The Use of Wetlands for Flood Attenuation



Photograph by Lauren Williams

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Front cover photograph: Groundwater fed depression wetland (fen), Watergrasshill, Co. Cork.

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EXECUTIVE SUMMARY

The Aquatic Services Unit (ASU) with technical assistance from the School of Biological and Earth Sciences (BEES) and the Hydraulics and Maritime Research Centre (HMRC), all part of UCC, were commissioned by An Taisce, the National Trust for Ireland, to carry out this review of the role of wetlands in flood attenuation in Ireland.

As required under the EU Floods Directive (2007/60/EC), Ireland is currently developing a catchment based approach to flood risk management. An integral part of this process, as directed by European best practise guidance, is the identification of strategies to improve water retention within the catchment.

The following review examines relevant wetlands types and their potential for flood attenuation in an Irish context, with an aim to their inclusion in future flood risk management in Ireland. Part I examined technical aspects and provides examples of wetlands in a flood attenuation role. Cost-effectiveness and economic values that can be attached to wetlands in a flood attenuation role are examined, through both market and 'ecosystem services' views. Part II identifies national legislation and policy affecting wetland habitat that may influence the potential for wetlands to become accepted as part of a national strategy for flood management. The report makes recommendations and is intended to inform national discussion on the future consideration of the use of wetlands for flood attenuation in Ireland.

The importance of wetlands for flood attenuation

Continuing urban and agricultural expansion in recent decades, often onto historic floodplains, has accentuated the need for cost effective flood prevention measures, particularly given future climate change scenarios of increasing frequency of extreme rainfall and storm surge events. At the same time, there has been a shift in focus in Europe and North America away from 'hard' engineering solutions, such as channel alteration and river embankment construction, towards encouraging more natural flood management (NFM) solutions within catchments. The UK's 'Making Space for Water' and Netherland's 'Room for Rivers' approaches, for example, promote spatial rather than purely technical flood management solutions by the provision of more room for peak river discharges. In this context, wetlands are increasingly seen as providing a potential valuable ecosystem service of flood attenuation. This is additional to their purported role as 'buffers' to prevent excess sediment and nutrient inputs into waterways and as conservation and biodiversity hotspots within intensively-used landscapes. The value of wetlands for flood attenuation is, however, often exaggerated and many wetlands in fact play only a very weak role, if at all, in attenuating floods. This is largely due to the very heterogeneous nature of wetlands in terms of location within a catchment, hydrological function and physical dimension.

The role of different types of wetland with respect to flood control

The main natural wetland types can be divided, hydrologically, into alluvial mineral soil floodplains ('washlands'), which can temporarily store water which spills over the channel banks and headwater peatsoil wetlands (chiefly bogs and fens) which can slow the movement of water from hillslope into channels. Coastal wetlands / estuarine

floodplains can be considered a type of washland, which also attenuate waves and storm surges. The two broad types of wetland differ both in their position in the catchment and in the hydrological properties of their soils. Floodplain wetlands are typically inundated by river floods during major storm events and, by allowing floodwater to move over the banks and 'spill' over onto low-gradient land adjacent to the river, can mitigate the peak water volume in the channel. Headwater peatsoil wetlands, in contrast, typically are not inundated by overbank flow to any great extent, but instead receive water from rainwater and hillslopes after precipitation events and can mitigate the speed with which water moves from land into headwater drainage channels. The peat soils of headwater wetlands are saturated for much of the time and therefore possess little soil storage capacity compared with the drier mineral soils of the lowland floodplains. Taken together, the flood attenuation potential for alluvial soil floodplains is typically much greater than that of peatsoil headwater wetlands, and this tends to be supported by most recent empirical evidence.

Wetland hydrological function and effectiveness in flood control

Within a wetland type, the physical nature of individual wetlands will play a large role in determining its flood attenuation value. Floodplains receive water from four sources: river, rainwater, groundwater and hillslope. River water will inundate floodplains intermittently resulting from over-bank flow during periods of high fluvial discharge. The water that moves from channel to floodplain is stored temporarily on the rough floodplain surface, consisting of a complex of depressions, pools and ancient channels, and in floodplain soils, delaying the flood peak, before being released later as channel water drops to below that of the water level in the bank. Rough topography - both of land form and woody, coarse vegetation – and unsaturated soils will also aid temporary water storage, and the high water evaporation and evapotranspiration of intact wetlands can also potentially reduce catchment runoff. The flood attenuation properties of individual floodplains will vary considerably, depending on their physical and hydrological characteristics. Floodplains with small surface area, high gradient, high hillslope flow and high groundwater levels will store water less effectively than large flat floodplains with low hillslope flow and low groundwater levels. The complex interaction between a given flood level and all these physical and biological characteristics of a floodplain makes it difficult to ascribe a quantitative flood protection value for particular wetlands without some kind of individual assessment.

The hydrology of headwater peatlands is very different to alluvial floodplains and they generally receive much of their water either as rainwater (particularly bogs) or groundwater and hillslope (fens), rather than overbank flood water from channels. Bogs and fens can attenuate floods by delaying the runoff of these sources of water into headwater channels. As their peat soils are saturated for much of the time, particularly for blanket bogs, they generally have little effective soil storage capacity and their attenuation value comes from their rough surface topography slowing the movement of surface and sub-surface water, and their capacity to reduce catchment runoff through enhanced evaporation. Peatlands possessing tall woody or coarse vegetation, many small surface depressions and pools and with little surface channel connectivity will tend to hold surface water for longer, so delaying water discharge to downstream channels. Whilst water retention by peatland surfaces may attenuate and delay runoff events, the

flood mitigation role of peatsoil wetlands is often overstated and it has been recognised for many years that not all peatlands reduce storm flows, particularly in winter, nor provide higher flows in summer.

Wetlands in Irish karstic landscapes (turloughs) are temporary in nature. Turloughs hold water in winter, when groundwater levels are high and fill valley basins and smaller depressions within the landscape. The seasonal inundation of these depressions in a function of complex surface-groundwater interactions, in which water levels are both drained and recharged through sinkholes. Their flood attenuation property is similar to that of fens and likely is determined by the rate at which they can temporarily store surface water, via soil storage and also in their somewhat greater evapotranspiration of water relative to non-wetlands. The complex nature of each catchment area and discharge route makes prediction of the flood attenuation of turloughs problematic, and the understanding of turlough hydrology and drainage is far from complete.

Coastal wetlands can attenuate seaward flooding, resulting from storm surges, high waves and high tides and landward flooding resulting from rivers spilling over banks onto estuarine floodplains. Salt marshes are effective dissipators of wave energy and provide a first line of defence against tides and waves, particularly during stormy conditions. Highly resilient emergent and near emergent salt marsh vegetation creates roughness that reduces wave height and speed as it travels across the intertidal surface, so attenuating waves. The large water storage capacity of the large expanse of flat estuarine wetlands will also be extremely important in attenuating water spilling over channel banks either due to high river levels or high tidal levels. Tidal flood attenuation is particularly important in areas where sea water is confined in narrow inlets, bays and natural harbours, such that the tidal flow cannot be displaced along the coast. The important function of riverine floodplains of delaying floodwater runoff, via a rough surface topography, is probably less important in coastal or estuarine wetlands than available storage volume capacity, as downstream flooding is rarely an issue, except in cases where urban settlements are located in the lower estuary.

The flood attenuation potential of function-specific constructed wetlands and artificial wetlands will depend largely on their location within a landscape and design and be governed by the same constraints and factors as for floodplains and headwater peatlands. It is important to note that their flood attenuation function may not necessarily be complementary with their primary function. For example, a wetland with saturated soils may have high denitrification, but low flood attenuation potential. Similarly, wetlands that are designed to store particulate phosphorus and sediment on their surface and shallow sub-soil may shed these to downstream receiving waters, with negative consequences for water quality, in the event of flood waters spilling onto the wetland.

Flood attenuation and land use changes

Human management can potentially increase or decrease the capacity of a given wetland to attenuate floods. Encouraging extensive surface water for long periods on natural floodplains (for example, to benefit wetland plant and animal communities, particularly wading birds) can raise groundwater levels, reduce soil moisture deficits and

infiltration rates and speed runoff, so negatively affecting flood attenuation potential. As for artificial or constructed wetlands, enhancing wetland biodiversity is often conflated with enhancing flood attenuation potential, whereas in fact the two may not be necessarily wholly compatible. Agricultural intensification of floodplains can have positive and negative effects on flood attenuation potential. Increased soil compaction and surface drainage may act negatively by reducing the infiltration of flood waters into floodplain soils, and speeding the runoff of surface water to the river channel. Greater surface drainage to dry out floodplains can, on the other hand, reduce groundwater levels and soil moisture, potentially leading to enhanced flood water storage. Removal of hedgerows, woody vegetation and surface depressions (including relict channels and pools) will all tend to reduce surface storage of flood waters. For peatsoil wetlands, the drainage channels cut in the past to drain bogs and fens can increase the soil moisture deficit of the peat surface, enhancing soil water storage capacity, but also speed water flow to channels. Similarly, rapidly removing floodwaters in wetlands with seasonally high groundwater levels, via runoff drainage channels, will lessen the overland water storage capacity of the wetland, although may enhance soil moisture storage capacity. Blocking drainage channels – a practice sometimes undertaken to 'restore' disturbed bogs and fens - may retard water flow to downstream streams but can also elevate soil moisture levels, so reducing soil water storage capacity. Although many wetlands have the potential to attenuate flooding, the planning process requires more definite and detailed information on the impact of individual wetlands and also on the likely impact of landuse changes, such as agricultural intensification, afforestation and urbanisation. However, the complex interactions between soil type, land use, landscape configuration and climate at a local sub-catchment level make it difficult to scale these processes up to large catchment scales.

'Hydrological' floods vs 'economic' floods

Where a particular wetland has the potential to attenuate downstream flooding, the realised attenuation will depend strongly on the rainfall and flood event. In general the influence of wetlands in reducing flood peaks is greatest for high frequency, low to medium rainfall events that occur when wetlands have a large capacity for storage. It is least for large events, particularly following a long period of prior rainfall, when soil and wetland storage are saturated. In this regard, a distinction can be made between 'hydrological' floods (high frequency, low to medium rainfall events that occur commonly without economic damage) and "economic" floods (low frequency events following high intensity rainfall, potentially causing economic damage). Wetlands may readily attenuate 'hydrological' floods but are much less likely to attenuate 'economic' floods. As flood height may be a critical determinant of the economic cost of a flood, the management of alluvial floodplains upstream of sensitive areas so as to maximise flood storage and thus to reduce flood height (although not duration) is likely to be the most cost-effective use of wetlands for flood attenuation.

Wetlands and Flood Management Policy

Irelands present Catchment Flood Risk Assessment and Management (CFRAM) approach indicates that policy is in place that recognises catchment scale processes in flood generation and management. However, there are significant hurdles that need to be overcome in order to achieve sustainable flood management, such as conflicts with

statutory drainage maintenance and, critically, socio-economic obstacles that prevent land use and/or land management changes required to achieve NFM solutions.

Dedicated agri-environmental schemes will be essential in Ireland to encourage the use of wetlands for flood attenuation, particularly in the most effective parts of the catchment, i.e., alluvial floodplains. The currently available mechanisms under CAP and national agri-environmental schemes are insufficient to encourage such changes. The opportunity should be explored for incorporating flood risk management at the farm level, perhaps under new 'greening' measures proposed for CAP 2014-2020. Measures such as 7% set aside of 'ecological' areas and use of 'innovative practices' could be applied to the concept of floodplain management. Two measures to enhance the flood attenuation potential of floodplains are: (1) restoring the natural hydrological connectivity between river and floodplain so allowing land to inundate more frequently; and, (2) retaining or restoring 'rough' floodplain surfaces, in the form of walls, hedges, coarse and woody vegetation, relict channels and depressions. Both of these measures can clearly conflict with the needs of intensive agriculture (with its emphasis on large uninterrupted field systems) and their implementation will require financial incentives or compensation.

International experience has shown the importance of agri-environment schemes to allow for NFM and successful catchment based flood management solutions. Effective, widely supported adoption of the types of land use changes required needs alteration of existing, or the development of new, mechanisms capable of providing long term support to co-operating farmers. The UK's 'Farming Floodplains for the Future' initiative provides a useful model by examining new incentives tailored to the delivery of flood management objectives through land use change. Using a template similar to agri-environment grants, it was suggested that a one-off capital payment to cover initial outlay, plus regular incentive payments, could be made to farmers who participate.

The creation, restoration and use of wetlands for flood attenuation (primarily floodplain storage, washland, polder and coastal sites) have become increasingly popular abroad over the past 20 years. Ireland clearly lags behind in this field. By far the most influential shift behind the growth of NFM solutions was the philosophical and practical adoption of an approach that promotes the controlled spreading out of excess water over the landscape as in 'Making Space for Water' and 'Room for Rivers'. The UK, in particular, has implemented a number of floodplain restoration, managed floodplain storage schemes, and coastal realignment schemes. These have realised flood alleviation benefits, and often a range of associated benefits, such as biodiversity enhancement and sediment control. Benefits, however, need to be examined on a case-by-case basis as flood alleviation and biodiversity goals are not always synonymous.

A key element in the process of utilising wetlands for flood attenuation abroad has been the involvement of other public and semi-State authorities as well as the general public. Funding for public consultation in particular is a central element of NFM. If the use of wetlands for flood attenuation is to be considered at certain locations in future, public engagement will be essential from the earliest stage of the catchment management planning process.

PART I The role of wetlands in Flood Attenuation

1. Introduction

Although the use of wetlands for flood attenuation is receiving much greater attention than previously, both in Ireland and abroad, there remains a degree of uncertainty about the relative value of different wetland types, in different parts of a catchment, for flood storage and attenuation. The commonly held belief that all wetlands always serve to reduce flooding and regulate river flows is not supported by readily available empirical data. The purpose of this review is to investigate literature and reported current practice, in Ireland and abroad, to examine what is known about the effectiveness of wetlands in a flood attenuation role and to assist in the understanding of their potential within future flood risk planning.

1.1 Flooding

Flooding is a natural part of the hydrological cycle and occurs whenever the capacity of the drainage system is exceeded by high channel discharges. Flooding is also important for maintaining the ecological functioning of wetlands. Three types of flooding and their associated wetland habitats in Ireland have been considered for the purpose of this review, (1) river flooding, where heavy rainfall causes flow to exceed the capacity of the river channel, overtop the banks and flood the surrounding areas (2) coastal flooding, where combinations of extreme weather conditions, high tides, surges and wave overtopping cause sea water to inundate land (Farrell, 2005), and (3) groundwater flooding, primarily confined to karst landscapes of the western seaboard, occurring when turloughs overflow their bounds (Peach & Wheater, 2009).

Floods vary considerably in size and duration. Local intense rainfall events can deliver high water volumes, chiefly via overland flow, into small headwater channels, but also via excess groundwater recharge. In the case of surface flows, smaller channels quickly develop a short acute peak flood discharge, which may overspill banks and lead to local flooding. These flood events are usually short in duration and rarely extend far away from banks owing to the generally steep nature of riparian habitats along headwater streams. Prolonged high rainfall over a wide area, however, can deliver high discharges from multiple tributaries into higher order channels. Peak discharges arrive later and take longer to reduce than those in the headwaters, giving a characteristic attenuated shape to the flood hydrograph. Flood events then may last for longer as it takes longer for water to drain from the system and extend far from the banks owing to the lower gradient of large order river floodplains (Gordon *et al*., 2004)

Flooding continues to pose a threat worldwide to life, property and infrastructure. Recent flooding in Ireland, the UK, Australia and Brazil, have shown that extreme events can overwhelm the capacity of large, populated catchments to shed water in a controlled manner. Flood flows have historically been managed in two ways, by: (1) increasing channel capacity or, (2) temporarily storing excess water. Traditional drainage methods of deepening and widening channels, or increasing flow velocity by

channel straightening, provides increased capacity and reduces the depth of local flooding, but will tend to increase flood risk downstream. Temporary storage of water, either on the catchment surface before it reaches a channel, or on floodplains once it has spilled over channel banks will reduce channel discharges and attenuate the flood. Those parts of the catchment that can retain surface water and retard its movement into channels, thus, provide a valuable function in flood mitigation.

1.2 Wetlands and flood attenuation

In response to climate change predictions, the understanding of how weather patterns create flood events has risen in prominence in recent years. However, there is still considerable interest in predicting the interactive effect of catchment land use and cover on flood generation. In particular, the potential for parts of the catchment to delay run-off during high risk, low frequency, precipitation events is of high importance for statutory bodies charged with managing floods and flood risk, e.g., UK Environment Agency (EA) and Irelands Office of Public Works (OPW) as these may offer a relatively low cost alternative to flood management compared with traditional, hard engineering solutions. In many places (e.g. UK, Netherlands) natural flood management (NFM) measures are now considered as an important part of sustainable flood management.

Wetlands are widely held to be important components of a natural landscape, through their value to local and regional biodiversity and particularly their functional hydrological role. Inland wetlands are often said to mediate groundwater recharge and discharge; to 'buffer' excess sediment and nutrient inputs, regulate base flow and, critical to this review, attenuate flooding (Maltby, 1991, MA, 2005).

Most prominent of possible, inland, sustainable flood management solutions is the use of catchment floodplains. The flooding of riparian land, leading to temporary storage of flood water, attenuation of the peak discharge of a flood event and reduction of flooding likelihood downstream has been well documented (e.g., Acreman, 2003; Bullock & Acreman, 2003; Morris *et al*., 2004, 2010).

Less well known is the ability of peatlands (bogs and fens) to attenuate flooding, although this is the focus of current and ongoing field studies (Holden *et al*., 2009, Grayson *et al*., 2010) and catchment based flood risk management simulations such as the Ripon Land Management Study, UK (JBA Consulting, 2007). Whilst some studies suggest that peatlands within a catchment can reduce floods, others imply that since peatland soils are normally saturated, they instead can act more as flood generating areas (Bullock & Acreman, 2003).

Attenuation and hydraulic performance of certain types of constructed wetland are more readily recognised since these are constructed to a design standard specific to the role. The ability of carefully designed wetlands or detention basins to slow the flood peak and alter downstream hydrographs is demonstrated by Sustainable Drainage Systems (SuDS) facilities, but less so by Integrated Constructed Wetlands (ICWs).

Many, if not all natural wetlands thus have the potential to alter downstream peak flows which gives them considerable economic and political value within a regional planning

framework (MA, 2005; TEEB, 2010). Flood attenuation provided by wetland water storage is increasingly seen as a useful complement to conventional flood defence (JBA Consulting 2005; OPW, 2004, Wheater & Evans, 2009, Morris *et al*., 2004) and has already been considered within large scale flood defence schemes within Ireland (OPW 2003a, 2003b, 2003c, 2005a, 2005b).

In Ireland, evidence is required of the level of flood alleviation that can be gained, before statutory and/or regulatory bodies may routinely include the role of wetlands in future flood risk management (Nathy Gilligan, OPW, pers. comm). Under the EU Floods Directive[1], the OPW are currently preparing the framework for Catchment Flood Risk Management Plans (CFRMPs) and this presents an excellent opportunity to examine the role of wetlands in a flood attenuation role in the context of a catchment based approach to flood risk management. The content of this review should assist such a task as it presents what is known about the effectiveness of wetlands in a flood attenuation role (Part I, section 3), which has a bearing on the prospect of accurately assessing cost-benefit scenarios for alternative flood relief strategies (Part I, section 7). Furthermore, possible opportunities and conflicts between the use of wetlands for flood attenuation and biodiversity roles are examined (Part I, section 5) along with the way in which management of wetlands affects their flood attenuation role (Part I, section 4). A review of international and national policy and legislation in relation to wetlands for flood attenuation is also presented in Part II of this report.

1.3 The use of inland wetlands in flood attenuation

There are two major issues concerning the function of inland wetlands as flood mitigation. First, although the proportion of a catchment that is wetland can be substantial, there appears to be little consensus on the role of the various types of wetland in flood attenuation (Bullock and Acreman, 2003; Kværner and Kløve, 2008). Second, they are under severe threat from conversion to other more profitable land uses, chiefly agriculture, urbanisation and forestry. Each of these land uses brings a significant change in the hydrological functioning of the previously wetland land area, ranging from increased drainage of wetland surface water to complete loss of wetland habitat in the case of housing developments.

Drainage of wetlands, particularly valley wetlands and floodplains, has been a historical process in Europe, with considerable drainage in the 17th century onwards. Agricultural intensification in the latter half of the 20th century accelerated this process and today little remains of the extensive naturally-vegetated floodplains of the larger European rivers. Both alluvial and coastal floodplains offer an enticing location for developers as they are generally flat and have aesthetic river or coastal views and locations. Estuarine floodplains have been extensively drained and reclaimed in Ireland for both agricultural and urban development and, as towns are often located on rivers, the historically undeveloped floodplains offer relatively cheap greenfield sites within easy reach of populated urban centres. House-building on these floodplains both can reduce the flood storage capacity of the floodplain and often will be accompanied by hard-engineered

[1] EU Council Directive 2007/60/EC on the assessment and management of flood risks

flood protection to protect the newly built houses, thus eliminating any flood protection function (Wheater & Evans, 2006).

1.4 Policy implications

In response to recent flooding events, and in anticipation of more frequent and perhaps more severe events in the future owing to climate change, restoring the natural functioning of wetlands (floodplains in particular) to accommodate more frequent and severe flooding may provide a range of benefits including flood defence for urban areas, biodiversity enhancement and improved water quality (English Nature Joint Statement, 2003). Murphy & Charlton (2006) report predictions of rainfall increases of 17% in western areas of Ireland; possibly as much as 25% in places under climate change scenarios. The likelihood of increased frequency of storms and rising sea levels could threaten to overwhelm sea defences and increase the risk of coastal flooding to low-lying towns and cities.

Increasing national and international attention is therefore being paid to wetlands for their potential in flood attenuation and planning authorities will be expected to give much greater emphasis to this role in future. Questions remain, however, about the ability of individual wetlands to attenuate floods and the relative value of the various types of wetland.

2. How do wetlands attenuate flooding?

2.1 Overview

Wetlands are transitional habitats between dry land and deep water. They are characterised by land periodically or permanently inundated by relatively shallow water, with plant communities adapted to anaerobic soils and flooding (Keddy, 2000). The hydrology of wetlands is complex and varies widely both between wetland types and between individual wetlands of the same type, which is a function of the relative complexity of their physical habitat (Acreman, 2011). It is thus difficult to make generalisations about flood reduction services of wetlands.

Notwithstanding, there is potential for wetlands of various sizes and at different locations within a catchment to play complementary roles in flood attenuation and prevention. Wetlands in the upper catchment can, theoretically, reduce and delay flood peaks by temporarily storing water before it enters stream channels, whilst large floodplains downstream can store water that has flooded over channel banks.

Since this review primarily examines flood attenuation, it must be based on consideration of the impact that wetlands may have on downstream flood peaks. This depends largely on the wetland's available water storage capacity and the intensity of the flooding at a particular time. Flood attenuation estimates need to be made on a case-by-case basis, preferably using continuous hydrological modelling that can take into account site specific and local factors. Factors to consider are spatial and temporal variations in precipitation and soil moisture, available storage capacity, outflow rate and flood route. Past and present disturbances, drainage patterns and local soil type differences also influence the hydrological processes of individual wetlands (Bullock & Acreman, 2003, JBA Consulting, 2005, Ramchunder *et al*., 2009).

It is, therefore, difficult to generalise in terms of which wetland habitat types are most effective for flood attenuation, since each wetland differs in direct relation to climatic, topographic and geological variation within Ireland. The only general statement that can be made is that the influence of wetlands in reducing flood peaks is probably greatest for high frequency, low to medium rainfall events that occur when wetlands have a large capacity for water storage. It is least for low frequency, large rainfall events, particularly when soils are saturated and wetland storage capacity has been reduced by preceding high rainfall - as is common in Ireland.

This review examines types of wetlands that may have a role in flood attenuation in Ireland. This is done on the basis of empirical data and demonstrated principles of wetlands in a flood attenuation role, and also through consideration of existing Irish and NFM projects.

2.2 The process of flood attenuation

"Attenuation" refers to loss of intensity of flux through any type of medium. Flood attenuation is achieved where there is a measurable change to the downstream

hydrograph[2] at a certain location in the catchment. Changes to the hydrograph (in very simple terms) that can signify attenuation are: (1) a reduction in flood peak[3]; and/or, (2) a delay in flood peak.

The ability of a wetland to attenuate flooding depends on two critical factors: wetland storage capacity, and the wetland storage-outflow relationship (Potter, 1994). These, in turn, are affected by an array of local factors, such as climate, terrain, soil type, inflow source (surface water, groundwater, and precipitation), drainage features and not least, management of the storage-outflow relationship within the wetland. It is the water storage function of wetlands that allows for flood attenuation. The critical factor influencing whether wetlands have an impact in reducing peak flood stages is the available storage capacity at a particular time (Schultz & Leitch, 2001), plus the rate at which excess water within the wetland is shed to either a downstream surface waterbody or via subsurface drainage.

2.2.1 Wetland Storage

Storage of water in a wetland during precipitation events attenuates and delays downstream flood peaks (Potter, 1994), although delaying a flood peak does not necessarily mean reducing it. This is important in cases where the volume of wetland storage is small compared with flood volumes. Evaluation of the impact of peak delay in specific cases requires careful attention to the spatial and temporal characteristics of rainfall, stormflow generation, and stormflow conveyance.

The delay in flood peak has the potential nonetheless to be very important at a catchment scale, since a time lag in flood peak from one tributary can reduce the overall flood peak much lower in the catchment. This may result in increased duration of downstream flooding but a reduction in flood depth (JBA Consulting, 2007). Delaying the flood peak may have positive implications for water quality by slowing the speed of runoff, thereby reducing channel erosion and limiting sediment export.

Wetland storage capacity is temporally variable, reflecting climatic conditions and, to varying degrees, land management. Table 1 broadly shows the factors that influence wetland storage capacity, and hence attenuation potential.

Variables (other than management practices) that increase useable storage tend to occur in summer months when rainfall is low. Factors that decrease storage capacity are common in the winter months when rainfall is high and temperatures are low. Wetland storage can be increased by management such as damming the outflow route to increase available overland water storage capacity or, conversely, by floodplain drainage to increase soil water storage capacity.

[2] Hydrograph = a graph showing changes in the discharge of a river over a period of time.
[3] Flood peak = he highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge.

Table 1: Factors influencing water storage potential of wetlands

Factor	Influenced by:	Storage capacity	
		Decrease	Increase
		< *Winter*	*Summer* >
Soil moisture deficit	Precipitation, drainage	Low – reduced soil infiltration	High
Surface water level	Precipitation; abstraction; drainage	High – wetland is "full"	Low – wetland has useable storage capacity
Ground water level	Precipitation; abstraction; drainage	High – reduced infiltration due to high water table	Low – increased infiltration due to low water table
Evaporation	Air temperature; wind speed; solar radiation; humidity	Low	High
Evapotranspiration	Air temperature; wind speed; solar radiation; humidity	Low	High
Wetland vegetation	Seasonal growth patterns; biogeography; wetland management	High levels can decrease pooling, but have the ability to retard surface-flow by increasing "roughness".	Low levels of vegetation may increase pooling, but the absence of "roughness" can increase surface- flow.
Management – high to medium frequency floods (small events)	Drainage pattern and frequency, land use.	High drainage decreases storage capacity and speeds up run-off.	Less drainage increases storage availability.
Management – low frequency floods (large events)	Drainage pattern and frequency, land use.	Low levels of drainage can prolong 'recovery time' of storage potential following large events as they remain saturated for longer.	Increased drainage shortens 'recovery time' of storage potential following large events as they dry out more quickly.

2.2.2 Wetland storage-outflow relationship

The relationship between storage capacity and outflow rate is critical in determining the effectiveness of any particular wetland in flood attenuation. Wetlands naturally drain to downstream waterbody connections through surface flow and/or infiltration[4]. Infiltrated water remains in the soil, drains to the ground water table, or joins a subsurface runoff route. Water is also lost from wetlands through a combination of evaporation[5] and evapotranspiration[6]. It is difficult to quantify available storage capacity in a natural wetland and estimates rely on hydrological models that generally have a number of limitations (Doeing & Forman, 2001). Apart from the obvious variables of wetland surface area and depth profile, other important factors include soil absorption characteristics, vegetation type and cover and artificial drainage, all of which will change seasonally. Holcova *et al*. (2009) traced the movement of water through a

[4] Infiltration = the process by which water on the ground surface enters the soil.
[5] Evaporation = the process by which water changes from liquid to gas
[6] Evapotranspiration = the loss of water from a vegetated surface through the combined processes of soil evaporation and plant transpiration.

constructed wetland system using fluorescein solution and found there was a 14 day retention time during the summer, vegetative period compared to 8.1 days during the winter, non-vegetative period of the year. Throughflow in the wetland was significantly greater during the non-vegetated period even though inflow rates were consistent between the studied seasons. The effect was attributed to higher evapotranspiration in the reed stand during the summer growing season.

Anthropogenic drainage of wetlands, unsurprisingly, can also markedly alter their storage-outflow relationship. Haan and Johnson (1968, cited in Leibowitz, 2003) found that increased drainage produced greater peak flows during long duration, low intensity rain events, but not for large volume, high intensity events. Similarly, Miller (1999; cited Shultz & Leitch, 2001) found that drainage of wetlands increased annual peak flood discharge by up to 57 percent during high-frequency (small) flood events but had little effect on low-frequency (large) flood events. Both drained and undrained wetlands have the capacity to store water; but because an undrained wetland empties much more slowly, it tends to store more water in a given storm event, despite the potentially higher storage capacity of drained soils. This slowly-draining nature of a natural wetland also means that all of its potential storage may not be available at the time of a subsequent flood. This is especially important for large regional floods, such as those encountered in Ireland during late 2009, whereby elevated flood waters accumulated over a period of days and weeks. Analysis of the hydrological conditions that have previously given rise to severe flooding in the Tolka River, North County Dublin, showed that the conditions for such flooding occurred during winter, when heavy rain in previous days and weeks led to saturated conditions and were then followed by a sustained severe rainstorm event of around 48 hours duration (OPW, 2005). Under such conditions, most of a catchments soils and wetland areas are fully saturated. When the volume of wetland storage is too small compared with the volume of flood entering, the peak discharge remains unaffected, i.e., when wetlands are “full”, there is little or no attenuation effect. This is a critical aspect of wetland water storage which has major implications for other wetland functions, explored below.

3. Wetland hydrology and flood attenuation properties

Much of the confusion about the value of wetlands for flood attenuation is probably owing to their highly variable nature. Not only do they consist of several major and multiple minor types of habitat, based on their hydrology, vegetation and location, but there is great physical and hydrologic variation among individual wetlands of the same type (Cole *et al*., 2003). The major divisions are related to their hydrological properties and broadly distinguish between: (1) wetlands in the lower part of a catchment dependent on water from parent water bodies such as rivers, lakes and coastal waters; and, (2) wetlands in the upper headwater parts of a catchment which are independent of any water body (Keddy, 2000; Regan & Johnston, 2011).

Fringing wetlands have a permanent connection with the parent water body, such as lakes or rivers and are flooded periodically during high flow events (Cole *et al.,* 2003). These floodplains can readily store water in soil (particularly following extended dry periods in summer) and as surface water. Floodplains are formed from the deposition of alluvial sediments in river valleys and have a rather flat, low gradient such that flood water tends to invade a large proportion of the wetland surface once banks have been overtopped. In their natural state, floodplains consist of a complex of abandoned relict channels, oxbow lakes, relict river pools and other depressions and aggradations of riverine gravels. These features fill with water during flooding and release it via subsurface drainage once the flood has receded. Natural floodplains are dominated by hydrologically rough woody wetland vegetation (carr or swamp) or tall reeds/rushes (marsh or reedswamp). This vegetation further increases the time that floodplains store water by retarding the flow of water back into the river. The natural levees which also form along many rivers, as a result of sediment deposition patterns, can also retard the return flow of water to the channel.

Non-fringing, independent, wetlands are supplied by groundwater (fen) or rainwater (bog, sometimes called mire), rather than river water. Bogs can be further divided into blanket bogs and raised bogs. Raised bogs tend to develop in groundwater-rich basins (on top of fens), blanket bogs on flat or undulating ground. The permanently wet conditions of these wetlands leads to anoxic waterlogged soils, such that decomposition of vegetation is retarded, leading to the build up of poorly decomposed plant material in the form of fen peat (grasses, sedges, reeds, woody shrubs) and bog peat (mosses, particularly *Sphagnum* spp). Peat soil wetlands occur in the headwaters of river catchments and supply water continuously to downstream channels, the rate fluctuating seasonally. They are not inundated by overbank flow to any great extent, but instead receive water from rainwater and hillslopes after precipitation events. They can attenuate high flows by retarding the flow of water from land into channels, rather than acting to store water flowing over channel banks, as for floodplains. The rate at which they retard water depends largely on; (1) soil (peat) storage of water; and, (2) retention of surface water by physical relief and vegetation.

The widespread view that wetlands, as a single habitat, are valuable for flood attenuation has arisen in the absence of synthesis of empirical data. The most comprehensive literature review on the hydrological properties of wetlands to date (Bullock & Acreman, 2003) found that:

- The large majority of wetlands studied were found to have significant impacts on the hydrological cycle;
- 82% of lowland floodplains ('washlands') but only 45% of headwater wetlands studied were found to attenuate flooding. Almost half of headwater wetlands studied (up to 2003) were found to increase either flood peaks or generate higher flood volumes.
- Evaporation rates of all wetland types were generally higher than other land use types with the result that 66% of wetlands reduced downstream flows during dry periods, and only 20% of wetlands increased river flows during dry periods. Although the majority of wetlands reduce flood peaks, a significant number of those studied either had little effect or may enhance flood flows (Bullock and Acreman 2003).

For the purpose of this review, we have assigned 6 broad categories of wetland types: (1) alluvial floodplains; (2) peatlands; (3) karstic landscapes; (4) coastal wetlands; and, (5) function-specific constructed wetlands. A process of literature review and consultation was undertaken to investigate basic hydrological principles and flood attenuation potential of these, presented in sections 3.1 to 3.5.

3.1 Alluvial floodplains

Floodplains are alluvial soil, fringing wetlands that receive water from four origins: river, rainwater, groundwater and hillslope (Burt, 2001) (Fig. 1). River water will inundate floodplains intermittently resulting from over-bank flow during periods of high fluvial discharge. The water that moves from channel to floodplain is stored temporarily on the floodplain surface and in floodplain soils, delaying the flood peak, before being released later as channel water drops to below that of the water level in the bank (Hunt, 1990; Whiting & Pomeranets, 1997).

The flood attenuation properties of individual floodplains will vary considerably, however, depending on their physical and hydrological characteristics. The ability of a floodplain to receive and discharge surface- and groundwater, as well as its ability to store flood water, will be dictated largely by local climate (particularly rainfall pattern), topography, geomorphology and soil, both of the entire catchment and the wetland area itself (Gleason & Tangen, 2008; Shane & Regan, 2011). This complexity would make it difficult to ascribe a quantitative flood protection value for particular wetlands without some kind of individual assessment (Acreman & Miller, 2006; Acreman, 2011).

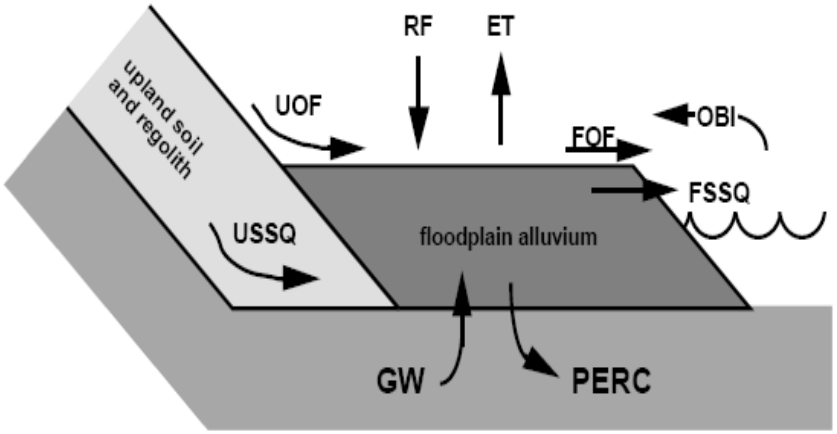


Fig. 1. Schematic diagram of the water balance of a floodplain. INPUTS: UOF = Overland flow from upland slope, USSQ = subsurface flow from upland slope, RF = precipitation directly onto flood plain, GW = Groundwater discharge from bedrock, BS = seepage from river channel through banks, OBI = overbank inundation. OUTPUTS: FOF = overland flow from floodplain to river, FSSQ = subsurface drainage to river, ET = evaporation loss, PERC = percolation to bedrock below. Adapted from Burt (2002).

The relative contribution of the four water sources to the water on floodplains will depend on many local factors particular to each floodplain. The water balance of a wetland is a function of the quantity of water transferred into and out of a wetland (Table 2).

Table 2: Balancing potential water transfer mechanism inputs to and outputs from a wetland (from Acreman and Miller, 2006)

Water transfer mechanism inputs to the wetland		Water transfer mechanism outputs from the wetland
P: precipitation (rainfall, snow, dew etc) directly on the wetland +	=	E: evaporation from the wetland +
R: surface and shallow subsurface inflow to the wetland +		δV: change in volume of water stored within the wetland +
L: lateral inflow +		D: drainage +
OB: over-bank inflow +		OF: overland outflow +
PU_i: water pumped into the wetland +		PU_o: water pumped out of the wetlands +
S: spring flow +		GR: groundwater recharge to aquifers +
GD: groundwater discharge into the wetland +		TO tidal outflow from the wetland to the sea
GS: groundwater seepage into the wetland +		
TI tidal inflow from the sea to the wetland		Where δV may be positive or negative

If inputs exceed outputs, storage (V) will increase and the water level in the wetland will rise. If inputs are less than outputs, storage (V) will decline and the water level in the wetland will fall. It is not possible to measure any rates of water transfer exactly, and it is inevitable that quantification of the water balance will not be precise (Acreman & Miller, 2006).

The storage potential of the floodplain wetland will depend both on the geomorphic properties of floodplain (wider, low gradient floodplains storing more than narrow, steeper floodplains), soil type, the antecedent[7] conditions (groundwater levels, volumes of water in depressions and pools, soil saturation levels) and prevailing conditions at the time of high channel flows. If, following prolonged wet periods, the floodplain groundwater level is high, surface depressions full of water and soils saturated, the flood retention capacity of the flood plain will be much reduced (Bengston & Padmanabhan, 1999; Ahilan *et al*., 2009). Wet floodplain soils also allow water to flow from floodplain and hillslopes into channel, such that flood peaks are higher (Burt *et al*., 2002). Floodplain water tables will be dictated by the geomorphology of the floodplain within its valley and preceeding rainfall. High water tables characterise many floodplains, particularly in winter (Burt, 1996).

Available flood storage will be similarly reduced if hillslope and rainwater contribute relatively high volumes to floodplains during floods (Archer, 1989; Okruszko and Querner, 2006). Lateral hillslope flow, consisting of overland flow and soil interflow, plays an important hydrological role in the water balance of floodplains, although is relatively more important in headwater catchments (Burt, 2001; Burt *et al*., 2002). Hillslope contribution will be particularly high where extensive, steep hillsides with thin peaty soils surround narrow valleys, typical of many upland and western regions in Ireland.

Water flow through a floodplain (route and speed of water) is influenced by a complex pattern of natural and artificial drainage channels and surface roughness (Nicholas and Mitchell, 2003). Wetlands characteristically develop rough vegetation that slows flow, whereas channel roughness may only be important during smaller floods, where shallow flood waters will interact more strongly with surface vegetation. Deeper water on floodplains will allow surface water to flow over vegetation more easily, such that the attenuation effect is lessened (Ahilan *et al*., 2009). As water levels rise in river channels, a certain amount of water will move from river channel to bankside soils – a process known as bank storage, and distinct from flood storage. Bank storage is a significant hydrologic process because it can attenuate a flood wave in a river (Squillage, 1996, Burt *et al*., 2002). In extreme events, rivers can burst their banks and cause large volumes of flood water to inundate the floodplain.

Evaporation and evapotranspiration can also remove large quantities of water from a floodplain, particularly during growing seasons (Gleason & Tangen, 2008). They will be less significant both during winter, when most flooding tends to occur and during large flood events (Bengston & Padmanabhan, 1999).

Murphy and Charleton (2006) modelled the impact of climate change on the storage potential of nine different catchments in Ireland based on soil type. By 2020, reductions in soil moisture storage throughout the year were predicted for each catchment, with the greatest reductions being during winter. This reflects the loss of infiltration capacity

[7] Antecedent = pre-existing, i.e., the saturation level of the wetland at the time of a new flood event. This is temporally veriable depending on rainfall and drainage characteristics of the wetland.

owing to increased precipitation. More extreme reductions were found for some catchments by the 2050s. The extent of decreases in storage depended on the soil characteristics of each catchment. Highly permeable soils of the Suir, Barrow, Blackwater and Ryewater all showed substantial reductions in storage, while reductions were not predicted to be as significant for the less permeable Boyne and Moy. This has parallels in terms of wetland storage and flood attenuation capacity, especially on floodplains, since wetland hydrology is closely linked with soil characteristics.

Full understanding of spatial and temporal hydrological patterns of floods on wetlands requires the use of complex models that have explicit representation of water table gradients and groundwater flow and how these change with time (Acreman and Miller, 2006; Gleason & Tangen, 2008). There are few field studies that allow a determination of the relative importance of each process in lowland regions, or provide field data with which to calibrate numerical models (Stewart *et al*. 1999).

Irish rivers experience considerable periods of out-of-bank flow and models from other countries most likely fail to reflect accurately floodplain attenuation effects in Ireland (Oliver Nicholson, OPW, pers.comm.). To address this, the Flood Studies Update (FSU) of the Office of Public Works (OPW) [8] is seeking to create an accurate model of Irish floodplain attenuation effects. The FSU study by Ahilan *et al*. (2009) used hydrometric data from the Suir catchment to model floodplain effects on simulated out of bank flow events. They found that the dominant influences on floodplain attenuation in this context were: flood duration, floodplain width and floodplain slope. The results of the study were somewhat inconclusive because of low resolution in the Digital Elevation Model (DEM) used. A rerun of the model at higher DEM resolution is planned, which can allow for generation of accurate flood risk maps required for the next stage of Catchment Flood Risk Management Plans (CFRMP). The current absence of good flood risk mapping in Ireland places considerable limitation on the potential to implement more natural flood management solutions (Oliver Nicholson, OPW, pers.comm.).

Wet woodland contributes to the natural flood retention function of floodplains by increasing the hydraulic roughness of floodplain areas, slowing the release of water stored on the floodplain surface. In Ireland, native woodland habitat associated with lowland floodplains is Alluvial Forest. Typical species include birch, willow, alder, ash, oak, hazel, (NPWS, 2008). Floodplain forests depend on particular flood regimes for their continued existence, as many of their tree species require flood disturbance and newly deposited sediments in order to regenerate. Bog Woodland occurs on intact bog or fen peat dominated by birch and some willow and is the native woodland habitat associated with raised bog (NPWS, 2008). Bog woodlands grow in permanently waterlogged soils and, as a result, have specialised flora and fauna. Typical tree species include birch, willow, alder and rowan[9].

[8] http://www.opw.ie/en/FloodRiskManagement/BackgroundPolicy/ManagingFloodRisk/StrategicInformationDevelopmentProgrammes/FloodStudiesUpdate/

[9] http://www.woodlandrestoration.ie/priority-woodland-types.php

On the Weinfluss (River) near Vienna a test section of "wooded" "floodplain" was constructed. It was an outdoor flume with channel and floodplain into which artificial floods were released from an upstream reservoir. Experiments using tracer solutions showed that the flood wave becomes attenuated as it flows across the floodplain and moves downstream. The experiments also showed that wooded floodplain can have the effect of increasing flood water levels upstream of the reach (FLOBAR2, 2003).

In a simulation modelling study conducted on Australian rivers, the additional resistence to flow provided by natural riparian vegetation was found to reduce peak discharge, so reducing the incidence of downstream flooding. Importantly, this effect is more marked during smaller floods, which are more sensitive to vegetation conditions than larger floods (Anderson *et al*., 2005, 2006). Similarly, Thomas and Nisbet (2007) conducted hydrological simulation studies on the ability of a floodplain woodland to attenuate flooding. They found that water velocities decreased within the woodland during floods, so leading to higher water levels and the creation of a backwater effect extending considerable distances upstream. Flood storage was increased and peak discharge downstream reduced. They concluded that strategically placed floodplain woodland could potentially alleviate downstream flooding.

3.2 Peatlands

The hydrology of peatlands is very different to alluvial floodplains and they generally receive much of their water either as rainwater (particularly bogs) or groundwater and hillslope (fens) (Fig. 2). Very little water flows onto peatlands from channel-fed overland flow because of the small size of channels owing to their headwater nature. Critical to understanding the flood attenuation ability of peatlands is knowledge of how surface water in the wetland, derived from rainwater, hillslope or groundwater interacts with the peat soil and surface vegetation (Gibson, 2000).

Within peatlands, water flow can include vertical and horizontal movement within the various layers and sheet flow and channel flow over the surface as well as water exchanges with upland systems (Kværner and Kløve, 2008). Whilst water retention by peatland surfaces may attenuate and delay runoff events, the flood mitigation role of peatsoil wetlands is often overstated (Keddy, 2000; Bullock and Acreman, 2003) and it has been recognised for many years that not all peatlands reduce storm flows nor provide higher flows in summer (Kay, 1960). In contrast to the knowledge of the hydrological properties of floodplains, the role of headwater peatlands in runoff generation and flood attenuation is still contentious (Kværner and Kløve, 2008).

3.2.1 Raised and blanket bogs

Raised- and blanket bog peatlands consist of two layers with distinctly different hydrological properties - the upper aerated 'acrotelm' and lower, anoxic 'catotelm' (Holden and Burt, 2003). The catotelm is darker and more humified than acrotelm and consists of more well-decomposed and denser peat. The catotelm is also constantly saturated, whereas the water level in the acrotelm can fluctuate more. Water flow through peat is related to the pore size between particles of peat. In poorly decomposed peat, consisting of larger particles of woody vegetation or stems and leaves

of reeds, rushes and grasses, the relatively large pore sizes allows high hydraulic conductivity. In well decomposed peat consisting of small pieces of *Sphagnum* stem and leaves, water flow is lower. For deeper bogs that have a high density layer of catotelm peat, most of the lateral flow through bog peat will be through the upper acrotelm.

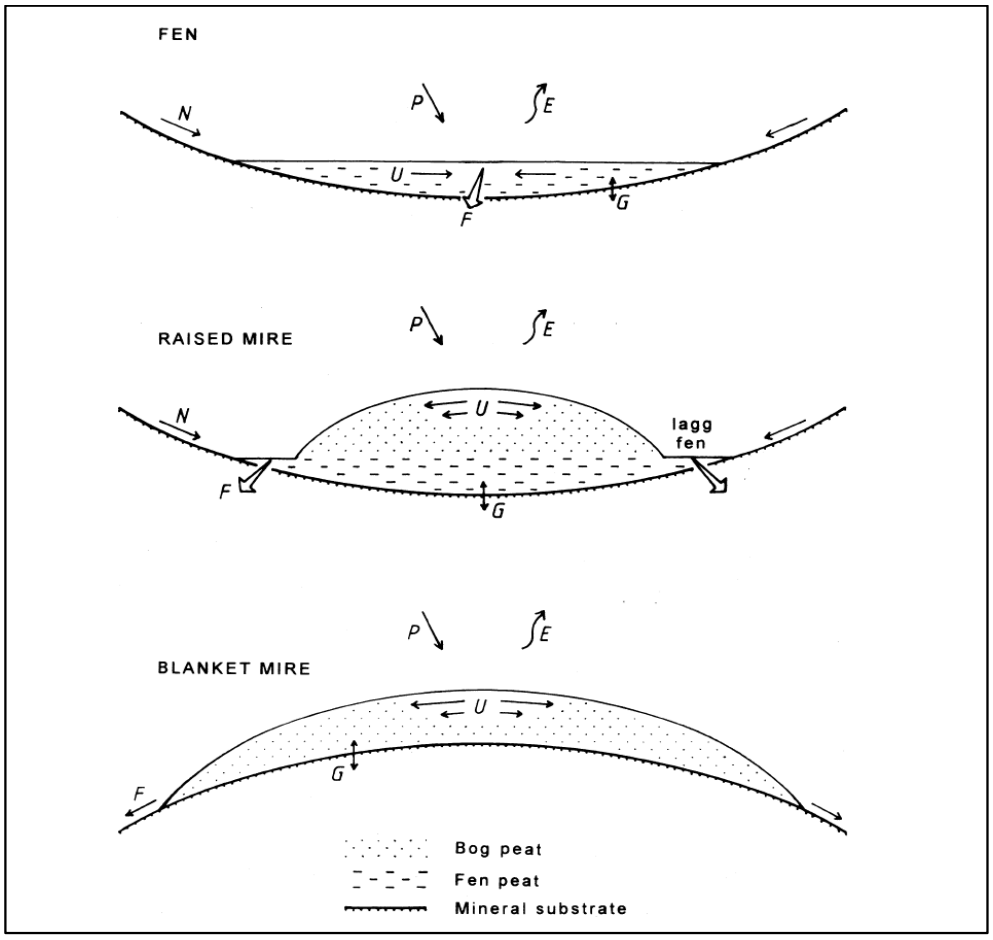


Fig. 2. Morphology and hydrological relationships of three mire types. Water fluxes: *P*, precipitation; *N*, surface water supply; *U*, lateral seepage in peat; *E*, evapotranspiration; *F*, surface water efflux; and *G*, exchange with deep groundwater (leakage). From Bragg, 2002.

Most research into surface runoff, therefore, concerns the more permeable acrotelm (Branfireun & Roulet, 1998; Holden & Burt, 2003). The position of the water table in the acrotelm, which is restricted to a layer less than 0.1m thick for most of each water year, controls the runoff response of a peatland to rainfall input. The efficiency of the acrotelm peat to temporarily store water, therefore, can strongly determine the role of bog peatlands in runoff generation and flood attenuation, but only if a well-developed acrotelm is present (Regan & Johnston, 2011). The available soil storage capacity of a bog peatland is thus usually small, so that precipitation gives rise to increasingly rapid runoff as the water table rises through the superficial living acrotelm (Bragg, 2002). Bog peatland runoff is then dominated by saturation-excess overland flow on more gentle

slopes with impeded drainage, and a greater contribution from within the near-surface layers of blanket peat on steeper slopes (Holden & Burt, 2003). Topography and preferential flow paths are important controls on the spatial production of runoff. No significant discharge emerges from the lower layers of peat except from preferential flow pathways ('soil pipes'), which contribute around 10% of the discharge to the catchment. Most flood storage arises, therefore, from a rough micro-topography and minimised sub-surface flow (Holden & Burt, 2003). The run-off hydrograph of a bog can thus be characterised by a small but perennial baseflow with superimposed storm peaks. Storage effects are unlikely to contribute significantly to attenuation of winter floods, although they may affect runoff arising from storms following long dry periods (Bragg, 2002).

Stream flow downstream of a bog peatland is a function of the amount and intensity of precipitation, antecedent conditions, the nature of the peat profile, the location of the wetland within the landscape and the topographic forms within the wetland (Bay, 1969; Verry *et al*., 1988; Branfireun & Roulet, 1998). The variation in these parameters can lead to very different conclusions about the flood storage potential of bog peatlands. In a study of a Minnesota raised bog peatland, Verry *et al*. (1988) found that effluent streamflow responded to large storms almost the same way as streamflow from a level, unregulated, reservoir, and that thehe peat, hummock-hollow topography, and tree boles reduced the streamflow rate slightly. Flow rates from the peatland following a very high storm event were actually higher than a reservoir, when wedge storage and a channel-like flow system developed in the lagg area of the peatland. Similar raised bogs in the same location were found earlier to have relatively little impact on streamflow, but that they did store storm runoff, particularly after summer dry periods when bog water tables were low (Bay 1969). In contrast to these findings, Bragg (2002) found that the effluent discharge response of a Scottish raised bog to individual storm events was delayed by up to 22 h relative to that of streams draining nearby, non-bog catchments, after a long dry spell in summer. The time lag amounted to 3–6 h even under conditions of zero storage deficits, indicating that the bog was more effective than the surrounding mineral slopes in delaying runoff, even in wet weather.

3.2.2 Fens

Few studies have been carried out on the flood attenuation properties of groundwater (fen) peatlands, and there is no great consensus as to their flood attenuation properties. The high groundwater tables prevalent in many fens will reduce their storage capacity and so limit their ability in many cases to reduce storm-flow volumes (Paavilainen & Päivänen, 1995). In flatter and larger fens, temporary surface water storage may however potentially regulate and attenuate peak runoff. In a study of the flood attenuation potential of Norwegian flat fen, runoff peaks following precipitation events were found to be delayed and attenuated by the fen through the temporary storage of water in surface depressions and to surface topography-induced friction to overland flow (Kværner & Kløve, 2008). Peak outflow was retarded more strongly during small runoff events, a function of the greater friction to overland flow at lower water-table levels. During large events, peak flow retardation occurred because of water storage provided by flooding and filling of local depressions. Further, water-table observations revealed that increasing areas of fen became saturated (leading to greater spatial extent

of temporary surface storage) at increasing runoff, indicating the importance of the size of the storage basin and the narrowness of the fen water outlet (Kværner & Kløve, 2008). The importance of temporary water storage in surface depressions of fens has been supported by recent work by Frei *et al*. (2010) who showed, using virtual models of wetlands, that the complex micro-topography efficiently buffered rainfall inputs and produced a hydrograph that was characterized by subsurface flow during most of the year and only temporarily shifted to surface flow dominance (> 80% of total discharge) during intense rainstorms. These recent studies demonstrate that intact peatlands with a well-developed micro-topography, (i.e., small pools and hollows) can attenuate storm flows by allowing greater surface water storage. In fens with extensive areas of peat diggings, the increase in depressions and hollows is likely to increase flood water storage.

North American 'Prairie potholes' and European fens are both groundwater-dominated depression peatlands and thus functionally similar hydrologically. As in Ireland, wetland drainage for agriculture has significantly decreased wetland storage volume (Gleason & Tangen, 2008) and this reduction has been linked to increased frequency of flooding in the Prairie Pothole Region. In an effort to mitigate wetland losses, wetland restoration has been widely advocated, leading to increased research to estimate the flood attenuation properties of such wetlands. Gleason and Tangen (2008) used morphometry data from multiple wetlands in the Prairie Pothole Region to estimate maximum water-storage capacity and interception area of wetlands on the studied lands. They found that pothole wetlands had significant potential to intercept and store precipitation that otherwise might contribute to downstream flooding. A similar pattern of the flood attenuation potential of depression wetlands was found by Lindsay *et al*. (2004) in a study of Canadian Shield groundwater wetlands. In their study, catchments containing extensive wetlands were marked by a significant decrease in maximum peak discharge and increase in duration of flow during wet periods.

The value of such wetlands to attenuate large flood events may, however, be overstated. In a case study on the flood attenuation value of wetlands within the Red River Basin, Manitoba, Canada, Simonovic *et al*. (2001) showed that although an increase in wetland area could potentially reduce total flood volume, the capacity of wetlands to attenuate large flood events was limited. Similarly, the results of simulation modelling in a US study found that Prairie Pothole wetlands reduced flooding of an annual event by 9–23%, compared with only 5–10% for a 100-year event (SAST, 1994, cited in Leibowitz, 2003). Bengtson and Padmanabahn (1999; cited Schultz & Leitch, 2001) found that restoration of 2,700ha of upland depression wetlands in the North Dakota's Maple River Watershed (US) resulted in flood peak reductions of 3.8% for small events, 2.2% for medium events, 1.7% for large events and 1.6% for very large events, with the assumption of 1 foot of storage 'bounce'[10]. When storage 'bounce' was increased to 2 foot the figures increased to 5.4, 3.2, 2.4 and 2.4 percent, respectively.

[10] 'Bounce' refers to the available storage potential of a wetland. This changes depending on the level of saturation. Wetlands can be at full capacity after heavy and/or prolonged rainfall, at which stage they would have no 'bounce'.



Fig. 3 Example of isolated inter-drumlin fens and lakes, south of Bellanode, Co. Monaghan

The Drumlin Regions of the north east of Ireland are peppered with small groundwater-fed depression wetlands (fens) (Foss & Crushell, 2007; 2008), and although many have been drained and converted to pasture, numerous small, isolated fens also occur in parts of Munster. The ability of these small, widely dispersed wetlands to decrease flooding at a catchment scale ultimately depends upon the total available water storage capacity relative to the volume of floodwater and the water balance (Potter, 1994). Individual wetlands probably have quite limited storage and attenuation potential on their own, but to illustrate the potential impact that isolated wetlands in a landscape may collectively have on flood attenuation, three examples are used:

(1) The increased severity and frequency of flooding at Devils Lake, North Dakota, prompted an investigation into the level of flood storage that could be gained by restoring the wetland resource within the lake's various sub-catchments. The region is characterised by many isolated groundwater wetlands, many of which have been drained for conversion to agriculture. Modelling estimated the storage potential in; (1) possibly[11] intact/undrained wetlands; and, (2) possibly drained wetlands. A number of scenarios were modelled, such as gains in storage capacity derived from restoring 25%, 50%, 75% or 100% of drained wetlands. The runoff reduction estimates based on possible storage capacity increases indicated that depression wetland restoration could reduce the volume of runoff entering Devils Lake, and contribute to reduction of flood risk (Doeing & Forman, 2001). Despite limitations within the model, the study shows the potential for a collective, isolated-wetland resource to contribute to flood risk management.

[11] The prefix 'possibly' was used as depressions were located and assessed using remote methods. Lack of ground-truthing is a major limitation to modelling for this purpose.

(2) Lane & D'Amico (2010) used remotely-sensed Light Detection and Ranging (LiDAR) data to estimate potential water storage capacity of isolated wetlands in north central Florida. They also modelled the water storage potential of what they highlighted as >8500 polygons identified as isolated wetlands and found that, collectively; they stored 1619 m^3/ha on average, with a median value of 876 m^3/ha. They discussed the difficulty of quantifying wetland ecosystem services, especially the difficulty of scaling the loss of numerous individual wetlands to effects at the catchment scale. Their results could be used to improve watershed models that incorporate isolated wetland recharge, discharge, and flow-through hydrodynamic processes, which may enable estimation of the potential attenuation role of such wetlands.

(3) Schultz and Leitch (2001) simulated restoration of depression wetlands in the Red River Catchment, North Dakota. They found that wetland restoration could improve flood attenuation at a catchment scale, but that wetland restoration was not a cost effective solution given the scale of the flooding problem (see section 8.3 for cost effectiveness in relation to this example).

The picture that emerges of the flood attenuation properties of peatlands is one of potential, rather than realised flood storage. Increasing flood storage potential is gained where: (1) surface water runoff is delayed and temporarily stored within dips and hollows of a hummocky, uneven surface topography , (2) peatland gradient is low, (3) peatland areal extent is large, (4) vegetation is dense and rough and retards surface flows, and (5) soil saturation is low. Thus, for undisturbed peatlands with a large surface area, low gradient, relatively unsaturated surface soils and rough surface topography, flood storage potential is high. Small, steeper wetlands with a high water table, smoother surface and enhanced drainage runoff (such as occur for grazed peatlands) would likely have lower flood attenuation potential. Ireland has a significant peatland resource (Conaghan, 2001) and better knowledge of the catchment scale effects of peatland management in Ireland is critical to inform flood management policy and strategy, and to inform conservation goals.

3.3 Karstic landscapes

Karstified areas of Carboniferous Limestone, common in the west of Ireland, are vulnerable to groundwater flooding and are categorized as either upland or lowland systems (Zaidman *et al*., 2010). Upland karst systems (such as the Burren, Co. Clare) are characterized by low or poorly-connected storage and a steep hydraulic gradient. These areas are subject to localized flash flooding, with little or no surface storage.

Lowland karst systems possess complex surface-groundwater interactions that influence the seasonal inundation of turloughs in which water levels are both drained and recharged through sinkholes (Zaidman *et al*., 2010). The conservation status of turloughs is currently being investigated through an NPWS project undertaken by the School of Natural Sciences, Trinity College Dublin (TCD), coordinated by Dr Steve Waldren. The work has involved investigations of ecology and hydrology at 22 Irish turloughs. Preliminary indications are that the hydrological processes of each individual turlough are unique and complex (Dr Laurence Gill, pers. comm.). Flood mitigation assessments at each site must, therefore, be evaluated on an individual basis (Ní Bhrion,

2008). As the understanding of turlough hydrology and drainage is far from complete (Zaidman *et al.,* 2010), this is likely to be a costly and difficult exercise.

Irish turlough floodplains have been extensively drained to protect rural and urban infrastructure (Ní Bhrion, 2008). Individual basins, drained or undrained, probably have very limited flood mitigation potential. Nevertheless, it is likely that collective turlough floodplains within a catchment, taken as a whole, have a high potential for storage during large flood events. The largest remaining naturally functioning turlough floodplain in Ireland is at Rahasane Turlough, near Craughwell, Co, Galway. A designated cSAC ([12]Site code 000322) and SPA ([13]Site code 004089), the area floods annually to an area of approximately 256ha. It is presently the subject of a study to ascertain the hydrological and ecological impact within the turlough of a proposed OPW drainage scheme upstream and downstream of the turlough.

3.4 Coastal wetlands

Coastal wetlands are the at the transition zone between land and sea and provide retention areas which can provide both riverine floodwater storage and tidal seawater storage (PWA, 2004). They thus perform an essential flood defence and coastal protection role (MA, 2005). Two types of coastal flooding processes have to be considered: (1) tidal flooding as a result of storm surges, high waves and high tides; and (2) flooding from a river catchment following heavy rainfall (Farrell, 2005). These can often occur together during storms and prolonged rainfall periods present a severe flood threat to many coastal settlements.

Field and laboratory studies have shown that salt marsh vegetation attenuates waves (Augustin *et al*. 2009; Feagin *et al*., 2011; Möller & Spencer, 2002). Salt marshes are particularly efficient at this because highly resilient emergent and near emergent rough vegetation reduces wave height and speed as it travels across the intertidal surface. The vegetation also binds sediment together, thus, increasing shoreline stability (Augustin *et al*., 2009). Möller and Spencer (2002) studied wave/tide datasets at 2 sites in the Dengie marshes, eastern England, addressing the effect of (1) marsh edge topography; (2) marsh width; (3) inundation depths; and (4) seasonal changes in marsh surface vegetation cover on wave height and wave energy dissipation. They pooled data from a similar previous study (Möller *et al*., 1999, cited Möller & Spencer, 2002) and found that on average >40% of wave energy arriving at permanently vegetated marsh edges was attenuated across the first 10m of a marsh; the following 28m attenuated a further 60% of the wave energy. The width and quality of salt marsh habitat clearly had a direct effect on wave attenuation properties. Salt marshes are, thus, effective in dissapating tidal and wave energy and provide a first line of defence, particularly during stormy conditions.

Coastal wetlands in Ireland include estuaries, tidal flats and mudflats, coastal lagoons, shallow inlets and bays; many with associated salt marsh, salt meadow and sand dune habitats. The Status of EU Protected Habitats and Species Report (NPWS, 2008)

[12] http://www.npws.ie/protectedsites/specialareasofconservationsac/rahasaneturloughsac/
[13] http://www.npws.ie/media/npwsie/content/images/protectedsites/sitesynopsis/SY004089.pdf

recorded infilling, land reclamation, embankment and coastal protection works as significant threats to the extent and quality of these areas. Curtis and Sheehy-Skeffington (1998) recorded 238 salt marshes in the Republic of Ireland and found that reclamation had greatly reduced the national area of salt marsh, primarily through embankment and agriculture (particularly in Waterford, Wexford, Wicklow, Donegal and Clare), and to a lesser extent owing to industrial and port development (Shannon, Cork, Dublin).

Any removal or reduction in the functional area of coastal wetland is likely to impact on flood storage / defence capability, as well as affecting habitat and important depositional and hydraulic processes in the coastal zone.

The flood relief role of coastal wetlands is widely recognised for coastal protection. The natural resilience and resistance to frequent inundation provided by salt marshes and estuarine floodplains has meant that their use is becoming a recognised alternative to hard engineering approaches for coastal protection. The strategy of 'managed coastal realignment' involves setting back the line of defence and allowing an area to become flooded, rather than trying to hold the sea at bay. It almost always involves a reversion of previously reclaimed land, where maintenance of specific design-standard seawalls is not economically viable in the long term. Methods and examples of coastal realignment are reported in sections 6 and 7. The solution has gained increasing international interest as countries recognise the need for long-term cost effectiveness in coastal adaptation strategies in the face of predicted sea level rise. The UK, in particular, have embraced 'soft' coastal protection solutions decision making is increasingly based on between 50 and 100 year futures with climate change scenarios in mind.

Climate change-driven increases in rainfall and storminess, coupled with sea level rise, would have wide coastal repercussions in Ireland (Devoy, 2008). The combined effects of river floods and marine surges create notable flood events in coastal areas, and these are predicted to increase in severity. Coastal flooding and storm surge damage has become more frequent and widespread in Ireland (Casey, 2009). In Ireland, even with a modest 0.4m rise in mean sea level, a 1 in a 100 year coastal flooding event will occur at least every 5 years, if not more often (IAE, 2007). Storm surge events are predicted to increase along all but southern Irish coasts in the future, with a significant increase in the height of extreme surges along the west and east coasts (over 1m), especially during winter (Wang et. al., 2008). Coastal wetlands are projected to be negatively affected by sea level rise, especially where they are constrained on their landward side (i.e., 'coastal squeeze'). Devoy (2008) predicts Ireland could lose 30% of its' coastal wetlands given a 1m sea level rise. With room to encroach landward, salt marsh-mudflat systems would provide some resilience or resistance to climate change generated sea level rise, through accretion of saltmarsh.

The OPW are responsible for coastal protection and flood risk management[14] and local authorities are responsible for identifying and implementing strategies. Schemes tend to predominantly involve hard engineering solutions in response to erosion. The Environmentally Friendly Coastal Protection – Code of Practice (ECOPRO, 1996) issued to all Irish local authorities (O'Connor *et al.*, 2009) outlines many coastal protection

[14] http://www.opw.ie/en/FloodRiskManagement/WhatWeDo/RolesResponsibilities/

solutions including consideration of coastal realignment and spatial planning approaches in addition to traditional, hard engineering strategies, but it is unclear to what extent this has been implemented. It was not possible to locate any Irish examples of coastal realignment during this review, although, with regard to spatial planning, the recent Fingal County Development Plan (2011-2017), for example, does specify that "Development should be set-back a sufficient distance from soft defences and erodible coastline to allow for natural processes, such as erosion and flooding, to take place" (p180).

Part II, Section 6.2, highlights the lack of a national coastal policy. Although a national policy document on Integrated Coastal Zone Management (ICZM) was published in 1997, it has never been taken forward in any Government department. It should be noted that all foreshore responsibilities were transferred to the DEHLG in February 2010, under the provisions of the Foreshore & Dumping at Sea (Amendment) Act, 2009, which means that for the first time in the history of the State, foreshore responsibilities are housed within the same Government department that is responsible for spatial planning, conservation of species/habitats, river basin planning and management. Given that local authorities are also under the aegis of the DEHLG all of this should, in theory, facilitate a more integrated approach to marine and coastal resource management but this has not, so far, transpired. A lack of national policy means that there is no framework within which to consider approaches to erosion management such as managed realignment.

3.5 Function specific constructed wetlands

3.5.1 Integrated Constructed Wetlands (ICWs)

Irelands Flood Risk Guidelines (DEHLG & OPW, 2009) state that "*The Department has commenced the preparation of good practice guidance on constructed wetlands which will look at, inter alia, the use and performance of constructed wetlands in the attenuation of flood hazard*." The ensuing ICW Guidelines (DEHLG, 2010) reported that adequately designed, shallow, vegetated wetlands provide cost effective, environmentally sustainable solutions in the treatment of waste water and make generic reference to their potential benefit in a flood management role. The document did not explore technical flood management aspects of ICWs further and, in fact, recommended in that they should not be considered if they can't be protected from flood damage.

Harrington *et al*. (2007) carried out an ICW demonstration project in the 25 km^2 catchment of the Dunhill-Annestown stream in south county Waterford. A performance assessment of 12 ICWs that intercept dirty farmyard water was conducted finding that ICWs are: (1) capable of treating farmyard dirty water; and, (2) effectively reduce nutrient and contaminant loss from farmyards, whilst providing additional new landscape values (flora, wildlife and aesthetic appeal). The authors argue that ICWs mimic the function of a once widespread wetland resource that has been lost.

Whilst hydraulic retention times and design standards for the ICWs were not reported, annual water balance was examined, showing that 23% of water exited the wetland through evapotranspiration, with 73% discharging into the ground. Almost half of the total inflow volume was lost at the fourth pond in the system. Only 4% of the total

inflow discharged to the surface water stream, and this was seasonal, occurring only for a short period in the winter/spring. This data suggests that the ponds have some level of flood storage, but their performances during high rainfall events were not reported. The work principally showed that attenuation of dirty water in ICW's provides short to medium term P-retention, N-immobilisation and significant reductions in concentrations of organic material, suspended material and faecal bacteria.

ICWs (for the treatment of polluted waste water) have been endorsed under the Department's Statement of Strategy and in the Water Services Investment Programme 2010-2012 (DEHLG, 2010). It is envisaged that ICWs will play an increasingly important role in Ireland's requirement to reach WFD water quality targets. In relation to flood attenuation, the ICW Guidelines suggest that additional ponds be incorporated into ICW design for a number of reasons including "increased capacity to store water for longer periods before discharge to surface water thus aiding flood control" (p 60).

It is important to note, however, that the various proposed functions of ICWs may not necessarily be compatible. The fact that these wetlands store sediment, organic matter and nutrients means there is a risk, during larger flood events, that these are mobilised downstream, with negative water quality implications. Such a situation has been observed by the authors for a constructed wetland south of Cork City, on the River Curraheen. It is likely that, as with any small isolated wetland, an ICW may have limited flood attenuation capacity during smaller events, but very little during large events. In fact, given the potential risk to water quality from flood-driven inputs of these stored materials, it can be argued that flooding of ICWs is highly undesirable and that their flood attenuation potential be strongly downplayed.

3.5.2 Sustainable Drainage Systems (SuDS)

Sustainable Drainage Systems (SuDS) have been mandatory in the Greater Dublin Area since 2006. This was introduced on foot of the 2005 Greater Dublin Strategic Drainage Study (GDSDS), which assessed Dublin's entire drainage system to take account of all potential development that might affect the city and environs up to 2030. SuDS are a management solution that deals with the problem of surface run-off at source as opposed to the traditional approach of rapidly conveying water elsewhere. It relies on strategies such as swales[15], filter drains, detention basins, porous paving and the use of storm water attenuation ponds, which can be developed into attractive and biologically important wetlands. Macdonald & Jefferies (2003) reported to the Irish Hydrological Seminar on the monitoring of fourteen different SuDS facilities in Scotland. Performance assessments between 1997 and 2003 showed they all provided flow attenuation to varying degrees (Macdonald & Jefferies, 2003). Two attenuation ponds recorded flow lag times[16] of 100 and 130 minutes compared with equivalent areas of hard paving. Peak flows from all the SuDS components studied were at least 50% of the peak flow from the equivalent paved surface. In addition, ponds had become integrated into the urban landscape, were visually pleasing, and had recorded increases in flora and fauna, creating a focus for biodiversity. A survey of public perception showed that the

[15] Swale = roadside detention
[16] Lag time = the time from the center of mass of excess rainfall to the hydrograph peak.

more natural the ponds appeared (plantings of appropriate vegetation and presence of wildlife) the more aesthetically pleasing they were, and the greater the amenity value. Property developers had located housing of a higher value in view of ponds. This is a clear demonstration, albeit at a local scale, of the potential for wetland creation for flood attenuation with additional benefits.

The River Carmac (a tributary of the Liffey) flows through Corkagh Park about midway between its source and its point of discharge near Heuston Station. Elements of the River Camac Improvement Scheme were devised to help alleviate flood risk following a significant, 1993, flood event in the vicinity of Clondalkin, Co. Dublin. The Scheme provided a design for the attenuation of floodwaters within constructed wetlands (large stromwater retention ponds) at Corkagh Park, a 120 hectare public park and amenity area maintained by South Dublin County Council. Hydrological modelling established: (1) the allowable peak flow of the river channel downstream was 12.5 m^3/s; (2) an event of 25-year return period was the appropriate basis for a cost-effective design, (3) storage volume required was 55,000m^3.



Fig 4: Corkagh Park flood attenuation ponds – River Carmac.

Five off-line lakes (Fig. 4), controlled by weirs, were constructed on the floodplain of the River Camac within Corkagh Park (Matt Rudden, pers.comm). This required removal of approximately 60,000 m^3 of soil which was used to create an elevated section of the park, from which views of the park and surrounding mountains were gained. One of the ponds is maintained with a permanent water level to facilitate a 'put and take' fishery that was designed into the project as an amenity[17]. The permanent wetland can

[17] Corkagh Park
http://parks.southdublin.ie/index.php?option=com_content&task=view&id=73&Itemid=133

accommodate a further 0.5m water level increase, which was estimated to yield a 13,500 m^3 storage capacity, equating to 25% of total emergency capacity required. When not in use, the remaining flood attenuation ponds act as wetland meadows. A combined area of 3.54 hectares is covered by the wetlands and they have a maximum water depth of 1.2m (Murray, 2000). Upstream floodgates are operated manually, with managed outflows controlled by pressure release which slowly discharges floodwaters.

4. Management of wetlands

In northern temperate regions, waterlogged or flooded land is rarely considered useful for agriculture or urban settlement. Exceptions (almost all commercially extinct) include harvesting of wetland products such as summer hay, thatching reed, wildfowl and fish and the ancient practice of allowing water meadows to flood in early spring to provide a spring flush of new grass. Since the onset of agricultural intensification and increased urban settlements in the 19th and 20th centuries, intensive efforts have been made to drain wet land so as to increase yields. Many river systems have been deepened, widened and straightened to as to lower local water tables and to speed the drainage of water from catchments (Blann *et al.,* 2009). For many lowland catchments, this has effectively completely removed overbank flooding onto floodplains or when it does occur, rapid flow back into the channel is facilitated (Acreman *et al.,* 2007). Floodplain changes typically include hedgerow loss, increases in field size, the installation of land drains connecting hilltop to river channel, and channelised rivers with no riparian zone. These landscape changes have been accompanied by increasing intensity of land use (Wheater & Evans, 2009).

For headwater catchments, many peat soil wetlands have been drained, particularly shallow fens, and converted to more productive pasture (Burt, 1995). It is estimated that 78% of Irish fens have been drained and reclaimed[18]. Large areas of blanket and raised bog in Ireland have been planted with exotic conifer, which require the bog peat surface to be drained. Bogs have also been drained for peat extraction and, for shallow peats, for conversion to pasture. In upland catchments in Ireland, often dominated by peaty podsols, sheep densities increased (driven by grant aid) between 1970 and the 1990s (Coulter *et al.,* 1998). Whilst there has been a more recent stock density decline (around the magnitude of a 15% reduction between 2000 and 2010 (Behan & McQuinn, 2004)) there has been considerable pasture improvement in upland areas involving drainage, ploughing, and reseeding. This process is continuing in Ireland with the potential for more land being converted to intensive grazing as a result of new CAP payments to support expansion of the dairy sector (DAFF, 2010; also see Part II, section 8.2).

The impact on flood attenuation of these types of land use changes to wetlands is explored in sections 4.1 - 4.3.

4.1 Floodplain management

The impact of more intensive agricultural land management practices on flooding in Europe, is thought to be largely a result of their impact on soil structure (Wheater, 2006). Land management can significantly affect the local generation of surface and subsurface runoff by influencing the soil structural conditions that determine both the inherent storage capacity, macropore structure and flow pathways within the upper soil layers and their saturated hydraulic conductivity (O'Connell *et al*., 2004). In lowland catchments, changes in crop type and land cultivation practices resulting from the more intensive use of floodplain land can increase runoff due to lower infiltration capacity of

[18] http://www.ipcc.ie/

intensively managed, compacted soils (O'Connell *et al*., 2004; Wheater & Evans, 2009). In the uplands, increased stock densities, exacerbated by removal of hedgerows and woodland buffer strips, can also lead to soil compaction and a greater amount of bare, eroded soils. The hydrological effects of such changes include reduced infiltration, increased overland flow and potentially higher flood peaks (Wheater, 2006). From an extensive meta-survey of published studies, O'Connell *et al*. (2004) found substantial evidence that land management practices affect local surface runoff and the timing and magnitude of field drain responses. Runoff was found to be more rapid and acute on intensively managed soils due to lower infiltration capacity. Old established grassland and woodland has the highest infiltration capacity (O'Connell *et al*., 2004). Overgrazing and trampling by stock can markedly decrease surface infiltration and can double surface runoff at the field and hillslope scale. They also found that both afforestation and field drainage can affect flows in the surface water network but the impacts depend on the local soil type and specific management practices used. Although it is generally accepted that such land use changes can lead to greater flood risk at local scales, the complex interactions of soil type, land use, landscape configuration and local climate at a local sub-catchment level make it difficult to scale these processes up to large catchment scales (Wheater & Evans, 2009). There is very little direct evidence that land management practices can affect flooding at larger scales (O'Connell *et al*., 2004). Further studies aimed at detecting such effects are needed, with the particular aim of detecting the impact of changing land management with other confounding factors.

In some cases, in fact, agricultural intensification of wetlands may, in fact, increase flood storage potential. Floodplain drainage can lower groundwater levels, reduce or divert hillslope flow and increase soil moisture deficit during dry periods. If hydrologic connectivity with the river channel is maintained, such that overbank flooding can still occur, the greater water uptake capacity of such dry floodplain may result in enhanced flood attenuation potential. The realised impact on flood attenuation from land use intensification of wetlands is then a sum of the various positive and negative impacts on water storage and runoff.

The concern over the loss of floodplains and the perceived reduction in floodplain water storage is leading to increased interest in reversing large-scale engineering of river corridors and restoring floodplain function. Reinstating more natural infiltration rates on floodplains can reduce runoff at the field scale. Allowing more natural wetland vegetation growth can also help to reduce post-inundation runoff rates, although may be accompanied by higher groundwater levels which may act to reduce soil storage capacity. Such restoration and rehabilitation efforts thus needs careful evaluation about their potential benefits. Although restoration of infiltration rates should reduce surface runoff at the field scale, greater subsurface runoff could also increase as a result, so mitigating the net impact (O'Connell *et al.,* 2004).

Some floodplain management measures can have more straightforward and concrete impacts on flood attenuation. Acreman *et al*. (2003) simulated the effects of embankment on the River Cherwell, (UK). Modelling showed that, at high flows, not allowing water to spill onto the floodplain could potentially increase downstream flood peaks by 150%. Conversely, restoration of more natural overbank flooding by reducing

the width and depth of the channel to pre-engineered dimensions increased water levels on the floodplain considerably and led to a 10-15% reduction in downstream flood peak estimates. This indicates that restoration of overbank flooding can alleviate downstream flood risk and points to the potentially beneficial role of restoring more frequent flooding to floodplains. However, it is important to recognise that restoring floodplain hydrology may not alleviate cumulative flood risk if floodplain water tables are maintained at a high level. In a subsequent study, Acreman *et al*. (2007) simulated the effect of wetland 'restoration' (raising water levels by ditch-blocking and allowing greater water residence time) in a SW English catchment with floodplains dominated by low-lying peatsoil wetlands. They showed that restoring riparian wetlands by raising water levels, particularly in winter, actually reduced potential flood storage which could have an impact on downstream flooding. Restoring or recreating wetlands by encouraging land to flood, particularly in winter, may therefore not bring about the expected flood attenuation benefits. This issue is explored further in section 5 below.

Given the hydrological complexities of floodplains, constructing artificial or 'recreating' wetlands to mimic the natural flood attenuation of natural wetlands is an uncertain exercise. Cole and Brooks (2000) compared the hydrological function of natural and artificial wetlands in Pennsylvania, USA. They found that natural wetlands had lower water tables, shorter periods of soil saturation and inundation and greater soil infiltration, and hence greater flood storage potential, than artificial wetlands.

Restoring or enhancing the natural floodplain vegetation may be feasible in some catchments or locations, particularly in areas of marginal agricultural value. Woody riparian or floodplain vegetation can provide a rougher channel profile during floods, slowing down flood flows and enhancing flood storage, so attenuating peak discharges and providing some measure of downstream flood protection (Thomas & Nisbet, 2007; Anderson *et al*., 2006). Natural wetland vegetation, such as reed swamp, rushes and carr, may need elevated water tables, however, thus reducing the benefit of reduced runoff rates.

It is clear from these examples that the flood storage potential created by riparian and floodplain vegetation management needs to be assessed from a scale-dependent view, both in terms of the flood attenuation benefit at larger, downstream scales and the capacity of such management measures to operate effectively during more extreme flood events.

4.2 Peatland management

Peatsoil wetlands have been intensively managed in recent decades, to facilitate grazing and forestry. In upland peaty catchments subject to intensification, the prevailing management practice is to cut drains ('grips' in the UK) through the peat in order to facilitate the flow of water from the saturated peat soils to create a drier soil surface, allowing for grass and tree growth.

These upland drain networks can drain large areas of peatsoil wetland. During rainfall events, flow velocities within drains have been shown to be much greater than over the hillslope surface, increasing flood generation. On the other hand, the drier soils of

drained peatsoil wetlands can increase soil moisture deficit and thereby increase available water storage, leading to reduced hillslope discharge to channels (O'Connell *et al*., 2004). The effects of an individual drainage network, therefore, depends upon its location within the landscape; slope, local rainfall and peat depth all having an important role (Lane *et al.,* 2003). Further complicating the picture is that drains cut in the peatland, whilst increasing throughflow in soils, can significantly reduce overland flows by increasing the ability of water to flow through the lower peat layers (Holden *et al*. 2006). Conversely, the *Sphagnum* moss on intact peat bogs provides greater hydraulic resistance to overland flow on improved, drained peatlands (Holden, 2008). Grayson (2009) showed that, whilst relative surface flow velocities depend on hillslope and water depth, flows over *Sphagnum* covered peat were slowest and flows over bare peat were significantly faster. Surface flows, where vegetation such as *Eriophorum* spp. (bog cotton) or *Juncus* spp. dominated, were intermediate. Flow velocity was slower within vegetated drains, even ones without dams and pools, compared with bare peat drains by at least 10-fold (Holden *et al*., 2008a, in Holden, 2009). There has been no work published on the effects of drain-blocking on catchment-scale flooding, but modeling work is ongoing in the UK at Newcastle University and Imperial College (Holden, 2009).

Wilson *et al*. (2010) demonstrated the complexity in predicting the effect of drainage management in peatsoil uplands. They showed that drains cut in an upland Welsh blanket bog led to the creation of drier peat soils around drains, particularly downslope. Blocking the drains reversed this effect and led to a re-wetting of the near-drain soils, with much greater surface water occurrence. Drain blocking increased the ability of surrounding peat to hold rainwater, whereas previously it would have flushed through more rapidly. It was found that, at this site, restoration increased water retention within the peat. This was further supported by observed declines in average and peak flow rates in streams draining the peat. An increased buffering between rainfall and discharge led to a decline in the occurrence and magnitude of local scale peak flows. The apparent contradiction between the increased water retention of peat during dry periods and reduction in discharge during rainfall events was explained by the diminished connectivity of the drainage network. By blocking drains, the importance of overland flow increased, which was significantly slower that flow through drainage channels, therefore leading to reduced peak flows. The rougher *Sphagnum*-dominated vegetation that is likely to recover over 'smoother' vegetation on drier peat soils will further enhance this effect.

The Ripon Land Management Study (JBA Consulting, 2007) modelled peatland management impact on flood flows in northern England. The study involved a catchment area of 120 km^2 comprised of about 22% moorland and wet blanket bog, located in the headwaters. Simulated changes to drainage of these areas produced discernable effects on hydrograph response at Alma Weir, lower in the catchment. Maintaining drainage channels on bogs and moors ('grip maintenance'), in association with other catchment wide soil degradation did not change the timing of flood peaks at a downstream point, but increased their magnitude (3-9%). Interestingly, within the main sub-catchment comprised of bog and moorland, a 'grip maintenance' scenario produced a 7-21% flood peak increase within that sub-catchment, despite floodplain attenuation effects there. In contrast, grip-blocking (simulated as a 1 hour delay in peak

discharge) had the effect of reducing flood peak by 1-8% at Alma Weir with up to half an hour delay compared with baseline. In terms of design events, it was found that a moorland improvement scenario (of grip blocking) had little effect on the magnitude of the 10 year peak but reduced the peak of the 50 year and 100 year events by 5-7%. It must be noted that the same 'moorland improvement' scenario did produce a more gradual recession limb on the hydrograph, indicating a longer flood duration at Alma Weir.

Blocking drains in peatsoil wetlands may therefore have the same effect as reducing the runoff from floodplains, i.e., a reduction in speed of runoff so attenuating downstream peak discharges. The role of peat saturation levels may thus be of secondary importance to the role of drains facilitating runoff. Overall, therefore, the effectiveness of restoring drained peatlands in order to reduce runoff and attenuate downstream flooding is still uncertain. Whilst there is evidence of local scale attenuation, it is not yet known how peatland restoration impacts flood peaks at a catchment scale.

An example of hydrometric response to catchment scale land management change has been reported for the Munster Blackwater, Ireland, as part of the Mallow Drainage Scheme Engineering Report (OPW 2003b). Since EU accession in 1973, wide scale intensification of land drainage and forestry has occurred within the catchment. Using historical data available from Killevullen hydrometric station, the periods 1955-1973 (pre- EU accession) and 1973-2003 (post- EU accession) were compared. Revealingly, only a minor difference was detected in mean annual flooding between the periods, which was attributed to higher average rainfall in the 1990s. No evidence was found that catchment-scale land management change had contributed to an increase in peak flood flows. This type of study requires replication using data sets from other catchments with varying soil types and should include a more rigorous land management correlation for any strong conclusions to be drawn. In addition, whilst there were no significant changes to flood peak height at Killevullen, the study could not account for the timing or frequency of flood peaks.

4.3 Variables affecting wetland management and flood attenuation

From the above account of how management of wetlands may affect their ability to attenuate floods, it is clear that there are two main variables driving the impact of a particular wetland to mitigate flooding – surface storage (soil moisture deficit and storage of water in pools and small depressions) and runoff rate (affected by surface 'roughness' and vegetation cover). For effective mitigation, the former should be enhanced and the latter reduced. The issue of drainage ditches, then, represents a particular management problem. Removing or blocking drains may retard the runoff of water during a flood, but will also tend to make the wetland 'wetter' outside of rainfall periods, leading to a greater soil water and, potentially, surface water content, in turn reducing the water storage capacity of the wetland. On the other hand, coverage and diversity of bog vegetation has been shown to increase as a result of drain-blocking (Holden, 2009, Section 4.2) which, as well as having biodiversity benefits (Section 6), is believed to contribute to the attenuation of surface water runoff.

A distinction in this regard may be made between wetlands in the west of Ireland and those in the east. Westerly wetlands could receive almost double the rainfall of those in the east. The value of soil or surface storage capacity during floods would be less where high rainfall allows little drying of soils. Reducing the runoff from westerly wetlands (e.g., through drain blocking) may therefore be the best management option. For easterly wetlands, there is greater potential for drier soils prior to flood events, so that encouraging drier wetlands may also be a viable management option. At a smaller scale, differences in slope and soil type will also influence wetland management for flood attenuation. There is very little research into this area, and wetland management for flood alleviation remains either conceptual or untested. Clearly, there is a need for a great deal more research into this area.

5. Conflicts between flood attenuation and other wetland functions

Several authors have made the point that encouraging greater flood storage on floodplain wetlands can not only potentially alleviate downstream flooding but will materially affect the profitability of agriculture on the wetlands. The benefit of flood alleviation (difficult to estimate and accruing to downstream populations) then needs to be set against the cost of lost productivity (easy to calculate and bourne by individual landowners). Any proposed scheme to enhance natural storage options must take due regard for all natural and man-made assets on the floodplain affected. All the environmental, economic and social issues should be given adequate consideration (Rose *et al*., 2005).

5.1 Biodiversity

Wetlands have potentially high biodiversity potential compared with many other ecosystems, principally as a result of their high habitat heterogeneity and productivity (McBride *et al*., 2010). Many wetland species are currently threatened (Trochlell & Bernthal, 1998). The isolated nature of natural wetlands also makes their populations naturally vulnerable to local extinctions. Approximately 17% of Annex 1 habitat types of the EU Habitats Directive are found in close association with river systems and at least 30 types are found in association with floodplains (Platteeuw & Kotowski, 2006). Many animals and plants referred to in the EU Habitats Directive are often found in floodplain habitats. Eight species of mammals, four reptiles, 24 amphibians and 63 fish from Annex II of the Habitats Directive commonly occur in and around riverine and floodplain environments and many of these are also mentioned in Annex IV. Birds are among the most conspicuous of wetland animals and are the focus of many conservation efforts. Water conditions are one of the main factors affecting the composition and abundance of bird communities on floodplains (Morris *et al*., 2004). Water level fluctuations influence the physical structure of habitats, the availability and accessibility of food and the presence of safe roosting or breeding sites. Out of 194 Annex 1 bird species of the EU Birds Directive, approximately 90 regularly occur in wetland landscapes (Platteeuw & Kotowski, 2006). Amphibians are also a notable feature of many European wetlands and are under global threat, primarily on account of habitat destruction.

Protecting biodiversity and enhancing the flood attenuation potential of a wetland are often thought to be compatible and the two objectives are often conflated. However, the biodiversity of a given wetland is largely driven by its particular hydrological nature, which may conflict with flood management. Conflict between flood management and biodiversity objectives on floodplains can arise with respect to the duration and seasonality of flooding (Morris *et al.,* 2004). Flood management generally requires the storage of flood water during the period of peak flows followed by evacuation of flood water as soon as possible in order to secure the storage facility for re-use. Biodiversity objectives, however, usually require some retention of water beyond the flood period. The management of wetlands for birds illustrates this problem. Areas of shallow, small-scale flooding within floodplains are of critical importance for breeding wading birds. For example, small drains containing standing water are very important for breeding lapwings, *Vanellus vanellus,* both for nesting adults and feeding chicks (Eglington *et al*.,

2008). Retaining shallow standing water on floodplains throughout the breeding season is vital for the successful breeding of this species. Such features, however, have been shown to reduce the potential water storage of a floodplain (Acreman *et al*., 2007). Changes in soil moisture levels can also have significant impacts on a range of wading bird species that use floodplains and obtain their food predominantly by probing the soil (Rhymer *et al*., 2010). Prime conditions for both invertebrate survival and reproduction and for foraging waders require a trade-off between soil conditions. Dry summer soil conditions can result in mortality of invertebrate larvae and force earthworms to descend deeper into the soil, thus reducing prey availability. Conversely, prolonged flooding results in invertebrate prey that are accessible but at low abundance because excessive waterlogging reduces populations (Rhymer *et al*., 2010).

Given the complex relationship between a particular bird species, seasonal water levels, soil moisture levels and prey availability, it is not a simple task to devise general rules for floodplain management. If all species, including birds, amphibians, plants, invertebrates, fish and mammals are taken into account, the task of managing water levels to maximise wetland conservation values becomes very large. Morris *et al*. (2004) created a 'habitat matrix' to classify washlands by flood and soil water regimes and identified modifications that could alter the relationship between them to enhance either flood protection or biodiversity aspects of a washland creation project. To integrate habitat specifics with managing wetland water levels to optimise flood attenuation in Ireland would require much greater knowledge and resources than are currently available.

Rose *et al*. (2005) found that the managed use of natural floodplains for attenuation of extreme, low frequency events, cannot provide concomitant benefits for biodiversity. By their nature, extreme floods would not provide the regular inundation (usually at least yearly) required to promote changes to existing biodiversity, particularly if land has been converted from productive agricultural use. In the case of peatlands, however, an improvement in the coverage and diversity of bog vegetation on restored blanket bog as a result of drain blocking has been shown to increase retention of surface flows (Wilson *et al*., 2010).

Clearly, however, natural flood regimes and wetland biodiversity are entirely compatible with each other – in fact, the hydrological regime of a wetland very largely governs its ecology. What is difficult to predict and assess is the impact of a particular management strategy on both flood levels and biodiversity. This is the subject of many inland and estuarine floodplain restoration projects, with examples documenting biodiversity gains in many cases (see Table 3, section 6, and EA, 2010b). However, there are cases where, in the absence of specific management to provide for habitat creation, biodiversity benefits would be minimal, e.g., Beckingham Marshes flood storage area (Table 3, Section 6, and Morris *et al*., 2004). What should be avoided are management strategies based on simplistic assumptions about how wetlands function ecologically and hydrologically.

5.2 Water quality

Wetland flood attenuation is often conflated with their nutrient and sediment retention properties, but caution must be applied to this assumption not least owing to lack of

experimental evidence that shows all three functions coexist. ICWs are a prime example (see Section 3.5.1), where high levels of particulate nutrients and sediment stored within the wetland are vulnerable to erosive flood flows, which may export such pollutants to the downstream channel, with negative consequences for water quality.

During overbank flooding, water velocities over extensive, low gradient lowland floodplains are, however, likely to be low, allowing particulate material to be deposited on the floodplain from the floodwater's suspended load. Though for floodplains constrained between narrow valley sides (which are relatively common in Ireland), overbank flood flows may attain relatively high velocities and erode, rather than deposit fine particulate material. The nutrient and sediment retention function of such floodplain wetlands may therefore conflict with their flood attenuation function when located in these valley forms.

A preliminary study showed that drain blocking on upland peatlands in Britain reduced the production (through biotic processes) of dissolved organic carbon (DOC) with the potential to reduce DOC export to watercourses (Bonnett *et al.,* 2008). Blocking of eroding gullies on upland peat was effective in reducing both stream flow and DOC flux in another UK study (O'Brien *et al.*, 2008). Such potential for DOC export reduction in conjunction with increased water retention function of peatlands is positive for downstream water quality. Elevated DOC can impact negatively on water quality and aquatic ecology through its influence on acidity, trace metal flux, light penetration and energy supply (Evans *et al*., 2005).

6. Methods to enhance and mimic natural drainage processes

6.1 Overview

The concept of allowing space for water to inundate tidal wetland and alluvial floodplains has been crystalised in policies such as the UKs "Making Space For Water" and the Netherlands "Room for Rivers" (see Part II, section 9). Such policies have been driven by increased frequency of severe flooding in Europe and the need to find cost-effective long-term strategies for flood defence that take future climate change scenarios into account. This has led to an array of solutions that protect, restore and emulate the natural regulating function of catchments, rivers, floodplains and coasts.

A recent UK Environment Agency report – Working with Natural Processes to Manage Flood and Coastal Erosion Risk (2010)[19] provides a comprehensive overview of a range of techniques for working with 'natural' drainage methods in all areas of a catchment – upland, lowland, urban, rural, and coastal. The report includes a comprehensive list of some UK and international schemes, and a detailed description of some of these. There are further international examples of similar projects in ECOFLOOD (2006), Morris *et al*. (2004) and Rose *et al*. (2005). Table 3 summarises a range of different techniques and projects with demonstrable flood mitigation properties. The examples were chosen to include schemes within different parts of a catchment, from headwater to coastal, with an international scope to demonstrate that such schemes have broad acceptance.

Within Ireland, other than small SuDS-type facilities (retention ponds and basins) and existing dams and resevoirs, only one example of specific use of wetlands for flood attenuation was found (Corkagh Park). Instead, methods that have been *considered* for floodplain storage options during design and feasibility stages for large OPW Drainage Schemes are reported on in section 7.3.

6.2 Restoring alluvial floodplain function

By far the most common strategy of employing wetlands for flood attenuation is the utilisation of floodplain function. This almost always involves a combination of engineered and non-engineered strategies. At one end of the spectrum is allowing water to spill over natural (or artificially raised) banks - spread out over the floodplain and drain, by gravity, back to the channel. At the other end of the spectrum is the use of engineered inflow/outflow and containment structures to hold water within floodplain storage areas ('washlands').

The solutions at a particular location will always be determined in relation to specific site attributes, such as, storage requirements, available area, topography, geography, biodiversity and economic constraints. Section 8 examines cost effectiveness issues. In general, strategies employed to restore river connectivity to floodplains are: removal of bank fixation; allowing/increasing lateral channel migration or river mobility; remeandering of water courses; shallowing of water courses; lowering river banks or floodplains to enlarge area for inundation; removal of hard engineering structures that impede lateral connectivity and setting back of embankments. Strategies employed to

[19] http://publications.environment-agency.gov.uk/pdf/GEHO0310BSFI-e-e.pdf

control inundation and storage of water on floodplains include: use of weirs; sluice gates; raised earth embankments; controlled inflow and outflow valves and mechanisms, including pumping (Morris *et al.*, 2004).

6.3 Managed coastal realignment

A primary driver for managed realignment is the provision of sustainable and effective flood and coastal defence, with the creation of wildlife habitat often being a complementary goal. Managed realignment involves the deliberate removal of existing sea defences and re-introducing tidal regimes to previously reclaimed land and is accomplished by combination of excavation work and natural recolonisation processes. Projects differ depending on the size and site characteristics, but usually involve - breaching of seawalls, reprofiling of shore gradient, excavation of lagoons and relic creeks, and construction of new inland seawalls (ECOPRO, 1996). The newly established mudflat-salt marsh system will act to absorb wave energy and accommodate water during flooding and extreme weather. New sea barriers can usually be built to a lower height, reducing costs, whilst often increasing the level of protection afforded.

6.4 International examples

6.4.1 Floodplain restoration: Southlake Moor, UK.



Fig 5: Southlake Moor, Somerset Levels and Moors, UK, winter 2009/10 (Image: Parrett Internal Drainage Board[20])

Table 3 summarises the Southlake Moor project which has been praised by the UK's Royal Society of Protection for Birds (RSPB) for its success in attracting a large population of winter waterbirds since its inception[21]. It was the first wetland restoration scheme to be completed in the Parrett catchment, marking a fundamental change in the Somerset Drainage Board's activities towards multi-functional and sustainable management of floodplain wetland systems. It involved the decommissioning of old water level management structures on the River Sowy and the use of inlet and outflow

[20] From http://www.somersetdrainageboards.gov.uk/Southlake_FC_IDB_newsletter_2_Autumn_2010.pdf
[21] http://www.rspb.org.uk/news/269060-rspb-welcomes-floodplain-restoration

control mechanisms, plus raised banks, to manage water levels and flows across the whole moor (Parrett Drainage Board, 2010).

The project forms part of a much larger initiative managed under the Parrett Catchment Project (PCP)[22], which received funding through the Joint Approach for Managing Flooding (JAF)[23], a European partnership of five organisations (in Netherlands, Germany and the UK, active in water management. JAF is subsidised by the European Regional Development fund. The PCP received £650,000 from JAF, which was match-funded by the UK Environment Agency and the PCP funding partners. The PCP is itself a partnership of 27 organisations including farming, nature and recreational interest groups as well as Drainage Boards, Environment Agency and local councils, that are working together to solve the flooding problems of the catchment through an integrated approach to land and water management. Devastating flooding in the Parrett catchment in 1999/2000 initiated the PCP approach which is introducing methods based on 50 year projections, a time frame within which climate change is expected to have further major impacts. The 12 areas of action that, when combined, were identified to have a significant part in reducing the adverse effects of flooding were:

1. Changes to agricultural land management;
2. Creating temporary flood storage areas on farmland;
3. Controlling runoff from development;
4. Creating new wetland habitats;
5. Dredging and maintaining river channels;
6. Raising riverbanks;
7. Upgrading pumping stations;
8. Spreading floodwater across the moors;
9. Building a tidal sluice or barrier downstream of Bridgwater;
10. Upgrading channels to enhance gravity drainage;
11. Restricting new development on the floodplain; and
12. Woodland development.

Southlake is the first of 10 similar proposed PCP projects on the Somerset Levels and Moors (SLM) whereby water levels will be managed more effectively in the aim to provide a high standard of water level management, flood protection, and suitable conditions for wildlife (Parrett Drainage Board, 2010). Details on the cost-effectiveness of the Southlake project were not readily available. Considering it is part of a catchment wide solution, it may not be possible to attach a figure to a single approach.

[22] http://www.parrettcatchment.info/introduction/
[23] From http://www.jaf.nu/nieuw/eng/home/index.html

6.4.2 Polder creation: Altenheim Polders, Germany



The Rhine Action Plan on Flood Defence endorsed in 1998, empowered by the Rhine Protection Commission advocated the removal of human interferences with the river regime as far as possible, the main principles of the Convention were:

1. All future channel engineering projects must take cognizance of the impacts on the entire river basin;
2. A cessation, and in some cases reversal, of land reclamation along the Rhine: wherever possible agricultural land were to be returned to floodplain - where land had been permanently lost to urbanization and industry, polders for flood storage were to be created.;

Fig. 6: Altenheim Polders (from Morris et al., 2004)

3. All superfluous dams and overly high banks were to be removed to allow the river to expand, channels redesigned to allow more natural overspilling.

The Rhine Action Plan is being implemented in phases, with a timescale operating between 1995 and 2020. The high level of development along the Rhine places limits on what can be achieved, but within the entire Rhine Basin, the plan currently forsees (1) the restoration of 1000 km^2 of former floodplain and 11,000 km of feeder streams, (2) creation of polders with a total storage capacity of 364 million m^3 on the Rhine and 73 million m^3 on the tributaries – these will function as the main flood protection mechanisms (Cioc, 2002). Table 3 describes an example of polder creation on the Rhine at Altenheim.

6.4.3 Wetland storage: Whangamarino wetland, New Zealand

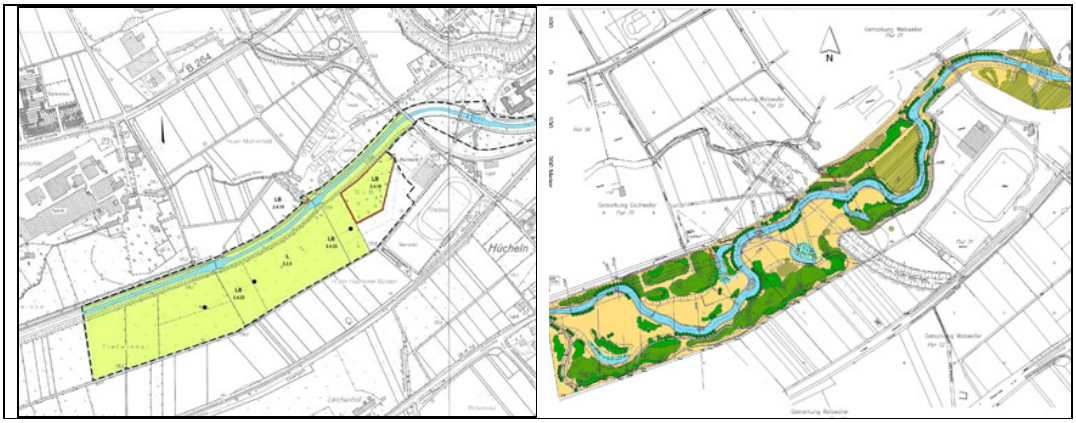
The Waikato-Waipa flood control scheme managed by the regional council (Environment Waikato) imitates the natural water storage functions of Lake Waikare and Whangamarino Wetland, but in a controlled way. Details of the method and storage capacity are shown in Table 3. A study showed that during a 100-year event in 1998, peak flow on the Waikato River was 1565 m^3/s, of which 200 m^3/s flowed into the wetland complex. This meant that flooding of an extra 7300ha was avoided, representing damages savings of NZ$3.8 million ($1998).



Fig.7: Whangamarino wetland complex – storing excess river flows as part of the Lower Waikato-Waipa flood control scheme.

6.4.4 Floodplain and river restoration: Eschweiler, Germany

Floodplain storage on the River Inde was created upstream of the town of Eschweiler, northern Germany to help manage downstream flood risk. The Inde, a tributary of the River Rur, had historically been straightened with narrowing of the channel and floodplain. Modern water management in Germany requires more space for water, to allow rivers to meander and overflow within safe limits. Giving more space to rivers is the aim of the Riparia project undertaken by the District Water Board, enabling for the increase of storage capacity of the Rur and tributaries in parts of the catchment basin. A 1.5km dike was removed from the river bank and moved further inland; meanders were excavated and the surrounding floodplain was lowered to create a larger storage capacity than three dams that were previously used for flood control. This project also received funding from JAF and provides a very good demonstration of a reasonably small scale river and floodplain restoration with direct benefit for the urban area in close proximity downstream. Fig. 8 shows plans and images of the situation before and after completion of the project. The photograph on the right illustrates the site as the river flowed back into the newly created channel, with a broad profile, low banks and wide floodplain.







BEFORE	AFTER

Fig. 8: Floodplain storage and restoration of meanders on the Inde River, upstream of, Eschweiler, Germany (images from the JAF website[24])

6.4.5 Coastal Realignment: Hesketh Out Marshes, UK.

The site is located on the south bank of the Ribble Estuary, Lancashire. The marshes had been reclaimed for 30 years by the time managed coastal realignment began. The dual driving forces behind the project, undertaken by the UK Environment Agency (EA), were to (1) increase flood storage potential and defence standard, and (2) restore salt marsh habitat for wildlife. Breaching was completed for the first part of the project in 2009. 15km of creeks were excavated (widths ranging from 17 to 2m), essentially reinstating historic creek system (most of which had been destroyed due to arable works); 11 saline lagoons were created and field boundary ditches were infilled.

Partnership between agencies (including the Environment Agency, Natural England and RSPB) made the scheme possible. Funding sources included the EA's flood risk management budget, and a contribution by Lancaster City Council – the latter to compensate for damage to another SPA in the region caused by defence works. Land purchase costs were higher than originally expected which was a problem on the scheme. Also, whilst the public were generally supportive of the project, concerns were raised about land drainage which the EA responded to by undertaking additional work to the land drainage system (a series of constructed upstream pools) (ABPmer web database[25]). Tides first inundated the entire site in March/April 2009 and, beneficially, the observed tidal inundation exceeded modelling predictions. It covers a total of 180ha comprised of 40ha mudflat, c.110ha saltmarsh, 7ha saline lagoons and 23ha transitional and floodbank habitat. Figure 9 illustrates the scheme.

[24] http://www.jaf.nu/nieuw/eng/home/index.html
[25] http://www.abpmer.net/omreg/easycontrols/database/details1.asp?ID=93&lstType=Managed%20breach

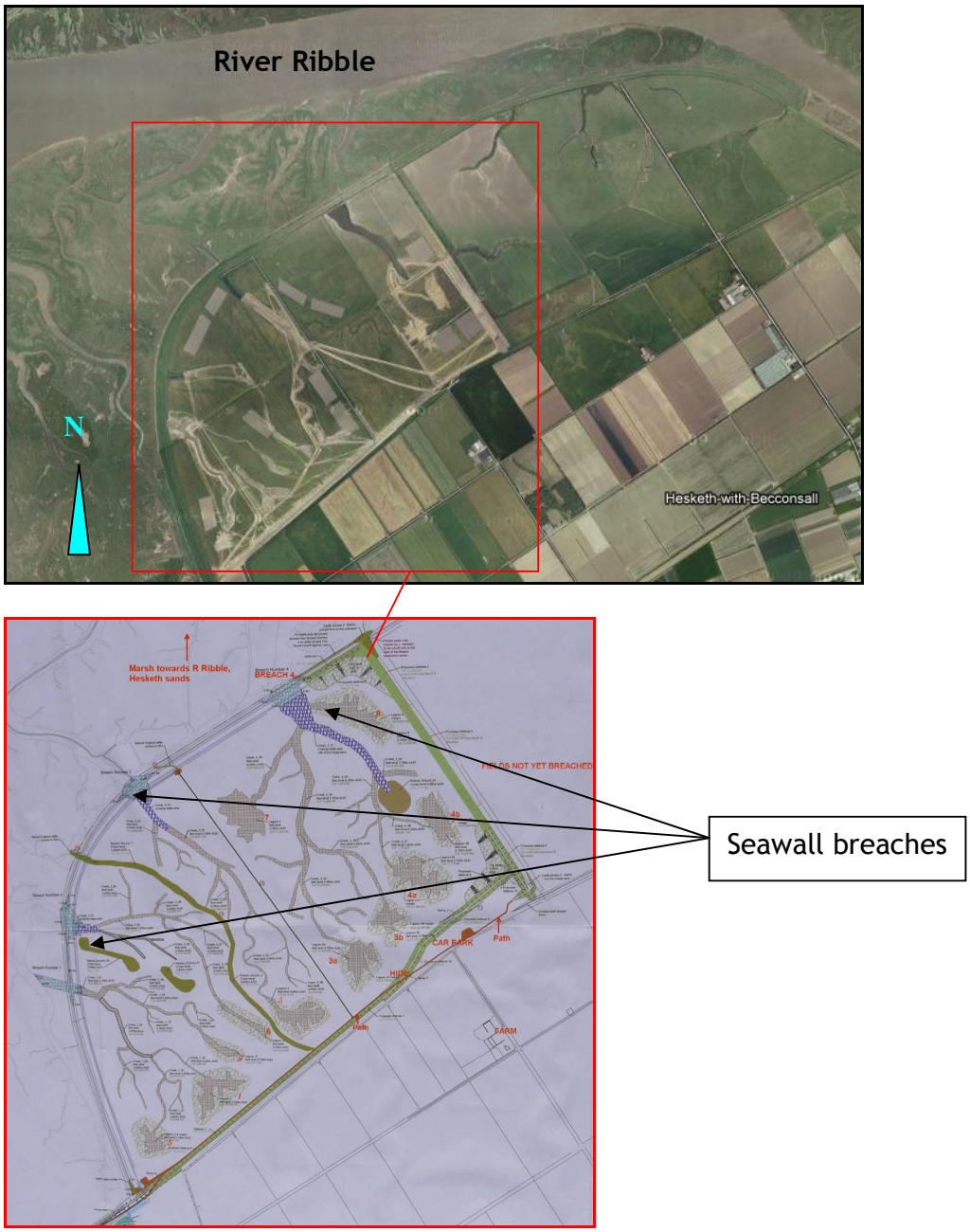


Fig. 9: Aerial map of the Ribble Estuary with a plan of the nature reserve created at Hesketh Out Marshes through managed realignment. Further fields to the east are planned for restoration (lower image from the RSPB Liverpool[26])

6.4.6 Washland creation: Long Eau, Lincolnshire, UK

The Long Eau, typical of many rivers with engineered flood defence banks for agricultural improvement, had little connection between river and floodplain. In the mid 1990s embankments were set-back along a section of the Long Eau at Manby (Lincolnshire) at a cost of £60,000 (in 1995), opening up the area for seasonal flooding to help alleviate downstream flooding. The National Rivers Authority (lead agency at the time) funded the setback out of an environmental conservation budget designed to

[26] http://www.rspbliverpool.org.uk/RSPB%20Hesketh%20Out%20Marsh.htm

promote biodiversity aspects of flood defence and river management works. A further £2,000 of capital funding for flood defence was used to undertake engineering works. Stewardship funding provides annual compensation to the farmer, which was essential to the implementation of the project. The resulting floodplain 'washland' had a storage capacity of 18,500m^3 offering flood defence benefits to downstream houses. The site has natural inflow and outflow with very limited control, flooding when river levels exceed a breach point in the low banks on the river (Morris *et al*., 2004). The site has developed a mosaic of marsh and grassland habitat attracting a variety of birdlife and improving biodiversity in the area. These gains are not as significant as they could be if the site had managed inflow/outflow as the site is naturally only flooded for an average annual period of 3 days to 2 weeks. In isolation, the flood mitigation benefits were deemed to be modest, because of the small storage capacity gained and limited control, but Morris *et al*. (2004) noted that if applied throughout a catchment this type of set back scheme may have considerable aggregate effects that are positive for flood management. This example was included since it may represent an achievable option in an Irish context given that many lowland rivers have similarly altered hydromorphology.

6.4.7 NFM demonstration project: Holnicote, UK

The Holnicote Estate, near Porlock, North Somerset, UK is managed by the National Trust and comprises approximately 5,000 hectares of land, from the uplands of Exmoor to the sea. In a joint initiative with the Environment Agency, they are undertaking a 3 year project whereby catchment wide changes to rural land management will be facilitated to reduce flood risk whilst also providing additional benefits (e.g., environmental, recreational, heritage and landscape). The project involves both monitoring and modelling elements (Steve Rose, pers. comm.). Focus will be on controlling headwater drainage, creating new woodlands, slowing down water flows through steep valleys and retaining water on lowland flood meadows. The project is being monitored (2009-2013) in terms of ecology, hydrology and water quality (JBA Consulting, Fact Sheet[27]). No further information is currently available but the outcomes from this project should be watched as they may add considerable empirical evidence to the body of information in relation to sustainable catchment-based flood management.

6.5 Irish examples

Corkagh Park flood attenuation ponds appear, other than some SuDS facilities, to be the only example of the utilisation of wetlands for flood attenuation in Ireland.

Upstream storage options were investigated during design and feasibility investigations for large-scale OPW flood relief schemes (OPW 2003 a, b, c, d; OPW 2005a, b). Schemes include: Ennis (River Fergus), Mallow (Munster Blackwater River), Fermoy (Munster Blackwater River), Templemore (River Mall) and Clonmel. Table 5, Section 7, summarises these options, detailing feasibility outcomes for the schemes. All schemes used standard protection levels of 1 in 100 year design-flow (1% AEP[28]). The options for upstream storage in the OPW schemes reviewed included:

[27] http://www.jbaconsulting.co.uk/Holnicote_Estate
[28] AEP = Annual Exceedance Probability

1. Creation of on-line dams/reservoirs with a managed storage-outflow relationship (e.g., Templemore, Ennis, Mallow);
2. Management and enhancement of off-line floodplain washlands to increase storage (e.g., Mallow);
3. Lowering of downstream floodplain to create extra capacity (e.g., Mallow);
4. Increasing storage capacity of downstream floodplain or washlands (e.g., Ennis)

None of these options reached the final design phase primarily on cost-effectiveness grounds (see Section 7.4.4). Studies of options did place emphasis on the positive attenuation role of floodplain washlands, but land acquisition costs were the primary deterrent. Woodland planting in the catchment headwaters was suggested as positive for flood attenuation, but under the caveat that benefits of increased evapotranspiration[29] and interception of rainfall reduce significantly as magnitude of rainfall increases and for events greater than mean annual, afforestation has little effect (OPW, 2003b).

In line with international best practice and in order to meet the requirements of the EU Floods Directive[30], Catchment Flood Risk Assessment and Management Studies(CFRAMS) are presently being conducted in Ireland. This new direction in national policy requires the development of Catchment Flood Risk Management Plans (CFRMP). The Draft Lee CFRMP was published in 2010, and whilst floodplain storage or wetland creation is not mentioned, the option of optimising the storage potential of Iniscarra and Carrigdrohid Resevoirs is proposed, so long as there would be no significant impacts on habitats and species of the Gearagh cSAC and SPA. The Dodder CFRAMS has proposed two large retention ponds at quarries at Firhouse / Tallaght as a climate change adaptation option. Fingal East Meath's Draft FRMP sets objectives for wetland and riparian habitats as a result of flood relief measures with the minimum requirement that there be "*No net loss of or permanent damage to existing riverine, riparian, estuarine, wetland and coastal habitats as a result of flood risk management measures*", and the aspiration that there be an "*Increase in extent of riverine, riparian, estuarine, wetland and coastal habitats as a result of flood risk management measures*." (FEM FRAMS, 2011). It does not outline how this might be achieved.

Increased water storage within Lough Allen and Lough Ree has been suggested since 1956 to help solve the problem of flooding in the Shannon. A 2003 report investigating the control of water levels in the Shannon in response to recurring flooding found that management of water storage at Lough Allen and Lough Ree would not help alleviate flooding on the Shannon to any significant degree (SRBMP, 2003). It was shown that the Shannon system has experienced a history of severe flooding incidents over the past 200 years, owing to the natural characteristics of the system especially the floodplain in the low gradients from downstream of Lough Allen to Parteen Weir. Photographs included in the report illustrate the nature of flooding in the Shannon as it spreads out over the floodplain and show that this is a natural phenomenon that brings to mind the concepts of 'Making Space for Water and 'Room for Rivers' that could be applied in this catchment. Hooijer (1996, cited by Acreman, 2003) calculated that flooding of 3500ha

[29] Evapotranspiration = the sum of evaporation and plant transpiration from land surface to atmosphere.
[30] EU Council Directive 2007/60/EC on the assessment and management of flood risks

of this former natural floodplain in the Shannon valley, to an average depth of 1m would represent a storage equivalent to one day of peak discharge (around 400 m^3/s), representing a significant attenuation potential. The Rydell Report of 1956 on flood management in the Shannon Basin suggested measures should be utilised that work in support of the flood-prone nature of the Shannon rather than against it. These included: reforestation of suitable non-agricultural lands; relocation of farm dwellings and raising of roads in places where benefits might not result from traditional measures. Exploring the potential of maximising development of the fishery, wildlife, recreational and navigation potential of the Shannon, its lakes, channel and tributaries in association with the flood control measures, was advocated (SRBMP, 2003). None of these suggestions were implemented, the reason for which is unknown.

Table 3: International and Irish examples of wetlands used in flood attenuation

Project	Objectives	Wetland Type	Project description, methods and outcomes	Additional benefits	Project Lead/ Reference
Corkagh Park, South County Dublin, Ireland River Carmac	Flood storage and control	Floodplain attenuation ponds	Creation of 5 offline flood attenuation ponds covering 3.54 hectares with a 55,000m3 storage capacity. Inflow controlled by weirs with outflow controlled by pressure valve to regulate discharge.	1. Recreation – one of the attenuation ponds is permanently wetted and supports a 'put and take' fishery. 2. Amenity – Numerous walking paths; coffee shop and timber viewing deck surrounding the ponds. A raised area was created in the park using material excavated for pond creation, from which views of the park and Dublin mountains are gained.	South Dublin County Council Murray (2000)
Beckingham Marshes, UK. River Trent	Flood storage and control	Washland, tidal flood storage resevoir	Site designed to store 2,000,000m^3 of flood water on former floodplain, for protection from events with a 1 in 10 year return period. Utilises embankments, inflow spillways and flapped outfalls to the River Trent, with a pumping station as back-up to control water levels. The water regime is highly controlled to allow for arable farming on the site, but restoration of 488ha to wet grassland is currently underway. This is an example of a highly controlled hydraulic storage scheme where wetland habitat creation was not the primary driver. If the site was managed for wetland habitat it would probably lose some of it's flood defence benefit.	1. Biodiversity – work began in 2010, as a joint RSPB UK and UK EA[31] initiative, to restore 488ha of natural wet grassland habitat to support wading birds, waterfowl, water voles, brown hares, dragonflies and barn owls[32]. Biodiversity aspects are presently secondary to flood defence benefits, but this is a very useful example of where conflicts can arise between large scale flood attenuation role and viable wetland habitat creation.	UK Environment Agency Morris *et al.* (2004)
Southlake Moor, Somerset, UK. River Sowy	Flood storage and control	Washland, floodplain storage	Extensive works to improve inlet and outflow structures and raised banks allowed the contrlloed flooding of the moors during an 8 weeks period of high discharge on the Sowy in the winter of 2009/10 when it stored 600,000m^3 with a maximum water depth in the centre of the moor of 30 – 50cm. Total capacity of the	1. Biodiversity – new flooding regime has provided habitat for winter water birds such as wigeon, teal and lapwing. 2. Socio-economic - a wide range of partners are working together to return wetlands to favourable condition in	Parrett Internal Drainage Board as part of a multi-agency project.

[31] RSPB = Royal Society for the Protection of Birds (UK and Scotland); EA = Environment Agency (UK)
[32] http://news.bbc.co.uk/local/lincolnshire/hi/people_and_places/nature/newsid_8977000/8977590.stm

			moor is 1,200,000m3. The new inlet was used to evacuate flood water back to the river and by early February all fields were drained and ditches were back to their normal winter level. The area is used for summer grazing. The site is one of a number of sites on the Somerset Levels and Moors that are having floodplain potential restored as part of catchment flood management strategy.	conjunction with flood defence goals - this has become a focus for sustainable management at a community level. Farmers co-operate by removing stock overwinter to allow flooding. 3. Amenity - local communities have access to new wildlife area.	Parrett Drainage Board (2010) [33]
Insh Marshes Floodplain, Scotland River Spey	Conservation of natural flood plain with recognized attenuation role	Open water, scrub, basin mire, swamp, tall fen, marsh.	Protected, naturally functioning floodplain adjacent to River Spey. Covers approx. 1000 ha of flat, poorly drained land, which extends approximately 7.5 km in length and up to 1.5km in width. Floods periodically, acting as a natural flood defence system – able to take water levels of 2m over the 1000ha - thus preventing extensive flooding to farms and properties downstream, including the town of Aviemore.	1. Biodiversity – important, largely unspoilt, wetland habitats plus breeding waders, wintering populations of whooper swans and hen harriers and rich diversity of plants and invertebrates. Owned and managed by RSPB Scotland. 2. Recreation and tourism – people attracted to the area for birding, fishing and wildlife interests. 3. Agriculture – managed grazing of wet meadows helps conserve biodiversity values.	N/A Rose *et al*. (2005)
Meddat, Nigg Bay, Cromarty Firth, Highland Region, Scotland	Managed retreat of reclaimed salt marsh	Coastal grassland/ mudflat/ sand flat/ saltmarsh	Two 20m wide breaches were made in existing sea walls to allow the tide to flood a 25ha field. The area had been reclaimed from Nigg Bay in the 1950s and was constantly in need of maintenance to keep the sea at bay. Approx. 2/3 of the field now floods at spring high tides. The site required some preparation to return it to coastal salt marsh, including culvert blocking, topping and grazing of terrestrial vegetation and tree removal.	1. Biodiversity – by 2005 the site had developed 3 zones (i) upper zone of terrestrial grasses, (ii) intermaediate zone of salt marsh species; (iii) lower zone, often inundated, where fine sediments have replaced terrestrial grasses. The RSPB recorded 19 species of wader and wildfowl during winter 04/05 (RSPB, 2005, cited Rose *et al*., 2005). 2. Education – the project has high value in informing.	RSPB Edinburgh SNIFFER (2010)
Skinflats Tidal Exchange Project, Firth of Forth;	Managed retreat of reclaimed salt marsh	Semi-improved pasture reverting to salt marsh and tidal	Involved 14ha of RSPB Scotland's land on Skinflats Reserve. 1m diameter pipe was installed through the sea wall leading to an internal weir; excavation of a creek network and 2 lagoons; creation of 2 shingle	1. Biodiversity: owned and managed by RSPB Scotland who will monitor changes in vegetation and birdlife for 5 years from 2009 onwards.	RSPB Scotland SNIFFER (2010)

[33] http://www.somersetdrainageboards.gov.uk/Southlake_FC_IDB_newsletter_2_Autumn_2010.pdf

Grangemouth, Scotland		flats.	topped islands. Difficulties were reported (SNIFFER, 2010) with a pipe joint breaking leading to erosion and sedimentation of the drainage creek, to be remedied by installation of a sluice structure instead.	2. Demonstration site: the aim is to demonstrate the potential of a flood management scheme, whereby former saltmarsh can be reinstated to accommodate floods, thus protecting more developed areas and improving wildlife habitat. 3. Amenity: planned walkway and birdwatching hide to allow close up views of birdlife[34].	
Lower Waikato – Waipa Control Scheme Whangamarino Swamp, New Zealand	Flood storage and control	Peat bog, mineralised and semi-mineralised swamplands	Lake Waikare- Whangmarino natural wetland complex is utilized by the regional council to store floodwaters from the lower Waikato River. During high river flows water enters Lake Waikare over a spillway, then artificial canals then connect the lake to the wetland where flood gates at the lower end close and store water until flood peak has passed on the river. The wetlands' storage capacity is 94.8 million m^3, enough to reduce the flood peak on the Waikato by 40-60cm and protect significant downstream flooding of lands. The water levels can be managed at levels to facilitate habitat requirements of wading birds (shallower areas) as well as other open water species.	1. Biodiversity: 5690ha of wetland habitat is protected at Whangamarino, important for it's diversity of native wetland birds, fish and plants. 2. Recreation /harvesting: Commercial and recreational fishing for eels and other fish species. 3. Socio –economic: Flood storage function of the wetland saves millions in reduced flood damages. The cost of replacing the flood control service provided by the wetland would be many millions of dollars. 4. Amenity: walkway has created outdoor amenity in close proximity to a major city.	Environment Waikato DoC (2007)
Altenheim Polders (Germany) River Rhine	Flood storage and control	Polder	Creation of 520 ha of washland in 2 polders adjacent to the Rhine, resulting in a storage capacity of 17.5 million m^3. Land use on washlands is 50% wooded; 35% gravel pits and small waterbodies; 15% arable (maize / tobacco). Polders fill through inlet structures in the embankment when discharge on Rhine exceeds 3800 m^3/s. Controlled outflow structures limit discharge.	1. Biodiversity: 'Ecological flooding' – controlled flooding of the site to encourage biodiversity – has resulted in measurable rehabilitation of the floodplain ecosystems, e.g., increase in plant and animal species tolerant to periodic inundation.	Project lead unknown Morris *et al.* (2004)

[34] http://www.wildlifeextra.com/go/news/skinflats-mudflats.html#cr

Harberton Flood Alleviation Scheme River Harbourne, UK	Floodplain storage	Floodplain washlands	Establishment of a 4.1ha flood storage area with a capacity of 150,000 m^3, 1km upstream of the village of Harbertonford where flooding had occurred on average 1 in 3 years, and on 6 occasions between 1998 and 2000. Clay core earth dam, with sluice gates to allow normal flows outside of flooding. This closes once flows exceed a 1 in 10 year event. This causes excess water to spread out over the washlands behind the dam creating flood storage. The dam has a 1 in 40 year design standard after which water overtops and flows safely into the channel below. The river bed downstream of the dam was raised, with riffle-pool sequences created to increase sediment transfer, reducing the need to dredge silt.	1. Biodiversity: washlands have become a mix of wet grassland and planted woodland biodiversity value. Site contributes to UK BAP targets. Children from a local school have monitored the process as part of nature studies. 2. Socio-economic - awareness of wetlands encouraged by local school involvement in planting and learning about flood risk. At a capital cost of £2.5m, including land purchase and river works downstream of the storage area, the scheme was justified in terms of flood defence benefits.	Environment Agency, UK Morris *et al*. (2004)
Łacha River, Poland	Flood alleviation through Increased retention capacity in the Łacha Valley, plus restoration of wet meadows.	Wet meadow, constructed retention ponds.	Following pond construction and wet meadow restoration, the increases in floodwater retention capacities of two restored areas were estimated as 102,000 m3 and 43 000 m^3. During a spring flood in 2001 the measures significantly reduced the d/s flood peak. Project supervision and co-ordination was financed by the EcoFund Foundation (Poland) and the Whitley Awards Foundation (UK), Land purchase was subsidized.	1. Biodiversity – marked increased in diversity of amphibians and wetland plants recorded following flood retention works. 2. Socio-economic - Biodigestion unit built at local school to run on hay cut from the wet meadows.	Polish Society of Wildlife Friends ECOFLOOD (2006)
Upper Drava River, Austria	Improve flood protection function and restore and improve habitats for riparian species.	Floodplain restoration	Restoration of 7 km of river channel over a 57km stretch resulted in an estimated increase in water retention capacity of the floodplain of 10 million m^3 over an area of 200 ha, which when modelled was shown to slow the flood wave by more than one hour. Methods used were - widening the main channel and reconnecting the side channels and other storage areas. The ability of the natural landscape to mitigate flood events was to be further enhanced by the restoration of floodplain forests in the same reaches. The project (€6.3million) was financed mainly by the Federal Ministry for Agriculture and Forestry (51%) and EU LIFE funds (26%).	1. Biodiversity - Alpine and floodplain habitats were re- created, including over 50 ha of islands, gravel banks and steep banks. These habitats support rare fish species such as the Danube Salmon (*Hucho hucho*) and Gray-ling (*Thymallus thymallus*), plus numerous birds and other species. 2. Morphology - The riverbed stopped eroding, and in some locations deposition has occurred.	Water Management Authority of Carinthia plus others. ECOFLOOD (2006)

Orda River, Poland	Decrease flood risk by preserving and restoring floodplain habitats and their biodiversity.	Floodplain and wet woodland	Removal of the existing embankments away from the river, allowing floodwaters to inundate floodplain areas - creating a natural floodwater retention area of 670 ha. Gravity fed flooding and draining is possible due to topography. The new embankment will be lower than the existing one - built on the river terrace, which further reduces flood risk. More detailed hydrological predictions were in preparation but could not be sourced. Initiated by WWF-Poland and implemented with funding from the 'Green Action Fund' (a local NGO), state bodies and NGOs.	Biodiversity – restoration and conservation of important floodplain forest and meadow ecosystems along river. The size and quality of floodplain forests makes them some of the best examples of the type in Europe.	WWF-Poland ECOFLOOD (2006)

7. Cost effectiveness

7.1 Overview

This section outlines, briefly, concepts and methods of economic valuation of wetlands in relation to flood attenuation services. Examples are also presented to examine the cost effectiveness of a number of projects that have been undertaken internationally.

It must be said at the outset that evidence tends to show that a number of factors additional to flood alleviation benefits of wetlands appear to have considerable bearing on whether a particular project is implemented:

1. Provision of ecosystem services additional to flood control, e.g., habitat creation, biodiversity, recreation, amenity.
2. Policy drivers, e.g., in the UK and Netherlands: 'making space for water' and 'room for rivers'; fulfillment of EU and national biodiversity targets under the Habitats Directive and Biodiversity Action Plans (BAPs).
3. Access to funding sources and mechanisms other than capital expenditure specific to flood defence, i.e., for community engagement processes; purchase or land tenure agreements; project management and monitoring.
4. Inclusion of cost-benefit estimation that encompasses long term climate change considerations (over 50 to 100 years), such as sea level rise and increased flood frequency and severity.

The issue of additional funding is raised here as it is particularly important for cost effectiveness, since independent funding (other than capital expenditure for flood defence) subsidises the cost of NFM solutions. At this stage it is questionable whether, in the absence of additional funding, NFM projects such as those outlined in this report would reach implementation. Biodiversity funding has been a common theme of NFM strategy (Morris *et al*. 2004, Rose *et al*., 2005, ECOFLOOD, 2005), whilst funding towards an initial and ongoing community engagement process has also been central to a number of partnership projects (Forum for the Future, 2005; EA, 2009). In some cases NFM sites have been purchased and subsequently managed by the RSPB as nature reserves. The need for additional funding may become less important when much longer term cost-benefit analyses become the norm under a climate change adaptation scenarios, i.e., NFM may be less cost-effective for a 20 year future, but the most cost-effective solution over a 50 or 100 year future when climate change is taken into account (e.g., Schultz & Leitch, 2001; Forum for the Future, 2005, EA, 2009). The costs of the community engagement process may also decrease as positive public perception of these types of projects grows and NFM solutions become an accepted component of flood risk management activity. Private ownership of land, costs and difficulties involved in land acquisition, and attitudes to land use changes are a few of the problems that can place constraints on the implementation of such schemes. Experience has shown that the costs of engineering works for traditional defences are likely to be minor

compared to land purchase costs (Halcrow, 2008). In addition to land costs, initial and ongoing funding is important to support the critical process of ensuring public awareness and acceptance which can involve issues arising from; (1) land use and land management change; (2) alteration of perceptions towards flood defence and safety issues; (3) education about habitat creation and biodiversity goals, (4) managing, monitoring and maintaining NFM sites. It is often political and socio-economic conditions (e.g., property; status of the area; community attitude; political decision-making) that play a key role in the successful implementation of NFM projects, as opposed to the primary benefits of the scheme (Morris *et al*. 2004, Forum for the Future, 2005, Broadhead & Jones, 2010). Examples of how additional funding has contributed to implementation of NFM schemes are:

(1) The Parrett Catchment Project (PCP) in Somerset was set up in 2000 in response to widespread local concern about regular flooding. The project developed as a partnership to examine long term sustainable solutions to flood management (a 50 year Action Strategy) involving both land and water management at a catchment scale. The initial vision and strategy were made possible by funding from an EU-LIFE environment initiative - the "Wise Use of Flood Plains" (Forum for the Future, 2005), with further financial input since gained from the 'Wetlands Vision'[35], a partnership between the RSPB, the Wildlife Trusts, English Heritage, the Environment Agency and Natural England. The Wetland Vision seeks to improve the quality, distribution and functionality of the UK's wetlands. Their contribution to the PCP match-funded a further £650,000 grant from JAF. These funds have been used to support the project in aspects such as: community engagement; creating flood storage and retention areas; wetland creation; riparian woodland planting; developing SuDS facilities in urban areas; maintaining traditional drainage and introducing new techniques such as JAF's 'farming water'.

(2) Following a UK EA decision to withdraw maintenance of flood defences due to economic constraints at the Cuckmere Estuary, East Sussex (Section 7.4.2) a partnership was formed by local councils, landowners, heritage and conservation agencies to investigate future options for the Estuary. The group was awarded almost £250,000 through DEFRA's[36] coastal change adaptation pathfinder, which has enabled a full community engagement process so that the public, in association with the Partnership, can reach a consensus on alternative strategies. The preferred option at Cuckmere is for a managed coastal retreat to re-create the former estuarine floodplain and salt marsh to achieve flood relief, biodiversity and recreational benefits in the area.

(3) The Regional Habitat Creation Programme in the UK funded by DEFRA, provides financial assistance to coastal projects that establish compensatory habitat to offset losses incurred by engineered 'hard' flood defence works elsewhere. The funds have been used to create coastal wetlands for flood management in cases where newly

[35] www.wetlandvision.org.uk.
[36] DEFRA = Department for Environment, Food and Rural Affairs, UK.

formed habitat contributes to UK Biodiversity Action Plan (BAP) targets (DEFRA, 2005). The Royal Society for the Protection of Birds (RSPB) in both England and Scotland are also a source of additional funding for NFM projects, specifically, those that result in recreating or protecting wetlands that are good bird habitat. Hesketh Out Marsh (section 6.4.5), was purchased by the RSPB in 2006 as a nature reserve. They received further funding from Biffaward and Natural England that has enabled them to monitor changes; provide visitor facilities, and manage stock to sustainably graze the marshes.[37] Biodiversity funding in particular alters the cost-benefit ratio of a project not only by subsidising costs, but by increasing perceived benefits in recognition of additional ecosystem services provided.

(4) Paris is highly vulnerable to severe flooding which has led to a planned scheme to create a controlled polder area of some 2,500 ha on the Seine River at la Bassée**,** about 70 km upstream of the city. The primary driver for the project is the reduction of annual damages from flooding (estimated as £29 million in 2003). Though it is a large and complex project, local opposition has been minimised by enmeshing the flood defence measures in a broader programme of regional economic development to promote benefits for the affected region. The need for a mechanism of inter-regional compensation for the affected region by the downstream beneficiaries was critical to the success of the idea. This is a very interesting example for Ireland because flood risk management at river basin level will require inter-regional co-operation. The French National Action Plan on Wetlands, which has a wider ecosystem services approach (e.g., biodiversity and habitat), has also been a major driver behind this project (FLOBAR2, 2003). The detailed design study (2009-2012) is preparing for the project implementation, with goals for a flexible land use future in the water storage area, including gravel extraction, agriculture, tourism, leisure activities, and ecological zones[38].

7.2 Estimating economic value of wetlands in a flood attenuation role

The Millenium Ecosystem Assessment (MA, 2005) states that "*wetlands provide numerous ecosystem services that have the potential for significant cost avoidance through the use of natural ecological capital to freely perform functions that are costly for humans to recreate*." This concept of ecosystem services has gained considerable international and national interest over recent years (e.g., MA, 2005, TEEB, 2010, Bullock et.al., 2008; Comhar, 2009). Ecosystem services are the benefits that people derive from functioning ecosystems; that is, actual and perceived value that flows from natural capital (TEEB, 2010). The Millennium Ecosystem Assessment (MEA), in a global review of ecosystem services defined four different categories: provisioning services (e.g. food, fibre, water), regulating services (e.g., pollination, climate regulation, flood protection), cultural services (e.g., aesthetics, recreation) and supporting services (e.g.,

[37] http://www.rspb.org.uk/reserves/guide/h/heskethoutmarsh/about.aspx
[38] http://www.alfa-project.eu/en/regional/seine/

photosynthesis) (MA, 2005). From an economic perspective they can be thought of as the 'dividend' that human society receives from natural capital (TEEB, 2010). The economic importance of ecosystems has gained ground because of an increased focus on how we can preserve natural capital to allow ongoing provision of essential services and benefits. This is especially true in the face of climate change predictions. In terms of flood attenuation, cost benefit calculations need to take account of an array of ecosystem services that might accrue from use of wetlands in this role.

Estimating the economic value of flood control services provided by wetlands has often been based on calculating the construction and ongoing maintenance costs of the engineered structures that would need to be built in the absence of the wetland. For example, the value of conserving wetlands for flood protection in the city of Vientiane (Lao PDR) has been estimated at just under US$ 5 million, based on the value of flood damages avoided (TEEB, 2010). An assessment of the economic benefits of the 1,150 - hectare Insh Marshes Ramsar Site in Scotland (UK) found that the capital costs of building replacement flood defences would be several million pounds (Ramsar[39]). Most flood relief scheme feasibility studies are based on such market value assessments, but these generally do not to take account the potential of provision of other beneficial ecosystem services.

The ecosystem services approach is based on the non-market[40] economic significance of the wetland. Value is estimated using complex models, but generally involves calculating the 'replacement cost' required if particular services are lost (per head of population dependant upon those services). The approach was taken to assess the economic value of some of Co. Monaghan's wetland resources (eftec, 2010), taking into account service provision such as flood control, water quality and quantity, recreation, aesthetics, biodiversity and carbon sequestration. The study involved a review of many methods of calculating the non-market value of wetlands (35 studies) in order to select a suitable model to represent the value per hectare of lost service provisions at the Monaghan wetland sites[41]. In summary, Table 4 shows the study results for the wetland habitat types. Note that the value of the flood control function is included within each of these figures, but due to the complexity of the model it was not possible to determine the relative proportion. Also these figures are not shown on a per hectare basis, so the larger sites like the Eshbrack bogs have a higher value. Given that most of the value generated by the wetlands are outside the market, these figures form the basis of more sustainable cost-benefit analysis when considering relative costs and benefits of development versus conservation (eftec, 2010). It's important to note that the study has been criticised since it is not possible to transfer the methodology between wetland types or in different geographic areas. The figures are, thus, indicative

[39] Wetland Ecosystem Services - Factsheet 1: Flood Control. Available at http://www.ramsar.org/pdf/info/services_01_e.pdf (January, 2011)
[40] Refers to uses and services supported by environmental resources that are not traded in markets and are consequently 'un-priced'.
[41] The model is too complex to show in any detail here and there are many important caveats that apply within both calculations and interpretations.

in relation to one another only, since the model was devised using data from different geographic areas and wetland types which is not technically robust.

Table 4: Economic value of Monaghan wetlands (from eftec, 2010)

Study site	Average value of site loss in € per year (2008)
Blackwater Flood Plain	16,000
Dromore Wetlands	31,700
Eshbrack bogs	135,500*
Cornaglare	2,170
Grove Lough	453
Castle Leslie constructed wetlands	2,286

A 2008 report on the economic and social aspects of biodiversity in Ireland examined the value of biodiversity as an ecosystem service within a number of sectors (Bullock et. al., 2008). Benefits of biodiversity were set against costs of failing to protect it, but given the range of topics covered, the study did not present full cost benefit analyses. Wetlands and peatlands in particular were recognised as acting as a buffer against flooding and as carbon sinks. The marginal annual value of the status quo on flood mitigation by wetlands is stated as being €20 million per year with a caveat that this is likely to increase 'steeply with climate change' (p.179). No detail was given as to how the figure was arrived at, and without any empirical evidence of flood mitigation by wetlands.

A more recent concept of "Green Infrastructure" builds on the ecosystem services approach by recognising that "*the protection and enhancement of ecosystem goods and services, should be viewed as critical infrastructure, in the same way as transport and energy networks and as vital to sustainable development*". Comhar (2010) explored the application of a green infrastructure approach in Ireland noting that floodplains, coastal areas and wetlands, amongst the many other benefits they provide, have a role to play in flood attenuation and therefore carry an economic value though they did not back this up with empirical evidence. In relation to how Green Infrastructure relates to North East Dublin city, Comhar suggested that "*watercourses and marginal land around the coast are important for flood protection and will become increasingly important to mitigate for sea level rise caused by climate change. All unbuilt land including farmland, parks and gardens provide for flood attenuation*". The green concept may underpin future policy direction given that best practice as a basis for an EU strategy is being investigated.

The 'ecosystem services' and 'green infrastructure' approach to establishing the economic feasibility of proposed NFM projects should receive more focus in Ireland.

7.3 Agricultural subsidies

Given the high degree of out of bank flow that characterises Irish rivers and the large proportion of lowland floodplain area under agricultural use, the impact of agricultural subsidies on NFM strategy is an important factor. Landowners are currently subsidised for land management which has led to intensification through, for example, Common Agricultural Policy (CAP) payments and OPW funded drainage maintenance. In 2009, the highest CAP single farm payment was €432,564[42]. The question must be asked whether, in order to promote flood reduction benefits through, for example, floodplain attenuation, de-intensification could be subsidised instead. Current CAP reform is discussed in this context in Part II, Section 8.1. Importantly, this would not mean an end to agriculture on lands in strategic locations, but would require a reversion to less intensive practises, which would have existed historically that allowed for periodic flooding of land (e.g., low stock density, cutting of wet meadows, limited or no drainage). CAP payments, for instance, could be made based on provision of flood alleviation services, with any efforts to incorporate other benefits such as habitat creation and woodland planting (to increase attenuation effects) rewarded financially. This needs to be aligned with national agri-environment schemes which can incentivise the use of wetlands, especially floodplains, for flood alleviation benefits, in the same way that, for example, stewardship funding operates in the UK for such purposes. This is an aspect that requires further detailed investigation as it is unlikely, in the absence of agri-environmental schemes or cross compliance linkages to CAP payments, that land management will change in a way that encourages the use of wetlands for flood alleviation.

7.4 Cost benefit case studies

The idea that wetlands can provide cost-effective solutions to flood management pervades conceptual literature, but it is difficult to find detailed evidence to support this. Four international examples are provided, for which some degree of the project's cost-benefit analysis detail could be found. There was evidence that schemes do show cost-effectiveness, but there is also evidence to the contrary. Evidence is confounded by a lack of detail in how costs and benefits are accounted for and whether these take a wider ecosystem services approach. Arguments in support of NFM schemes utilising wetlands draw strongly on the financial benefits in terms of reductions in the cost of downstream flood damages, however, the cost of implementing such schemes has not been found to be fully reported. Whilst capital costs of engineering works; maintenance and so on are often reported, it is unclear if, and how, the cost of aspects such as a community engagement process, land purchase, and ongoing management for biodiversity goals are included. As already discussed above, many of these projects may not be feasible under traditional cost-benefit scenarios, and would not have reached implementation without some form of additional funding. Where possible the examples

[42] http://irishfarming.ie/2009/05/06/top-earners-from-cap-payments/

in Table 3 showed how the projects were implemented due to funding from, for example, WWF, EU LIFE funds, EcoFund Foundation (Poland) and Green Action Fund' (Polish NGO) (ECOFLOOD, 2006).

7.4.1 Maple River Watershed, Red River Valley, North Dakota, USA

A dedicated feasibility study within the Maple River Watershed in the Red River Valley, North Dakota, USA (Schultz & Leitch, 2001) found that wetland restoration for the purpose of flood attenuation was not economically viable based on cost-benefit calculations for 20-year futures. Natural depression wetlands had been extensively drained throughout the catchment for agriculture. The study simulated potential reduction in peak flooding associated with a number of wetland restoration scenarios, namely: partial restoration by plugging existing drains, partial restoration using drain plugging with outlet control devices, and complete restoration intended to provide a full range of wetland-based ecosystem services. The available wetland storage capacity was modelled as 1 acre foot per surface acre (afpsa) for simple restoration and 2 afpsa with outlet devices. Benefits were calculated as downstream flood damage reductions based on peak flow dynamics, whilst costs were accounted for by capital expenditure for restoration work. The further inclusion of non-flood related wetland benefits (e.g., sedimentation; recreation) did not make any of the wetland restoration scenarios economically feasible. It was found that the use of public funds could not be justified for extensive wetland restoration projects throughout the Maple River Watershed or the Red River Valley in order to reduce flood damage, but did add that these implications were limited to the local geographic area. They also found that this does not negate the potential feasibility of wetland restoration for flood control and/or the generation of other wetland-based environmental goods and services on a more limited and site-specific basis. This could apply in cases where simple restoration on low cost land can provide two or more additional feet of available storage capacity, have clear impacts on localized flood damage, and provide the additional (non-flood related) benefits.

7.4.2 Cuckmere River mouth, East Sussex, UK

Cost effectiveness has prompted a decision by the UK EA to withdraw maintenance of flood defences at the mouth of the Cuckmere River, East Sussex, UK. The river, including the stretches that were once estuarine has been highly managed in the past, with evidence that embankment of the Cuckmere River began in the 1300s. The river was straightened in the 1840s. Natural fluvial processes are interrupted by the existing inland and coastal flood defences meaning that shingle has to be dredged from the river mouth twice a year to prevent the mouth from blocking up, at a cost to the UK EA of £30,000 - £50,000 pa. In the face of predicted sea level rise over the next 100 years it would cost £18m to continue with the current coastal flood defence strategy. This was deemed no longer to be a viable approach since no homes were at risk of flooding. Maintenance will be withdrawn in April 2011, meaning that flood defences will eventually fail with the preferred option being that the area will revert to estuarine

floodplain and salt marsh (EA, 2009). Since the decision, the Cuckmere Estuary Partnership, a coalition of local councils, heritage and conservation agencies[43], formed and is developing a long-term management plan for the estuary to reflect the views of local residents and businesses. The Partnership currently favours working with natural processes, i.e., managed realignment, to restore to the estuary. A number of approaches to the future of the site are still under investigation[44], with a final decision expected in April, 2011. Importantly, funding from DEFRA's coastal change adaptation pathfinder DEFRA (c. £250,000) has facilitated the Partnership in community engagement, as well as looking at how to support the local economy through any change to the landscape.

In relation to both the Cuckmere and Medmerry (below) projects, at present there exists considerable uncertainty regarding benefits and costs of managed realignment particularly concerning salt marsh vegetation and invertebrate colonization, ecologists having found that succession in re-created salt marsh can be slow (e.g., Hemingway *et al*., 2008). In some cases land acquisition costs have been higher than expected. There can also be costly delays in the process because of public consultation and planning complexities that were not envisaged (Halcrow, 2008).

7.4.3 Medmerry Coastal Realignment, West Sussex, UK

The UK EA were granted planning permission in November, 2010 for a large managed realignment scheme at Medmerry (Pagham to East Head Coastal Defence Strategy). It is one of the stretches of coastline most at risk of flooding in southern England. Long term sustainable flood protection and cost effectiveness has been the main driver behind the project, but creation of new salt marsh and intertidal habitat has been equally important. Each year floods have threatened to break through existing sea defences – the maintenance of which was projected to become very costly over the next 100 years. The scheme will involve construction of new defences inland from the coast and allow a new intertidal area to form seaward by the breaching of old defences (Fig. 10). This will increase flood protection in the area by a factor of 1000, safeguarding 348 properties, and other existing infrastructure (EA, 2010a).

Most of the area was purchased by the Environment Agency Regional Habitat Creation Programme through negotiation with private landowners. The project was funded on the basis that creation of new salt marsh habitat offsets cumulative losses of intertidal habitat in other parts of the southern coast. Land prices were calculated as price per acre based on market value plus disturbance compensation and a premium for where the land had an irrigation system in place[45]. 263 hectares of new habitat is projected,

[43] The National Trust, Seaford Town Council, Natural England, EA, South Downs Joint Committee, East Sussex County Council, Wealdon County Council, Owners of the lower coastguard cottage.
[44] http://cuckmerepathfinder.org.uk/Escc.CuckmerePathfinder/media/Cuckmere-Documents/Community-Forum-Options-report---Dec-workshop---website.pdf
[45] http://www.environment-agency.gov.uk/static/documents/Leisure/Medmerry_MR__Frequently_asked_questions.pdf

including 183 hectares of intertidal/saltmarsh and a further 80 hectares of transitional grassland. The intertidal area will contribute towards UK Biodiversity Action Plan (BAP) targets, hence the additional funding. The following was included in the cost-benefit summary, though details were not provided (EA, 2008):

1. realignment construction cost = £10m (plus £6m for habitat creation).
2. cost of 'holding the line' (maintaining old defences) = £30m
3. overall long-term benefits = £92m
4. overall benefit : cost ratio = 5 : 1

Works have commenced and the seaward breach is proposed for Autumn/Winter, 2012. . Fig. 10 illustrates the scheme.

7.4.4 OPW flood relief schemes, Ireland

Cost-benefit analyses were carried out at design phase for six of Irelands more recent large town Flood Relief Schemes (Tolka River, Templemore, Mallow, Fermoy, Ennis and Clonmel) including consideration of NFM strategies. Cost effectiveness summaries for the NFM options are shown in Table 4. None of the options were considered viable in any of the catchments based on one, or a combination of, factors, including lack of cost effectiveness; a low level of flood protection offered; land acquisition issues and safety issues (OPW 2003a, b, c; OPW 2005a, b; OPW 2006) It is unclear how costs and benefits were assigned and whether these took into account a wider ecosystem approach. It is important to note that feasibility assessments were based on expected peak flow reduction at a specified point in each catchment, e.g., the town of Ennis, the town of Mallow, etc.. In many cases it was acknowledged that certain strategies, such as floodplain storage and provision of washlands, would have a locally positive effect on flood mitigation, but that these would not necessarily provide cost-effective flood reduction at the specific landmark or town in question.

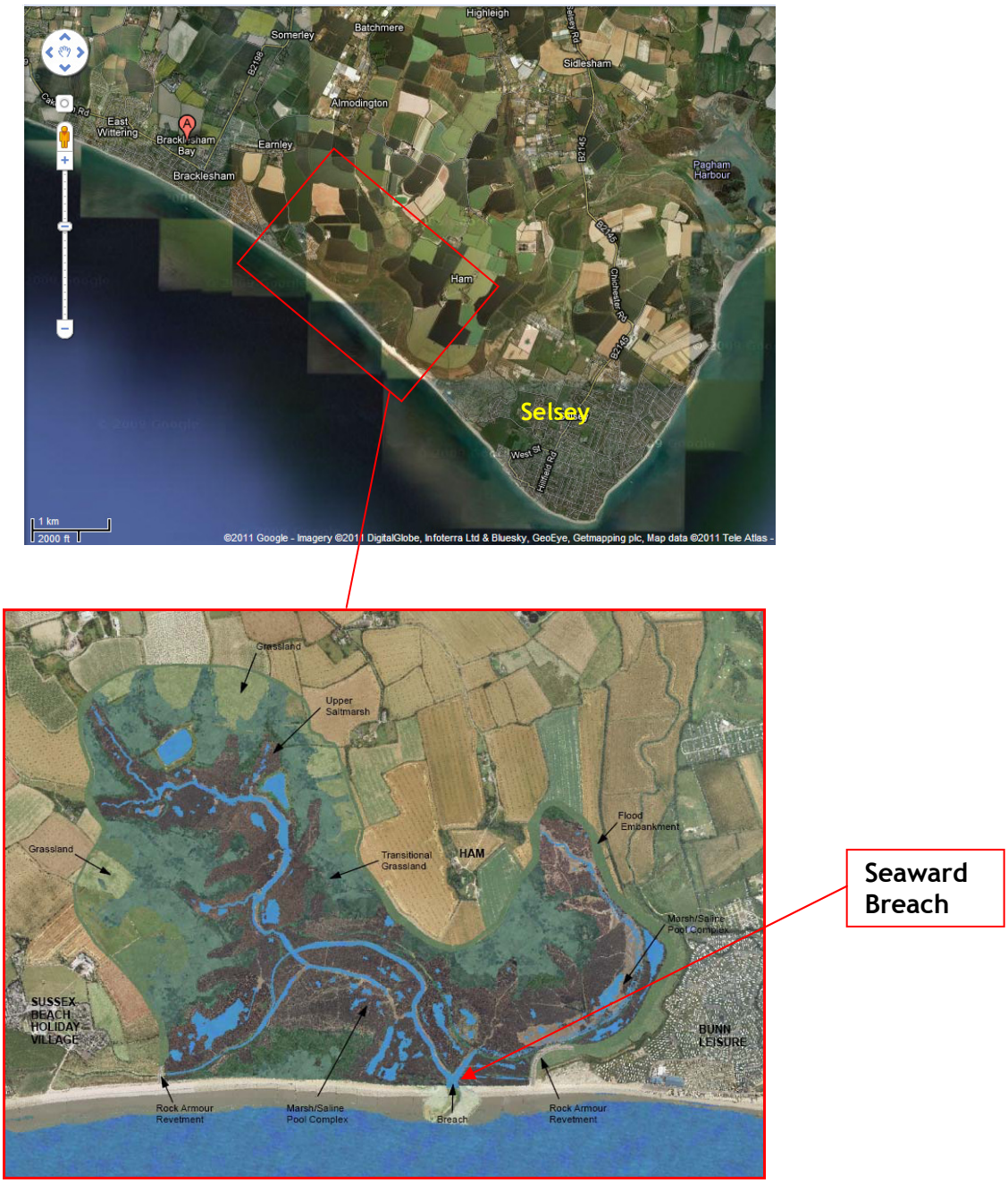


Fig 10: Medmerry coastal realignment scheme, West Sussex, UK, showing projected intertidal habitat creation following construction of new inner seawall and outer seawall breaching (lower image by ABP MER from EA, 2010a, *Contains Environment Agency information © Environment Agency and database right*)

Table 5: Feasibility of floodplain storage options assessed as part of OPW flood alleviation schemes, Ireland.

Scheme	Floodplain storage option	Feasibility
River Tolka Flooding Study. OPW (2003a)	Possible retention areas in the catchment were identified and investigated in detail during the modeling stage but found that large-scale floodplain attenuation schemes offered limited flood mitigation - flood reduction confined to local downstream reaches. 6 small potential attenuation schemes were looked at and were considered to offer mitigation potential under existing conditions with the potential to help protect against increased flood risk from climate change and future development. These areas had a combined storage capacity of approximately 600,000m³. The report did acknowledge the value of existing floodplain storage where it was located unhindered by development and urban infrastructure – a recognition, perhaps, of the need for spatial planning restrictions on such lands. In areas that required traditional flood defence approaches (e.g., embankments) it was acknowledged that this would decrease floodplain storage, which would necessitate design offsets to accommodate extra downstream flood peaks.	**Not Feasible:** The issues of land acquisition, detailed design, construction, and potential consequence of failure indicated attenuation schemes were not viable alternatives to traditional flood protection measures in the Tolka catchment. Combined, smaller, local storage possibilities could have a useful role in the future in augmenting the safety margin to take account of development or climate change impacts and these areas were to be preserved as options. Overall, it was concluded that increased flood storage may have benefits where schemes could be located just upstream of vulnerable areas, but the scale of works involved were (i) too substantial and (ii) had potential to increase flood risk and public safety risk locally, while the benefits were relatively minor and could not significantly mitigate flooding in high risk areas.
Templemore Flood Relief Design Study. OPW (2005b) .	2 options for upstream storage on the River Mall, Co. Tipperary. **Option 1: ABBEY ROAD FIELDS** These fields flood naturally during events, so the function would have been formalized by construction of raised embankments to create a flood storage unit that included the fields and the existing Town Park lake, with a controlled discharge mechanism. This would alleviate downstream flooding in parts of Templemore town. **Option 2: FIELDS UPSTREAM OF BIDDY'S BRIDGE** Would have involved construction of embankments to contain water on fields upstream of the bridge during events, with controlled discharge and emergency spillway. Embankment height of 114.15mOD (limited by existing demesne walls) would create a storage capacity of 320,000m^3.	**Option 1 - Not Feasible:** Additional flow to the existing Town Lake would actually increase flood risk given that the lake's storage structures would overtop even in small events and the attenuation role would be negligible. A new spillway from the lake would be required to increase the viability of the option, which raised the issue of liability in the case of dam failure. OPW could not take on the responsibility of the Town Lake structures given that they were (i) aging and unsuitable for impoundment use and (ii) were outside their remit. **Option 2 - Not Feasible:** The impoundment required would be classed a 'Category A' due to proximity of residential housing and Templemore town. Outflow structures would have to be able to pass a PMF[46], conferring considerable costs plus maintenance and inspection obligations on the OPW (for which OPW staff were unqualified). Furthermore, freeboard for wave run-up would require the level of the spillway to be lowered meaning storage capacity would only provide a 2m^{3}s^{-1} flow reduction. In view of the amount of capital works entailed (840m of new embankment over 1.7m high, 80m long spillway) and the legal and maintenance liability incurred through the construction of a Category A dam, it would not be reasonable to combine this option with other capital works to achieve a reduction in flow of merely 2 m^3/s.

[46] PMF = Probable Maximum Flood (average return period 1,000,000 years) – in this case a peak flow of 73m^{3}s^{-1}

Scheme	Floodplain storage proposals	Opinions on the feasibility of proposals
Munster Blackwater (Mallow) Drainage Scheme. OPW (2003b)	**Option 1: UPSTREAM STORAGE – RESEVOIRS and WASHLANDS** To remove the necessity for defences within Mallow an upstream storage volume of 10 million m^3 would have been required. The construction of dams to store water in some of the narrower upstream valleys was briefly considered. The use of managed, offline storage on floodplain washlands was considered -using all available washlands from Mallow through to Allow, with control structures for inflow (low bunds) and outflow the achievable storage (at 1.4m depth) was 3.5 million m3. This would reduce the peak flow from 549 to 445 m3/s and with climate change from 631 – 510 m3/s. Overall a 0.5m decrease in water levels in Mallow could be achieved. The merits of river restoration (e.g., introducing meanders, planting woodland in the upper catchment) were also considered. **Option 2: LOWERING OF DOWNSTREAM FLOODPLAIN** It was acknowledged that opening up the floodplain downstream may reduce peak flow in Mallow. Most practical was the option to construct a lowered section through the floodplain south of the town bridge in a way that angling usage and other amenity values were not interfered with. A 10m wide lowered floodplain channel of >2.9km was modelled and achieved a projected reduction of water levels in Mallow of 0.5m.	**Option 1 - Not Feasible:** Overall the upstream flood storage option was not feasible as it was too expensive in comparison with the degree of protection achieved. It was also considered to have had potential for major impacts on the aquatic environment (in the case of dams) and a social impact on landowners close to the various facilities. Management of washlands could not provide the necessary level of protection. It was concluded that these works would not cause sufficient reduction in flood levels to remove the requirement for flood defences in the town. The cost of upstream storage options was estimated at €42.4 million which was well in excess of other options during cost-benefit stage. River restoration solutions were rejected as a part of the scheme since the levels of flood reduction were considered negligible in relation to the risks in Mallow. Woodland planting in the upper catchment was considered to have a very small localized attenuation effect. **Option 2 - Not Feasible** The cost of this option was estimated at €8m and was rejected on basis that it would fail cost-benefit analysis and would cause significant environmental impacts (river ecology and archaeology).
Munster Blackwater River: Fermoy Flood Alleviation Scheme OPW (2003c)	Required an estimated upstream storage area of 25km^2 i.e. 6175 acres. Aerial footage on the video of the 2000 flood showed that most of the available floodplains are already utilised during big events. The report stated that to be most effective the storage area ought to be provided immediately upstream of the flood risk area.	**Not Feasible:** Due to the topography of the Blackwater River in the reaches upstream of Fermoy, there were no available large floodplains adjacent to the river that could be managed to store large volumes during extreme floods. This option was deemed not feasible due to the little effective additional storage that could be utilised.
Clonmel Urban Flood Relief Scheme. River Suir OPW (2006)	**Option 1: UPSTREAM STORAGE USING HYDROELECTRIC DAM** The construction of a dam and hydroelectric power station in an upper catchment valley was investigated. A 500m long dam, 34m high would create significant storage capacity and power generation in the region of €20,000 pa, but would only reduce the flood risk in Clonmel by 1.3% (26mm). **Option 2: UPSTREAM FLOODPLAIN STORAGE.** To retain channel flow to normal levels (279 m^3/s) through the town, 12 million m^3 of upstream storage capacity would have been required at the location investigated. This would have involved constructing berms, 10m high, to retain floodwaters at an estimated cost of €30 million. Hard engineering defences downstream could be built to a lower height under this scenario.	**Option 1 - Not Feasible**: The reduction of the impact of the 100 year flood was not considered great enough to justify the cost or environmental impacts of a large dam construction. **Option 2 - Not feasible**: The reduced cost of constructing defences downstream of the floodplain storage area were not enough to justify the greater expense of constructing and managing the upstream storage option.

Scheme	Floodplain storage option	Feasibility
River Fergus (Ennis) Certified Drainage Scheme Stage 1 – Outline Design Report OPW (2005a)	**Option 1 : UPSTREAM STORAGE** Creation of an upstream lake to store flood waters considered. On the River Fergus this required a storage volume of 8.7 million m^3 and a lake area of 15km^2 i.e. 3700acres. Existing lakes did not have the required capacity and widespread flooding of large land areas would be required. On the Claureen River estimated total volume of required storage was 165,000 m^3; achieved by an impoundment of 0.5 km2, a weir length of 3m and a rise in water depth of 0.5m which would have resulted in flow reduction from 20 to 15 m^3/s. **Option 2: DOWNSTREAM STORAGE** Consideration was given to increasing downstream storage which would be managed by the existing Clarecastle Tidal Barrage. Lands would have been required for flooding. A valuation on the estimate of compensation was completed for a portion of these lands – ranged from approx. €8000/acre for agricultural lands and up to €80,000 for lands with development potential (some lands had been zoned and/or had development proposals).	**Not Feasible:** In summary, land compensation costs rendered flood storage options unacceptable and the recommended design option instead was improving conveyance through Ennis town. The use of storage was seen to have potential to be partially effective in the Claureen catchment since land area required was smaller, but it was decided that in view of the fact that no lakes already existed, benefits were unlikely to match the cost of the disruption involved.

PART II Law and policy relating to wetlands in a flood attenuation role

1. Introduction

Whilst the case for the use of some wetland types in future flood mitigation strategy is good, there also remains a degree of contention. Notwithstanding, European Best Practise dictates that retention of water within the landscape should underpin all future flood risk management policy. This section, therefore, investigates law and policy that applies in Ireland with regard to wetlands in this role. The legal instruments are separated into different levels of governance, namely, international, European and national. An overview is provided of the coverage by various legislative and policy instruments that could be best utilised to support the use of wetlands in a flood attenuation role. It is important to note that there is currently no legislation in Ireland that specifically applies to wetlands for flood attenuation. A somewhat broader legal framework is, therefore, presented as many instruments recognise the value of wetlands and the ecosystem services they provide. These may act as drivers for action as well as help promote the use of wetland function in flood attenuation.

It should be stated at the outset that policy is not law. A policy is a set of rules formulated to achieve certain goals and should comply with the law. In Ireland, there is no national policy on wetlands *per se*, which is in contrast to other jurisdictions. Given the lack of a dedicated policy, it may be useful to look briefly at both wetland policies and policies which could be applied to wetlands, such as those applicable to coastal erosion and flood management, in other European Member States and further afield. This includes the 'Making Space for Water' policy in the United Kingdom which addresses flood and coastal erosion risk management in England and the 'Room for Rivers' approach in the Netherlands.

Wetlands cover a broad range of land and water types and consequently they are affected by almost all aspects of government policy in Ireland. As is clear from Ireland's experience with coastal and marine management, however, integrated management approaches tend not to exist and sectoral inconsistencies are pronounced. It is not possible, within the scope of this work, to review all potentially relevant national law and policy. For this reason, the key sectors, in an Irish context, are presented here. These are drawn from where: (1) the use of wetlands in flood attenuation has been specifically mentioned, and/or (2) where there exists potential for such inclusion. These sectors are: biodiversity and conservation; climate change adaptation; river basin and flood management; planning, development and impact assessment; and finally agricultural and rural development policy.

2. Biodiversity and conservation

2.1 International Conventions

Convention on Wetlands (Ramsar)

The Ramsar Convention on Wetlands[47] is an inter-governmental treaty that provides the framework for national action and international cooperation for the conservation and "wise use" of wetlands and their resources. The Convention does not mention the potential of wetlands for flood attenuation as such, however, many of its more recent resolutions highlight the potential of wetlands in climate change mitigation and adaptation and by that rationale their role in flood attenuation is implicit. The 'wise use of wetlands' is central to the Convention and applies not only to Ramsar listed sites (Ireland has 45 of these), but to all wetlands in the territory of the Contracting Party. Central to the implementation of the concept of wise use is the development of a national wetland policy (Ramsar Convention Secretariat, 2007). Ireland does not currently have such a dedicated policy, though wetland protection is implicit in many other policy documents.

The Ramsar Convention is the only international instrument protecting migratory species that makes explicit reference to climate change calling upon parties, *inter alia*, to 'manage wetlands to increase their resilience to climate change and extreme climatic events, and to reduce the risk of flooding … through promoting wetland and watershed and protections' (Resolution VIII.3, para. 14). In addition to the value of wetlands in climate change adaptation and mitigation, the Ramsar Secretariat have continuously strived to promote the ecosystem services provided by wetlands, including their role in flood control, groundwater replenishment, shoreline stabilisation and storm protection. There is widespread recognition within the Convention Secretariat of the role of wetlands in flood attenuation. No national report is available on implementation progress for Ireland since 2002. A draft policy on wetland protection was supposed to be in place by 2005, but this has not materialised.

Most recently at COP10 in Korea in 2008, Contracting Parties were urged to include in their national climate change strategies the protection of mountain wetlands, to reduce the impacts of extremes in precipitation, restore water storage in mountain areas and restore management of degraded lowland and coastal wetlands, resulting in the attenuation of large storms and sea-level rise (Ramsar Resolution X.24 para 31). It is up to Contracting Parties to progress the actions contained in the Resolution.

Convention on Biological Diversity (UNCBD)

The 1992 Convention on Biological Diversity[48] links traditional conservation efforts to the economic goal of using biological resources sustainably. A Memorandum of Cooperation between the Ramsar and Biodiversity Convention Secretariats was signed in 1996 to promote cooperation, exchange and joint conservation action. This has resulted in a number of Joint Work Programmes between the two Conventions. With respect to adaptation to climate change it is recognised that the conservation and sustainable use

[47] http://www.ramsar.org/cda/en/ramsar-home/main/ramsar/1_4000_0__
[48] http://www.cbd.int/

of biodiversity can provide opportunities for adaptation and is an adaptation option itself. The protection or restoration of salt marshes, for example, can offer increased protection of coastal areas to sea level rise and extreme weather events. Likewise, rehabilitation of coastal wetlands can help regulate the flow in watersheds, thereby moderating floods from heavy rain and ameliorating water quality.

Without expressly endorsing the precautionary principle, the Convention states that measures should not be avoided or postponed where there is a lack of full scientific certainty. This is particularly important in the context of using wetlands for flood attenuation as many management agencies state lack of evidence as a reason not to consider this as an option. Under the CBD Parties must develop national strategies, plans or programmes and policies with an ecosystem approach as the primary framework for action. The Ecosystem Approach can be defined as a strategy for integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Within the CBD wetlands are addressed in a number of thematic and cross-cutting programmes. All of these have implications for the use of wetlands in flood attenuation. Thematically, the CBD's programme on inland waters recognises the importance of wetlands for flood management, mitigation against the impacts of natural catastrophes and climate change. Adaptation to Climate change is also one of the cross-cutting areas of work in the CBD (CBD Secretariat, 2009).

2.2 European law on biodiversity

Directive on the conservation of wild birds (79/409/EEC as amended by 97/49/EC and 2009/147/EC)

The Birds Directive (BD) seeks to protect, manage and regulate all bird species naturally living in the wild within the European territory of the Member States, including their habitats. It is the protection of these habitats which is of most relevance to wetlands and their uses. If any proposed plan or project is likely to have a significant adverse effect on an SPA but must go ahead for reasons of overriding public interest, compensatory habitat must be provided. Provision of habitat for breeding waders and wildfowl, including access to funding for this purpose, has been highly instrumental in the implementation of a number of large UK flood management projects that protect or utilise wetlands or washlands.

In terms of potential implications of the Birds Directive for use of wetlands in flood attenuation, it is suggested that where compensatory grounds are to be provided, these grounds could also provide an ecosystem service in terms of affording coastal protection or buffering from flood risk.

Directive on the conservation of natural habitats and of wild fauna and flora (92/43/EEC).

The Habitats Directive (HD), on the conservation of natural and semi-natural habitats and species of flora and fauna establishes a European ecological network known as 'Natura 2000' comprising Special Areas of Conservation (SACs), designated under the Habitats Directive, and Special Protected Areas (SPAs). A large proportion of SACs in Ireland include riparian and associated riverine habitats and consequently appropriate

restoration measures and management is required to fulfil the Habitats Directive criteria. Wetland areas in general and floodplains in particular may play crucial roles in this pan-European network of protected nature reserves. River maintenance and drainage operations are all subject to restrictions under the HD (see section 8.3). Restoration of floodplain wetlands for attenuation may help fulfil HD requirements to maintain favourable ecological status of wetland dependant species, although it's important to note that biodiversity and flood management goals are not always compatible (see Part I, section 5).

2.3 European policy on biodiversity

In May 2006, the European Commission adopted a Communication entitled "Halting Biodiversity Loss by 2010 – and Beyond: Sustaining ecosystem services for human well-being" (COM/2006/216 final). In order to achieve this, the Commission also adopted a detailed Biodiversity Action Plan (BAP). Objective 2 of the Communication contains a specific target - that flood risk management plans (FRMPs) will be in place and designed in such a way as to prevent and minimise biodiversity loss and optimise biodiversity gains by 2015. The associated action is to ensure that FRMPs optimise benefits for biodiversity through allowing necessary freshwater input to wetland and floodplain habitats, and creating where possible and appropriate additional wetland and floodplain habitats which enhance capacity for flood water retention [by 2015].

The UK has developed specific BAP targets for habitats and species[49] and these have contributed to the implementation of a number of UK wetland projects for flood management. Ireland does not currently have BAP targets (Dr Jim Ryan, NPWS, pers.comm.).

A Communication in January 2010 (COM(2010) 4 final) recognised that appropriate forms of land and maritime management are needed to maintain and enhance ecosystems that provide ecosystem services to society at large. It was stated that Common Agricultural Policy (CAP) is the policy tool having the most significant impacts on biodiversity in rural areas (see below). This resulted in the identification of biodiversity as one of the five new challenges of the CAP, the introduction of a new optional standard on the establishment and/or retention of habitats and the introduction of a new compulsory standard on the establishment of "buffer strips" along watercourses.

While the EU has not formulated a specific policy to encourage action on the use of wetlands for flood attenuation, many of their recent policy documents recognise the ecosystem services wetlands provide. A new policy area in this regard is the development of green infrastructure (see Part I, section 7.3). The Commission is supporting exchanges of best practice as a basis for an EU strategy on green infrastructure to be developed after 2010 (COM(2010) 4 final). Currently development and strengthening of green infrastructure is primarily achieved through the LIFE programme (see EU, 2010) which outlines a number of projects where wetlands have

[49] http://ukbap-reporting.org.uk/outcomes/targets.asp?C=3&X=&P=&F=&submitted=1&flipLang=&txtLogout=

been restored to provide their full range of ecosystem services including flood attenuation.

In addition to biodiversity law and policy some European floodplain habitats have also been offered protection by the Pan-European Biological and Landscape Diversity Strategy (UNEP, 1996) and many other habitats have also recently been included on the lists of protected habitats and priorities of European Member States to comply with agri-environment schemes (Council Regulation EC No. 1257/1999; and Council Regulation EC No. 1750/1999) (see below).

2.4 National law on biodiversity and conservation

Ireland's law on biodiversity and conservation is encapsulated primarily in the Wildlife Acts, 1976-2000. Wetlands are not mentioned *per se* in either legal instrument. Likewise neither are they mentioned in any of the statutory instruments[50] transposing the Birds and Habitats Directives. The foreshore is, however, covered by all these instruments and this area may have associated wetland habitat(s).

2.5 National policy on biodiversity and conservation

In April 2002, Ireland's National Biodiversity Plan was published (DAHGI, 2002). Inland waters and wetlands were specifically included within the Plan, but no attention was given to ecosystem services or the use of wetlands for flood attenuation. Similarly neither climate change nor climate change adaptation featured in the Plan. The Plan had a time frame of five years. An Interim Review of the National Biodiversity Plan was published in 2005 and found 'further action' was required in developing local biodiversity action plans (DEHLG, 2005). Climate change was mentioned under implementation of many of the actions but not adaptation. Along with a number of other recommendations, the review of the Plan recommended that prioritised targets and timescales for species and habitat protection and conservation be established, but this has not happened. As mentioned above, experience in the UK has shown this can have implications for the implementation of 'natural flood management' strategy.

[50] S.I. No. 94 of 1997; S.I. No. 233 of 1998; S.I. No. 378 of 2005; or S.I. No. 293 of 2010.

3. Climate change

3.1 International Conventions

UN Framework Convention on Climate Change

The Framework Convention on Climate Change is associated primarily with the stabilisation of greenhouse gas concentrations in the atmosphere. However, it is also a key driver for adaptation actions. Article 4 calls on contracting parties to implement programmes containing "measures to facilitate adequate adaptation to climate change" (Art. 4(1) (b)). While the concept of adaptation has been included since the beginning of the Convention, the Bali Action Plan recognised that there was a need for enhanced action on adaptation. As a result of the Bali Action Plan, adaptation is now one of the five key building blocks (along with shared vision, mitigation, technology and financial resources) for a strengthened future response to climate change up to and beyond 2012. Effectively this places the concept of adaptation on an equal footing to mitigation for the first time in the history of the Convention. Increasing the natural defence function of inland and coastal wetlands is recognised as something that can help mitigate against flooding and is an appropriate adaptation to increasing flood risk. In Copenhagen, the COP invited all Parties to the Convention to undertake to plan, prioritise and implement adaptation actions including specific projects and programmes[51] and actions identified in national adaptation plans and other relevant national documents (UNFCCC/AWGLCA/2009/L.7/Add.1, 2009). Irish work on adaptation is outlined in the policy section below.

3.2 European policy on climate change

In light of the fact that utilising or restoring wetlands for flood attenuation could be an adaptation to the impacts of climate change, this section will focus solely on EU work on climate change adaptation. Work on adaptation in the European institutions is still in the early stages. Progress includes, for example, the Environment Impact Assessment Directive, the Strategic Environmental Assessment Directive, the Habitats Directive, the Floods Directive, the Water Framework Directive and the Marine Strategy Framework Directive. The Commission launched the European Climate Change Programme (ECCP) II in October 2005 establishing a Working Group to look at adaptation to climate change (ECCP Working Group II, 2006a). Wetlands for flood attenuation have not been, specifically looked at.

In the agriculture and forestry sector, several potential adaptation responses have been well explored. Proactive adaptation options identified include, for example, suitable upland farm or land management so that upland areas are used to slow run off and reduce peak water flows and restoring natural features (ECCP Working Group II, 2006b). The sectoral report on water management makes no mention of wetlands but recognises the need for flood risk management. It states that the WFD is a key instrument in climate adaptation policies in the water sector which includes the requirements needed for addressing climate impacts (ECCP Working Group II, 2006c). It is important that the EU has stated consistently that the development of national

[51] in the areas of water resources, health, agriculture and food security, infrastructure and settlements, ecosystems, oceans and coastal zones (para. 4(a), FCCC/AWGLCA/2009/L.7/Add.1)

climate change adaptation strategies is the responsibility of the individual Member State, not the EU. In future, however, the EU could mandate Member States to develop national adaptation strategies (ECCP Working Group II, 2006d, p7).

More recently the European Council's conclusions from March 2010[52] explicitly recognised the fact that, when it comes to helping countries adapt to climate change, biodiversity provides many of the same services as man-made technological solutions, often at significantly lower cost, e.g., "green infrastructure". Protecting and restoring biodiversity may provide some cost-effective opportunities for climate change mitigation or adaptation, though this is not thoroughly proven for flood attenuation (see Part 1, section 5). The December 2009 Conclusions include a recommendation that ecosystem-based approaches for the mitigation of, and adaptation to, climate change be developed and used.[53]

3.3 National level work on climate change and adaptation

Ireland's response to climate change focuses more on mitigation of climate change, with the sectoral analysis fixed on reduction of emissions. Less attention is paid to adaptation which is more relevant in the context of the use of wetlands for flood attenuation. The section on adaptation begins by outlining the possible impacts of climate change in Ireland, highlighting the probable increase in flooding, storms and extreme events. McElwain & Sweeney (2007), for example, state that as temperatures rise, there will be a greater capacity to store water in the atmosphere with the result that rainfall could increase by 17% in western areas and possibly as much as 25% in places. The strategy states that "as part of a comprehensive policy position on climate change, the Government is committed to developing a national adaptation strategy over the next two years" (DEHLG, 2007, p.45). This is intended to provide a framework for the integration of adaptation issues into decision-making at national and local level. Progress on the development of a national adaptation plan has been slow. In December 2010, the Climate Change Response Bill 2010 was published and it remains to be seen how it will progress under the new Government. The national plan must address climate change mitigation and adaptation issues.

[52] http://www.countdown2010.net/2010/wp-content/uploads/Council-Conclusions-new-biodiversity-target.pdf
[53] See http://www.consilium.europa.eu/uedocs/cms_Data/docs/pressdata/en/ec/113591.pdf

4. Water Management

4.1 European law on water management

Directive establishing a framework for Community action in the field of water policy (2000/60/EC).

The central objective of the Water Framework Directive (WFD) is to prevent the deterioration of ecological quality and the restoration of polluted surface and groundwaters by the end of 2015. To achieve Good Ecological Status (GES), Member States are required to adopt implementation strategies as stipulated by the WFD. The impact of pressures on wetlands will have consequences for achievement of WFD objectives. Drainage of floodplains, for example, alters the physical extent and biological composition of the water body; changes surrounding vegetation and changes some physical elements of the water body, including flow regime, depth, substrates all of which has relevance to objectives set for surface water bodies.

Member States must establish a Programme of Measures (POMs) to achieve the objectives of the Directive, including 'basic' and 'supplementary' measures. Under POMs, wetland creation, restoration and management, may prove a cost-effective and socially acceptable mechanism for helping to achieve the environmental objectives of the Directive (Article 11.4; Annex VI, Part B(vii)). Guidance issued to date recognises that wetlands "have the potential to offer benefits in terms of flood prevention, nutrient and pollutant load abatement, wildlife protection, tourism and recreation" (EC, 2003). Importantly, in some circumstances, wetland management may be necessary to achieve the objectives of the WFD thus making wetland restoration and creation obligatory.

Specific measures are required to ensure that the hydro-morphological conditions of water bodies are consistent with ecological status objectives. In the context of wetlands this could include measures to control pressures on wetlands where changes to those wetlands could cause a significant adverse effect on the status of the water body. Guidance on this aspect of the WFD lists indicative hydro-morphological pressures that could affect water quality status. This list includes traditional 'hard' engineering solutions to flooding (such as the canalisation of rivers, and the construction of walls, embankments, culverts and reservoirs) as well as land infrastructure, land reclamation and/or agricultural enhancement (EC/IMPRESS, 2003). This is a very important point, since the disconnection of the floodplain from the river channel through engineering has the potential to increase downstream flood peaks (Acreman *et al*., 2003). There may be scope to address, for example, restoration of floodplain functionality through hydromorphological criteria under the WFD.

Implementation of measures under the WFD can be closely linked with the objectives of the Habitats Directive (see Section 2.2) in that maintenance and improvement of the status of water may be necessary to improve the conservation status of certain habitats and species (Mayes, 2008). Water dependant habitats in Ireland fall into the following groups: coastal marine habitats; coastal transitional and intertidal habitats; coastal onshore habitats: surface water dependent habitats; groundwater dependent habitats (e.g. turloughs) and precipitation dependent habitats (e.g. bogs). Increasing the flood

attenuation potential of wetlands may be a consequence or driver behind measures implemented under the WFD / HD.

Guidance states that "consideration of how wetlands can be used to manage floods and droughts in a manner compatible with WFD objectives could greatly assist Member States with implementation, and in integrating flood management strategies with RBMPs" (EC, 2003).

Under the Common Implementation Strategy (CIS) group research and action specifically on Climate Change and Water began in 2007. A 2009 guidance was produced on how to incorporate climate change into the next phase of river basin management planning (EC, 2009). The CIS group are working to ensure that the requirements of the WFD and the Floods Directive (see below) complement each other. In this respect, the CIS has also established a separate working group on floods.[54] Adaptation could be explicitly incorporated into the WFD through a climate change impact assessment for each river basin district and inclusion of associated catchment-wide actions in the programmes of measures.

4.2 National level River Basin Management Planning

The Water Framework Directive was transposed into Irish Legislation by the EC (Water Policy) Regulations 2003[55]. The River Basin Management Plans (RBMPs) published to date do not explore how wetlands could be used to manage flooding. All seven plans mentioned flooding and flood prevention with the exact same wording that "sustainable flood management measures such as floodplain reclamation and restoration, have ancillary benefits for climate change, biodiversity and nutrient attenuation and have an important role to play in flood risk management planning". It is also recognised within each Plan that "measures to reconnect wetlands and riparian ecosystems to the river channels may have an important role to play, e.g. in terms of water storage, nutrient attenuation and can also contribute towards providing habitat for native species". However, no greater exploration of the topic is evident from any of the supporting documentation.

All of the River Basin Management Plans published to date mention climate change and flood management specifically. No consideration is given to adaptation actions or improving resilience of the region more generally. An ESBI (2008) report states that with sea level rise and increased flooding certain physical modifications will be required within river basins. Given the emphasis the European Commission has placed on integrated climate change considerations into other sectoral policy areas, climate change adaptation actions are likely to appear much more strongly in the next round of River Basin Management Plans.

This presents an opportunity to include ecosystem services in river basin management planning, specifically, the use of wetlands for flood management.

[54] See http://ec.europa.eu/environment/water/water-framework/objectives/implementation_en.htm
[55] S.I. No. 722 of 2003.

5. Flood Risk Management

5.1 European law relating to flood risk management

Directive on the assessment and management of floods (2007/60/EC)

The aim of the Floods Directive (FD) is to reduce and manage the risks that floods pose to human health, the environment, infrastructure and property. Climate change is explicitly included in the Floods Directive under Article 4. Under the Floods Directive, Member States are firstly required to carry out a preliminary assessment to identify the river basins and associated coastal areas at risk of flooding by 2011. Flood risk maps need to be produced by 2013 and Flood Risk Management Plans (FRMPs) by 2015. The Directive applies to both inland waters and coastal waters across the European Union. The Floods Directive can therefore be said to provide a comprehensive mechanism for assessing and monitoring increased risks of flooding owing to climate change and for developing appropriate adaptation approaches.

With respect to the preliminary assessment, Member States are required under Article 4(2), to include an assessment of the potential adverse consequences of future floods for human health, the environment, cultural heritage and economic activity, taking into account as far as possible issues such as the topography, the position of watercourses and their general hydrological and geomorphological characteristics, including floodplains as natural retention areas, the effectiveness of existing man-made flood defence infrastructures, the position of populated areas, areas of economic activity and long-term developments including impacts of climate change on the occurrence of floods.

The Common Implementation Strategy referred to above (under the WFD) also supports the implementation of the Floods Directive. In terms of tangible outputs the Working Group proposes to deliver (by mid 2011) a catalogue of good practices of 'no regret' and 'win-win' measures in view of climate change - that is, measures that turn out to be of benefit no matter how or if the predicted climate change impacts materialise. Another output will be a dedicated report on flood risk management and economics and decision making support which is due in late 2011 (Water Directors, 2009). It is hoped that this material will address the lack of information currently available on the use of wetlands for flood attenuation under the Floods Directive.

5.2 National level implementation of flood risk management

5.2.1 Flood risk management in the planning system

In Ireland, flooding is, and always has been, a regular occurrence and this is expected to continue, or increase, owing to the potential impacts of climate change. Similarly there is a tradition of development in flood-prone lands, a fact that is being addressed through the Flood Risk Management Guidelines for Planning Authorities (2009), reviewed below. In Ireland the Office of Public Works (OPW) is the lead agency for flood risk management. Traditionally, the office was tasked with property maintenance and management, architectural and engineering services, project management and procurement services. This includes the maintenance of arterial drainage and

embankment schemes and monitoring of maintenance by Local Authorities of drainage districts schemes. The Flood Review Group recognised a need to manage flood risk on a proactive basis, resulting in publication of draft Planning Guidelines in 2008 followed by agreed Planning Guidelines for Flood Risk Management in November 2009. The approach Ireland has taken is to ensure that risks of flooding in the future are integrated into the planning process, first through the spatial planning process at regional, city, county and local levels, and also in the assessment of development proposals by planning authorities and An Bord Pleanála. According to the Planning Guidelines "flood hazard and potential flood risk from all sources should be identified and considered at the earliest possible stage in the planning process and as part of an overall hierarchy of national responses coupled to regional appraisal and local and site-specific assessments of flood risk" (DEHLG & OPW, 2009, p.21).

The Guidelines recognise that many wetland habitats are dependent on annual flooding for their sustainability and can contribute to the storage of flood waters to reduce flood risk elsewhere (DEHLG & OPW, 2009, p.11). Furthermore, the Guidelines expressly state that it is important to "identify and, where possible, safeguard areas of floodplain against development in both urban and rural areas" (p.18). They state that land required for current and future flood management, e.g. conveyance and storage of flood water and flood protection schemes, should be proactively identified on Development Plan and Local Area Plan maps and safeguarded from development.

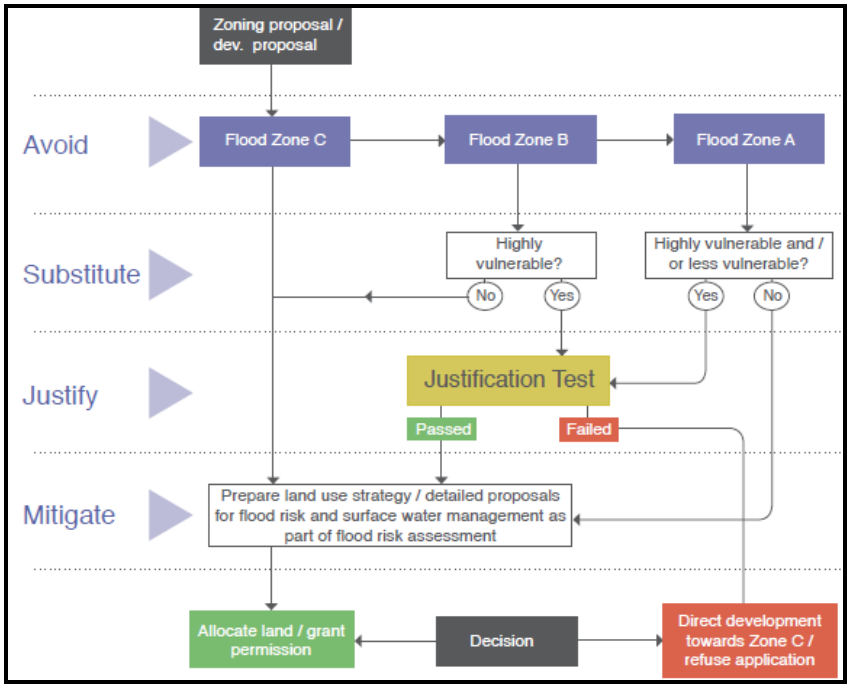


Fig. 1 Sequential approach mechanism in the planning process (DEHLG & OPW, 2009, p.23)

With respect to new developments, the Guidelines assert that these should be managed through "location, layout and design incorporating SuDs and compensation for any loss of floodplain as a precautionary response to the potential incremental impacts in the catchment" (p.22). In the Guidelines a schematic sets out the sequential approach mechanism to be used in the planning process. This is reproduced in Fig. 1. It is clear that at the mitigation stage detailed proposals for flood risk and surface water management as part of flood risk assessment must be incorporated. The use of wetlands, or other soft measures, for flood attenuation could easily be accommodated here.

The second process is the Development Management Justification Test which is used at the planning application stage where applications have been made to develop land at moderate or high risk of flooding for uses or development vulnerable to flooding that would generally be unsuitable for that land. At the strategic level identification of areas of natural floodplain to be safeguarded should be one outcome of the process.

The Guidelines state that Development Plans should be "pro-active in addressing flooding by including, for example, general policies to protect, improve or restore floodplains or the coastal margins. Planning authorities are encouraged to consider whether there are areas where a previous and natural flood risk management function can be restored through appropriate actions, such as managed re-alignment of existing coastal defences or river or wetland restoration projects and the provision of flood storage (DEHLG & OPW, 2009, p.38). It is conceivable that a map of wetlands and their potential for accommodating flood waters would be a useful inclusion here. If wetland creation or floodplain restoration is to be given consideration it would be helpful for both developers and planners to know where this is a possibility.

Generally the Planning Guidelines advocate a precautionary approach in order to reflect uncertainties in flooding datasets and risk assessment and the ability to predict the future performance of existing flood defences. This fits well with adaptation to climate change. Both the flood maps and the identification and outline design of flood risk management measures, under the CFRAMS programme (below), will consider a range of potential future scenarios, including the potential impacts of climate change, ensuring that capacity for adaptation is built into the flood risk management strategy and measures.

5.2.2 National policy on Flood Risk Management

Parallel to consideration of flood risk management within the planning system is Ireland's implementation of the Floods Directive, transposed by the European Communities (Assessment and Management of Flood Risks) Regulations 2010.[56] Implementation of the Directive at national scale will be through the CFRAM programme which began in 2006. One of the objectives of the CFRAM is to identify viable structural and non-structural measures and options for managing the flood risks. It would appear, however, that non-structural measures in this context may be limited to development control and flood forecasting mechanisms (e.g., Lee CFRAMS, 2010). The CFRAMS puts

[56] S.I. No. 122 of 2010

forward the measures and policies that should be pursued by Local Authorities and the OPW to achieve the most cost effective and sustainable management of flood risk.

Other pilot CFRAM Studies are progressing in the Dodder and Suir Catchments, and in the Fingal – East Meath (FEM FRAMS), with a view to a national plan. The Regulations state that preliminary flood risk assessments should include at least: "an assessment of the potential adverse consequences of future floods … taking into account as far as possible issues such as the topography, the position of watercourses and their general hydrological and geomorphological characteristics, including floodplains as natural retention areas" and should include impacts of climate change (Article 7(2)(d)). Flood risk management plans may also include the "promotion of sustainable land use practices, improvement of water retention as well as the controlled flooding of certain areas in the case of a flood event" (Article 15(3)).

The Environmental Scoping report associated with the Lee CFRAM study recognised that increased flooding, either naturally or deliberately, presents opportunities for the expansion of wetland habitat, both freshwater and estuarine, within the catchment with benefits to associated species (Halcrow, 2007). With the CFRAM approach, policy is now in place in Ireland that recognises the importance of understanding catchment scale processes, which is also the underlying philosophy of the WFD. If the use of wetlands for flood attenuation is considered in certain locations in future, public engagement will be essential from the earliest stage of the catchment management planning process.

6. Coastal and Marine

6.1 European law relating to status of marine and coastal waters

Marine Strategy Framework Directive (MSFD) (2008/56/EC)

This directive follows a similar approach to the WFD, in calling on EU Member States to ensure "good environmental status" of all of Europe's marine regions and sub-regions as its core objective.

6.2 National level implementation of the MSFD

Ireland so far has no statutory instrument to enact the MSFD. A national policy document on Integrated Coastal Zone Management (ICZM) was published in 1997 but this has not been effectively adapted by any Government department. The lack of a national coastal policy has implications for management of other pressures on the coastal zone, including wetland habitats. There is no national plan or strategy on coastal erosion, for example, which can lead to different approaches being taken in different locations. A lack of national policy also means that there is no framework within which to consider more recent approaches to erosion and coastal flood risk management such as managed realignment.

7. Impact Assessment

7.1 European law on Impact Assessment

Directive on the assessment of the effects of certain public and private projects on the environment (85/337/EEC as amended by Directives 97/11/EC, 2003/35/EC and 2009/31/EC).

This Directive requires an assessment of the environmental impact (an EIA) of any project likely to have significant effects on the environment before consent can be granted. The EIA Directive is currently under review. The Commission's Communication on the effectiveness of the EIA Directive (COM(2009) 378 final) explicitly states that adaptation to climate change is not sufficiently considered within the EIA.

Directive on the assessment of the effects of certain plans and programmes on the environment [SEA Directive] (2001/42/EC).

The Strategic Environmental Assessment (SEA) Directive involves the systematic identification and evaluation of the impacts of a strategic action (e.g. a plan or programme) on the environment. It works in conjunction with the EIA Directive. The consideration of alternatives within project planning is a legal requirement of the SEA Directive. Under Irish SEA planning guidelines it is argued that alternatives must be realistic and capable of implementation, and should represent a range of different approaches (DEHLG, 2004). Arguably, the SEA could be viewed as a more suitable process within which to consider alternatives such as soft approaches to flood management, as traditionally by the EIA stage there is little opportunity for considering alternatives to the proposal (Lee and Walsh, 1992). The inclusion of alternatives at the strategic planning and programme level provides the opportunity for more sustainable decision making.

Potential impacts should include secondary and cumulative effects. Climate change is a cumulative effect yet to date SEAs have tended to focus almost entirely on mitigation of climate change and not adaptation which is more directly related to the use of wetlands for flood attenuation.

7.2 National Planning, Development and Impact Assessment

7.2.1 Development Planning

Under the Planning & Development Act 2000, local authorities must publish a development plan for their area which is the main instrument for regulation and control of development. County Development Plans must take all practicable steps to ensure the prior identification of any areas at risk of flooding and flood zones in order to effectively shape the drafting process (DEHLG & OPW, 2009). This is done in consultation with the OPW. Alongside the County Development Plans, sit the Local Area Plans (LAPs) which allow for more detailed and area-based planning. Many LAPs are equivalent in size to smaller development plans.

Flood risk assessment at the site-specific level in areas at risk of flooding is required for all planning applications, even developments appropriate to the particular flood zone. Planning legislation allows for permission to be refused on the basis of flood risk without

attracting compensation. No studies have been conducted on the number of planning applications that have been denied on the basis of flood risk. If a catchment management approach is to be fully adopted in Ireland, only developments which are consistent with the overall policy and technical approaches of the Guidelines should be permitted. Likewise if the use of wetlands for flood attenuation is to gain ground, an argument could be made for 'graded' protection of floodplains within the regional, county-level and local planning systems. Naturally available floodplain areas upstream of a town or in coastal locations, for example, should warrant a higher degree of development control than other areas given the potential role such habitat could have in flood attenuation.

Development Plans are sufficiently flexible to replicate such an approach and could derive this information from the flood risk mapping process that is already underway. Generally the spatial planning system has the potential to play a more far-reaching and imperative role than it currently does regarding future land use.

7.2.2 National level issues in Impact Assessment

One issue arising with respect to impact assessment in Ireland may be the fact that, in most cases, EIA is restricted to individual projects and does not fully address cumulative and indirect effects of several projects and strategic plans, programmes and policies. An indirect impact, for example, would be one where a development changes the water table and thus affects a nearby wetland causing an impact on hydrology (and ecology) of that wetland. In the context of the use of wetlands for flood attenuation, it would be very important to ensure that EIAs address external influences and interactions (i.e. upstream/downstream impacts) among components of water systems at the catchment level. There is no clear guidance on using EIA in a catchment sense though this may be something to be developed as implementation of the WFD and Floods Directive progresses. A useful exercise may be to examine completed EIAs to determine to what extent both wetlands, and flood risk more generally, have been taken into account in the EIA process. It should be noted that wetlands are specifically included in Annex III of the EIA Directive as a specific area where particular attention should be paid to the *absorption capacity of the natural environment* (emphasis added).

7.2.3 Future national planning law developments

The Planning and Development Bill 2009 put forward a number of provisions to support implementation of the WFD. The Bill includes a new mandatory objective requiring local authorities to integrate water management with broader planning policies (NWIRBD, 2010, p.50). In the context of wetland storage capacity, an important stipulation was included in the Bill that would remove the exemption status for infill of wetlands carried out under the Land Reclamation Acts, as amended (NWIRBD, 2010, p.50). Other forms of planning exemption for wetland infill would also be restricted or removed in forthcoming amendments to the Planning Regulations. This has considerable positive implications for flood attenuation potential of wetlands. It needs to be recognised that a drained wetland still retains water storage capacity to some extent, whilst a reclaimed or infilled wetland does not.

8. Agriculture and rural development

8.1 European law and policy

Common Agricultural Policy

This specifies the principles under which agri-environment and rural development schemes should operate, and the contents of agriculture support payments. The CAP is determined at EU level and is then operated by the Member States. Many accuse the CAP of being one of the main offenders in the promotion of river and floodplain degradation in recent times (ECOFLOOD Guidelines, 2006). Historically, the CAP has promoted intensification through the increased use of fertilisers, pesticides, high stocking densities and land drainage. The 'Agenda 2000' reform attempted to address these issues along with reductions in surplus production. The reform placed an emphasis on more environmentally sound farming. In order for farmers to receive a payment under the Single Payment Scheme they must follow rules, known as 'cross compliance', on environment, public health, animal health, plant health, animal welfare and land maintenance. In Ireland, cross compliance was phased in from 2005 onwards and an element of this relates to Good Agricultural and Environmental Condition (GAEC). Following a "health check" of the CAP in 2009, the GAECs of cross-compliance were amended.[57] In order to ensure that all agricultural land, particularly land that is no longer used for production, is maintained in good agricultural and environmental condition, Member States define minimum requirements, at national or at regional level[58].

There is obviously an inherent degree of flexibility in the application of the GAEC which may be useful in the context of wetlands. Given the Commission's emphasis on integration of environmental concerns into broader policy areas there is nothing to forbid the recognition of flood attenuation potential of, say, lowland floodplain areas and include recommendations within future policy on CAP cross-compliance or future 'greening' measures (see below).

GAEC mainly covers soil (erosion, organic matter and structure) as well as minimum levels of protection and management of water, all of which are interrelated in terms of runoff retention. A new measure to establish buffer strips along water courses must be implemented by January 2012 at the latest. Again while this does not explicitly pertain to wetlands for flood attenuation there is potential for this to be included under such a standard. Riparian woodlands for flood attenuation, for example, could be explored in this context.

CAP has a role to play in facilitating climate change adaptation by providing wider ecosystem services dependent on land management (SEC(2009) 417, p.2). At farm level, improving soil management by increasing water retention to conserve soil moisture; and

[57] Following the 'health check' compulsory set-aside was abolished which was seen as a setback as regards biodiversity. Set aside had been made compulsory in 1992 and provided significant benefits for the protection and enhancement of biodiversity.

[58] In the context of cross-compliance, the term 'standard' means the standards as defined by the Member States according to Annex IV of Council Regulation (EC) No 73/2009.

landscape management, such as maintaining landscape features, can help the sector adapt to climate change.

In October 2011, the EC presented proposals to reform CAP for the period 2014-2020, under which further 'greening' measures were proposed (D'Oultremont, 2011). This would link direct payments with the delivery of public goods, for example: biodiversity, water quality, countryside, climate change adaptation. Presently the proposal is that 30% of single farm payments are conditional on greening measures. One aspect of proposed greening measures requires farmers to devote 7% of their land for 'ecological' purposes, but detail as to the focus of this measure has not been given. Another suggestion is that greening measures include use of 'innovative practises and technologies' that provide a better use of soil and water, for example. This presents an opportunity for 'ecological' land to be devoted to innovative flood management practises, e.g., use of floodplains as washlands, with potential biodiversity benefits.

8.2 National policy on agriculture and rural development

Irish policy on agriculture is informed and guided by the CAP. Consequently, CAP reform (2014-2020) will have important implications for the future. The Rural Development Programme (RDP), under Pillar II of the Common Agricultural Policy (CAP), and the National Rural Development Strategy, was introduced in 2007. This sets out three main priorities: competitiveness, protection of the environment through land management and the improvement of the quality of life in the wider rural economy. A major revision of the programme took place as a result of the changed economic situation, the introduction of the Health Check and the European Economic Recovery Package (EERP). This resulted in the closure of the Rural Environment Protection Scheme (REPS) scheme to new applicants and the introduction of a number of new schemes including a new agri-environment scheme and a targeted investment scheme. Under the CAP Health Check an additional €120 million was made available under the RDP from 2010 to 2015. Furthermore an additional €26.8 million was allocated under the EERP (DAFF, 2010). The EU funding under the HC and EERP has been specifically assigned to meet broader EU requirements relating to climate change adaptation and mitigation, renewable energies, water management, biodiversity, innovation, restructuring of the dairy sector and broadband internet infrastructure in rural areas. In addressing the new challenges Ireland opted to prioritise biodiversity, water management, climate change and broadband (DAFF, 2010), though it is unclear, to date, how these aspirations have been furthered. An investigation into the outcome of any work undertaken in these priority areas would be useful especially since natural flood management would come within the remit of biodiversity and water management.

Reform of the CAP for the period 2014-2020 has included, apart from 'greening', a number of possible developments could have more negative implications for wetlands and their use in flood attenuation. One example has been as a result of challenges faced by the European dairy industry since 2009. In response to this, the EC reactivated a range of support measures provided for in the CAP Health Check (intervention, export refunds, aid for private storage) to help stabilise the dairy sector. Arguably this represents a retrograde action, towards intensification of a specific sector. At a meeting of the Agriculture Council in November (2009), approval was given for some short-term

measures to be implemented to assist the dairy sector. This took the form of an additional €300 million made available to the dairy sector in the 2010 budget of which Ireland will receive approximately €11 million (DAFF, 2010). The issue arising is that it could cause an increase in both stocking densities, causing compaction, and conversion of rough pasture to improved agriculture. The latter usually requires drainage works which can be detrimental to wetland habitats. In Nagoya, at COP10 of the CBD, the EU agreed to end, reduce or reform economic incentives that negatively impact biodiversity which obviously includes farming subsidies. CAP reform is an important means for facing up to this challenge. Further research is needed on the effects of farming practices on ecosystem services at several scales of analysis: from farm level to catchment level.

8.3 Arterial drainage

Certain legislation has had profound impacts on the intensification of agriculture in Ireland. At least 30% of the land area of the country has been drained through arterial drainage programmes and widespread field drainage under the Arterial Drainage Acts, as amended (Heritage Council, 2003). The OPW maintains these schemes, delivered through their arterial drainage maintenance programme. Alongside are older Drainage Districts, managed by Local Authorities. Under section 9 of the 1945 Act, the OPW may consent to alterations to existing watercourses or structures in Drainage Schemes if the proposed works would not increase the risk of flooding or have a negative impact on drainage of land. This applies to re-grading or relocation of watercourses, replacement or relocation of embankments and various other works on Drainage Schemes. Section 9 could allow for the setting bank of embankments on lowland rivers that may reduce downstream floodpeaks.

Under the Planning & Development Act 2000, the following are considered as exempted development meaning they do not require planning permission: (1) development consisting of the use of any land for the purpose of agriculture; and (2) development consisting of the carrying out of any of the works referred to in the Land Reclamation Act, 1949. Proposals to amend these were tabled by the Green Party, but were not implemented. The DEHLG have stated that there are plans to amend Planning & Development Regulations 2001 to provide that Class 11 (Land Reclamation) shall not apply to any development where that development involves an area in excess of revised EIA thresholds. A strict reading of Class 11 (f) relating to “the reclamation of estuarine marsh land or of callows, where the preservation of such land or callows is not an objective of a development plan for the area” would suggest that where this is an objective of the development plan it could not be considered exempted development. However, given that the EIA threshold is >50ha, many wetland areas would clearly still be exempt. By not subjecting drainage works to the planning process it is unlikely that ecosystem services can be taken into account, of which flood attenuation potential is of great relevance here. Reclaimed and infilled coastal and inland wetlands signify a loss to the natural water storage potential of these landscape features. This appears to go against the catchment management and ecosystem based management approaches advocated in European best practise (UN & EC, 2003) and national policy documents acoss a range of governance scales.

Inconsistency between biodiversity and drainage legislation has already become an issue, resulting in the OPW undertaking Ecological Impact Assessments (EcIAs) pertaining to ecological effects of statutory drainage maintenance activities on protected habitats and species (e.g., raised bog, fens and mires, turloughs, whiteclawed crayfish, freshwater pearl mussel, otters and atlantic salmon). The OPW have adopted a new suite of Environmental Management Protocols and Stanadard Operating Procedures[59] designed to reduce environmental damage and, in places, to enhance river habitat in the course of river maintenance work. This was developed in conjunction with Inland Fisheries Ireland (IFI, formerly Central Fisheries Board) under the Environmental Drainage Maintenance (EDM) Programme[60]. A further development has been the Environmental River Enhancement Programme (EREP) which utilises river restoration methods for habitat and water quality improvement. Strategies include replacing hard substrates, increasing flow diversity and encouraging riparian vegetation[61]. There is a need to further investigate potential and inherent conflicts between flood risk management policy / legislation, and statutory arterial drainage. European best practise states stipulates that enhancing and protecting water retention capacity within catchments (including soil and wetlands) is important at all landscape scales (UN & EC, 2003). National law and policy should be consistent with this, and be consistent within the legislative tools of a jurisdiction.

It should be noted that the EC (Assessment and Management of Flood Risks) Regulations 2010 explicitly states that "Notwithstanding anything in the Arterial Drainage Acts, 1945 - 1995 or in any other Act or Regulation, the Commissioners shall not be required to do anything that is contrary to or inconsistent with the aims, provisions or requirements of the [Floods] Directive" (Article 24(2)). The Regulations also permit the Minister [for Finance] to designate an existing drainage scheme, which is vested in the Commissioners [OPW], as a flood risk management scheme by Order and the Minister may also make an order under these Regulations abolishing the drainage district containing the drainage scheme and its works (Article 55(1)). This process may be critical to allow for the controlled flooding of certain stretches of riparian floodplain, or creation of washlands and storage areas, for example.

8.4 Agri-environment schemes

'Farming water' is the subject of at least 2 UK pilot projects[62], plus others in the Netherlands and Germany[63]. These aim to demonstrate how the farmed landscape can be viably managed in ways that reduce flood risk downstream, whilst enhancing the natural environment. One UK initiative is a partnership project hosted by Staffordshire Wildlife Trust and funded by DEFRA through its Flood and Coastal Erosion Risk Management Innovation Fund (see Staffordshire Wildlife Trust, 2010, for further information). Such schemes involve compensating landowners for lost agricultural production as well as supporting a reversion to farming practises that work with the

[59] http://www.opw.ie/media/OPW%20Environmental%20Management%20Protocols%20&%20SOPs%20April%202011.pdf

[60] http://www.opw.ie/en/media/Issue%20No.%203%20EcIA%20Atlantic%20Salmon.pdf

[61] http://www.opw.ie/en/media/EREP%20Leaflet.pdf

[62] http://www.parrettcatchment.info/ and Staffordshire Wildlife Trust, 2010.

[63] See Joint Approach for managing Flooding (JAF) http://www.jaf.nu/nieuw/eng/projecten/farming.html

flood prone nature of their land, e.g., washland creation, reducing stock density and hay-cutting on wet meadows.

In Ireland, under REPS, there was a requirement to retain all habitats identified on the REPS Plan including wetlands such as callows, turloughs, bogs, fens, marshes and swamps. This measure, however, had a biodiversity basis, not a flood attenuation one (DAFF, 2007). Whilst this was a pilot measure, its inclusion showed opportunity to promote alternative farming practices through REPS. A policy, plus financial incentives advocating 'farming water' could have important implications for increasing the water storage potential of wetlands, or washland creation in Irelnd .

Agri-environmental schemes have potential to contribute to the use of washlands for flood attenuation if they are linked into strategic planning of an area. Because REPS was not designed to deliver flood protection benefits, funding for it was generally only forthcoming where there was also strong delivery for biodiversity targets. Use of wetlands for flood attenuation may be of limited immediate or localised benefit to farmers, but can provide a wider public benefit.. Studies have shown that other drivers may encourage landowner participation into such schemes, but ultimately financial mechanisms are necessary to secure delivery, including both capital outlay and compensation for profits forgone. This is where, in Ireland, CAP reform could play a major role to incentivise land use change for flood risk reduction, however, the whole area of financial incentives needs to be explored in much greater detail than can be included in this report.

Experience to date with the Farming Floodplains for the Future scheme found that where a farmer was already in receipt of an agri-environment payment for biodiversity management, and implementation of a flood management scheme did not require a major change in that management, no further incentive was necessary to secure co-operation (Staffordshire Wildlife Trust, 2010). The project team, however, added a caveat that on farms visited where agri-environment schemes did not apply, farmers asked the question 'what's in it for me?' This confirmed the need to provide incentives for land use change to acheive flood management benefits, but the implication from the case studies was that payments required need not be prohibitively expensive (Staffordshire Wildlife Trust, 2010).

There needs to be some communication mechanism to enable information on, for example, county level biodiversity targets, river basin management objectives and/or flood management, to be incorporated into both agricultural and rural development policy and individual farm level planning. Farming and forestry are crucial in rural areas. There ought to be a concentrated effort on integrating these sectors into spatial planning of catchments with regard to flood attenuation potential.

8.5 Potential future developments

Recent CAP reform proposals for 2014-2020, could have implications for wetlands and runoff generation at local scales. Along with the removal of current milk quotas in 2015, EU total milk quota will be increased by 1% per annum. The Irish government allocated a quarter of the 1% increase in Ireland to new entrants to the industry. This has, so far,

resulted in about 230 new dairy operations (81% of which are concentrated in the south and south east) with milk quotas of 200,000 litres (Teagasc, 2012). The change from predominantly beef and mixed beef/sheep and tillage to dairy farming involves significant land management change, and potential water quality issues arising from concentrated run-off from dairy facilities. Increased stocking densities can also cause soil compaction (reduced infiltration) and encourage conversion of rough pasture to improved grassland through drainage. Apart from water quality issues, there are implications in terms of flood generation at the local scale as a result of land compaction and increased run-off potential (O'Connell *et al*., 2007).

In Nagoya, at COP10 of the CBD, the EU agreed to end, reduce or reform economic incentives that negatively impact biodiversity which obviously includes subsidies. CAP reform is an important means for facing up to this challenge. Further research is needed on the effects of farming practices on ecosystem services at several scales of analysis: from farm level to catchment level. The relationship between CAP and its related instruments and the WFD is the subject of on-going research. It is unclear whether similar considerations are being made with regard to the relationship between CAP and runoff generation at similar scales. Such widespread, policy driven, agricultural land management change should require SEA.

8.6 Forestry

Any new forests in Ireland must be managed in accordance with Sustainable Forest Management principles, including a requirement that broadleaf buffer strips be planted in commercial forests adjacent to streams and rivers to decrease the speed of runoff from new developments and enhance the riparian environment (Forest Service, 2000b). The Forest Environment Protection Scheme (FEPS) requires that 18-20% of new plantation must qualify as an 'Area of Biodiversity Enhancement', which can include buffer zones along aquatic zones (DAFF, 2008a). Creation of new habitat such as ponds or extension of wet areas, creation of ecological corridors between habitats, increases in riparian zone and planting with suitable species are some examples of the optional measures that can be carried out under FEPS (DAFF, 2008b). Most of these measures have to be carried out in consultation with the Forest Service. Clearly there is scope for promoting flood attenuation by the strategic planting of permanent buffer areas with suitable (wet or floodplain) woodland species or by altering the shape and location of such plantings to maximise flood attenuation potential. These are factors amongst others that have been identified as having an impact on flood attenuation potential of floodplain and riparian woodland (Nisbet & Thomas, 2008). However, there may also be conflicts arising due to increased levels of drainage required for productive woodland areas. Buffer zones should be designed for maximum retention between the planted areas and watercourses.

In the context of the use of wetlands for flood attenuation it would be useful to explore how Forest Service objectives could ensure that broader regional flood management considerations could be delivered through the FEPS and other afforestation-related grants.

9. Policy frameworks abroad

Owing to increased flooding in recent years and the enormous economic cost associated with maintaining engineered flood defences, "allowing more space for rivers" has been gaining ground across Europe (Moss and Monstadt, 2008; Ostaficzuk and Ostrowski, 2003). This is evidenced through the change in terminology used by many regulatory bodies. Adaptation to climate change has been an important driver to engage national, regional and local planners into floodplain and wetland management, as have recent large flooding incidents such as those that occurred in Ireland in 2009. Already a number of strategic initiatives have been launched to facilitate this process. A brief overview of some of these is presented below.

9.1 United Kingdom - Making Space for Water

DEFRA launched '*Making Space for Water*' in 2004[64]. The objective is to implement a holistic approach to managing flood and coastal erosion risks (DEFRA, 2004). *Making Space for Water* aims to include flood risk assessments at all stages of the planning process and includes "greater use of rural land-use solutions such as the creation of wetlands and washlands, and managed realignment of coasts and rivers" (DEFRA, 2005, p.9). Where land and property is needed for works associated with managed realignment under a flood management scheme, the UK Government will provide the finance.

Catchment scale land-use management impacts are being investigated as part of *Making Space for Water* (DEFRA, 2007). Studies highlight where successful rural land management practices have been implemented through flood management schemes, and where barriers to the uptake of agri-environment schemes lie (DEFRA, 2007). The Innovation Fund was also established under the Strategy to encourage the development of new solutions for flood and coastal erosion risk management. Six projects were funded from a pool of £1.5 million over a 3 year period. These are presented with a brief description in Table 6.

Table 6: Projects funded under DEFRA's Innovation Fund

Project Name	Aim	Further information
Development of an Educational Tool for Shoreline Management	To develop an educational tool to improve public understanding of difficult decisions required in relation to coastal management and thereby assist in the uptake of more sustainable long term management policies.	http://www.defra.gov.uk/environment/flooding/risk/innovation/sld2313.htm
Farming Floodplains for the Future – Staffordshire Washlands	To enhance land management practices in the Staffordshire Washlands catchment of the Rivers Trent, Sow and Penk. The project will provide a positive model of holistic flood risk management, with added socio-economic and environmental benefits. This in turn will introduce more sustainable methods to land management - in line with *Making Space for Water*.	http://www.defra.gov.uk/environment/flooding/risk/innovation/sld2314.htm

[64] http://archive.defra.gov.uk/environment/flooding/documents/policy/strategy/strategy-response1.pdf

Table 6 (continued): Projects funded under DEFRA's Innovation Fund

Project Name	Aim	Further information
A Collaborative Approach to Sustainable Coastal Land Management	To promote and enable change in land management on the Essex coast by providing groups of landowners with the tools they need to adapt to political and climate change. This project will review existing studies into the future flood management of the Essex coast, and identify coastal strips, management units or 'cells' where 'quick wins' are possible.	http://www.defra.gov.uk/environment/flooding/risk/innovation/sld2315.htm
Restoring Floodplain Woodland for Flood Alleviation	To facilitate the establishment of floodplain woodland (c.15 ha) in the River Laver catchment to demonstrate and help communicate the benefits of this for flood alleviation. There is also an opportunity to develop win-win solutions given the ability of floodplain woodland to benefit water quality and freshwater habitats, which would contribute to meeting the targets set out under the WFD.	http://www.defra.gov.uk/environment/flooding/risk/innovation/sld2316.htm
Slapton Coastal Zone Adaptation Plan	To develop and implement an innovative and sustainable community-based adaptation programme for Slapton in South Devon which is very vulnerable to coastal erosion and not suitable for hard, engineered protection works.	http://www.defra.gov.uk/environment/flooding/risk/innovation/sld2317.htm
LIFE – Long-term Initiatives for Flood Risk Environments	To demonstrate the benefits of integrating a number of important environmental approaches within developments; such as sustainability, natural flood mitigation, zero carbon/zero waste in such a way the whole is greater than the sum of the parts. The long-term ambition of the project is to see these ideas implemented across the country.	http://www.defra.gov.uk/environment/flooding/risk/innovation/sld2318.htm

9.2 The Netherlands – Room for Rivers

In the Netherlands, the *Room for the Rivers* initiative[65] aims to address flood protection, master landscaping and the improvement of environmental conditions in the areas surrounding Holland's rivers. The project began in 2006 and is expected to run until 2015. Specifically the initiative applies to the lower reaches of Rhine and Meuse rivers and follows-on from earlier preliminary studies on the feasibility of spatial rather than purely technical flood solutions providing more room for peak river discharges (Blackwell and Maltby, 2006). This Plan has three objectives:

- by 2015 the branches of the Rhine will cope with a discharge capacity of 16,000 cubic metres of water per second without flooding;
- the measures implemented to increase safety will also improve the overall environmental quality of the river region;
- the extra room the rivers will need in the coming decades to cope with higher discharges due to the forecast climate changes, will remain permanently available.

To achieve this, forty projects will be completed in the period up to 2015, with a budget of €2.2 billion, making more room at a total of 39 locations (Room for River factsheet, undated). The types of measures to be carried out include lowering of floodplains and groynes, relocating dikes, de-poldering, removing obstacles, deepening summer beds, high water channels and creating water storage. Projects underway include, for

[65] http://www.ruimtevoorderivier.nl/

example, the lowering of the floodplain at Millingerwaard on the Rhine where a 9cm decrease in water levels will be achieved during peak discharge. The excavated floodplain will be managed as a nature reserve. Room for Rivers involves co-operation between numerous authorities at local, regional and national levels. Netherlands Ministry of Transport, Public Works and Water Management carries overall responsibility, with assistance in the provinces from water boards and municipalities in the river regions (Dutch Government/Room for River, 2010).

9.3 Sustainable Flood Risk Management Planning in Europe

The Floods Directive (FD) is a primary driver behind Sustainable Flood Risk Management Planning (SFRMP) in Europe. To assist member states in implementing SFRMP, the EU has responded by forming the Strategic Alliance for Water Management Actions (SAWA) - a consortium of 22 partner institutions from Norway, Sweden, Germany, The Netherlands and the United Kingdom that are co-operating to develop guidance documents and tools to help member states implement SFRM strategies that comply under both the WFD and the FD[66]. One output from SAWA has been the development of a guidance manual that provides a rapid assessment tool for the survey of water bodies with Sustainable Flood Retention Basins (SFRB) (McMinn *et al*., 2009). SFRBs can contribute to flood mitigation within a catchment and can range from engineered Hydraulic Flood Retention Basins (HFRBs) to Natural Flood Retention Wetlands (NFRWs). The classification tool provides a rapid screening method for water bodies and flood defence structures, assessing both flood and diffuse pollution control purpose. This can be applied as a rapid screening method to identify water bodies and impoundments, which have the potential to be used as part of a SFRM strategy. The tool uses field methodology that takes into account variables such as: catchment size, urban catchment proportion, mean annual rainfall, floodplain height, drainage, vegetation cover, seasonal influence, dam height and length, outlet arrangement, etc. The result is a numerical categorisation of a particular SFRB and provides a quantifiable measure to identify infrastructure (including green infrastructure) with the potential to contribute to flood risk management planning. The guidance manual suggests that each site assessment can be completed within one hour; however, this would involve both expertise and experience to achieve given the list of variables that must be considered. Bullock and Acreman (2004) proposed that a rapid assessment methodology was needed to classify the likely hydrological functioning of wetlands since it is not feasible to study every site in detail. This is essential to underpin policy making and planning decisions and still remains a challenge in the realm of water management with regard to the flood attenuation potential of various wetlands.

[66] http://www.sawa-project.eu/index.php?page=sfrb-edin

PART III Conclusions and Recommendations

1. Technical review

1. Wetlands have a major impact on the hydrological cycle and certain wetland types have been shown to have a role in flood attenuation but there is uncertainty as to the effectiveness of this for some wetland types.

2. Wetlands represent a heterogeneous group of habitats, each with unique hydrological processes. Attenuation potentials are affected by many geographic, climatic, seasonal and land management variables, but are primarily a function of wetland water storage capacity at any specific time. i.e., when a wetland is saturated it's water retention capability is diminished, or nil.

3. The main natural wetland types can be divided, hydrologically, into a number of broad categories: (1) peatsoil wetlands which can slow the movement of water from hillslope into channels; (2) alluvial floodplains, which can temporarily store water which spills over the channel banks, and (3) coastal wetlands / estuarine floodplains, which store riverine and tidal flood water and attenuate the erosive action of waves.

4. Within a category of wetland, there can exist considerable variation in the ability of a particular wetland to attenuate flooding, making it difficult to predict the flood attenuation value of a particular wetland.

5. Alluvial floodplains have been shown in most studies to provide considerable flood attenuation potential, but there is little strong consensus on the same role for peatsoil wetlands.

6. Alluvial floodplain attenuation effects are the subject of ongoing studies in Ireland by the Flood Studies Update (OPW) to establish a reliable model that accounts for the large amount of out of bank flow experienced by lowland Irish rivers.

7. This review has led us to make a distinction between 'hydrological' floods (high frequency, low to medium rainfall events that occur commonly without economic damage) and "economic" floods (low frequency events following high intensity rainfall, potentially causing economic damage). Wetlands may readily attenuate 'hydrological' floods but may fail to attenuate 'economic' floods. The literature doesn't distinguish between these events, and tends to group 'floods' into a single meaning.

8. In general the influence of wetlands in reducing flood peaks is greatest for high frequency, low to medium rainfall events that occur when wetlands have a large capacity for storage. It is least for large events when soil and wetland storage are saturated in advance.

9. Although it is generally accepted that many land use changes can lead to greater flood risk at local scales, the complex interactions of soil type, land use, landscape configuration and local climate at a local sub-catchment level make it difficult to scale these processes up to large catchment scales. This is an area of ongoing international research.

10. Most evidence of flood plain attenuation effects are derived from modelling rather than empirical studies. Factors influencing flood attenuation properties of floodplains include: surface water levels, contribution of hillslope flow, soil moisture deficit, topography (particularly surface depressions), antecedent rainfall conditions, surface vegetation characteristics, drainage characteristics and the degree of connectivity between channel and floodplain.

11. For floodplain wetlands, large surface area, low gradient, relatively unsaturated surface soils and rough surface topography increase the potential for more effective flood storage.

12. For undisturbed peatlands with a large surface area, low gradient, relatively unsaturated surface soils and rough surface topography; the flood storage potential is high. Small, steeper wetlands with a high water table, smoother surface and enhanced drainage runoff (such as occur for grazed peatlands) would likely have lower flood attenuation potential.

13. Increased flood storage potential is gained from peatlands that store surface water effectively through complex surface topography, rough vegetation and by soil saturation, but more evidence is required on how this affects flood peaks at stream and catchment levels.

14. Factors that are generally thought to enhance 'hydrological' flood attenuation (for floodplain wetlands) or enhance surface water storage (peatsoil wetlands), such as tall, woody semi-natural vegetation and complex surface topography are unlikely to provide much benefit for attenuating large, low frequency 'economic' flood events.

15. Coastal wetlands, especially salt marshes, attenuate wave energy very effectively, providing a first line of defence against tides and waves, particularly during stormy conditions. The natural resilience and resistance to frequent inundation provided by salt marshes and tidal floodplains has meant that their utilisation is becoming a recognised alternative to hard engineering approaches for coastal protection. This is especially important in Ireland given climate change predictions of rising sea level and increased coastal surge and storminess.

16. Small isolated groundwater wetlands within a landscape probably have limited storage capacity and flood attenuation potential on an individual basis, but modelling studies show that when many small wetlands occur within a catchment, the aggregate storage capacity may give rise to considerable flood attenuation potential. This however depends on numerous factors that affect

the available storage in such wetlands, particularly antecedent groundwater levels and soil moisture saturation.

17. Some function specific constructed wetlands have demonstrable flood peak attenuation properties (e.g., SuDS). In addition to the same variables that govern the storage capacity of natural wetlands, their effectiveness in flood attenuation relies heavily on their size and design-standard.

18. Human management or interference can potentially increase or decrease the capacity of a given wetland to attenuate floods. For floodplains, encouraging extensive surface water (typically those occurring in 'restored' wetlands) can raise groundwater levels, reduce soil moisture deficits and infiltration rates and speed runoff. Agricultural intensification can increase soil compaction, leading to reduced infiltration rates and enhance surface drainage, leading to increased runoff. More natural vegetation, particularly trees and rough vegetation can increase infiltration rates and slow runoff rates. For peatsoil wetlands, increased drainage of wetlands can increase the soil moisture deficit of peat surface, enhancing soil water storage capacity, but also speed water flow to channels. Blocking drainage channels can elevate soil moisture levels, so reducing soil water storage capacity, but also retard water flow to channels.

19. Drainage interactions with wetland storage potential are complex and even paradoxical and require careful consideration to estimate attenuation effects.

20. It is important to recognise that there is interaction between the storage effects of soil, wetlands and vegetation, and each is capable of retaining water for a certain length of time. In light of this, catchment land-use management needs to consider the role of wetlands relative to other catchment features in flood attenuation. Soil degradation and compaction, and removal of rough vegetation, can increase local flood generation. Wetlands can thus be pushed beyond their ability to attenuate runoff at a local scale because of excessive inflows. but this does not mean that they are not functioning in terms of attenuation.

21. Wetland flood attenuation function is commonly conflated in the literature with their role in nutrient and sediment retention and biodiversity enhancement. The evidence , however, tends to show that these functions do not necessarily coexist. The flood attenuation potential of ICWs, for example, should be strongly downplayed given the potential for flooding to mobilise pollutants and impact negatively on downstream water quality

22. It appears that alluvial floodplain wetland and coastal wetland have the greatest known potential to contribute attenuation services to address 'economic' flooding. Peatland attenuation effects are not as well understood, as yet. Isolated wetlands may play a considerable role, cumulatively, within a catchment but not enough is known about this in an Irish context.

23. In terms of using floodplains as 'washlands' within large scale flood relief schemes, there is a spectrum in terms of degree of engineering involved in

managing these areas for flood control. At one end of the spectrum are natural floodplains (such as Insh Marshes, Scotland), and at the other are highly engineered washlands with various levels of water level management (e.g., Beckingham Marshes, UK, or Altenheim Polders, Germany).

24. There is a large body of conceptual literature on the cost effectiveness of employing wetlands in flood management strategy. Whilst many of these gave examples of projects that demonstrated flood alleviation benefits, few gave transparent, detailed, cost-benefit analyses. It was often unclear as to what criteria were used to assess costs and benefits, such as whether, for example, agricultural subsidies and biodiversity funding were included, or whether provision of additional 'ecosystem services' were factored in.

25. It was not possible to assess the true cost effectiveness of many natural flood management solutions that have been implemented. Most projects have availed of additional funding over and above infrastructural expenditure, mainly for biodiversity goals (e.g., RSPB reserve creation and BAP target funding) and public consultation.

26. The creation, restoration and use of wetlands for flood attenuation has become increasingly popular over the past 20 years (primarily floodplain storage, washland, polder and coastal sites). This has been driven, largely, by European Guidance and subsequent policies that promote strategies such as 'Making Space for Water' (UK) and 'Room for Rivers (Netherlands). Sucessful floodplain restoration, managed floodplain storage schemes, and coastal realignment schemes are well documented, particularly in the UK. In addition to flood alleviation benefits, a range of associated benefits, such as biodiversity enhancement and sediment control have been realised. Benefits, though, need to be examined on a case-by-case basis as flood alleviation and biodiversity goals are not always synonymous.

27. Ireland clearly lags behind with regard to NFM approaches and has no underpinning policy to embrace the concept of making space for water. The one operational Irish example - Corkagh Park flood attenuation ponds - were reported to have been a cost effective solution, resulting in protection of downstream urban areas. The fact that the land was already in public ownership almost certainly contributed to this.

28. In Ireland, to date, NFM options considered as part of large OPW flood relief schemes have not been found to be feasible. Though upstream storage is often considered at the design stage of large flood relief schemes, socio-economic factors preclude this as a viable option, primarily owing to the cost of agricultural land and also to potential safety, planning, cost and insurance issues surrounding the storage of a large body of water. Consultation with OPW revealed that there is a will to incorporate NFM strategies into larger projects, but it was felt that limitations currently exist, primarily in the lack of empirical evidence that wetlands help attenuate large events (1 in a 100) and also owing to the current absence of realistic catchment flood risk maps (progressing under CFRAMS).

2. Law and policy

1. Almost all legislation and policy documents at international, European and national level recognise the importance of wetlands and the ecosystem services they provide. What appears from this review is that while there is little or no legislation which enables the use of wetlands for flood attenuation *per se* a number of legal instruments and policies contain sufficient flexibility to be adapted for this purpose. It is clear that there is scope, and indeed an imperative, to develop national policy on the ecosystem services of wetlands, including flood attenuation where this can be demonstrated to be effective.

2. The Ramsar Convention Secretariat (2007) has expressed concern over the lack of direction from governments, generally, in wetlands policy, stating that this results in a lack of 'profile for wetland issues'. In turn, inadequate attention is being paid to wetland values when land use decisions are made or are subject to review. From the review of European and national law it is clear that there is limited connection made between various sectoral policies. Attempts are being made to address this, for example, by integrating spatial planning with flood risk management and river basin management.

3. The CFRAM approach indicates that policy is in place that recognises the importance of understanding catchment scale processes, nevertheless there are still hurdles that need to be overcome in order to achieve sustainable river enhancement (e.g., conflicts with statutory drainage maintenance). A key element of this process is involvement of other public and semi-State authorities as well as the general public. If the use of wetlands for flood attenuation is to be considered in certain locations in future, public engagement will be essential from the earliest stage of the catchment management planning process.

4. The CFRAM approach could be more specific in advocating the use of wetlands and washlands in flood risk management, perhaps through criteria to identify and map existing wetlands and areas where, for example, floodplain restoration could contribute to flood alleviation.

5. One of the main objectives of any future national wetlands policy must be to provide a coherent framework for management of wetlands within a broad context. The lack of accurate information on the distribution and status of many of Ireland's wetlands gives rise to the need for a thorough inventory, the production of a specialised wetland map and specifically a mapping of opportunities for spatial planning restrictions where undeveloped floodplains, for instance, are located upstream of developed areas.

6. Although conservation must remain a key pillar of EU biodiversity policy, any new target must factor in the role of ecosystems and ecosystem services. The importance of ecosystem services is already recognised in the current policy and is for instance an important element of the Marine Strategy Framework Directive, as a part of the EU Integrated Maritime Policy, but this has not yet

sufficiently been turned into specific measures. It is important to identify and assess key ecosystem services and to factor them in to future targets.

7. A review of available schemes under CAP indicate that agri-environment schemes in their current form do not provide sufficient incentives for flood management benefit. Effective, widespread adoption of such change requires the alteration of existing, or the development of new, mechanisms capable of providing long term support to co-operating farmers. Experience in the UK from the 'Farming Floodplains for the Future' initiative provides a useful model. This examined new incentives specifically tailored to the delivery of flood management objectives through land use change. Using a template similar to agri-environment grants, it was suggested that a one-off capital payment to cover initial outlay, plus regular incentive payments, could be made to farmers who participate. Funding mechanisms to support alternative flood management solutions in Ireland needs to be explored.

8. Opportunities for incorporating flood risk management at the farm level should be explored under new 'greening' measures proposed for CAP 2014-2020. Measures such as 7% set aside of 'ecological' areas and use of 'innovative practices' could be applied to the concept of floodplain management in Ireland.

9. The current lack of a national coastal management strategy results in a somewhat piecemeal approach to erosion management and this could have implications for future decisions dealing with coastal flooding and coastal zone management as an impact of climate change. Management of erosion in Ireland has tended to focus on hard, engineered protection works. Consideration should also be given to coastal realignment, river corridor widening and some river restoration techniques such as reconnection of floodplain function, setting bank of embankments and raising channel bed levels.

10. At a national level, when considering the linkages between water, wetlands, agriculture and forests, serious consideration needs to be given to how the various Government departments, semi-State bodies and other interested parties can communicate and integrate their various policy goals and objectives so as to achieve as many objectives as possible and benefit society as a whole.

11. NFM options are becoming common in practise and underpin policy in neighbouring countries in response to climate change predictions and severe flooding experiences. Given that Ireland faces the same 'economic flooding' issues, there seems to be a limit to the extent to which Ireland is prepared to integrate such strategies at present. The reasons for this are unknown. The Lee and Dodder CFRAMS did not appear to be very far reaching in identifying NFM solutions within the approach. Fingal East Meath FRMP is aspirational, but did not show a definite commitment to the use of NFM. Arguably this is because adequate flood risk maps are not yet produced. There is a scope for inclusion of a dedicated 'Making Space for Water' type strategy within the current CFRAMS process.

12. CFRAMS, whilst catchment based, does not encapsulate the ethos of a strategy that seeks to accommodate excess water in the catchment rather than contain it. If policy makers adopted a self-explanatory, narrrative terminology, alongside CFRAMS ,for a similar approach in Ireland (like 'Making Space for Water' and 'Room for Rivers'), it would be likely to increase the acceptance and understanding of the approach during community engagement processes. Education and ultimately public acceptance of NFM is required to promote its use in response to increased flood risk in Ireland.

3. Recommendations

1. Experimental studies that measure attenuation effects for different wetland types are required in Ireland, especially on peatlands. The OPW Flood Studies Update (FSU) is investigating floodplain attenuation effects through hydrological simulation, but little is known about runoff generation and attenuation on Irish peatlands.

2. It may be useful to study full hydrometric datasets in combination with land use change statistics across different catchments types in Ireland to help determine the impact of catchment land use change on flooding. This may help target where land management changes can influence water retention in the future.

3. Given the highly variable nature of wetlands, even within each wetland type, considerably more study is needed to develop a rapid and cost-effective method to estimate the attenuation potential of individual wetlands.

4. The Corkagh Park scheme in Ireland is a modest but good example of what can be achieved, but, ultimately, Ireland needs a number of pilot NFM projects. It is only by demonstrating and working through the issues involved in undertaking such schemes (e.g., public participation, compensation, design) that the way can be opened for NFM as a broadly acceptable strategy.

5. In terms of realising flood alleviation benefits of (in particular) floodplain restoration or managed storage options in Ireland there are three main areas of investigation required: (1) a review of additional funding sources for biodiversity goals and the community engagement process; (2) a review of economic incentives and compensation mechanisms for landowners; (3) a review of the social mechanisms for encouraging landowners, particularly on alluvial and tidal floodplains and to change management practices that could incorporate set aside land for the purpose of flood relief; (4) a review of the Partnership approach to realising land-use and management changes that are required to deliver natural flood management schemes; and possibly (5) a review of engineering issues that may limit use of NFM in Ireland, e.g., safety of dam structures (raised embankments for flood storage) upstream of populated areas.

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