

Low Head Hydro Technologies and the need for greater uptake and implementation in the UK

An Engineer's Perspective

by Steve E Dalton

Clean Energy Solutions Ltd

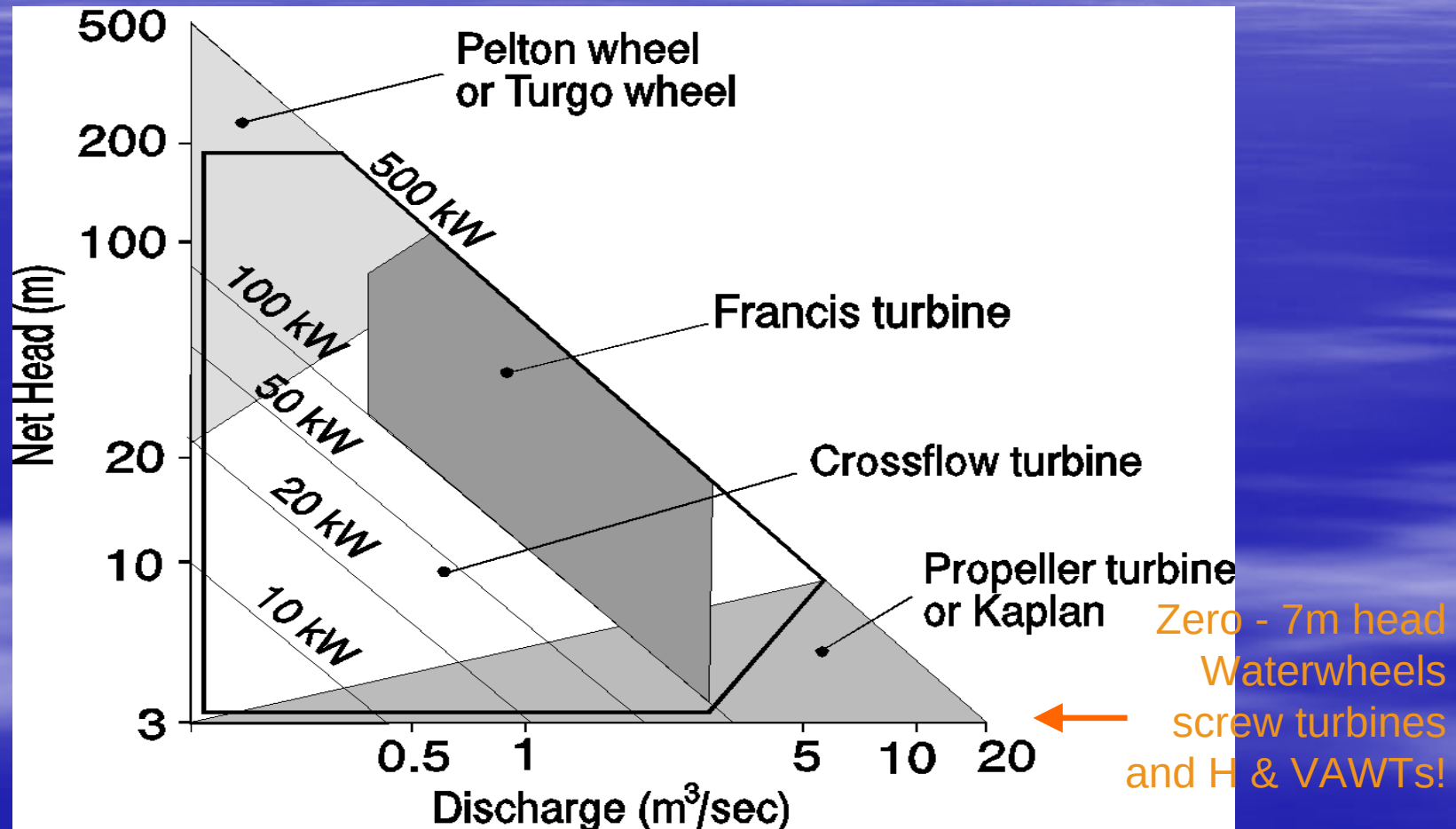
1. Low Head Hydro Technologies

- A range of technologies have been developed for low head higher flow sites which tend to rely on '**reaction**' rather than '**impulse**' machines.
- **Reaction** machines develop torque by reacting to the weight and low pressure of water and are lighter and cheaper to manufacture.
- **Impulse** machines develop torque from high pressure high velocity jets and therefore require casings (Pelton, Turgo, Ossberger Crossflow, Motor Pump Sets). Crossflow turbines are also suitable for low heads.
- **Reaction** machines which are suitable for rivers and becks include:-
 - Traditional Waterwheels (overshot, midshot, undershot, backshot)
 - Propeller (Kaplan, Francis, compact axial, bulb type, stratflo, H&VAWT)
 - Archimedean Screw Turbines (old but proven technology)
 - Optimisations of these machine types to increase efficiencies and others:-
 - Zuppinger (German), Sagebien and Poncelot (French)
 - Venturi (suction) effect to reduce net head or Siphon device (water to air)
 - Floating wheel (much less efficient but no civil & low environmental effects)
 - Other novel turbine devices (e.g. conveyor, gravity wheel, contra rotating)
 - Darius & Gorlov turbines (developed for deep rivers and tidal streams/estuaries)

Classification of hydropower and numbers of potential UK sites which could be developed.

- **Large-hydro**: More than 100 MW and usually feeding into a large electricity grid (only a few potential sites left to develop in the UK)
- **Medium-hydro**: 15 - 100 MW - usually grid connected (5-15 new sites)
- **Small-hydro**: 1 - 15 MW - usually grid connected (20-80 new sites)
- **Mini-hydro**: Above 100 kW, below 1 MW; most often grid connected (100 - 150+ potential sites)
- **Micro-hydro**: From 5kW up to 100 kW; usually provided power for a small communities but many now being grid connected (thousands)
- **Pico-hydro**: From 300 watts up to 5kW (usually stand-alone) but some small systems have been successfully grid connected (10 - 50,000+)

Head v Flow hydro turbine selection graph (+ those that work very well below 3m head!)



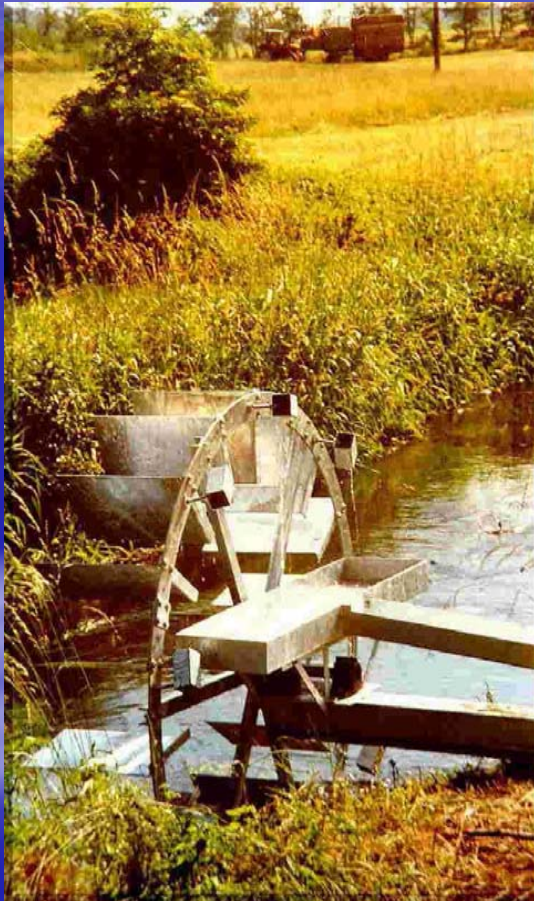
Examples of Zuppinger undershot waterwheels installed for grid tied clean energy production (10- 30kW, from 0.5- 1.5m head, courtesy of Hydrowatt)



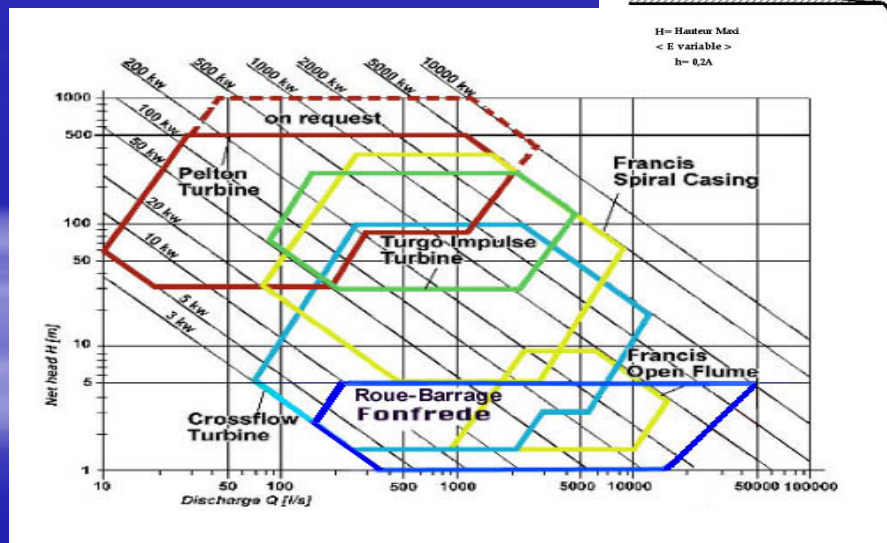
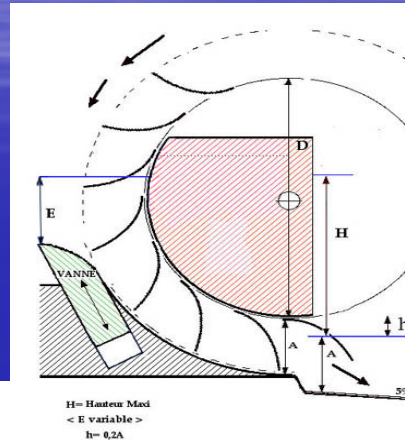
Modern efficient waterwheels – showing how old principles and modern technologies can work together (35 and 80kW courtesy of Hydrowatt)



Clean and efficient hydro power generation - from simple tests to commercial installations (80kW breast shot wheel courtesy of Hydrowatt)

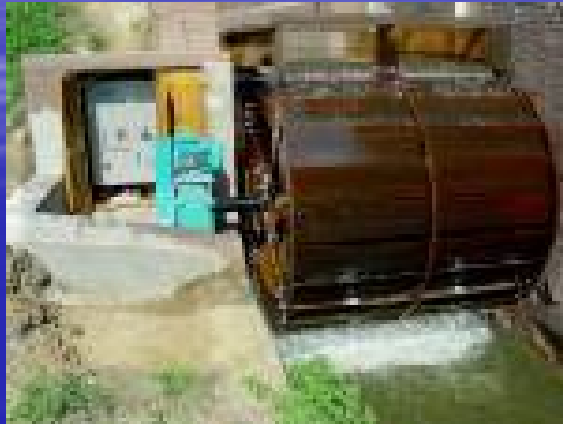


One solution for river and weirs: for low head and moderate flow conditions: Sagebien (Fonfrede) Waterwheel producing 50kW.



<http://perso.orange.fr/michel.fonfrede/63cf/ROUERM.htm>

Several other micro hydro solutions using waterwheels on moderate to low head sites: (standalone & grid connected, Courtesy of Hydrowatt Ltd, Powerpal-DW).



Watermills and the need to restore existing sites and develop new run of river systems (1)

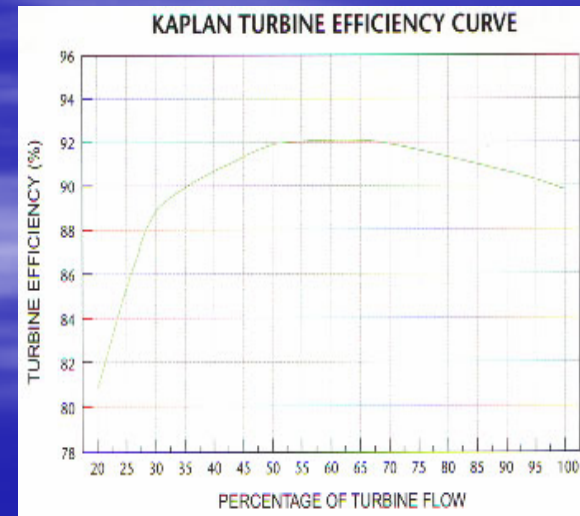
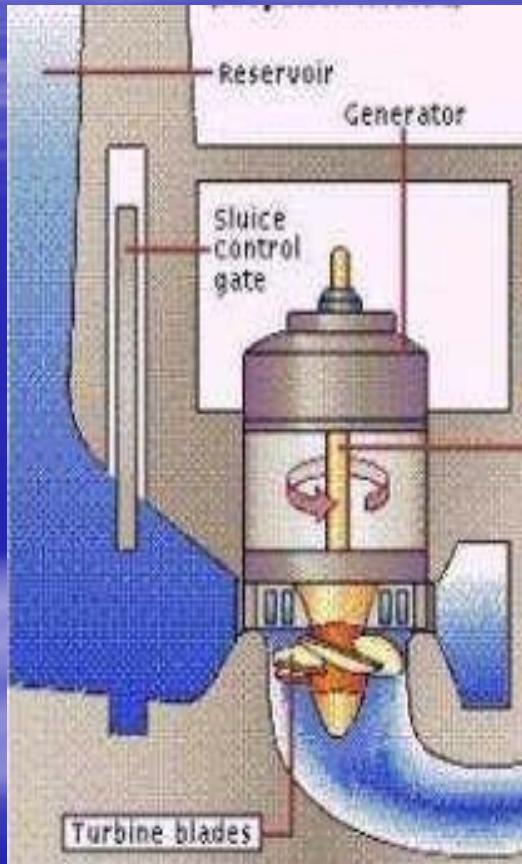
- **Common misconception:** That waterwheels and other low head devices are inefficient and unreliable for generating electrical power. This is not true using modern technology and control systems on suitable sites. Costs have fallen to (£3 - 6K/kWe).
- **Fact No. 1.** A combination of over-regulation and water pricing combined with cheap fossil fuel power sources in the 1960-80's killed off many small hydro plants and led to the run down of many Mill sites.
- **Fact No. 2.** There used to be over 30,000 working mills in the UK (1850). The number of working mills is now less than 400 and whilst many are now visitor attractions, less than 100 mill sites are generating clean electrical power. Largest EP o/shot wheel at Aberdulais, 25kW.
- **Fact no. 3.** Many existing low head sites can be used to generate clean electrical power cost effectively (PB << solar or micro-wind <6y-12y).
- **Fact No. 4.** Some reaction machines are very fish friendly and have negligible to positive environmental impact (multiple studies).

Watermills and the need to restore existing sites and develop new run of river systems (2)

- **Fact No. 5.** Improvements in technology and EC&I combined with higher energy costs, climate change issues and co-operation by all stakeholders could bring about a renaissance of low head hydro (DTI).
- **Fact No. 6.** Educating people of the benefits and winning 'hearts and minds' is key to the success for a micro-hydro revolution to occur.
- **Fact No. 7.** Raising awareness of micro hydro benefits needs to be better communicated by developers with councils, local authorities, the DNOs, RECs, government and the environment agencies to ensure that the process becomes simpler, more proportional & fit for purpose.
- **Fact No.8.** Too much emphasis has gone on micro wind and solar PV without understanding the benefits hydro provides (higher efficiencies, LFs and therefore PB's with low environmental impacts).
- **Fact No.9.** Although waterwheels are large they can produce reliable power at high efficiencies (WtW efficiencies up to 80% and $LF=0.9$) for o/shot, although 65% and 0.7 are more common for LH. ($P= 6.Q.H$)
- **Fact no. 10.** Francis, Crossflow & others are proven for MH-LH sites.

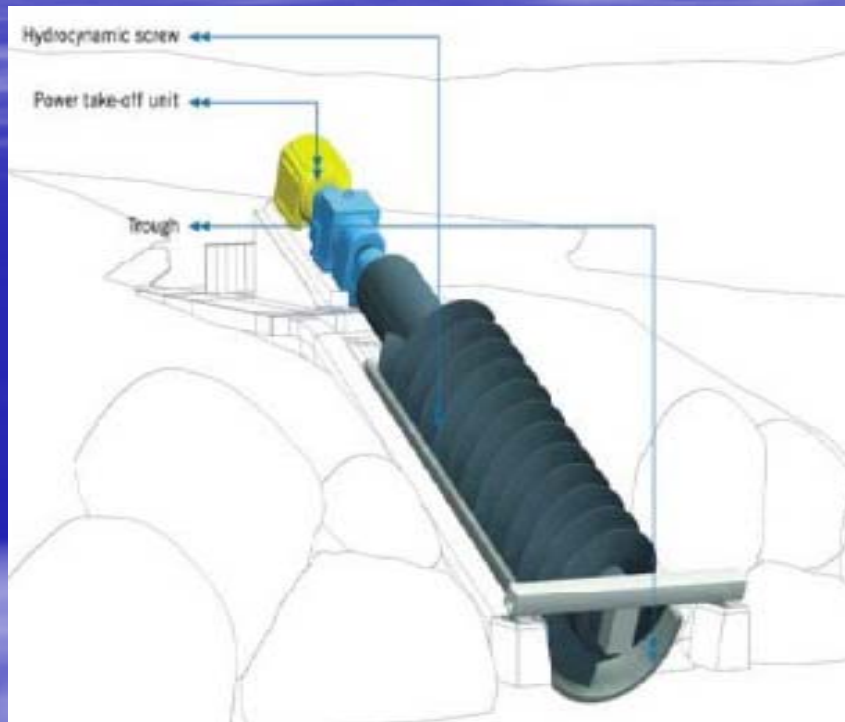
Low head hydro – Kaplan turbines

(courtesy of Gugler and Powerpal) 1- 5m heads, 20 to 200kW
wide range of flow characteristics for low to medium heads



Low head hydro – Screw turbines

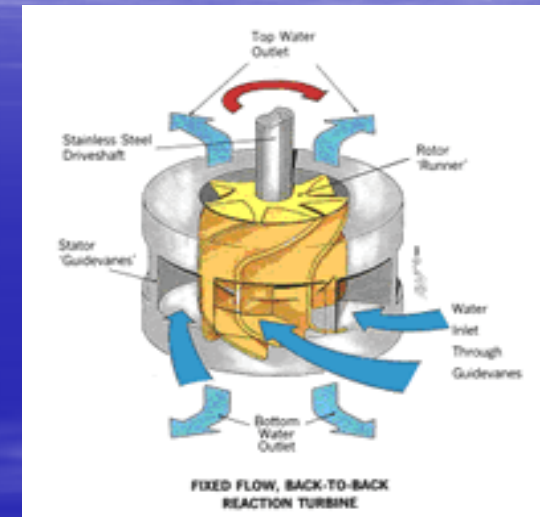
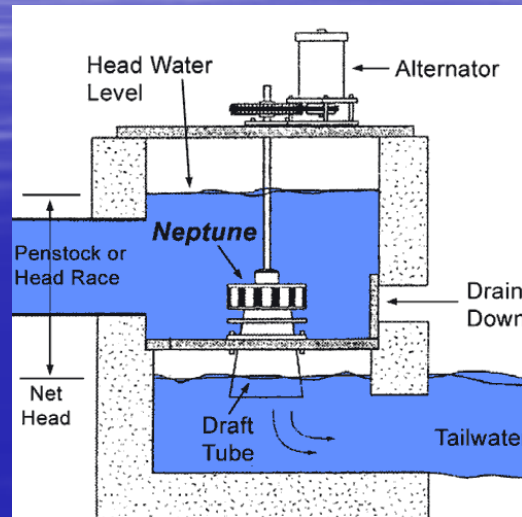
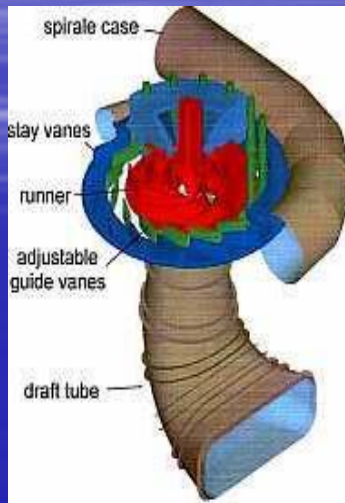
(courtesy of Ritz Atro; WRE Ltd, Castleford Engineering and GP Electronics) 5m head, 40kW and totally fish friendly.



Recent installation of Archimedes screw turbine on the River Dart Country Park

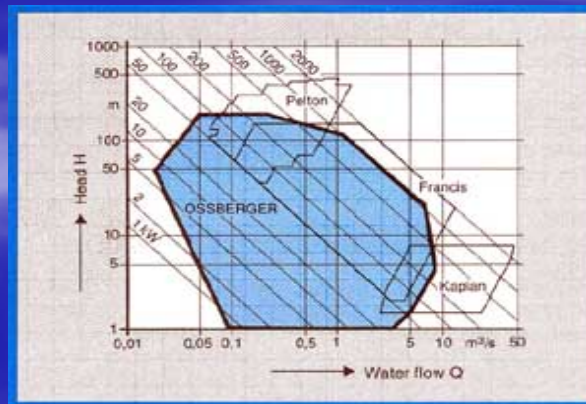
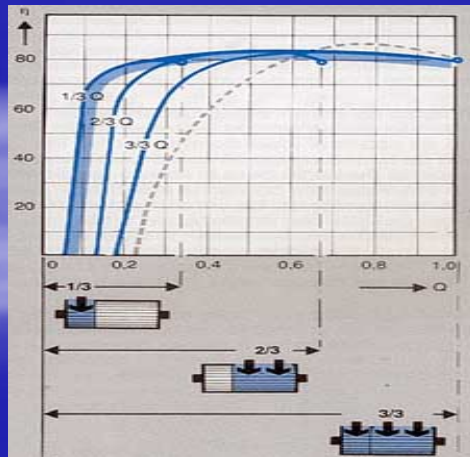
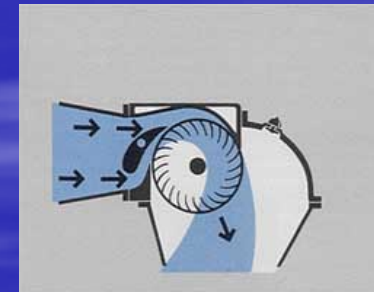
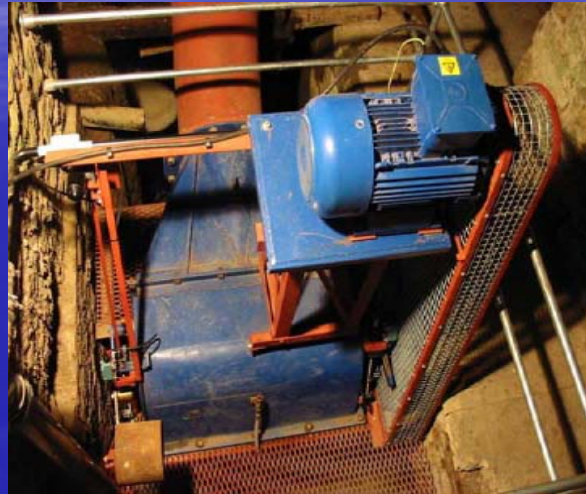
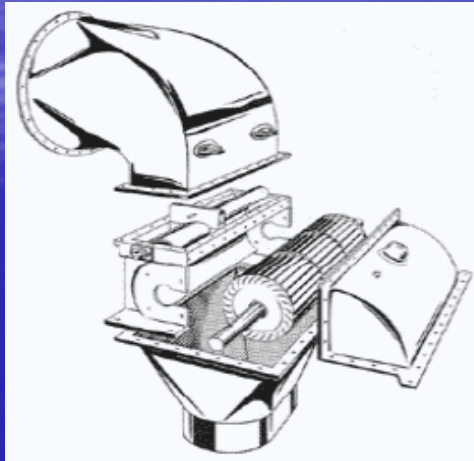
Low head hydro – Francis Turbines

(courtesy of Cineca, Nautilus & Hydrogeneration, KWG)
widest range of head and flow characteristics



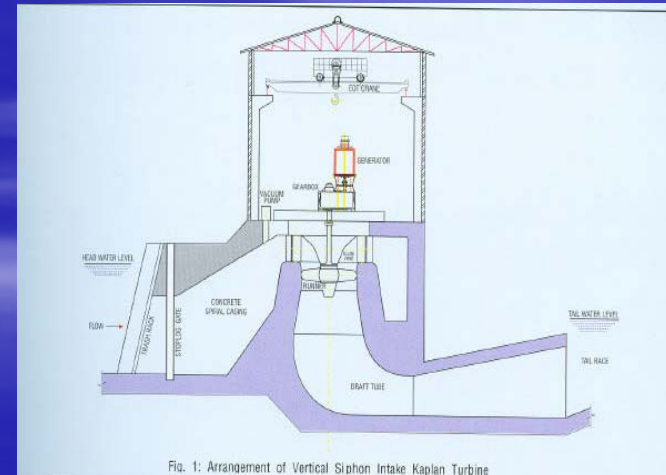
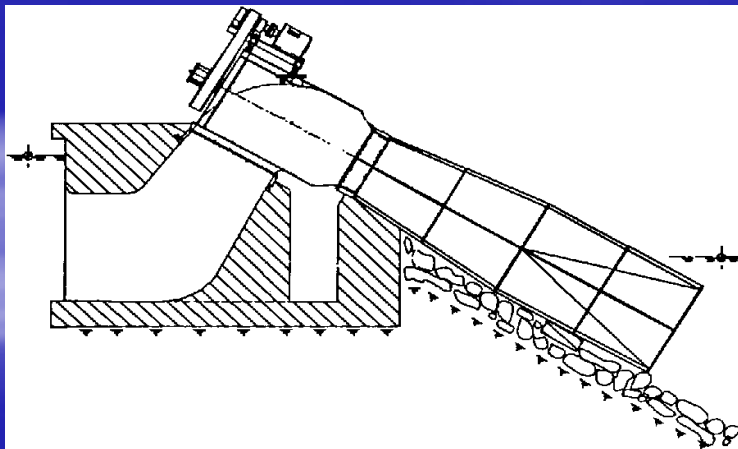
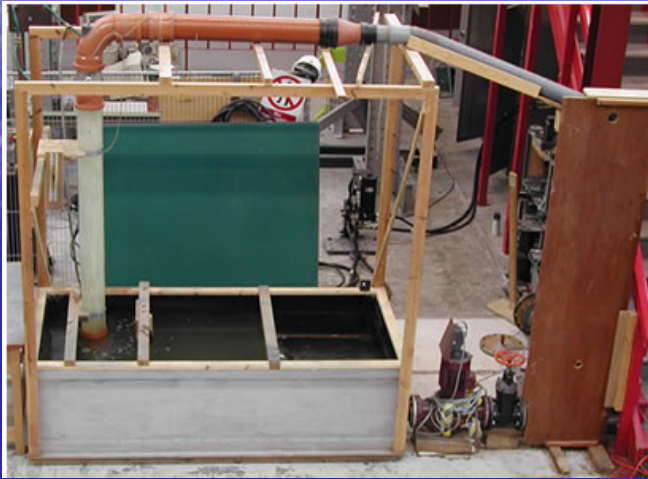
Low head hydro – Crossflow Turbines

(courtesy of Ossberger, Hydrogeneration, KWG & Powerpal)
can be used over wide range of flows for low to medium heads



Low Head Siphon Turbines

(courtesy of LUREG and TCE)



Ultra Low Head Devices (0.5-1.5m)

(courtesy of Beck Mickle Hydro and SOTON)

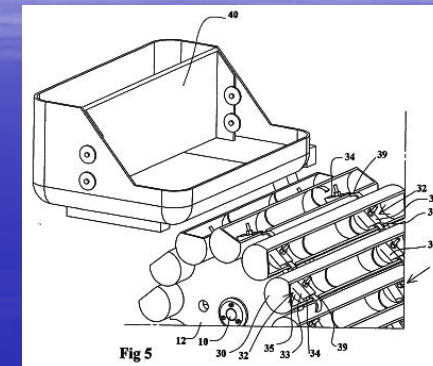
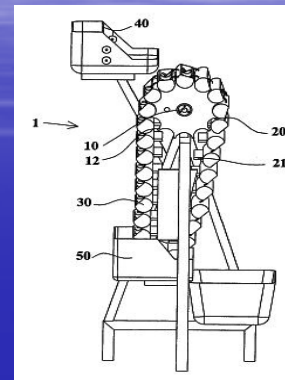
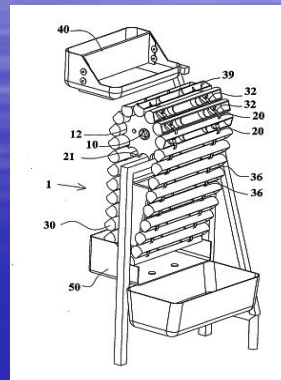
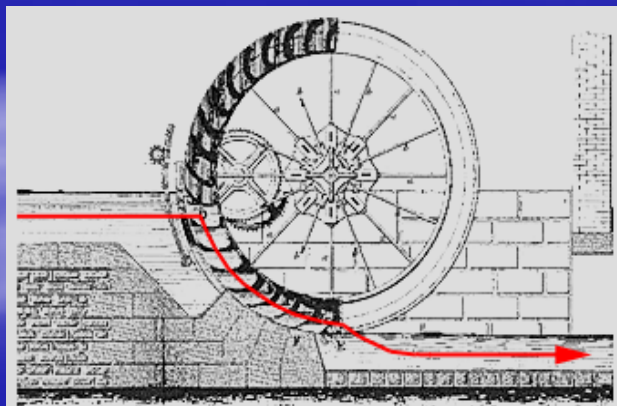
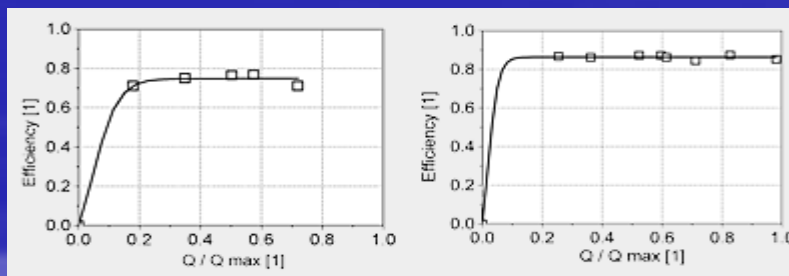


Fig 5



Zero and Ultra Low Head Devices

(courtesy of Hydro-turbines, Powerpal, SOTON, Carbonconcepts and Pieter Mann, Floatingwaterwheel.co.za)

<http://www.powerpal.co.uk/pictures1.html>



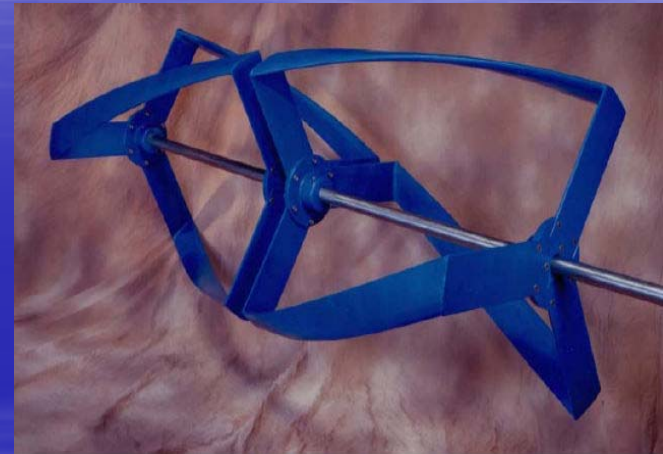
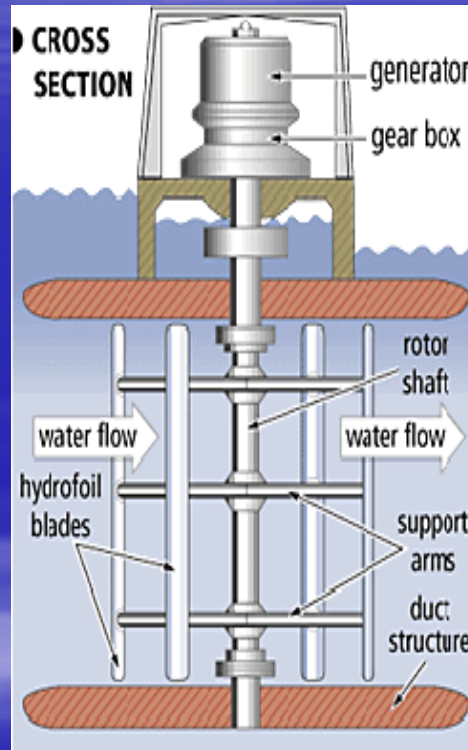
Pico+ Family from Az-ing.com

Pico hydro-power plant, fully submersible, of
300 Watts capacity.
working with a flow of between 35 to 45 litres
of water / second.
with heads between 1.5 meter and 3 meters.
power supplied : **110V 60Hz or 230V
50Hz. operating at constant power &
frequency.**
body material : moulded plastic
(total weight = 7 kg for the complete turbine)



Zero Head Turbines for deep channels, rivers and tidal streams

(courtesy of SOTON and Ampair)



Other technological developments

-many spin offs from wind & solar

- Motors (Permanent magnet, SE Induction Motors)
- Variable speed reduction drives
- Electronic load controllers (regulators)
- Grid Connection Inverters (G83 complaint)
- Deep cycle Batteries and UPS systems
- Flywheels for mechanical storage
- Supercapacitors for electrical energy storage
- Compressed Air Systems (Air Motor)
- Heat Pumps (C.o.P up to 5) i.e. 5kW heat per 1kW

2. Opportunities & Challenges

■ Opportunities

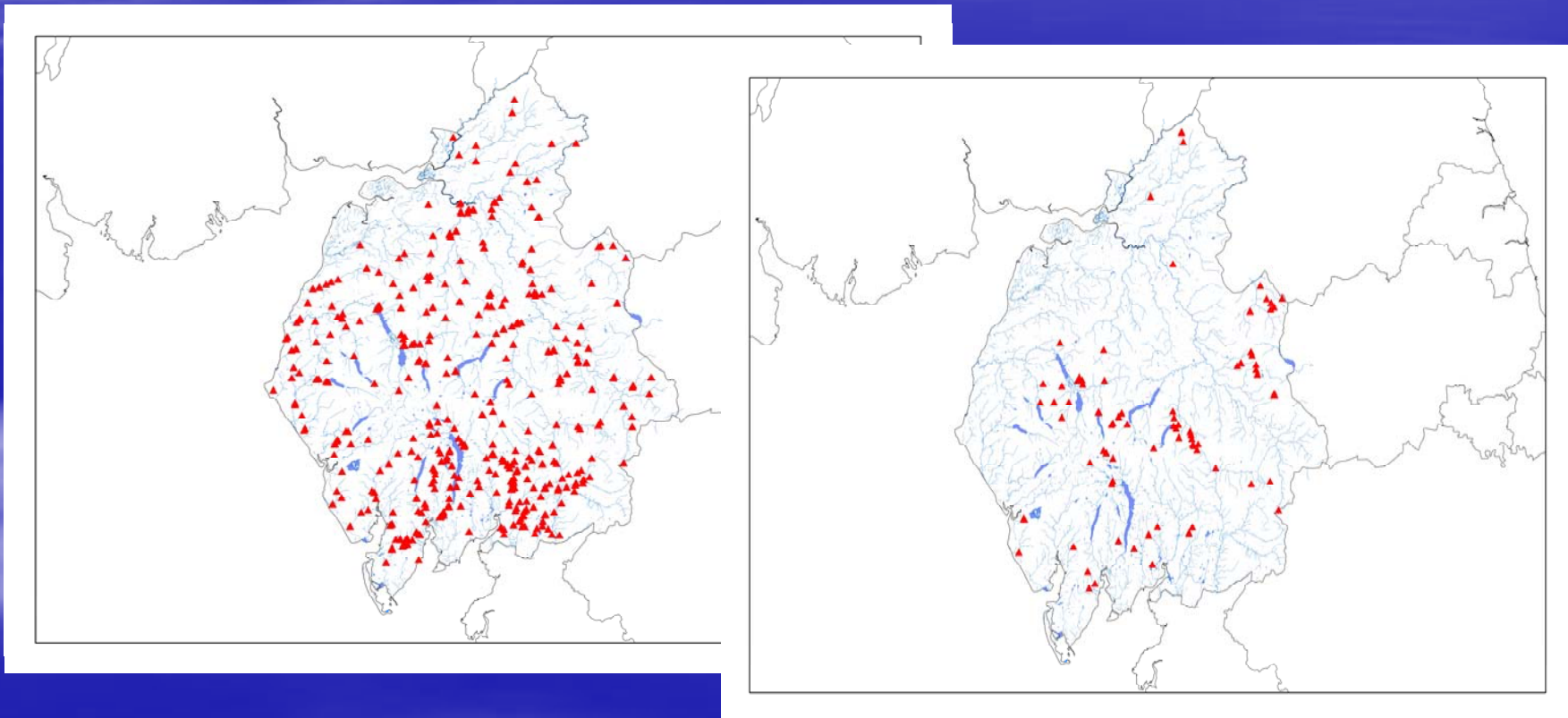
- DEFRA / BERR state that if many rivers, streams and canals could be tapped, this could provide 10,000GWh/year = 3% of total UK demand.
- This includes rivers and weirs with less than 2 - 3m head which have been ignored in previous studies done. Civil costs vary from low to high.
- The resource amounts to over 600 - 1000 MW in the UK.
- Learning from experience of best practice installations at home / overseas.

■ Challenges

- Raising the awareness of the benefits that micro hydro power can offer.
- Obtaining environmental consents (especially for pico hydro) can be lengthy, WFD needs to be applied more proportionally and consistently.
- Reducing total installation costs, securing finance, PPA, ROCs, land and site ownership and reducing cost uncertainty with connection charges.
- Total capital costs are still too high for developing some low head sites.

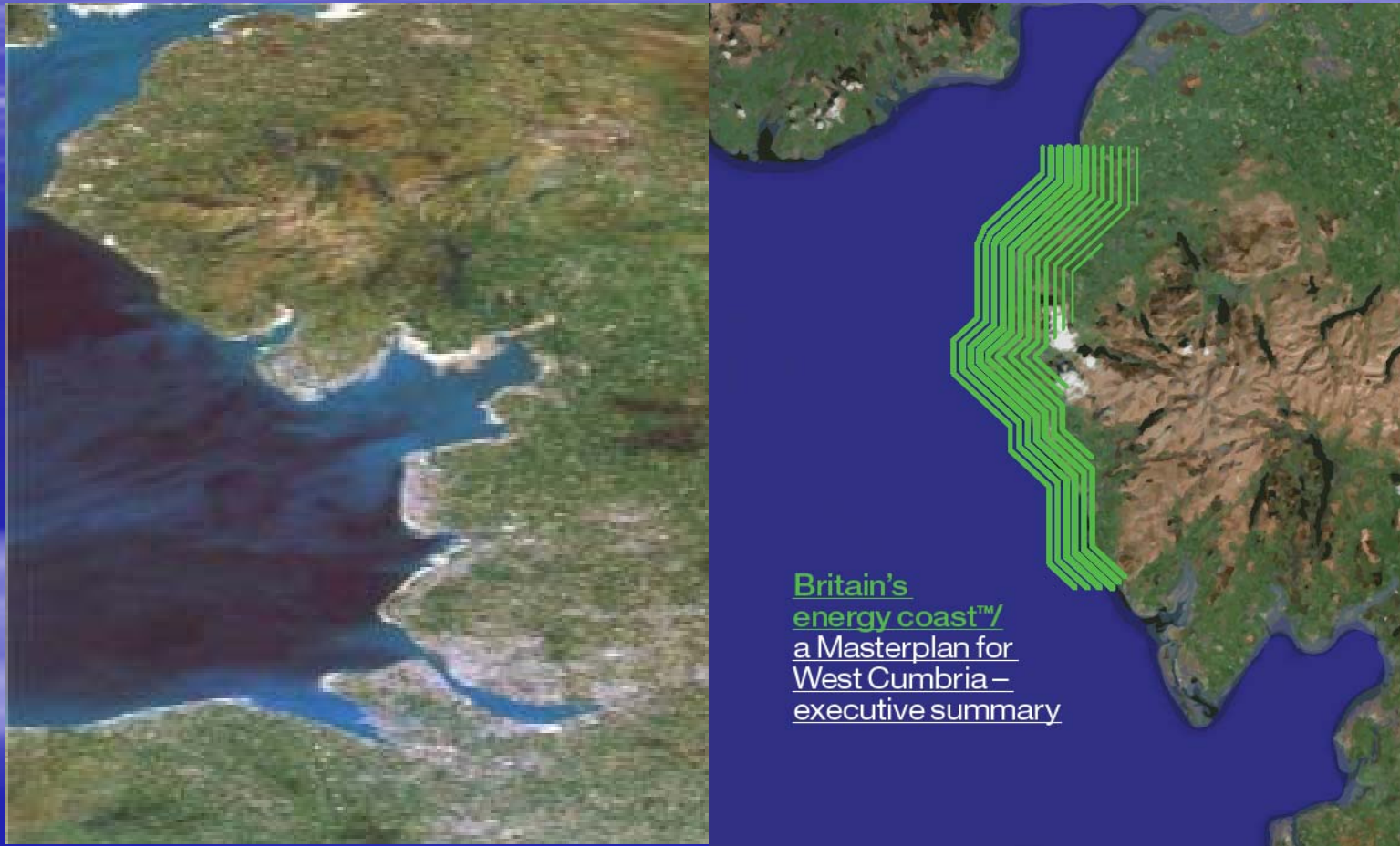
3. Site Identification for Low Head Micro and Small Hydro

- Via local knowledge, surveys and studies, and assistance from the EA, LUREG and Joule project (weirs and dams)

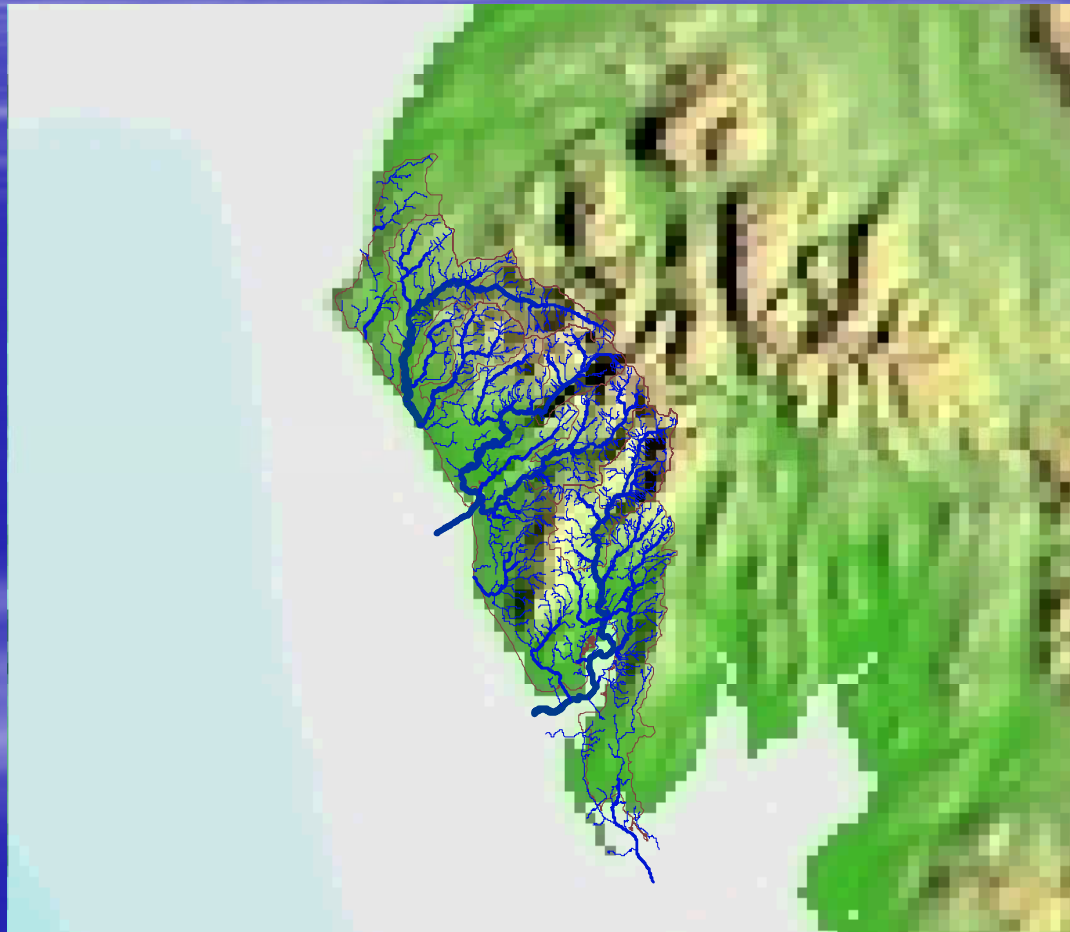


4. Resource: North West England:-

A vast resource and untapped resource for hydro, wind, wave and tidal power for 2007-2050+

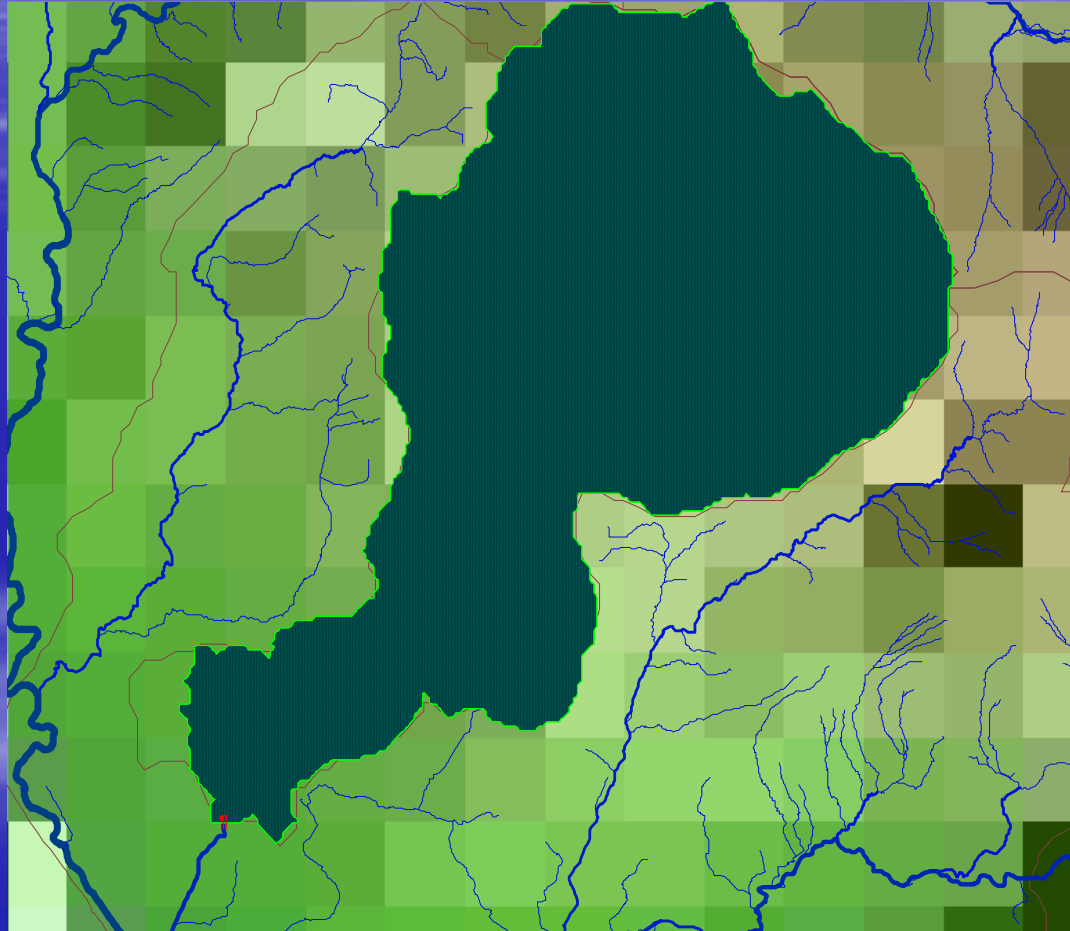


Resource Models and site measurements for feasibility (courtesy of the Joule project)



River Calder catchment, West Cumbria

(courtesy of the Joule project)



River Calder catchment characteristics

(courtesy of the Joule project)

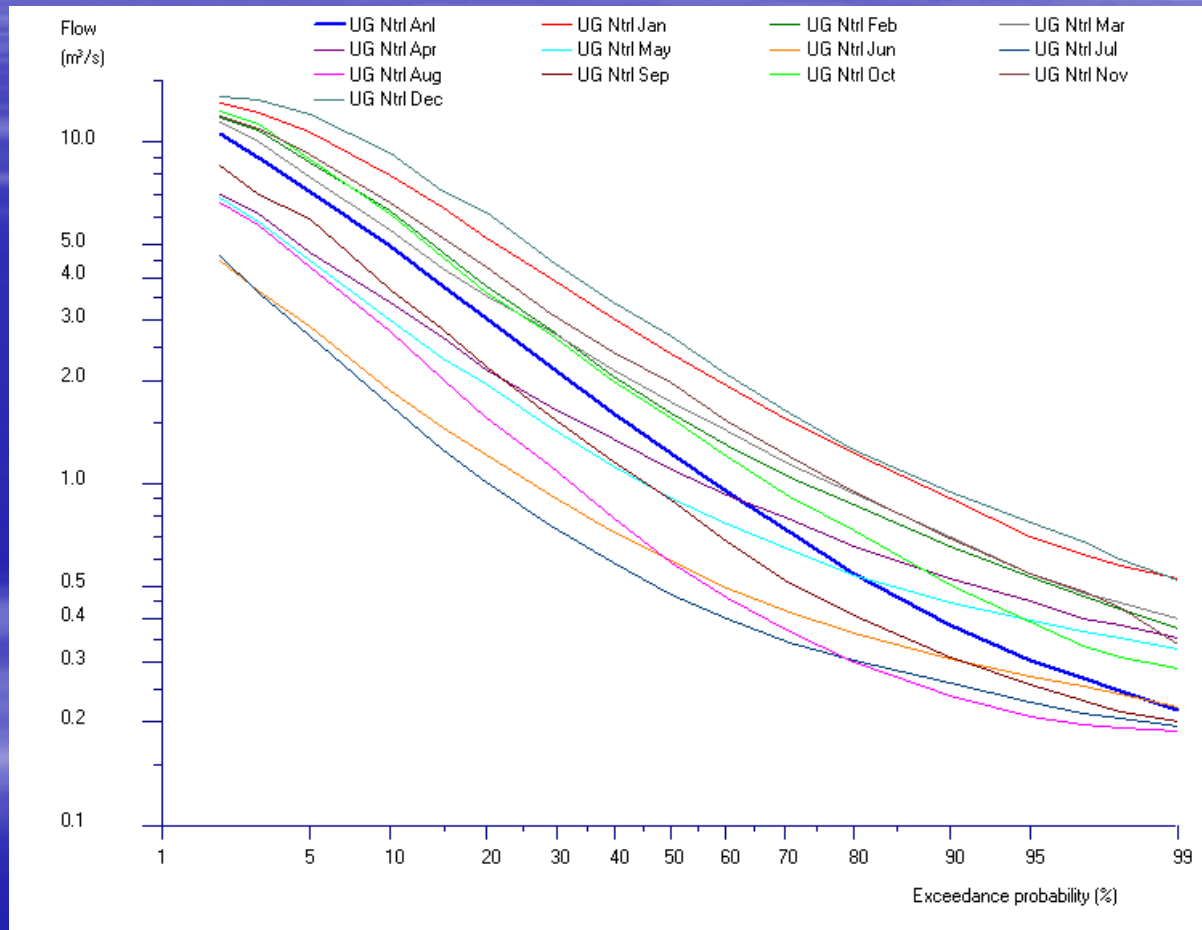
- **Basin details**

▪ Basin area:	46.2 km ²
▪ Rainfall (average annual):	1792 mm
▪ Potential evaporation (average annual):	471 mm
▪ Runoff (average annual):	1467 mm
▪ Base-Flow Index:	0.45

- **Natural low-flow summary Interval**

	Mean Flow (m ³ /s)		Q95 (m ³ /s)
▪ Annual	2.148	0.304	
▪ Jan	3.507		0.700
▪ Feb	2.620		0.534
▪ Mar	2.580		0.541
▪ Apr	1.629		0.452
▪ May	1.450		0.396
▪ Jun	0.955		0.272
▪ Jul	0.864		0.228
▪ Aug	1.180		0.207
▪ Sep	1.599		0.257
▪ Oct	2.583		0.391
▪ Nov	2.861		0.546
▪ Dec	3.954		0.767

River Calder monthly & annual flow duration curves (courtesy of the Joule project)



5. Planning & Environmental Issues - improved guidance & and a simplified process?

- Whilst important to have legislation on any power generation projects, to develop them in an environmentally wise manner, the process needs to be applied proportionally with respect to size. (5MW is not 5kW!)
- Especially the case when refurbishing existing sites for domestic & small scale use, should be much simpler than developing a larger site.
- Exemptions from lengthy consents and EIA needed for pico systems as effects are low to negligible, e.g. floating waterwheels do not abstract, impound, increase flood risk or adversely affect river life.
- PPS22 is still overly complicated and disproportionate for low head Pico/micro hydro systems, although planning acceptance is improving.
- Some pico hydro projects have become unviable based on overly stringent and inconsistent grounds e.g. why should reinstating undershot wheels require expensive fish screens and passes (£40+k)?
- It is hoped that the launch of the new EA good practice guides together with improved awareness by all stakeholders of the issues, will help streamline the process for developers to install more pico & micro hydro. For instance, exemptions (as for micro wind) or at most a Self Assessment route (BMH) and a simplified ES may be way forward?.

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6. Main Findings from review

- A Micro-generation revolution? (DTI led) Many papers and strategies but poor delivery, partly due to little government aid in RD&D and TT.
- Lots on media coverage and support for energy efficiency and RE, especially wind, solar, CHP, HPs but much less for micro-hydro?
- Poor recognition and understanding (by policy makers and the public) of the benefits that micro hydro does & can bring and too much hype and misinformation about wind & solar (giving the wrong perceptions).
- There is great potential for much more pico, micro and mini hydro to be implemented on many suitable UK sites, however still low awareness.
- Good technology and some excellent installations in the UK to learn best practice from, however, the profile needs to be raised with policy makers and best practices need to be better communicated to all.
- Head is best but flow is also!. Low head hydro (0.5 to 3m) have been widely rejected until recently as being too inefficient & expensive but is not the case with right technology, but does the will to implement them
- If other countries can implement much more pico, micro and mini-hydro then why not in the UK with its abundance of rain, rivers and coastline?

7. Towards Implementing Low Head Hydro:- The Future 2007 to 2020

- RE and micro-generation are important parts of energy mix to help achieve energy, climatic and environmental targets. However, a better understanding of scale & effect is needed to get a more balanced view.
- The technology exists now for extending the use of micro-hydro but is the will there from government and the environment agency to work to help achieve this, as being done more for wind & solar technologies?.
- Simplifying the consent process for pico and micro would offer significant manufacturing opportunities in the UK, although it is a highly competitive market and more government funding for technology transfer, RD&D and training people are needed to make it work.
- We should be developing many more existing mills, canal locks and weir sites that are available now, subject to getting a more simplified process, and obtaining grants to make them more financially viable.
- Tidal and wave power is now moving towards commercialisation and will become mainstream by 2020 to compare favourably with offshore wind, utilising river estuaries and coastal strips. Tidal lagoons, tidal energy bridges (Morecambe Bay, Solway Tidal, Severn Barrage).

8. Conclusions

- Potential is v high, Implementation v slow (DTI, B&V, BHA, BWEA, G&H)
- Austria>58% (11.8GW), Italy>13% (13.7GW), Romania>29% (6.3GW), France>13% (25GW), Germany> 5% (4.6GW), UK (less than 2%) 1.4GW !
- High head is best but many low head moderate flow sites viable ($P < 7.Q.H$).
- Low Head sites are not being developed due to a lack of awareness of technologies, perceived costs and disproportionate regulation.
- Many UK feasibility studies in recent years are positive but the majority never seem to get implemented, (like onshore wind), but the situation is improving.
- Much can be learned from best practice schemes in the UK and overseas, to understand technologies & get a balanced view of energy & environment.
- Still a slow uptake in micro-hydro but this can be resolved by using the right technologies, a more fit-for-purpose approach and simplified consents.
- Whilst some improvements have been made, much more needs to be done by stake-holders to reduce legislation, integrate technologies and reduce costs.
- Technologies are available now for many head and flow combinations and 1000's of sites are financially viable (£3- 6/kWe) with PB of around 10 years.
- But is their enough will, resource, all round interest and government support for academia, manufacturers, and specialists to deliver a micro hydro revolution? It is happening for solar and wind. Hydro in small pockets in a disjointed way.