Weedon Flood Storage Scheme - the Biggest Hydro-BrakeÒ in the World

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SYNOPSIS. The Northamptonshire villages around Weedon in the upper River Nene valley, suffered disastrous flooding in 1947, 1992 and 1998, with Weedon Bec being particularly badly affected. The channel through the village is constricted by historic developments and the opportunity to enlarge the channels was not available. Restricted culverts under the railway embankments downstream compounded the flood situation. To alleviate the problem the Environment Agency and Halcrow Group developed an upstream on-line storage reservoir scheme.

The project includes a 450m long, 6.8m high clay embankment across the valley, with a culvert on the line of the original river channel to carry the controlled outflow. A 150m long concrete-block spillway carries excess flood flows over the embankment. The embankment site has been landscaped to minimise visual impacts and the borrow area has been developed into a large wetland area as a habitat for aquatic flora and fauna.

The key component of the flow control system is a 6.5 tonne, stainless steel Hydro-Brake® Flow Control device located in the dam inlet structure. The Hydro-Brake® was designed by Hydro International to control the maximum outflow rate despite fluctuating head, and incorporates the facility to adjust the controlled outflow between 8 and 12m^3/s. The use of the Hydro-Brake® helped reduce the upstream storage requirement and hence the land take and frequency of flooding involved.

This paper provides a description of the options considered during the design stage of the flood defence scheme, details of the actual design and construction of the dam, an explanation of how the Hydro-Brake® operates and the benefits it provides over other forms of flow control.

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

BACKGROUND TO THE PROJECT

The Problem

The village of Weedon Bec is situated west of Northampton and suffered serious flooding from the River Nene during Easter 1998. The village had no formal flood defences and there was a risk of flooding once every three years. 95 properties were at risk of flooding, 45 were flooded in the Easter 1998 event and many others were affected. The major cause of flooding was the restriction to flow at a road bridge within the village and at the culverts under the railway embankment downstream of the village.

A range of options was considered, but it soon became apparent that all options other than upstream flood storage were unacceptable. Channel improvement to pass flood flows required the existing river channel to be doubled in size, producing unacceptable loss of land and disruption. The cost of enlarging the road bridge and railway culvert would also have been very high. This option also produced an unacceptable increase in downstream flows through several villages and Northampton, which were already at risk of flooding. Containment of floodwater within the river channel would have required construction of flood walls through 30 private gardens. The cost would have been high, there would have been unacceptable disruption to residents and there would be access problems for future inspection and maintenance.

Conveniently, within one kilometre upstream of the village, the river flows through a well-defined valley with little habitation and this forms a suitable location for flood storage.

Scheme Selection

Having determined that flood storage was a viable and acceptable option, studies continued to determine the location of the dam and storage area and the most economic standard of flood protection.

The dam location was determined by consideration of:-

- Minimising the size and cost of the dam while achieving the required storage capacity.
- Avoiding flooding of property within the flood storage area.
- Minimising visual impact.

The location was largely dictated by the position of public roads and the Grade II Listed Dodford Mill, which is adjacent to the river approximately one kilometre upstream of the village. The dam is located approximately 100 metres upstream of the Mill, behind a belt of trees that obscures the view of the dam. Consideration was given to locating the dam 100 metres further upstream at the confluence of two branches of the river, but this would have resulted in a lower, longer, more expensive dam. A smaller dam could have been located further downstream but this would have resulted in the regular inundation of Dodford Mill, making it uninhabitable.

The standard of flood protection provided by the flood storage area was determined by economic evaluation. The project was grant aided by Defra. The economic evaluation, carried out using Defra procedures, determined that the project qualified for grant aid and that the most economic standard of protection would be 1 in 50 years.

DESCRIPTION OF THE PROJECT

The scheme was completed in autumn 2002 and comprises an earth fill dam with a maximum height of 6.8m and a crest length of about 450m. The storage area occupies the valleys of the Newnham and Everdon arms of the River Nene as shown on Figure 3. The capacity of the reservoir to spillway level is 810,000 m^3, providing a 1 in 50 year standard of protection to Weedon Bec. The flooded area at full capacity is 370,000m^2. The in-bank capacity of the river channel through the village of Weedon Bec is 10 m^3/s. The flood storage reservoir reduces the peak flow through Weedon Bec from 26 m^3/s to 10 m^3/s during a 50-year event. Figure 1 shows the dam under construction.

Figure 1. Weedon Dam under construction. The borrow pit is at the lower right. Note retained tree and hedge lines screening the embankment.

Embankment & Cut-off

The underlying geology at the dam site is blue Lias Clay. On the sides of the valley this was found directly beneath the topsoil. In the valley bottom it was covered to depths of up to 4m by mixed alluvial deposits ranging from soft silty clays to shallow sand and gravel beds. The gravel beds were considered to be potentially interconnected to the existing river channel and sufficiently permeable to provide seepage paths beneath the embankment.

The embankment was founded on the surface of the alluvium after topsoil and surface stripping. A cut-off trench was excavated to the Lias Clay beneath the centre of the embankment on either side of the outlet culvert, itself founded on the solid clay in the original channel bed, and backfilled with clay. The gravelly material excavated from the foundation was retained and used to improve the roadway on the dam crest.

The embankment was formed as a homogenous clay bank, generally with 1:3 side slopes, using some 32,000m^3 of firm Lias Clay. Initial plans were to excavate this from a borrow pit on the hillside, but this was rejected in favour of a borrow pit in the valley bottom, reinstated to form a wetland, even though this required the removal and stockpiling of between 1.5 and 4 m depth (12,000m^3) of alluvial overburden. Consideration was given to using the alluvial material in the upstream shoulder of the embankment, but it proved too soft to withstand tracking without drying.

The clay fill was placed and rolled at natural water content to form a hard fill material. Despite this, the clay material has the potential to crack on drying, always a concern on flood embankments normally kept empty. To help counter this, a horizontal geo-mat was incorporated in the non-spillway sections of the bank 0.5m below finished crest level, and the crest was topped with hoggin formed by mixing the clay fill and alluvial sands and gravels from the cut-off trench, stockpiled for the purpose.

The borrow area has now been landscaped to form a lake surrounded by tree and shrub planting. As much as possible of the original, established hedge and tree lines around the site have been preserved, and additional areas around the dam have been planted as woodland to break up the view of the dam from a distance.

Spillway

Located upstream of Weedon Bec, the reservoir is Category A in accordance with “Floods and Reservoir Safety” and was designed to safely pass the Probable Maximum Flood (PMF) which was assessed to be 195m^3/s. The spillway is formed by a 150m long lowered section of the dam crest. The crest, downstream slope and buried stilling basin are reinforced with tied cellular concrete blocks so that the spillway can safely pass the PMF with a depth of some 800mm over the crest and a maximum velocity on the downstream face of less than 8m/s. The downstream face of the spillway section was flattened to 1:4 to achieve this. The concrete blocks have been covered by a sacrificial layer of topsoil planted with grass so that the embankment blends in with the surrounding countryside when viewed from a distance. The non-spillway section of the embankment has a crest level 1.6m above the spillway crest to provide the recommended wave freeboard.

Downstream of the buried stilling basin, the water discharging from the spillway passes through an existing mature hawthorn hedge, on to fields forming a gently sloping flood plain, and from thence back to the river. As the spillway will only operate with the downstream channel already bank full, only minor erosion is expected downstream of the spillway, even in extreme floods, and out-of-bank flooding downstream is expected to be less frequent than at present.

<u>Outlet Structure and Controls</u>

The flow from the reservoir passes through a 2.4m wide by 2.1m high box culvert constructed on the line of the original river channel. Alternative options for controlling flows through the culvert were considered. An essential requirement of any option was that it had to be capable of permitting passage of both fish and small aquatic mammals through the culvert and control structure under normal operating conditions.

Alternative controls considered included:-

- A fixed orifice with an area of $1.2m^2$, limiting the downstream discharge to 10 m^3/s at full head.
- A penstock located at the upstream end of the culvert. This would have initially been set to provide a fixed orifice with an area of $1.2m^2$. Use of a penstock would permit manual adjustment should this prove necessary. However, because of the height of the dam, it would have been difficult to provide a visually acceptable arrangement to allow the penstock to be adjusted during a flood event with the reservoir full.
- A penstock housed in a chamber within the dam so that it could be adjusted manually from the crest during an event.
- An electrically or hydraulically actuated penstock to automatically adjust the penstock as the reservoir filled to maintain a constant downstream peak discharge of 10 m^3/s.
- A float operated radial gate to maintain a constant discharge of 10 m^3/s
- A Hydro-Brake® which provides a reasonably constant discharge up to a maximum of 10 m^3/s.

Controls at the downstream end of the culvert were avoided because this would have pressurised the culvert though the dam, which has the potential to lead to leakage and consequent hydrostatic pressures within the dam fill.

Various of the above options were rejected for the following reasons:-

- Arrangements to allow manual operation of penstocks during a flood event were not considered to be of practical benefit because it would be unrealistic to expect Agency staff to operate them safely during a flood event. The penstock would therefore, in effect, act as a fixed orifice.
- A penstock housed in a chamber within the dam would create a confined space, which was not acceptable to the Agency.
- A fixed orifice would cause unnecessary, frequent and significant flooding upstream of the dam which would limit use of the land for agriculture, which was unacceptable to the affected landowners. Early storage of water did not, however, have a great influence on the height of the dam.
- There is no power supply near to the site for automatic gate operation and to provide this added greatly to the scheme cost. There would also be a risk of power or equipment failure during a flood event.
- There is a risk of failure of operation of equipment only intermittently used or tested, which was unacceptable to the Agency.
- There would be a significant maintenance requirement, which the Agency wished to minimise.
- A float operated radial gate across the culvert exit controlled by downstream water level was rejected because it would have pressurised the culvert and required maintenance.

The Hydro-Brake® was chosen on the basis of its simplicity, low maintenance requirements and relatively low cost for this site. The final arrangement is shown in Figure 2. The Hydro-Brake® restricts the flow more at low head than an automatically controlled penstock, but it does allow a reasonably constant discharge to pass at both high and low heads. A comparison of the stored flood levels and storage areas for the control options is given in the following tables. Figure 3 shows the flooded areas.

The data in these tables show that the use of a fixed orifice rather than a Hydro-Brake® would have only increased the dam height by 300mm. However at low return periods (when there is no need for flood storage to prevent flooding in Weedon Bec) the flood level and area flooded are much lower with a Hydro-Brake® or automatic penstock. With a Hydro-Brake®, in a 1 in 3 year event, the flooded area is limited to the area immediately in front of the dam, which is largely occupied by the borrow pit. With a fixed orifice the flooded area would extend into the surrounding fields.

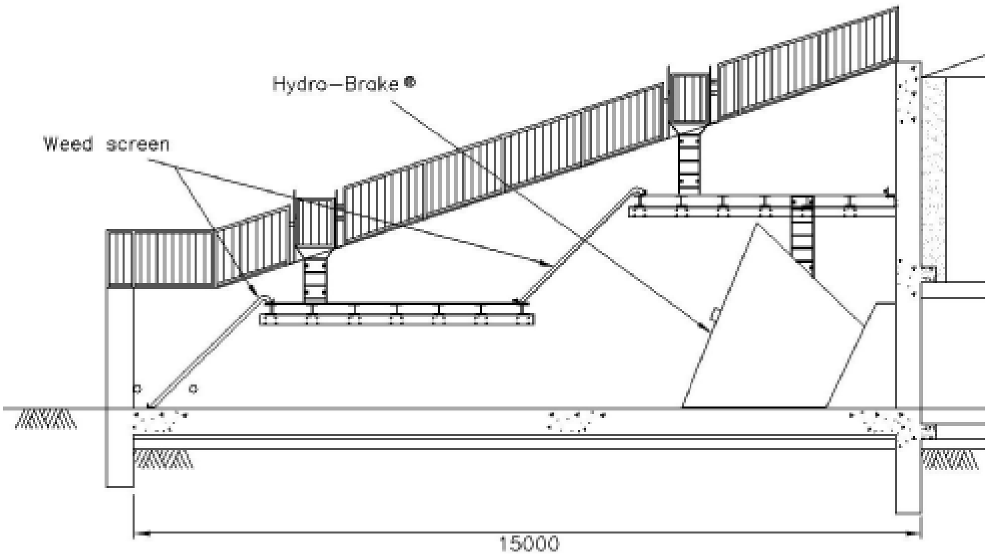

Figure 2. Section through the intake structure and Hydro-Brake®

Table 1. Storage Areas and Levels

Control	1 in 3 Years		1 in 50 Years	
	Level (mAOD)	Flooded Area (m^2)	Level (mAOD)	Flooded Area (m^2)
Fixed Orifice	89.6	146,145	91.7	417,890
Automatic Penstock	88.2	21,660	91.5	379,610
Hydro-Brake®	88.6	49,635	91.4	369,370

Table 2. Approximate Return Periods at which Storage would Commence

Control	Return Period when Storage Begins
Fixed Orifice	1 in 1 year
Automatic Penstock	1 in 3 years
Hydro-Brake®	1 in 1 year

As can be seen from the above figures an automatic penstock would have reduced the flooded area in low return periods further than a Hydro-Brake® but this was not possible for reasons explained previously.

Adjustment of the Hydro-Brake® is possible so that the peak discharge can be varied from the value determined by computer modelling should this prove to be necessary in practice. The peak discharge can be varied from 8 to 12 cumecs by the removal or addition of stop logs bolted across the Hydro-Brake® inlet.

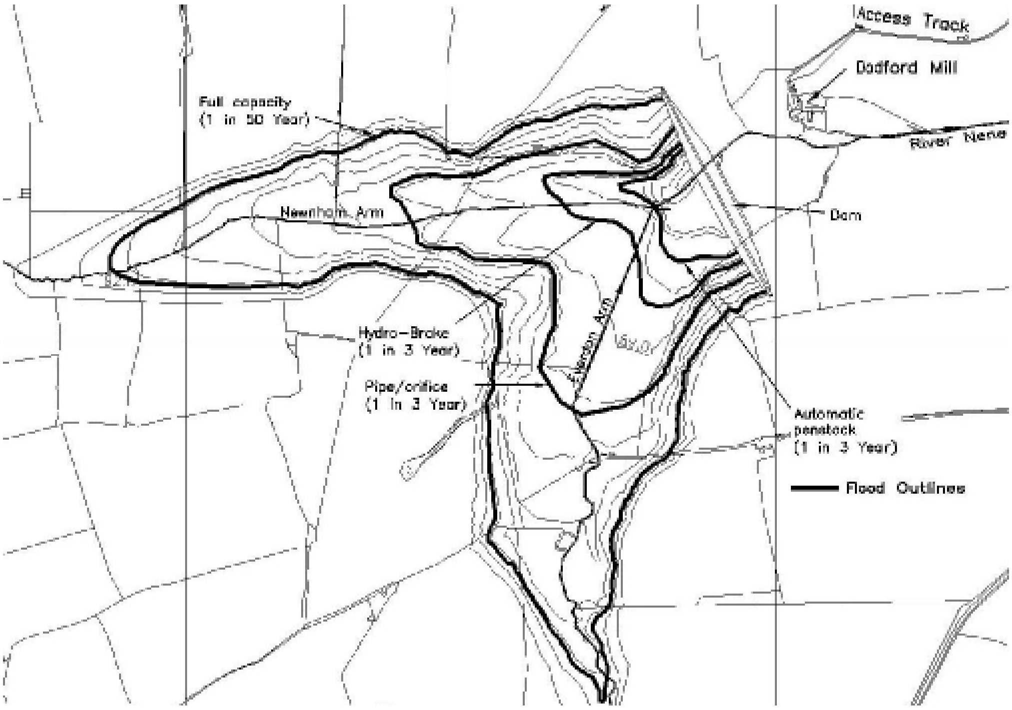

Figure 3. Comparison of flooded areas.

A trash screen has been provided upstream of the Hydro-Brake® and there is also a security screen at the downstream end of the culvert to prevent access by unauthorized people, particularly children.

Water level sensors are provided upstream and downstream of both the trash screen and the security screen, these are linked by telemetry to the Agency's control centres in Peterborough and Kettering. This allows monitoring of water level upstream and downstream of the dam and also shows if there is a difference in water level across the screens indicating that there may be a build up of trash.

USE OF THE HYDRO-BRAKE® FOR FLOW CONTROL

History of development and previous use of the Hydro-Brake®

The Hydro-Brake® is a proprietary gravity operated vortex flow control device designed by Hydro International plc. Outwardly having the appearance of a coil-shaped or conchoidal 'shell', units typically range from less than 1m to over 3m in length. The secret of their proven performance lies in the precise design of their shape, size, inclination and approach characteristics – not in expensive and complicated mechanical engineering.

In the United Kingdom, the first known major use of vortex flow control was to control and dissipate energy in drop shafts. The first commercial application in the UK as an integral part of drainage infrastructure to attenuate flows and alleviate flooding, was in 1980. Worldwide, more than 13,000 Hydro-Brake® Flow Controls are already in use, the majority having been installed on new developments to maintain flow rates equivalent to those of the greenfield site (pre-development run-off rates).

Prior to the Hydro-Brake® at Weedon becoming the 'Biggest Hydro-Brake® in The World', its predecessor had been installed as part of the Ashford Flood Alleviation Scheme over 12 years ago. This unit, which is basically the same shape and type as the Weedon Hydro-Brake® (without the in-built adjustability), has an outlet approximately 1.25m in diameter, whereas the Weedon Hydro-Brake® has an outlet diameter of 1.75m.

Experience to date with the Aldington installation has been very positive with the Hydro-Brake® performing exactly as expected. During the flooding experienced in that area in October and November 2000 the storage area at Aldington was actually overtopped, whilst the Hydro-Brake® discharged at precisely the correct levels. This reservoir was designed to retain floods of up to 1 in 100 year return period with a controlled discharge, illustrating the severity of the rainfall at that time. It has been well documented that had the Ashford Flood Alleviation Scheme not been in place at that time, Ashford would have suffered enormously. Older parts of town, close to the international railway station, would have flooded and about 100 houses would have been under water.

There has been much development of the Hydro-Brake® Flow Control since its original conception over 20 years ago, with constant ongoing testing and research to improve the hydraulic characteristics and develop more efficient units. Several new types have been introduced in recent years providing larger openings thus reducing the risk of blockages, as well as improved head / flow characteristics which reduce the amount of upstream storage required without exceeding the maximum required flow rate.

<u>Hydraulic characteristics</u>

The Hydro-Brake® is a self-activating passive flow control device with no moving parts and requiring no external sources of power to operate it. Instead, it uses the inherent energy in the flow field to control flows in sewerage systems, drainage channels and outlets from storage systems.

As flows build-up, a Hydro-Brake® typically exhibits two distinct modes of operation (see Figure 4 below). In the first mode, termed pre-initiation, the unit behaves like a large orifice, allowing relatively high flow volumes to be discharged at low operating heads. As the operating head increases, the volute of the Hydro-Brake® fills and the upstream water energy is converted into rotary motion within the device. This generates increasingly higher peripheral velocities, which eventually results in the creation of an air core, occupying most of the outlet of the device. In turn, this produces a back pressure that opposes the through flow of water. This second mode, is termed post-initiation, the 'throttling' effect causing the device to behave like a conventional orifice control or throttle pipe having a significantly smaller opening than the outlet size of the equivalent Hydro-Brake®.

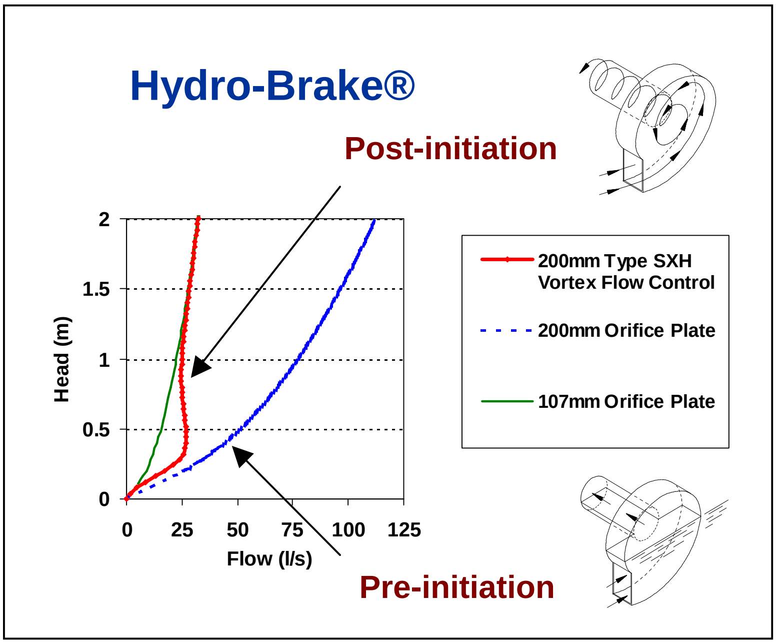

Figure 4. The Hydro-Brake® : Flow and Head Characteristics for the Pre and Post-initiation Phases

The two most obvious advantages in the use of a Hydro-Brake® at Weedon were reduced upstream storage requirements and comparatively larger openings. Other advantages include the lack of power required to operate as well as the absence of any moving parts. These factors coupled with the typical self-cleansing properties of a Hydro-Brake® result in a much reduced maintenance commitment.

Any drawbacks with the use of Hydro-Brake® Flow Controls tend to be either perceived or avoidable. The purchase costs are often quoted as a barrier, but can virtually always be outweighed by the savings in storage requirements and reduced maintenance costs. Another perception is that they are sometimes prone to blockage, especially when used in a foul / combined sewer application. Any flow control in a drainage or sewer system is, by its very nature, a restriction of some sort with an outlet size generally smaller than the system leading up to that point. The passage of objects larger than that opening is potentially a problem with any form of control and it is therefore important that consideration is given to preventing large masses from reaching it. It is true to say that the unique shape of a Hydro-Brake® generally prevents there being a straight path through the control, but with a correctly designed chamber or inlet structure including good benching etc., problems can always be avoided.

SCHEME CONSTRUCTION

An ECC Option C contract for the project was let to Edmund Nuttall Ltd in February 2001 with the flood storage dam comprising one section of a four-section contract for the Environment Agency. The agreed target price of £1.0 million was negotiated in April 2002 following completion of detailed design and having value engineered the project with the contractor.

Construction work commenced in April 2002 with a 34 week construction period. The planned sequence of operations is summarized below, although in practice there was some overlap of these activities.

- Establish site
- Install temporary bridge and divert the river into a temporary channel
- Construct culvert, headwalls and associated structures on the line of the existing channel
- Divert the river back through the culvert and reinstate the temporary river diversion
- Strip surface, excavate cut-off and place fill to the cut-off and dam
- Place erosion protection to the embankment and spillway
- Install Hydro-Brake®, trash rack and security screen
- Place topsoil, reinstate site and landscape

After some delays early in the contract, fine weather allowed the earthmoving to proceed quickly, so that it was essentially completed in October 2002. High river flows then caused delay in installing the Hydro-Brake®, which was completed in November 2002. Completion of topsoiling, seeding and finishing works was delayed until spring 2003.

Installation of the Hydro-Brake® was programmed to take place after placing of the spillway blocks, as this would effectively cause the reservoir to become operational. As it turned out, placing of the Hydro-Brake® under winter rather than summer flow conditions was difficult, and would have been easier if done earlier. This could have been possible by leaving a temporary opening in the upstream headwall to supplement the flow through the Hydro-Brake® and prevent impounding in the reservoir until the spillway was ready.

Environmental Aspects

A mineral extraction licence had to be obtained from Northamptonshire County Council who were the approval body for the borrow pit and its restoration, whereas the building of the dam was subject to planning permission from Daventry District Council who were the approval body for the dam landscaping. The two bodies had different landscape approaches.

The dam landscaping was relatively straightforward. Cellular concrete blocks used on the spillway were topsoiled and seeded. Elsewhere, grass seed was sown on prepared topsoil. An area of this on the upstream face was covered with fibre erosion protection matting over the topsoil. Hedges that had been removed were replaced with new planting, and some additional screening woodland was planted.

The borrow pit area was less straightforward because Northamptonshire C.C. did not want to have a significant body of water in the restoration, although this had been part of the scheme concept preferred by the Environment Agency. As a value engineering exercise, the original restoration plan was modified using input from the main contractor with a specialist landscaping sub-contractor and the Halcrow project environmental scientist. The accepted restoration incorporates areas of native tree planting and wild flower mix seeding which provides a diversity of habitat. This area has now been handed back to the farmer owner who continues to manage it as envisaged although there is no formal agreement relating to it.

CONCLUSION

A detailed study of the options to address the frequent flooding in Weedon Bec identified an upstream on-line flood storage reservoir on the River Nene as the only viable solution. Investigation and design, with due regard to flooding frequency and environmental factors has produced an economic scheme, with minimum adverse impacts on the surroundings, largely using materials available on-site.

The selection of a Hydro-Brake® as a flow control has significantly improved the scheme hydraulic performance, particularly in reducing the frequency of flooding of the storage area, which in this case is actively managed arable farmland. While use of a Hydro-Brake® at Weedon is not unique in flood control schemes, this installation has pushed the boundaries forward in the scale of what can be accomplished using these proprietary devices.