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Chapter 14

Design of an environmentally aligned flood alleviation scheme: the Burn of Mosset, Moray, Scotland

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Forres, Scotland, has a long history of flooding from the Burn of Mosset, and it was forecast that, without investment in flood risk management, flood damages were likely to exceed £43 million over the next 50 years. The decision was taken to implement a flood alleviation scheme (FAS) featuring an earth-fill dam upstream of Forres, capable of storing up to 3.8 million m^3 of water and limiting peak discharges into the urban area to 8.5 m^3/s. It was recognised that sediment- and debris-related risks to the performance of the structure had to be managed and Burn Management Works were designed using cutting-edge river restoration techniques for channel rehabilitation and habitat creation to enhance the capacity of the flood basin to store sediment and debris. The FAS was opened on 28 August 2009 and the dam impounded flood water for the first time on 4 September 2009, avoiding approximately £9 million of flood damages to the town of Forres. The Burn Management Works have evolved mostly as expected, although some features have not functioned as intended, and lessons have been learnt concerning the need to allow for unexpected developments when using 'prompted recovery' in flood risk management and river rehabilitation.

14.1. Introduction

Forres is a market town (population 9000) located 16 km west of the city of Elgin in Morayshire, Scotland (Figure 14.1). The Burn of Mosset is a small but geomorphologically active, gravel-bed stream that drains an area of 49 km^2. It flows northwards through the centre of Forres, before confluencing with the River Findhorn in Findhorn Bay. Forres has a long history of flooding from the Burn of Mosset, with six events causing serious property damage and disruption of daily life within the last 50 years.

14.2. Background

The most recent severe flooding occurred in 1997, but significant events also occurred in 2000 and 2002. The 1997, 2000 and 2002 events had estimated return periods of 50, 5 and somewhat less than 5 years, respectively. Base flow in the Burn of Mosset at Forres is less than 1 m^3/s, and the 1 in 100-year flow is estimated to be 68 m^3/s, making a 15%

Figure 14.1 Forres location map

allowance for climate change up to 2080. Peak flow during the 1997 event was estimated at 48 m^3/s. During that event, approximately 430 homes and 27 commercial properties were inundated (Figure 14.2) and regional communications were seriously disrupted, with both the A96 trunk road and the Inverness to Aberdeen mainline railway being closed due to flooding.

Economic losses caused by the 1997 flood alone were of the order of £3.7 million, and it was forecast that without investment in a flood alleviation scheme (FAS), flood damages in Forres would be likely to exceed £43 million over the next 50 years. The economic case for a FAS for Forres was, therefore, clear.

However, geomorphological reconnaissance surveys (performed using methods described by Thorne *et al.* (2010)) performed as part of feasibility studies for a FAS revealed that the Burn of Mosset is highly active geomorphologically, and that it transports substantial quantities of sediment ranging in size from cobbles to sand and silt-sized material. Most of the cobble and gravel-sized bedload is deposited in the channel upstream of Forres, in the form of both shifting gravel bars and semi-stationary riffles, which have historically been managed for agricultural land drainage by dredging, with the dredge spoil used to build flood embankments on an *ad hoc* basis (Figure 14.3).

Substantial quantities of suspended sand/silt load, derived from field erosion associated with agricultural practices in the upper catchment, are also transported as wash load, but

Figure 14.2 Flooding in Forres during the 1997 event

these are carried into urban area of Forres, where they are mostly deposited in Sanquhar Loch, which is an artificially impounded water body located on the southern edge of the town The field survey further revealed that the Burn carries considerable quantities of organic debris, including leaves, twigs and large wood. The findings of the geomorphological assessment indicated that, to reduce the unacceptably high flood risk in Forres sustainably, it was essential to design a scheme that accounted for the dynamics of sediment and organic debris, as well as those of the floodwaters.

14.3. Option development and appraisal

A variety of potential solutions were considered for addressing the flooding problem. These included a number of contrasting flood risk management strategies. Options ranged from hard engineering solutions (involving construction of a diversion channel around Forres, channel enlargement, or the raising of existing flood defences within

Figure 14.3 Gravel removal and *ad hoc* embanking of the channel of the Burn of Mosset upstream of Forres

the town) to flood storage, removal of properties in vulnerable areas, and changes in catchment management. The criteria by which the options were appraised were developed by the stakeholders at a value management workshop.

- *Environment* – The FAS will aim to create sustainable development that recognises the importance of the environment, minimises construction impacts and enhances the environment where possible. The scheme will aim to preserve the local character of the town and its surroundings.
- *Sustainability* – The FAS will aim to ensure the best achievable balance between environmental, social and economic well-being through use of the Morayshire Flood Alleviation Group's sustainability criteria and indicators. In the absence of any locally accepted methodologies available at that time, a document entitled *Rethinking Sustainability: Design Guidance and Procedures* was produced in November 2002 to inform management of scheme development.
- *Geomorphology* – The FAS will aim to minimise disturbance to natural geomorphological processes.
- *Stakeholder consultation* – The public, statutory consultees and interest groups shall be consulted at key stages of the development of the FAS. The views and opinions of stakeholders shall be taken on board and reflected in the development process and its outcome. Community values shall be central to the scheme.
- *Landowners* – The FAS will aim to minimise the impact on landowners and property occupiers.

- *Planning development* – The FAS will, where possible, accord with the Moray Development Plan (2000), planning policies and objectives. The FAS will avoid constraining future development opportunities.
- *Operation and maintenance* – The selected option will be designed with the aim of minimising future operation and maintenance requirements. The design shall accommodate safe access and egress for all operations and maintenance activities.
- *Opportunities* – The FAS design shall fully consider opportunities for improving recreation and amenity values.

Three options judged to be technically feasible and capable of delivering a minimum flood defence standard of service of 1 in 100-years were appraised according to these criteria.

14.3.1 Option 1: Channel diversion

The principal works would include the following.

- Construction of a diversion channel from the Burn of Mosset upstream of Forres to the River Findhorn, including:
  - 1.9 km long diversion channel
  - culvert or bridge under the A940 road
  - cascade to grade the diversion channel into the Findhorn valley.
- Works through Forres, including:
  - rehabilitation of floodwalls and embankments
  - removal of existing weirs and channel bed reprofiling
  - flood-plain lowering.

14.3.2 Option 2: Floodwalls and embankments through Forres

The principal works would include

- raised floodwalls and embankments throughout the urban area of Forres
- modifications to seven bridges (including the A96 trunk road bridge and the Inverness to Aberdeen mainline railway bridge)
- removal of existing weirs and channel bed reprofiling
- flood-plain lowering at selected locations
- raising the dam at Sanquhar Loch upstream of the town centre.

14.3.2 Option 3: Flood storage dam at Chapelton

The principal works would include

- construction of an earth-fill dam situated on the Burn of Mosset at Chapelton and capable of storing up to 3.8 million m^3 of water, including a flow-control structure to limit peak discharges into the urban area to a maximum of 8.5 m^3/s
- construction of a sediment and debris trap upstream of the dam
- earth embankments to protect properties close to the perimeter of the storage area from flooding.

14.4. Preferred option

The preferred approach for the FAS was identified by evaluating the three options using the sustainability criteria outlined above, while also considering the benefit–cost ratio for each option. As noted earlier, sustainability was evaluated with reference to a guidance document *Rethinking Sustainability*, which provided a framework for assessing sustainability based on economic, social and environmental factors.

This appraisal resulted in option 3 (flood storage dam at Chapelton) emerging as the preferred option. The main structural element in this option is a dam at Chapelton (Figure 14.4), which restricts peak flows passing through it during flood events to a maximum of 8.5 m^3/s, with the excess flow being stored temporarily in a flood reservoir upstream of the dam, to provide a standard of service to Forres of at least 1% annual exceedance probability (i.e. the 1 in 100-year flood event).

One of the major concerns in designing the dam was to avoid the possibility of blockage of the flow control structure by sediments or floating material, such as large woody debris (LWD). The design selected for the flow control structure was novel, being a baffled crump weir. This is a passive flow control system (i.e. it has no moving parts and, therefore, meets the criteria for low operation and maintenance requirements) that had not been used in a dam of this size before.

Like any hydraulic control structure, the hydraulic performance of the baffled crump weir may be compromised if it were to be partially obstructed, or even completely blocked due to the excessive accumulation of sediment or debris. Consequently, the control of sediment and floating debris being conveyed downstream by the Burn

Figure 14.4 Chapelton dam

during high-flow events had to be considered, and the associated risk to the performance of the structure managed very carefully.

Conventionally, sediment and debris management involves construction of a sediment trap immediately upstream of the control structure. If designed correctly, a gravel trap can be highly effective in catching and retaining sediment and debris, provided that it is emptied by excavation whenever a significant amount of material has accumulated within it. In the Forres FAS, this option was, however, not favoured, because the need for repeated excavation of the trap meant that it failed to meet the criterion that the design should minimise future operation and maintenance requirements. Also, such a trap would pose a potential barrier to fish passage and disrupt geomorphological processes. Consequently, it was decided to seek a softer solution that would be consistent with the requirement to minimise the maintenance and the environmental and geomorphological impacts of the scheme.

Hence, in place of a conventional sediment trap, Burn Management Works were designed for the reaches of the Burn of Mosset within the flood storage basin immediately upstream of the new dam. The principle underpinning these works was to take maximum advantage of the natural processes and landforms adjacent to the Burn. The dam is located at the downstream limit of a large, morphological basin, which should naturally act as a storage area for sediment and debris. However, the natural functioning of the basin in storing sediment and debris had been degraded by past realignment and channelisation of the watercourse to improve agricultural land drainage. It was, therefore, decided to perform Burn Management Works within the flood storage basin, reinstating and enhancing the capacity of both the channel and its flood plain to store sediment and debris. This approach relied on cutting-edge river restoration techniques for channel rehabilitation and habitat creation, to produce a sustainable solution to managing the sediment and debris-related risks to the baffled crump weir in the dam.

14.4.1 Burn Management Works

Most of the flood storage basin comprises a broad, low relief area of peat bog. Prior to construction of the FAS, the Burn of Mosset flowed through this area along two straight reaches connected by a right-angle bend, which is also the confluence with a tributary, the Rafford Burn (Figure 14.5).

This pre-FAS alignment was clearly unnatural, the Burn of Mosset having been realigned and resectioned for land drainage. The channel was also constrained on both banks by *ad hoc* flood embankments, and along much of the upper, straight reach within the flood storage basin the bed of the channel was perched above the elevation of the surrounding flood plain. This was the outcome of historical dredging and dumping of dredge spoil on the adjacent banks by landowners (see Figure 14.3). The frequency and extent of this practice was, however, reported to have declined more recently.

It was recognised that, during a major flood event, the *ad hoc* embankments constraining the perched channel would overtop and/or breach, with the potential for the channel to

Figure 14.5 Aerial view of dam, flood basin, controlled breaches (1 and 2) and Burn Management Works
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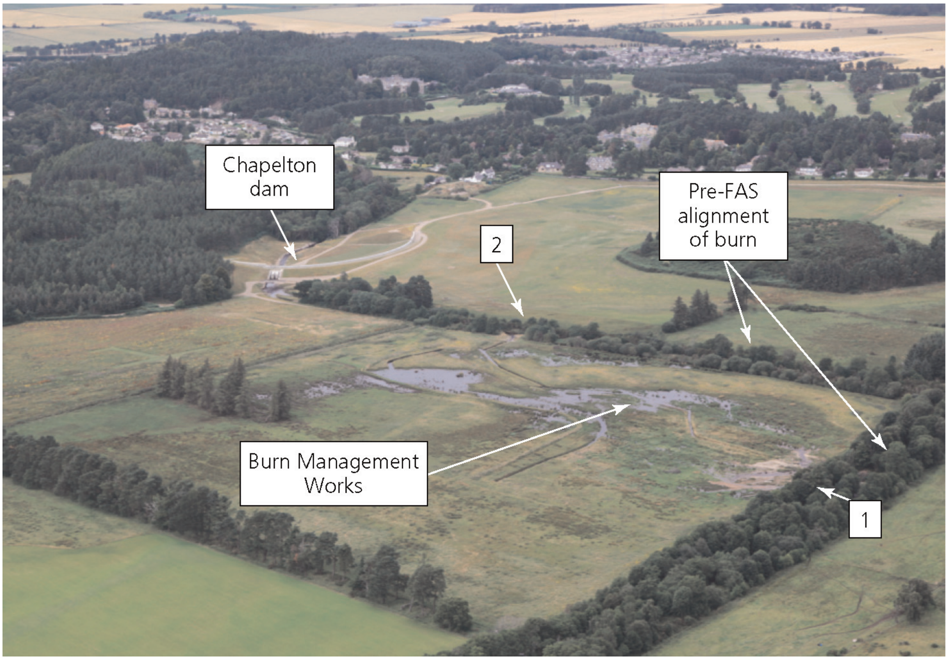

avulse onto a new alignment. If breaching of the embankments occurred on the left descending bank, the new alignment would cut off the right-angle bend (see Figure 14.5), taking flow towards the dam structure. If, however, a breach occurred on the right bank, the channel would have no obvious connection with the channelised reach approaching the control structure, and reconnecting it would require significant engineering works (see Figure 14.5). It was, therefore, decided to manage the alignment of the channel by constructing controlled breaches in the left descending bank (Figure 14.6), which ensured connectivity between the point where flow enters the flood basin and the control structure within the dam, where it leaves it.

In light of the pre-scheme alignment of the Burn within the area of the flood basin, and in the context of the wider aspirations for the FAS, the main aims of the Burn Management Works were to reduce the risk of blockage of the baffled crump weir in the dam by sediment and/or LWD to an acceptable level, and to reduce to a tolerable level the risk of the Burn avulsing onto an alignment that would disrupt connectivity between the channels entering and exiting the basin. Nested within these broad aims were objectives to

1. create an anastomosed planform (i.e. a watercourse with multiple subchannels, each of which operates semi-independently as a dynamically adjusting alluvial

Figure 14.6 Engineered breach as constructed in November 2008 to divide flow between the new channel (left) and the existing Burn (right). Note the block stone and riprap scour protection

stream) that would act as a natural sediment accretion zone with a large capacity to store material ranging in size from cobbles to sand

2. create a wet woodland around the anastomosed channel that would retain LWD while enhancing the habitat value of the area
3. configure the anastomosed channel and wet woodland so as to require minimal future management and little, or preferably no, maintenance throughout the project life of the Forres FAS
4. position the anastomosed channel so that channel shifting or avulsion would be unlikely to disrupt connectivity in the fluvial system.

Consideration of these aims and objectives according to the criteria for options appraisal developed by the stakeholders indicated that it was the most sustainable option for managing sediment, LWD and morphologically related risks to the FAS.

14.5. Implementation

Rather than attempting to construct an anastomosed channel system in the centre of the basin to restore the Burn to a more natural planform, it was decided to use a form of 'prompted recovery' in which natural processes would be encouraged to produce the desired morphological outcomes. This was initiated through controlled breaching of the existing artificial embankments at two locations along the left, descending, bank to allow flow to spill out across the flood plain and return to the original channel, while leaving it to nature to establish the pathways joining the two breaches (see Figures 14.5 and 14.6). The breaches were sized to divert 10–20% of the volume of run-off during low flow conditions, rising to a much larger proportion during floods. The aim was to avoid too rapid abandonment of the pre-FAS channelised course, which might strand fish and degrade the existing in-stream habitat faster than new habitats were being created in and around the new course. In this regard, a pilot channel was constructed between the two breaches, to ensure that passage for migratory fish was maintained (see Figure 14.5). A programme of tree planting was undertaken to encourage development of a wet woodland and associated aquatic, riparian and flood plain habitats along the new course. Only tree species native to eastern Scotland and of local provenance were selected for planting. These included

- common alder – *Alnus glutinosa* (25%)
- silver birch – *Betula pendula* (25%)
- sessile oak – Q*uercus petraea* (25%)
- rowan – *Sorbus aucuparia* (15%)
- goat willow – *Salix caprea* (10%).

The specification was for bare-rooted transplants (whips) with lengths of 450–600 mm, as these tend to establish better and grow more quickly than older specimens. The whips were planted in clumps of 3–5 of same species, spaced at 2 m centres. The planting density was selected to allow for some failures. A decision was taken against installing mesh guards to protect the whips from grazing rabbit or deer due to the risk that the guards might be washed off during a flood event and pose a hazard to wildlife further downstream in the Burn of Mosset.

Design and implementation of the Burn Management Works were aligned with the objectives of the EU Water Framework Directive, and were intended to improve the ecological status of the watercourse. This was possible because they replaced the artificially straightened, single-threaded, embanked course of the Burn with a multi-channel, anastomosed system that is fully connected to its flood plain. The works were also planned to work with, rather than against, natural processes. In this respect, it was recognised that the majority of coarse sediment delivered to the flood storage area during a flood event would be deposited where the energy gradient decreases as flow enters the flood basin. The breaches and area planted for wet woodland were, therefore, positioned to take advantage of and enhance this natural sedimentation process. Consequently, the works were approved by Scottish Natural Heritage and permitted under the relevant Controlled Activities Regulations by the Scottish Environmental Protection Agency.

Creation of a wet flood-plain woodland is also consistent with a range of environmental and habitat targets for the region, including the North East Scotland Biodiversity Action Plan (North East Biodiversity Steering Group Partnership, 2000). In addition, the Burn Management Works not only facilitated restoration of a previously heavily modified reach of the Burn of Mosset, but also created a valuable area of wetland habitat in an area of the flood plain that was previously disconnected from the channel by artificial embankments.

It was anticipated that the pilot channel and its surrounding wetland and wet woodland would develop slowly under the action of natural processes to form a larger wet woodland feature that would, in time, link to adjacent areas of woodland and the area of wet woodland found less than 1 km downstream, at Sanquhar Loch.

14.6. Post-project performance and appraisal

When the left embankments of the Burn were artificially breached in November 2008, flow was divided between the pre-FAS, artificial course of the Burn of Mosset and the pilot channel cut through the Burn Management Works. Initially, the upstream breach did in fact divert 10–20% of the base flow, as planned. It was anticipated that the Burn Management Works would prompt recovery of a more natural form to the watercourse relatively slowly, with the new course taking perhaps 3–5 years to develop a multi-channel, anastomosed morphology that would convey the majority of flow formerly in the artificial channel. This was intended to allow time for the fluvial corridor to adjust progressively, thus avoiding a dramatic change in the geomorphology and ecology, which might lead to even a temporary loss of biodiversity.

The dam and associated FAS were officially opened on 28 August 2009, albeit that construction had not quite been completed at that time. The dam impounded flood water for the first time just a few days later, on 4 September 2009, and the FAS functioned well during what was estimated to be a 1 in 20-year flood event (Figure 14.7). The 'instantaneous' peak discharge entering the storage area was estimated to be around 36 m^3/s. Based on existing flood magnitude versus damage curves, implementation of the FAS avoided approximately £9 million of flood damages to the town of Forres.

The 4 September event supplied a considerable quantity of coarse sediment to the Burn Management Works, which was deposited as flow expanded across the flood plain. It also allowed floating debris to leave the artificial channel, and several pieces of LWD grounded in association with bars developing in the flood plain. Accretion of sediment and LWD triggered significant changes to the pilot channel, through the initiation of anabranching behaviour downstream of the first breach (Figure 14.8).

The Burn Management Works performed as anticipated during the flood, although failure of rock and riprap protection and enlargement of the upstream breach during the event resulted in abandonment of the old course in favour of the new one more quickly than intended (Figure 14.9).

Post-project monitoring has shown that the realigned channel is rapidly becoming an established feature within the fluvial environment, with flow, wetlands and areas of open water being evident throughout most seasons (see Figure 14.5). Natural functioning of the low-energy system is trapping coarse sediment and preventing it from

Figure 14.7 First impoundment by the Chapelton Dam on 4 September 2009 – less than a week after implementation of the FAS

Figure 14.8 Anabranching downstream of the upstream breach following the 4 September 2009 flood event. Note the development of anabranching upstream of the straight, pilot channel in the left foreground

Figure 14.9 (a) Controlled breach 1 in the left embankment following the 4 September 2009 flood. Note the disturbance to rock scour protection, widening of the breach, accretion of coarse sediment and accumulation of LWD. (b) The abandoned channel, viewed looking downstream of breach 1

(a)

(b)

Figure 14.10 Interaction between grounded LWD, fluvial processes and sediment dynamics in the Burn Management Works. Note the remnant of the pilot channel in the upper left of the photograph, the scour pool in the foreground, the anabranch on the left and the extensive coarse sediment deposition

approaching the control structure within the dam. LWD permanently grounded in the Burn Management Works is also interacting with fluvial processes and sediment dynamics to drive local scour, deposition, bar building, channel evolution and habitat diversification (Figure 14.10).

The wet woodland habitat is in the early stages of establishment, but it has already attracted a diverse range of flora and fauna (Tables 14.1 and 14.2). Following a site visit, a representative of Scottish Natural Heritage commented:

> 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 flood plains. (Scottish Natural Heritage, personal communication, 13 November, 2009)

In 2010, the Saltire Society of Scotland (http://www.saltiresociety.org.uk/3) in association with the Institution of Civil Engineers awarded the Forres FAS its 'environmentally sustainable construction' commendation in recognition of the innovative way that the Burn Management Works were designed and constructed with 'high regard for the environment and surroundings'.

Table 14.1 Fauna observed in the Burn Management Works area

Common name		Latin name
Birds	Mallard	*Anas platyrhynchos*
	Teal	*Anas crecca*
	Grey heron	*Ardea cinerea*
	Snipe	*Gallinago gallinago*
	Goldfinch	*Carduelis carduelis*
	Wren	*Troglodytes troglodytes*
	Great tit	*Parus major*
	Carrion crow	*Corvus corone corone*
	Buzzard	*Buteo buteo*
	Grey wagtail	*Motacilla cinerea*
	Common darter	*Sympetrium striolatrum*
	Black darter	*Sympetrium danae*
	Red darter	*Sympetrium fonscolombii*
Insects	Painted lady butterfly	*Cynthis cardui*
	Emerald damselfly	*Lestes sponsa*
	Golden ringed dragonfly	*Cordulegaster boltonii*
	Peacock butterfly	*Inachis io*
	Bumble-bee	*Bombus* sp.
	Shield bug	*Pentatomidae*
	Ground beetle	*Carabidae*
	Hoverfly	*Syrphidae*
	Cranefly	*Tipuloidea*
	Ant	*Myrmicinae*
	Wolf spider	*Lycosidae*
	Elephant hawk moth	*Deilephila elpenor*
Fish and amphibians	Trout	*Salmo truta* sp.
	Common frog	*Rana temporaria*
Mammals	Roe deer	*Capreolus capreolus*
	Otter	*Lutra lutra*

14.7. Knowledge transfer and lessons learned

Notwithstanding the award winning success of the FAS and the Burn Management Works to date, there are lessons that should be learnt concerning the design and construction of measures intended to meet multiple goals for flood control and environmental enhancement. It is also important that knowledge gained through experience with the Burn of Mosset is transferred to other practitioners so that they can take advantage of it when future schemes are designed and implemented.

1. It was anticipated that the new channel would capture the majority of flow in the Burn relatively slowly, over a period of perhaps 3–5 years. In fact, a significant,

Table 14.2 Flora observed in Burn Management Works area

Latin name		Common name
Grasses	*Agrostis canina*	Velvet bent-grass
	Agrostis capillaris	Common bent-grass
	Alopecurus geniculatus	Marsh foxtail
	Arrhenatherum elatius	False oat-grass
	Dactylis glomerata	Cock's foot
	Deschampsia cespitosa	Tufted hair-grass
	Glyceria fluitans	Floating sweet-grass
	Holcus lanata	Yorkshire fog
	Lolium perenne	Rye-grass
	Phleum pratense	Timothy
	Poa trivialis	Rough meadow-grass
Sedges	*Carex rostrata*	Bottle sedge
Rushes	*Juncus articulatus*	Sharp-glowered rush
	Juncus bufonius	Toad rush
	Juncus effusus	Soft rush
	Luzula sylvatica	Great wood rush
Ferns	*Dryopteris felix-mas*	Male fern
	Pteridium aquilinum	Bracken
Flowering Plants		
Ranunculaceae	*Ranunculus repens*	Creeping buttercup
Ulmaceae	*Ulmus glabra*	Wych elm
Urticaceae	*Urtica dioica*	Common nettle
Fagaceae	*Quercus petraea*	Sessile oak
Betulaceae	*Alnus glutinosa*	Alder
	Betula sp.	Birch
Caryophyllaceae	*Cerastium fontanum*	Common mouse ear
	Sagina procumbens	Procumbent pearlwort
	Silene latifolia	White campion
	Spergularia arvensis	Corn spurrey
	Stellaria alsine	Bog stitchwort
Polygonaceae	*Persicaria amphibia*	Amphibious bistort
	Rumex obtusifolius	Broad-leaved dock
Clusiaceae	*Hypericum perforatum*	Perforate St John's wort
Salicaceae	*Salix cinerea*	Grey willow
	Salix sp.	Willow
Brassicaceae	*Cardamine hirsute*	Hairy bitter cress
	Rorippa nasturtium-aquaticum	Watercress

Table 14.2 Continued

Latin name		Common name
Rosaceae	*Potentilla anserina*	Silverweed
	Rubus fruticosus	Bramble
	Sorbus aucuparia	Rowan
Fabaceae	*Cytisus scoparius*	Broom
	Trifolium campestre	Hop trefoil
	Trifolium hybidrum	Alsike clover
	Trifolium pratense	Red clover
	Trifolium repens	White clover
	Ulex europaeus	Gorse
	Vicia cracca	Tufted vetch
Onagraceae	*Epilobium ciliatum*	American willowherb
	Epilobium palustris	Marsh willowherb
Aceraceae	*Acer pseudoplatanus*	Sycamore
Geraniaceae	*Geranium robertianum*	Herb robert
Apiaceae	*Anthriscus sylvestris*	Cow parsley
	Heraclium mantegazzianum	Giant hogweed
	Heraclium sphondylium	Hogweed
Lamiaceae	*Galleopsis tetrahit*	Common hemp nettle
	Mentha sp.	Mint
	Prunella vulgaris	Selfhealt
	Strachys palustris	Marsh woundwort
	Strachys sylvatica	Hedge woundwort
Boraginaceae	*Myosotis scorpioides*	Water forget-me-not
	Pentaglottis sempervirens	Green alkanet
Callitrichaceae	*Callitriche* sp.	Water starwort
Plantaginaceae	*Plantago lanceolata*	Ribwort plantain
Oleaceae	*Fraxinus excelsior*	Ash
Scrophulariaceae	*Digitalis purpurea*	Foxglove
	Mimulus guttatus	Monkey flower
	Mimulus luteus	Blood-drop emlets
	Parentucellia viscosa	Yellow bartsia
	Scrophularia nodosa	Common figwort
	Veronica beccabunga	Brooklime
Rubiaceae	*Galium aparine*	Cleavers
Asteraceae	*Achillea millefolium*	Yarrow
	Arctium minus	Lesser burdock
	Cirsium arvense	Creeping thistle

Table 14.2 Continued

Latin name		Common name
Asteraceae	*Chrysanthemum segetum*	Corn marigold
	Hypochaeris radicata	Cat's ear
	Lapsana communis	Nipplewort
	Leontodon autumnalis	Autumn hawkbit
	Matricaria discoidea	Pineapple weed
	Senecio jacobaea	Common ragwort
	Senecio vulgaris	Groundsel
	Tanacetum vulgaris	Tansy
	Tripleurospermum inodorum	Scentless mayweed
	Tussilago farfara	Coltsfoot
Typhaceae	*Typha latifolia*	Reedmace

but not particularly extreme, flood event that occurred in September 2009 (less than 2 years after implementation of controlled breaching) diverted the entire flow of the Burn of Mosset into the new course. This occurred partly due to deposition of cobbles and gravel on the bed of the old channel just downstream of the first breach, but principally because failure of rock and riprap scour protection, followed by erosion that enlarged the dimensions of breach 1, allowed it to capture the entire discharge of the Burn. These morphological changes accelerated what was intended to be a more progressive, evolutionary trend. While abrupt switching of the flow did not trigger any unforeseen morphological developments or deviation from the longer term plan for evolution of the Burn Management Works, rapid transfer of the flow into the new channel must have led to some degree of unintended environmental degradation in the reach of the artificial, pre-FAS channel, which is now dry except during high-flow events.

During the September 2009 flood, block stone and riprap scour protection installed at the upstream breach were unable to prevent bank erosion, with unintended consequences. This is similar to experience on the Jubilee River when it experienced a flood soon after construction, in January 2003 (Thamesweb, 2003). It is, therefore, recommended that additional attention should be paid to ensuring the stability of diversions or outlets in order to reduce the risk of their being damaged or bypassed, especially soon after construction and before the bank vegetation that provides natural erosion resistance has been able to recover from the disruption that is inevitable during project implementation.

It is further concluded that, when using 'prompted recovery' to drive channel restoration and environmental enhancement, it is impossible to predict the timing of flow events of sufficient magnitude and duration to trigger significant geomorphological changes to either the pre-existing channel, the new channel or both. Hence, the risks associated with unintended and abrupt fluvial and morphological adjustments must be carefully considered and accounted for when 'prompted recovery' is selected as a component in the design approach.

2. In late 2009, significant erosion was observed on the right descending bank opposite breach 1, the upstream of the two controlled breaches. Appraisal of the erosion suggested that, left unaddressed, this could lead to breaching of the right embankment, and the possibility of channel avulsion to the right of the old channel and away from the Burn Management Works. This would have been highly undesirable, as it would have resulted in the avulsed flow having no obvious pathway to the baffled crump weir in the dam. Also, it would have arrested, or at least significantly impeded, evolution of the anastomosing channel, wetland and wet woodland system in the Burn Management Works area.

   The cause of the bank erosion was identified as being a large, fallen tree that had grounded close to the right bank in the vicinity of breach 1. It was decided to move this tree away from the bank (although not to remove it from the watercourse) in order to reduce its effect in constricting the flow, locally increasing near-bank velocities and elevating fluid shear stresses on the right bank. Continued monitoring shows this management intervention to have been effective. Some bank erosion is also occurring opposite breach 2 (the downstream breach) and, while this does not currently pose a significant risk of right-bank avulsion, monitoring is, and must be, ongoing.

   The point is that, without post-project monitoring and adaptive management, bank erosion opposite breach 1 would probably have continued, perhaps to the point of jeopardising the effective operation and intended development of the Burn Management Works. It follows that appropriate monitoring and adaptive management are integral and essential components of any river works that involve, or allow for, sediment transport and a degree of channel evolution. This is the case because the magnitude, timing and sequencing of future morphological adjustments are not just unknown, they are unknowable. This is because channel changes are the outcomes of flow and sediment transporting events that have not yet happened and the ways that they interact with random factors (e.g. grounded tree) – which can be predicted deterministically.
3. The detailed drawings for excavation of a pilot channel as part of the Burn Management Works specified a sinuous course, aligned to connect the upstream and downstream breaches via low areas identified using light detection and ranging (LiDAR) imagery. However, this element of the intended design was not implemented accurately by the contractor and site staff who actually constructed the channel.

   The outcome was a channel alignment comprising relatively long, straight reaches connected by short-radius bends, as it was easier for the excavator driver to dig a channel with this planform rather than the continuous curves of the intended design. It was always intended that the pilot channel would evolve away from its constructed form and should respond morphologically to the occurrence, sequence, magnitude and duration of channel-forming flow events. Consequently, it was concluded that the fact that the channel was not built according to plan would not be crucial to the long-term success of the Burn Management Works. In hindsight, it would have been wise for the design team to have given more specific setting-out instructions to the contractor and also to have briefed site staff on the significance of design details in the planform of the pilot channel.

Figure 14.11 Low boulder weirs constructed in the pilot channel and intended to encourage formation of a pool and riffle sequence. These have been successful in trapping LWD, but have not been effective in promoting pool and riffle formation

These steps would have resulted in a better functioning and more aesthetically pleasing initial channel form.

This experience should be borne in mind when restoration requires construction of a channel with the morphological complexity required to provide the diverse habitats necessary to support a sustainable ecosystem. This is likely to include many environmentally aligned channels constructed within the spirit or the letter of the EU Water Framework Directive.

4. Finally, it is now realised that more attention should have been given to the design of microtopography and bedforms within the pilot channel. The design implemented included low, boulder weirs constructed at intervals along the pilot channel that were intended to encourage formation of a pool and riffle sequence (Figure 14.11).

   Post-project monitoring shows these structures to have been ineffective and, with hindsight, it would have been preferable to vary the cross-sectional geometry and conveyance capacity along the pilot channel to create in-channel non-uniformity and facilitate exchange of momentum and sediment between the channel and its flood plain. This would have better coupled in-stream and flood-plain processes, encouraging localised scour and deposition and stimulating interactions between water, sediment and vegetation over a wider area.

The general point here is that, in an era when stakeholders expect to see positive results in months rather than years, anything that can be done to accelerate morphological and ecological development in a constructed or restored channel must be welcome. However, to optimise this type of 'process forcing', highly detailed, topographic data, extending along the project reach and across the active flood plain, are essential in identifying locations where the terrain is amenable to flow leaving or returning to the channel and mapping the pathways suitable for overbank flow and/or storage. Successful delivery of morphological complexity and the diverse habitats it supports early in a restoration also depend not only on a deep understanding of hydromorphology and ecohydraulics on the part of the design team, but also a recognition by the contractor that design details are important, and effective application by the machine operator of specialist, practical skills.

The transferrable message is that the best designs are bespoke with reference to both the catchment context and the local terrain, and that, unless designers have the luxury of reporting to stakeholders who are both understanding and patient, the devil actually does lie in the detail.

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