Bridgend Report

A review of the causes of flooding and suggestions for alleviation

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A report reviewing the flooding at Bridgend in Stonehouse, Gloucestershire, granted to the Bridgend Action Group by Water 21. This study compiles information collected by the group with further research. The report offers a thorough explanation of likely causes of the flooding, suggestions to solve the issues, and a set of recommended next steps for implementation.

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1 Aim

This report compiles evidence for the causes of frequent flooding at Bridgend, and puts forward a set of solutions to prevent this. It applies Water 21 principles of multi-benefit (least cost) land use, holistic planning, community support and goodwill, providing a long-term, complete solution.

This report aims to inform local residents, represented by the Bridgend Action Group, as well as interested commercial and non-for-profit organisations, local authorities and government agencies. It seeks to provide an overview of the problems and a suitable way forward.

1.1 Bridgend Action Group

The Bridgend Action Group (BAG) was initiated following the floods in 2000. They represent local residents and property owners and involve various interested parties in discussion: landowners, local authorities, local MPs, governmental bodies (Defra, Environment Agency, and Highways Agency), the regional water company (Severn Trent Plc) and non-for-profit non-governmental organisations.

The group aim to alleviate the flooding problem, whilst improving the local environment in a sustainable and economically viable way. They were introduced to Water 21 by David Drew MP, and have requested advice in finding a solution.

1.2 Water 21

Water 21 is a non-for-profit organisation arising from the 1997 Water For Tomorrow conference at Slimbridge WWT (Young and Ray 1997). It is a department of Vision 21, which is a Gloucestershire-based environmental organisation working with the County Council. Vision 21 implements Agenda 21 locally, and in summer 2008 it merged with Cheltenham Centre For Change.

Water 21 focuses on local water problems, promoting safe and economically viable management, based on traditional and indigenous principles, to problems such as flooding and water quality. It acts as a facilitating framework for water sustainability, dealing directly with individuals (consumers and landowners), other organisations, local authorities, governmental agencies, academic institutions, water companies, and local suppliers of expertise and equipment. It offers support for and co-ordination between community action groups.

Local and national projects undertaken by Water 21 include:

- Cainscross Parish Plan,
- River Cree Abstraction Scheme Prevention,
- Equipment and setup of Archway School River water quality laboratory,
- Microbial Standards for Watercourses – co-ordinating research with Gloucestershire NHS, Cranfield Postgraduate School of Medicine and University of Gloucestershire,

- Swift WFD Barcelona – EU Water Framework Directive presentation on microbial standards for watercourses (Jones and Barr 2006),
- Pathfinder community water groups, each of which have £3000 'cash and kind' seed funding from W21,
- Postgraduate & undergraduate student bursaries & internships,
- Stroud Pilot – Community Led Least Cost Flood Alleviation,
- A range of other projects (research, community, domestic & industrial) underway.

Water 21 operates on the following key principles, which set it apart from other environmental organisations:

- Take responsibility,
- Work with others (form partnerships),
- Work with nature,
- Pay the real price,
- Promote equity,
- Use the precautionary principle,
- Not for profit,
- Non party political.

Water 21 has provided a £3000 cash-and-kind seed funding grant to the Bridgend Action Group, which is used to represent them and provide technical expertise. This report is the output of the first phase of Water 21 involvement with the action group.

2 Flooding

2.1 Stroud Valleys

Bridgend (SO 80 04) is situated to the south of Stonehouse, Gloucestershire, on the floodplain of the River Frome. This river rises from springs in Brimpsfield (SO 94 12), and cuts through the Lias layers of the Cotswolds via the Chalford valley to Stroud, where it is fed significantly by the four other Stroud valleys – Ruscombe, Painswick, Slad and Nailsworth. From Stroud, heavily culverted, the river passes down the main valley onto the Severn floodplain at Ebley, whereupon it drains narrowly westwards, feeding the Gloucester-Sharpness canal, and finally joining the River Severn at Framilode. The Frome drains an area of approximately 310 km^2.

2.1.1 Geology

The Cotswold strata originally stretched to the other side of the Severn valley at the Royal Forest of Dean, but have been denuded and folded over several million years. The Cotswolds drained by the Frome and its tributaries run over various layers, which are not evenly developed over the area.

The deepest beds are the layers of shales, clays and limestone belonging to the Lias formation (Figure 1). Water percolates through the layers until it reaches the aquitardant clays, at which point the folded strata are such that allow springs to form at the surface.

The next layer above is the Cotswold Sands, which, despite heavy abstraction for public water supply, is a principle aquifer in the area. Historically, winter rains replenished the aquifer, feeding springs until late summer. Nowadays, some springs no longer function, or generally have reduced discharge, (though some others have newly formed). Confined aquifer layers further west in the strata feed local rivers, such as at Chalford. Many smaller settlements such as Ruscombe were built at the base of the sand layer for water supply.

This layer is topped by inferior Oolite limestones, which are still visible at the highest beacons on the Cotswold escarpment, yet have been heavily denuded. Above this is the easily denuded Fuller's Earth, a shallow band of sand and clay between Upper and Great Oolite layers. Fuller's Earth is rarely seen on the valley slopes today, where its spongy uppermost layer retained valuable nutrients and moisture; it has been washed into the water courses, causing siltation issues. Where Fuller's Earth remains, fertile land exists. Where it has been denuded, the Inferior Oolite below provides a thin, nutrient poor soil which is lightly wooded or bare (Witchell 1882). Fuller's Earth also provides some potable spring water in places, although this supply is easily polluted by surface runoff.

Downstream of the Cotswold escarpment the river flows over the Lias clay and alluvial deposits of the Severn Valley (Fernando 2007).

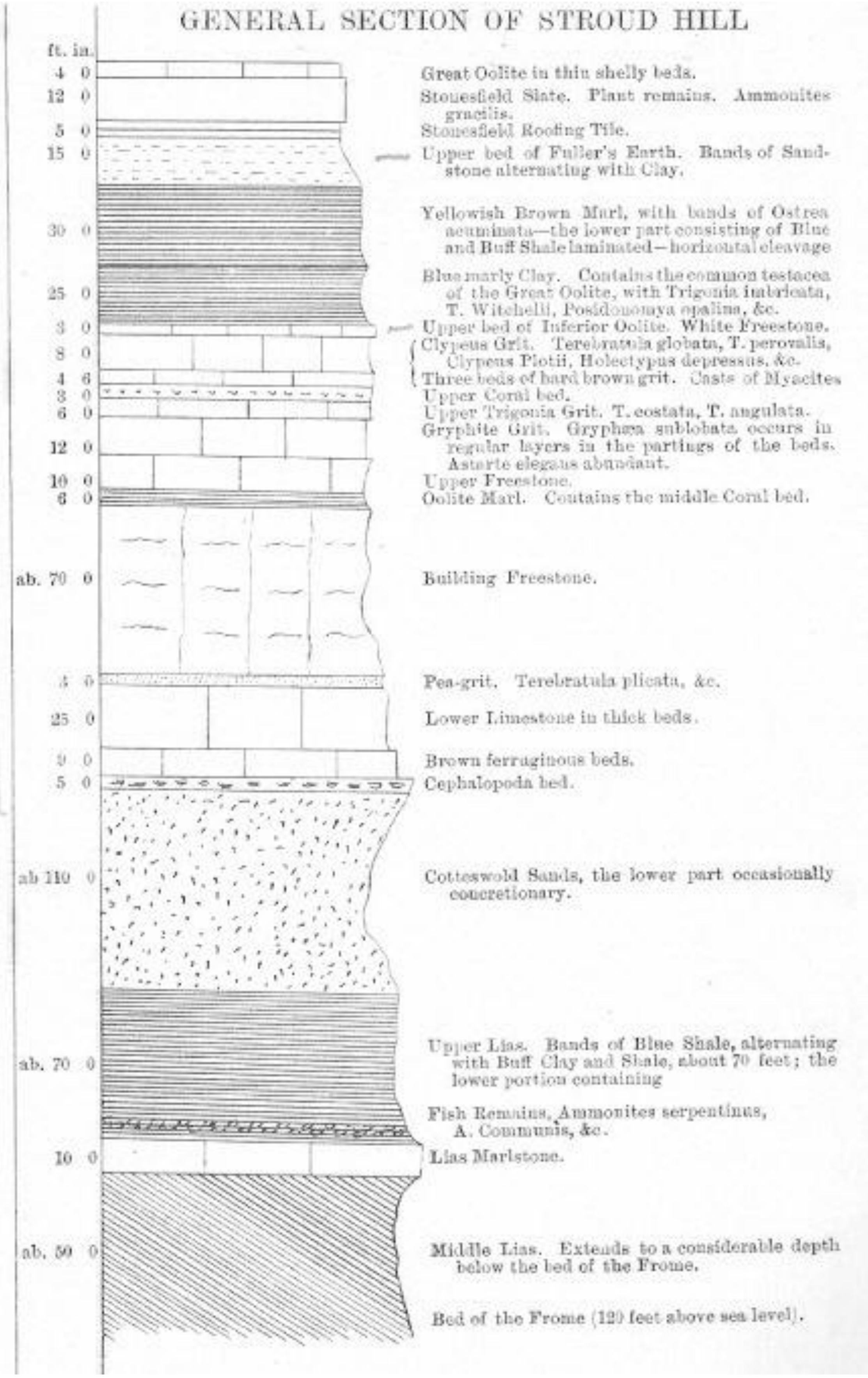


Figure 1: Stroud geology. Source: (Witchell 1882).

2.1.2 Hydrology

The complex geology of the Stroud Valleys gives rise to complex hydrology. Natural denudation of the rock layers, accelerated by urbanisation and intensification of agriculture, has resulted in failure of some springs, creation of others (Witchell 1882), and increasing siltation of water courses.

The low latitude and v-shapes of the valleys indicate that they were not caused by glacial erosion, rather erosion and wasting from fluvial processes. The original drainage network of the Frome and its tributaries was probably initiated by periglacial freeze-thaw of small faults (fractures) in the bedrock caused by tectonic folding millions of years before. Thousands of years of incision and carving have produced the current valley system. The valleys generally follow the position of lateral fractures from the main Frome Valley fracture.

The hydrology is further complicated by artificial modification. Water power has been used in the Stroud Valleys for centuries, and by the Industrial Revolution, there were over 100 water mills along the Frome, and its tributaries. The mills brought disputes of water flow allowances and available head, and watercourses were modified, bifurcated, or impounded.

2.2 Bridgend

Bridgend is a small settlement in the Stroud and Stonehouse conurbation. It lies on the narrow floodplain of the Frome, topographically bordered by the Stonehouse Oolite outcrop to the north, and the raised hills of Leonard and King's Stanley to the south. To the west, the railway embankment provides a break in the natural floodplain.

At Bridgend, three channels of the Frome exist, and the original natural channel is empty. The channels were created to serve various mills, including Stanley Mill, Ryeford (Saw) Mill, Upper Bridgend mills, Lower Bridgend (Paper Bag) Mill and Beard's Mill. In addition to the three channels, the Stroudwater Canal runs to the north of Bridgend, although it is currently in disrepair and does not normally allow for uninterrupted passage of water.

The floodplain downstream of Ebley Meadows is known as the Ryeford or Bridgend meadows. Historically, these were intentionally inundated as flood meadows, but it is uncertain as to whether they were at any point managed as irrigated water meadows. Some of the floodplain has been developed upstream at Ebley, despite being in the flood risk zone defined by the Environment Agency (Environment Agency 2008).

At Bridgend, the meadows cover approximately the same area as they did at the end of the nineteenth century, although development at Bridgend has filled in the space between the canal and the mills.

2.3 Flooding

Flooding occurs at Bridgend from a variety of sources. After heavy or prolonged rainfall, river channels may breach, the canal may overflow, and flash flooding can occur on impermeable surfaces, at blocked drains or on saturated ground. The Bridgend Action Group has collected primary and secondary anecdotal data from several floods since 2000, which supplements additional research undertaken by Water 21.

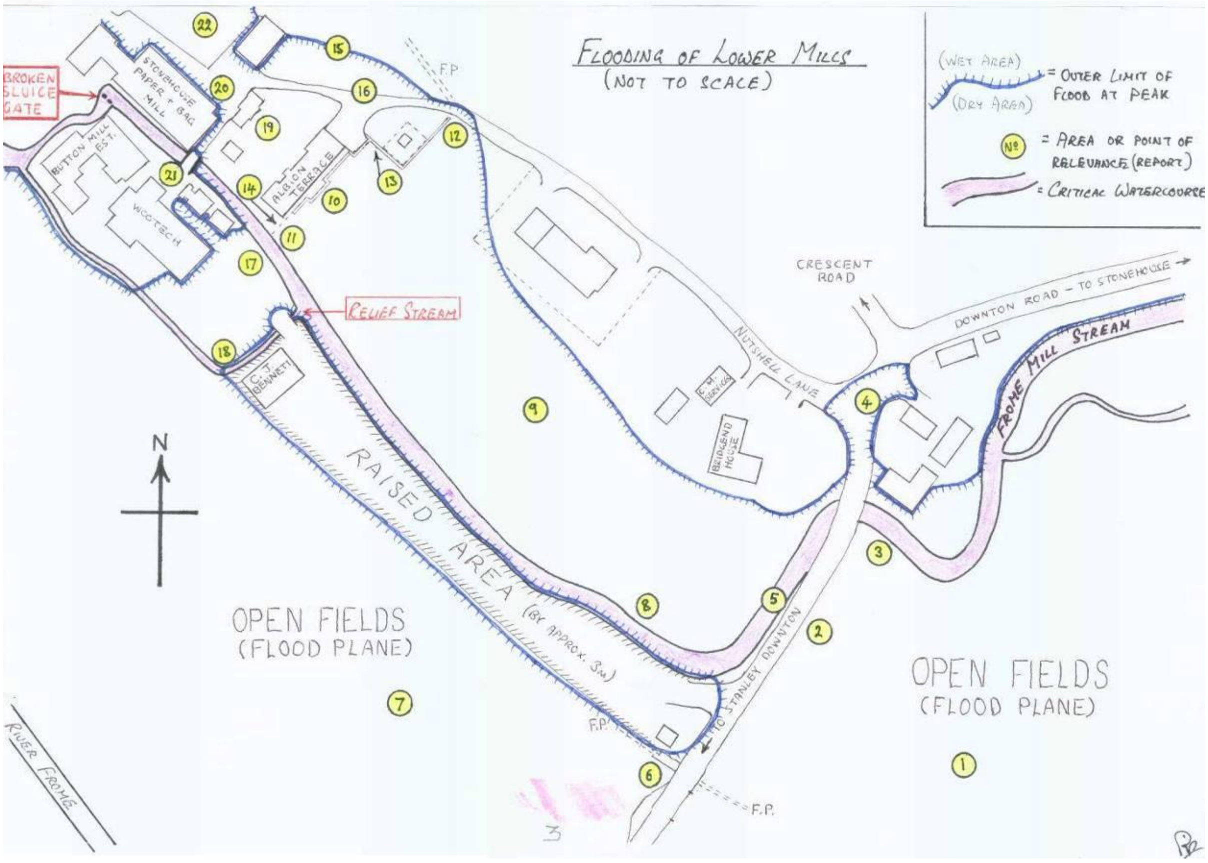


Figure 2: Sketch map of flooding. Source: Bridgend residents.

Flood extents have been identified for recent floods by residents, but no survey data are available to support this. The following information would have been useful:

- flood depths at various locations,
- hydrograph of catchment rainfall and river flow in each of the channels and canal,
- progression of the flooding and receding time,
- flow routes.

Residents produced a sketch map of flooding in 2000, with informative notes (Figure 2).

2.4 Flood damage

Damage from July 2007 flooding was widespread and severe for many people across the region. Situated close to the watercourse, Bridgend residents fared no differently.

Estimates supplied by residents indicate typical damage costs were in excess of £30,000 per household. An estimated £100,000 of damage was done on Albion Terrace. At least one property experienced damage costs of £320,000.

Damage from previous flooding is also high. Insurance costs have risen. Although no properties have been declared uninsurable, excesses have in some cases been raised to effectively untenable levels (£20,000).

2.5 Other considerations

Although the main focus of the Bridgend Action Group is flood alleviation, the group also expresses an interest in improving the water quality and reducing pollution. Water 21 promotes a multi-benefit approach to water management issues, and potential solutions need to be evaluated with consideration of the following:

- Least-cost, maximum effectiveness,
- Naturalistic, sympathetic to the landscape,
- Flood risk alleviation for properties and key infrastructure,
- Improvement of water quality and river environment for public health, outdoor recreation,
- Control and mitigation of river and canal siltation,
- Improved irrigation and productivity of farmland,
- Improvement of fisheries, restoration migratory salmonids,
- Conservation and restoration of habitat and biodiversity,
- Clean local renewable energy,
- Local organic food production,
- Restoration of heritage canal,
- Improve the local community attitudes to water management.

These related issues are interconnected (Figure 3).

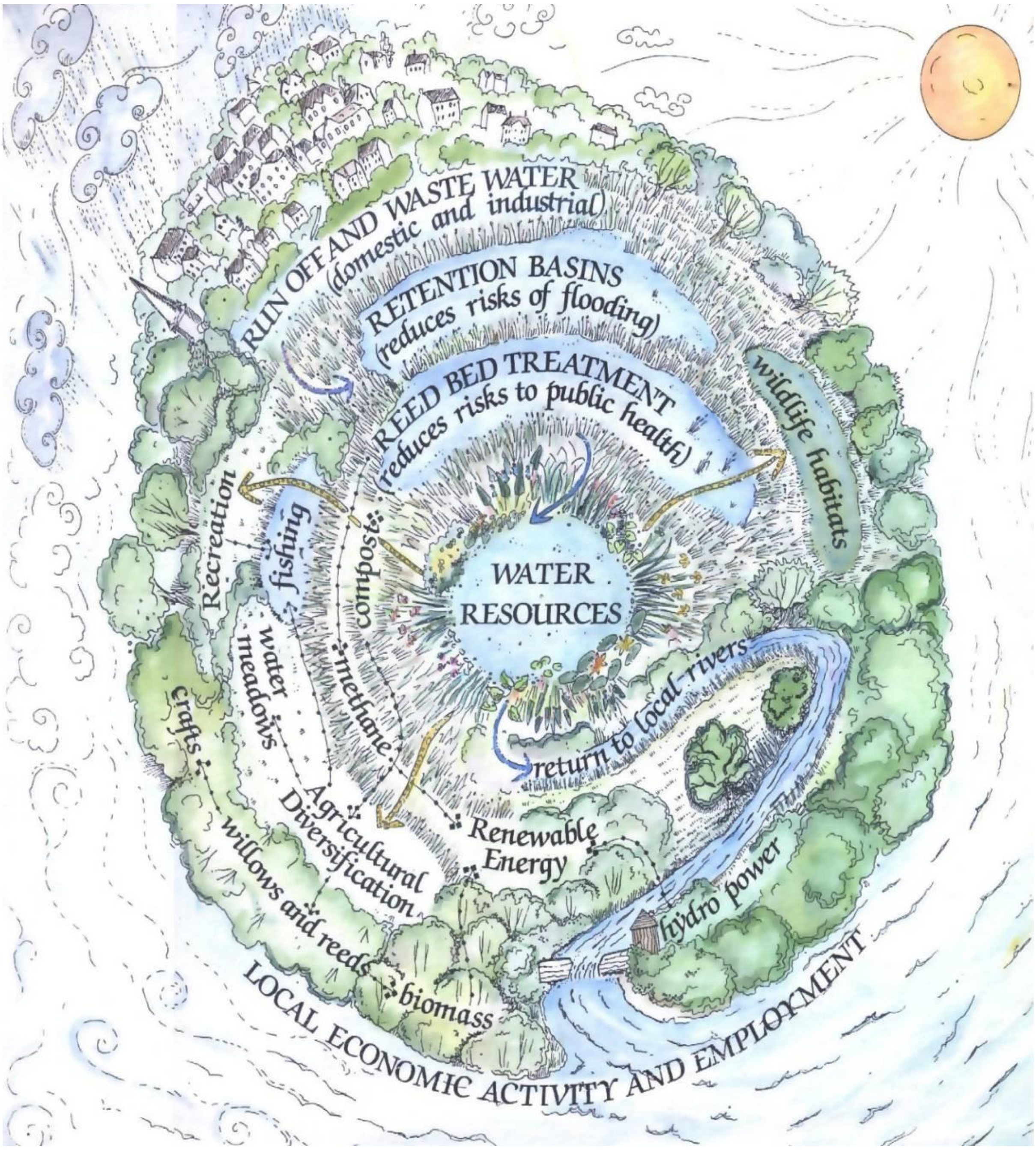


Figure 3: Water resources issues. Source: Illustrated by Lydia Eeles 1997, Copyright © Water 21 1997.

3 Causes of the flooding

The primary causes of flooding at Bridgend may be categorised as resulting from too much river water and ineffective drainage. The reasons for these are identified below.

3.1 Too much water

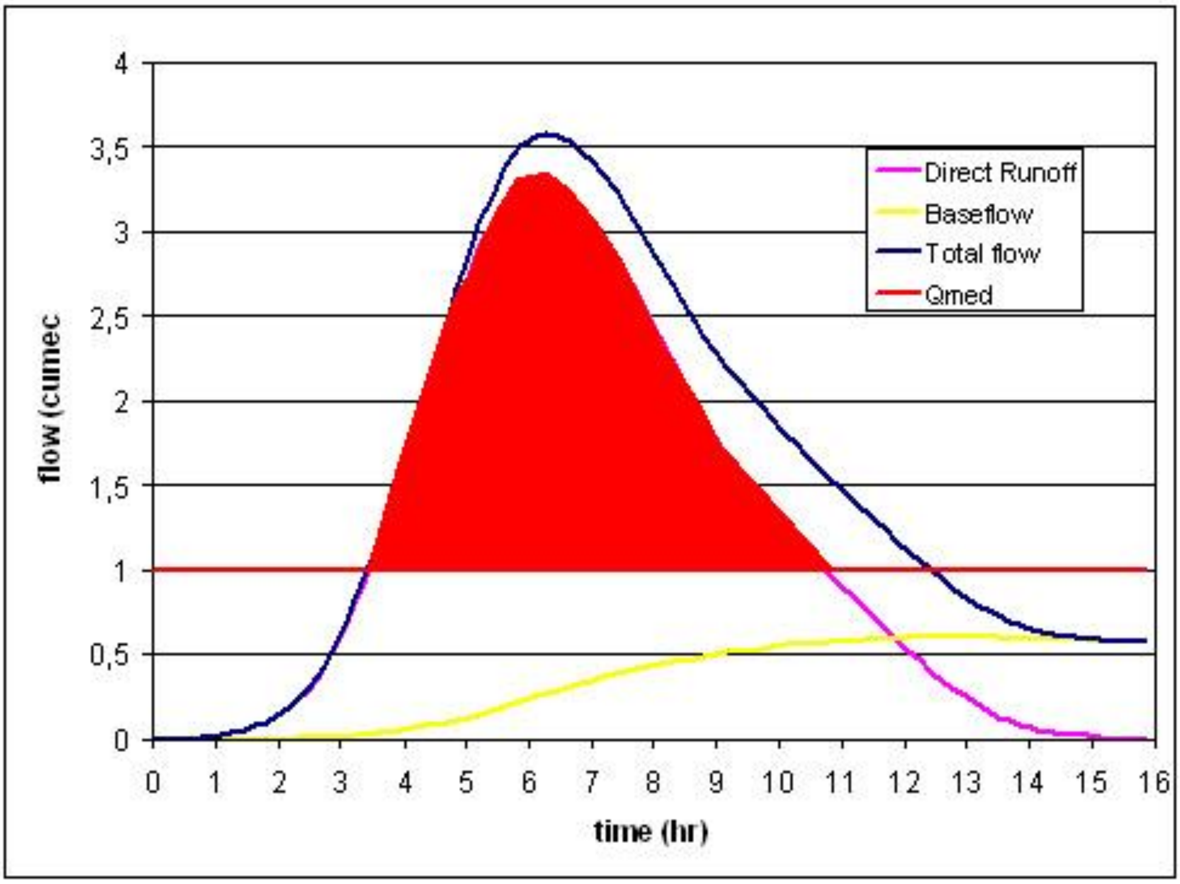
Too much water flows through the catchment during heavy rainfall events for the river and drains to contain.

3.1.1 Loss of natural upstream attenuation

Historically, the undeveloped, pristine Stroud Valleys catchments comprised impenetrable hazel and willow woodlands in the upper reaches (pers comm. Lionel Walrond 29.06.2008). The name "Stroud" comes from the old English "ströd" – marshy wetland that once covered the area. This historic landscape would have better retained rainfall, controlling runoff, in turn promoting aquifer recharge and slowing the drainage into water courses. In recent centuries, large areas of upland woodland and wetland have been replaced with agricultural land and open fields. During the Industrial Revolution, water courses were exploited for milling. Creation of mill ponds partly compensated for the loss of natural wetland, providing both significant attenuation and watercourse control, for example through sluice gates. Since the 1950s and the decline of mill activity, few such structures still exist. These functions have been lost, with no apparent consideration of the many negative consequences, or any attempt to replace them.

The water cycle in the Stroud Valleys has been thus disrupted, with rainfall draining into the rivers and the Severn far quicker than in a natural system. Modern hydrographs are flashier than the historic pre-industrial ones (Hollis 1975, Konrad 2003). This means that nowadays, rivers rise higher and faster than ever, presenting a greater risk of flooding at choke points such as culverts, at low river banks, and from sewer overflows. This not only causes flooding, but is also symptomatic of an overall decline in aquatic ecology resulting from ill considered land management and development policy. Siltation and pollution effects from agricultural and urban runoff, loss of habitat and fish spawning grounds, and loss of potential renewable, clean power generation comprise just part of the loss of local 'ecological capital'; a range of secondary incurred 'costs' to the local community in addition to those of flooding.

Data records are insufficient to identify how river flows have changed since pre-industrial times. However, the river hydrographs calculated for the Slad Valley using surrogate data (Pretto 2008) (Figure 4), and hydrographs recorded at Ebley Mill (Figure 5) indicate a large constituent storm flow volume and flashy regime. Anecdotal evidence from long term residents also supports this, with many remarking how quickly the river rises after rainfall compared with decades ago.



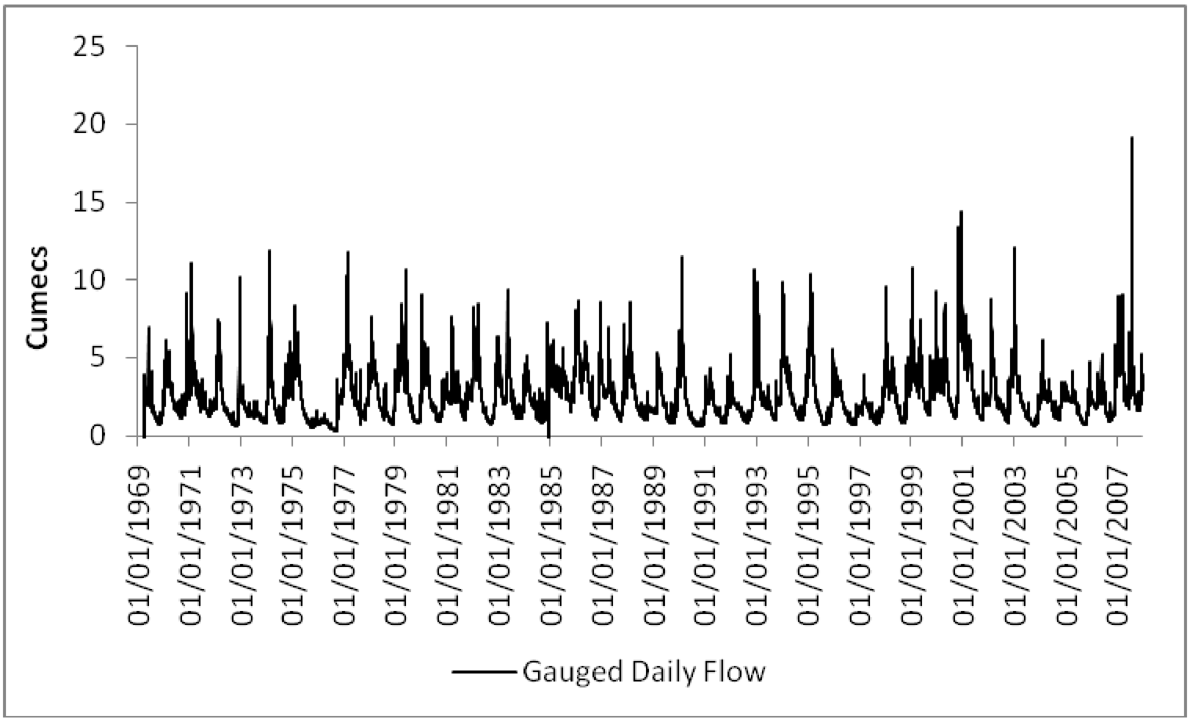


Figure 4 (above): Modelled estimated hydrograph response of the Slad Valley to rainfall. Source: Pretto (2008).

Figure 5 (below): Gauged daily flows from Ebley on the Frome, showing a distinctly flashy regime.

3.1.2 Increased surface runoff

During heavy rainfall periods, surface runoff exceeds infiltration capacity (Kirkby 1978). With increasing development on and around the floodplain area, infiltration zones such as fields and woodlands have been lost to paved, impermeable surfaces. In the local floodplain, recent development includes the Ebley bypass and housing development at Ebley. Drainage from urban surface runoff has also increased from Stonehouse and Stroud, with much of it entering the canal or river directly, or from surcharging sewers and storm overflows. Surface runoff is a major cause of increased flashiness of water courses following rainfall, and therefore is an important source of floodwater (Konrad 2003).

Encroachment onto the floodplain of housing reduces the effectiveness of the floodplain, and puts additional houses into the flood risk zone. Expansion of Stonehouse in the 1970s will have increased the volumes of water draining into the Frome catchment. Road drainage also enters these sewers and delivers into the canal, interacting with Frome water levels.

Although the hypothesis is theoretically sound – even included in the Pitt Review (Pitt 2007) – no measurement of historic drainage can be made. It is therefore not possible to identify how far increased runoff from urban areas has influenced the recent flooding. However, measures to reduce the contribution of surface runoff should be considered.

3.2 Ineffective drainage

Floodplain borders the Frome along the flat Severn Valley. The floodplains are marked by alluvial deposits of clays and gravels over the mudstone bedrock.

People have lived on and adjacent to the floodplain for many centuries; the risk of flooding outweighed by a convenient water supply, water power and fertile soils. Buildings may have avoided flood risk by virtue of subtle understanding of river morphology and topography. However, such characteristics change with time through natural processes or artificial intervention, and so what were once safe areas may no longer be so. This is especially the case in the Bridgend area, where the river and adjacent land have been heavily modified, and development has encroached on the floodplain.

The complex artificial hydrology and clay deposits of the Bridgend area mean that floodwater is drained ineffectively. Several specific issues have been identified by the Bridgend Action Group, which Water 21 has sought to validate:

- The first is an uneven distribution of flow through the three channels of the Frome at Bridgend,
- The second is the presence of blockages, which hinder the free passage of water over the floodplain,
- The third issue is the lack of floodplain management,
- The final problem is a lack of collaborative water management, particularly in times of flood.

These problems combine with an accelerated hydrological cycle to increase the risk of flooding, as well as degradation of water quality, siltation, and loss of potential economic resources such as silt and hydro-power.

The full permanent solution to Stroud-wide flooding is to restore the hydrological cycle (discussed in previous section), and ensure floodplains function correctly. The latter point follows government plans called "Making Space for Water" (Defra 2005), also in line with Water Framework Directive and other protocols, Agenda 21 etc.

3.2.1 Distribution

The channel braiding in the Frome is not natural. The river was bifurcated to feed the mills and irrigate the land in the nineteenth century. Historically, the stone bifurcation structures would have precisely allocated water as per millers' water property rights. Further control would have come from manually operated sluice gates. The historical values are unknown, but are possibly deducible from the deeds of local mill properties.

The local milling industry is mostly defunct, and control of flows is by local riparian landowners (control of sluices is required in the deeds), and, because the river interacts with the canal, by lock operators downstream. Historical considerations of water provision for irrigation and milling rights are no longer acknowledged in the area, but maintenance of canal water level during summer and months requires operation of sluices.

It is possible that if total flows and flashiness have changed over centuries, the operation rules are no longer valid. Flooding may be worsened in some areas by uneven distribution of the water, with one channel bursting banks, while another is within capacity. In addition to flooding property, this would also reduce the effectiveness of the remaining floodplain by concentrating floodwater in one area.

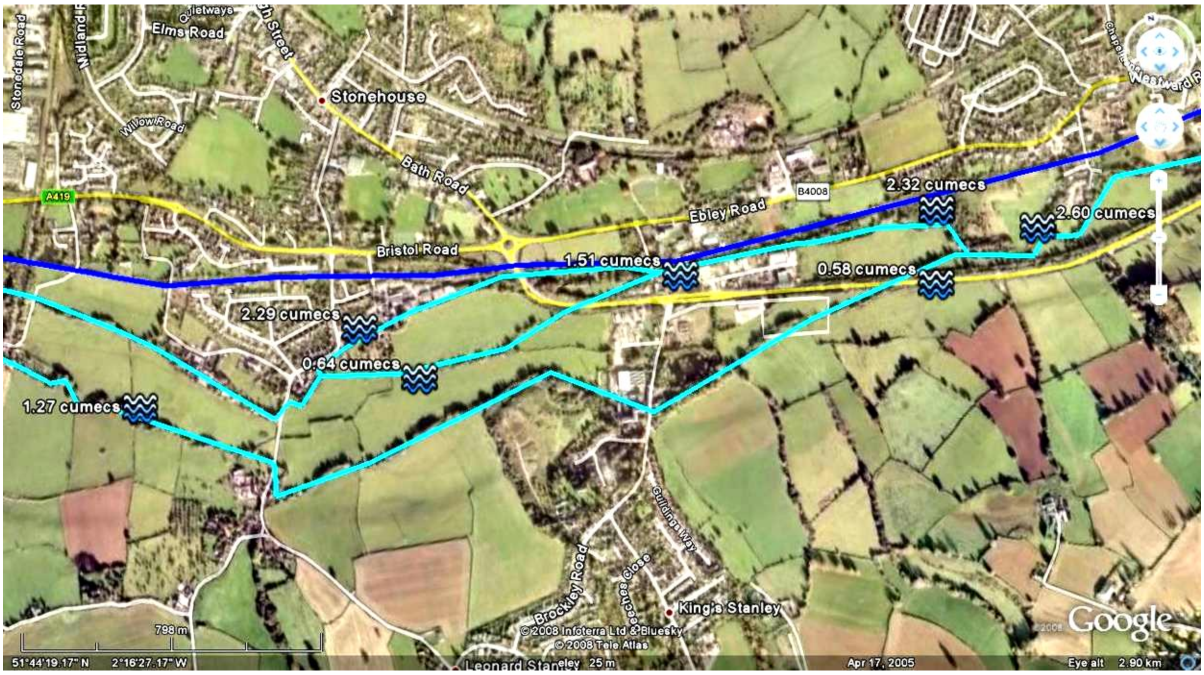


Figure 6: Results from flow gauging on 18.07.2008.

Figure 7: Photos showing the slabs at the bifurcation in early July (above), and removed in later July 2008 (below).

Flow monitoring (Figure 6) revealed that approximately 80% of the flow is directed into the north channel at the Ebley bifurcation (SO 823 044). The north channel bifurcates again at Ryeford, where another 80% of the flow enters the mill leat (northernmost channel). At the Bridgend area, the north channels are visibly nearer capacity than the south channel.

The current bifurcation structure was installed in 1889 and has been recently deteriorating. Stone slabs were present in the south channel at the bifurcation until days before the monitoring. It is believed these were put into the channel two years ago. Sometime in July 2008, they were removed (Figure 7). Flow was visibly greater in the south channel at the bifurcation after removal, but the canal (fed by the north channel) fell to an all time low (pers. comms. Julian Jones, Colin Wood 27.07.2008). Ryeford residents suggest the stones were put in place to maintain the canal level (pers. comm. Martin Hyde 27.07.2008). Bridgend residents attribute it to increased flooding downstream from the northern channels. While a contributory factor, it is unlikely that the traditional management of canal levels in this manner is the main cause of flooding at Bridgend. A more likely cause of recent issues would come from blockages or poor sluice control, together with accelerated run-off.

Local experience suggests the tendency for inundation is around the northern side of the floodplain at Bridgend, while the south channel is thought to remain within capacity.

3.2.2 Blockages

The Bridgend Action Group has a long documented correspondence with the Environment Agency regarding overgrown channels. Overgrowth reduces effective channel capacity, increasing flood risk. The North Frome was clearly overgrown on several site visits throughout summer 2008.

Another concern is blockages of culverts, particularly following floods, where large items are washed downstream. These must be regularly checked and cleared. Culvert capacity should be sufficient to not restrict flows; however, local residents expressed concerns regarding the capacity of culverts on the railway embankment on the Bridgend floodplain.

Another blockage is caused by the Downton Road, intersecting the floodplain at Bridgend. Anecdotal reports by local residents suggests that during inundation of the upstream floodplain, the road acts as a barrier, preventing flow of water to the downstream field. Due to the apparent full capacity of the North Frome, the meadows upstream of the road flood to the channel exceeding capacity. Excess flow is forced onto the Bridgend properties. Local residents believe the road has been raised over time by consecutive resurfacing without prior digging to retain the elevation. Lidar data suggest a slightly raised elevation. A site visit clearly shows that the kerbs and thick hedges would cause a blockage, and the slope of the road would direct water down towards the north channel confluence at the Bridgend bridge and downstream to Albion Terrace. During the 2007 floods, residents removed a section of hedgerow on the Downton Road, which they believe relieved flood levels by several inches from their properties (pers. comm. Ivor Ward-Davies 06.07.2008).

Figure 8 (overleaf): Lidar image of topography, clearing showing old dry channels and drainage channels. Source: OS 2008 for map data, Environment Agency for lidar, Global Mapper for processing.


STROUD DISTRICT
Bridgend
Stanley Downton
Stanley Downton Farm
Lower Mills
Mill Pond
Ryeford
Haywards Bridge
Playing Fields
Old Brook House
Path
Weir
0 m
125 m
250 m
375 m
500 m
165 m
150 m
125 m
100 m
75 m
50 m
25 m
0 m

3.2.3 Loss of floodplain channels

The floodplain between Ebley and Bridgend has significantly altered over centuries. Ancient paleo-channels of the natural river course are still visible, such as a meandering depression either side of the central Frome channel at Bridgend (Figure 8). Although aiming to increase the flow velocity and drainage efficiency, straightening of channels reduces the capacity of the brook in that area, thus increasing its likelihood to exceed capacity in high flows. Straightening of the channels through the floodplain transports more water more quickly to pinch points downstream. For example, at the small bridge of the Downton Road, two river channels form a confluence, one of which is a straightened channel. The bridge has little storm flow headroom, and just after the bridge there is a 90° bend. This is a recurring flood spot, affecting homes and vehicle access. If stormwater followed the original meandering course, it could act as a brief attenuation before this pinch point.

Encroachment of development onto the water courses has also straightened them in places, and thus also acts to reduce capacity and increase the velocity of flow (Figure 9).

There is a ridge-and-furrow like pattern of undulating ridges visible in the Bridgend and Ryeford meadows (Figure 8). The pattern is difficult to observe in places, as the furrows have been filled in. It suggests these fields were at one time managed as irrigated meadows; lidar images clearly show this. Long term residents recall managed nightly flooding of the fields until the 1950s (this indicates either a frost protection measure for early hay or water backup for daytime milling). Main carrier drains would take excess storm flow from the river, or by controlled sluices. Residents report that during most floods, large areas of the floodplain are presently not inundated. The old drainage pattern would have dispersed some of the water over a wider area, importantly, away from flood-prone buildings. The primary purpose of the flood meadows was not flood protection, but nutrient cycling & irrigation for increased productivity (Cook et al. 2003; Cook and Williamson 2007). Currently, the floodplain is tenanted by farmers who make hay and graze livestock.

3.2.4 Lack of water management

At the height of local milling operations rivers would have been carefully managed. The regulator in disputes was usually the House of Lords. In particular, the milling rights to water would have dictated the control of flow through carefully built structures such as the bifurcation at Ebley, and through control of the river and canal with locks and sluice gates. The floodplain community relied on the Frome. Not only were mills allocated flow, and farmers allocated irrigation water, but flood damage limited by the control of sluices.

Catchment-wide management declined as a consequence of the decline of the mills and flood meadow floating. Now, control of the river is in the hands of those local residents who own sluice gates on their land, mill-owners who retain or delegate control of the sluices, and British Waterways who operate canal locks and river sluices. There is no formal or informal agreement between these actors on how to operate the flows during normal or emergency conditions, other than retaining elements of the historic pattern. However, this manner of operation may no longer be applicable today: the flow characteristics have changed through increased runoff, building on floodplains, canalisation and straightening of channels.

Figure 9: Photographs of Bespoke Kitchens, Bridgend, with a new building modifying, restricting and straightening the watercourse.

There are also disagreements regarding management of the flows, which are due to a lack of community communication. For example, there is a misunderstanding between some Bridgend residents and Ryeford residents. Sluice gate operator Martin Hyde at Ryeford used to close the gates during heavy rainfall to prevent Bridgend flooding. Instead, the Saw Mill flooded, which had adapted to inundation. The mill has since been developed as the Ryeford Industrial Estate, which objects to flooding. By keeping the gate open, the estate could be kept safe, but the risk of flooding Bridgend increased. The estate built a flood wall following 2007 floods, preventing the natural inundation of that former floodplain. The influence of the sluice gate control is now lessened. In recent years, British Waterways forced a handover of control of Mr Hyde's sluice gate, and he does not believe they operate it as regularly (four times a day in wet weather) as he used to (pers. comm. Martin Hyde 27.07.2008).

Another dispute at the Paper Bag mill at Bridgend saw a sluice gate owner taken to court by the Environment Agency over maintenance and operation. By not controlling the gate or allowing others to access it, a blockage was caused flooding homes on Albion Terrace. The Environment Agency achieved a resolution after one year, and another resident now has access to control the gate.

The lack of co-ordination is particularly evident during flood events. Residents suggest river levels peak three hours after heavy rain, which is in line with predicted hydrographs (Pretto 2008). There is little time for to prepare for flooding and operate the gates, particularly when some are controlled by non residents or external and remote organisations such as British Waterways.

Lack of water management extends even to development on the floodplain. Environment Agency flood risk maps, Defra statements and what may be considered common sense have been ignored in some cases. Development of Ebley Wharf near to the Ebley Council Offices is situated on flood meadow. Development here was preceded by protests from downstream residents, concerned about increasing runoff and loss of floodplain storage, however consent was granted by Stroud District Council. An appeal to the Government to halt the development was made based on the following points:

- Development contravened Government national planning guideline PPG25,
- PPG25 is insufficient, considering a 1 in 100 year flood event acceptable, even though Bridgend residents experienced that flood several times in as many years,
- Development went against the local plan,
- Environment Agency "very strong objection" (Stroud District Council 2001: 35) to the development,
- Development plan ignored flood risk outside the development area,
- Conflict of interest between Ebley Wharf development and Stroud District Council, regarding possible acquisition of further development land.

The flood risk assessment for the development neglected to consider implications downstream, only upstream, and falsely asserted that artificial flood barrier banks could "maintain the status quo" (Lewin, Fryer and Partners Ltd 2001), and that flood water could be contained in the canals and a new pond. The canal was the first source of Bridgend flooding in 2007, overtopping and flowing down the Downton Road. Development of Ebley Wharf went ahead, arguably dishonestly and deceptively.

4 Solutions to the flooding

4.1 The dual approach to managing water

It is not in the scope of this report to identify the detailed solutions to solve Bridgend flooding, rather suggest the principle causes and a range of possible solutions to consider. Potential solutions should be further investigated with thorough hydrological modelling, in order to identify any possible side-effects of the proposals and satisfy regulatory protocol.

The problems identified are all inter-related, and generally stem from overall mismanagement of water as a resource, within a context of regulatory failure.

With flooding as a focus, the optimum solution will come from a holistic, catchment-scale and long-term plan. This should be a normal consequence of any duty of care to existing residents in the preparation of local planning strategies.

Flooding is controllable at Bridgend and across the Stroud Valleys if a dual approach is considered:

> "water must be attenuated upstream, and contained in the available space downstream".

This way, water in flood events is stored and dispersed in the natural system, such that there are no isolated flood risk zones. Sharing the water will reduce the overall flood risk. This approach may be more accurately expressed as:

> "re-creation of the natural upstream attenuation characteristics to restore the balance of the hydrological cycle, and containment of any excess floodwaters in the downstream areas by restoring the naturally designated floodplain zones to maximum efficiency".

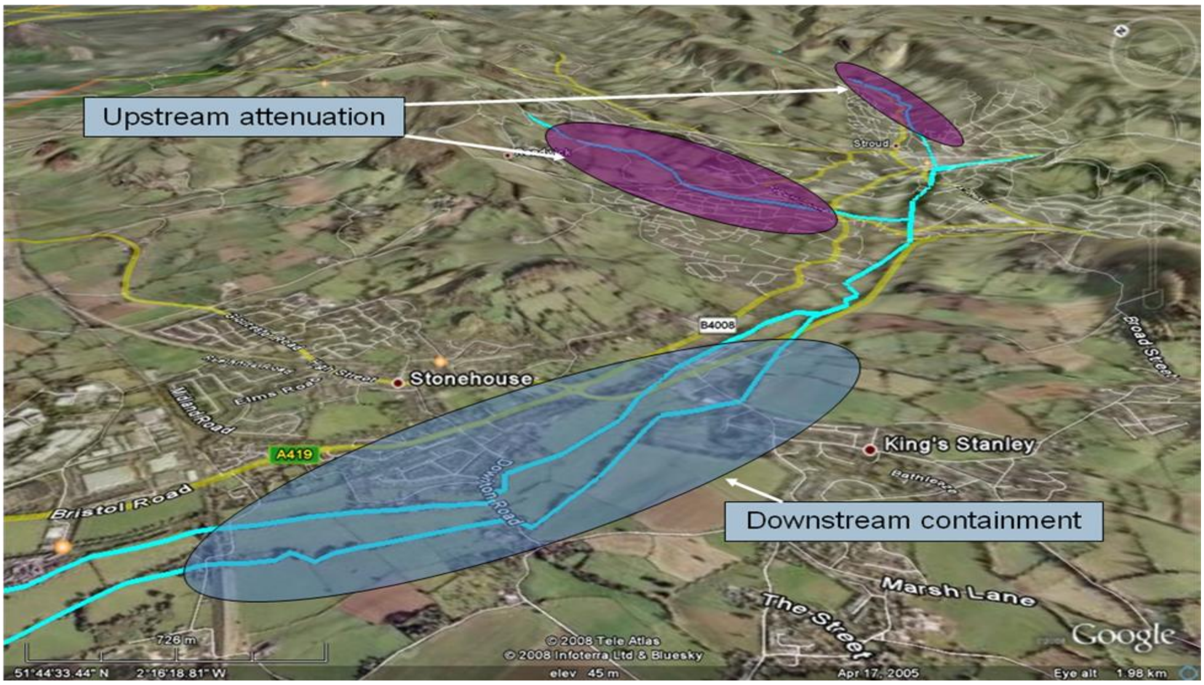


Figure 10: 3-D map looking from above Bridgend towards Stroud, and the Ruscombe and Slad valleys. Illustrates the concept of the dual approach to managing water.

4.2 Too much water

4.2.1 Upstream attenuation

Although the contribution of climate change is recognised; land use change is likely to be the single most important factor in the acceleration of the hydrological cycle here. This is partially recognised by the academic community (e.g. Hollis 1978; Konrad 2003; Pitt 2007; WWF 2007; $WWF_{(a)}$ 2007; $WWF_{(b)}$ 2007), but few studies have been able to offer quantitative proof of how far it has affected hydrological response. The concept, however, is widely accepted as part of the hydrological cycle.

It stands that by restoring the catchment hydrological cycle, many of problems (not least flooding) can be managed. Upstream attenuation, both permanent ponds and temporary wetlands, would hold back, absorb and infiltrate storm flow from heavy rain, and distribute the excess water over a longer period. If the upstream valleys (Slad, Ruscombe, Painswick and the Golden valleys) were attenuated, significant water volume would be prevented from causing flooding at Bridgend. These upstream valleys would also benefit from the attenuation, relieving various localised flooding here also.

Attenuation could be achieved through simple, low-cost, naturalistic and multi-function solutions, as proposed by Water 21. They would bring a variety of additional benefits, which could be exploited to provide long-term self-funding options. Hydraulic and hydrological modelling by Water 21 has validated this approach as a viable alternative to larger attenuation structures or flood defences (Pretto 2008), and supports findings from WWF pilot schemes ($WWF_{(b)}$ 2007). Specifically, the volume of water to be attenuated in Slad for a large flood such as in 2007 (1 in 150 year event (Pitt 2007)) is 44,000 cubic metres. The study found that the catchment has the space to attenuate even larger volumes. To store this volume of water with a single impoundment, the flooded area would need to be 1 km long. Dispersed upstream attenuation features provide the same flood protection, but at lower risk and cost, with greater economic benefit. This would reduce the flooding downstream on the Frome at Bridgend considerably, although storm flow originating below Stroud would still need to be contained.

If planned holistically, this method would bring many benefits:

- Effective flood alleviation,
- Aquifer recharge,
- Naturalistic, lower visual impact,
- Lower cost, simple technology,
- Improved aeration of water; absorption and treatment of pollutants,
- Silt retrieval for bioremediation as cheap, organic fertiliser for biomass,
- Improved agricultural food productivity (temperature buffering and irrigation),

- Diversification of agriculture through woodland and wetland options,
- Protection of rare habitat, and biodiversity benefit,
- Fisheries development,
- Substantial small scale hydro power with integrated fish passes,
- Provide the basis for a completely decentralised, community based approach to municipal water services (flood control, sewerage and spring water supply).

Attenuation features include restoration of wetland fringes and vegetation and small dams to hold back water. The impoundments must be planned carefully so as to benefit baseflow, and allow the occasional smaller floods which are part of a natural system. Mill ponds in some valleys provide an ideal starting point as impoundment features, and can be managed to maximise the emergency storage. Other smaller impoundments may be created by raised earth and gabions to impede flow beyond a pre-determined volume, and may become seasonal wetland habitats. There would be many of these smaller structures, which because of their size will not require large areas of land to be set aside. Silt retrieval as a cheaper alternative to agro-chemicals may be developed as a way of part-funding maintenance.

Example locations for impoundments in the Slad Valley are shown below (Figure 11).

Pretto (2007) validates the Water 21 proposal that dispersed upstream attenuation can be an effective way of preventing damaging floods. This concept has not featured in academic literature to date as a real alternative to conventional flood management, and is not yet

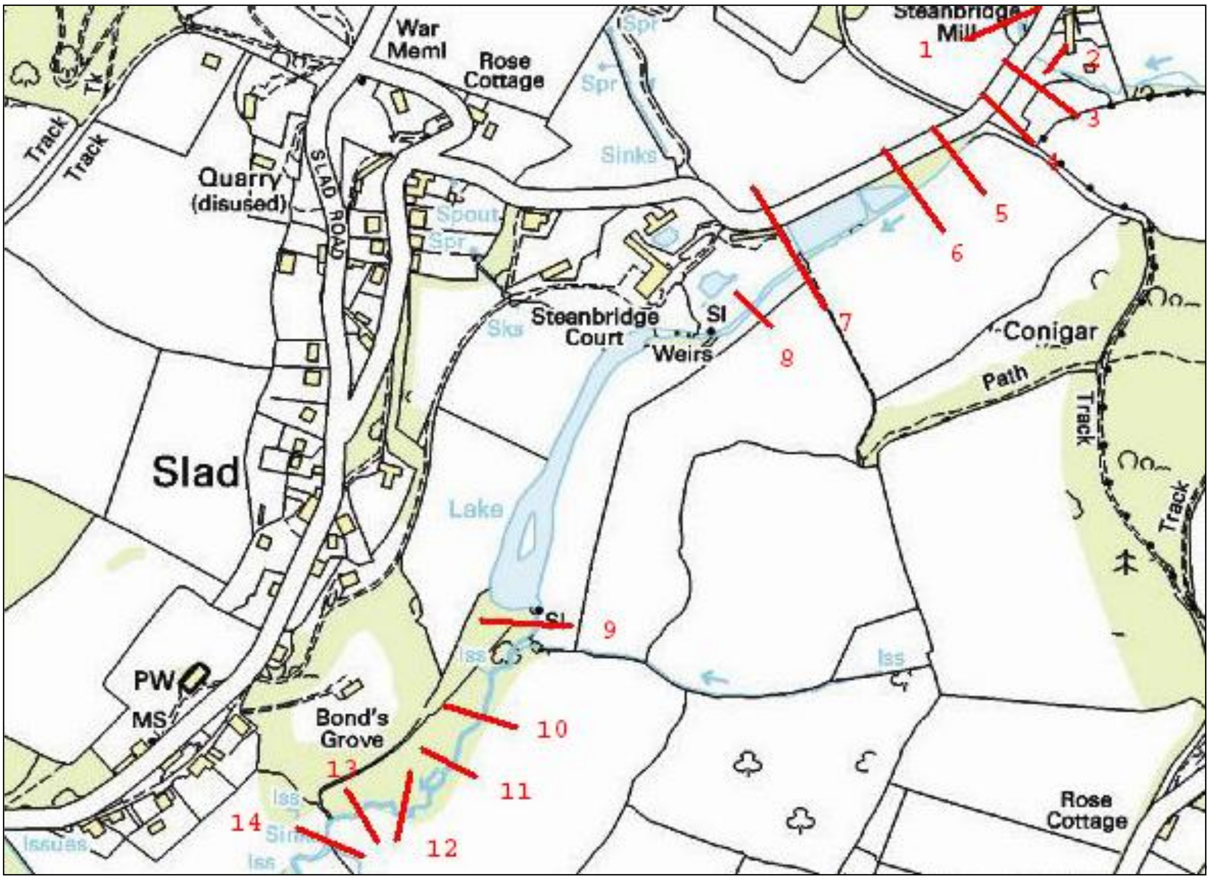


Figure 11: Map showing locations of survey cross-sections (red) along a section of the Slad valley. Mill ponds are also shown. The red lines could indicate attenuation points. Source: Pretto 2008.

considered a mainstream solution by authorities, but is in many respects simply a return to traditional indigenous river management. Water 21 is working with a number of local community groups around Stroud to implement a multi-benefit, community led approach to flood management. A demonstration site is proposed for Stagholt Brook nearby Stonehouse. If the concept can be proven with a small scale demonstration, it will gain support for plans on the wider Stroud Valleys as a permanent solution to flooding, including Bridgend.

The alternative is continued conventional flood defence, consisting of sandbag supplies and barriers along the river. Flood defence has proven to be an expensive and unsustainable long term option in river and coastal defence. However, conventional methods may be considered as interim solutions while upstream attenuation is planned, but these are only valid if part of an effective long term strategy, which does not appear to be in place.

It is the recommendation of this report that upstream attenuation should form a major part of the long-term and holistic solution to flooding at Bridgend. Its flood alleviation benefits are not limited to Bridgend; for example, issues at Puckshole in Ruscombe and on Slad Road in Stroud would also be resolved. Its other benefits, particularly in economic respects, give this approach a clear advantage over conventional flood defence approaches at Bridgend.

4.2.2 Surface runoff

To reduce surface runoff in the catchment, the effects of hard standing/paved areas should be addressed. This is in line with current recommendations (Defra 2005; Pitt 2007), which are seemingly not properly addressed by local planning authorities.

Further development on the greenbelt floodplains should only be permitted if it can be demonstrated that these will not have a contributory effect on surface runoff or flooding, within a complete river catchment hydraulic model. New developments should incorporate permeable pavements and other Sustainable Urban Drainage System (SUDS) features. These also need an agreed plan for operation and responsibility for maintenance of these features before development takes place.

The Highways Agency and Local Authorities should develop a long term SUDS strategy to not only protect the wider environment from road runoff, but also to protect roads from flood damage. Providing permeable zones, particularly at low points which form ponds after rain. Planting of woodlands and creating seasonal wetlands to improve the rate of ground infiltration, should be implemented in road verges to collect and treat polluted runoff.

Surface & roof runoff can be reused where possible for non-potable water usage such as watering gardens, washing cars or flushing toilets. New developments should be designed to recycle water. This would reduce drainage to the Frome and canal, and reduce the use of the potable supply, reducing water bill costs as well as moderating drought.

The community should be engaged to make aware the implications of paving gardens. Community-led incentives for preserving lawns and green spaces will increase infiltration while gathering community support for the issues. Where gardens must be covered, permeable paving should be used.

The onus is on reversing the effects of existing development. This can be achieved through naturalistic infiltration zones, as well as finding environmentally friendly replacements for current surfaces. Currently, permeable paving is more expensive than standard options.

4.3 Ineffective drainage - downstream containment

This report has identified problems with the floodplain and river at Bridgend, which may be contributing to the flooding. If resolved, this will restore the natural flood containment characteristics of the floodplain, which could, in conjunction with upstream attenuation, provide protection for the largest of flood events as well as bring many other local benefits.

4.3.1 Distribution of flows

Because more water flows into the north channels of the Frome (and therefore into the canal), redistribution of flows during flood events will ensure the meadows inundate fully before buildings are affected. In order to identify an optimum distribution of water in the Frome channels and the canal, local knowledge should be pooled with technical expertise and historical information from deeds regarding water rights. The south channel could be allowed to take more water during heavy rainfall, thus reducing the load on the north channels and allowing the canal to drain safely into the river without over-topping.

4.3.2 Blockages

Blocked culverts and overgrown channels must be kept cleared. This maintenance is currently undertaken by the Environment Agency and local residents. Stroud District Council is promoting a scheme of Flood Wardens to better co-ordinate watercourse maintenance. Other local groups and organisations (such as local Watercourse Action Groups or the Stroud Valleys Project) should also be involved, thus generating a network of river-clearance volunteers. Funding should be found to provide equipment if necessary. The value of trash screens should not be underestimated, though they provide little protection against major flood events. But if regularly checked, screens can benefit localised flood 'hot spots', but this only passes the flood problem downstream where further flooding can then occur. The community should also be encouraged to reduce the amount of rubbish/pollution entering the river. The proper development of river resources such as hydropower and fisheries, or at least a strategy for this, would be the correct approach for enabling river maintenance.

Removal of the Downton Road blockage would ease the passage of water along the floodplain, and thus be less likely to direct water to Bridgend homes. This should be resolved. An engineering survey would ideally be undertaken to identify the best solution. Further re-surfacing of the road without prior lowering should be discouraged. The road should be sunk down to the level of the fields, and the kerbs should be redesigned to discourage flow towards Bridgend. The landowner should be engaged by the community to investigate the possibility of strategically cutting back the hedgerows. If the road cannot be sunk, other options should be investigated to restore flow at this location (installation of a suitable cattle-grid for vehicles to pass, or raising of the road and installation of several culverts. The latter option is not recommended, as it still impedes flow). Water 21 could help the BAG to engage with landowners.

4.3.3 Floodplain channels

The old drainage channels across the meadows could be restored such that they disperse flood water evenly across the fields. This would have the effect of reducing the concentration of water at Bridgend, relieving the pressure on choke points, and restoring the floodplain to its natural effectiveness. Water will be more quickly infiltrated into the ground on the fields, and if designed carefully, shallow occasional flooding of the meadows will provide irrigation and natural nutrients will improve productivity.

The ancient drainage network seen from lidar data should be mapped and the potential volume of water storage as a shallow layer of moisture should be estimated.

With co-operation between the landowners and the community, and an arrangement for maintenance (part-funded through the value of nutrient-rich silt), restoration of the main drainage channels would be another valuable multi-benefit, flood alleviation measure, achievable at a low-cost volunteer level. The landowner or tenant farmers would be compensated through increased yields. Further groups such as Local Authorities, Environment Agency, Defra, Natural England, WWF, Stroud Valleys Project, the Wildfowl and Wetlands Trust could also be engaged for partners in pilot demonstration schemes, biodiversity enhancement, heritage land use or habitat recreation.

4.3.4 Management

All measures suggested thus far will require community cohesion. All those individuals and groups who have control of water management in the area should be identified. These will include riparian landowners, farmers, mill-owners, sluice gate owners, British Waterways, Severn Trent, the Environment Agency and more. Water 21 would be ideally placed to co-ordinate the interested parties in order to pool local knowledge with technical expertise. A plan for long term goals should be drafted, although it is recognised this level of community co-operation may not be simple; a dedicated co-operative structure might assist here.

In addition, and perhaps more urgently, a plan for co-ordinated management of sluices during flood events should be agreed on. Currently with no co-ordinated operation, some reaches of the river overflow while others are well within bank capacity. Co-ordinated timing of sluice gates allows the storm flow to be carefully managed through the catchment, flooding the meadows and protecting property. This will probably provide the single most influential immediate alleviation to flooding at Bridgend. The community group must identify a suitable plan for flood events and ensure that sluices are accessible and in working order. The Environment Agency or Water 21 would be suitable organisations to co-ordinate the creation of a flood event plan. A telephone-tree should be created to co-ordinate the sluice gate operators along the river. Funding could be found for automated or remote-access control of sluices as a long-term project (sensibly as part of hydropower development).

It is stressed that the plan for sluice control should be developed within the community, using local knowledge and experience, and aided by experts such as at the Environment Agency. It must ensure public safety firstly, and be sensitive to natural processes and environmental quality.

4.4 Summary of solutions

The following should be addressed:

- Restore required upstream attenuation to achieve full downstream resolution of flood hazard within a complete (hydraulic/economic) river catchment plan,
- Reduction of surface runoff,
- Identify ways of redistributing flow to reduce flooding,
- Set up a group to maintain channels and culverts,
- Identify a suitable solution to the Downton Road,
- Restore floodplain drainage channels to increase infiltration and divert floodwater,
- Develop an emergency flood event plan for operation of sluice gates,
- Engage all interested parties into a co-operative community partnership, which could also enable a range of other water related developments (e.g. hydropower or community based sewage treatment).

5 Next Steps

This report may be used by the Bridgend Action Group as they see fit. It is recommended that an Executive Summary is distributed to local press, residents, councillors and the full report to the Environment Agency and other planning authorities.

Water 21 will continue involvement with BAG through its other projects, which will provide a long term benefit to Stroud-wide flood alleviation plans. The action groups will be strengthened by collaborating and sharing information, so Water 21 should arrange a conference day to co-ordinate this. Together, the groups will also be better placed to identify what they require from Water 21.

It is proposed that of the suggested solutions, there are several suitable grassroots level measures that could be taken on by the BAG, such as encouraging community cohesion. To aid this, a map of "responsibilities" could be developed, labelling a map of area with all the landowners, tenants, property owners, companies, Environment Agency and Local Authority responsibilities. The group should write, with support from Water 21, to the Highways Agency, Environment Agency and Local Authorities regarding the Downton Road blockage and other suggested solutions proposed herewith.

The development of a hydrograph and initial associated volumetric modelling for Slad Brook conducted concurrent with this study (Pretto 2008), demonstrates, for the first time, that effectively complete control of likely river flooding is not only feasible but also of great potential benefit to the local ecology and economy. This places a fresh impetus on local planning authorities in now actually achieving this, as a normal duty of care in their protection of all residents within the context of an appropriate local strategy and plan for urgent implementation.

Initial discussions with landowners indicate a mostly favourable attitude to water resource storage on their property. Interestingly, the only local landowner so far encountered that has categorically refused co-operation is a local authority. Technical studies required should now investigate and hydraulically model the storage on the floodplain and in all the upstream valleys; expanding the scope of the previous Water 21 report (Pretto 2008). Auditing the associated full economic benefits (hydropower, food productivity, nutrient cycling etc) will further inform this process.

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