Integrating design with the environment to maximise benefits from a flood storage dam: successful implementation at Harbertonford

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SYNOPSIS. Environmental enhancement is not just about changing the seed mix and planting a few trees to hide the structures we build. Designing using the environment rather than seeing it as a constraint can help to produce cost-effective designs that bring great benefit to the environment and raise the public perception of the benefit dam engineering can bring to their lives. So often, the potential of embankment dams to benefit the environment is not taken advantage of. This paper explores what can be done to fully realise the potential of flood storage dams.

The award winning Harbertonford Flood Defence Scheme, described as "the future of flood defence schemes" by Sir John Harman, Chairman of the Environment Agency, was a combination of in-village channel lowering and upstream flood storage (Palmers Dam). This paper focuses on the flood storage element of the scheme and demonstrates the multifunctional benefits that have been delivered through the integrated work of design professionals, driven forward by the flood defence aim.

BACKGROUND

The UK flood defence industry

The flood defence industry is at present the source for the greatest number of Reservoirs Act dams being constructed in the United Kingdom. There are currently over 30 dams either recently constructed or under development. These dams vary in height from under five metres to over 15 metres and are generally earthfill embankment dams providing the temporary flood storage element of flood alleviation schemes. Such structures can provide cost-effective protection and offer flood defence benefits to the rest of the river catchment downstream through slowing floodwater progress and reducing flood peaks.

Long-term benefits and performance of dams. Thomas Telford, London, 2004

The Harbertonford Flood Defence Scheme

The Harbertonford Flood Defence Scheme, costing £2.6 million, provides flood alleviation to the picturesque village of Harbertonford, near Totnes in South Devon (refer to figure 1).

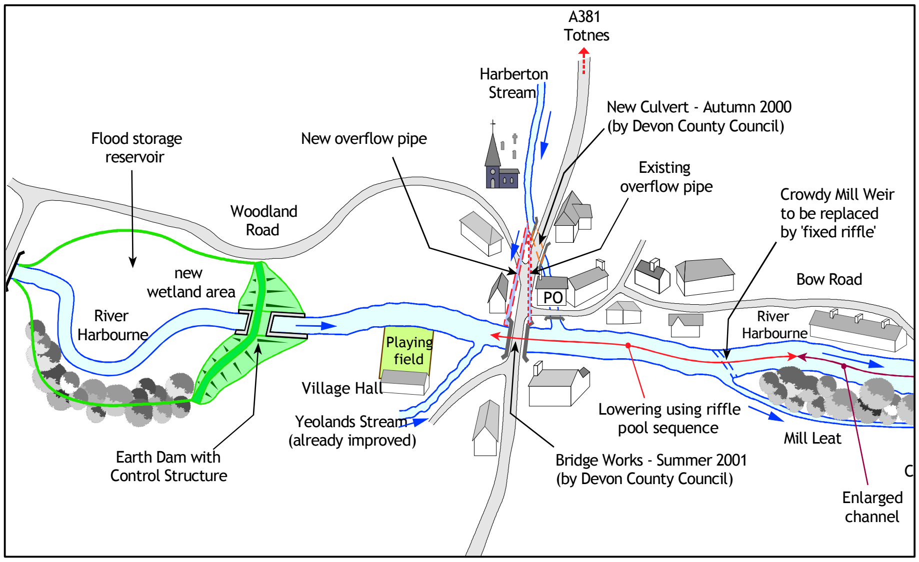

Figure 1: Schematic of overall scheme

Originating on Dartmoor, the River Harbourne flows through the village, where in the centre, by the historic bridge, it is joined by two tributaries. These watercourses have flooded the village 21 times in the past 60 years, including six times between 1998 and 2000. Flow in the River Harbourne varies from less than 1 cumec at low flows, to 28 cumecs at the 10 year flood flow, through to 300 cumecs for the PMF event (Probable Maximum Flood). The flashy nature of the catchment meant there was little warning for the residents of the village to prepare for the flooding and the misery it causes. One elderly resident of the village had resorted to living solely on the upper floor of her house.

This high frequency of flooding and associated damage resulted in considerable disruption and in January 2001, the scheme was accelerated by the Environment Agency (the client) to ensure that remedial works were designed and constructed in time to protect the village against possible flooding in winter 2002/03.

Solutions to the problem had been proposed during the previous thirty years, but all schemes previously put forward were deemed to cause too much damage to the environment and could not be justified. The village of

Harbertonford is designated as a Conservation Area and several listed structures, including the village bridge are also contained within it. Atlantic salmon, bullhead, sea trout and brown trout occur in the river and protected species are also present within the catchment, including otter and common dormouse.

The restrictions on the scheme development and the limited timescale focused the team to look at processes that could be used to achieve the scheme aim of providing a sustainable flood defence solution in place by winter 2002/03. This type of scheme would usually take four years to develop and implement. Only two years were available for this project.

Early studies showed that neither channel improvement nor upstream storage alone were capable of providing an appropriate level of flood mitigation. Storage sites available were too small to store the volumes of water required without unacceptable flooding of the upstream valley and channel works to carry full design flood flows required unacceptably large channels in the village centre or removal of downstream mill structures, which was also unacceptable. However an acceptable scheme was developed from a combination of both approaches.

THE DESIGN PHILOSOPHY

The benefits

Attention focused on five main objectives to ensure the design maximised the long-term benefits delivered. These were:

- maximise justifiable flood defence capability
- ensure reservoir safety
- minimise future operation and maintenance through working with the fluvial geomorphology of the river
- maintain and enhance biodiversity, amenity and landscape value
- minimise adverse effects on cultural heritage value

Through adding site-specific detail to these objectives, a clear framework was established to achieve the scheme aim of sustainable flood defence.

To deliver further long term benefits, the local school visited the dam under construction, and team visits to the school ensured the scheme construction and design were used as an educational resource, informing the children and teachers of the achievements of the scheme and the benefits it would bring. This promoted an understanding of their environment and allowed community ownership.

<u>The design process</u>

In describing the designs developed and techniques used at Harbertonford to deliver multifunctional benefits, it is worth summarising the approach used to generate these, which the authors believe represents a change from traditional practice.

The design philosophy adopted was to work with the environment, seeing it as an opportunity rather than a constraint. This meant using each other's skills most effectively; in particular, bringing the environmental scientist and other specialists to provide input directly into the design and not just comment on issues that needed to be considered, then periodically review designs.

Figure 2 below represents the values and perspectives held within the team. The process centred around the core values of Teamwork, Innovation and Consultation (TIC).

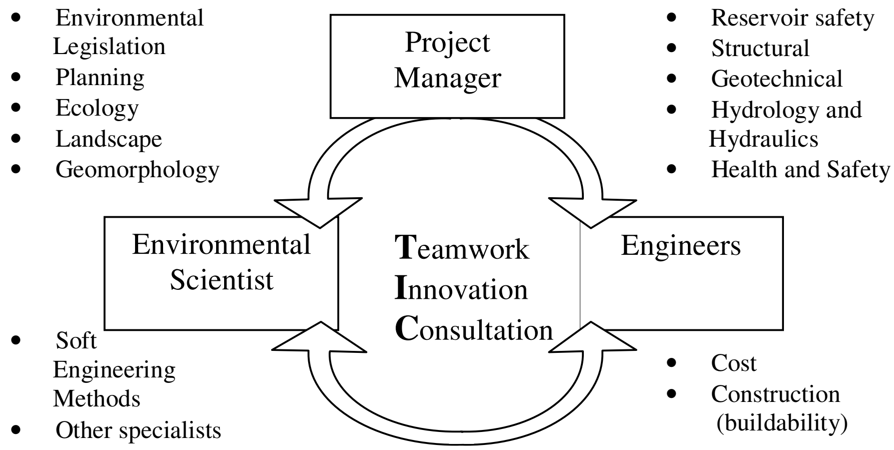

Figure 2: The TIC Process

Specialist advice was brought in at key stages throughout the overall scheme design, including notable inputs from the River Restoration Centre. Public consultation was also undertaken throughout the design process, the outputs of which further influenced the nature of the final scheme. This gave local 'ownership' of the scheme, which was considered to be very important for construction and operation phases.

All approvals were gained first time, on a fast-tracked schedule leading to a reduced design development time, earlier design certainty and more efficient designs.

THE DESIGN OF PALMERS DAM

Overview

The dam structure spans a 100 metre width of valley and is up to five metres high, constructed of 10,000m^3 of fill material. A concrete box culvert passes through the dam to carry the normal river flow. The outflow is controlled by two actuated penstocks with an automated control system and the structure can retain 150,000m^3 of floodwater, so is subject to the Reservoirs Act 1975. An overflow spillway occupies the majority of the dam crest.

Dam

The dam is located two kilometres upstream of Harbertonford in a quiet valley area with rural landscape that contains areas remaining from previous quarrying and milling industries. The area is designated as an Area of Great Landscape Value which was an important influence on the dam design. The structure was located away from public areas, but still provided good operational access and minimised tree loss.

The zoned, clay core embankment dam creates an online temporary impoundment of floodwater and by improving the channel capacity through the village from 15 cumecs (3 year flood) to 28 cumecs (ten year flood), the flood storage site available has been used to deliver the greatest flood defence benefit. Any further improvement of the channel capacity could not have been justified on cost and environmental grounds and the dam height was restricted to avoid flooding the public road and upstream properties and this determined the maximum justifiable standard of scheme.

The underlying geology at the dam site is slatey shale, weathered at the surface and overlain in the valley bottom by alluvium, typically to a depth of about 2m, consisting of a mixture of clays derived from weathered shale, and quartz sands. The valley sides consist of shale, weathered *in-situ*. The bedrock is exposed in the riverbed just downstream of the selected dam site.

The single-track, restricted-width public road to the site from the village was seen as a major constraint to construction, and it was decided early in the design process that as much of the material for the dam as possible should be sourced on site. This also minimized traffic impacts in the village.

Materials investigations showed that only a limited quantity of suitable alluvial clay for an impermeable core was available from a field upstream of the dam, typically as a 0.5m thick layer. To minimise the land area disturbed in excavating this, a zoned, clay core embankment dam with alluvial shoulders was adopted.

Spillway design

In view of the flood-prone village downstream, the spillway is designed to pass the Probable Maximum Flood (PMF) flood flow of 300 cumecs. The structural integrity of the dam is protected from the PMF overtopping flow by incorporating rock gabions in a stepped arrangement into the downstream face. These were placed at a gradient of 1 in 2 above the shoulder material surrounding the clay core. Integration of the landscape with the reservoir safety design is achieved by the addition of a zone of non-structural 'sacrificial' material above the rock gabions, creating a varying surface profile of between 1 in 4 and 1 in 8 (figure 3). This changed the visual appearance of the dam considerably.

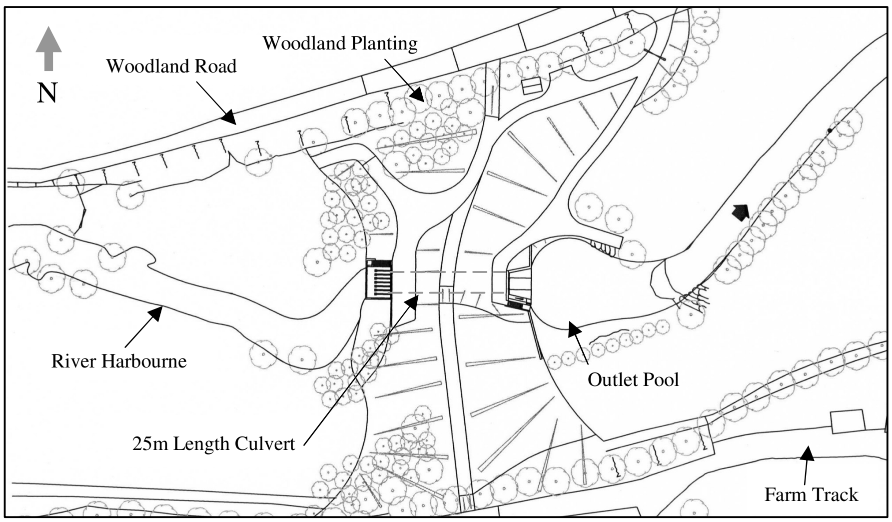

Figure 3: Layout plan of Palmers Dam.

The sacrificial material is covered with a mix of slower growing native grasses and wildflowers. The species chosen increase biodiversity whilst still retaining a good vegetative cover. Erosion resistance has been improved through the use of a 3-D geotextile in the root system. Importantly, the geotextile protection beneath the grass sward allows machine cutting of the grass when needed.

A Grasscrete crest locks the slope protection in place and the spillway occupies the full 100 metre length of dam crest to reduce overflow depth and the corresponding erosive force. Half of the spillway is set 0.5 metres lower and this is located on the southern section of dam, allowing continued operational access to the outlet structure (if needed) once overtopping flow has commenced.

Other design concepts

The upstream slope also incorporates a zone of non-structural material, again creating variable slopes, but also allowing the planting of broad-leaved woodland and scrub. This increases biodiversity and also provides a wildlife corridor linking the woodland on either sides of the valley. Badger protection mesh was placed against the 1 in 2 structural dam slope surface beneath the sacrificial material to protect from burrowing animals.

The sacrificial material represented an additional 5% on the cost of the dam, but since a minimal structural specification was needed, a wider range of materials could be used. This led to the project, including the channel enlargement works downstream, generating less than 10 percent waste to be taken away from site, most of this associated with contaminated material from the clean up of historic petroleum tanks during works through the village itself. The sacrificial material offers protection to the structural material, especially with regard to weather influences and retaining moisture contents.

Initial consideration was given to sourcing the gabion fill from waste in an abandoned slate quarry close to the dam site, so further reducing the amount of material brought to site. However enquiry revealed that the quarry and spoil tip posed difficult access issues and the area was an environmentally important area, so this idea had to be abandoned.

Culvert Design

The concrete box culvert which carries normal water flows through the embankment is designed to a four metre water width, similar to the natural river channel. This prevents throttling of the river flow and maintains the passage of the migratory fish, including salmon and sea trout, but also delays the point at which the culvert causes water to backup, reducing storage before the dam is designed to come into operation and associated sediment deposition.

The culvert is set with a lowered invert to allow a natural gravel bed formation and a minimum 300mm water depth. This follows best practice on migratory fish passage and has led to the creation of a varied bed profile, mimicking the natural river channel. The varying topography of the dam minimised the length of culvert needed to 25 metres, reducing build cost and length of river channel affected. With an internal height of over two metres, good airflow and access to both inlet and outlet structures, the lower risks for both authorised and unauthorised entry into the culvert ensures the culvert has not been classified as a confined space. This gives direct benefit related to future maintenance costs and safety liabilities.

<u>Inlet arrangement</u>

Screening of the culvert is achieved through bars at 600mm spacing. This allows most organic debris to pass through the culvert, fuelling the river system, reducing the risk of blockage and reducing the frequency of clearing operations. Screening to restrict unauthorised access would require a bar spacing of not more than 150mm, posing a higher risk of blockage, which could lead to earlier overtopping and consequential flooding of Harbertonford. This reasoning, together with the reduced safety liabilities of the culvert allowed agreement of the wider spacing. Additionally, the larger bar spacing allowed a smaller structure to be designed which has less impact on the landscape.

Constructing the culvert offline minimised the construction effects on the river and so consideration was therefore given to the best arrangement to guide the river to the new alignment. Previous dams have lined a new channel with hard bank protection such as gabions or walls, but the need for this was questioned. The main requirement is preventing scour of the embankment structure. This is most likely along the previous river path, so keying in a short length of blockstone into the bedrock in this location offers protection and a new channel excavated and lined with riverbed gravels guides the river to its new path. A bed check constructed upstream of the pool made from natural stone prevents long-term nickpoint erosion progressing upstream and contributes, with the natural curve of the river, to maintain a resting pool created at the inlet for fish passage (figure 4).

Figure 4: Photograph of inlet arrangement

<u>Outlet arrangement</u>

To dissipate energy and enable flow measurement, reinforced concrete stilling basins, as detailed by The United States Bureau of Reclamation (USBR) have regularly been used in south-west England. However to maintain accurate flow measurement, regular maintenance is needed to clear sediment deposition and ensure the structures dissipate energy as intended. At Palmers Dam, naturally outcropping rock was used to create a scour pool that improves fish habitat, is self maintaining and provides better landscape and visual amenity value. Water levels in the pool and culvert are maintained using a bed check created using natural slate. This was simple to construct and has performed exactly as intended from hydraulic perspective and visually mimics the existing rock outcrops.

Around the outlet (and throughout the scheme generally), sloping ground has been used rather than vertical drops wherever possible to reduce the need for fencing and allow members of the public who may get into this area a safe means of egress. Bird boxes were installed in the masonry faced walls as part of additional habitat creation.

<u>Flow control system</u>
Flood storage commences during a 1 in 10 year flood event. At a 1 in 40 year event the scheme standard will be reached and overtopping flow will cause the increased in-bank flow capacity through the village to be exceeded and progressive flooding to occur. The maximum storage efficiency making best use of the limited storage volume, the wide culvert, and the minimal screening were all possible due to the decision to adopt a variable gate control structure. This is located on the outlet structure which has minimised the impact on the landscape and allowed access to the gates even when the reservoir is impounding. A watertight culvert capable of withstanding up to a six metre head of water internally was achieved through using a combination of standard waterproofing seals between joints and a casing of mesh reinforced concrete around the box culvert structure.

The vertical penstock gates are normally held fully open, but are closed progressively to limit flows downstream to what can be accommodated within the river channel. The automated penstocks are controlled by a programmable control system which is operated in response to water levels downstream of the dam. Alternatively the gates can be closed remotely by a central flood control room in Exeter, however the gates can only be opened by manual control on site to ensure that the gates are not accidentally opened during a flood event.

Local power supplies were used and additional benefit delivered to the village through arranging the supply to be supported from two separate sources, thereby increasing the dependability of supply to the village as well as the dam. The programmable control system allows changes to be made to the operating regime in the future. Backup power systems have been put in place at the dam to minimise the risks of operational failure.

Sensors detecting the water level at the dam inlet now allow flood warnings well in advance of the level that was previously possible.

Washland creation

The benefits have been extended still further through taking advantage of the potential the borrow area provided. Twenty thousand tonnes of material was needed for the dam construction and this was substantially sourced from the field immediately upstream in such a way to create shallow scrapes. The remainder of the fill came from material excavated as part of the village works. The field was previously semi-improved grassland used for grazing and biodiversity has been increased through creating a wet woodland/grassland nature reserve. This design contributed to achievement of the Department of the Environment, Food and Rural Affairs (DEFRA) high-level biodiversity targets

Figure 5: Photograph of washland area one year after construction

Construction costs were saved through considering the final wetland profile at the outset, using the geotechnical information to target specific areas and depths and minimising earthmoving needed at the end of dam construction. The seeding and tree planting, which greatly surpassed the number of trees lost during construction has already started establishing within a year, creating an area that is regularly visited by the local population and a seating area has been provided to maximise this amenity value.

Wetland creation was only possible through the Environment Agency's decision to purchase the area involved. This aspect of the project has since been presented at the DEFRA annual conference as a case study project in best practice washland creation and showed the benefits of combined flood defence and biodiversity (Morris, 2003). Effective consultation from early stages with the landowners concerned has led to support for the solution and even an offer of assistance in the future management of the area.

CONCLUSION

There are a large number of embankment dams being constructed in the UK for flood defence purposes and consideration of the environment is a key factor associated with these. Palmers Dam was developed using an integrated team of professionals that brought the latest knowledge and experience into the process. This, together with proactive public and stakeholder consultation throughout, brought ideas and encouraged ownership of the scheme, all of which led to maximised benefits to the community, ecology and landscape. The designs also have reduced future operation and maintenance requirements and long-term health and safety liabilities through considered design and integration with the fluvial geomorphology of the river.

The reaction received from the residents at the opening of the scheme has shown the high regard with which they perceive the scheme and the integrated team that delivered it in time to save them from flooding that would have occurred on New Years Day 2003.

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