WETLANDS AS BUFFER ZONES IN CATCHMENT WATER RESOURCE MANAGEMENT

David HOGAN [1], Edward MALTBY [2] and Martin BLACKWELL

Royal Holloway Institute for Environmental Research, University of London
[1] E-Mail: david.hogan@bbsrc.ac.uk, Fax: + 44 1837 82139
[2] E-Mail: e.maltby@rhbnc.ac.uk, Fax: +44 1784 477427

Abstract

A conventional approach to the establishment of buffer zones is to locate them alongside watercourses, for which protection from environmental pollution is required. However, the strict application of a prescriptive approach may not be the best way of utilising wetland functioning, and buffer zones may be more effectively sited at some distance from the river channel. There are many factors to consider, including the important requirement of optimising the period during which polluted water is contained within the wetland, thereby enabling biogeochemical process interactions to take place. Functional assessment can identify hydrological pathways and inherent properties of the wetland ecosystem in order to indicate the likelihood that key functions for water quality improvement are capable of being carried out. An example is given of studies undertaken in south-west England, which demonstrate the importance of selecting wetlands in optimal locations for the most effective establishment of buffer zones.

Keywords biogeochemical process, buffer zones, catchment management, hydrological pathways, policy development, recource management, wetland characteristics, wetland conservation, wetland location, wetland restoration

INTRODUCTION TO WETLANDS

What are wetlands?

Wetlands are often described by words such as bog, fen, mire, marsh and swamp, all of which suggest a particular kind of habitat in which water is crucially important. In simple terms, as the name suggests, wetlands can be thought of as occupying those intermediate areas between dry land and aquatic ecosystems, and as such have several important characteristics in common with both. They are at least seasonally waterlogged, have physical, chemical and ecological properties dependent on the timing and nature of water movements, and the plants and animals they support often possess specialist adaptations for life in saturated conditions. Although a universally acceptable wetland definition has not yet been agreed, the main characteristics (after Mitsch and Gosselink 1993) used in defining wetlands are:

1. Wetlands are distinguished by the presence of water, either at the surface or within the root zone.
2. Wetlands often have unique soil conditions that differ from adjacent drier uplands.
3. Wetlands support vegetation adapted to permanently or seasonally wet conditions

Wetland loss and degradation

Wetlands occupy about 6 percent of the world's land surface Maltby and Turner (1983) but, according to some experts, the world may have lost half of its wetlands since 1900. Though details are uncertain for developing countries, it is no exaggeration for the developed world, where drainage has long been seen as a progressive, public spirited activity, which enhances the health and welfare of human society. Maltby (1991) suggested only half of the mediaeval resource remains today.

The impacts on wetland ecosystems and the resultant changes brought about are many and varied. They range from a reduction in area to an alteration in the way they work, from direct and planned effects to indirect, often unintentional ones, from immediate point source impacts to diffuse impacts with gradual long-term and/or chronic degradation, and from local to catchment, regional or even continental scale. The resulting changes vary from temporary to permanent and irreversible.

It is important to appreciate that whereas wetland loss represents an absolute and final disappearance of the resource, exploitation and degradation still allow the possibilities of wetland restoration by reduction of damaging impacts. The challenge today is to develop practical means of wetland conservation and restoration, which are based firmly on the many human as well as ecological benefits that wetlands can provide.

Conservation of wetlands

It is important to protect those wetlands which remain intact, and to conserve their functional capability by managing them in a sustainable way, integrated where possible into farm management plans or catchment management strategies. Appropriate land management may involve continuing the traditional activities such as grazing, which have sustained them, and in this context can be regarded as *wetland conservation*. However some very wet swampy sites would be damaged by any grazing at all; tall herb fen communities in these sites can be self-sustaining without resort to grazing or other management tools. Conservation of sites for wildlife conservation can also provide some buffering capacity to protect watercourses from risks of diffuse pollution from adjacent, more intensively farmed land. In some situations, however, care should be taken to avoid incompatibility of functioning, where, for example, nutrient-rich waters are permitted to flow into habitats dependent on water of better quality.

In some cases wetlands exist in a degraded form, in which the capacity for functions to be performed may be limited. Options for management depend on target objectives, which should be identified at a preliminary stage prior to undertaking restoration activities. Improvements in degraded wetlands are undertaken as *wetland restoration*. Where a wetland formerly occurred but has since been lost altogether, it would require the task of *wetland re-creation* in order to bring the site back to its former wetland status, though this is unlikely to be precisely in the original form.

Where a wetland is established on a site for the first time, this is regarded as *wetland creation*. A large amount of information is available on the types of wetland that can be created, their method of construction and their management (eg Nuttall et al, 1997), though many of these are targeted towards the treatment of specific point-sources of pollution.

Benefits of wetland protection and conservation

The conservation and good management of wetlands can provide a substantial range of environmental benefits including:

- Improving water quality through the removal of nutrients (especially N and P) and other pollutants.
- Providing a water supply for livestock
- Reducing flood risk downstream
- Helping to maintain river levels during dry times of the year
- Providing summer grazing when forage production on better drained land may be limited by droughtiness
- Contributing to wildlife conservation and biodiversity by providing specialised habitats for increasingly rare species of plants and animals
- Forming important elements of the landscape, contributing to the overall character and amenity value of the countryside
- Providing an educational resource for schools and other groups
- Providing alternative sources of income such as biofuel (eg willow coppice)
- Preserving the palaeo-environmental record (eg pollen and archaeological remains preserved in peat deposits, which provide a record of past landscapes and human activities)

The destruction of wetlands reduces or removes the possibilities of delivery of these benefits.

THE WETLAND POLICY ENVIRONMENT

A number of key features have characterised the wetland policy environment:

- Wetlands have been considered generally within the context of nature conservation, sustainable development, natural resource or other environmental policy. Hence wetland-specific issues or considerations are often subsumed by other interests.
- The historic policy framework for wetlands, especially in Europe, has been set by the nature conservation lobby rather than related to the water policy agenda. This is changing together with the obvious recognition of the importance of water for the genesis,

development and functioning of wetlands e.g. the 1992 legislation in France on water and wetlands (Loi sur l'eau No. 923, J.O. 04.01.1992).

- There has been a rapid increase in attention to wetland policies and/or strategies in both developing as well as developed countries in tandem with appreciation of their functional benefits. Thus whilst in 1987 only five signatory nations to the Ramsar Convention indicated they were involved in any sort of national wetland policy, strategy or plan, by March 1996, 55 nations had national wetland strategies or plans and 27 of the 92 Ramsar Contracting Parties indicated they were engaged in development or implementation of wetland policies (Rubec *et al.*, 1998).
- Despite the strength of this trend there has been very limited attention to matching the scientific/socio-cultural/economic case for wetland protection and 'wise use' (*sensu* Ramsar Convention) with appropriate policy instruments.

Throughout much of the developed world the primary instruments for wetland protection have been based on the requirements of wildlife and a traditional nature conservation approach utilising criteria such as rarity, uniqueness, population abundance or particularly good examples of ecosystem or habitat type. Until recently in Europe neither national nor supranational policies have separated out wetlands for special consideration from the wider nature conservation agenda. Typical of the approach at the European level is the Habitats Directive (92/43/EEC) which has established a network of Special Areas of Conservation (SACs) to promote biodiversity. Member states are required to protect these sites and manage them having regard for impacts from anthropogenic activities that will affect their conservation status. Yet links have not been made between the wider functional benefits of wetlands and the environmental policy framework, with the result that protected area status and consequent management actions may not fully realise the full range of benefits for conservation of the environment.

In Europe this is illustrated by the current lack of linkage between the science of how wetlands function in terms of water quality regulation and the precise location of buffer zones in the landscape, a clear indication of the poorly co-ordinated relationship between science and policy (see below).

The forthcoming European Union Water Framework Directive (Council Directive 6404/99) provides an opportunity for more effective translation of the emerging wetland science base into European policy. This can be achieved through measures to support key articles such as a methodology for determination of the ecological and chemical status of surface water fluxes into and out of wetlands (Art 10), development and implementation of tools and methodologies for linking information on wetland functioning directly to River Basin Management Plans (Art 16) and development and implementation of methodologies for involvement of all interested parties in the wise use of wetlands as required by such plans (Art 17).

INTRODUCTION TO BUFFER ZONES

What is a buffer zone?

A buffer zone is a piece of land, often having rough or semi-natural vegetation, situated between agricultural land and a surface water body such as a river or lake, and acting to protect that water body from harmful impacts such as high nutrient, pesticide or sediment loadings that might otherwise result from land use practices It offers protection to a water body through a combination of physical, chemical and biological processes, and some of the most beneficial processes for water quality improvement occur optimally in wetlands. It can be particularly effective for treating diffuse (non-point source) pollution from agriculture. The degree to which this protection is provided depends on a number of factors including the size, location, hydrology, vegetation and soil type of the buffer zone (Dosskey *et al*., 1997; Leeds-Harrison *et al*., 1996), as well as the nature of the impacts by which the water body is threatened.

Buffer zones can comprise both natural and constructed systems. Where a natural system is not available or is unsuitable for use as a buffer zones, it may be possible to construct an artificial system. Constructed wetlands are used primarily to treat point source pollution, such as industrial discharges, and prescriptions for their design, construction and maintenance are readily available (Nuttall *et al.,* 1997), but are not described further here, where the focus is on the opportunities available to use existing wetlands as buffer zones. Appropriate location of a buffer zone is essential to achieve optimal performance of a desired function (discussed later).

Buffer zones and wetlands

A buffer zone may or may not be a wetland, while, conversely, a wetland may or may not be acting as a buffer zone. Sometimes the driest land occurring on a floodplain lies alongside a watercourse, where it can act to some degree as a buffer zone, but may not normally be a wetland, except during brief periods of over-bank flooding from the river channel. But in order for wetlands to be effective as buffer zones, they need to be located in positions in the landscape best suited to intercept hydrological pathways (natural or artificial lines of drainage), which may be located some distance from the river channel, perhaps on footslopes above the level of the river floodplain.

Types of wetland buffer zones

These may be described by their appearance in terms of general *habitat type*, for example grass, tall herb fen, scrub, woodland or mixed/combination buffer zones. However vegetation can rapidly change due to management or abandonment (eg felling of woodland or scrubbing up of grassland following removal of grazing). An alternatively approach is to described wetland buffer zone types in terms of their position in the landscape and hydrological characteristics. Some of these are often synonymous with the concept of *riparian* or *river marginal wetlands*, that is, they occur in valley systems, within which they are linked to water bodies, perhaps by pathways of water flow, though are not necessarily found adjacent to them. They are identified in terms of their *location* (on floodplains or valley slopes) and of *hydrological inputs* including, singly or in combination, over-bank flooding from the river channel, high levels of groundwater, discharge of groundwater at the surface, particularly on footslopes, run-off and rainfall.

Other types of wetland such as those of topographic depressions (basin wetlands) or estuarine locations can also be important for the removal of nutrients from ground- and surface waters, though it is the river marginal types which are best placed to perform water quality functions due to their siting between agricultural land and the aquatic environment.

Benefits of wetland buffer zones

The main purpose of targeting wetlands for use as buffer zones is to protect the water environment (primarily rivers, streams and lakes) from pollution from agriculture. However other environmental benefits will occur with the establishment of wetland buffer zones.

Where pollution problems result from stock having direct access to a river for drinking supplies, it is often possible to fence off a strip of land (which may or may not be wetland) alongside the river and provide an alternative drinking source elsewhere. This will preclude both direct pollution of river water by animals entering the river for drinking, and damage to the banks at points of access. The establishment of rough or semi-natural vegetation in such areas provides other important environmental benefits including extended areas of riparian habitat for wildlife conservation, stabilization of river banks to limit erosion and reduce sediment loads in the river, providing shady conditions for fish populations, and providing vegetative material to the watercourse as food supplies for aquatic organisms

Buffer zones for water quality improvement

The ability of wetlands to improve water quality depends on the various natural processes taking place within them. Wetlands are capable of reducing nitrate concentrations in ground- and surface waters, and can also inactivate large amounts of phosphorus, including that derived from fertiliser run-off, thereby reducing the risks of harmful eutrophication of adjacent open water. However it should be noted that phosphorus occurs in many forms and some may be actually released into the environment under waterlogged conditions. Wetlands can remove heavy metals, pesticides, industrial residues and other toxicants, generally in forms which adhere to sediments or soil particles, while sediment removal in its own right can be a useful function. Aside from acting as an agent for the transport of pollutants, large amounts of suspended sediment in rivers can be deposited in riverbed gravels, thereby reducing their effectiveness for spawning salmonids.

Optimising buffer zones

Recognition of the possible controls by natural wetlands on water quality has motivated many investigations of the potential of using both natural and constructed wetlands for the removal of pollutants, especially nutrients, from both diffuse sources and in wastewater treatment (e.g. Godfrey *et al.*, 1985; Hammer, 1989, Richardson 1985; Kadlec and Knight, 1996). The example of nitrate dynamics is given in Box 1.

Box 1

Using wetlands to remove nitrate

Nitrate is a potential major problem in the aquatic environment because it is highly soluble and it represents a large proportion of land-based fertiliser applications which have increased significantly in recent years. Above certain concentrations it may be hazardous to human health and in excess contributes to ecological harm especially through eutrophication. Wetlands can play a key role in reducing the nitrate flux to groundwater and especially surface waters. As in other ecosystems this might be achieved through plant uptake but the particularly luxuriant growth that may occur in wetlands often without the limitations imposed in other ecosystems by dry season water stress means that nitrate-nitrogen storage can be particularly effective. If harvesting of the vegetation subsequently occurs, then removal from the system is complete and the plant uptake process has resulted in a sink function. However, in addition the waterlogged soil or sediment environment can provide an ideal medium for denitrification. This is the microbially mediated reduction of nitrate by facultatively anaerobic bacteria abundant in wetlands. The result is conversion of nitrate to gaseous nitrogen compounds which are lost from the wetland system to the atmosphere. Notwithstanding the possible contributions of any nitrous oxide component to the greenhouse effect, there is major potential benefit in protection of ground and surface-waters from nitrate pollution. This possibility has been part of the rationale for the maintenance or establishment of wetlands as buffer zones especially in river marginal areas.

While riparian buffer zones are often highly effective at removing nitrate and other potential pollutants from diffuse sources such as shallow groundwater or surface run-off (Ambus and Christensen, 1993; Cooper, 1990; Haycock and Burt, 1993; Weller *et al.*, 1994), they are often bypassed where natural hydrological flows are intercepted by ditches or drains which are common features in many landscapes. In such cases a riparian buffer zone can be rendered ineffective for nitrate removal from water draining agricultural land. It may prove more effective and cost efficient to establish buffer zones in wet areas associated with ditches or areas of discharge that may be acting as zones of enhanced denitrification (Blackwell and Maltby, 1998).

Similar conclusions have been drawn from work by Haycock and Muscutt (1995) who reported that while 85% of some sub-catchments of the River Avon in Hampshire, UK were served by effective riparian buffer strips, 60% of polluting material in the river was delivered by roads and drains that effectively bypassed them.

IDENTIFYING THE RIVER MARGINAL WETLAND RESOURCES OF A CATCHMENT

River marginal wetland types

Wetlands can be identified in terms of their position in the landscape and their hydrological characteristics. River marginal wetlands can be separated broadly into those located on floodplains and those on slopes.

Floodplain units are susceptible (in the absence of flood defence embankments) to flooding from a river or stream, with the consequence that a range of flood-related functions such as sediment retention and detention of flood peaks can be performed. Slope units refer to wetlands found in locations other than on floodplains, and by implication, flood-related functions resulting from over-bank flooding are excluded from these units, though there may be opportunity to detain run-off, thereby alleviating flooding further down the catchment. In general slope units are preferable to floodplains as buffer zones, since they can act to remove nutrients from water at more distant locations from rivers and streams, allowing subsequent further treatment, perhaps in floodplain units, to take place if further improvements are required to meet environmental standards or objectives.

Location of wetlands

Many floodplains, especially in the upper parts of catchments, show some indications of wetness, perhaps by the presence of characteristic wetland species (sometimes confined to field margins or abandoned areas) or by indications of attempted drainage improvement. Ditches often occur around field margins and sometimes are seen crossing fields, though these may be defunct, or may have originally followed the course of field boundaries, now removed. Other minor depressions, sometimes following a sinuous course, represent the line of former stream channels. In some places the land may have been abandoned from agricultural use, allowing scrub or woodland to develop. The wettest soils of floodplains are often found farthest away from the river channel in low-lying areas (backlands). Here surface water can lie for prolonged periods following overbank flooding from the river, with wetness often supplemented by groundwater discharging from footslope seepage zones.

In small headwater stream systems wetlands often occupy most of the valley bottom and sometimes adjacent footslopes the wetness and inaccessibility tending to preclude agricultural improvement in many areas.

Where shallow groundwater emerges along footslopes, wetness is expressed in springlines, discharge points and areas of less distinct seepage. Areas of stronger discharge are generally associated with distinctly different vegetation, where plant species adapted to growing in waterlogged conditions have survived due to excessive wetness hampering attempts to drain the land for more intensive agricultural use. Weaker or more intermittent seasonal discharge areas may simply be marked by patches of characteristic wetland plants in fields. On grazed ground the surface may show localised poaching (physical damage to topsoils and vegetation by the trampling action of livestock under wet conditions) compared with surrounding areas, resulting from the lower bearing strength of the wetter topsoils

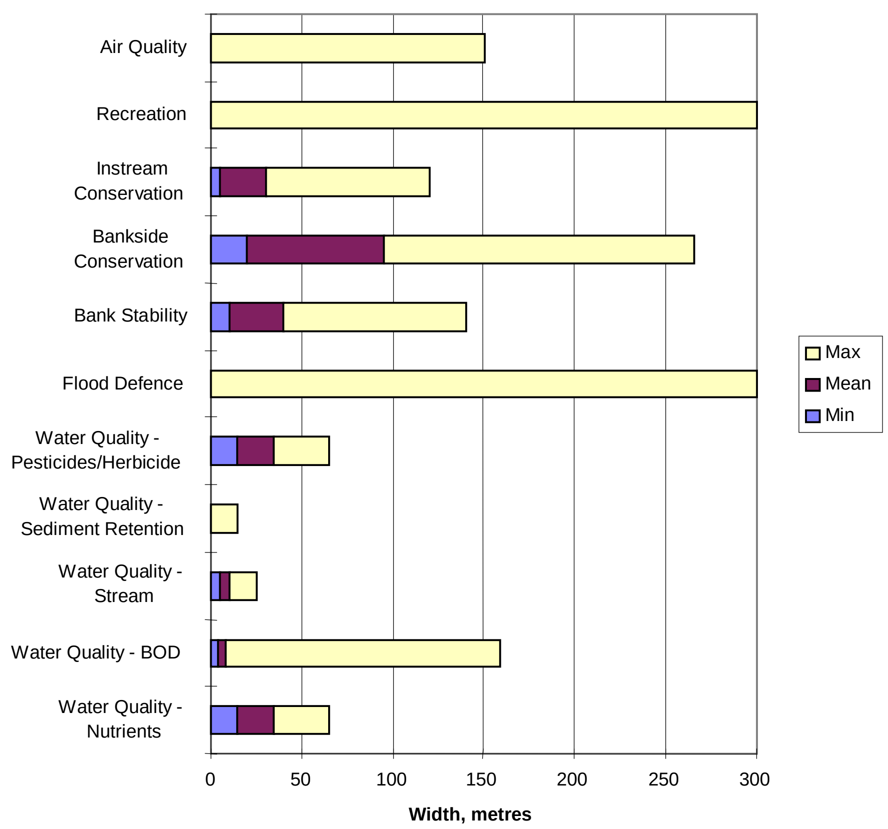
Alternatively the presence of wet land can result from the interactions between rainfall and soils of low permeability. Much of this type of land would have received artificial drainage with former wetlands having been replaced by more intensively managed croplands. However, in areas of high rainfall, even following land drainage for more intensive agricultural use, careful management is required to avoid damaging the land by compaction or erosion. In such areas, restoration of wetlands may be a more economic option than retaining land in more intensive agricultural use, given the costs of maintaining adequate land drainage. In areas where there has been a tendency towards amalgamating fields into larger management units, this can lead to problems when applying a uniform management regime to areas of land in which significant variation in soil type occur may occur. It may be possible to restore some of these former fields as wetlands, if appropriately located, to act as buffer zones.

Location of buffer zones

In the UK the current protocol for the implementation of buffer zones is described by both the Environment Agency (Environment Agency, 1996) and the Ministry of Agriculture, Fisheries and Food (MAFF, 1997). Generally it is recommended that buffer zones should be situated in riparian areas adjacent to main water courses and extend to between 5 and 30m in width.

However a review of international literature reveals a much wider range of recommendations for effective buffering of watercourses from many potential impacts as shown in Figure 1.

Figure 1 Buffer zone widths for particular purposes



Based on Haycock and Muscutt (1995) plus additional sources.

Potential pollutants can be removed from hydrological flows through wetlands by processes of storage or transformation. Riparian buffer zones are often highly effective at removing nutrients from diffuse sources such as shallow groundwater or surface run-off, but can be by-passed where natural hydrological flows are intercepted by the ditches or drains commonly found on agricultural land. In such cases a riparian buffer zone can be rendered ineffective for nutrient removal. It may prove more effective and cost efficient to establish buffer zones in association with existing features such as oxbow lakes, ditches, overland flow zones or groundwater discharge areas, even though these may happen to be located at some distance from the river bank and beyond the limits of conventional riparian zones.

The application of a systematic functional approach to the identification of wetlands enables the most efficient locations for buffers to be identified. This approach has been recognised by the European Union through it's support of a series of wetland functional analysis research projects under the Environment Programme of Directorate General XII (Science, Research and Development) of the European Commission. This research has involved detailed process studies to be carried out as a basis for the development of a methodology for evaluating the functioning of European wetland ecosystems (Maltby *et al* 1996). The next step is currently underway to tailor the core structure to provide specific tools to meet the requirements of a range of users in relation to wetland management. The functional approach to wetland evaluation also enables those areas to be identified, where opportunity exists to extend present buffer zones, thereby increasing the overall capability for protection of watercourses. In many cases the buffer zone will comprise more than one type of land unit, varying in terms of slope and degree of wetness.

A key location for wetland buffer zones to protect catchment water quality is within headwaters areas, which generally lack floodplain development, and where riparian wetlands lie alongside watercourses, thereby meeting the requirements of current protocols for buffer zone establishment. Figure 2 summarises some typical options available for buffer zone location on first order streams (Strahler 1964) in headwaters locations, based on studies carried out in South West England, UK. Effectiveness depends both on the hydrological pathways present and the concentrations of nutrients in water entering the wetland.

In contrast, at points lower in the catchment, where more extensive floodplain development is likely to have taken place, river marginal wetlands can often be located at some distance from the river channel, with better drained land often associated with levées found adjacent to the channel. In places where footslopes are underlain by relatively impermeable rocks, discharge of shallow groundwater can take place, resulting in the presence of wetlands elevated above the level of the floodplain.

A combination of field observations, on-site research and literature review has indicated that the most efficient locations for buffer zones to be sited are likely to vary throughout a catchment, and also depend on the functions required to be performed. Riparian buffer zones can function to stabilise banks and provide wildlife habitat in most parts of the catchment. In the low order streams of the upper reaches, these locations may also be useful for nutrient removal from diffuse water sources. However, there is a tendency for them to become less efficient in this respect lower in the catchment where they are increasingly by-passed by ditches, sub-surface drains or natural flow paths such as through underlying river gravels. In such locations, alternatively-located buffer zones such as oxbows or within ditch systems can be more efficient. The role of ditch systems in the buffering of both point source and diffuse pollution potential offers promise, but requires quantifying benefits requires further investigation.

WETLANDS WITHIN A CATCHMENT

A major challenge is how to manage wetlands effectively within the catchment context. The greater part of the wetland resource is currently and likely to remain outside any network of protected areas in conventional conservation terms or special site designations. But in any case wetland boundaries are often inappropriate for the purposes of maintaining functional integrity. Particular problems of wetland management may arise because of their particular location in the drainage basin. At one scale this has exposed river marginal wetlands to extreme competition from agriculture, industry and urbanisation which also favour proximity to the river and use of the flat, often fertile land of the floodplain. At a smaller scale wetlands at the lower end of drainage basins are particularly vulnerable to the effects of environmental impacts in the catchment as a whole even if the wetland ecosystem is afforded legal protection. For example, in the case of the Danube Delta, the effects of upstream dams have been compounded by a series of artificial impoundments or polders devised for intensive agriculture and fish culture reducing water quality and sediment input to the wetlands (Vadineanu *et al*., 1998).

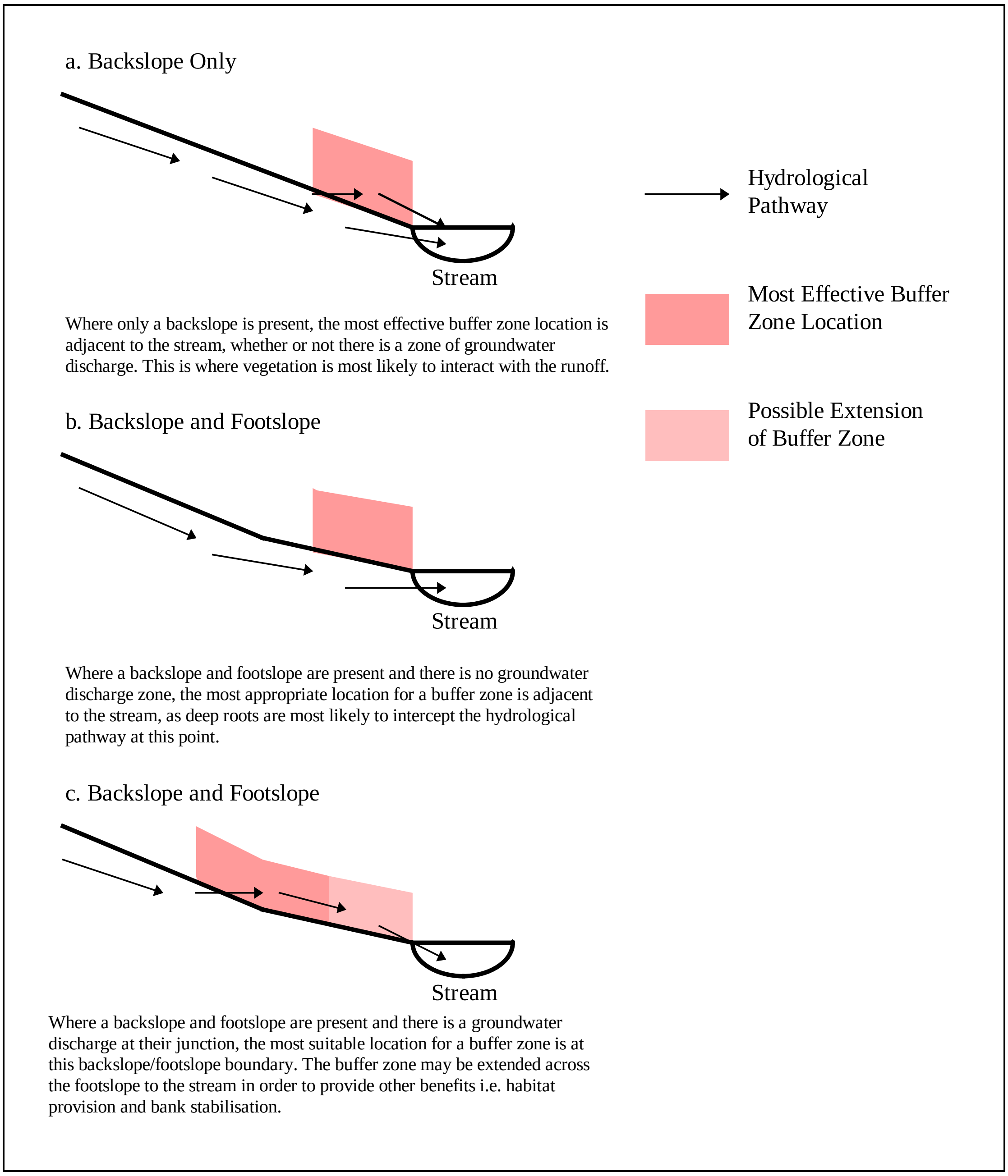


Fig. 2. Effective buffer zone locations on first order streams

THE WAY FORWARD FOR POLICY DEVELOPMENT AND CATCHMENT MANAGEMENT

An holistic approach is required to catchment management which *inter alia* incorporates considerations of land use, water resources, ecosystem functioning (especially wetlands), socio-cultural practices and economics based on a shared vision of the desired environmental quality.

A strategic base is being established in Europe for a policy "aiming at the sustainable use of wetland resources and the conservation of functions and values for future generations"(Commission of the European Communities, 1995). It is essential that this vision should not be restricted to the territory of the European Union but should underpin co-operation with governments world-wide and in association with various global commitments corresponding to the principle of Agenda 21.

Implementation of any new wetland policy will require the close co-operation of many sectors of society: government, non-governmental, private, industrial and scientific. Wetland loss and degradation arguably have been promoted by the fragmentation of responsibility for wetlands among many different organisations. There is unlikely to be a successful reversal of this situation in any country until there is a single body with designated responsibility for wetlands and the resources to make it at least capable of co-ordinating the implementation of wetland policy. It is essential that effective operational approaches are adopted. These should include:

- Integrated catchment policy, management and land-use planning
- Legal frameworks and administrative provisions
- International cooperation where appropriate
- Efficient and innovative financial mechanisms

Integrated catchment management planning is being promoted increasingly as a means of achieving effective implementation of the above approaches. It takes on a number of forms depending on the country, region and responsible agency, but in any case it is likely to have the greatest chance of success where the participation of local people is fully included.

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