Introduction to micro and small hydropower

This document tries to explain all of the essential issues you should know about if considering developing a micro hydropower or small hydropower system. Just a quick mention of terminology; micro hydro refers to hydropower systems up to 100 kW power output, and small hydro to systems up to 10 MW output.

Micro and small hydropower builds run-of-river hydropower systems, not storage hydropower systems. The key difference is that run-of-river hydro uses the water that is available in the watercourse at any instant rather than storing it behind a dam for use later. Run-of-river hydro has no way of storing water, so it makes use of hydro turbines that can operate on wide flow ranges so that they can efficiently generate energy on high or low flows, whatever is in the watercourse at the time.

The rest of this page describes in detail all of the factors you need to consider if you are thinking of developing a small hydropower or micro hydropower site. It starts with the fundamentals of head and flow, then describes how the flow characteristics of a site determine the best type of hydropower system, and then how much energyand revenue a small hydropower or micro hydropower site could generate and what it would cost.

Contents

What is head?

Hydropower all comes down to head and flow. The amount of power, and therefore energy that you can generate is proportional to the head and the flow.

Head is the change in water levels between the hydro intake and the hydro discharge point. It is a vertical height measured in metres. The two diagrams show how the head would be measured on a typical low head and a typical high head site. The more head you have the higher the water pressure across the hydro turbine and the more power it will generate. Higher heads are not only better because they generate more power, but also because the higher water pressure means you can force a higher flow rate through a smaller turbine, and because turbine cost is closely related to physical size, higher-head turbines often cost less than their low- head cousins even though they might generate the same power. Getting a bit technical now, but higher head also means a faster rotating turbine and generator, which means lower torque. The cost of drive train is closely related to how much torque it has to transmit, so higher heads = less torque = less cost.

Of course you only have what you have so if your site only has 2 metres of head you won not be able to increase this significantly. However, even small increases in head can make a difference. Sometimes it is possible to clear silt or re-grade a tailrace or discharge channel to lower the downstream water levels slightly which increases the overall head at the site. Or it may be possible to raise the water level on the upstream side by raising weir crests or sluices, though this must be done carefully to avoid increasing flood risk, and sometimes requires the construction of new spillways or installation of fail-safe tilting weirs toensure that flood risk is not increased during extreme flood events.

Generally speaking the cost of even small increases in head at low-head sites is repaid hundreds of times over from increased energy production for the next few decades, so is always worth the effort.

What is flow?

The flow rate and how it varies over a year is the next and equally important parameter. The simplest way to characterise the flow in a watercourse is to work out what the long-term annual mean flow is. This is important because it is the overall average flow in a watercourse that is important; it doesn't matter if it is a raging torrent after heavy rains (all watercourses are…) because in the big scheme of things we only have really heavy rains for a few days or weeks a year, and for the other 50 weeks when it is lightly raining, drizzling or bright summer sunshine you would still want you hydro system to be working and generating energy.

The fundamental piece of information that characterises the flow in a watercourse is the flow duration curve. Although simple once you understand them, they are quite complicated to newcomers. Figure 1 below shows the long-term flow duration curve of a small river in Somerset.

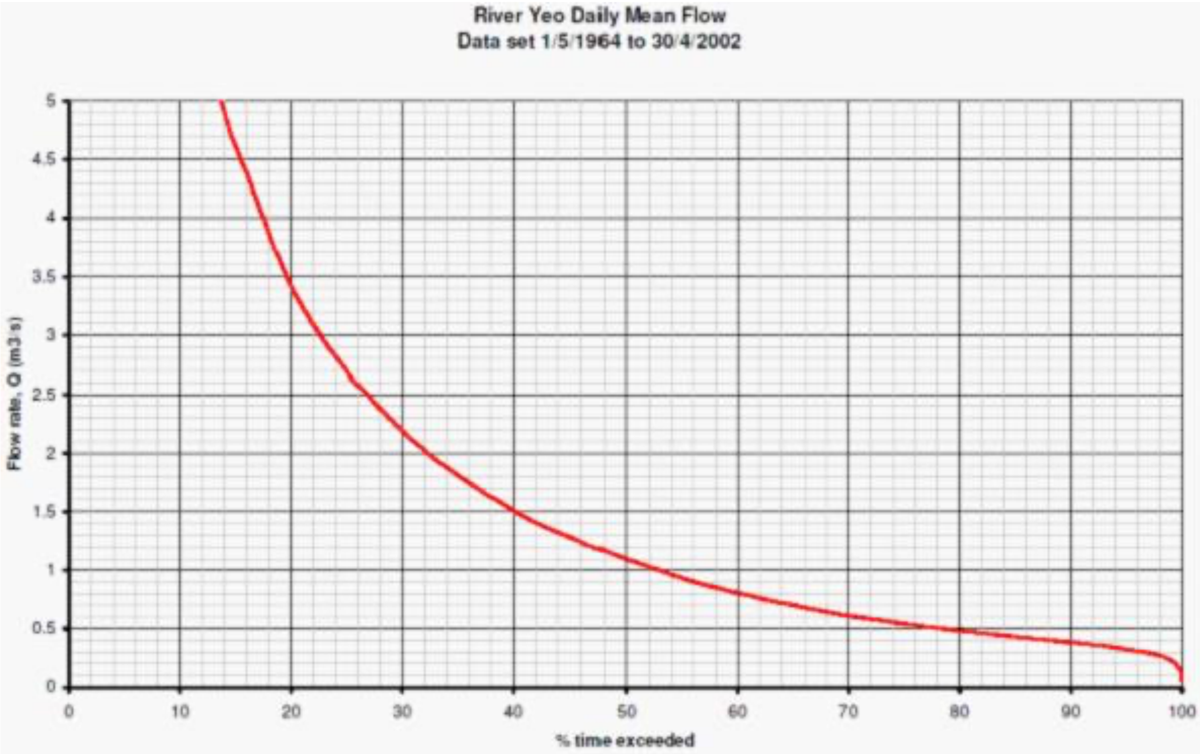

Figure 1 – Long-term flow duration curve for the River Yeo in Somerset.

The y-axis is the flow rate in cubic metre per second (m^3 /s), or sometime in litres per second (l/s) for smaller watercourses. When the flow duration curve is constructed all of the flow rate data is sorted into descending order, then the highest flow rates are plotted on the left of the curve, then progressively lower flow rates to the right until the very lowest flow is plotted at the extreme left-hand end. The x-axis is the percentage exceedence. This is normally the difficult part to understand. For a given percentage exceedence it shows the flow rate equalled or exceeded for that percentage of time. For example, if you look at the 50% percentage exceedence on Figure 1 and read off the flow rate at that point you will seethat it is 1.1 m^3 /s. This does not mean that the flow rate in the watercourse is 1.1 m^3 /s for 50% of the year,it means that the flow rate is 1.1 m^3 /s or more for 50% of the year. The or more is important because it is clear from the shape of the curve that apart from the instant that the line crosses the 50% mark it isalways more than 1.1 m^3 /s.The x-axis is always plotted as a percentage exceedence from 0 to 100%. This is so that any data set spanning any interval can be plotted. The data set may span 10 days or more likely several decades of data from a local river gauging station.

Generally speaking flow duration curves present long-term annual data, so the flow rates read off them are the annual flow characteristics. The percentage exceedences are often called Q values, so Q95 is the flow rate exceeded for 95% of a year and Q10 the flow exceeded for 10% of the year. The data set can also be analysed using a spreadsheet to work out the average (arithmetic mean) of all of the flows, and this is called Qmean. In the UK the Q mean is normally somewhere between Q25 and Q30, and in the case of Figure 1 is Q26.5. Once you understand how a flow duration curve is constructed it can tell you a great deal about the flow characteristics of the water course. Firstly you can work out the Q mean, which is the average flow, and often if you are negotiating with the environmental regulator you will be discussing the Q95 flow, as this is often used as the representative low flow that must always flow in any depleted stretches of river while the main volume of water passes through the hydro turbine.By comparing different Qvalues you can see how flashy a watercourse is, or whether it has a high3 baseflow. The flow duration curve in Figure 1 has a Qmean of 2.54 m /s and a Q95 of 0.32 m /s, so the Q95is 8% of the Qmean. This is typical for a flashy river that rises and falls quickly in response to rainbecause the rain runs straight of the land and into the river without getting stored in bogs or porous rocks before flowing into the river sometime later.If you make the same comparison using Figure 2, you will see that the Q is 11.30 m^3 /s and the Q5.83 m^3 /s. In this case Qis 52% of the Qmean. This would be a high base flow river, typical of the rivers that flow in Hampshire with chalk catchments where the chalk stores the rain in its porous structure andthen releases it to the rivers slowly and over a long period of time, rather like a sponge. It is also interesting to note that Qmean is at Q41; much lower on the flow duration curve than a flashy river like in Figure 1.

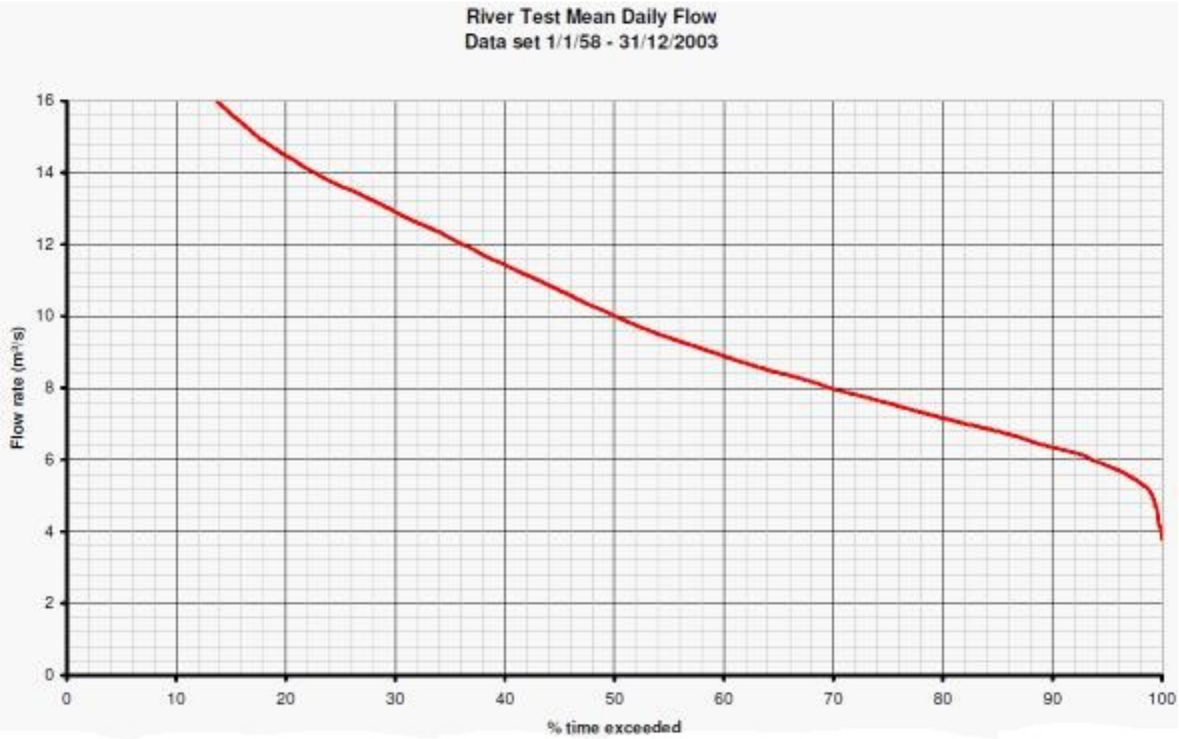

Figure 2 - Long-term flow duration curve for the River Test in Hampshire.

In both flow duration curves you can see that the red line is heading steeply upwards at the left-hand end of the graph. This is the ‘extreme flow’ region, which is not much use for energy generation because such extreme flows occur for a relatively small proportion of the year, but they are very important when designing a hydropower systems to ensure that the hydro structures and turbine house don’t get flooded, or even worse, washed away during the next major storm!

What is the minimum head and flow rate required?

The answer to this depends very much on what return on your investment you want. For a commercially viable site it would normally need to be at least 25 kW maximum power output. For a low-head micro hydropower system you would need at least 2 metres of gross head and an average flow rate of 2.07m^3 /s. To put this in context this would be a small river that was approximately 7 metres wide and around1 metre deep in the middle.

For a site with 25 metres head a much lower average flow rate of 166 litres/second would be needed. This would be a large stream of 2-3 metres width and around 400 mm deep in the middle.

It is technically possible to develop smaller hydropower sites with lower power outputs, but the economics start to get challenging. This is particularly true for low-head sites; when the head drops to 1.5 metres it isn't normally possible to get any kind of return on investment, though the site could still be technically developed using Archimedean screws or modern waterwheels.

The table below shows the average flow rates needed for a range of heads from 2 metres to 100 metres for system 25, 10 and 5 kW maximum power outputs. 25 kW would normally be considered the minimum for a commercial project, though a 10 kW system can still produce an acceptable return if the civil engineering works are simple (hence don't cost much). 5 kW systems are not normally viable, but the figures are shown for interest and may be useful for sites that can generate value from non-tangible benefits such as attracting visitors or positive publicity.

	Low-head hydropower sites			**High-head hydropower sites**		
Hydro Max.Power	**Gross Head 2 metres**	**Gross Head 5 metres**	**Gross Head 10 metres**	**Gross Head 25 metres**	**Gross Head 50 metres**	**Gross Head 100 metres**
5 kW	0.414 m^3/s	0.166 m^3/s	0.083 m^3/s	0.033 m^3/s	0.017 m^3/s	0.008 m^3/s
10 kW	0.828 m^3/s	0.331 m^3/s	0.166 m^3/s	0.066 m^3/s	0.033 m^3/s	0.017 m^3/s
25 kW	2.070 m^3/s	0.828 m^3/s	0.414 m^3/s	0.166 m^3/s	0.083 m^3/s	0.041 m^3/s

Table 1 – Minimum flow rates required for a range of (gross) heads.

How does micro hydro and small hydropower work?

There are lots of different types of hydropower turbines that will work on different combinations of head and flow. Fundamentally they all work on the same principle by converting the pressure in a head of water into rotary mechanical power, and then use a generator to turn the mechanical power into electricity.

The an typical micro hydro system with the main system parts identified. Working from the upstream-side and working downstream, the first thing the water flows into is the intake. The intake always has a screen which has two important purposes, firstly to prevent debris from entering the hydro system that could block and/or damage the hydro system and secondly to prevent fish from entering the system which could cause them injury.

Once the water has passed through the intake screen it flows through the penstock pipe to the turbine. The penstock is a pressure-pipe, which means that it is 100% full of water and as it moves downwards the water pressure inside the pipe increases as the head increases.

At the end of the penstock pipe is the turbine which has a rotor to turn the high-pressure water into rotational mechanical energy that can be usefully used by humans. The turbine discharges the water at the lowest possible level to maximise the head across the system, and normally uses a 'draft tube' to do this.

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The draft tube a clever device that is full of water, and much like you have to reduce the air pressure inside your mouth to suck water up a straw, by having a column of water inside a draft tube that always wants to fall downwards because of gravity, it creates a negative pressure underneath the turbine. This is called ‘suction head’ because it is a negative pressure, whereas the pressure in the penstock is positive and called ‘pressure head’. Draft tubes don’t mean you can get more head from a site, but they do allow you to physically locate the turbine up above the downstream water level, which can make it much easier to construct and maintain because it won’t be in such a wet environment.

The mechanical rotational energy produced by the hydro turbine is not much use to people nowadays, but historically would have been used directly to power mill stones to grind flour or looms to make cloth. Nowadays we want electricity, so normally the low-speed, high-torque mechanical power from the turbine is changed to high-speed, low-torque power by increasing the speed using a belt-drive or a gearbox.

The high-speed low-torque power is then supplied to a generator which converts the mechanical power from the turbine into useful electricity that we can all use. Depending on how the system is configured, the electricity could be used on-site instead of importing electricity from the grid, or it could be exported and sold to the grid, or often a combination of the two.

How much hydropower could I generate?

As mentioned before, this comes down to how much head and how much flow. If you don’t like equations scroll down a bit, but for those that don’t mind equations the easiest way to explain this is to look at the equation for calculating hydro power:

P = m x g x Hnet x System efficiency
Where:
• P = Power, measured in Watts (W).
• m = Mass, flow rate in kg/s (numerically same as in l/s because 1 litre weighs 1 kg).
• g = the gravitational constant, which is 9.81 m/s2.
• Hnet = the net head. This is the gross head physically measured at the site, less any head losses. To keep things simple head losses can be assumed to be 10%, so Hnet is the gross head x 90%.
• System efficiency = the product of all of the component efficiencies, which are normally the turbine, drive system and generator. For a ‘typical’ small hydro system the turbine efficiency would be 80%, drive efficiency 95% and generator efficiency 90%, so the overall system efficiency would be 0.80 x 0.95 x 0.90 = 0.684 or 68.4%.

Therefore, if you had a relatively low gross head of 2.5 metres, and a turbine that could take a maximum flow rate of 3 m^3 /s, the maximum power output of the system would be:

First convert the gross head into the net head by multiplying it by 0.9, so Hnet = 2.5 x 0.9 = 2.25 metres.

Then convert the flow rate in m^3 /s into litres/second by multiplying it by 1000, so 3 m^3 /s=3,000 litres/second. Remember that 1 litre of water weighs 1 kg, so ‘m’ is the same numerically as the flow rate in litres/second, in this case 3,000 kg/s. Now you are ready to calculate the power:

Power (W) = m x g x Hnet x System efficiency
= 3,000 x 9.81 x 2.25 x 0.684= 45,293 Watts or 45.3 kW

Now, do the same for a high-head hydropower site where the gross head is 50 metres and maximum flow rate through the turbine 150 litres / second. In this case Hnet = 50 x 0.9 = 45 metres and the flow rate in litres / second is 150, hence:

Power (W) = m x g x Hnet x System efficiency
= 150 x 9.81 x 45 x 0.684= 45,293 Watts or 45.3 kW

What is interesting here is that for two entirely different sites, one with a net head of 2.25 metres and the other 45 metres, can generate exactly the same amount of power because the low-head site has much more flow (3,000 litres / second) compared to the high-head site with just 150 litres/second.

This clearly shows how the two main variables when calculating power output from a hydropower system are the head and the flow, and the power output is proportional to the head multiplied by the flow.

Of course the two systems in the example above would be physically very different. The low head site would need a physically large Kaplan turbine inside a turbine house the size of a large garage because it would have to physically large to discharge a large volume of water with a relatively low pressure (head) across it. The high-head site would only need a small Pelton turbine the size of an under-counter fridge because it only has to discharge 5% of the flow rate of the low-head system and under a much higher pressure.

It is interesting that in the 'real world' the example above isn't too far from reality, because high-head sites tend to be at the heads of rivers in upland areas, so the ground slopes steeply enabling high heads to be created, but the rainfall catchment of the watercourse is relatively small, so the flow rate is small.

That same upland stream 20 km downstream would have merged with countless small tributaries and formed into a much larger river with a high flow rate, but the area would now be lowland agricultural with only a modest gradient. It would only be possible to have a low head across a weir to avoid risking flooding the surrounding land, but the flow rate in the lowland river would be much larger to compensate.

The UK has a range of all types of high, medium and low head hydropower sites. England has more low- head sites, Scotland more high-head, and Wales a mixture of everything but still with significant medium and high-head opportunities.

How large should a hydro turbine be?

Ideally a hydro turbine should be 'sized' to generate the maximum amount of energy from the available flow at the site. If you look at the flow duration curve in Figure 1, essentially the area underneath the red line is proportional to the amount of energy that a hydro system could generate. However there are a few caveats.

Firstly, even though good quality turbines can operate over a range of flow rates from maximum down to around one-sixth of maximum, it would be impossible to have a turbine that could operate on all flows from the very highest extreme flows (on the far left of the flow duration curve) all of the way down to the very lowest summer draught flows at the far right. In reality a turbine that has a maximum flow rate just above the annual average flow rate, so about Q25 on the flow duration curve will operate on lower flows down to around Q90, and such a turbine could be shown to generate the most energy from the site.

The second biggest factor is the 'hands-off flow (HOF)' that the environmental regulator requires to flow in any depleted river channels while the main flow is diverted through the hydropower system. HOFs are (quite rightly) left in any depleted channel 24/7 to maintain the river ecology, so they are effectively a volume of water removed across the whole width of the flow duration curve, as shown in Figure 3. The HOF might be a relatively small flow rate, but because it must be maintained at all times, it represents a significant volume of water that isn't available for energy production. This is why the negotiation of an appropriate HOF with the environmental regulator is often a contentious issue; the regulator will want a higher HOF to maintain the ecology in the depleted reach, while the hydro developer will want to minimise it so the hydro system generates more renewable energy, and therefore revenue. Normally a sensible compromise is arrived at.

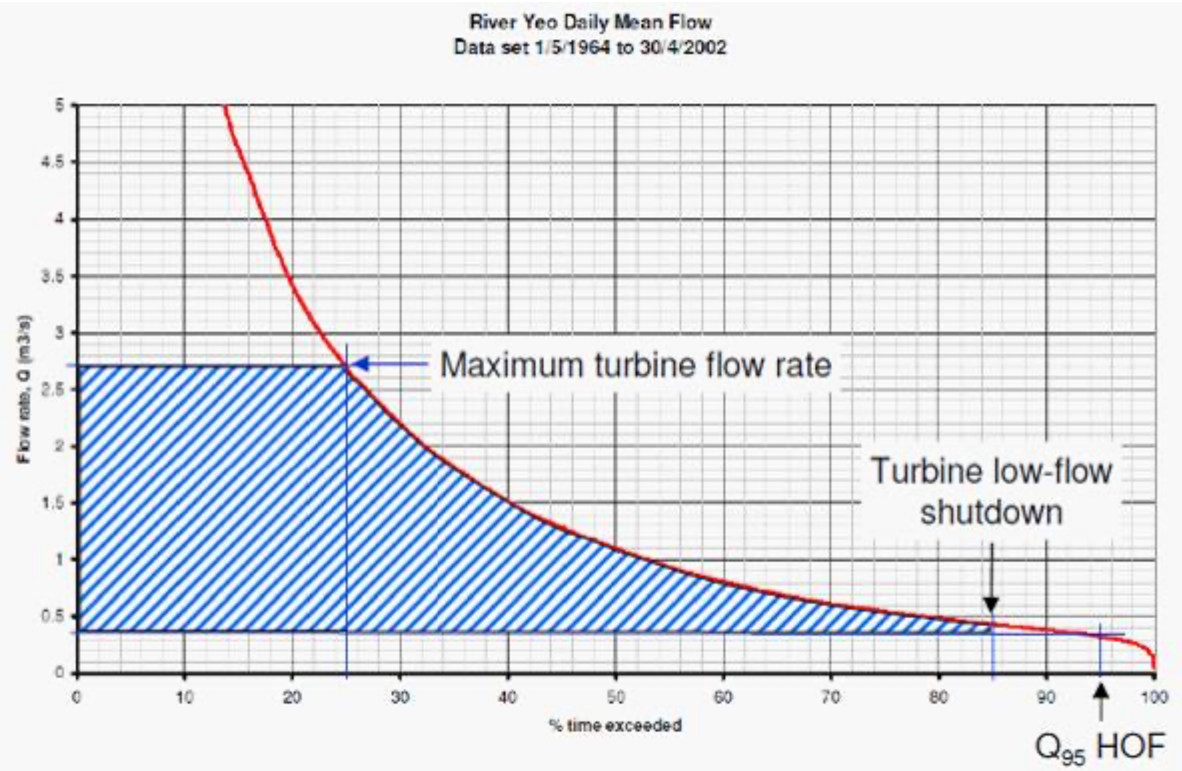


Figure 3 – Hydro turbine operating flow regime shown on the site flow duration curve.

Figure 3 also shows the maximum flow rate of the hydro turbine at Q25, and then the horizontal line to the left of this point represents the maximum flow through the hydro turbine, even though the flow rate in the river is ever increasing as you move left on the flow duration curve; it is still only possible to get the turbine's maximum flow rate through the turbine. In the real world the flow rate actually reduces at very high flow rates and sometimes reduces to zero as the downstream water level 'backs up' and the head across the hydro system reduces.

Looking to the right of Q25, the flow rate through the turbine reduces in line with the flow available in the river, until at very low flow rates the power output from the hydro system has reduced so much that the hydro system automatically shuts downs and waits for it to rain and the flow rate in the watercourse to increase. Therefore the energy generated by the hydro system is proportional to the area shaded blue in Figure 3. Good hydropower design is all about making the proportion of blue shading compared to the total area under the flow duration curve as high as possible, because this ensures maximum energy production.

In summary, a good quality hydro turbine that has a wide operating flow range, on a river that had a Q95 HOF requirement, would have a maximum flow rate around Q_{mean} x 1.2 .

How much energy would a hydro system generate?

Energy is everything; you can sell energy, but you can't sell power (at least not in the context of small hydropower). People often get obsessed with wanting the highest possible power output from a hydro system, but this is really quite irrelevant. When you sell electricity you are paid depending on the number of kWh (kilowatt-hours) you sell (i.e. based on the energy) and not for the power you produce. Energy is the capacity to do work, while power is the rate at which work can be done. It is a bit like miles and miles-per-hour; the two are clearly related, but are fundamentally different.

If your aim is to maximise how much money a hydropower system can make, then you must maximise the amount of energy it produces. As described above under 'how large should my hydro turbine be?', it would be possible to oversize the maximum flow rate through a turbine to get a higher maximum power output, but because it only has a finite operating flow range an oversized turbine would shut down at a 'higher low-flow'. The aim is to maximise the blue shaded area under the flow duration curve as shown in Figure 3 above. For each site, once all of that site's peculiarities have been considered and the HOF agreed with the environmental regulator, there will be a single optimum turbine choice that will make best use of the water resource available and result in the maximum energy production. Maximising energy production within the project budget available is really the key skill of a hydropower engineer.

To estimate how much energy a hydropower system produces accurately needs specialist software, but you can get a good approximation by using a 'capacity factor'. A capacity factor is basically the amount of energy produced by a hydro system divided by the theoretical maximum. To see it graphically look at Figure3. The area shaded blue represents the amount of energy produced by the hydropower system, and the total area under the red flow duration curve represents the theoretical maximum amount of energy that could be generated if the hydro system could accept all flows from Q0 to Q100. If the smaller blue-shade area is divided by the larger area under the red curve, the resulting number would be the capacity factor.

For a good quality turbine with a wide operating flow range, with a maximum flow rate of Qmean x 1.2 and a HOF of Q95, it can be shown that the capacity factor would be approximately 0.5. Assuming you know the maximum power output from the hydro system the annual energy production from the system can be calculated from:

Annual Energy Production (kWh) = Maximum power output (kW) x No. hours in a year x capacity factor. Note that there are 8,760 hours in a (non leap) year.

As an example, for the low-head and high-head example sites above, both of which had maximum power outputs of 45.3 kW, the Annual Energy Production (AEP) would be:

AEP = 45.3 x 8,760 x 0.5=198,414 kWh

The AEP for a range of hydropower systems with different maximum power outputs, all based on a typical UK capacity factor of 0.5 are shown in Table 2 below. It is interesting to note that an 'average' UK home uses 12 kWh of electricity every day, or 4,368 kWh per year. Hence the number of 'average UK homes powered' is also shown.

Hydro Max. Power	AEP	No. homes powered
5 kW	21,900 kWh	5
25 kW	109,500 kWh	25
50 kW	219,000 kWh	50
100 kW	438,000 kWh	100
250 kW	1,095 MWh	250

Table 2 – Annual energy generation for a range of micro hydro and small hydro systems.

How much money could I earn?

This is slightly complicated, but we will try to explain. There are up to five components that make up the total value of hydro electricity generated, namely:

- Feed-in Tariff (also known as the FiT or Clean Energy Cashback);
- Export value; Offset value for energy used on-site;
- Renewables Levy Exemption Certificates (Renewables LECs);
- Renewable Energy Guarantee of Origin certificates (REGOs)

If you don not want to read about the details of what makes up the total value, look at below table;Summary of potential revenue from hydropower systems; on page 12.

Feed-in Tariff.

By far the largest component of the value is the Feed-in Tariff. This is paid for every kilowatt-hour (kWh) of electricity generated regardless of whether it is consumed on-site or exported. The amount paid under the Feed-in Tariff is banded for different sizes of hydropower system so that smaller systems which normally cost proportionately more to implement are not penalised. The Feed-in Tariffs applicable for hydropower projects are:

Hydro system size	Feed-in Tariff
Up to 15 kW	19.9 p/kWh
15 kW - 100 kW	17.8 p/kWh
100 kW - 2 MW	11 p/kWh
2 MW - 5 MW	4.5 p/kWh

Notes:

- For turbines that sit on a tariff threshold, the higher tariff will apply.
- Once a hydro system is registered for the Feed-in Tariff it is locked into that tariff for 20 years. In addition the tariff will be index-linked to RPI, so its value in real terms will not be eroded by inflation.

The export value and the offset value are a slightly more difficult to explain because depending on the site either one may apply or both. For clarity we'll explain each individually first, then what happens when both apply.

Export value

This is payable for every kWh of electricity exported, and the value can vary between the guaranteed minimum amount of 3 p/kWh under the Feed-in Tariff, or the 'market rate' which is currently closer to 5 p/kWh. Exported means that it must pass outwards into the local electricity distribution network (what most people call 'the grid') through an export meter. An export meter looks the same as a normal import meter, but records the flow of electricity outwards from a site rather than inwards, which is done by the import meter. Increasingly nowadays the meter is a combined import/export meter.

To export all of the energy produced by a micro hydro or small hydro system it would have to be directly connected to the grid with its own dedicated electrical supply and not first pass through the site distribution board (see more details below under 'offset value'). Under this arrangement every kWh generated by the system would be exported, and the export tariff, typically between 3-5 p/kWh would be paid.

<u>Offset value</u>
This is where the micro hydro or small hydro system connects into the site owner's main distribution board. It is important to remember that electricity flows like water and will always follow the easiest route to the nearest load. This means that all of the site owners loads (i.e. lighting, sockets, machinery, air conditioners etc.) that connect to the same distribution board will be supplied firstly by the hydropower system, and only once all of these loads have been satisfied will any surplus energy from the hydro system flow backwards through the incoming supply cables, either to the next nearest distribution board on the site, or out through the export meter to the grid.

Also, because the electricity produced by the hydropower system is fully grid-synchronised, it will mix seamlessly with grid-imported electricity. This mean that if the hydro system cannot meet all of the site owners loads, then all of the electricity from the hydro system will go towards the loads and any deficit will be seamlessly imported from the grid. Equally, if the hydro system was supplying all of the local loads but then a reduction in the river flow rate caused the output to drop, then the grid would instantly supply more to make up the deficit. From a consumers point of view the source of the electricity would be unknown; it could be from the hydro system, the grid or a combination of both.

In the situation where the on-site loads far exceed what the hydropower system could produce, then all of the electricity generated by the hydro system would be consumed on site. For example, if a hydropower system with a maximum power output of 100 kW was connected to a site that had a baseload (i.e. the minimum load 24/7) of 500 kW, then 100% of the energy generated by the hydro system would be consumed on site. Financially this would be a good arrangement because the price paid for importing electricity from the grid is typically 12 p/kWh (varies between 8-16 p/kWh depending on the import tariff), so if the amount of import can be reduced, for every kWh it is reduced by the site owner saves 12 p. If you compare this saving of 12 p/kWh to an export price of 3 – 5 p/kWh, you can see that offsetting on-site loads is worth two to three times more than exporting the electricity.

<u>Combined offsetting and exporting</u>
This is actually the most common arrangement and is basically the arrangement described above under 'offset value' except where the on-site loads are less than the power being produced by the hydropower system. Under this arrangement the onsite loads would be supplied first, then the excess power exported.

The value would be made up of the amount of energy offset at 12 p/kWh (or whatever your import electricity price is) plus the amount of energy exported for between 3-5 p/kWh. Obviously the actual value would depend on the relative proportions, but these can be estimated at a feasibility stage based on existing electricity bills and forecast energy production for the hydro system.

Generally speaking it is best to offset imported electricity first, then export any remaining surplus to get the highest revenue from a hydropower system.

Renewables Levy Exemption Certificates (Renewables LECs)

This is an exemption from paying the Climate Change Levy (CCL) if renewable-sourced electricity is used in place of normal grid-supplied electricity. The CCL is currently set at £4.70/MWh (or 0.47 p/kWh) of electricity consumed. For renewable generators this means that subject to registration of the renewable generation system with Ofgem, you would be issued with a ‘Renewables Levy Exemption Certificate’ or ‘Renewables LEC’ for every MWh of electricity you generated, and this would be worth £4.70 / MWh.

You could use this to offset against your CCL bill if you are a commercial consumer of electricity, or you could simply sell the Renewable LECs to your electricity supplier or one of the established trading companies. The bottom-line is that this adds an additional 0.47 p/kWh value to renewable electricity you generate from your hydropower system.

Renewable Energy Guarantee of Origin certificates (REGOs)

Confused yet? Well, try this.Now we have Renewable Energy Guarantee of Origin certificates or REGOs. These started appearing in 2003 in response to the EU Renewables Directive. They are basically a guarantee that the electricity has been certified as ‘green’. The REGO certificates are issued by Ofgem in a similar way to Renewables LECs, so it as well to apply for them and keep them in a safe place. Currently there is no established market to sell REGOs on, so they have no value. However, many people advise applying for them and keeping them because they may become essential to show that your electricity is certified as green before you can sell LECs etc.

Renewable Obligation Certificates (ROCs)

So think of REGOs as important facilitators to realise value, rather than being valuable in themselves. This was the old system for incentivising renewable electricity generation. Generators that are larger than 50 kW still have the option of joining the ROC scheme instead of the FiT, but generally speaking for all ‘normal’ projects the FiT provides a greater financial return, so the ROC system will be ignored here.

Non-tangible benefits

Also worthy of mention, many hydropower sites generate a great deal of positive publicity and improve a company’s image through association with clean renewable energy generation. Sometimes the value of this is greater than the revenue generated by the system, but because of its non-tangible nature it has been ignored here.

Summary of potential revenue from hydropower systems

Due to the different permutations possible of the different components of the total value for generated electricity, a few assumptions have to be made if a simple table of annual revenues is to be constructed. To keep things simple, in the table below no value for offsetting has been included, and the default export price of 3 p/kWh has been assumed. This would be the ‘worst case’ for revenue; the ‘best case’ with 100% offsetting could provide substantially more revenue. Therefore the generated electricity values used are:

Hydro Max. Power	Feed-in Tariff	Export price	LEC	Total value
5 kW	19.9 p/kWh	3 p/kWh	0.47 p/kWh	23.37 p/kWh
25 kW	17.8 p/kWh	3 p/kWh	0.47 p/kWh	21.27 p/kWh
50 kW	17.8 p/kWh	3 p/kWh	0.47 p/kWh	21.27 p/kWh
100 kW	17.8 p/kWh	3 p/kWh	0.47 p/kWh	21.27 p/kWh
250 kW	11 p/kWh	3 p/kWh	0.47 p/kWh	14.47 p/kWh

Table 3 - Feed-in Tariff, export & LEC value for different sizes of hydropower system.

For a range of different sizes of micro hydro and small hydro system the annual revenue is shown below. These are all based on a typical UK capacity factor of 0.5.

Hydro Max. Power	AEP	Annual Revenue
5 kW	21,840 kWh	£5,104
25 kW	109,200 kWh	£23,227
50 kW	218,400 kWh	£46,454
100 kW	436,800 kWh	£92,907
250 kW	1,093 MWh	£158,157

Table 4 - Annual revenue for different sizes of micro hydro and small hydro systems.

Remember that different sizes of micro hydro and small hydro systems qualify for different Feed-in Tariffs, so even though larger hydro systems generate more energy, the annual revenue generated doesn’t always scale in line with the annual energy production because a larger system may fall into a lower Feed-in Tariff band. This means that in some situations a smaller hydro system may produce a greater revenue than a larger one. This is particularly true for hydro systems between 100 and 150 kW, where it is often economically better to reduce the size of the system to qualify for the higher 15 -100 kW Feed-in Tariff. This is an unfortunate anomaly caused by too-larger gap between the less than and greater than 100 kW Feed-in Tariffs.

How much do micro hydro and small hydro systems cost?

It is difficult to make generalisations about what micro hydro and small hydro systems cost because they are always designed to suit the particular site. Also the extent of civil engineering works is very site dependent, with some new-build sites requiring everything to be built from scratch, while other retrofit projects can make use of and adapt existing civil engineering structures. However, the table below is a vary rough ball-park estimate of typical project costs for systems requiring an ‘average’ amount of civil engineering works and grid connection upgrades, and assuming access to the site was reasonable. In all cases it is assumed that good quality hardware is used throughput (which is always the most cost effective option anyway in the long run).

Hydro Max. Power	Project Cost	Annual OpEx
5 kW	£100k	£1,000
25 kW	£250k	£2,500
50 kW	£313k	£4,500
100 kW	£500k	£7,500
250 kW	£1M	£16,250

Table 5 – Indicative total project costs and annual operational expenditure.

It is possible to install systems for a lower cost, particularly at the lower power outputs if the existing infrastructure at the site lends itself to easy adaption to a modern hydropower system so only modest or no civil engineering works would be needed. However even in the most favourable circumstances it is unlikely that the cost would reduce by more than 50%.

An indicative cost of annual operational expenditure (OpEx), which includes routine maintenance, is also provided. This assumes that willing and low-cost labour would be available to manually clean the intake screen for the smaller systems, but then as the systems get larger (50 kW+) someone would be paid on a part-time basis to keep an eye on the (automatically cleaned) intake screens. It also assumes that monthly greasing would be done by the same part-time attendant, and an annual service and system check would be carried out by a professional hydro company.

What would be the return-on-investment on a micro or small hydro system?

Using all of the various assumptions, revenues and costs discussed above, and assuming a design life of 20 years (see 'How long do they last' below), the following table of Internal Rates of Return (IRRs) can be constructed.

Hydro Max. Power	IRR
5 kW	-1.8%
25 kW	5.4%
50 kW	12.0%
100 kW	16.2%
250 kW	13.0%

Table 6 – Internal Rates of Return over 20 year for a range of typical hydro project sizes.

Table 6 clearly shows that the smallest micro hydropower systems struggle to make economic sense. We normally say that the smallest commercially viable hydro systems are minimum 25 kW, unless the site is a historic hydro site that lends itself to easy redevelopment.

It is worth mentioning that sometimes intangible benefits can be worth a lot, for example at sites frequented by tourists a micro hydro or small hydro system can add a lot of additional interest as a visitor attraction and in other cases the marketing benefit to a company from being able to say that their energy is generated on site from zero emission hydropower can be significant. The best sites are generally larger, with higher heads, easy to adapt infrastructure, easy access and a good grid connection.

What is the physical size of a hydropower system?

Once again it is difficult to make generalisations. Low-head hydropower systems take up much more space than high-head hydropower systems because the turbine has to be physically large to get a higher flow rate through it with only a low water pressure across the turbine. On smaller (<25 kW) systems it is possible to not have a turbine house and instead have a steel-fabricated turbine enclosure with a weatherproof cladding, similar to the Cricklepit Mill enclosure, clad in cedar wood, shown at the top of this page. Penstock pipework is normally buried, so is out of sight. On low-head sites the intake and discharge channels can be covered over and turf laid, so are effectively invisible. Even though penstock pipes and channels can be invisible when the system is finished, bear in mind the size of the excavations required during the construction phase.

The table below gives indicative dimensions for the main system parts to give you an idea of turbine house sizes, diameters of pipes and cross sectional areas of channels and intake screens. In this example 'low-head' is assumed to have a net head of 2.5 metres and 'high-head' 50 metres.

	Turbine House Footprint		Low Head	High Head	Low head
Hydro Max. Power	**Low Head**	**High Head**	**Intake Channel Area (m²)**	**Penstock Diameter (m)**	**Intake Screen Area (m²)**
5 kW	$4m^2$	$1\ m^2$	$0.6\ m^2$	0.125 m	$1.2\ m^2$
25 kW	$16\ m^2$	$4\ m^2$	$3\ m^2$	0.28 m	$6\ m^2$
50 kW	$20\ m^2$	$5\ m^2$	$6\ m^2$	0.40 m	$12\ m^2$
100 kW	$36\ m^2$	$9\ m^2$	$12\ m^2$	0.56 m	$24\ m^2$
250 kW	$64\ m^2$	$16\ m^2$	$30\ m^2$	0.90 m	$60\ m^2$

Table 7 – Indicative sizes of main parts of low-head and high-head micro hydro and small hydro systems.

What permissions do I need to build one?

All micro hydro and small hydro systems must be licensed by the Environment Agency (there are a couple of rare scenarios where licensing isn't necessary). The EA will license the system using an abstraction or impoundment license, or both. The process to obtain the EA licenses is a little bureaucratic and takes on average nine months for a typical site.

Also the EA will require Flood Defence Consent for all works in or near a watercourse and for any new structures constructed within the main channel or flood plain. Obtaining Flood Defence Consent is more straightforward provided you have proper drawings and the system is well designed. Planning permission will be required for any new structures, though generally this is simpler to obtain than the EA consents because hydropower is visually relatively unobtrusive.

Permission is also required to grid connect the system, but this is normally simple to obtain assuming any required grid upgrades are paid for. Note that in areas with weak electrical infrastructure the cost of grid upgrades can be very high, so obtaining permission to grid connect the system and a quote for any upgrades should be done early in the project design stage.

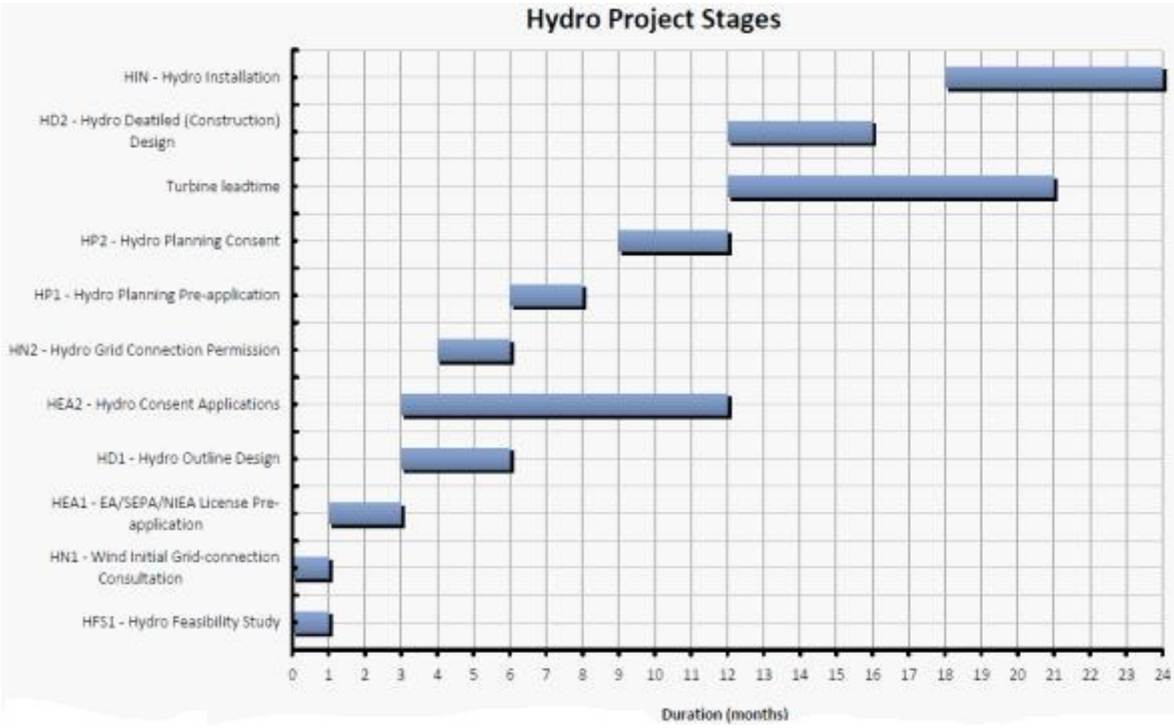
How long do micro hydro and small hydro systems last?

Hydro systems have very long operational lives. The oldest operating hydropower systems are over 100 years old, including some utility-scale systems up in Scotland. Hydro turbines by their nature are relatively low-stressed pieces of machinery and operate in very steady loading conditions with no sudden load changes. This lends itself to a long life provided they are regularly maintained (mainly lubricating the bearings).

The civil engineering infrastructure should last forever provided it is maintained. The drive systems (gearboxes or belts) will require periodic replacement along with bearings in all of the rotating machinery. Most hydro hardware manufacturers quote design lives of 25 years, though this is normally because they have to set a figure, and in many cases the same manufacturers have turbines out in the field that are over 50 years old and still operating reliably and efficiently.

I want to move ahead, what's the next step?

The normal project stages for a small hydro or micro hydro project are shown in the diagram below, along with the typical durations. We break down each stage into clearly defined segments and try to minimise risk capital by establishing the key facts at an early stage before significant consultancy fees are incurred. The project stages are described in more detail under their respective website sub-menu items. The first step for any prospective site is a Hydro Feasibility Study (HFS1).



If you think you have a suitable hydro site for development, please log an enquiry through below email or phone, including as much detail as possible. We will give your a prompt feedback to discuss the options in more detail.