Hafod y Rhedrwydd micro-hydro scheme - construction method.

Contents

Location

The stream is the main tributary of Afon y Foel.

Stream works at the extraction point and stream crossings 1 & 2 (SC1, SC2 in Figure 1) will require temporary flow diversion. Other constructions (settling tank ST beside the stream, turbine hut) will not require any diversion. The turbine hut tailrace discharges through the bank above water level.

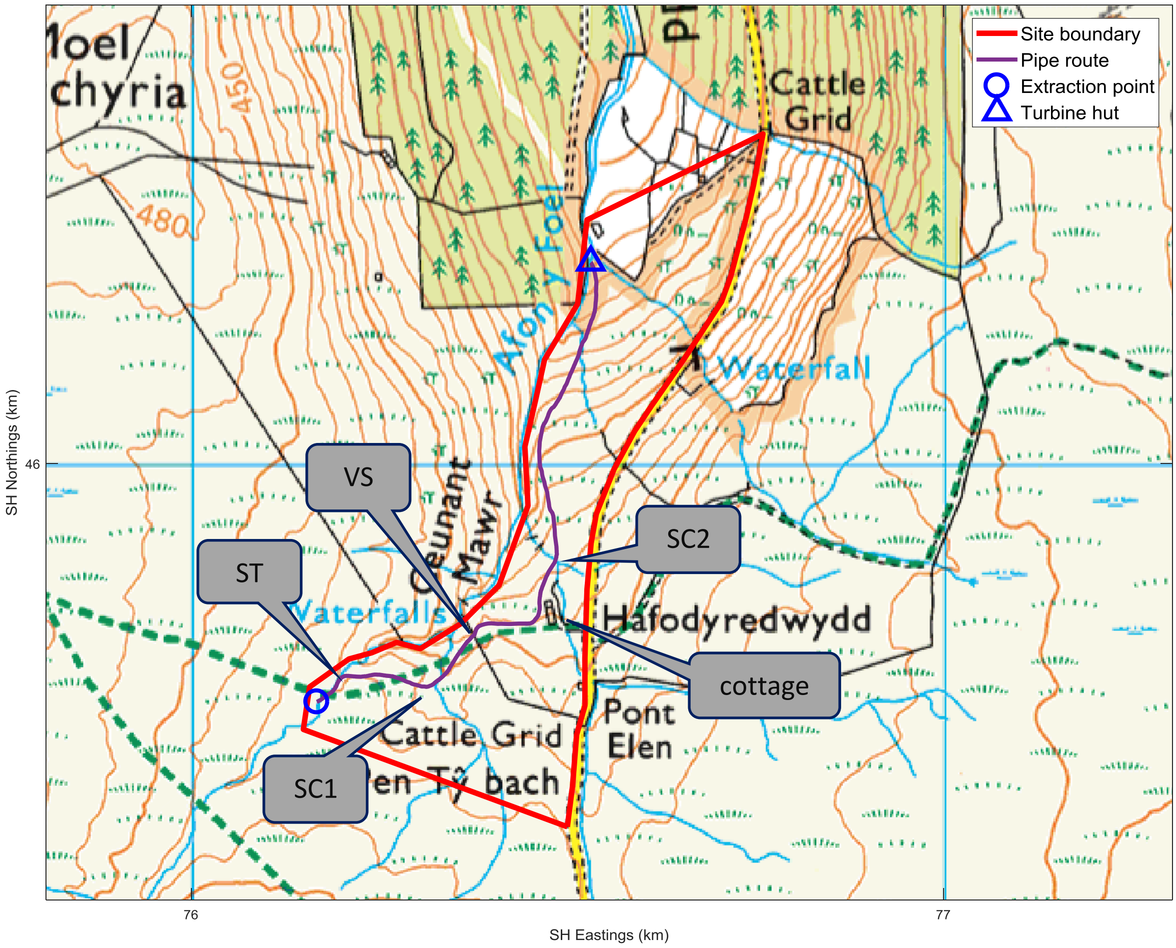

Figure 1. Map showing extraction point, settling tank, pipe route, stream crossings and turbine hut. Map scale 1: 10000 (grid squares are 1 km wide). OS map is © Crown Copyright, reproduced by permission of Ordnance Survey. (Map purchased from Blackwells Mapping Online 5/12/2018, order number BW1-899389-43094-051218). ST = settling tank, SC = stream crossing, VS = volcanic sill.

Extraction point methodology

The gradient of the stream at the extraction point and the presence of deep pools (Figure 2) allows a syphon to lift water above bank level and return it further downstream (Figure 3a,b) during construction operations.

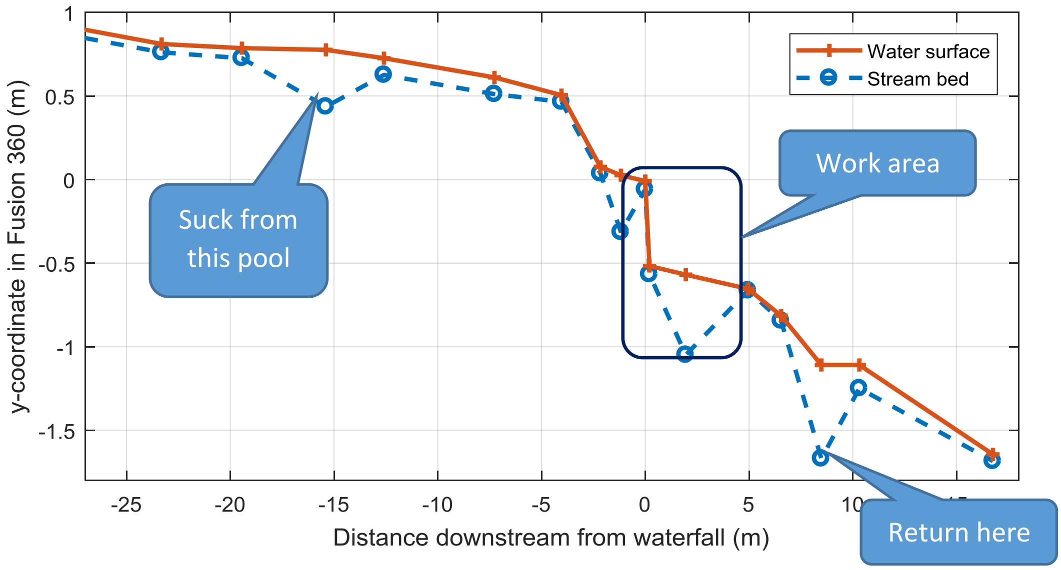

Figure 2. Stream bed and surface levels.

Reducing the water level in the top pool by 15 cm will prevent any flow out of that pool to the work area. The syphon will need to bypass 25 m of stream and operate with a surface-surface drop of 1.7 m. A battery-operated butterfly valve will restrict the flow rate to prevent the upper pool level falling so low that the syphon sucks air (controlled by a float switch in the upper pool).

Stream works will be carried out in dry weather with stream flow rates of 6 litres/sec or less; the syphon has been designed to handle 10 L/s. It will use 160 mm flexible corrugated drainage pipe (135 mm bore); the exit nozzle for 10 L/s is equivalent to 47 mm diameter.

The syphon will be started by sucking at the highest point using a vacuum cleaner. The vacuum cleaner can suck a 2 m head so a pipe will be passed over a ladder to avoid water passing into the vacuum cleaner. Once the syphon is full of water the vacuum cleaner line will be closed with a ball valve to allow continued operation without running the generator.

The syphon intake will be covered with a 6 mm mesh to avoid sucking fish or debris.

Figure 3 (a, b) Syphon route past working area.

The stream works at the extraction point will include:

- Carving pockets into bedrock for the screen fairings and plunge pool (Figure 4).
- Small concrete in-fill under fairing 3 (Figure 5).
- Bolt plunge pool wall, screens and fairings to bedrock using stainless fastenings (Figure 6).
- Core-drill a hole 160 mm diameter beside the stream for stilling well. Cross-drill through to stream (alternatively it may prove possible to cast this as part of the downstream weir). Figure 6.

- Clean up stream bed and carve slight rebate for the downstream weir
- Cast weir using concrete and plywood forms, temporarily bolted down to rock (Figure 7).

Concrete will be mixed as close as possible to the weir (a few yards) using a small portable cement mixer, then carried by bucket and poured into the forms. This will be done with no stream flow (100% bypass) to avoid any possibility of wet concrete washing away downstream. Sacks of sand, gravel and cement will be carried from the road using a powered wheelbarrow. All spare construction materials will be removed from site at the end of the build.

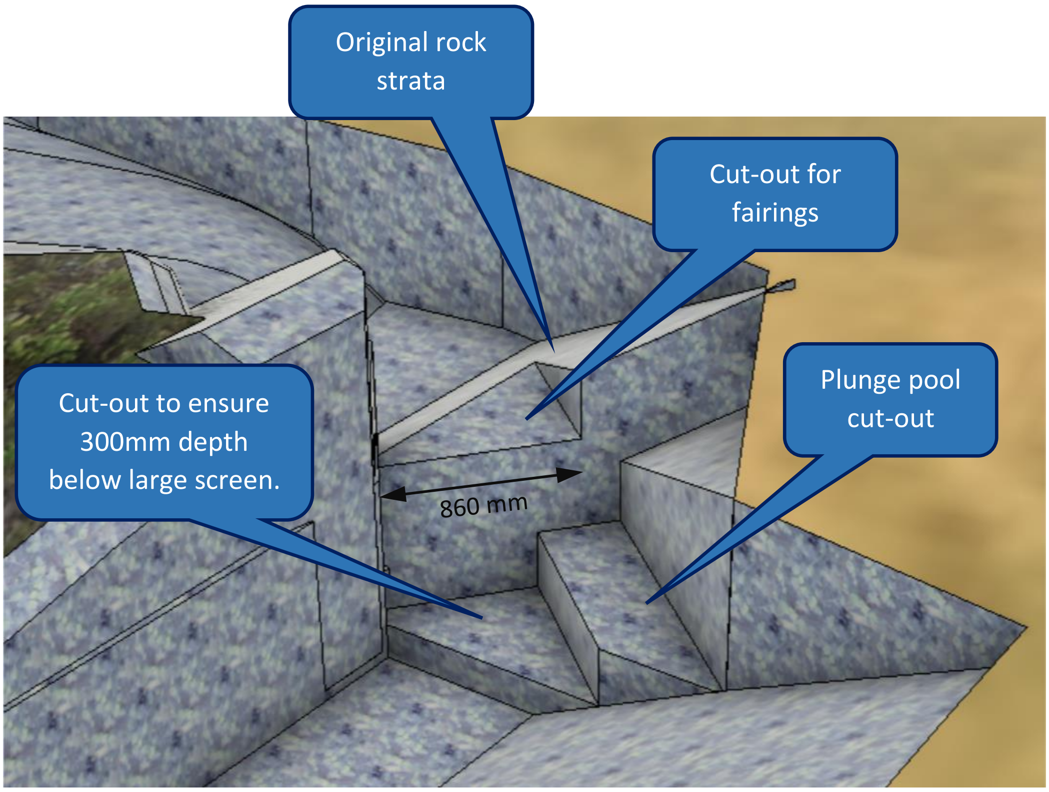

Figure 4. Stream bed cut-outs for screens and plunge pool.

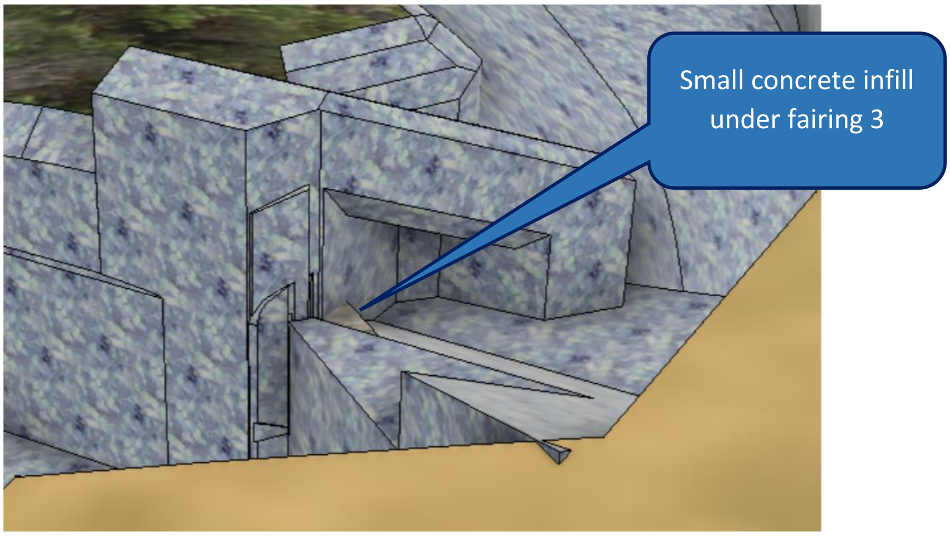

Figure 5. Supporting fillet for fairing 3.

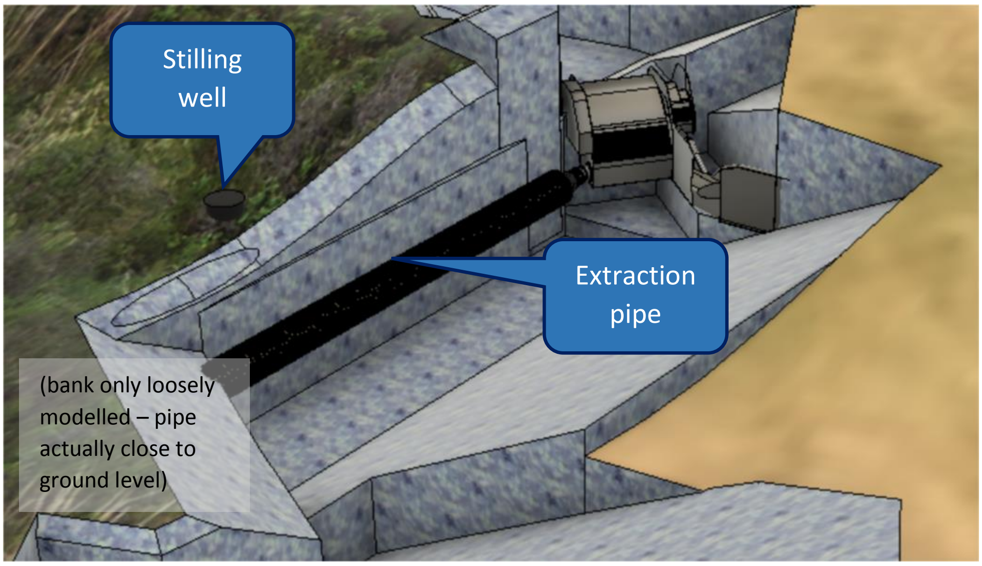

Figure 6. Screens, basin wall and extraction pipe in place.

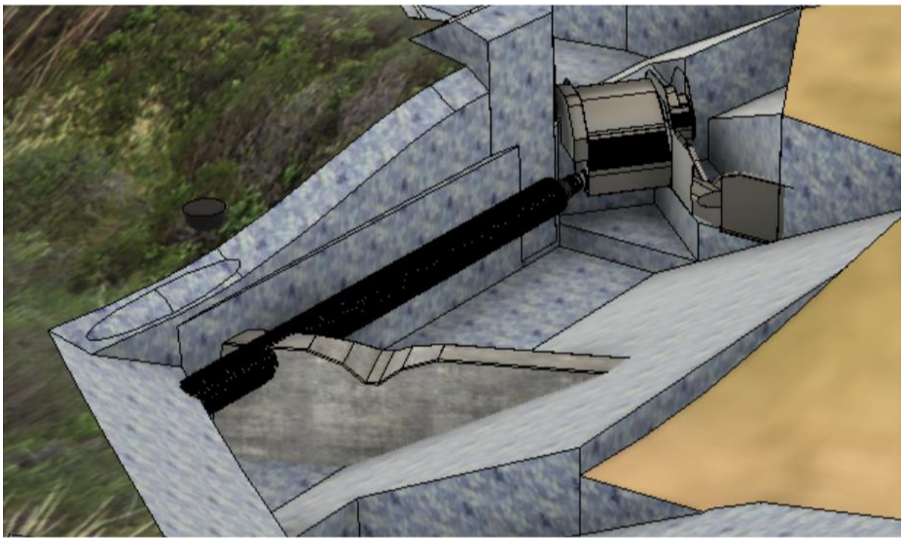

Figure 7. Downstream weir with flow-metering notch.

Settling tank and electronics cabinet.

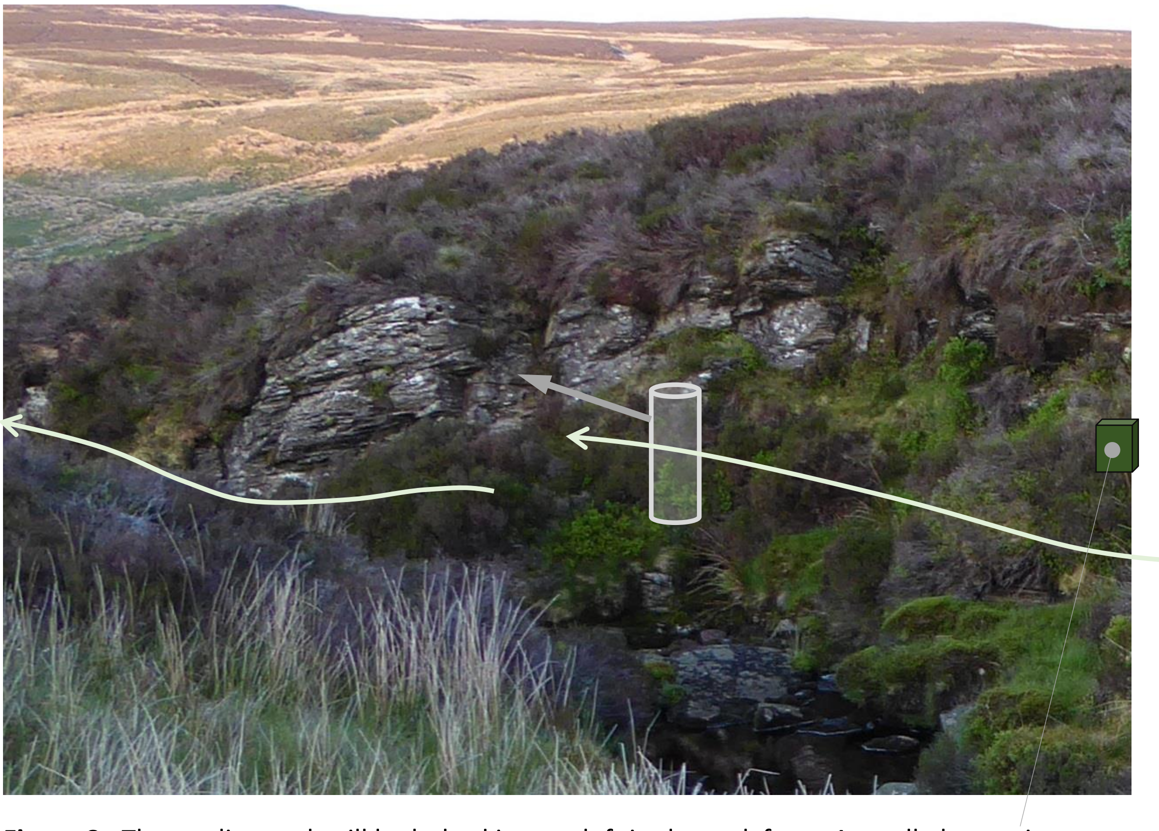

Figure 8. The settling tank will be bolted into a cleft in the rock face. A small electronics cabinet will be located against the rock wall part-way between the extraction point and settling tank (Raspberry Pi interface to settling tank and stilling well water level sensors).

A temporary working platform (some planks) will be needed while making a base slab for the tank and putting the tank in place. A stone saw and/or SDS chisel will be used to dress the cleft in the rock face slightly (as required) to ensure the tank can stand vertically and be hidden from view, as far as is practicable. Rock bolts and metal straps will stabilise it in position.

n.b. Whilst the tank is nominally to be build from 500-600 mm OD MDPE tube, the actual diameter will be chosen to fit the space available and may be smaller in diameter. (600 mm is an upper limit).

To ease servicing, the pipe entering the tank will include a butterfly valve to shut off the flow and the tank itself will have a drainage valve (with ducting to return water to the stream without scour or soil erosion). The tank will be covered to prevent frogs and other wildlife from entering. It will however be vented to atmosphere (via a fine mesh) so that the penstock can if required be emptied without creating a vacuum and to give valid readings of the internal water level.

Stream crossings.

Methodology for burying pipe at stream crossings

Stream work will be carried out in very dry weather (stream flows 1.5 – 2 litres/sec). A sheet of EPDM roofing rubber, held down by sandbags, will be placed across the stream immediately above the work location and will funnel the water into a twin-wall drainage pipe. The pipe will run horizontally until above bank level (possible because both streams have an appreciable gradient). This temporary pipe will carry the water and return it to the streambed immediately below the workings.

Figure 9. Stream crossing 1. This is a very small tributary. The flow falls to 0.6 litre/sec in dry weather; a more typical flow might be 1.5 litres/sec. Ramps will be used to help the mini-digger and power barrow cross the stream e.g. https://www.therampppeople.co.uk/vehicle-ramps/profile-height-up-to-80mm/trp80-series

Figure 10. Second crossing point. The pipe will have an air-relief valve near each crossing point. These should never leak water but for safety a conduit will be provided to return any small leaks directly to the stream.

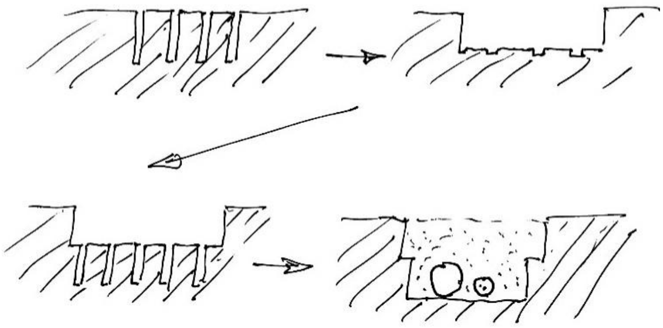

Figure 11. Stream crossings will be cut by hand, using a stone saw (petrol or electric) to make a series of grooves and breaking out the tongues using an SDS drill.

Where the penstock is laid in a trench cut into the bedrock of the stream it will be reinstated using concrete. As for the extraction point, concrete will be mixed on site using a small portable cement mixer, carried in a bucket and poured into the trench. This will be done with the stream bed dry (100% bypass) to avoid any risk of concrete washing away and polluting the watercourse downstream; it will be allowed to cure before passing water back over it.

Cement manufacturers will be consulted as to the best mix and possible additives to provide durability against freeze-thaw cycles.

If the stream bed is sloping, boards will be held down on the wet concrete surface to make it follow the rock profile rather than slumping to a horizontal plane.

The penstock will be wrapped in a thin layer of rubber sheet or closed-cell foam prior to concreting. If the water in the penstock freezes, this will accommodate the expansion without cracking the concrete or lifting it out of the bedrock. A protective sheet is also necessary to protect the pipe from fretting against the concrete in the event of any movement due to thermal expansion.

It is hoped that the burial methods will prevent the penstock freezing except in the most severe winters. The stream itself may not freeeze but the flow through the penstock (0.6 litre/second or less in dry conditions) may not be enough to stop it freezing at points close to the surface; then once one point freezes and stops the flow, freezing could become more widespread along the pipe. HDPE pipe is very tough and will not be damaged by freezing; the time taken to defrost after a cold spell could however be a nuisance.

Alternative (above-ground) stream crossings

NRW have commented "*the pipeline crossing the stream at two points if left as per the current design may be subject to scour and impoundment themselves. It is recommended that these crossings are undertaken via above ground bridging of the watercourses (small abutment set back either side of the banks and short length of I beam to support".*

Pipe burial was chosen as the only way of achieving a completely invisible system. If an above-ground crossing would be visually acceptable, this would be a much easier solution.

Each crossing point would then have two pipes: one for the penstock and one for the electrical conduit (Figure 12). The location would be the same as for a buried crossing (SC2 shown in Figure 13).

Figure 12. Possible arrangement of supporting tubes for penstock and conduit.

The penstock would be supported by a larger diameter pipe (304L stainless steel, 200 mm OD, 2 mm wall thickness). Annular rings of Kingspan or similar insulation would be slid over the penstock to locate it within the larger tube and provide thermal insulation against freezing. This diameter and thickness provides a safety factor of about 6 against a worst case load with 3 children sitting in the middle of a 3.6 m span.

The electrical conduit (65 mm OD) would pass through a smaller stainless steel tube (80 mm OD, 2 mm wall).

Figure 13. Nominal pipe location for an above-ground crossing. The metal sleeve pipes would be painted with a suitable drab colour such as Halfords ultra matt camouflage green https://www.halfords.com/motoring/paints-body-repair/specialist-decorative-paints/halfords-camouflage-spray-paint-green-300ml.

Crossing the volcanic sill

The large waterfall behind the cottage occurs where Afon y Foel passes over a volcanic sill. The penstock will also have to cross this feature (Figure 14), about 10-15 m above the stile.

Figure 14. Approximate penstock route over volcanic sill.

The sill itself is very hard rock; a large ditch or cleft runs down it (just beyond the fence in Figure 14). The penstock will be sunk into the side of this ditch as far as possible to minimize the bending needed to follow the ground profile. If there is insufficient soil to allow this, a more oblique route (dashed line) will be taken to avoid sharp bends in the pipe; this will rise uphill and require an air release valve at the highest point. Any sharp pipe bends will require a concrete thrust block so that thermal expansion does not shift the pipe from side to side.

Preliminary surveys suggest that either route would pass above the small patch of European Gorse.

Penstock pipe diameter and welding

The scheme requires 840 m of buried pipe. The pipe will be butt fusion welded from straight-section black PE100 pipe stock e.g. http://www.gpsuk.com/range/44/excel-pe100-pipe-black.html sizes as per their Application Guide for Water.

The head is 150m; a combination of PN10, PN16 and (if available) PN20-rated pipe will be used. A pressure relief valve inside the turbine hut will ensure that these pressure ratings cannot be exceeded.

An approximate drop versus distance curve is given in Figure 15.

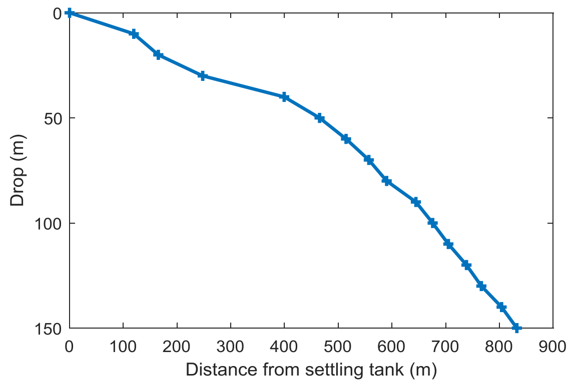

Figure 15. Drop from extraction point ("head") versus distance along penstock. Under no-flow condiitons this head will produce a static pressure of 15 bar at the turbine hut.

When the water is flowing, frictional effects will reduce the delivery pressure (Figure 16).

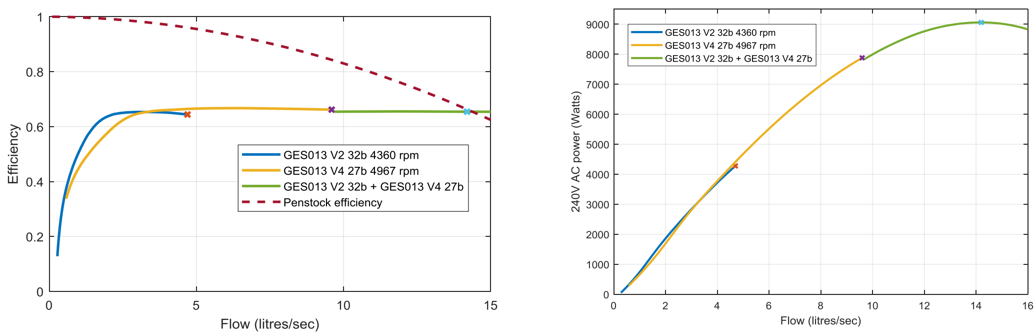

Figure 16. (a) Penstock efficiency, (b) net power output versus turbine flow rate.

The Coanda screens are capable of supplying 14.8 litres/sec at high stream levels but this flow is not expected to be used in practice. The absolute maximum power would be 9.06 kW (net) at 14.2 litres/second (Figure 16(b)). This is probably not a sensible operating condition due to the fall-off in rpm when losing 1/3 of the head to friction.

8.8 kW (at 12.14 litres/sec) is a more sensible "maximum" operating point for both turbines running together. The maximum power from just the main turbine is 7.88 kW at 9.6 litres/sec.

The pressure might rise above the no-flow curve while the spear valves are closing or (more importantly) if a large air bubble passed through the spear valves. This would lead to an increase in water velocity and a pressure surge when the bubble passed through and water hit the valve. The theoretical pressure increase may be calculated from the pressure needed to deliver water through the spear valve at the volume flow rate achieved by air at 15 bar through the same area. The pressure relief valve is necessary to limit this effect.

Design guidance for PE pipe systems is that occasional pressure surges should not exceed 2× (or 1.5 × if recurring) the pipe's temperature-compensated pressure rating (https://plasticpipe.org/pdf/chapter06.pdf) . The pipe design therefore needs to simply ensure the pipe has a sufficient life under the steady-state loading.

GPS define standard 100-year life pressure ratings of 10 bar (SDR 17) and 16 bar (SDR 11) with other sizes e.g. 20 bar (SDR 9) available on request (SDR = outer diameter/wall thickness).

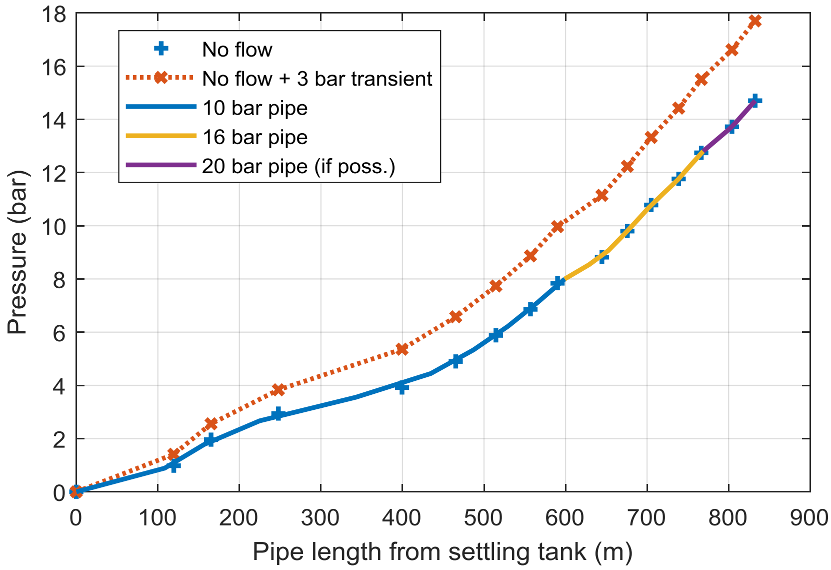

Figure 17. No-flow and possible peak pressures.

The pressure relief valve cannot be set too close to the 15 bar produced by the 150 m head without risk of leakage. If the valve is set to open at 18 bar the peak pressures would be limited as shown in Figure 17.

The tubes will be delivered to the roadside in 12m lengths and welded into 48 m lengths using a butt fusion welder. Tee-pieces and joints between dissimilar thicknesses which cannot easily be welded on-site will be added by the manufacturer prior to delivery. The 48m lengths will then be towed behind the power barrow, sliding over the ground, until they reach their destination and are welded on the end of the previously positioned pipe section.

Pipe sections:

- Initial shallow-gradient section, extraction point to settling tank (40 m approximately):
  - 160 mm OD pipe (black PE100 pipe, SDR 17 (10 bar) e.g. http://www.gpsuk.com/range/44/excel-pe100-pipe-black.html , 141 mm bore)
  - This will be sleeved with 225 mm bore/265 mm OD twinwall (e.g. https://store.jdpipes.co.uk/225mm-unperf-twinwall-6m/). Closed-cell foam to be injected into the annular gap between the two (through small holes drilled in the twin-wall pipe, on site after cutting to length) to reduce risk of freezing since this section cannot be properly buried.
  - In-stream section to be strapped and rock bolted to the rock wall to resist both weight (low stream level) and buoyancy forces (high stream level).

    - Wrapped with hessian to encourage growth of vegetation.
    - Flexible couplings at each end (to Coanda screen, to settling tank) at accommodate thermal expansion.
- Next 600 m stretch will be 110 mm OD black PE100 pipe, 10 bar SDR 17 (97 mm bore). Butt welded as above. Tee-joint beside house with pipe into bathroom.
- Final 230 m will nominally be 110 mm OD 16 bar pipe SDR 11 (90 mm bore). This should be sufficient for a 100 year life. If however 20 bar (SDR 9) pipe can be sourced the last 60 m will use 125 mm OD SDR 9 (102.3 mm bore) to obtain even longer life.

Penstock route.

Dafydd Roberts has commented that he would expect the penstock to be as high as possible over the section from SC2 to the turbine hut to avoid the flush area. The route can certainly be adjusted to pass through dry ground wherever possible. Since the ground slopes steeply upwards on the road side, it seems better to keep the route closer to the gorges (Afon y Foel). The ground above the gorges is better drained than the area further towards the road.

Cable conduit

Two sections of 65 mm conduit (https://www.tlc-direct.co.uk/Products/FXKVR63.html) will be buried alongside the pipe:

- one from the electronics cabinet (see below) to the cottage outhouse, containing optical fibre and 4 mm^2 SWA cable e.g. https://www.tlc-direct.co.uk/Products/SW4slash2.html (240V ac from house to sensors at the extraction point; TT-earthed system with earth rod beside cabinet and RCD protection).
- one from the cottage outhouse down to the turbine hut containing optical fibre and 16 mm^2 SWA cable eg https://www.tlc-direct.co.uk/Products/SW16slash2.html . This cable will carry the rectified output from the alternators (400-500 VDC depending on final choice of alternator and turbine rpm).

The optical fibre will carry control signals and data between the extraction point (water levels), house (power requirement) and turbine hut. The control software in the turbine hut and the cottage will continuously monitor the connection and fall-back to an intrinsically safe mode of operation if communications are interrupted.

Turbine hut details

Turbine hut location

The proposed turbine hut position has been chosen to minimise the penstock length: it is the earliest location where water can conveniently be returned to Afon y Foel at the bottom of the slope.

It is also largely hidden when viewed from the road above (though the recent tree-felling means it is now visible to drivers coming up the hill). Security is a concern (Hafod y Rhedrwydd had its slate roof stolen shortly before we bought it in 1999 and the outhouse roof was stolen a few years later) so it seems sensible for the turbine hut to not attract attention.

Regarding Dafydd Roberts comment about the turbine hut being in the toe of an M6 flush, it would be perfectly possible for the hut to be sited approximately 20 m North of this position i.e. on the grassland the other side of the tributary running down from the road. I would be happy with this and in some respects (damp-proof courses etc) it would be easier.

I did not suggest this initially because the hut would then not back onto the slope and would be more visually intrusive. Given the traditional stone walls and the turf roof the appearance may however be acceptable if situated in the grassland area.

I had thought that the boundary marked on OS maps along the line of the tributary was a National Park boundary and that there would be advantages in dealing with just one Planning Authority. Closer examination shows an oak leaf marker on the map indicating an NT boundary rather than a park boundary. It appears however from the NT ownership website that the map is incorrect and the NT own the land on both sides.

Operation and control

To allow efficient operation at very low flows and ease maintenance there will be two turbines and alternators, one set larger than the other. They can run individually or together.

The turbine runners will be obtained from Hartvigsen Hydro (Figure 18).

Figure 18. Typical stainless steel Turgo runner.

The alternators will be 3-phase permanent magnet devices made by MOOG, models GES013-V2 (dry conditions) and GES013-V4, 6 or 8 (main turbine depending on rpm, see below).

When ordering Turgo runnners the number of “spoons” must be specified. This sets the pitch-circle diameter and hence the optimum efficiency rpm. The combination of alternator model and number of spoons will be chosen so that the dry weather and main generating sets both produce the same voltage at their optimum operating point.

[Comment: I was initially expecting to use the GES013–V2 and –V4 alternators (dry and main respectively) but Hartvigsen Hydro have just had a cancelled order and are offering me a stainless Turgo runner at a very favourable price. This is slightly larger (lower rpm) than originally intended. If I take this it will require the –V6 or V8 alternator for the main set].

Figure 19 shows the communication and control system with fibre-optic links passing data between the extraction point, cottage and turbine hut. When increased power is needed in the cottage the system will decide whether enough water is available to generate that power level (based on the stream level sensor). If so, the spear valve(s) will open to supply more water to the turbine(s). If this is not possible, short-term loads will be met from a small battery bank; long-term loads however (electric radiators) will only be connected if sufficient power is available. Similarly when the power requirement falls the spear valves will close to reduce the turbine flow rate.

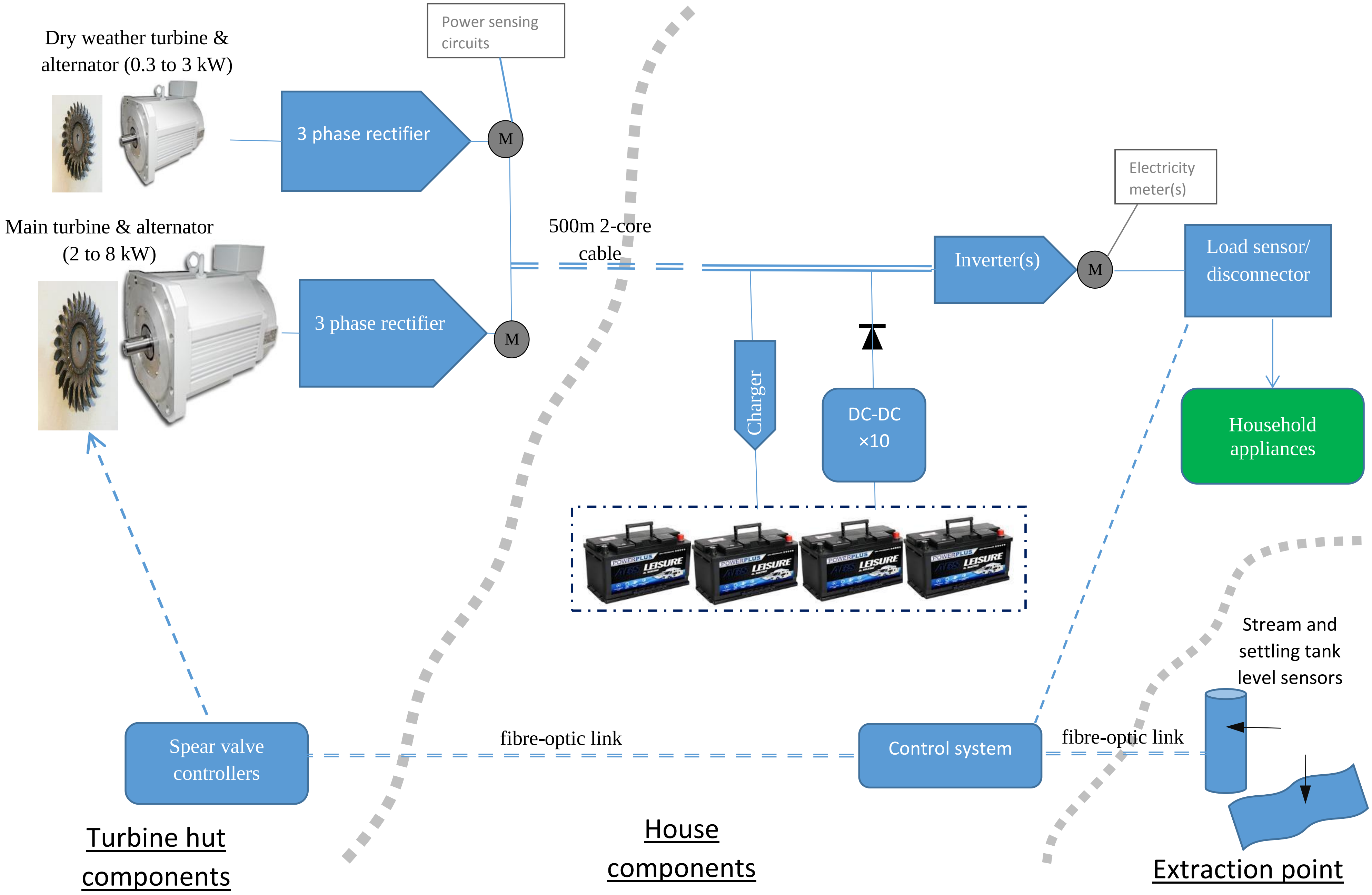

Figure 19. Schematic diagram of the turbine control system.

Tailrace details

Figure 20. Tailrace will be cut into the stream bank (bedrock) as a channel with slate covering plates (900*600*20 mm), then recovered with soil and turf (not shown). Channel cross-section 360 mm * 150 mm. Water then flows down the bank like any other tributary joining Afon y Foel from the side.

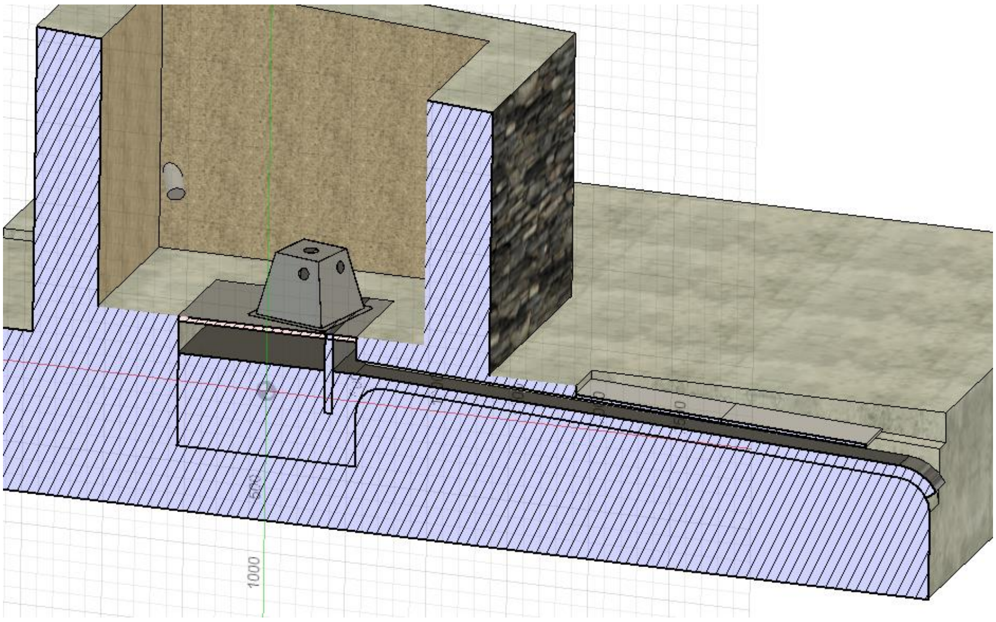

Figure 21. Cross section (approximately to scale). A sound baffle dips into the sump so that water can come out via the tailrace but not noise. The turbine housings sit on a sump cover plate above the sump. The sump will have a waterproof and insulating lining (not shown).

Figure 22. Approximate tailrace discharge position.

Access routes and pipe burial.

Burial methodology

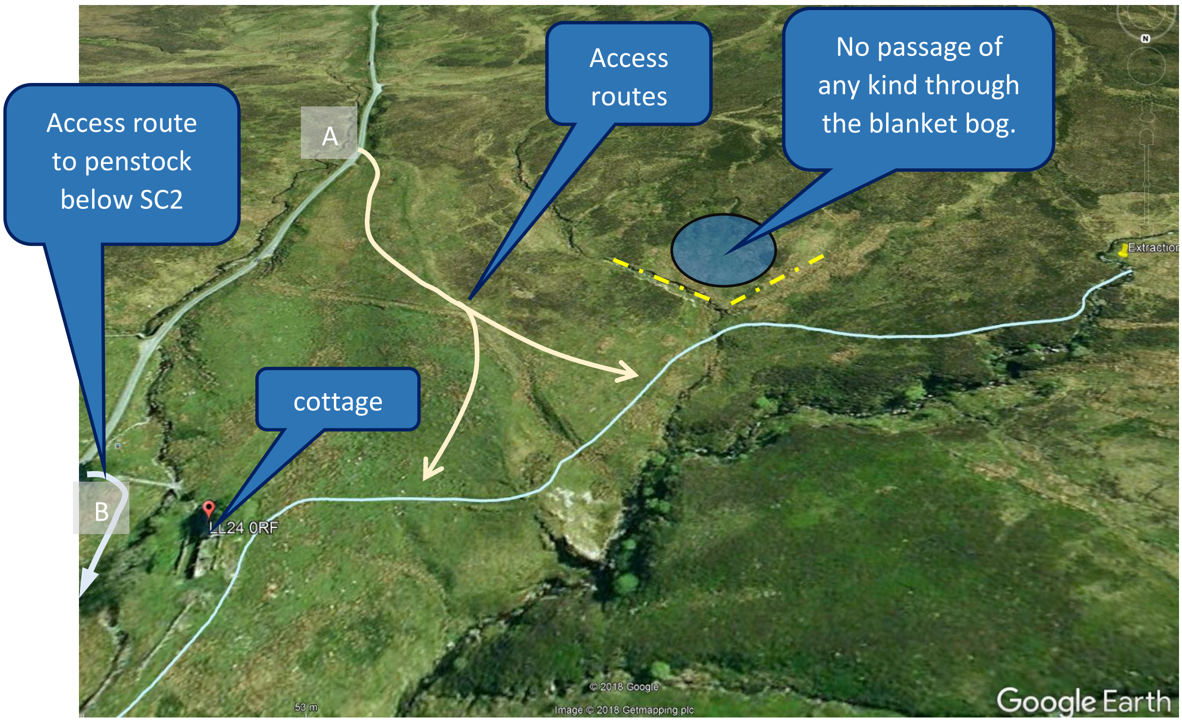

Figure 23. Machinery (mini-digger, power barrow) access route to upper section.

Figure 23 shows the proposed access routes to the top of the site. There is an existing exit from the road at point A that has been used by the farmer when he used to mow this area, Fig. 24. Ground works would be carried out in dry weather when the ground is hard to minimise any wheel marks or other damage to the terrain.

This route would follow the hard ground along the top of the ridge and has been chosen to pass below the two streams (yellow dashed lines in Fig. 23) that drain the nearby blanket bog – there will be no impact at all on this bog.

Access to the pipe route below stream crossing 2 would be from the roadside at point B in Figure 23. This is the Hafod y Rhedrwydd parking area.

Figure 24. Google Earth image 31/12/2006 showing mown areas above cottage and access point from road.

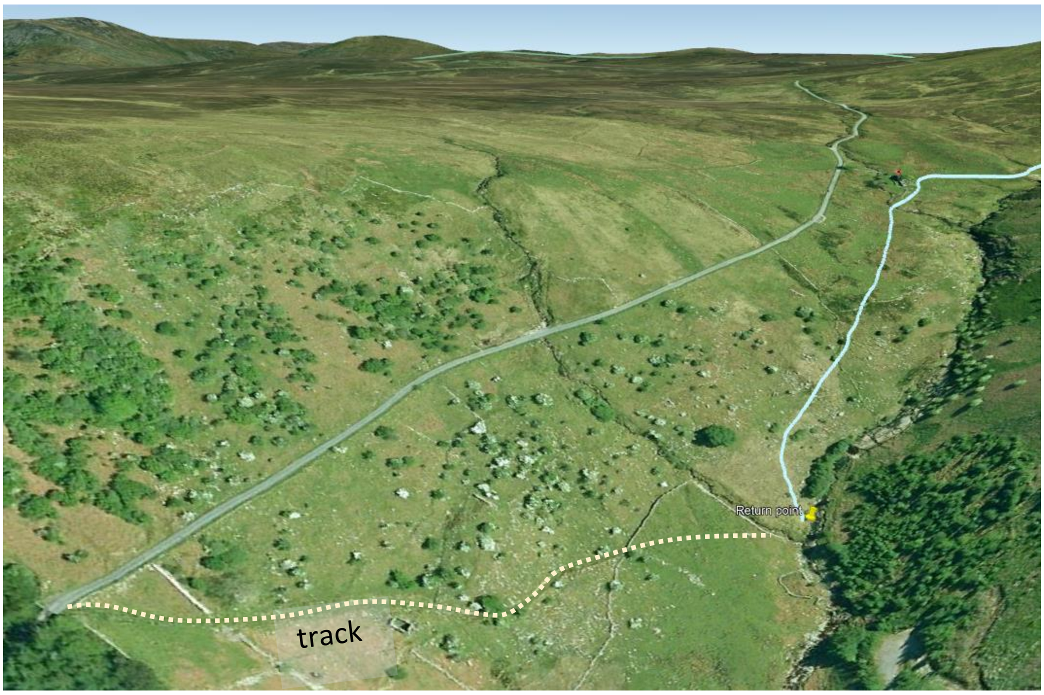

Figure 25. Access track to turbine hut location.

The trench for pipe burial will be no larger than necessary to accommodate the pipe and conduit.. Where possible, the top of the pipe will be 200 mm below the surface (i.e. a trench 20 cm wide for pipe and conduit side by side × 30 cm deep). A sheet of Terram geotextile will be laid beside the trench to separate excavated soil from the grass so that it be cleanly returned to the trench later. Turf, top soil and sub soil will each be laid out separately beside the trench to facilitate the back-filling process and ensure rapid regrowth of vegetation.

It is proposed to use a 1.5-2 ton class mini-digger to make the trench because such a small trench does not require machinery any larger than this. A machine such as https://www.shellplant.co.uk/KX018-4_Mini_Excavator.html would be a suitable size (the track width of 1.3 m gives better stability on uneven ground than very small machines that are designed to fit through doorways). The farmer has suggested that his son who has a mini-digger might be very happy to do the digging.

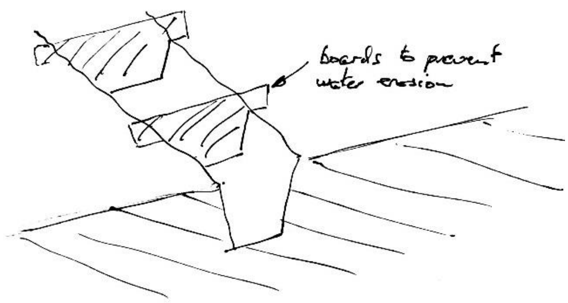

Figure 26. To avoid water erosion during construction, digging will be done in dry weather (as far as possible). If there is any risk of rain, sloping sections will have boards hammered into the trench to impede water flow and prevent erosion.

When backfilling the trench, clay bands will be packed around the pipe at 30 m intervals. These will prevent water from running downhill around the pipe and causing underground erosion. The glacial till seen in Figure 27 appears suitable for this purpose.

Figure 27. (Fig. 38 from geomorphology survey). Sheep scrape showing soil characteristics.

Alternatives to burial

It has been suggested that all or part of the penstock could be covered over rather than buried thereby minimising any risk of damage to the peat and avoiding potential problems with rainwater running down the trench. (NRW: “To limit damage to the site the pipe may need to be installed on the surface and covered rather than buried”). This would be entirely possible but would involve more traffic to fetch covering materials (slate chippings, perhaps) from the road access points; the advantage of in-situ burial is that it avoids this traffic.

The pipe could either be laid flat on the surface (Fig 28(a)) or recessed flush with the surface (Fig. 28(b)). The latter would be easier to cover and less visible afterwards. In either case a thin layer of insulation (25 mm Kingspan) immediately above the pipe would be desirable to protect against freezing; the alternative would be to use a greater depth of chippings.

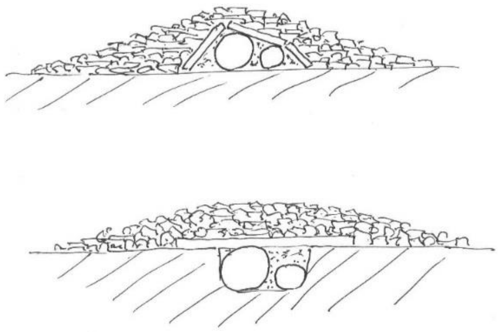

Figure 28. Pipe covered with chippings. (a) Pipe sitting on ground surface (covered area 1.2 m wide by 0.2 m high), (b) pipe flush with ground (covered area 1 m wide by 0.1 m high).

To cover the entire penstock route to 10 cm depth (roughly to scale in Fig. 28) would require approximately 75 m^3 chippings (28a) or 45 m^3 (28b). It would be sensible to use a larger capacity dumper eg https://www.cwplant.co.uk/shop/1-2-tonne-tracked-swivel-dumper/ (instead of a little 4-wheel drive dumper http://www.altrad-belle.com/?p=products&id=3 as originally planned) to minimise the number of journeys if shifting this volume of material.

If adopting this method the road access point in Figure 23 would only be used for the upper half of the site. Materials for the lower half would be dropped beside the road at Hafod y Rhedrwydd itself: this would reduce the distance over which chippings had to be carried.

The track down to the turbine hut is an alternative delivery route but the gradient of up to 1 in 3.2 could make it tedious if carrying significant quantities of materials. There is also more space by the roadside to accept material deliveries near Hafod y Rhedrwydd (hard ground beside Pont Elen, 50 m up from the cottage) than down by the turbine hut track.

To avoid any risk of damage to the slate footbridge at Hafod y Rhedrwydd we have never allowed vehicles to pass over it. Ramps (https://www.therampppeople.co.uk/vehicle-ramps/profile-height-up-to-80mm/trp80-series) would be hired to span the bridge so that the weight of a mini-digger or power barrow would be supported by the ground each side. A dumper carrying chippings to cover the pipe section immediately behind the cottage could then cross the stream at this point without risk of damage to the slate bridge.

Ecological protection

In accordance with the recommendations in the ecological survey, vegetation along the pipe route will be cut back using a brush-cutter to deter ground-nesting birds from building nests that might later be disturbed. This will be done before the nesting season starts in April each year.

Construction order

- Extraction system
- Settling tank
- Stream crossing 1
- Stream crossing 2
- Pipe & conduit access to cottage

- Pipe burial over the volcanic sill (halfway between crossing 1 and the cottage)
- Burial of top 380 m of pipe and conduit. For security reasons, each cable and conduit assembly will need to be put in place and buried (or covered) in one operation within the space of a few days. The cable and optical fibre are each one continuous length. 50m sections of conduit will be threaded over them and tied together using conduit clamps immediately prior to burial.
- Turbine hut
- Burial of final 460 m of pipe and conduit

I have spoken to RW Masonry about building the turbine hut and the choice of materials for it. I am expecting local micro-hydro companies (Hydrover Turbine Services and/or Nick Bard) to assist with the other work - particularly the pipe welding and conduit burial.

All works to be completed by March 2021 in time for commissioning and ROOFIT accreditation for the Feed-In Tariff.

RWM

30/1/19