Chapelton Flood Storage Reservoir

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SYNOPSIS. The Moray Council has completed a scheme to protect the town of Forres (Moray, Scotland) against flooding from the Burn of Mosset up to a standard of at least 1 in 100 years. The main component of the scheme is a 3.8Mm³ capacity flood storage reservoir situated at Chapelton.

The Paper describes the development of design, which includes the first baffled crump weir flow control structure constructed in a UK dam and the first large-scale use of open stone asphalt on a UK dam spillway. The design also includes features to minimise the visual impact of the dam, such as a sacrificial layer of topsoil and grass over much of the engineering work and an aesthetically pleasing curved dam crest. The Burn Management Works dramatically illustrate the combination of cutting-edge river restoration techniques, habitat creation and a sustainable solution to a geomorphological problem.

The main impounding structure is an earth dam, approximately 200m in length and up to 6.9m high. It is constructed from locally won material and has a sheet piled cut-off to control seepage. The flow control structure will accommodate fish passage and fine debris thus removing the need for conventional trash screens. The paper describes the design for the flow-control structure with the aid of a physical model. The design is based on earlier work by Ackers et al and reported at the 13th BDS Biennial Conference.

INTRODUCTION

Background

Forres, a town with approximately 9,000 inhabitants, is located 30 miles east of Inverness in northern Scotland. The Burn of Mosset drains an area of 49km² upstream of Forres before flowing through the centre of the town towards Findhorn Bay.

Managing Dams: Challenges in a Time of Change. Thomas Telford, London, 2010

Prior to the flood alleviation scheme nearly 1 in 5 houses in Forres were at flood risk from the Burn of Mosset at the 1 in 100 year return period (Figure 1). Without investment in flood alleviation the flood damages in Forres would exceed £43million over the next 50 years. Moray Flood Alleviation was established in 2001 for the purpose of delivering flood alleviation to a number of communities in Moray, including Forres. It is an integrated team comprising The Moray Council, Royal Haskoning, Morrison Construction and EC Harris. The Construction Engineer under the Reservoirs Act is Ian Gowans.

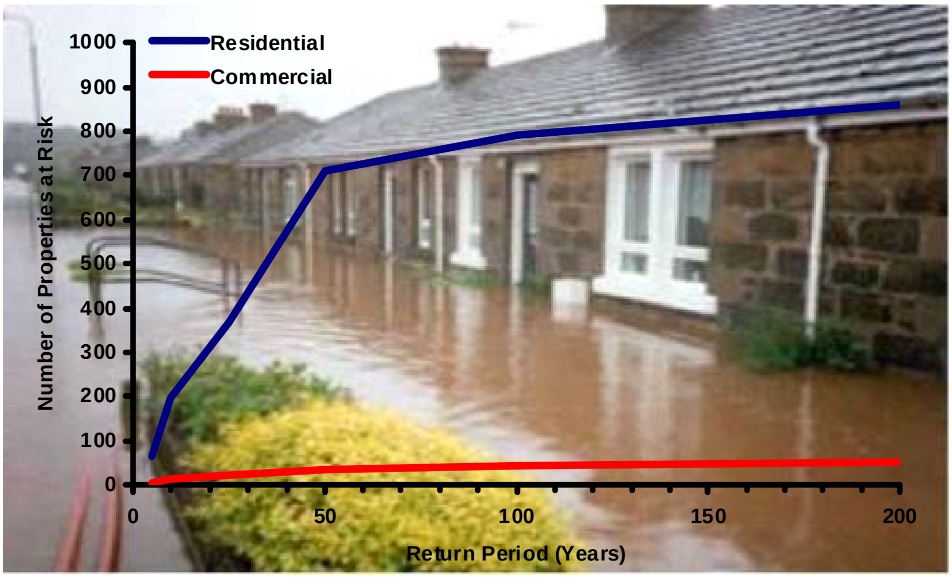

Figure 1. Flood risk prior to the scheme

<u>The solution</u>

The Forres (Burn of Mosset) Flood Alleviation Scheme (the Scheme) alleviates flooding in Forres arising from the Burn of Mosset. It comprises a flood storage reservoir, situated on the Burn of Mosset at Chapelton just upstream of the Forres, combined with flood defences through the town. It is estimated to provide a standard of protection of at least 1 in 100 years, including an allowance for climate change up to the 2080s. Work commenced on the Scheme in 2002, with construction occurring between November 2007 and November 2009.

The flood storage reservoir has the following components and characteristics (Figure 2):

- Embankment dam with a maximum height of 6.9m and a length of about 200m.

- A 160m wide open stone asphalt overflow spillway running over the crest of the dam and the downstream face.
- A stilling basin comprising two layers of rock armour and, at the toe of the spillway, a voided concrete slab.
- A flow control structure incorporating a baffled crump weir.
- Two penstock controlled fixed orifices for maintenance purposes (both closed under normal operating conditions).
- 3,800,000m^3 storage capacity.

The flow control structure will throttle the Burn of Mosset to give a maximum discharge of 8.5m^3/s. Flows in excess of this will be stored within the reservoir and discharged from the reservoir after the passage of the flood. The spillway will allow the more extreme floods to be safely discharged when the reservoir is full. The spillway is designed to pass the extreme flood events required for this Category A reservoir (PMF Summer inflow = 313m^3/s, 1 in 10,000 inflow = 163m^3/s).

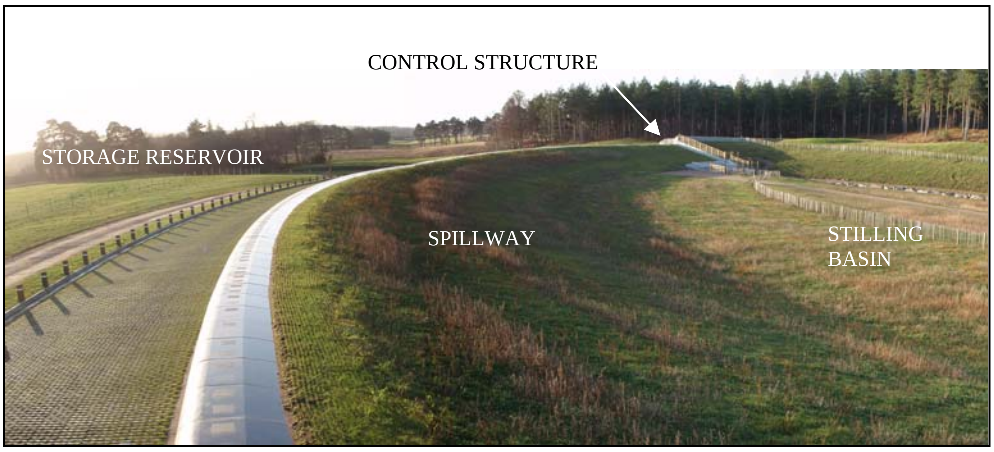

Figure 2. Chapelton Dam

BAFFLED CRUMP WEIR

Concept

The Scheme was required to operate without user intervention, without power and allow passage of migratory fish. A range of discharge control mechanisms were reviewed during design, including a simple orifice, a flume, and other controls. However, to achieve a discharge of not more than 8.5m^3/s over the range of heads it was decided to develop a baffled crump weir device along the lines of that described at the 13th BDS Biennial Conference by Ackers et al.

The baffled crump weir concept is illustrated in Figure 3. There are three main flow regimes: normal (low flow), upstream baffle control and downstream baffle control. Physical modelling was used to determine the optimised geometry of the baffled crump weir and the stage vs. discharge relationship.

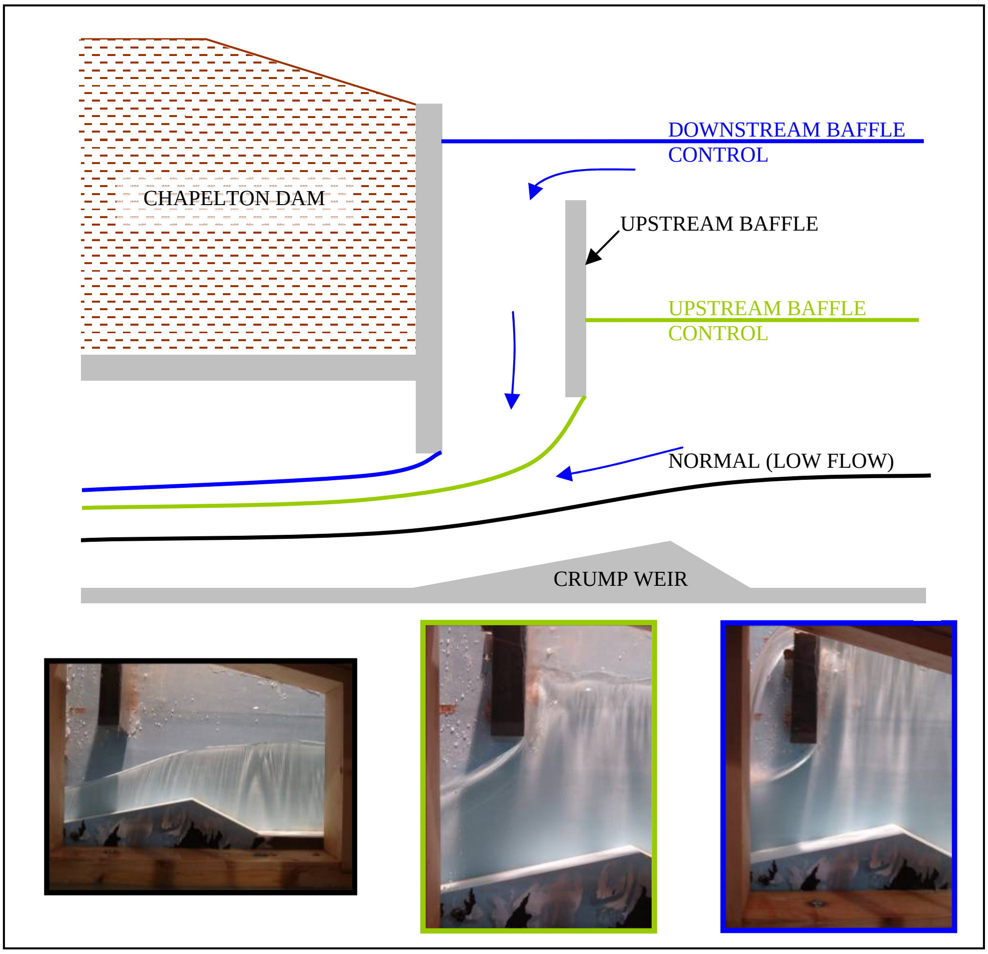

Figure 3. Baffled crump weir concept

Model Study

A physical model (Figure 4) was constructed and tested to a natural scale of 1:10. This was sufficiently large to provide accuracy of water surface measurement and the determination of the discharge characteristics of the control structure. It was also considered large enough to avoid potential scale effects and was consistent with the available pump and tank facilities. The control structure, weir and baffles were constructed mainly from PVC, which provided a boundary roughness for the structure similar in model terms to the finish of the concrete structure. The right-hand side wall of the model at the control structure was constructed from Perspex allowing full flow visualisation through the structure (Figure 3).

Figure 4. Physical model

Flow was supplied by a centrifugal pump and measured by a pre-calibrated electromagnetic flow meter (accuracy of about 1%). Water levels were controlled at the downstream boundary of the model using an adjustable weir tailgate. Water levels within the inlet area were measured using a twin wire capacitance probe. Water levels at other key locations were measured using micrometer point gauges reading to an accuracy of 0.25mm (i.e. 2.5mm in prototype terms).

<u>Testing</u>

Initial testing focused on determining the optimal arrangement of the control structure to achieve the required performance (head vs. discharge). The model was then used to determine the performance rating for the favoured arrangement over the full range of upstream water levels for both rising and falling water levels and where performance would be influenced by tail water.

Tests were undertaken to observe flow conditions in the Control Structure Culvert downstream of the control structure and to assess the need for energy dissipation/tail water control measures. The performance of the bypass channel, which may be used if the control structure were to block, was also tested. Measurements relating to the performance of the crump weir for assessing the ability of migratory fish to pass over the weir were made.

<u>Final tests</u>
The optimised baffle design was identified and tested. It met the target stage/discharge relationship for the flow control element. The optimised baffle arrangement (Figure 5) consists of two vertical baffles, the downstream baffle having an angled lip. The channel is 1m wide.

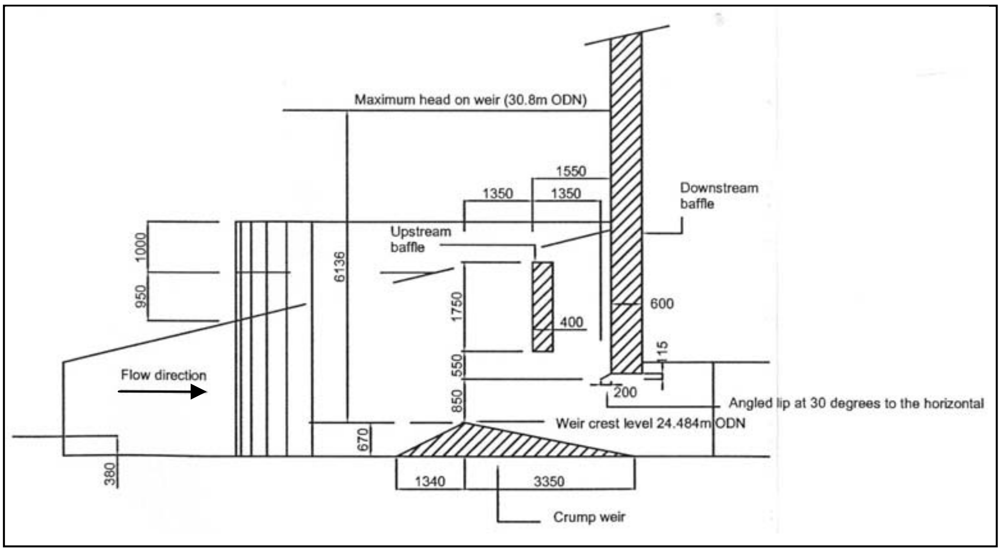

Figure 5. Optimised arrangement

The stage vs. discharge relationship is shown in Figure 6. The average discharge through the structure from the onset of the baffle control, at a reservoir level above the weir crest of 2.64m, to a reservoir level above the Crump weir of 6.32m was about 7.6m³/s within an envelope of results either side of the average discharge of approximately 12%.

SPILLWAY AND STILLING BASIN DESIGN

<u>General</u>
The spillway has a long curved crest that allows the 10,000 year event to discharge over the dam whilst minimising the flood surcharge and also fitting-in with the local topography of the valley. During such events, water velocities in the spillway will reach up to 7m/s for a period of up to 30 hours.

It was deemed desirable to maintain the ‘green’ appearance of the dam to blend in with the surrounding landscape. Therefore, the design of the spillway and stilling basin combines “hard engineering” beneath an aesthetically pleasing grass covering.

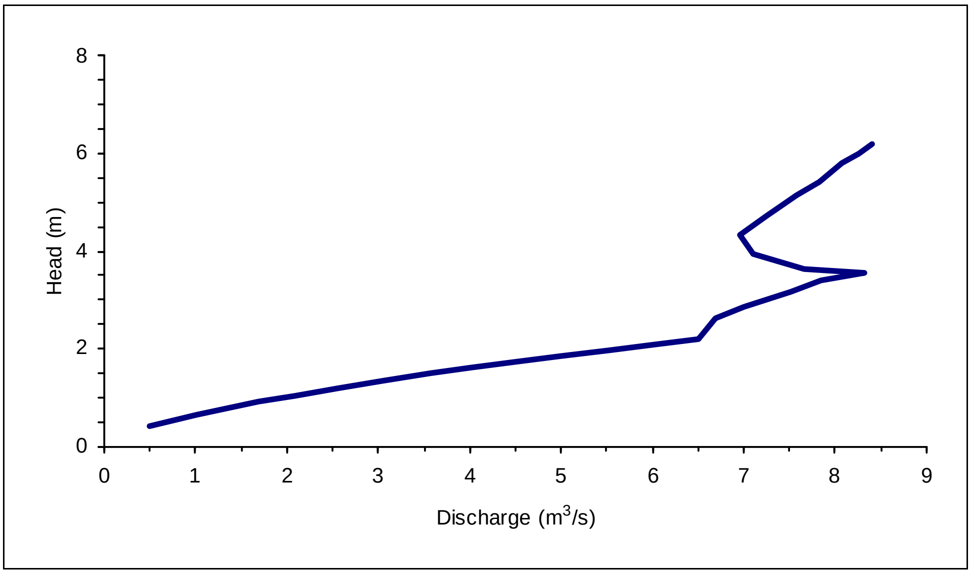

Figure 6 Baffled crump weir stage vs. discharge

<u>Selection of materials</u>

A number of options to reinforce the spillway and stilling basin were considered, including concrete blocks, proprietary paving systems, open-stone asphalt, concrete slabs and rock armour.

Open stone asphalt was considered the best option on the upper slope of the spillway because it can easily be vegetated and is sufficiently flexible to accommodate settlement. A more robust solution was required on the lower slope of the spillway because of the higher velocities and turbulence associated with the hydraulic jump. A voided concrete slab system was developed for this area; this also allows grass to be sustained. Rock armour was utilised for the remainder of the stilling basin.

<u>Upper slope – open stone asphalt</u>

Open stone asphalt (Figure 7) is an inert material that does not deleteriously affect water quality. It is also a permeable material with approximately 20% voids spread throughout the material. The irregular surface of the open stone asphalt provides good interaction with the topsoil, thus reducing the topsoil’s susceptibility to creep down the slope. The 150mm soil cover also helps reduce the rate of degradation of the hydrocarbon elements of the material by ultra violet light.

Figure 7 Laying open stone asphalt

The factor of safety against sliding between the earth fill and the spillway materials was critical. The most important factors being: the slope angle, the flow depth/velocity and the angle of internal friction. In the final design the earth fill surface was benched and covered with a needle punch geotextile. A 600mm layer of coarse gravel was placed on the benched profile and covered with a 400mm layer thickness of open stone asphalt.

Lower slope and stilling basin – voided concrete slab and rock armour

The voided concrete slab (Figure 8) was constructed along the toe and on the lower part of the spillway slope. The rock armour was placed in the stilling basin area and the voids filled with sand and gravel and then topsoiled.

Topsoil and grass

The whole of the spillway and stilling basin is top-soiled and seeded. The top soil will probably be lost during any major overtopping event. But, given the infrequency of such events, the grass should be able to grow undisturbed for many years.

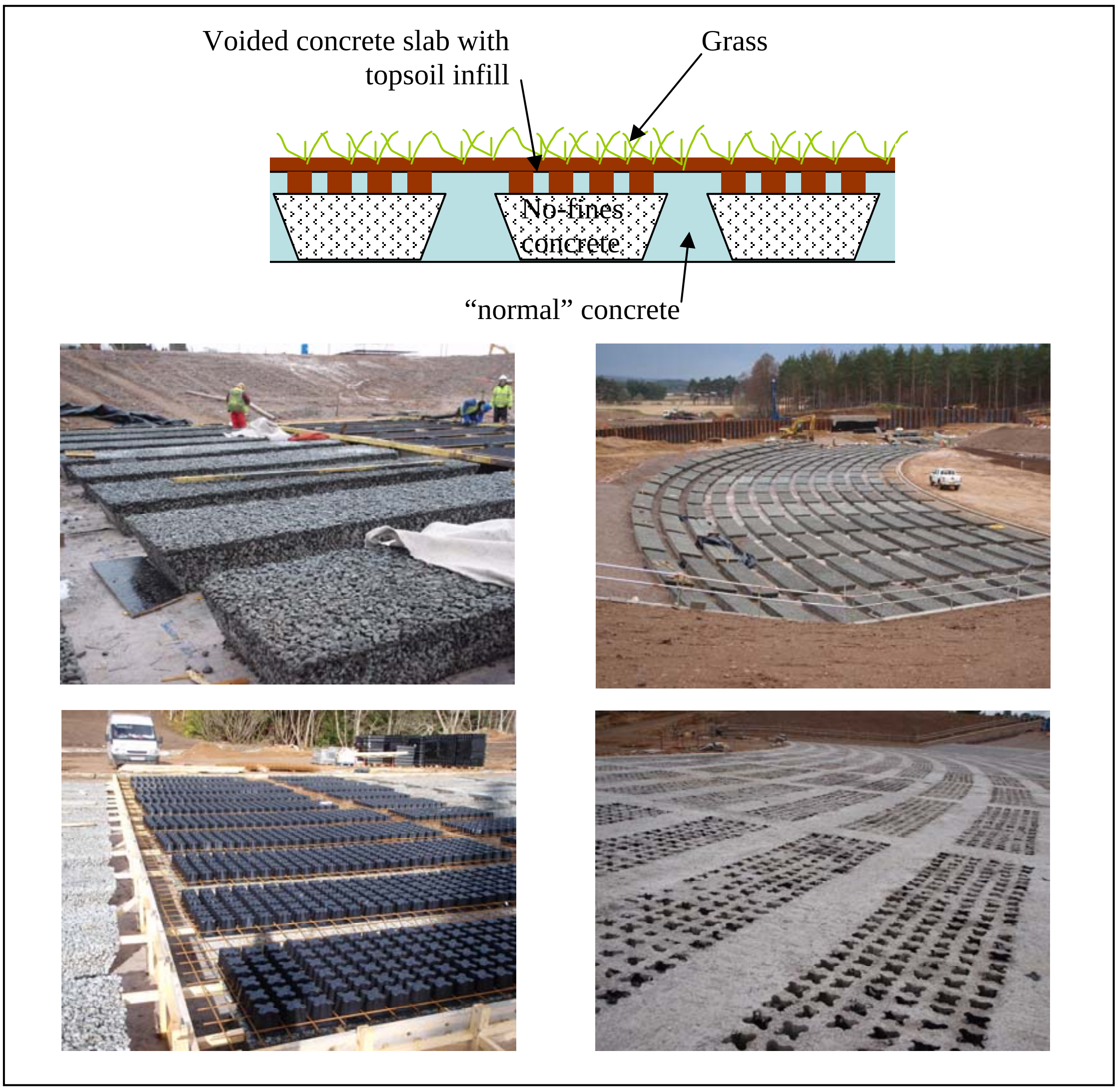

Figure 8. Voided concrete slab

BURN MANAGEMENT WORKS

The reach of the Burn of Mosset within the storage reservoir was probably once more geomorphologically active than today, with areas of anabranched channels, wet woodland and bog. The Burn Management Works illustrate a rare example of ecologically beneficial long-term river restoration undertaken as an integral part of a flood alleviation scheme.

The main body of the flood storage area comprises a wide flat area of peat bog. Prior to the scheme, the Burn of Mosset flowed through the area along an alignment comprising two straight reaches connected by a right-angled bend. The channel is confined on both sides by man-made embankments, constructed over decades by the dredging activities of riparian owners. The dredging activities have been insufficient to keep pace with the incoming sediments and therefore the bed of the burn is generally perched above the level of the surrounding floodplain.

The significant quantity of sand and gravel transported by the burn during flood events is deposited in the relatively flat reaches through the storage site. Dredging of the burn by landowners has declined over recent years, partly due to discouragement by statutory environmental bodies. Without this ongoing (and ecologically damaging) intervention the embankments would eventually breach. Because the burn is perched, this would result in a dramatic one-off change, with all the flow being diverted onto the adjacent floodplain. In the long-term this may have created a natural system with good habitat, but there would be a significant short to medium-term detrimental impact on the remainder of the original river corridor. The location of the breach would also be unpredictable, with some locations being less desirable than others (from a land-use perspective).

The burn management works comprise channel realignment/restoration and planting that will deliver a smooth transition from the existing managed river corridor to a more natural anabranched channel with associated valuable habitats. A shallow ‘secondary’ channel, between two deliberate breaches in the left bank of the burn (Figure 9), was excavated on a sinuous alignment. Initially, under low flow conditions, about 20% of the flow in the burn was diverted into the adjacent floodplain. Areas adjacent to the new channel were planted with native trees of local provenance, whilst the lowest lying areas that remained permanently wet were left open.

During the first major high flow event after construction of the works (approximately 29m^3/s, on 4 September 2009), the upstream breach to the new channel was doubled in width and a significant fan of sand and gravel was deposited onto the local flood plain. Some woody debris was also ‘stranded’ on the newly active flood plain.

Figure 9. Burn Management Works, before and after 4 Sept 09.

The works will take a few years to fully naturalise, but already there is a noticeable increase in the amount of wildlife, particularly wildfowl, and a vast local geomorphological change. Following a recent site visit, a representative from Scottish Natural Heritage said "…I was really impressed to see this area of work and just how well the water is spreading out across the area. The area provides a really good example of…measures that can be taken to try and reconnect our rivers with their floodplains…".

THE FIRST TEST

The scheme was officially opened on 28 August 2009 by Richard Lochhead MSP. One week later 93mm of precipitation was recorded over a thirty-hour period in the Burn of Mosset catchment. Despite a few key elements of the scheme being only partially complete, the scheme successfully operated (Figure 10) and prevented flooding of hundreds of properties and an estimated £9million of flood damage.

The community was obviously delighted to see the scheme avert what would otherwise have been a devastating flood. Positive feedback has also been received from members of the community regarding the overall appearance of the scheme, which demonstrates the successful integration of "hard engineering" with green landscaping.

Figure 10. First successful operation, 4 September 2009

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