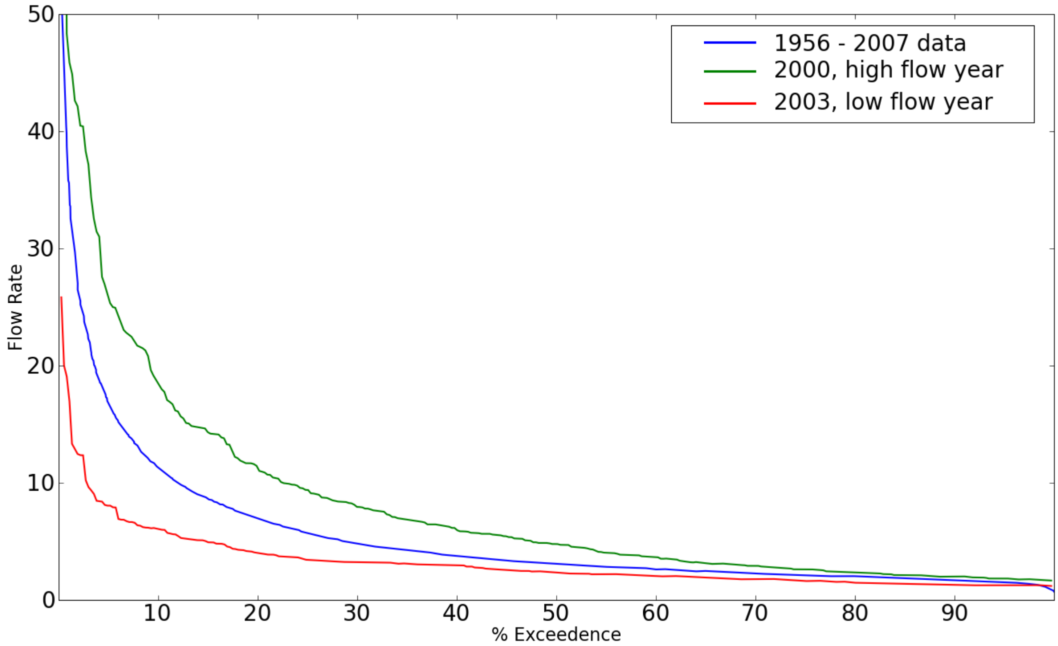

Figure 8: Flow Duration curves for high and low flow years at Jordans Dam. The year 2000 has a mean flow rate of 8.28 m3s-1 , 2003 mean flow rate of 3.19 m3s-1 , and the whole period from 1956 to 2007 has a mean flow rate of 5.42 m3s-1

Sensitivity Analysis

A sensitivity analysis of the energy outputs of Jordan's Dam to a number of variables was carried out. Jordans Dam is located on the outskirts of Sheffield on the lower River Don, it also straddles the Sheffield City Council and Rotherham City Council borders. The variables investigated are:

- Flow duration curve: this is the method of determining the flow in the River Don over the period of a year. It is important that the effect of very dry year and very wet years is investigated.

$$F_{duration} \in [\text{High Yearly Mean, Overall Model, Low Yearly Mean}]$$

- Installation of a fish pass: the installation of a fish pass will divert some of the available flow from the turbine.

$$F_{fish} \in [0, 0.1, 0.2, 0.5]\ m^3s^{-1}$$

- Head factor: this is the empirical factor that relates how the head over the weir changes under different flow conditions.

$$H_{factor} \in [13, 20, 27]$$

- Turbine size: Varying the size of the turbine will have an effect on the energy output, do we size for the mean flow rate of the river, mean flow rate of the available flow or some other measure.

$$T_{size} \in [4, 6, 8] \ m^3s^{-1}$$

Sensitivity Results

	Fish Pass Flow 0								
	Maximum Turbine Flow 4			Maximum Turbine Flow 6			Maximum Turbine Flow 8		
	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27
Total Energy Output (kWh)									
Flow Regime									
Model Ouput	**287,391**	**320,438**	**336,349**	**327,433**	**372,851**	**394,719**	**346,085**	**402,072**	**429,029**
High Year	**329,959**	**376,888**	**401,669**	**400,426**	**466,333**	**501,344**	**443,261**	**525,713**	**569,784**
Low Year	**237,039**	**252,299**	**259,647**	**249,871**	**269,049**	**278,283**	**245,364**	**267,082**	**277,539**
% High to Low	139.20%	149.38%	154.70%	160.25%	173.33%	180.16%	180.65%	196.84%	205.30%

	Fish Pass Flow 0.1								
	Maximum Turbine Flow 4			Maximum Turbine Flow 6			Maximum Turbine Flow 8		
	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27
Total Energy Output (kWh)									
Flow Regime									
Model Ouput	**275,857**	**308,569**	**324,320**	**315,077**	**360,055**	**381,710**	**333,803**	**389,283**	**415,995**
High Year	**321,219**	**367,837**	**392,468**	**390,429**	**455,894**	**490,693**	**432,800**	**514,724**	**558,540**
Low Year	**224,380**	**239,311**	**246,499**	**236,994**	**255,790**	**264,841**	**232,785**	**254,064**	**264,310**
% High to Low	143.16%	153.71%	159.22%	164.74%	178.23%	185.28%	185.92%	202.60%	211.32%

	Fish Pass Flow 0.2								
	Maximum Turbine Flow 4			Maximum Turbine Flow 6			Maximum Turbine Flow 8		
	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27
Total Energy Output (kWh)									
Flow Regime									
Model Ouput	**265,092**	**297,485**	**313,082**	**303,396**	**347,949**	**369,400**	**322,241**	**377,231**	**403,707**
High Year	**312,738**	**359,040**	**383,519**	**380,823**	**445,855**	**480,446**	**423,056**	**504,473**	**548,046**
Low Year	**212,393**	**227,004**	**234,039**	**224,922**	**243,349**	**252,221**	**220,881**	**241,734**	**251,774**
% High to Low	147.24%	158.16%	163.87%	169.31%	183.22%	190.49%	191.53%	208.69%	217.67%

	Fish Pass Flow 0.5								
	Maximum Turbine Flow 4			Maximum Turbine Flow 6			Maximum Turbine Flow 8		
	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27	Head Drop Factor 13	Head Drop Factor 20	Head Drop Factor 27
Total Energy Output (kWh)									
Flow Regime									
Model Ouput	**234,946**	**266,340**	**281,455**	**272,536**	**315,894**	**281,455**	**291,441**	**345,042**	**370,849**
High Year	**289,517**	**334,913**	**358,956**	**354,415**	**418,191**	**358,956**	**395,517**	**475,443**	**518,298**
Low Year	**180,918**	**194,637**	**201,243**	**193,065**	**210,465**	**201,243**	**189,399**	**209,055**	**218,519**
% High to Low	160.03%	172.07%	178.37%	183.57%	198.70%	178.37%	208.83%	227.43%	237.19%

The above table details the energy production per year for each of the model set-ups. There is a large variation in the results, however the following seem broadly true:

- You lose about 15-20% of the energy changing from head factor of 27 to one of 13
- You lose about %3.5 of the energy on the installation of a 0.1 $m^3 s^{-1}$ fish pass and double that for the larger fish pass size, for the largest fish pass size considered ($0.5m^3 s^{-1}$) you can lose between 9% (high flow year, large turbine, high head drop factor) and 30% (low flow year, small turbine, low head drop factor) of the energy.
- You can get up to double the energy output on a high flow year as on a low flow year
- Turbine sizing is important (can't really get a true judge here it always appears bigger turbines are better, as the cost of turbine isn't considered)

Conclusions

We have made considerable progress in understanding the River Don and the possibilities for installing a low head hydroelectric generation scheme. We have inspected the weirs on the river, using these visits to highlight which sites warrant further investigation. We have modelled the flow conditions, as flow duration curves, and received independent corroboration of the results. Further we built a spreadsheet model to calculate the energy produced by each of the weirs.

We also note that there are a number of areas of uncertainty left, particularly relating to the Head Factor, but also the size of any installed of a fish pass.

Appendix

Here is a list of the feasabilty studies and other useful sources of information currently available to SCR:

Planning for Renewable Energy Targets in Yorkshire and Humber , AEAT

A Guide To UK Mini-Hydro Developments , British Hydropower Association

River Dart Hydro Performance Assessment (Archimedes Screw Efficiencies Assessment), MannPower

Kelham Island Feasibility Study, PicoHydro

River Derwent Mini-Hydro Efficiency Feasability Study, IT Power

New Mills Feasibility Study, MannPower

Niagara Weir Feasibility Study, MannPower

Sheffield City Council Scoping Study, Renewable Energy Scoping and Feasibility Study, IT Power

The Potential for Developing Small Scale Hydroelectricity from River Weirs in Sheffield , H2ope

Guide on How to Develop a Small Hydropower Plant , European Small Hydropower Association.

Small Hydroelectric schemes, Report to the Sheffield Community Renewables Group, Spela Zeleznikar