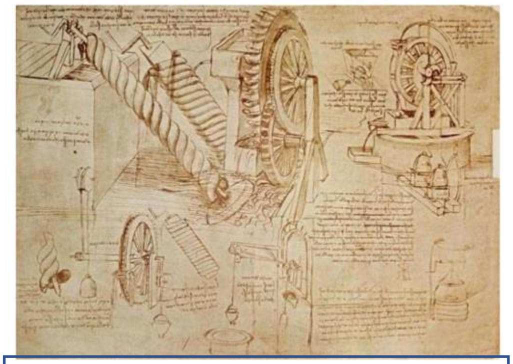
Where did the idea come from?

The Archimedes screw and the Water Wheel are the oldest hydraulic machines in use. Archimedes of Syracuse is considered to be the inventor of Archimedes screw the 3rd century B.C, although there seems to be some debate as to whether it's actually been around since the 7th century B.C. Apparently the Hanging Gardens of Babylon were watered by screws. The Roman engineer and architect Vitruvius gave detailed description of Archimedes screw in one of his books the 1st century B.C. and his description had a great role to keep this device known until our time.



Screw and Water Pump by Da Vinci

Until recently the Archimedes screw was used only as pump. Only in the beginning of the 19th century it started to be used for power production. Only a few years ago the first tests of the performance as hydro turbine for electricity generation for use in low head sites were published.

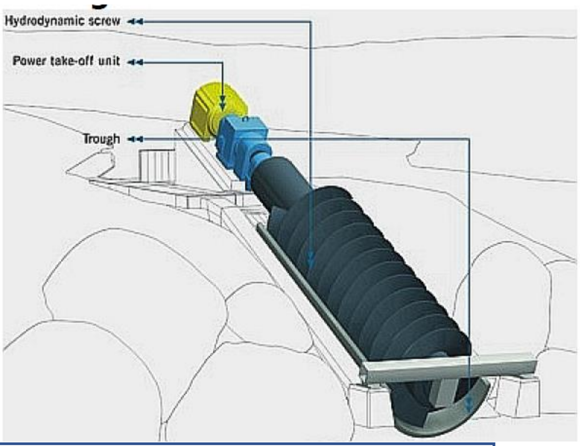
Why did we choose an Archimedes Screw?

There are various types of turbine; *Impulse,* driven by a high velocity jet, *Reaction* where rotor is entirely immersed in water and enclosed in pressure casing and *Gravity* which are driven simply by the weight of water entering the top of the turbine and falling to the bottom. Given the head and mean flow of water available at Havannah Weir (about 4m and 2.5m^3/s respectively) only the Kaplan turbine (reaction type) and the Archimedes screw (gravity type) were practical options.

The Havannah Weir Screw in the Landustrie Factory

Like all reaction turbines the Kaplan exploits the oncoming flow of water to generate hydrodynamic lift forces to propel the runner blades. These blades are similar in principle to the propeller of a ship, but operate in reversed mode. A feature of the Kaplan is that the pitch of the blades can be adjusted. While this greatly improves the efficiency over a wide range of flow rates, the mechanics for adjusting turbine blades can be costly and tend to be more affordable for large systems.

So we went with an Archimedes screw. It's principle of operation is the same as the overshot waterwheel, but the clever shape of the helix allows the turbine to rotate faster than the equivalent waterwheel and with high efficiency of power conversion (over 80%). However they are still slow-running machines, which require a multi-stage gearbox to drive a standard generator. A key advantage of the Screw is that it avoids the need for a fine screen and automatic screen cleaner because most debris can pass safely through the turbine. In addition, the 3 helix variant being installed at Havannah weir is proven to be a 'fish-friendly' turbine. Furthermore, the



The Component Parts

visual appearance of an Archimedes screw is much more interesting for students and spectators than other types of full enclosed turbines.

How do we know how much power (and revenue) it can produce?

The peak power P output can be estimated from the design flow Q_D and head H as follows:

$$P(kW) = 7 \cdot Q_D(m^3/s) \cdot H(m).$$

H is the difference in height of the water at the top and bottom of the weir (known as the gross head) less any head losses due to friction in passing through the inlet pipe and the turbine channel.

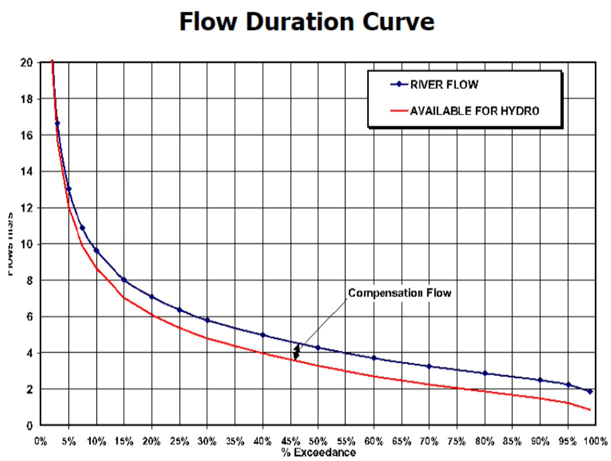
The constant “7” is roughly approximated as the product of the acceleration due to gravity (9.81m/s^2) and the total average electrical and mechanical efficiency of the turbine and generator over their operating range (about 70%).

The annual energy output is then estimated using the Capacity Factor (CF) as follows:

$$\text{Energy (kWh/year)} = P\text{ (kW)} \cdot CF \cdot 8760$$

There is clearly a balance to be struck between choosing a larger, more expensive turbine which takes a high flow but operates at a low Capacity factor, and selecting a smaller turbine which will generate less energy over the year, but will be giving full power for more of the time i.e. a higher Capacity factor. The Capacity factor for most mini-hydro schemes would normally fall within the range 40% to 60% in order to give a satisfactory return on the investment.

Furthermore, Archimedes screws can operate over a range of flows (typically down to 10-20% of their rated flow) in order to increase their energy capture and sustain a reduced output during the drier months. As discussed later the use a variable speed drive for our project will minimise the loss of efficiency at lower flow rates and maximise the capacity factor.



Of course, the design of our scheme has taken into account much more refined predictions of capacity factors over a range of operating flow rates, as well as statistical evidence of the actual flow rates in the River Dane obtained from various gauge stations. This latter information is expressed as a flow duration curve such as that shown opposite

When will the power output be at its maximum; when the River is flooding you might think?

An important factor on low head schemes like ours is that the gross head is not a constant but varies with the river flow. As the river fills up, the tailwater level usually rises faster than the headwater level, thus reducing the total head available. So the scheme will generally produce it maximum power output when the river flow rate is equal to the turbine design flow plus the so called minimum compensation flow which the Environmental Agency requires us to be maintained over the weir. Any significant increase in river flow and the power output starts to drop.

So the answer is not as you might at first think?

References

1 The British Hydro Association “A guide to Mini Hydro Developments” (V3)
2. Lancaster University, Faculty of Science and Technology, ”A Performance Improvement Study for Archimedes Screw turbine using Mathematical Modelling” Iilias Kotronis, MSc Research Thesis.