Edgeworth, Matt. 2018. Rivers as material infrastructure: a legacy from the past to the future. In Holt, Emily. (ed) *Water and Power in Past Societies*. Albany: SUNY Press, 243-257 (pre-publication version)

RIVERS AS MATERIAL INFRASTRUCTURE: A LEGACY FROM THE PAST TO THE FUTURE

Matt Edgeworth

Abstract *In 2010, a total of almost 26000 sites on rivers and streams were identified as having potential for small-scale hydropower generation in England and Wales alone. This paper examines the historic character of many of the river features, structures and layouts involved. It argues that a material infrastructure for the development of hydropower already exists in the form of heavily engineered watermill landscapes representing over a thousand years of human-river interaction, from at least the Late Saxon period (9^{th}-11^{th} centuries CE) to the present day. As a legacy from the past, this infrastructure of leats, weirs and reservoirs could potentially be modified and re-used for production of renewable energy in the present and the future.*

Introduction

The starting point for this paper is a map produced by the UK Environment Agency in 2010 (Figure 1). It identifies sites on rivers with potential for small-scale hydropower generation. Astonishingly, the map pinpoints nearly 26,000 sites in England and Wales alone. The report does not give detail on what these sites consist of, where they come from or how they got to be there. It simply classifies them in terms of the potential kilowatt power that might be generated at each site (Environment Agency 2010).

The report acknowledges that not all the sites identified on the map will be adapted and utilised for hydropower generation. Some are in unpopulated areas where maintenance would be difficult, or too far away from points of connection with the National Grid. Even if all the identified sites were developed, small-scale hydropower can never match the scale of output from coal-fired or nuclear power stations. The theoretical maximum outage for all of the sites together is 1178 MW, which is equivalent to just 1% of the UK's projected electricity demand in 2020 (Environment Agency 2010, 19).

But that is beside the point. Renewable energy has important symbolic value to society that goes far beyond economic value, and in this context the small scale of operation can have advantages over more industrial processes of energy production. Development of 'green' energy programmes is crucial to the broader aim of achieving sustainable living, and to tackling problems associated with climate change, environmental pollution and depletion of resources. Even if only a third of the sites identified on the map were developed, small-scale hydropower could provide a substantial portion of the country's renewable energy, alongside wind and solar power.

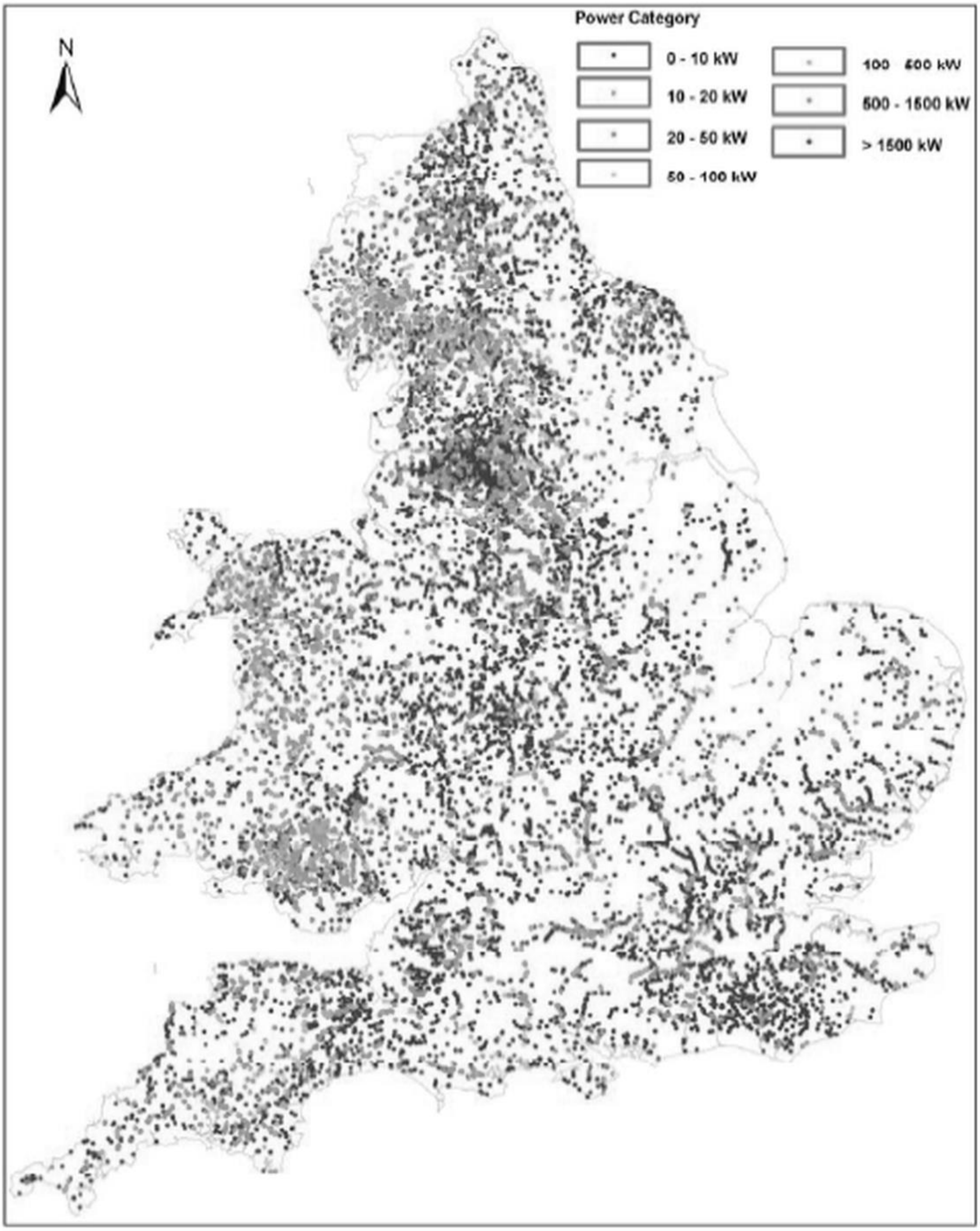

Figure 1 Map of sites in England and Wales with potential for small-scale hydropower generation (Environment Agency 2010).

Even so, this paper takes a neutral stance towards energy policy and argues neither for nor against development of small-scale hydropower. Issues, as always, are complex and there are valid arguments on both sides, as in the debate about wind farms. The aim of the paper is to use the debate on hydropower as a kind of window through which to look in on aspects of the state of rivers in England, and to explore implications of the concept of rivers as material infrastructure.

What is truly extraordinary about the map, as this paper will show, is that the vision of the potential future development of rivers it presents is based upon a material infrastructure that is already there, in the form of older but often still functioning river structures and layouts. This temporal and cultural dimension to rivers – the fact that they have been shaped by past generations of human beings in ways that both enable and constrain what can be done in the future – will be crucial to the analysis presented here.

The first step is to look in detail at some of the individual sites indicated on the Environment Agency map, to establish what kind of sites they are and why they are deemed so suitable for development for hydropower generation.

Weirs and Associated River Structures

The Environment Agency map was generated mainly from mathematical data on river water levels, assembled by the use of LIDAR (Light Detection and Ranging) and other remote sensing techniques on rivers and floodplains throughout England and Wales. River 'barriers' were identified wherever a sudden drop in water level of at least 1.5m was indicated. For each barrier, data on height of the structure and amount of flow was used to calculate an estimate of the amount of power that could potentially be produced if a hydropower turbine was installed on that location.

What exactly is meant by the term 'river barrier?' The report notes "These sites are mostly weirs, but could be other man-made structures, or natural features such as a waterfall" (Environment Agency 2010, 7). Beyond this basic information, no further enquiries were made about the historic character of many of the sites. Environmental sensitivity of sites was evaluated on the basis of likely impact of the structures on the movement of fish. Since few if any weirs are designated to be sites of historic interest, and none are protected as Scheduled Ancient Monuments (archaeological sites or buildings protected by law), the potential historic significance of the structures was not taken into account.

Let us therefore zoom in to focus on a particular group of 'river barriers' or weirs, on the edge of one of the densest clusters on the map.

Case Study 1: New Mills, Derbyshire

The following case study takes as its subject area a 500m stretch of the River Goyt in the town of New Mills in Derbyshire.

In this short section of river there are five river barriers or weirs, neatly spaced about 100m apart. Each weir is effectively a small dam, retaining and deepening the water on the

Figure 2 Weir on the River Goyt, New Mills, Derbyshire

upstream side, while allowing flow of water over the top and down a sloped apron or series of descending steps on the downstream side. These structures are mainly made from large blocks of quarried local stone, sometimes augmenting rocky formations in the river bed. The weir creates a 'head' or 'fall' of water, which is the vertical distance between the respective levels of water upstream and downstream of the weir. This artificially created drop in level is typically part of a more extensive river layout, where several weirs in succession effectively step the river into a series of descending levels in the direction of flow, as in this case (Figure 3).

As the place-name New Mills suggests, the weirs on the river were associated with watermills. Before the introduction of steam turbines, in the 18th and early 19th centuries, it was water that powered the development of the cotton industry. The weirs created the head or fall of water needed to turn the waterwheels, which in turn were connected through gearing to further machinery for industrial production and processing. All the mills had fallen out of use by the mid-20th century. Some of the mill buildings are still standing while others survive only as ruins or have been demolished.

The weirs were never intended to be standalone features, but rather were designed to be part of complexes of water features that functioned together. In most cases water was directed into a leat or head-race, the inlet of which was placed at the higher water level *above* the weir. This brought the water to the mill, where the fall of water in the wheel-pit can be understood as a direct counterpart of the fall of water at the weir itself. Once the energy of the falling water had been used, a continuation of the leat or tail-race took water back to the river, with the outfall at the lower water level *below* the weir. The traces of several such leats can be discerned on the map shown in Figure 3.

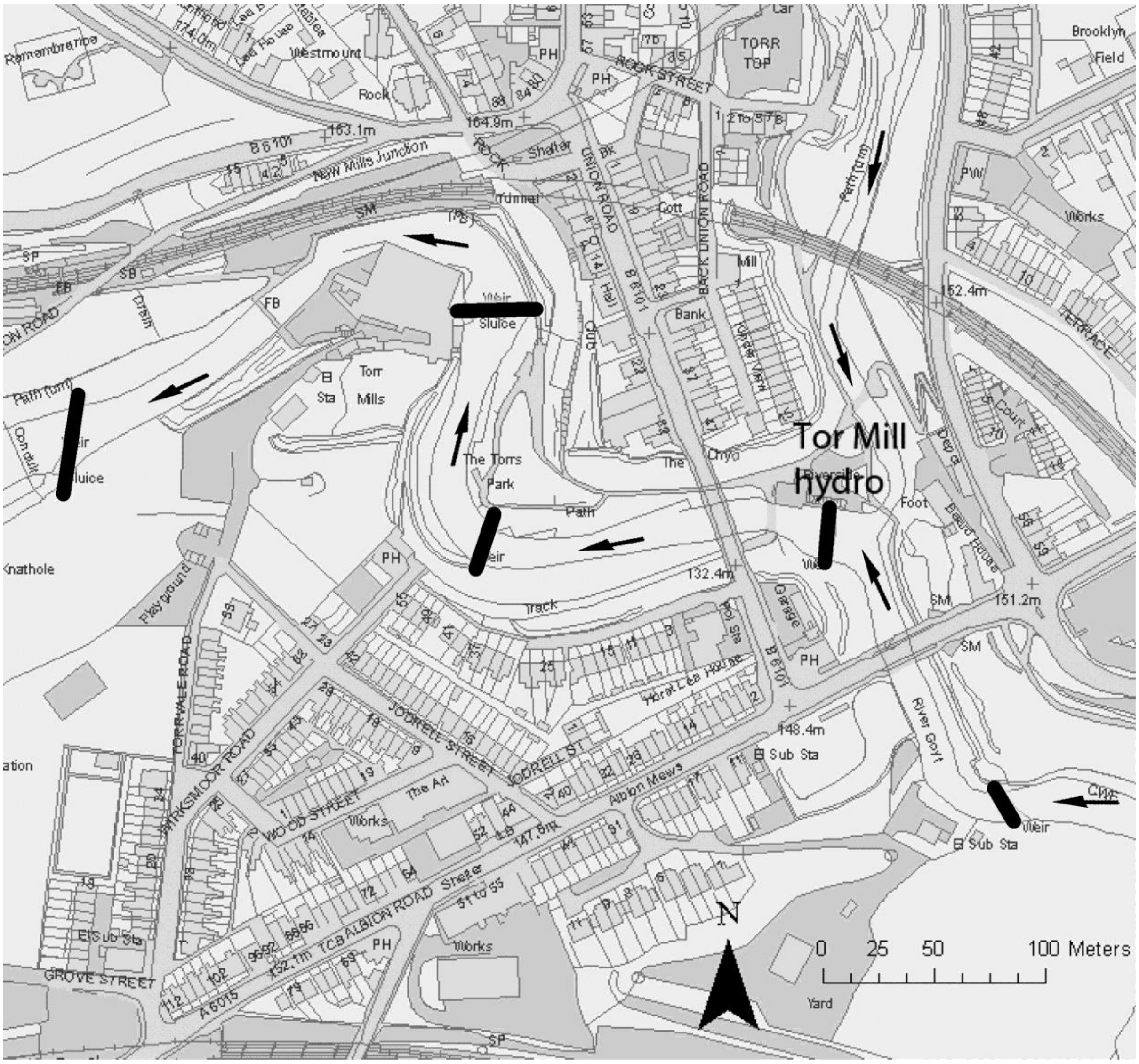

Figure 3 Map of New Mills, showing a stepped river layout with five weirs marked by bars. Direction of flow is indicated by arrows.

The functioning of weirs and their associated leats was subject to the vagaries of river flow, and modifications to the system had to be made accordingly from time to time, leading to complex developmental histories. Disentangling these histories comes within the remit of an interpretive approach that I call ‘archaeology of flow’ – a form of analysis which takes account not only of human agency in the past but also the agency of material currents flowing through the landscape, and the entanglement of these different kinds of forces (Edgeworth 2011a).

In the case of Torrs Mill, the mill buildings and weir were constructed right next to each other, with a very short head-race and tail-race taking water to the wheels. Problems were encountered with the flow of water into the leat, however. The shortness of the leat may have been one reason, making water flow more difficult to control. Another reason was that water supply to the wheel was being disrupted by flow from the tributary coming in to join the main river a short distance upstream, causing eddies and inconstant flows. An attempted solution was to build the weir much higher to increase the head of water – but the problem persisted. Eventually the solution devised was to construct a second weir further upstream and to divert water using a long leat or channel running alongside the river for about 100m, bringing it over the tributary and into the mill by means of a bridge. In other words, the mill was now powered by water fed into it from two weir-and-leat systems.

All this and more can be deduced from a study of the material remains on the ground (or more accurately in some cases, in the water). Both weirs are still functioning (Figure 4a, 4b), so that the river layout of a descending series of steps or levels is largely intact and working. Mill buildings have long since been demolished. But the long leat running alongside the river survives, albeit dry and partially filled in and used as a public footpath (Figure 4c). And the fact that the system of water flow is still at least partly viable is attested by the recent addition of a small hydropower plant (Figure 4d), of which more will be said below.

It is evident from such remains that people in the past were involved not merely in shaping the river to a particular design, or managing and utilising water as a passive resource (the implication of the somewhat bland term 'water management'). On the contrary, they were engaged in a kind of wrestle with a material force that, though it could be channelled and corralled up to a point, acted back in unpredictable ways, forcing original schemes to be adjusted and further measures to be taken to deal with it. The archaeologist of flow, like a kind of river detective, has to unravel the ways in which human projects and river currents have become materially woven together. Rivers are artifacts (Scarpino 1997; Edgeworth 2011) to be sure, but something more than that as well. It is not just about human agency. River forces and human forces intermingle – sometimes flowing together, sometimes pitched against each other. Instead of calling them artifacts, the term human-river entanglements would be more appropriate.

Figure 4a

Figure 4 Systems of flow at Torrs Mill: a) first weir, built higher than normal to increase head of water, b) second weir 100m upstream, c) former leat from second weir to mill, now a footpath, d) Torrs Hydro.

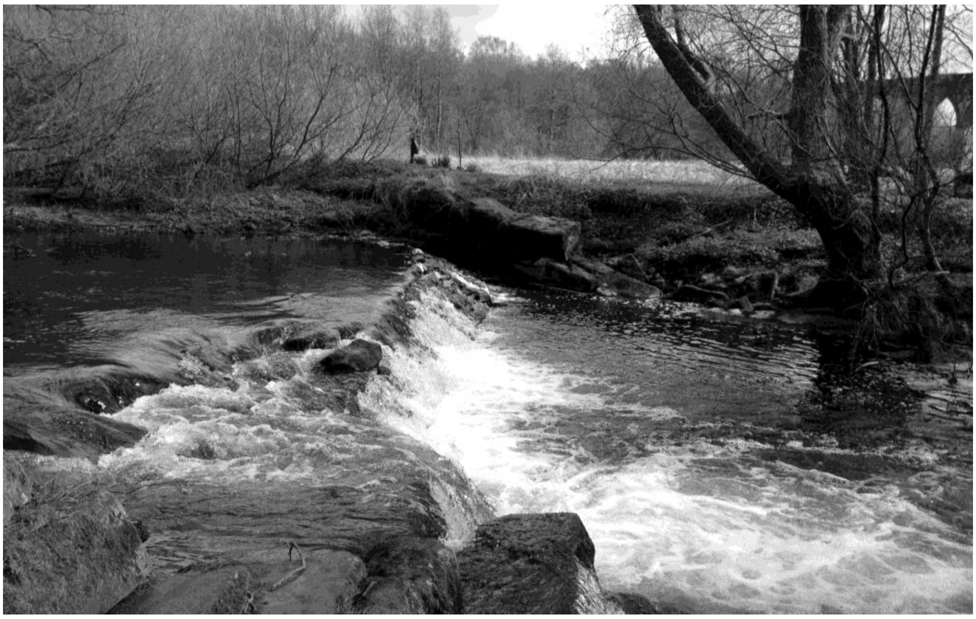

Figure 4b

Figure 4c

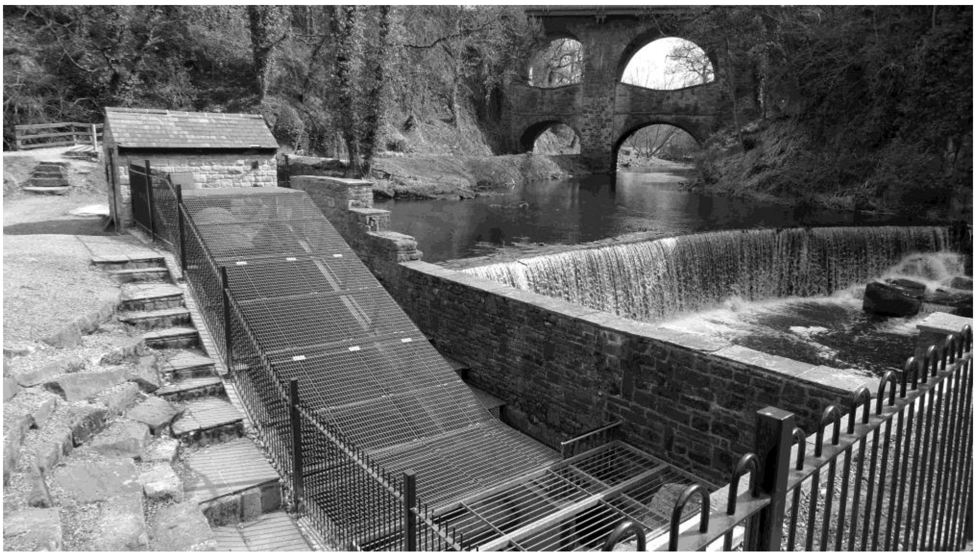

Figure 4d

An example of how existing and still functioning structures such as weirs can be re-used to serve contemporary and future needs is provided by the Torrs Hydro, built next to the weir on the site of the former mill in 2008. The first hydro plant in England to be owned and maintained by a local community, it uses a 'reverse archimedes screw' turbine to generate about 200,000 kilowatt hours of electricity over a typical year – the equivalent of the annual electricity consumption of around 50 typical British homes. It utilises the same head of water as the old mill did before the construction of the second weir. This is an exemplar of exactly the kind of contemporary re-use of existing river structures that the Environment Agency has in mind when it speaks of the potential of the 25,000+ sites identified on rivers and shown on the map.

Although the generation of hydroelectric power at Torrs Hydro is a success, problems are still encountered with irregularities of water input caused by disruptive flows from the tributary. Should the problem ever become more serious, a viable course of action, already tried and tested in the past, might be the re-opening of the leat from the second weir 100m upstream, and the construction of a small bridge to carry it over the tributary to the hydropower plant.

Figure 5 depicts a large mill building that is still standing about 200m downstream of Torrs Hydro, around a bend or two in the river, showing a) where the water entered the mill through a metal sluice and short head-race, taking water from above the weir, and b) where the water came back out again through a short tail race below the weir.

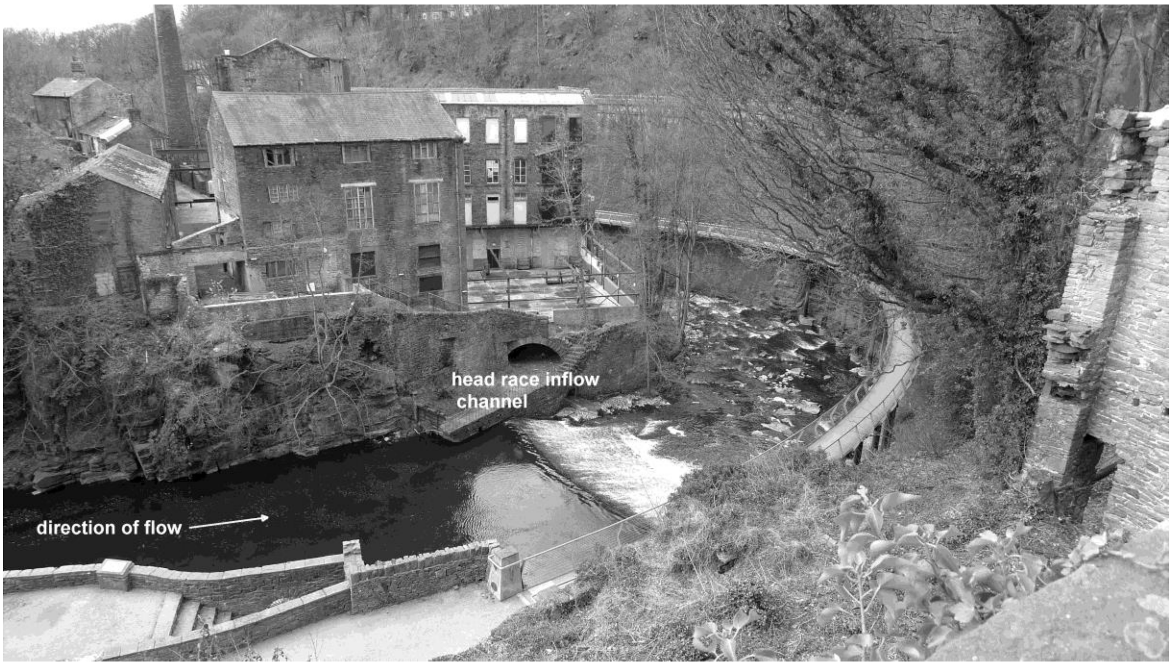

Figure 5 (a) Former mill building, showing head race with inflow upstream of weir. River Goyt, New Mills, Derbyshire.

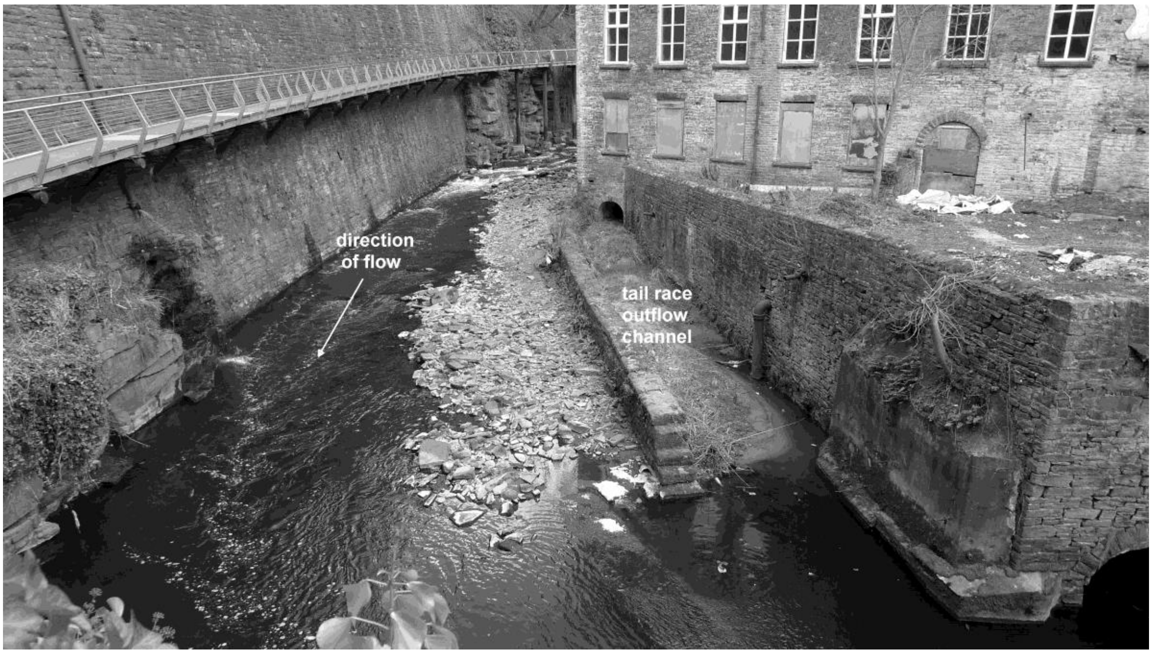

Figure 5 (b) The same former mill building, showing tail race downstream of weir. River Goyt, New Mills, Derbyshire.

Head-races and tail-races are short on the River Goyt because the watercourse here is fast and steep and it is relatively easy to create the necessary fall of water through construction of a weir alone. On slower rivers races or leats tend to be much longer, as illustrated by a later example.

The Force of Local Community Action

A significant force in the movement towards small-scale hydropower generation, as in the example of Torrs Hydro above, comes from local community involvement. This is often more than just community groups being led by national policies and strategies of state bodies such as the Environment Agency: there are notable instances of local groups taking the lead and pioneering a way forward.

This is certainly the case with the *Power in the Landscape* project in the Upper Calder Valley, based at the Alternative Technology Centre (ATC) in Hebden Bridge, West Yorkshire. The River Calder runs about 60 miles to the north of the River Goyt in the middle of a dense cluster of river barriers shown on the Environment Agency map. Numerous tributary streams flow into the Calder down steeply wooded valleys, with the same step-like succession of weirs that was identified on the Goyt. Nearly all the weirs here too, as in New Mills, were associated with textile mills. And again, the weirs are linked with other structures and features, such as connected chains of leats and reservoirs running alongside and above the water – mostly either ruined, silted up or overgrown. But many of the weirs are still intact and functioning. The project has 1) drawn attention to the existence of all these interconnected features through historical research and field survey, 2) shown the high potential for re-use for small-scale hydropower generation, and 3) provided support to communities and organizations to encourage the installation of hydropower turbines (refer to the Power in the Landscape website, listed in the references section).

This adds something very important to the Environment Agency map shown in Figure 1. What is missing from the map is the dimension of time, for the historical aspect of river barriers is almost completely neglected in the accompanying report. Yet the sites identified as having such potential for present and future are clearly inherited from the past. The stepping of watercourses into staircase-like series of descending levels, far from being a natural feature, is the product of human-river interaction over many hundreds of years, a part of historical process. Weirs are components of a material infrastructure that has been inherited as a legacy from the past, to be passed on to the future as a kind of river heritage.

The concept of river heritage may seem strange. ‘River’ and ‘heritage’ are words not often used together, and river features are rarely described as being of historic or archaeological value. Bringing the terms together may mean a rethinking of the definitions of both. For in seeing rivers as culturally and historically constituted rather than as natural entities, rivers challenge us to think of heritage and heritage conservation in new ways. Many historic river structures and layouts are best preserved precisely by keeping them in use, or by adapting them to present and future needs. Weirs need water running over them or they quickly dry out, develop cracks and become ruins. Mill leats and other channels need water running through them or they rapidly silt up, clog with vegetation and become buried archaeological features.

An example of such re-use is provided by the hydropower turbine installed on a tributary of the River Calder is at Gibson Mill on Hebden Water. Here the turbine has been placed not on the weir itself but in the former wheel pit of the mill, replacing an earlier turbine of 1925. It makes use of an elaborate water system that includes the weir on the river, the head race taking water from above the weir, a large reservoir that stores the water, the former wheel pit in the mill itself and the tail race taking water back into the river below the weir. All these river features are preserved by the act of using them. Gibson Mill is now run by the National Trust and is its flagship sustainable building, using the hydropower turbine alongside solar panels to generate all its own electricity (refer to National Trust webpage on Gibson Mill).

Other Examples

It has not been possible in such a short paper to give examples of the full range of rivers that have been shaped or stepped extensively through the construction of weirs, mainly for the purpose of milling, although the map in Figure 1 gives a good indication of the number of river barriers that exist. The Upper Calder and the Goyt are both small but fast-running rivers in upland areas. But similar processes have been at work on larger and slower-running lowland rivers too, with variations in the form of weirs and especially on the length of leats (which tend to be longer in order to create the necessary fall of water).

While referring here mainly to rivers in England, very relevant examples could be drawn from other countries. An important paper about streams in Pennsylvania and Maryland, USA, appeared in *Science* (Walter and Merritts 2008), drawing the attention of the scientific community to the impact of mill dams or weirs on the geomorphology of meandering rivers and their floodplains, previously thought to be natural. Here numerous 18th and 19th century mill dams had mostly fallen out of use and been partially buried, due to build-up of sediment behind them, with river barriers inserted across streams (and across the floodplains too) every kilometre or so. The paper shows how floodplains were transformed through changing patterns of sedimentation and erosion, leading to development of a distinctive type of meandering channel running through a deeply layered floodplain easy to mistake for a natural formation, but in which human as well as river agency have played a part. The paper by Walter and Merritts is highlighted here as a must-read for anyone researching the impact of mill weirs on wider landscapes. Many of its conclusions can be applied (with modification to allow for variations in river type and forms of technology) to understanding of historical transformations of rivers and floodplains in lowland areas of England and other parts of Europe.

All the examples looked at so far are from the Industrial Age. Would it be reasonable to assume, then, that this great transformation of rivers has occurred solely in the last few hundred years since the start of the Industrial Revolution? That would be an easy but mistaken assumption to draw. Suppose we had a database listing river barriers on English rivers a thousand years ago, from which we could generate a map roughly equivalent to that produced by the Environment Agency of river barriers today. How would the two maps compare?

Actually, such a database exists, at least for most parts of England. The Domesday Survey of 1086 recorded mills along with other information for taxation purposes. Although there were some animal-powered mills at that time, nearly all the mill sites recorded would have been watermills and most would have required a weir or dam to function properly. There are upwards of 7000 mill sites recorded in England alone. Allowing for those sites where two or more waterwheels on the same site were counted separately, it can be estimated that at least 6000 water mills existed at that time. Most of these would have used weirs or dams on the river to provide the head of water to drive the waterwheels. In some cases a single weir might have served more than one mill, but it can be reasonably inferred from the Domesday records that several thousand weirs existed at the time, perhaps equivalent to about a fifth of the number of river barriers shown on the Environment Agency map. That is a significant proportion, and even if the assumptions and inferences drawn are only half correct, there are indications that the artificial stepping of riverscapes was essentially already well under way by the Late Saxon period (9th-11th centuries CE). There was undoubtedly considerable acceleration of the river stepping process in the industrial period, but this and other kinds of human-river interaction go back much further in time than might be assumed (Blair 2007).

Material evidence also exists in the form of archaeological structures in abandoned river channels. A stone dam of 11th century date was recently excavated on a former course of the River Trent at Hemington in Derbyshire (Clay and Salisbury 1990). The line of a medieval weir has been identified, from an aerial photo on Google Earth, as an ‘underwater crop mark’ or linear pattern of vegetation rooted in the disturbed riverbed (Edgeworth 2011, 92). Such structures impacted in multiple ways on the geomorphology of rivers.

It must not be thought, however, that weirs of medieval and Saxon date are necessarily buried or submerged – or for that matter swept away, dismantled or ruined, though some certainly are. Many have been in continuous use, regularly repaired and sometimes rebuilt on the same site since Middle Saxon times (7th– 8th centuries CE). The same is true of mill leats. Generally the water management systems associated with mills show an extraordinary durability and longevity of use. A considerable number of those listed in the Domesday Survey remained in use until the advent of electricity in the early 20th century. Some, like Otterton Mill described below, are still functioning.

Figure 6 Watermill landscape on the River Otter, Otterton, Devon, listed in the Domesday Survey and dating to the Late Saxon period.

Case study 2: Otterton Mill, River Otter, Devon

Otterton Mill on the River Otter comprises a whole watermill landscape rather than just the mill building itself. The mill is part of a much broader system of flow, which includes the weir, head-race and tail-race (leat). In fact, a good way of defining the extent of a watermill landscape in space is to take it from the place where water is taken from the river to the place where it is directed back in again. At Otterton there is a fine example of the longer type of leat mentioned earlier, in this case measuring 400m from inflow to outflow, as shown in Figure 6. These long leats were used, in conjunction with weirs, to create the required fall of water in low-lying areas where slope of land was slight. This was done by skilled manipulation of gravity-driven water flow – raising the height of the head-race above river level as it approached the water wheel, and lowering the height of the tail-race below river level immediately downstream of the mill.

Note the medieval priory south of the mill. This would have used water from the mill leat to service its fishponds, flush out its drains and sewage systems, and so on. In such ways the water management system extended far beyond the river itself, and was interbedded with other forms of social and economic life.

Otterton Mill was only one of a series of such mills, each with its own weir, on the river. Thus the Otter was stepped into the same characteristic staircase-like formation discussed earlier. It was a pattern that could be added to in later periods, by increasing the number of levels within the already existing stepped layout. The great acceleration in the building of mills and their associated landscapes in the industrial period often took place on riverscapes that had already been stepped in preceding periods. Thus on the stretch of the River Goyt at New Mills described in Case Study 1, for example, there was at least one mill - and therefore at least one weir and change in river level – in existence in the Late Saxon period.

The stepping of the river that took place back then through the construction of weir-and-leat systems for mills, appended onto in later periods, is what makes the re-utilization of such landscapes for hydropower generation possible.

Conclusion

Returning now to the Environment Agency map shown in Figure 1, and to the 25,000+ sites it shows with potential for hydropower generation, we can see that this is a map of the past as well as the future – or rather, a *map of potential for the future based on a map of the past.* Installation of hydropower turbines would in almost all cases not entail starting from scratch. Most of the essential infrastructural work has actually already been done: a material infrastructure, as we have seen, already exists. In many cases what would need to be done is to modify existing structures and layouts to accommodate turbines, if deemed appropriate to do so.

This often applies to structures that seemingly have little to do with mills. In Bedford, for example, hydropower turbines were installed inside a former Edwardian boat slide structure on the River Great Ouse. There are no records or traces of a mill on this particular site. But the boat slide was constructed to provide easy transition for punts and other pleasure boats from upper to lower levels of the river, and it is this stepping of the river in Bedford that (initially accomplished for the purpose of milling) goes right back to late Saxon times. So electricity generated by the turbines is still making use of the work that was done in shaping the river almost a millennium ago, as well as the countless human-river interactions that have happened since.

This chapter has been partly about hydropower sites, but actually it has tried to look beyond hydropower to get at something more fundamental – the sheer extent of the entanglement of rivers with human affairs, not just in the industrial period, but over the last thousand years and beyond. Making use of and following on from an Environment Agency report, it has brought to light a vast material infrastructure passed on as a legacy from the past, with potential to be re-fashioned and re-utilised in new ways into the present and into the future.

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