babyHydro

Small hydro from idea to operation

CLIENT	PROJECT TITLE
Association of Cairngorms Communities (AoCC)	Hydropower Options Appraisal in the CNP Region

Hydropower Appraisal in Cairngorms

Final report

16th March 2016

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Version	DATE	Prepared by	Checked by
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1 Executive summary

Further to an initial desktop assessment of the remaining hydro potential in the Cairngorms National Park Region, using Hydrobot® surveying software, this document includes a longlist of 57 sites identified by the model. These sites were selected as having a return on investment of 5%, or a Simple Payback Period of 20 years. The longlist of sites was subjected to technical screening, and the results are presented. The necessary financial changes or incentives required to make more projects attractive are discussed.

2 Background

The Cairngorms National Park is a plateau of almost contiguous high land, surrounded on many sides by steep slopes to the lower ground. As such, there are many rivers and burns with a sizeable flow and steep gradient: the two primary ingredients for a good hydro site. However, a hydro site also depends on specific topography and access around the river that make construction possible at a reasonable cost. In an old landscape such as the Cairngorms, where water has been eroding deep channels into the mountainsides, the precious steep sections of river can often be inaccessible.

There are numerous hydro developments in and around the National Park, both historic and contemporary (Figure 1). The hydro schemes developed to date are firstly the large, cross-catchment schemes built between the 30s and 50s; other small to medium hydro built between the 50s and the turn of the last century; and a large number of micro to medium hydro built since the Renewables Obligation (Scotland) was introduced in 2002, followed by Feed-In Tariffs. Naturally, prospectors have targeted the easiest to build and the most profitable schemes, so that 'low-hanging fruit' has become harder to find with time.

The Hydrobot model has been successful in identifying some otherwise unknown sites, by virtue of its analysis of all watercourses, rather than just waterfalls and spectacular rivers. While AoCC are aware that the Scottish hydro resource has been extensively developed, and that recent cuts in Feed-In Tariffs have decimated the various Renewable Energy industries, the Association is keen to establish what the hydro resource could be, should the financial climate improve.

3 Methodology

3.1 Hydrobot desktop survey

Hydrobot was applied to the Cairngorms National Park, and analysed 1795 stretches of river, avoiding those corresponding to existing schemes. The model uses detailed topographical data along with rainfall, river flow, distribution grid, turbine and other equipment pricing, and costs for various professional services, to calculate the cost and return for layouts on each river stretch. By re-iterating with different sizes of scheme and grid connection points, the model selects an optimum layout at each site.

Further details of how the model works can be found in *The Employment Potential of Scotland's Hydro Resource* (N. Forrest and J. Wallace 2009)[1].

[1] http://www.gov.scot/resource/doc/299322/0093327.pdf

3.2 Feed-in Tariffs

Recent cuts in the Feed-in Tariffs available to hydro schemes, and likely ongoing "degression", have had a severe impact on the number of attractive sites in Scotland. Ofgem have resumed the option of Preliminary Accreditation of hydro schemes, allowing schemes with planning consent and licenses to lock-in to the prevailing FIT rate. Assuming that a hydro project would obtain the necessary consents by the third quarter of 2017, the prevailing rates paid for all generated electricity would be:

- For schemes below 100kW, 8.45p/kWh
- For schemes 100kW to 2MW, 6.10p/kWh
- For schemes 2-5MW, 4.43p/kWh

These rates have been used in the model, and are paid in addition to the market price for exported electricity of minimum 4.85p/kWh.

Figure 1. Map of Cairngorms National Park, outlined in blue, showing existing hydro schemes as pink dots.

3.3 Threshold for viability

Experience has shown that it is useful to initially include sites whose financial returns may be weaker than the client requires, as it is often possible to improve on the layout produced by the model. The initial measure of financial attractiveness is the simple payback time in years, calculated by dividing the total capital cost by the annual gross revenue less operating costs. A seven-year payback may be attractive to a commercial developer, while for a community or a sub-50kW scheme, a payback of 10 years or more may be acceptable. This does not take into account inflation or the cost of borrowing (i.e. interest payments). Because the layout identified by the model may be improved upon visual inspection, the threshold is usually relaxed further. And because communities may value non-commercial benefits, in this case it was relaxed to 20 years for the first filter. Previous Hydrobot surveys have used a threshold of 10 years, but the recent halving of the FITs rates means no sites at all would be found, hence the need to relax the threshold to 20 years.

It is desirable to have a pipe gradient of 10% or more, as the cost of the pipe is a significant proportion of the cost. Also, consenting by SEPA is easier if the gradient is more than 10%, and it is very much harder for small schemes that are shallower than 6%.

In this case, in order to generate a sufficient number of sites for the technical screening, the 1795 sites mentioned above were filtered for those with a simple payback of less than 20 years. The filter produced a set of 57 sites, of which 38 had a gradient greater than 6%.

The distribution of sites is illustrated in Figure 2 below.

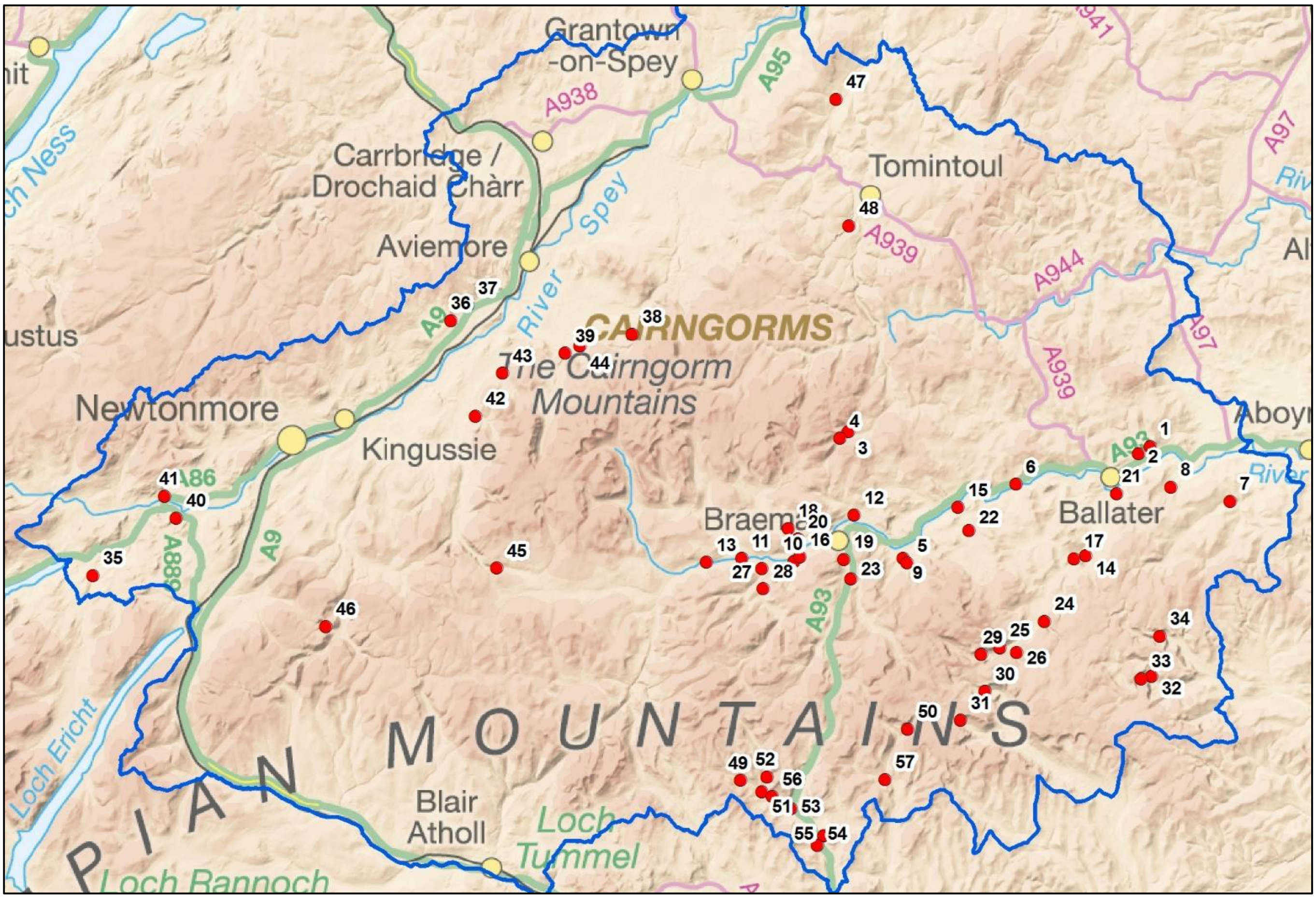

Figure 2. Map of 57 sites identified by Hydrobot as having a Simple Payback Time of 20 years or less.

3.4 Technical Screening

The Hydrobot model is able to assess numerous aspects of topography and hydrology to locate potential sites. Once the 'low-hanging fruit' has been picked, the features that can make the difference between an easy and impossible site are often quirks in the landscape that a hydro engineer is trained to spot. Over the last two decades, hydro engineers have become more and more resourceful in finding ways to make a poor site acceptable, and to allow for this, we have gradually been relaxing Hydrobot's selection criteria, so that sites with a vague chance of being saved are not rejected prior to inspection – known as false negatives. The downside is that the model then generates more false positives, and these must be identified through visual inspection of the maps: Technical Screening.

Technical Screening was carried out on the 57 results. This involves scrutinising 1:25,000 OS maps and cross-referring to a number of websites in order to check the following characteristics:

- **Site access**: is there a road or good track within reasonable distance of the site?
- **Powerhouse and intake access**: is there already any access route up the hill?
- **Intake site**: is there a suitable and safe spot where an intake could be built?

  In the example below, the intake point at the top of the red line is in a gorge, and so is unsuitable for an intake. The bank on the west is approximately 20m high, and the east bank rises to a hilltop. Downstream, at around 470m, the bank has flattened out on the east side and an intake could be possible, though the head is significantly reduced.

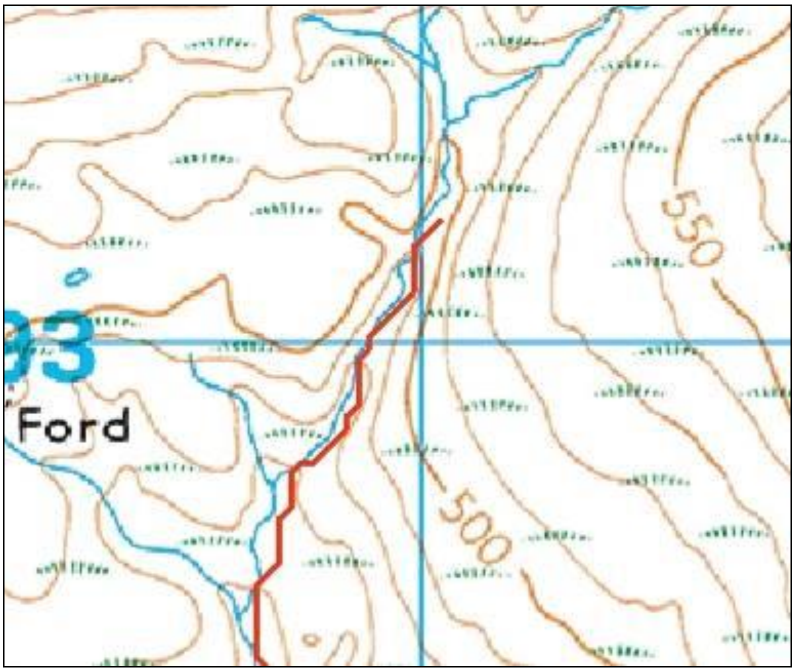

Figure 3. Example of potential site identified by Hydrobot, showing poor intake access at the top, but better access near the bottom around 470m AOD.

- **Improvements**: where Hydrobot's layout is too shallow or sub-optimal, can it be improved to produce an attractive scheme?
- **Buildings and railways**: are there any existing structures or railway lines that would pose a barrier to a hydropower scheme?

- **Existing schemes:** would the abstraction affect, or be affected by, any existing hydro schemes, whether operating or in development? Or any other water uses e.g. drinking water?
- **Flow uncertainties:** are there splits in the river, or uncertainties about its course?
- **Natural Heritage Designations:** for example, SSSIs or Special Areas of Conservation. If the scheme passes through any designated land, does that designation have any relevance to hydro? Is it likely to be a showstopper?
- **Grid connection**: how far is it to the nearest connection of suitable voltage and number of phases? Over what terrain? Could the scheme share a connection? If the local substation is congested, when is it scheduled to be upgraded?
- **River status:** what is the river's current and aspirational ecological status? If 'Good' or 'High', penstock length may have to be limited to 1500m or 500m respectively.
- **Bryophytes:** has the site been surveyed for rare mosses and lichens, and if so, is it a nationally important site?

3.5 Assumptions and caveats

Technical Screening involves subjective judgements about whether a suitable intake site and pipe route exists, where the detail available on maps and electronic datasets can be inconclusive. Therefore, babyHydro makes no guarantee that the shortlisted sites will yield viable projects.

Hydrobot's costing formulae are based on average costs for machinery, labour and materials, but these vary geographically and between suppliers, which means that project costs can vary massively. Hydrobot's predicted costs are a good starting point, but there will inevitably be uncertainty about costs for any site until the detailed designs have been produced.

3.6 LowFlows data

For each site that was classed as "Good" following Technical Screening, a more detailed flow report was generated using LowFlows 2 software from Wallingford Hydro Solutions, which is SEPA's preferred method of flow prediction. Half of the outputs agreed with Hydrobot's prediction, while half were somewhat lower. This is largely due to LowFlows' ability to model permeable geology, which reduces the flow available to hydro. In the example in Section 4 below for Garbh Allt, the LowFlows flow data has been used.

3.7 Forestry Commission

Forestry Commission Scotland has been granting rights for development of hydro sites on FCS land to companies and communities as part of a general renewable energy resource development programme. The 'Hydro Residuals' have largely been allocated, but some sites were not applied for. Because of the huge response, some sites that were applied for were not allocated to any developer. A definitive list of sites that are still available and unallocated has not been generated, so while we have screened out sites that were earmarked one year ago, we cannot tell whether all are still available, and FCS must be contacted for updates on specific sites.

3.8 Grid availability

While a line on the distribution network may be within a reasonable distance at the correct voltage, there is no guarantee that there is capacity on the grid at that point. If there are other renewable energy schemes in the area, or if it is located at the end of a spur, the grid may be deemed ‘congested’, which means that the hydro scheme would not be able to connect without significant upgrades to the grid. Strangely, on the 26th January there were various unconstrained sub-stations near the National Park, but on 27th January, their status had changed to constrained. As of 26th February, the sub-stations are once again unconstrained. This may simply be an issue with the website.

The exact capacity on any line can only be known when the Distribution Network Operator models the system. Where there is a constraint, SSE typically state a date when a scheme could connect to the grid with export limited to maximum 50kW, and a second date when the constraint will be lifted and the scheme can export more. Therefore, provided the local LV network is not suffering overheating or voltage fluctuation, SSE have indicated that schemes of 50kW or lower should be able to connect relatively quickly. As this applies to Garbh Allt, which is the example illustrated below, we have presented a reduced option, showing how it would be affected if it were constructed at 50kW.

It should be noted that connections at a voltage of 33kV are far more expensive than 11kV. Sometimes it is possible to connect at an existing transformer, but where an entirely new transformer is required, a 33kV connection can be upward of £200,000. Where possible, an 11kV connection is sought.

4 Results and conclusion

The initial filter of Hydrobot outputs for sites within the National Park and with a payback of less than 20 years produced a set of 57 sites. These are presented in Appendix 1 - Table 2, along with the main reason why they were screened out. Jpeg images of each layout have will be supplied on a CD.

Technical Screening yielded 6 sites that babyHydro regards as technically feasible using today's technology and accepted methods of construction. Of these, Garbh Allt is explored in a little more detail. A financial summary is provided in Table 1 below, and the layout is illustrated in Figure 4.

Table 1. .Financial summary for Allt Garbh, site number 9. The *Name* is a combination of Hydrobot's turbine reference number and the river or site name. The *Installed power* is followed by the total capital cost, from feasibility and consents through to commissioning. *Annual costs* include maintenance, insurance and spares – community-led schemes of this size should be exempt from business rates. *Annual gross revenue* includes Feed-in Tariffs (assuming commissioning by September 2017) and export revenue. *Simple payback* is *Initial cost* divided by *Annual gross revenue* less *Annual cost*. Note that an alternative layout at 50kW is provided for Garbh Allt, as this would avoid possible grid transmission constraints.

Number	Name	Installed power (kW)	Initial cost (£)	Annual cost (£)	Annual gross revenue (£)	Simple payback (years)
9	12001766 Garbh Allt	254	1,399,510	17,283	136,368	11.8
9	12001766 Garbh Allt (reduced)	50	512,490	6,966	48,856	12.2

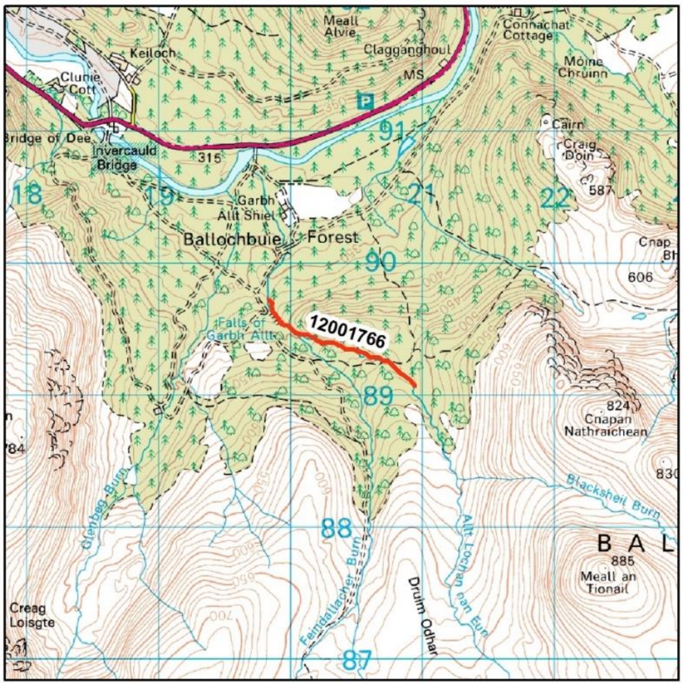

Figure 4. 12001766 Garbh Allt NO209890.

Garbh Allt's intake would supply a pipe to north bank, possibly following the crest of a ridge with a steep, short penstock. Three-phase 11kV lines could provide a grid connection 1.5km away. This project is greater than 50kW, but is served by the Tarland GSP, which is currently unconstrained meaning that a 50kW restriction may not be necessary. The site has the following environmental designations: Special Area of Conservation, Special Protection Area, National Scenic Area and National Park. The river has good ecological status, which means abstraction may be limited to avoid degrading the river – another reason why reducing to 50kW may be necessary.

The choice of whether to take a project forward is greatly dictated by the number and nature of landowners, as well as local knowledge of barriers or indeed favourable factors. Also, AoCC or babyHydro would need to consult Malcolm Crosby of Forestry Commission Scotland, to establish whether sites bordering or within FCS land are still available.

BabyHydro will be happy to discuss the sites in order for AoCC to consider whether any should be visited for a Pre-feasibility Survey.

4.1 SAC Consulting report

A report on the renewable energy potential of the Cairngorms produced by SAC Consulting in 2011 did not list any specific hydro sites, but highlighted a number of valleys and tributaries that were thought to have good hydro potential. These were identified by excluding areas of high environmental sensitivity, and focussing on those with high rainfall and which are less remote from likely grid connections.

It is natural to assume that large rivers near population centres must have untapped hydro potential. An example would be the Monadhliath Mountains to the west of the National Park. The southern slopes supply many burns running southeast to the River Spey, in particular around Kingussie and Aviemore. BabyHydro has carried out various hydro surveys in this area and provided technical due diligence on the Pitmain Estate hydro schemes.

The Hydrobot model had analysed 87 burns and tributaries in this area, and only three showed a payback period of less than 20 years. All three were within incised gorges as described in section 3.4 above, and therefore not suitable for hydro. In fact, a quick look at the Ordnance Survey maps of the region show this is a particular feature of the watercourses. Where more suitable burns exist (such as at Pitmain) they are the exception to the norm, and have previously been signed up by the many hydro prospectors scouring Scotland over the past decade.

5 Future opportunities

In order for the projects that are currently unattractive to become attractive, the revenues from the projects need to increase. This is because the cost of hydro technology, due to its maturity, is unlikely to reduce over time unlike solar and wind. It is unlikely that FITs will be re-instated to their former levels, but if international carbon reduction targets are applied and upheld, an alternative form of grant or revenue support may be available. For example, if a grant were received for 50% of the capital cost of a project, the project's payback period would also reduce by 50%, and 20-year paybacks would become an acceptable 10 years.

The wholesale price of electricity has been suppressed due to low fossil fuel prices. Some oil-industry workers suggest the glut of fossil fuels is driven by the producers' knowledge that they will soon be prevented from extracting fossil fuels, if anthropogenically-driven climate change is universally accepted. The timescale for governments taking such significant action is unknown, but could be somewhere between two and five years. At this point, electricity prices should recover and we would expect new incentives for renewables.

The electricity export price used in calculations above is 4.85p/kWh, determined by Ofgem as the minimum any renewable energy installation should receive for exported power. The wholesale electricity price has fallen since 2011 from around 5p/kWh to todays 3.5p/kWh so Ofgem is already subsidising the export tariff. This would be combined with a FIT of 8.45p/kWh for <100kW, and 6.10p/kWh for 100-500kW, to give total revenues of 13.3p/kWh and 10.95p/kWh respectively. To be attractive by last year's standards, these revenues need to approximately double.

In the case of Garbh Allt, whose payback is approximately 12 years, we would suggest that a total revenue approximately 50% greater would be enough to make it worthy of taking forward. The total revenue would therefore need to increase to 16.42p/kWh.

A hydro scheme can become far more attractive if a large local user can be identified, such as a Scottish Water sewage treatment plant. Scottish Water is keen to establish 'private wire' agreements where they directly purchase electricity from embedded generators. This can result in a negotiated tariff significantly higher than that available to grid-tied exporters.

Battery storage is another method of marginally increasing profitability, allowing users to consume more of the power they generate. However, the savings are not likely to half the payback time as they do require the purchase of additional equipment. As the technology becomes cheaper, commercial and industrial battery storage should spread rapidly. With medium-term electricity price rises, the storage capability might be the determining factor in some hydro scheme's viability, though it is not possible to quantify the benefits within this study.

In conclusion, the technically viable hydro potential of the Cairngorms National Park has been extensively developed already, despite the abundance of steep rivers. The financially viable hydro potential is now almost non-existent, save the projects that received FITs pre-accreditation before December 2015. For the rest, the general consensus in the hydro industry is to wait it out, until renewables are once more in demand, when incentives and wholesale electricity prices will kickstart the industry. A 50% increase above the tariff levels described in section 3.2 would be enough to make some of the results attractive to communities, and would indicate that it is time to revisit the theoretical hydro potential in the National Park.

6 Appendix 1: Results table and comments

Table 2. Sumary of 57 sites located within the National Park that have a payback period less than 20 years. The *Installed power* is followed by the total capital cost, from feasibility and consents through to commissioning. *Design flow*, *Gross head, Gradient* and *Connection distance* are three parameters critical to the size and cost of the scheme. *Simple payback* is *Initial cost* divided by annual net revenue. *Status* has the following meanings:

2: gorge
4: distance/terrain to grid
5: impacted by existing hydro scheme
7: very low gradient
8: good
9: poor powerhouse access
10: poor intake access

Notes are shorthand, indicating Forestry Commission, details of grid connection options, natural heritage designations, Grid Supply Point governing transmission constraint, and in some cases a general comment on alternatives that might have a better chance of success.

Number	Turbine number	Installed power (kW)	Initial cost (£)	Design flow (m3/s)	Gross head (m)	Connection distance (m)	Payback period (yrs)	Gradient (%)	Grid reference	Status	Notes
1	12000304	70	515,178	0.085	107	1,209	18	10	NO394985	8	Part FC; 3ph; SSSI,SAC,NP; Tarland 15
2	12000354	320	1,676,107	0.612	68	508	15	5	NO385980	2	
3	12000741	260	1,548,328	0.156	217	8,169	19	14	NO155997	2	
4	12001184	233	1,334,082	0.089	341	7,644	18	22	NO148992	2	
5	12001433	333	1,654,606	0.343	126	5,109	15	8	NO201893	2	
6	12001445	90	585,830	0.093	126	1,381	16	12	NO288956	8	Int 350m,50kW; 3ph 11kV 250m; access ok; NSA NP
7	12001479	604	3,221,044	1.657	46	2,335	18	3	NO457942	7	
8	12001741	303	1,505,728	0.188	209	1,598	14	8	NO410953	2	
9	12001766	447	1,977,832	0.472	123	4,653	13	8	NO198897	8	N bank; 3ph 1.5km; SAC,SPA,NSA,NP; good status
10	12001837	250	1,215,726	0.295	110	1,441	14	8	NO112895	5	Braemar Community taking forward 2011
11	12001850	1,059	5,058,931	3.203	42	2,455	15	3	NO070897	7	
12	12001874	276	1,737,743	0.627	57	1,806	19	4	NO159931	7	Salmon ladder and dam, but feels wrong! Pico?
13	12001922	173	1,100,368	0.127	177	5,241	20	13	NO042894	10	Good except no access to top
14	12001928	213	1,344,508	0.146	190	4,371	19	8	NO343899	2	
15	12002048	268	1,570,422	1.225	28	760	20	4	NO241937	5	

Number	Turbine number	Installed power (kW)	Initial cost (£)	Design flow (m3/s)	Gross head (m)	Connection distance (m)	Payback period (yrs)	Gradient (%)	Grid reference	Status	Notes
16	12002092	83	566,524	0.084	129	1,828	16	17	NO116898	2	15kW below road? NSA,NP; Tarland 15
17	12002160	808	3,047,198	3.519	29	4,915	12	7	NO334897	7	
18	12002352	80	630,056	0.090	116	2,291	20	10	NO107921	2	
19	12002404	47	355,939	0.020	299	906	19	31	NO151896	10	
20	12002532	900	3,803,458	3.175	36	2,097	13	4	NO115912	7	
21	12002631	84	549,999	0.075	145	588	16	10	NO367948	2	
22	12002758	443	2,696,338	0.538	107	2,650	19	4	NO250919	5	Might get 40m=100kW? 3ph 400m; Tarland 15
23	12003275	703	3,286,347	1.580	58	2,535	13	4	NO157881	7	
24	12003329	494	2,601,700	0.360	178	9,804	16	6	NO310847	2	
25	12003341	351	1,849,101	0.158	288	11,657	16	19	NO274826	4	
26	12003365	297	1,811,063	0.295	131	11,988	18	14	NO288822	4	
27	12003808	707	3,729,965	2.462	36	987	17	3	NO086889	7	
28	12004015	580	3,245,763	2.193	34	2,193	18	3	NO087873	7	
29	12004633	577	2,505,871	0.403	186	12,254	12	13	NO260821	9	
30	13000259	550	2,607,748	0.385	186	14,659	14	12	NO263791		Track; 1ph Glendoll; 3ph Clova 9km
31	13000416	406	2,171,853	0.321	164	13,705	16	15	NO244769	2	
32	13001357	556	3,422,750	0.500	145	11,410	19	5	NO395803	7	
33	13001457	2,351	6,555,309	1.330	230	12,238	10	16	NO386802	2	
34	13001467	642	3,296,741	1.109	75	11,636	15	5	NO402835	7	
35	91002361	1,074	4,669,291	3.358	41	2,444	16	3	NN557883	5	RWE
36	320000814	127	708,880	0.093	177	981	19	12	NH840085	2	
37	320001084	82	547,708	0.051	208	1,306	18	15	NH853097	2	
38	320001169	326	1,718,331	0.568	75	4,825	17	7	NH984074	2	FC
39	320001427	636	2,901,780	1.438	56	4,105	16	4	NH930059	2	
40	320001731	58	423,499	0.080	95	360	20	9	NN622929	2	

Number	Turbine number	Installed power (kW)	Initial cost (£)	Design flow (m3/s)	Gross head (m)	Connection distance (m)	Payback period (yrs)	Gradient (%)	Grid reference	Status	Notes
41	320002059	59	406,306	0.034	223	217	19	13	NN613946	2	
42	320002275	337	1,702,477	0.233	188	2,153	17	6	NH859010	2	
43	320002331	264	1,347,861	0.269	127	2,776	17	9	NH881043	2	
44	320003256	373	2,040,807	0.306	158	4,511	18	6	NH942065	2	
45	320003376	976	4,813,380	2.978	42	11,026	19	3	NN876889	2	
46	320003655	337	1,762,354	0.192	228	10,163	18	16	NN741843	2	
47	321001354	98	618,986	0.091	139	774	18	9	NJ145260	2	Small 10kW option on Allt Balnabeinne to north
48	321002226	739	3,235,597	1.943	48	2,768	17	4	NJ155160	7	
49	322000008	338	2,169,515	0.329	134	4,064	19	5	NO069721	7	
50	322000429	327	1,755,825	0.171	248	9,546	16	16	NO202762	2	
51	322000456	371	2,208,981	0.909	53	2,170	17	4	NO086712	7	
52	322000514	208	1,096,888	0.181	150	2,821	15	11	NO090724	2	
53	322000682	78	504,180	0.085	118	603	15	11	NO109699	8	WHW; dam; 3ph 150m; CoupAng Oct20; NP
54	322000706	58	456,389	0.070	108	1,393	19	13	NO130669	8	3ph 150m; 2020; NP,SSSI,SPA; CA20
55	322001009	283	1,699,349	0.689	53	1,036	18	4	NO135677	7	
56	322001268	60	470,133	0.049	158	1,290	19	12	NO094708	8	3ph 550m; NP,nr SPA; CA20
57	322001530	254	1,620,439	0.376	88	5,450	19	6	NO184722	2	Lot of water, but just a bit gorgy

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