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**Britain’s Damaged Rivers**

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Good evening everyone, and thank you for joining me here at Gresham College today. Welcome too to online listeners, of whom there appear to be a growing number. This will be the fifth in my series of lectures on the subject of ‘Britain In Troubled Waters’. I continue to be indebted to the Frank Jackson Foundation for supporting my role as Professor of Environment here, and allowing me the indulgence of a public lecture series.

Tonight I want to talk to you about rivers, or more specifically about river channels. Rivers were my first love as a young environmental science researcher back in the 1970s, and I am going to tell you something about that research this evening, and also explain why it is still relevant today. My research forty years ago concerned the impact of urbanization, the construction of buildings, and the laying down of sewers and roads, on British river channels. As we will see later, I am not referring only to the direct effects of rivers being diverted or engineered into concrete channels, such as in the illustrations here, but the indirect effects of changes in the flows of water and sediment in the catchments around the rivers. Changes in these inputs to the river system make the channels’ shapes and sizes alter, providing a kind of ‘living laboratory’. They show how rivers in a more general sense adjust over time, by eroding and silting up in different places and at different times, to maintain a dynamic balance with their surroundings. My research was undertaken at a time when urban environments were not comprehensively planned, and river landscapes had largely escaped the attention of all but dedicated civil engineers. Once an area had had sewers put in to take surface water from roads and roofs to the nearest small river, any other consequences tended to be ignored. As such, the 1970s was a time when one could explore the exciting science of ‘fluvial geomorphology’ without worrying over much about whether you were looking at something entirely artificial; the bulldozers had yet to encroach in any major way directly on many suburban channels. So, it was a genuine laboratory. Later on, that became less true, and urban channels in particular were very much altered by bulldozers, and consequently of less interest in the 1980s and onwards. As an aside, the 1970s was also a time when many urban rivers were very polluted with a range of effluents, and as a consequence rather challenging to explore.

Why is this research still relevant? Those of you who have been kind enough to attend previous lectures will have heard me talking about climate change potentially creating new regimes of intense rainfall and drought, driving different flow regimes for rivers. More floods, and more low flows. To my mind, the impacts of urban development on rivers offer a model of what we may also expect to happen in the face of significant future climate change, and this is something worth knowing about. The other relevant reason is that we have begun to landscape our rivers artificially in ways that have never previously been attempted, to restore them where they have been obviously and seriously damaged, so it is worth knowing a little about their history, and how they may react to our rather puny interventions, perhaps fighting back, or just giving up and dying. You can see here, of course, that I have a rather anthropomorphic view of the ‘personality’ of rivers channels!

Here we see a couple of images of the Thames, our local big river, flowing towards the North Sea between skyscrapers and under bridges, dotted with boats and looking beautiful, serene even. By contrast some smaller urban rivers are deeply unattractive, as is this one in Manchester, with its brick lining, industrial debris and lack of wildlife (other than rats and some urban foxes enjoying a diet of discarded fast food). Here, however, we can see a South London river, the Ravensbourne, that has in the past been polluted, straightened, realigned and hidden away, now brought back to light as an attractive feature for people to enjoy. This is a process called river restoration; we are bringing back to life, a river that was ecologically and aesthetically dead, and involving local people in choices about its rebirth. To many people, it looks to be a great improvement. But tonight, I would like to explore more about the background to Britain’s damaged rivers, what the word ‘damage’ actually means, what benefits there are to come from river restoration, and whether there are any drawbacks.

I would like firstly to ask you to imagine yourself in another time. A few thousand years ago, the London area, and indeed much of lowland England would have been covered by open forest, a ‘wildwood’ mainly of oak and hazel, with grazing herbivores, natural fires and wind-throw maintaining some grassy clearings. We know this as a result of analyses of pollen grains and remains of particular beetle species trapped in sequences of carbon14-dated sediment in lake beds. Rivers would probably have meandered through the woods and clearings, with large boggy areas of wet woodland or marsh being associated with their floodplains. As soils developed slowly by weathering of the rocks and debris emerging from under the retreating ice sheets, they acted increasingly as a sponge, holding water (and indeed carbon) and reducing the speed of runoff, and the flood peaks. Sediment yields from the catchment areas reduced. (Did you know that it was the International Year of Soils last year?). We also know that from early Mesolithic times onwards, that is about 10,000 to 5000 years ago, there is evidence of fire and an increase in the abundance of grasses and trees such as beech, lime (or linden) and elm; people had arrived onto the scene and had begun to manipulate their surroundings, principally to secure their food supplies. The climate warmed up too.

If we jump forwards to medieval times, a little before Thomas Gresham was alive, the English countryside was different again. Most of the tree cover had probably been cleared (in fact by Roman times a lot had already gone), in order to allow arable cultivation of strips of wheat, oats, peas, beans and similar crops. For much of the year the ground would have frequently been disturbed and loosened by ploughing, denuded of winter vegetation and open to heavy rainfall, and the landscape brown rather than the green of the previous pictures. Actually we know relatively little about what rivers were like, apart from what we see in contemporary illustrations and descriptions, such as those shown here. And because rivers are commonplace, the answer to how much we know about their size and shape is ‘not much’. Early maps shown in tapestries, maps, and engineering plans tell us something but only about the river channels of the last couple of centuries and they are undoubtedly inaccurate and partial. There are techniques of stratigraphy, investigations of river-borne sediments laid down by waters in the newly-named ‘Anthropocene Age’ (the age dominated by human beings, where river ‘sediments’ include pottery, and more recently non-degradable plastics) that can tell us more, but the research is painstaking.

The point I want to make here is not so much to clarify the postglacial history of Britain’s landscapes and ecology, but to point out that our island’s environments have always been changing. Specifically of relevance to river channels, the amount of water running over and through the ground after rainfall, and the amount of sediment that can be easily picked up and transported by that water, have undoubtedly changed too, in ways of which we can only see glimmers. This is true of areas that today we call ‘rural’ as well as those we call ‘urban’. Most of our rivers have not been ‘pristine’ for millennia, nor do they really represent some lost Elysian world; despite the apparent attractiveness of small corners of land, our rivers have for thousands of years been degraded by some agency, including people.

Let me now return to my earlier thread about the science of fluvial geomorphology. The natural forms of alluvial river channels (not rocky channels) are a function of the flows of water and sediment that move through them. The channels carry various types of sediment from the catchment areas over which the water has fallen, and flow through deposits that they themselves have transported. They are a response to the forces exerted by the water on account of its velocity, depth and turbulence, and the size, shape and weight of the sediment particles it carries. At different times and in different flow conditions, the water sorts and organizes the sediment and moves it around to yield bars, pools and riffles so loved by fly fishermen, sandy ripples and clusters of gravel. Channels shift, the water cutting new pathways through the floodplains at high flow, filling up old abandoned channels and occasionally encroaching and undercutting hillsides. Their cross sections and patterns can adjust to be wide, shallow and sinuous, or deep and straight, or even multithreaded. However, it is a very complex picture, because not only does every channel reflect contemporary processes and surroundings, it also carries a legacy of its previous history. It will show evidence of a major flood in the undercutting on its bed and banks, for example, and the sediment it has piled up in new places. It may also contain sediments that were delivered to it by the ice sheets of the past – boulders and cobbles that the river is too small now to carry. Summarising, the water in an alluvial channel carries sediment, and cuts its own channel especially in floods, but in turn also is influenced by it in many complex ways.

On top of all of this ‘inorganic debris’ is a biological component too. Rivers can obviously teem with life, and support an amazing variety of ecological assemblages – some of which we value, and some not. But the forms of river channels are directly and indirectly influenced by vegetation and animals to greater or lesser degrees as well. Trees are particularly important both in the channel and in the catchment more widely, and in the past so were animals such as beavers, whose woody debris dams held back astonishing volumes of water in headwater reaches of many rivers. Research into this is taking place in the River Otter today. Now, all of this is what makes fluvial geomorphology, in my opinion, one of the most complex of the sciences. If we want to understand river channel form in any detail, we have to use a whole battery of scientific (geology, sedimentology, physics, biology, maths, chemistry) and archaeological or historical techniques. If we want to understand anything about the changes that river channels experience, we have to understand firstly something about what makes them tick.

The advent of large-scale urbanization undoubtedly created big changes to anything that we might have cast as a natural channel. As urban areas expanded, rivers and streams that had at first provided drinking water and waste disposal opportunities, became overloaded with dirty water and a nuisance. In cities, smaller streams were covered over and lost, becoming mere sewers discharging into the Thames. Only a few legacies still remain. Barton’s ‘The Lost Rivers of London, describes using a variety of sources to find these rivers again. Not that these rivers are entirely ‘lost’ to the perceptive observer. Apart from the ups and downs of London streets as we walk into and out of fossil rivers, tiny legacies can be seen in street names and businesses – the Walbrook, the Fleet and others less well known. Perhaps the most ‘lost’ is the Tyburn, despite the fact that an antique shop in Mayfair claims to have it running, clean and sparkling, through their basement mall…. the electric pump and the goldfish may suggest that all is not exactly as described…and one wonders if that also applies to the antiques…

These rivers also became totally polluted. We are told that in 1810, 400 boats fished the Thames between Deptford and London Bridge, providing roach, plaice, smelts, flounder, salmon, eel, dace and dab to a growing and hungry population. Fish was the food of the poorer sorts. But by 1828, the run-off from privies, gasworks, combined with factory effluent, had destroyed the fisheries, damaging the rivers’ ecology beyond recognition. I am sure tonight’s audience may have read previous descriptions, but this one is particularly evocative:

*‘When the Queen and Prince Albert attempted a short pleasure cruise on the Thames in 1858 they were forced to turn back to land after a few minutes, the odours were so terrible…..In the bright light it appeared the colour of strong green tea, and positively looked as solid as black marble in the shadow – indeed, it was more like watery mud than muddy water, and yet we were assured this was the only water which the wretched inhabitants had to drink. As we gazed in horror at it, we saw drains and sewers emptying their filthy contents into it; we saw a whole tier of doorless privies in the open road, open to men and women, built over it; we heard bucket after bucket of filth splash into it … we asked if they did drink the water? The answer was, they were obliged to drink the ditch…’*

There are nonetheless less obvious forms of river damage to which I want to evaluate for a few minutes. If we examine the nature of urban water systems in more detail, what we see are a range of ways in which a built up area interacts with a river channel. Whereas in the nineteenth century and earlier, towns often had a few ‘combined’ drains into which surface water and dirty water from houses drained into the nearest river, or later on through some form of treatment plant, today’s arrangements are more typically as shown in diagram A on the slide. Surface water drains into the nearest river, and foul water drains through a treatment plant for most of the time, prior to being returned to the river. These arrangements have different implications for the hydrology of the river, but it is the first on which I want to concentrate now. Here is a real example of a river basin in Lancashire, the River Tawd, into which from the 1950’s onwards, a town was built – Skelmersdale New Town, to accommodate people moving out of the unhealthier parts of Liverpool and Manchester. The town was built up over three or four decades, and by the 1970s encroached over half of the river basin surface, and draining into the Tawd. Finding information on river flow is difficult particularly when we wish to establish changes over time, and I have summarized here some data that was available. New towns are places where we might expect to find the best evidence of hydrological changes arising from urbanization, and productive analyses have been done for several UK rivers. In this case, the gauge was frequently subject to vandalism, was overtopped by flooding, and the record was short. But there are indeed indications that flood flows, those actually responsible for maintaining the shape and size of the river channel, were increasing. Modeling this mathematically, it appears as if the flood that we might expect to occur every year, the so-called ‘Mean Annual Flood’ has probably doubled or trebled in size as a result of the impermeable areas and the surface water sewers, and the seasonality in the flow has reduced a little. Naturally, as we move away down the river, this effect decreases as the proportion of the catchment occupied by the built up area reduces, and more rural areas drain into the river. There are no records of sediment moving through the river, so nothing definitive can be said about that.

Turning to the channel, damage by excessive erosion in urban streams is sometimes obvious as I indicated previously. We can see erosion around sewer outfalls, scour below pipes, undercutting of bankside trees, and sometimes rapid changes in the plan form or pattern of the river across its floodplain. This informs a conceptual model, where a river firstly experiences high sediment loads arriving in the channel as the first sods are cut and cleared for houses and roads, followed by an increase in flood frequency as surface water sewers are connected in, and possibly a small increase in total rainfall, as this has been documented in many major urban areas, including London. As a consequence we may expect the river first to silt up, and then to erode as the sequence of higher flood peaks starts to impact. However the challenge is to identify the amount of the long term change, or lasting damage, more precisely, because in most cases we do not have data describing the size and shape of the channel prior to the urban area being built. To do this, we can use a clever trick, known as an ‘ergodic hypothesis’. Rather than waiting and watching what happens whilst a town is built (and research of this sort is rarely funded, since most PhD projects last for only three years), we can look at equivalent channels in rural areas and compare them with the situation in our urban channel.

Since we have relatively few gauging stations in areas that are useful for this type of analysis, we also have to look for surrogates for the flow volumes, and we typically use catchment area (that is, drainage area) as a rough starting point; bigger catchments generate larger flows, and will typically lead to larger river channels. The diagram shows the situation for a number of rivers in the UK. As drainage area increases, the cross sectional area of the river channel (its width multiplied by its depth, or the cross section of the ‘pipe’ it cuts for itself, in shorthand) also increases. It is actually a logarithmic function, and you can see that different rivers grow in size at different rates, The slopes of the relationships are different but regionally there are similarities for adjacent rivers. Turning back to the River Tawd at Skelmersdale, the diagram shows observations of cross sectional area (and width and depth separately) in the urban channel and a comparison with observations in adjacent rural channels. The urban channels are inferred to be much larger than expected below the town, perhaps some seven or eight times the cross sectional size of the equivalent rural channel. They also inferred to be, using this ergodic hypothesis, considerably wider, and somewhat deeper.

Nevertheless, simple bivariate relationships are not statistically very robust on which to base an evaluation of erosional damage, and so in my research I began to look at the influences on the size of non-urban river channels in more detail. This diagram shows the relationships for rivers on different geologies, and it is apparent that rivers on porous and calcareous rocks (chalk, limestone) are much smaller than their equivalents on impermeable non-calcareous rocks. The catchment substrate influences the size of the channel because it influences the flood flows. Now, I am going to skip quite a bit of the statistics here, but suffice it to say that we can identify about half a dozen influences on the size of a channel, and use a multivariate equation of the sort shown here to make estimates of the size of any channel, whether there is a nearby equivalent or not. You can see the various influences on river channel size – the drainage area of the catchment, the drainage density of streams in the catchment, the typical rainfall intensity in the catchment, its underlying geology (as we already saw) and soils, and the shape of the catchment. On the basis of that we can make better predictions of the rural channel size that we would expect in any river. The relationships change from being straight, to a general increase downstream with increasing drainage area, but not a linear one. This is a ‘multivariate model’.

Returning to the Tawd river below Skelmersdale New Town, we see that using the multivariate model to estimate rural channel size, or capacity gives us a better basis on which to determine the enlargement that has undoubtedly happened as a result of the urbanisation. Moving downstream along the channel, we see that just below the town centre the river channel has eroded to some eight times its previous size, falling away downstream to become roughly double its previous size. This is real river channel damage, and explains why the series of bridges that were built by the engineers during the 1960s and 70s kept falling down – they were undermined by increases in the channel’s width and depth.

Here is another example closer to London. The Ingrebourne River in Harold Hill flows south into the Thames, and by the 1970s had had a lot of development and a lot of sewers draining into it. The development was a little earlier than in Skelmersdale, so the channel has had longer to adjust, but the proportion of the catchment occupied by the built up area is smaller. There is no hydrological data for the period of urbanization, but there is a remarkably good set of historic maps that allow us to identify some of the changes in the course of the river – its plan form. Rescaling, manipulating and superimposing these maps, we can show small changes in the course over some four hundred years, mainly a limited straightening of the meandering course. It is not possible to say whether this reflects direct influences on the course by bulldozers or picks and shovels, or natural adjustments, but they are anyway slight. Using the same type of analysis as described previously, an ergodic hypothesis and our multivariate statistical model for estimating the size of the non-urban or pre-urban channel, we can identify the extent of erosion in this channel, as we progress downstream through the outskirts of Brentwood and Harold Hill towards the Thames. There is less channel erosion than in the Tawd, but nevertheless significant changes in cross section, if not in the course of the river. This is typical of many lowland UK rivers, but is widely unrecognised.

My research also took me into a further round of generalisations about the nature of urbanization that was most damaging, and you can see in this diagram for instance, that increases in the extent of urbanization in a catchment cause roughly proportionate increases in the amount erosion for most channels. That is perhaps not surprising, given what we know about the increase in flood flows of moderate size. If we completely smother a catchment with buildings, roads, schools, factories and so forth, we may, other things being equal, expect to end up with erosion scouring out a channel between three and four times the size it was previously. That is some considerable damage, in most cases, regardless of whether the ecology is also compromised, and regardless of whether attempts have been made to pour concrete to control the erosion. Channels cut into clay or sand on impermeable substrates are more affected by urbanization than channels on chalks and limestones; these latter are very robust as they have small flows and tough materials in their banks.

We have many small, ugly rivers in the UK, damaged in the way I have described by direct and indirect human activity. But attempts are being made to ‘restore’ channels to something that is regarded as more ‘natural’ and beautiful, to provide amenity to local residents. I am indebted to Sian de Bell of Leeds University who is researching one such river. The Medlock has been canalised or suffers from erosion along much of its pathway through the northwest of Manchester. It experienced poor water quality as a result of sewer leaks and overflows and was virtually an ecological desert too. Here we see pictures of its situation before, during and after restoration. There is some improvement, of course. However, the main problem, as Sian notes, is that only a couple of kilometres of the river have so far been tackled, in the middle of the river’s course. Since rivers feed their water and sediment downstream, and downstream erosion can also have upstream consequences, this limited approach to restoration is problematic. It is also expensive, and in this case, the majority of local residents actually were not keen on the ‘rewilded’ outcome. When asked, they tended to prefer the controlled and manicured look of a stable channel with mowed grass and concrete paths. There are some other pictures here of ‘rewilding’ of the River Wandle, which has involved removing concrete and brick constraining walls, and planting of new species of trees and shrubs, plus some engineering of a new course for a reach of the river. In this case the effect is more natural, and other restored sites will no doubt evolve to be less trimmed and tidy over time. I show here some photographs of what has been achieved in the River Lippe in Germany, and two kilometres of the River Veyle in France. In the former, the river has been reinstated to a shape and size it may have had prior to Roman straightening and canalization, at great expense. In both cases, the natural ecology for rivers in the region is expected to regenerate, assisted by some planning of native species.

Restoration can have other benefits too. If done in particular ways it can increase downstream flood protection by allowing water to be slowed and retained on floodplains rather than being routed rapidly downstream, and associated conservation can increase biodiversity. Here are two short video extracts, both of prizewinning schemes in the UK where local people have been involved in the decisions to ‘restore’ or ‘rewild’ sections of damaged rivers. The first is of the River Adur in West Sussex and the second of the Kennet and Lambourne, headwaters of the Thames.

The Environment Agency positively evaluated (in 2015) what they found had happened in six years of projects to be a diversity of geomorphological methodologies for approaching river restoration, but certainly wished to see standardization. But there are problems too. I have seen schemes in Austria where steep rivers were engineered in the early twentieth century to stop mountain gravels moving downstream too quickly into urban areas. This had involved putting a large number of concrete weirs into dramatically straightened and narrowed channels, to hold back its transport in the fast flowing water, but release land for building close to the channel. Experimental restoration involved removing these weirs from a couple of kilometres of channel, reopening some old cut off meanders and planting some trees. The problem here is that because the scheme is short and space very restricted, the large volumes of gravel passing downstream had to be extracted from the bottom of the restored reach periodically, trucked back up to the top and replaced in the river. This is not a holistic or sustainable solution reflecting the geomorphology of the river channel, and the same problem (perhaps less acutely) applies to every area where short reaches have been ‘restored’ or ‘rewilded’. The reaches are simply too small for the rivers to be able to respond in any geomorphologically-natural way, even if some local ecological opportunities do present themselves. In the event of a very large flood, and that will occur at some point in every river, these schemes may just be wiped out and will need rebuilding. That is expensive, particularly where such schemes are highly ‘landscaped’, even though the evidence suggests that this is what a lot of people prefer.

Scientists and decision makers are therefore faced with an environmental dilemma in this complex situation: what to do for the best, given all the constraints. I have previously made reference to the work of Roger Pielke in considering the different potential roles of scientists who work with government or similar agencies, and it is certainly relevant in this case. Scientists can merely present a multitude of facts, we can give opinion, or we can try telling them what to do. Personally, in this case, I tend towards the latter position, given the complexity - let’s tell them what to do. And politicians may listen – some do appear have fallen for river restoration projects!

Nevertheless, challenges remain. River restoration can lead to improvements in river ecology and some flood protection, and improve amenity and public access but there are cautionary notes because it is expensive and needs to be handled appropriately.

The catchment setting of the river, and the sediment and water that feeds into it need consideration, and something may need to be done about what is going on further upstream. This might include the tricky task of tackling the activities of farmers in the headwaters, and the downstream urban runoff and sediment patterns that can enlarge channels. Without reflecting that, any restoration scheme will have a short life.

Secondly, a careful decision needs to be taken on the outcomes that are wanted for the river channel. If we want a more ‘natural’ river, what is the ‘natural’ state of a UK river, anyway?

Thirdly, tackling short stretches of the river simply will not work. Rivers are integrated systems of water, sediment and ecosystems, and changing one piece in the system, one short reach, will be expensive and lead to minimal impact, certainly on flood protection.

Fourthly, use the river to assist – making space for the water and for the channel to adapt and shift within the urban landscape will probably enhance its ability to respond, and ignoring that will only lead to other problems.

Finally, scientists must recognize that there may be local opposition to a ‘wild’ river in an urban area. Many people today appear to prefer their rivers to be ‘manicured’, and kept within close-cropped boundaries. We like to see them padlocked into a small space. In the longer term, attitudes may need to move away from appreciation of ‘tidy’ river scenes to ‘messy’ as being appropriate. Messy can be beautiful.

Thank you.

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