READING THE LANDSCAPE: SELECTING DIFFUSE POLLUTION ATTENUATION TOOLS THAT WILL MAKE A REAL DIFFERENCE

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Abstract

Riparian fencing and planting, grass filter strips and constructed wetlands are some of the common attenuation tools farmers can use to improve farm water quality. But can Farmer J. Bloggs or their farm advisor pick the best attenuation tools for the landscape? Probably not. Existing environmental guidelines do not provide information or tools to help farmers/land management officers/farm advisors compare the real world applicability of attenuation tools or match suitable attenuation tools with major pollutant flowpaths. In addition, as scientists we tend to focus on, and promote, our own favourite attenuation tool, process or pollutant, barely stopping to consider how to best use a range of attenuation tools/processes at the farm and catchment scales. As a solution to this problem, we are developing a hydrology-based framework for guiding the selection of attenuation tools. The framework is an on-the-ground, qualitative and educational tool. The method requires a site inspection equipped with an aerial photograph/map. During the site inspection three basic steps are required. Firstly, the framework guides the user and farmer through a series of landscape related questions to identify dominant runoff generation processes. Then the active flow network is defined and finally, existing and additional attenuation tools are evaluated. The tool is under development and requires further field testing.

Introduction

The Pastoral 21 Stocktake Report (McKergow et al., 2008) reviews the attenuation tools available to manage diffuse pollution from grazed pasture in New Zealand, and identifies knowledge gaps limiting their uptake and use. One key gap in current farm environmental guidelines was information to assist farmers, land management officers (LMO) and farm advisors with the selection of suitable attenuation tools for different landscape and soil types, and farming systems. None of the existing guidelines provide tools to aid identification of priority pollutants, key hydrological flowpaths and attenuation tools suitable for their particular combination of receiving waters, landscape and farming operation. Guidelines tend to focus on one particular attenuation tool (e.g., constructed wetlands) with the emphasis on tool engineering design rather than landscape placement. Strategic placement of attenuation tools, rather than a blanket approach is required in order to maximise the water quality benefits and minimise the costs. Meals et al. (2010) identifies several reasons why catchment diffuse pollution projects have reported little or no improvement in water quality in at least five catchments, despite large investment in attenuation tools and conservation measures, including (1) improper selection of attenuation tools or selection of tools for purposes other than water quality improvement, (2) inadequate level or distribution of BMPs, (3) mistakes in understanding pollution sources, (4) poor experimental design, (5) insufficient landowner participation, (6) uncooperative weather, and (7) little appreciation of lag times. The framework we propose will help address (1) and (2) and help avoid or improve understanding of 3, 5 and 7.

The framework allows farm advisors to work with farmers in a systematic way to identify the landscape and hydrological features that determine where and how pollutants are transported and attenuated. This will help educate farmers so that they can adapt their farming practices so as to minimise stream pollution. The framework will also help identify where attenuation occurs naturally (so these areas can be protected and enhanced) and where constructed attenuation tools would be beneficial. The framework is qualitative and is applicable to pastoral farming and cropping. Use of the framework requires that farm water quality targets (e.g., key pollutants, reductions required and time scales) have been set previously through a participatory or regulatory framework. The framework is multi-pollutant (sediment, nutrients and faecal microbes) and consequently little emphasis is placed on specific pollutants until the final step. Each of these pollutants has various forms, sources and routes of transfer in the landscape (Table 1).

Table 1: Pollutant forms and sources (N and P forms after McCutcheon et al., 1993).

Pollutants and forms	Key sources	Key references
TOTAL NITROGEN (excluding nitrogen gas) organic nitrogen: dissolved; particulate inorganic nitrogen: ammonium; nitrite; nitrate	(1) urine patches, (2) fertiliser, (3) effluent irrigation	Williams and Haynes, 1994; Ledgard and Menneer, 2005; Houlbrooke et al., 2004
TOTAL PHOSPHORUS dissolved/soluble (<0.45 µm): reactive; organic particulate: organic; inorganic	(1) fertiliser, (2) soil erosion, (3) animal excreta/effluent irrigation	Haygarth et al., 2006; Nash and Halliwell, 1999; McDowell and Stewart, 2005
SUSPENDED SEDIMENT organic mineral: clay; silt	(1) grazed pasture, (2) stream bank/bed erosion, (3) animal excreta, (4) animal tracks, (5) unpaved roading	Davies-Colley and Smith, 2001; Bilotta et al., 2007
FAECAL MICROBES viruses — Indicator: phages; Pathogens: human enteroviruses and adenoviruses, rotaviruses, noroviruses, hepatitis A bacteria — Indicator: *E. Coli,* Pathogens: *E. coli, Campylobacter, Salmonella* protozoa — Indicator: *Clostridium perfringens* spores; Pathogens: *Giardia, Cryptosporidium*	(1) grazed pasture, (2) effluent irrigation, (3) wild and feral animals, (4) stock in or close to waterways	Collins et al., 2007; Donnison and Ross, 1999; Till et al., 2008; Houlbrooke et al., 2004

Throughout this paper the term attenuation tool is used rather than mitigation tool or best management practice. This is a deliberate move to focus attention on the attenuation processes occurring. Attenuation is the transformation, temporary storage and/or permanent loss of pollutants between where they are generated (e.g., paddock, farm track) and where they impact water quality (e.g., stream, lake, estuary). Attenuation may be physical (e.g., flow attenuation, deposition), chemical (e.g., sorption) or biological (e.g., plant uptake, denitrification, see McKergow et al., 2008). Educating farmers and their advisors about attenuation processes is a good starting point for the proper selection, design, maintenance and management of any attenuation tool.

Hydrology framework

The intention is to field map dominant runoff generation areas using a series of questions/criteria which, together with mapping the dominant flow pathways and existing or potential attenuation tools, will result in reduced contaminant loads to waterways. The method requires a site inspection, equipped with an aerial photograph/map. During the site inspection the following 3 basic steps of the framework are required: (1) identify the dominant runoff generation process, (2) define the active flow network and (3) evaluate existing attenuation tools, select additional tools and evaluate their potential.

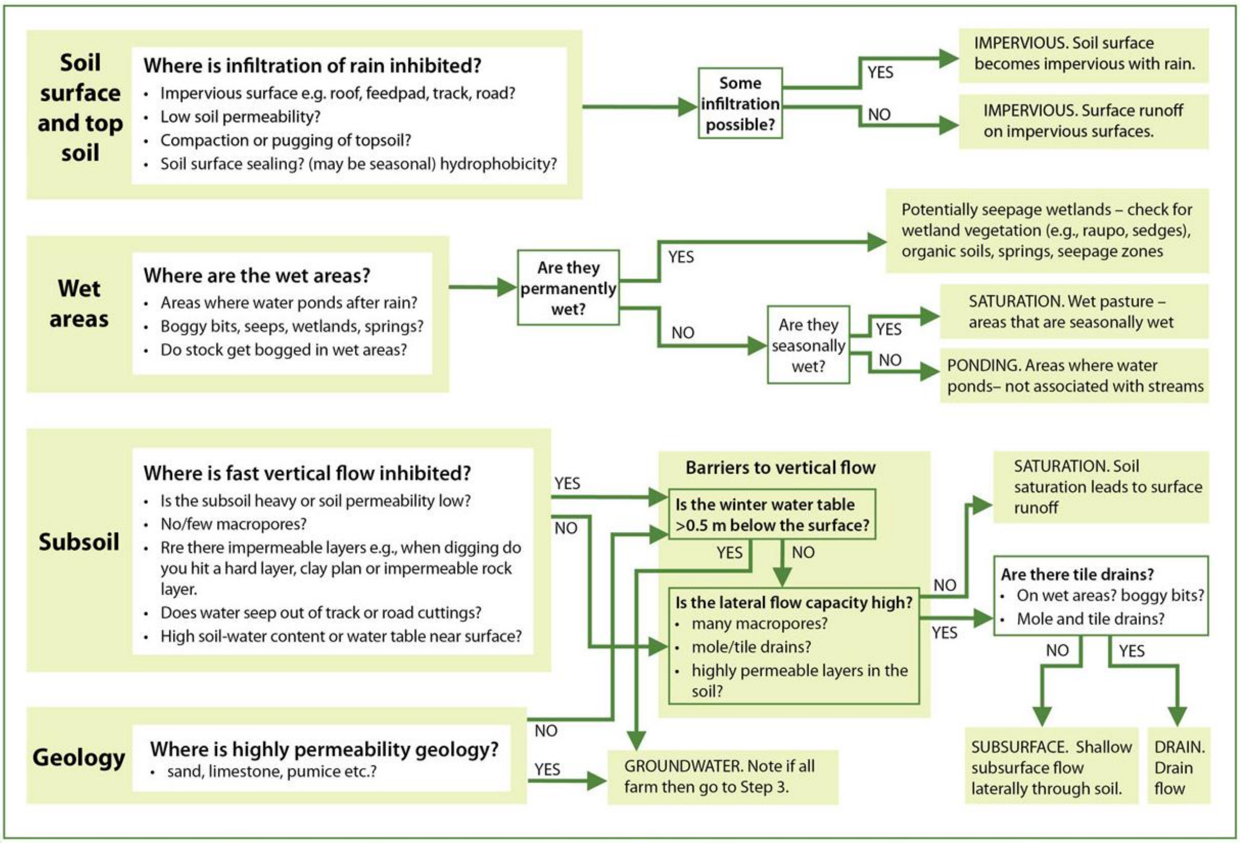
A large (A3) printed aerial photograph of the farm (e.g., GoogleEarth image) is annotated in the following steps. Information about the farm and landscape, such as the soils would be useful to guide Step 1 and Step 2. Soil maps are available nationally at 1:50,000 (Fundamental Soil Layers), but detailed farm soils maps (~1:5,000) would be preferable. Any previously collected data on soil structure and quality (e.g., visual soil assessment score cards) would also be valuable.

Step 1. Identify dominant runoff generation areas (RGA)

The basic unit of the framework is the runoff generation area (RGA). Runoff is defined as any water that leaves the paddock and eventually enters streams – it includes surface or overland flow during rainfall events, and drainage to groundwater which re-emerges as streamflow further down the catchment, either through natural springs and seepages or through artificial drainage. Each RGA has a dominant water flowpath, for example, surface runoff, percolation to groundwater, or artificial drainage. Farmers tend to manage their farm at paddock level, but paddocks can be separated/combined into units with similar hydrology. Having units with the same runoff generating processes is a bottom-up approach versus the more traditional top-down landscape unit approach (e.g., hillslope vs riparian; Schmocker-Fackel et al., 2007). The initial focus on runoff generation (rather than the active flow network) allows areas that behave similarly to be identified. It also provides an appreciation of the area draining to any attenuation tool and the intensity, duration and frequency of the flowpath.

This step involves identifying areas that behave similarly and is based on farmer knowledge. Many field studies have concluded that field observations, particularly during rainfall, are crucial to locating areas where water runs off (e.g., Lyon et al., 2006). Farmers' observations during rain (or recalling observations) are an integral component of this framework. A "decision tree" (Figure 1) enables the farmer/LMO to identify areas where these five different processes dominate. Only one code can be assigned to an area, so the dominant runoff generation process must be identified. This requirement is at the cutting edge of hydrology and has **not** been previously tested in New Zealand. However, the framework is loosely based on the findings of a Swiss group (Scherrer and Naef, 2003; Schmocker-Fackel et al., 2007) who established a decision tree to guide identification of the dominant runoff process in temperate grasslands. They recently compared an automated spatial approach using spatial soils information with point sprinkler experiments and found good correspondence between the runoff processes (Schmocker-Fackel et al., 2007). They also compared the automated approach with observed and mapped hydrologically relevant features. They found that saturated areas could be mapped in the field and that the presence of springs help identify areas of subsurface flow (Schmocker-Fackel et al., 2007). This decision tree appears to be suitable for New Zealand conditions, although it has not yet been fully tested. Testing will involve independent on-farm assessments in contrasting landscapes followed by an evaluation of any discrepancies in outcomes.

Figure 1: Runoff generation process decision scheme (after Schmocker-Fackel et al., 2007).



Step 2. WHERE does water move on the farm?

This step is important to link the process information (Step 1) to the active hydrology network. For example, surface runoff is generated on tracks, but if the runoff is then directed onto a permeable area and infiltrates it is unlikely to contribute to streamflow during the same event (Ambroise, 2004). In addition, even if a channel dries up in summer, there is still evidence that it needs protection from grazing to avoid a build up of easily transported material (e.g., McDowell, 2006). The active network (i.e., water flowing at any given time) is defined using the proposed definitions in Table 2. The network includes any locations where run-on occurs (e.g., neighbours paddock drains onto your farm). All flowpaths should all be marked on the aerial photograph and should link the RGA with the receiving water body. Permanent flowpaths are denoted using solid arrows and dashed arrows for transient features.

Step 3. Review existing attenuation tools and identify potential tools

The third step focuses on consideration of key pollutants and identification of existing and potential attenuation tools. Catchment water quality targets provide information on target pollutants. The major sources of pollutants are listed in Table 1 and in most instances these can be quickly identified and marked on the aerial photograph. All existing attenuation tools (e.g., riparian buffers, grass filter strips, natural wetlands, livestock exclusion zones, farm dams etc.) are also marked on the aerial photograph. The management and performance of each existing attenuation tool is then reviewed by examining whether conditions are suitable for attenuation to occur. An example flowchart is provided for grass filter strips (Figure 2). The review of existing attenuation tools is undertaken as an educational process while also investigating their functioning and management.

Table 2: Proposed active hydrological network definitions.

Network component	Definition/comment
perennial stream	flows all year
intermittent stream	flows late autumn-spring
ephemeral stream	defined channel; flows with rain
swale	gentle concave drainway, flows with rain
surface drain	to remove standing water, flows with rain
tile drain (may have moles)	to remove subsoil water, flows with rain
standing water	areas where water ponds (not flooded from stream)
seeps / wetlands	permanently/ seasonally wet organic soils
springs	permanently/seasonally flowing
ponds / dams	standing water and/or detention pond (storm only)
wet stream banks	riparian seeps
culverts/bridges	
barriers	such as fences, humps, hedges

The following example uses faecal microbes as the key pollutant. Key sources of faecal microbe sources include: (1) grazed pasture, (2) effluent irrigation, (3) wild and feral animals, (4) stock in or close to waterways (Table 1). Of these sources (2) and (4) can be easily identified on the aerial photograph and (1) encompasses the entire grazed area. Farmers will be able to identify areas where wild and feral animals are seen (e.g., ducks, swans, pigs, etc.) Tools that can intercept runoff from the RGA and are suitable for attenuating microbes become the attenuation focus. For example, for RGA with surface runoff there are three attenuation tools available – grass filter strips, dams/ponds and farm design to reduce hydrologic connectivity – and all are suitable for attenuating faecal microbes (Tables 3 and 4). All existing attenuation tools (e.g., riparian buffers, grass filter strips, natural wetlands, livestock exclusion zones, farm dams etc.) are marked on the aerial photograph. The performance and management of existing tools are then evaluated using flowcharts (e.g., Figure 2). The suitability of additional attenuation tools are evaluated using knowledge gained on farm runoff generation and the active flow network gained in Steps 1 and 2.

Conclusions

This tool is under development and requires further field testing. Initial evaluation with farmers suggests that the focus on hydrology is a new and valuable approach .In addition farmers were enthusiastic about the focus on attenuation processes, as this approach gives them a better understanding of the tools they already have and how to best manage them.

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Table 3: Distributed attenuation tools (FM = faecal microbes, H=high, M=moderate, L=low).

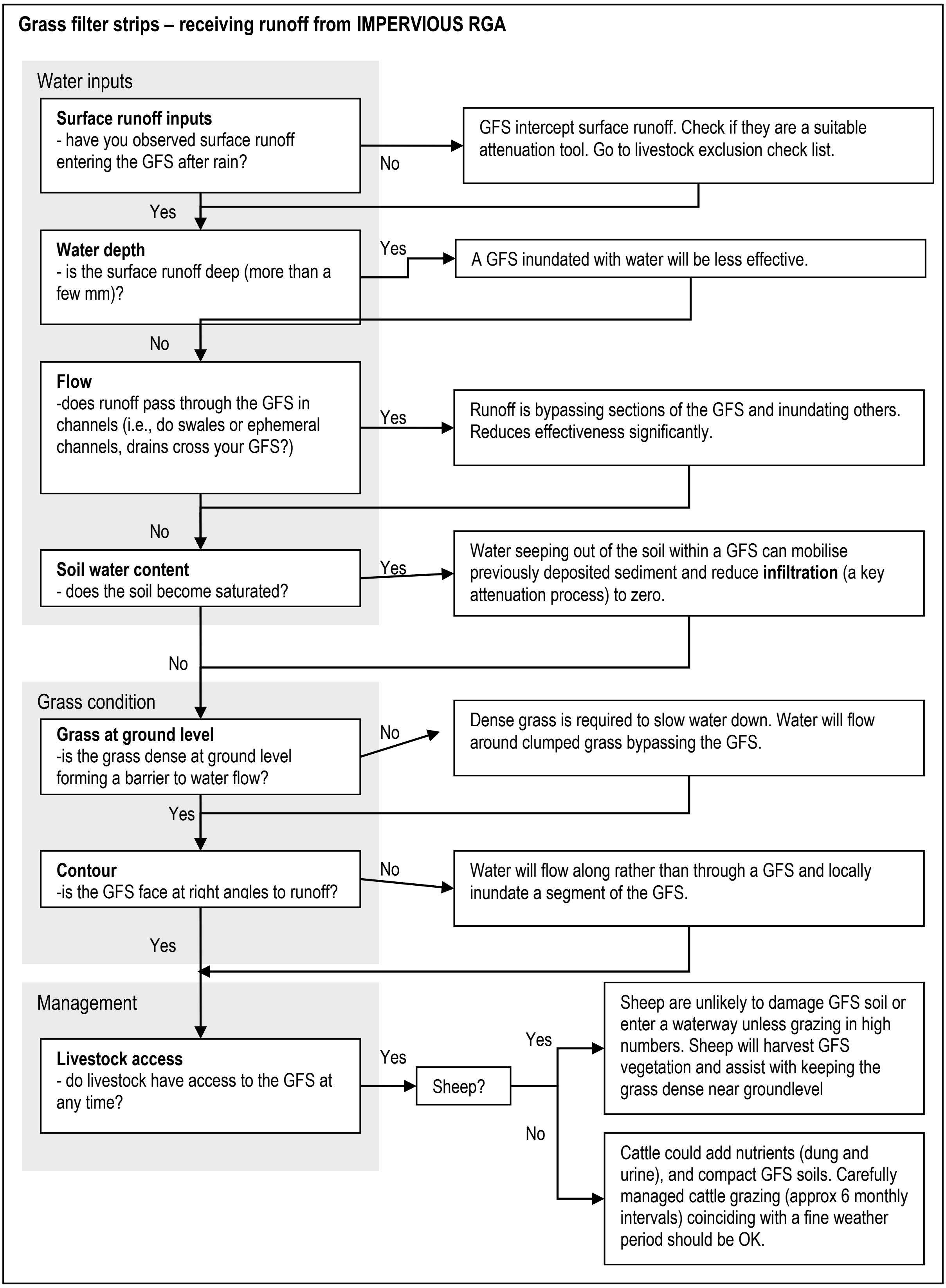
RGA code	Tool	Description	Target pollutant	Key processes	Knowledge level	Efficacy	Cost	Other indirect **b**enefits/**d**isbenefits	Info sources
IMPERVIOUS	grass filter strip	managed band of dense grass	Sed,N,P,FM	infiltration, deposition, filtering	M	L-M	L	**d**: potential weed management issues	DEC, 2006, various regional council guides
	farm design to reduce connectivity	water sensitive placement of troughs, gates, tracks to reduce connectivity with hydrometric network	Sed,N,P,FM	disconnectivity	L	L-M	L		
	dams and ponds	sedimentation ponds (outlet throttled)	Sed,P,FM	deposition, UV disinfection, flow attenuation	L-M	M-H	M	**b**: stock water supply; duck shooting; flood attenuation; and improve landscape aesthetics **d**: can have negative impacts on downstream flows, water temperatures and dissolved oxygen impacting aquatic life.	
SATURATED	natural seepage wetland	seeps/springs via wetlands	Sed,N	denitrification, assimilation, deposition, adsorption, mineralisation	M	M-H	L	**b**: aquatic habitat and biodiversity; improve landscape aesthetics; recreational hunting, cultural harvesting of flax and other plants; flood attenuation; water storage **d**: potential weed management issues	
	livestock exclusion	exclude livestock from wet areas	Sed,N,P,FM	avoid faecal inputs and grazing disturbance	H	H	L	**b**: reduced stock losses; aesthetics **d**: potential weed management issues	DEC, 2006, various regional council guides
	farm design to reduce connectivity	water sensitive placement of troughs, gates, tracks to reduce connectivity with hydrometric network	Sed,N,P,FM	disconnectivity	L	L-M	L		
SUBSURFACE	denitrification wall	addition of sawdust to soil to produce suitable conditions for denitrification	N	denitrification (adsorption and immobilisation in short term)	M	M-H	H	**b**: below-ground so little reduction of usable grazing land	
	riparian buffer	managed band of trees/shrubs along stream banks	N,P	deposition, infiltration, filtering, denitrification, assimilation	H	M-L	M	**b**: channel shading; improved aquatic habitat, wood and leaf supply to stream; recreation; cultural harvesting of flax and other plants; biodiversity value; landscape aesthetics **d**: requires some active vegetation management.	DEC, 2006, various regional council guides, Landcare Research posters

	constructed wetland	artificial wetland	Sed,N	denitrification, assimilation, deposition, adsorption, mineralisation	H	M	H	**b**: aquatic habitat and biodiversity; improve landscape aesthetics; recreational hunting, cultural harvesting of flax and other plants; flood attenuation; water storage **d**: potential weed management issues	DEC, 2006, Tanner et al., 2010
	natural seepage wetland	drained wetland fed by spring or seep	Sed, N	denitrification, assimilation, deposition, adsorption, mineralisation	M	M-H	L	**b**: aquatic habitat and biodiversity; improve landscape aesthetics; recreational hunting, cultural harvesting of flax and other plants; flood attenuation; water storage **d**: potential weed management issues	
	permeable reactive filters	addition of carbon-rich material to produce suitable conditions for denitrification	N	denitrification (adsorption and immobilisation in short term)	H	H	H	**d**: discharges from C-rich filters may initially have elevated BOD and humic colour	DEC, 2006
DRAIN	managed or controlled drainage	manipulation of water table to temporarily retain flood waters to promote conditions suitable for denitrification	N	denitrification	L	M	L-M	**b**: soil water storage; flood attenuation **d**: requires active management	
	reactive materials	addition of reactive materials to enhance p sorption	P	adsorption, precipitation	L	M-L	H	**b**: in soil or below-ground so little visual impact or reduction of usable grazing land; loaded materials may be able to be reused as slow-release fertilisers or as aggregates on farm raceways **d**: instream filters may affect water quality and aquatic habitat; need to be close to suitable source of reactive materials; relatively expensive to retrofit existing drainage systems; likely to require periodic replacement or rejuvenation of materials; fly ash results in caustic discharge- alkalinity must be reduced to be useful.	
	vegetated drains	vegetated surface drains with wetland vegetation or water tolerant grasses	Sed,N,P	deposition, denitrification, assimilation	L	M	L-M	**b**: improves biodiversity and provides seasonal aquatic habitat **d:** may require redesign of drainage systems to prevent flooding; potential weed management issues	

Table 4: Bottom of catchment tools suitable for streamflow (particularly groundwater fed).

Tool	Description	Primary attenuation processes	Target pollutants	Knowledge level in NZ	Efficacy	Cost	Other indirect benefits /disbenefits	Info Sources
Aquatic plant/algae uptake and harvesting	harvested beds of watercress or other aquatic macrophytes or filamentous algae	nutrient uptake + deposition, filtering, denitrification	N, P	L	M-L	H	**b**: forage crop for stock **d**: requires active management	
Floodplain wetlands	stream flood flows intercepted by riverine wetlands, meanders, oxbows, billabongs, lagoons, deltas etc.	flow attenuation, deposition, nutrient uptake, denitrification	Sed, P, N	L-M	M-L	L-H	**b**: aquatic habitat and biodiversity; improve landscape aesthetics; recreational hunting, cultural harvesting of flax and other plants; flood attenuation; water storage **d**: potential weed management issues	
Constructed wetlands	artificial wetland created at bottom of catchment	denitrification, nutrient uptake, deposition, adsorption, mineralisation	Sed, N	H	M	M-H	**b**: aquatic habitat and biodiversity; improve landscape aesthetics; recreational hunting, cultural harvesting of flax and other plants; flood attenuation; water storage **d**: potential weed management issues	DEC, 2006

Figure 2: Evaluation framework for grass filter strips



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