Landscape typing based on hillslope and floodplain soil water models to functionally target sixteen riparian management options

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Summary

Considering the developments in research and application of mitigation measures for runoff, sediment and other pollutants it should be possible to recommend effective measures in riparian and other farmed and developed areas to support improving water quality. However, measures attain their best effectiveness when the designs are site-specific. Matching the dominant landscape runoff pathways to selection of target measures that intercept and retain water and pollution differently for surface and subsurface pathways is a key factor in overall mitigation measure performance, water quality and wider ecosystem outcomes. We utilise concepts of soil groups that are based on the dominant soil water flowpaths to characterise hillslope and adjacent floodplain (where present) into six models, each with four to six subtypes, that we call 'riparian context models'. The aim of these context models is to represent the diversity of riparian areas within groups that can be related to pollution pathways and, in turn, to the suitability of sixteen presented pollution mitigation measures. The resulting rules are primarily based on matching the pollution interception functions to the riparian mitigation measures against the dominant flowpaths of the thirty-two riparian context models (potential for surface runoff, prevalence of artificial drainage, water table) but also additional factors of site-specific measure suitability (e.g. slope, stream flow variation, protection of carbon-rich soils). The report demonstrates the diversity of the riparian context models at catchment scale (two example NE Scotland catchments) and at field scale for a group of fields where mitigation measure selection is made, including examples of how this may look for field-scale plans. An important message is how the presented methods will inform farm level to catchment screening of how landscape variation dictates groups of mitigation measures as more to less suited. A subsequent field survey is a crucial next step in understanding local factors toward measure selection, design and maintenance.

1. Rationale

Some form or riparian buffer zone is a common management measure between agricultural fields (and other developed land) and watercourses (Stutter et al., 2019; Cole et al., 2020). Often this is based on a need to address fast runoff water volumes or diffuse pollution such as the transfer of sediments, nutrients and agro-chemicals. However, many such riparian margins only utilise relatively narrow strips intended to be grasses but often dominated by nutrient-loving weeds such as nettles. Many issues associated with the placement, varying of width for localised pressures, design and ongoing management mean that often such margins fail to provide adequate protection of the watercourse or wider ecosystem benefits (Stutter et al., 2021).

A common failure contributing to ineffective riparian management is the mismatch between the measure itself and the pathways transferring runoff and pollution from the field to the watercourse. This leads to an inability of common designs such as a 2-5 m wide grass buffer zone to effectively deal with converging and therefore aggressive, localised surface runoff, or even subsurface pathways such as artificial field drains. Therefore, an ability to bring understanding of the pathways of runoff prevalent in different topographic and soil type combinations across the hillslope to riparian zone transition would aid understanding the correct management measure for the site of interest. This also requires understanding of the way that groups of potential riparian management options operate for different surface and subsurface runoff pathways.

The aims of this research were therefore to:

- Understand how the principals of a soil hydrological classification system describing the dominant water flowpaths through soil and substrate can be translated to consider typical sequences of flow from hillslope to watercourse (with and without a floodplain) to describe main water pathways across riparian zone soil sequences for Scotland.
- Understand how such soil-based landscape models can guide the selection between riparian management measures spanning conventional buffer strips, surface runoff, subsurface pathway and in-channel management options.
- Demonstrate for exemplar Scottish catchments the diversity of the occurrence of the differing landscape models at a small catchment scale and show examples of how they may be used at the farm to field scale to short-list measure options and the recommended next steps for field survey.

2. Development of a set of hillslope-floodplain riparian context models

2.1. Development stages

The horizontal and vertical distribution of soils and soil properties, as depicted on soil maps and in the soil profile, have a profound influence on catchment hydrology and on pollutant transfer from land to waters. In this context, we developed a set of models representing water movement from hillslopes to riparian transition zones in Scottish catchments using our understanding of the dominant soil hydrological pathways as shown by the Hydrology of Soil Types (HOST) classification system (Boorman et al., 1995).

HOST was developed to predict river flows in ungauged catchments based on the pathways and rate of water movement through the soil and substrate, and on the spatial distribution of soils within the catchments. HOST was based on several soil morphological attributes systematically recorded from soil profile data held within national soil databases and which are known to represent key features of soil hydrology (Lilly et al., 2012a). HOST classifies soils by distinguishing between those soils developed on a permeable parent material with mainly (a) groundwater tables at depth or (b) with mainly groundwater tables at a shallow depth and those soils (c) developed on slowly permeable substrates which limits infiltration. Based on these three physical settings (presence and/or depth to an aquifer), 11 HOST response models were defined to account for differences in soil properties, water regimes and flow characteristics (Figure 1). These were further subdivided based on whether the dominant flow type was via macropores or micropores and the rate of water movement through the soil and substrate to form 29 different HOST classes with similar hydrologic behaviour. Of these 29, 22 HOST classes are most common in Scotland (Figure 1).

A further advantage of using HOST for the development of the riparian context models is that HOST classes can be directly linked to soil spatial datasets and maps and also takes account of soil-water interactions at a landscape scale and, hence, can be used to distinguish soils that are present on hillslopes or on floodplain areas. This distinction between hillslope vs floodplain areas based on HOST class alone is given in Table 1, which also gives the description of respective HOST classes. Table 1 does not show those peaty HOST classes (HOST 15, HOST 26, HOST 27, HOST 28 and HOST 29) which are either not cultivated or not present in floodplains and, hence, not relevant for this work.

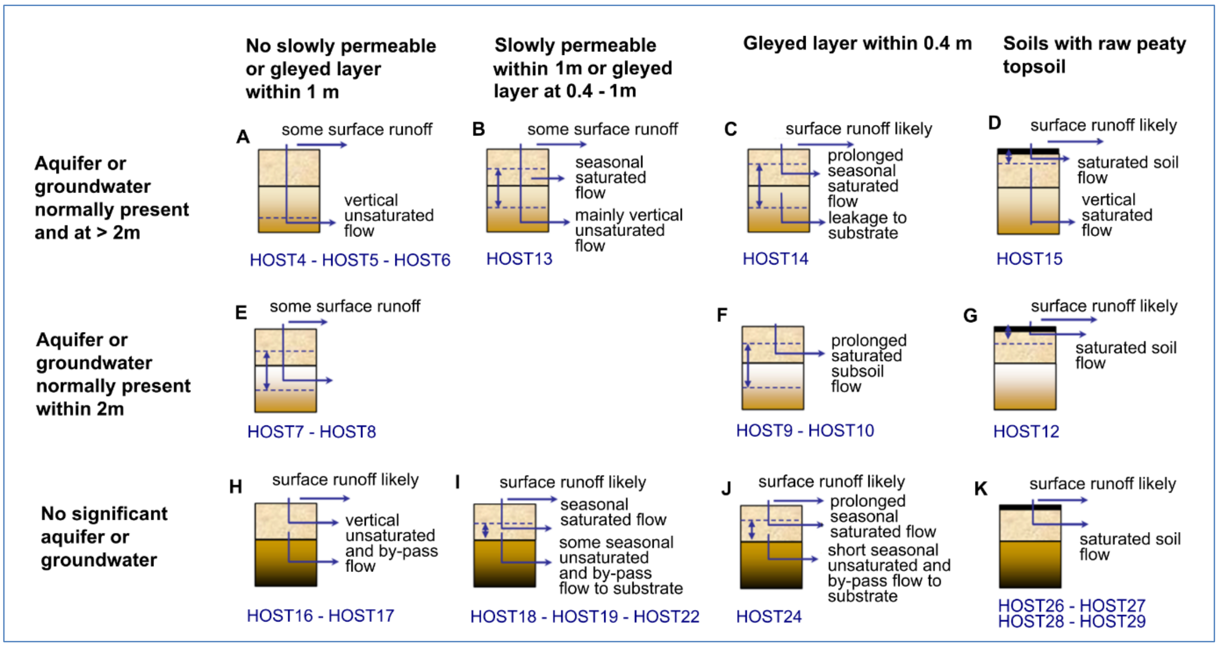


Figure 1. HOST conceptual models of water movement and respective HOST classes. Those HOST classes that are present in Scotland are shown.

Table 1. Description of HOST classes for those present on hillslopes (HS) or on floodplains (FP).

HOST class	Description	Landscape Setting
4	Free draining permeable soils on hard but fissured rocks with high permeability	HS
5	Free draining permeable soils in unconsolidated sands or gravels with relatively high permeability	HS
6	Free draining permeable soils in unconsolidated loams with low permeability	HS
7	Free or imperfectly draining permeable soils in unconsolidated sands or gravels with groundwater at less than 2m from the surface	FP
8	Free or imperfectly draining permeable soils in unconsolidated loams with groundwater at less than 2m from the surface	FP
9	Soils seasonally waterlogged by fluctuating groundwater and with relatively slow lateral and horizontal saturated conductivity	FP
10	Soils seasonally waterlogged by fluctuating groundwater and with relatively rapid lateral and horizontal saturated conductivity	FP
12	Undrained lowland peat and peaty soils with shallow or confined groundwater table	FP
13	Soils with slight seasonal waterlogging from fluctuating ground water tables	HS
14	Soils seasonally waterlogged fluctuating ground water tables	HS
16	Relatively free draining soils over slowly permeable substrates	HS
17	Relatively free draining soils with large storage capacity over hard impermeable rocks	HS
18	Slowly permeable soils with slight seasonal waterlogging over slowly permeable substrates	HS
19	Relatively free draining soils with moderate storage capacity over hard impermeable rocks	HS
22	Relatively free draining soils with low storage capacity over hard impermeable rocks	HS
24	Slowly permeable, seasonally waterlogged soils over slowly permeable substrates	HS

2.2. Finalised set of models

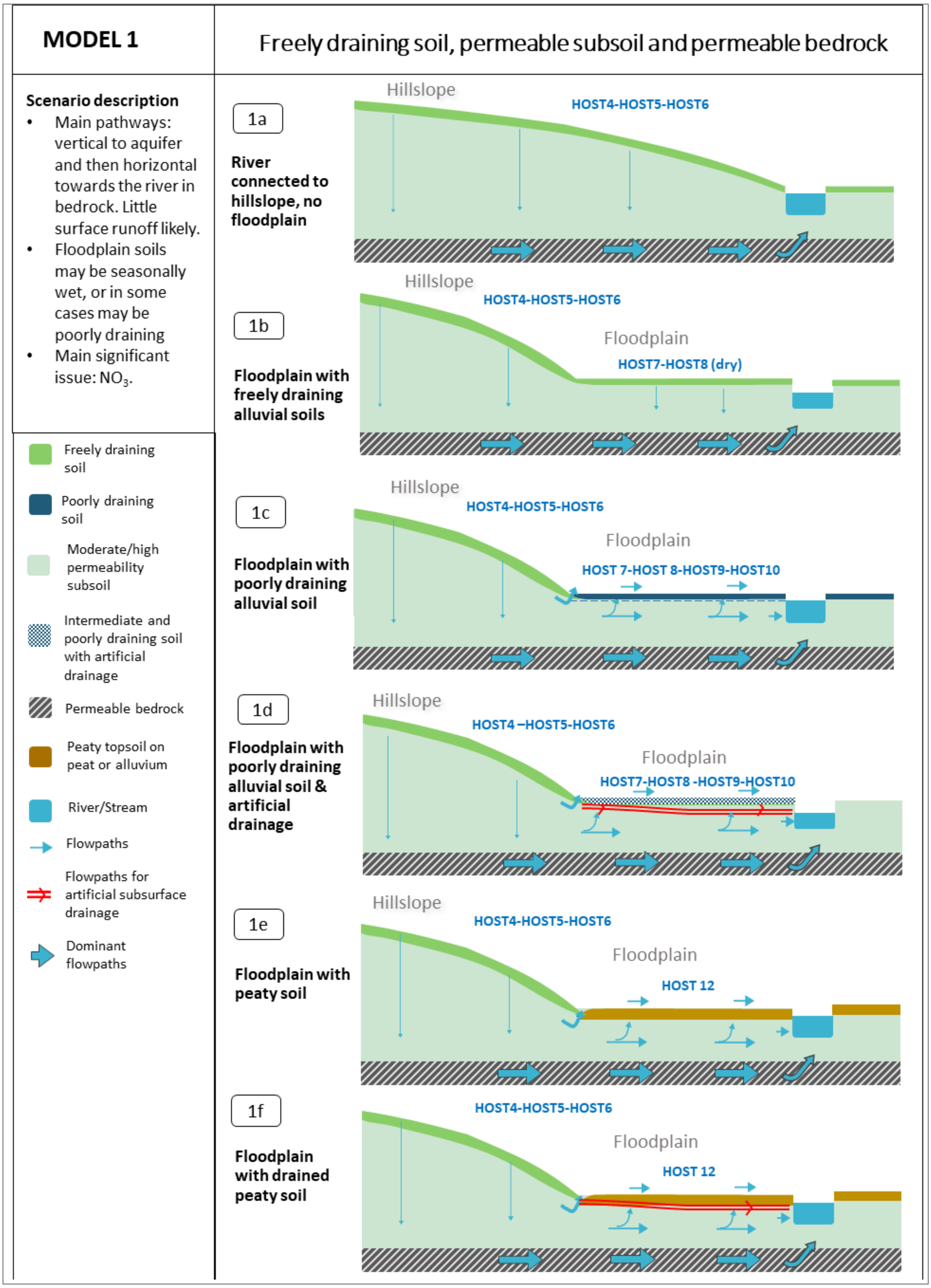
The finalised conceptual models of riparian context were developed by translating the HOST response models with regards to flow pathways, inherent soil drainage class and wetness conditions of individual soils. This approach enabled modelling water movement and subsequent pollutant transfer from hillslopes to floodplains via the main identified hydrological and soil hydrological pathways. A set of 32 individual sub-models were identified and developed (Table 2) based on the combination of:

- Six (6) hillslope models grouped based on inherent soil drainage class from drier to wetter soil conditions and including the presence or absence of artificial drains for the wettest soils (Models 3-6).
- Direct connectivity of hillslopes to watercourses / no presence of floodplains (Setting a)).
- Five (5) floodplain settings
    - Setting b): Floodplains comprised of free-draining alluvial soils with unconsolidated sands and gravels.
    - Settings c-f): Floodplains comprised of seasonally wet or poorly draining mineral (Setting c) and d)) or peaty (Setting e) and f)) sandy, gravelly, silty or clayey alluvial soils, with or without the presence of artificial drainage systems.

Table 2. Matrix of the model groups and subgroups. Major groups 1-6 are defined by the hillslope soil and substrate hydrological characteristics (rows down far left column) including wetter classes with and without artificial drainage on the hillslope. Subgroups a-f comprise characteristics of floodplains adjacent to the watercourse in terms of absence/presence, wetness, drainage and mineral versus peaty soil.

Hillslope Models			a) River connected to hillslope	Floodplain Settings based on HOST classes				
				b) Dry mineral alluvial soils	Seasonally wet or poorly draining soil		Peaty alluvium	
				HOST 7 HOST8	HOST7 HOST8 HOST9 HOST10		HOST12	
A/A	Description	HOST class			c) Undrained	d) Drained	e) Undrained	f) Drained
1	Freely draining soil, permeable subsoil & permeable bedrock	HOST4 HOST5 HOST6	1a	1b	1c	1d	1e	1f
2	Freely draining soil, moderately permeable subsoil & slowly permeable bedrock	HOST16 HOST17 HOST19 HOST22	2a	2b	2c	2d	2e	2f
3	Poorly draining soil, permeable subsoil & permeable bedrock	HOST13 HOST14	3a	3b	3c	3d	3e	3f
4	Poorly draining soil with artificial drainage, permeable subsoil & permeable bedrock		4a	4b	na	4d	na	4f
5	Poorly draining soil over slowly permeable subsoil	HOST18 HOST24	5a	5b	5c	5d	5e	5f
6	Poorly draining soil with artificial drainage over slowly permeable subsoil		6a	6b	na	6d	na	6f

The schematic representation of the conceptual models and sub-models of riparian contexts of Table 2, which includes graphical illustrations of hydrological pathways and water movement in the different hillslope and floodplain settings, is given as Appendix 1. Figure 2 gives an example illustration of Hillslope Model 1 and respective floodplain sub-models.



MODEL 1

Freely draining soil, permeable subsoil and permeable bedrock

Scenario description

- Main pathways: vertical to aquifer and then horizontal towards the river in bedrock. Little surface runoff likely.
- Floodplain soils may be seasonally wet, or in some cases may be poorly draining
- Main significant issue: NO_3.

Figure 2. Schematic of Hillslope Model 1 and respective floodplain sub-models.

2.3. Mapping the distribution of the models in catchments

An important consideration during the development of the conceptual models of riparian context was to enable the mapping of the different hillslopes and floodplains models in catchments to guide the targeted placement of effective riparian management measures. In this context, we developed a method that enables the mapping of the conceptual models of riparian context shown in Table 2 in any catchment in Scotland using available soil maps translated into HOST classes. This approach is based on assessing the relative location of soils within the landscape (hillslope vs floodplains) and the likely presence of artificial drainage systems and using this information to map the conceptual models of riparian context at a specified regular grid.

The grid cells of the hillslope were identified and assigned to a hillslope model (Hillslope models 1-6) based on the HOST class. Where there was no adjacent floodplain (as identified by the presence of HOST classes 7-10 and 12), the Hillslope models 1a to 6a were allocated based on the underlying HOST class of the hillslope. In the situation where there was an adjacent floodplain, the models allocated were a combination of the hillslope (Models 1-6) and the floodplain characteristics (b) to (f) as shown in Table 2. The combinations of hillslope models and floodplain settings of Table 2 were translated in R scripts that can be used for the automated classification of data points into conceptual models of riparian contexts and their subsequent mapping at specified regular grid intervals.

An example of mapping of conceptual models of riparian contexts is given in Figure 2 for two exemplar catchments with contrasting soil hydrological conditions: the Tarland catchment close to Aboyne, Aberdeenshire and the Lunan catchment close to Forfar, Angus. Maps were produced for a 200m riparian zone and at a 50m grid resolution to correspond with previous risk assessments at this resolution, such as in soil erosion risk (Lilly and Baggaley, 2014) and in land use intensity (Cloy et al., 2021). Spatial pre-processing was done in QGIS 3.12.2. and comprised of extracting HOST class information at each 50m grid cell from the Phase 6 digitised Soil Map of Scotland (partial cover) (Soil survey of Scotland Staff, 1970-87) to which HOST classes had been previous allocated (Lilly, *pers comm*), calculating distances between hillslope grid cells and the river network to determine their connectivity, and identifying areas under artificial drainage.

Because records of where artificial field drains have been installed are not available for cultivated areas in Scotland, their location and distribution had to be inferred. We used the approach of Lilly et al. (2012b), who estimated that almost all the soils in Scotland under cultivation that had inhibited natural drainage (that is, imperfect, poor or very poor drainage classes) did have such artificial drainage systems. We identified which soils were likely to have artificial soil drainage by combining areas of imperfect, poor and very poor soil drainage from the Soil Map of Scotland (partial cover) and the polygons of cultivated fields from the 2015 Integrated Administration and Control System (IACS) database. In areas with missing IACS crop information, cultivated land cover (i.e., arable and horticulture and improved grasslands) was determined from the Land Cover Map (LCM) 2015 (Rowland et al., 2017).

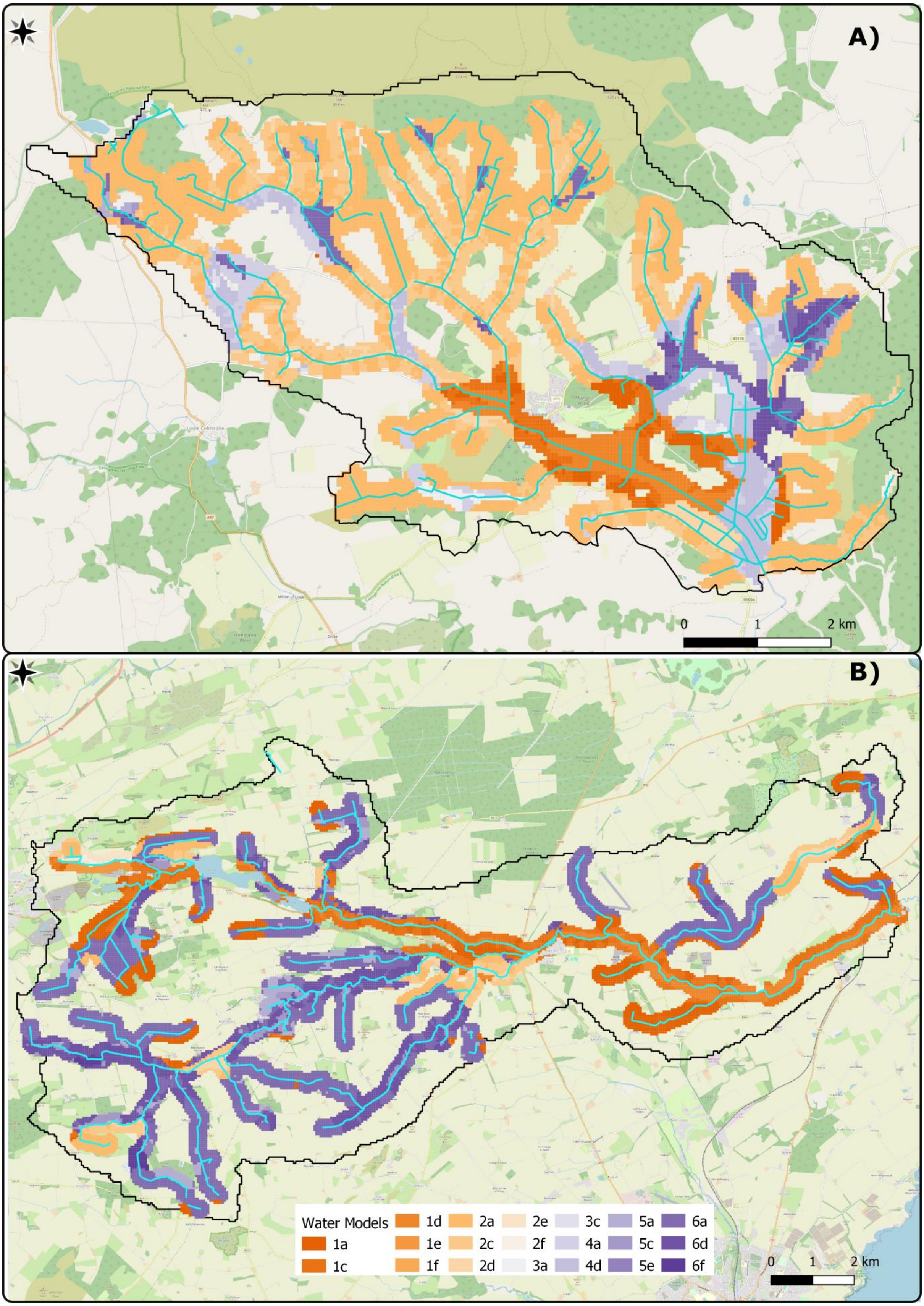


Figure 3. Maps of conceptual models of riparian contexts at 50m grid resolution in a 200m riparian zone around the river network in the A) Tarland and B) Lunan catchments. © Crown copyright and database right (2022). All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

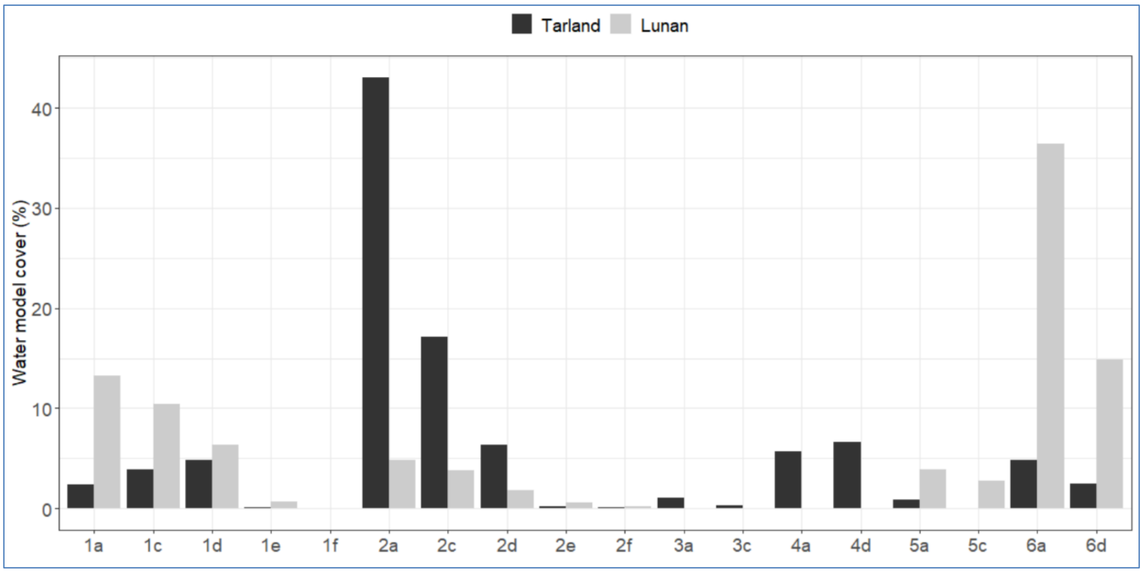


Figure 4. Areal coverages (in %) of individual conceptual models of riparian context within the Tarland and Lunan catchments. Model codes are given in Table 2.

Both Figures 3 and 4 show the prevalence of relatively free draining soils on hillslopes in Tarland, which cover around 60% of the 200m wide riparian zone, either draining directly to watercourses (Model 2a) or in undrained floodplain areas (Model 2c), while the wetter Models 5a, 5c, 6a and 6d cover around 58% of the riparian zone in the Lunan catchment.

Producing maps of conceptual models of riparian context as the ones shown in Figure 2 for the Tarland and Lunan catchments enables linking them with riparian management measures shown in Section 3 and other risk factors as discussed in Section 4 to facilitate a targeted approach towards planning and placing effective riparian management measures on the ground.

3. Utility of the models for targeting mitigation

3.1. Considered riparian management measures

A summary of sixteen selected management measures suitable for riparian zone applications has been developed by the SmarterBufferZ project (www.smarterbufferz.ie). These include four groups of measures:

- Three basic buffer zones, capable of being used alone, but also delivering the space for the modular incorporation of other measures as part of management packages;
- Five measures targeting surface runoff, sediment and particle associated pollutants and in one case overbank flow from the watercourse;
- Six measures targeting subsurface pathways including artificial drainage;
- Two measures that include the channel itself as part of the riparian management zone.

The sixteen measures are presented in Table 3 and are described in full in Stutter et al. (2022) in terms of their functioning, evidence base and effectiveness for different pollution and wider ecosystem benefits. Many of the sediment and runoff controlling measures developed originally from concepts in Rural Sustainable Drainage Systems (SUDs) approaches and latterly within the Natural Flood Management research community. Subsurface measures have developed especially in the U.S. and Scandinavia.

3.2. Rule-base for measure suitability against conceptual models

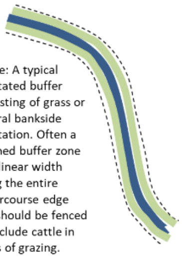
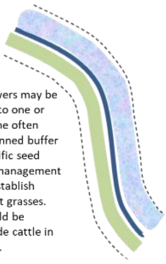
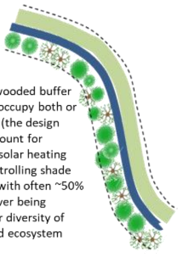
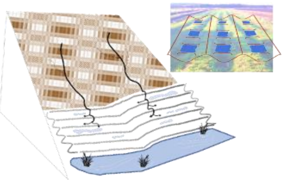
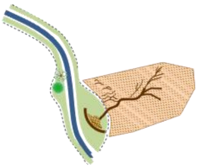
Whilst some of the management measures in Table 3 have general suitability to multiple landscapes, some groups target specific pathways and many have certain aspects of integration with landscapes in terms of suitability, enhancing their effectiveness or negative interactions that can be used to exclude them for certain landscapes. To enhance the use of the hillslope-floodplain riparian context models for the screening of different riparian management measures against parts of a landscape (e.g. small catchment area, farm, or fields) we have developed a simple rule-base on landscape model against measure suitability. Some key rationale in the development of the rules is presented in Table 4.

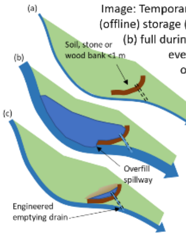
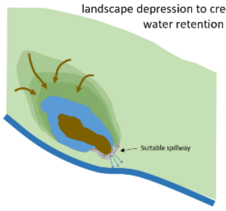
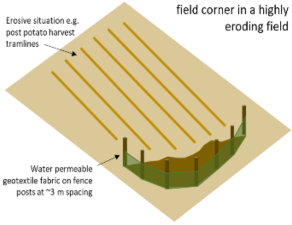
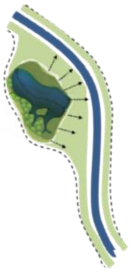
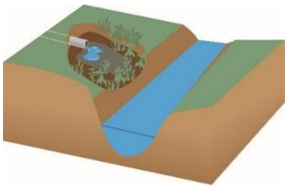
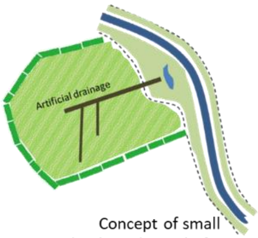
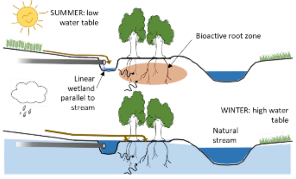
Following from this consideration of key factors of functioning and pathways the rule-base assesses measures against the hillslope-floodplain riparian models according to five criteria (Table 5):

- unsuitable and therefore excluded;
- potentially suitable;
- suitable;
- highly suitable with particular match between landscape and measure design;
- those only considered for high erosion risk.

The integration of management measures with the landscape models presented in Table 5 and explained in Table 4 involves mainly their diffuse pollution and runoff mitigation functioning and how this interacts with soil water pathways, soil wetness and water table. In this report we consider that the rationale for choosing a measure based on habitat and wider ecosystem aspects such as requirements for protection of aquatic habitats and functions (e.g. shading, leaf litter) are beyond the scope of this present work, but will always influence decisions made in the field (Cole et al., 2020).

Table 3. The sixteen riparian management measures brought together in a synthesis by the Smarter BufferZ project (summarised from Stutter et al., 2022)

Measure group	Measure	**Photo**	**Schematic of how it functions**	**Brief description and *key reference***
Baseline margin space	**Grass buffer strip**		 Image: A typical vegetated buffer consisting of grass or natural bankside vegetation. Often a planned buffer zone is of linear width along the entire watercourse edge and should be fenced to exclude cattle in areas of grazing.	Popular agri-environment scheme measure provides a physical barrier from agricultural activities, limited surface runoff trapping and bank stabilisation. Best if fenced for cattle exclusion. *Ref: Stutter et al. (2021)*
	Wildflower buffer		 Image: Wildflowers may be incoprorated into one or both banks of the often linear width planned buffer zone using specific seed mixes. Certain management is required to establish flowers amongst grasses. The buffer should be fenced to exclude cattle in areas of grazing.	Enhancement on the grass filter strip using wildflower seed mixes for specific biodiversity, or even nutrient uptake or biomass goals. *Ref: Cole et al. (2020)*
	Wooded buffer		 Image: A wooded buffer zone may occupy both or one banks (the design should account for dominant solar heating angles controlling shade benefits), with often ~50% canopy cover being optimal for diversity of habitat and ecosystem services.	Inclusion of trees improves airborne pollution interception, deep rooting and nutrient uptake into biomass, habitat, hydromorphology and aquatic protection. *Ref: Stutter et al. (2019)*
Surface runoff and sediment options	**Magic margins**		 Image: Magic margin ridges perpendicular to slope (left) and showing the mini-dam concepts in the furrows (right)	A practical addition to grass buffers for soil erosion using a farm tied-ridger and potato drill plough to create min-dams (sown with wildflowers to stabilise) that encourage water and sediment retention. *Ref: not yet developed*.
	Raised buffer: field runoff		 Image: The concept of a raised buffer positioned at the base of a major pathway of muddy runoff, perhaps using a locally widened riparian space.	A bund (soil, stone or wood) can be placed across an overland flow pathway to interrupt the path, temporarily retain water and trap sediment. Spillways and exit pipes can be engineered to suit. *Ref: Wilkinson et al. (2013)*

	Raised buffer: overbank storage		 Image: Temporary filling of overbank (offline) storage (a) empty, pre-flood, (b) full during a flood (overbank) event, and (c) emptying of water after ~24-48 hours but having retained sediment after the event.	A bund (soil, stone or wood) placed onto floodplains temporarily stores overbank floodwater and traps sediment, engineered to drain back to the watercourse in <48 hours. *Ref: Nicholson et al. (2020)*
	Sediment trap		Image: Sediment trap, intercepting surface runoff pathways and enhancing existing landscape depression to create sufficient water retention for sediment settlement 	Enhancing of natural landscape depressions to trap water and sediment temporarily. Large surface areas benefit sedimentation. Outlets can be engineered. *Ref: Duffy et al (2016)*
	Sediment filter fences		Image: Sediment filter fence retaining sediment at lowest field corner in a highly eroding field 	Especially for high erosion risk from surface runoff on steeper slopes or after (often temporary in a rotation) high risk cropping. A geotextile barrier for sediment retention. *Ref: Vinten et al. (2014)*
Sub-surface pathway options	**Surface-, ground-water wetlands**			Permanently wet, vegetated wetlands enhancing natural ones or constructing new. Fed by upwelling groundwater and surface water. Requires adequate retention time for treatment. *Ref: Ockenden et al. (2014)*
	Tile drain-fed wetlands		 Concept of small wetlands at the end of a tile-drain in a widened riparian space.	Cutting back a main arterial field drain from exiting directly to water, instead directed into a small wetland zone (with permanent vegetation and higher C soils for treatment). *Ref: Carstensen et al. 2020.*
	Integrated buffer zones		Image: Integrated buffer zone functioning as a sediment trap and bioactive root zone in summer (top), compared to a particle deposition bed for surface runoff with winter high water tables (bottom). 	A zoned buffer approach comprising linear wetland and tree zone for interrupting pathways of surface erosion and field drains, with subsurface treatment amongst tree roots and particle deposition onto

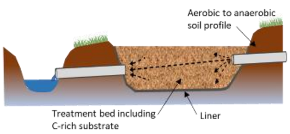
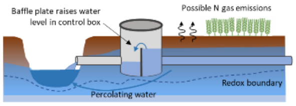
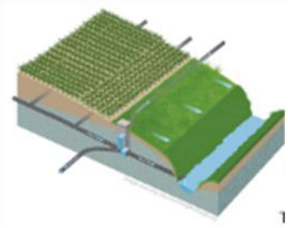
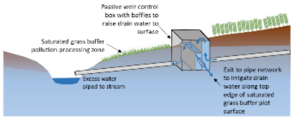
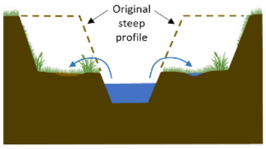
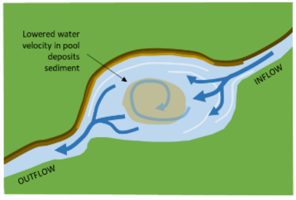
				seasonally waterlogged soils. *Ref: Zak et al. (2019)*
	Denitrifying bioreactors	 Photo: J. Johnson, Iowa NRCS	Image: Denitrifying bioreactor fed by tile drainage waters and using a C-media such as woodchip, mixed or graded with gravel to maintain hydraulic properties 	Engineered solutions for channelling high nitrate load pathways into a bioreactor fed with enriched organic C. Engineered in terms of flow rates, bed particle size and infiltration and C-dosing. *Ref: Carstensen et al. (2020)*
	Controlled drainage	 Image: Typical pre-made chamber used at the point of intervening on the drain.	Image: Drainage management structure used at end of subsurface soil drain to raise soil water level during autumn and winter to promote denitrification. 	Field tile drain discharges with high nitrate loads are seasonally shut off at a control valve so that the field slope becomes a saturated wedge to encourage natural denitrification. *Ref: Carstensen et al. (2020)*
	Tile drain irrigation onto saturated soils	Taken from www.transforming drainage.com 	Image: Drain water management structure using baffles to passively raise soil drain water to enable irrigation onto a saturated grass zone of carbon-rich topsoils 	Field tile drain discharges with high nitrate loads are raised to surface levels by a control structure to enable water distribution onto topsoils of suitable organic C content for natural denitrification. *Ref: Jaynes and Isenhart (2019)*
In-channel options	**Two stage channels**	 Image: Indiana watershed initiative	Image: Steep sided channel reprofiled to have widened, vegetated side 'benches' capable of temporarily holding flood water and retaining sediment as the second bed stage. 	Artificial, steep-sided, open drainage ditches are reprofiled to contain mini-floodplains that retain sediments during high flows, become vegetated and treat nutrients and stabilise banks. *Ref: Davis et al. (2015)*
	In ditch sediment trap, or filter	 An engineered wood chip in-stream filter trialled in UK. Photo credit: Newcastle University.	Image: Sedimentation pool in a stream channel; one of two types of in-ditch sediment retention. 	In-channel sediment traps comprising widened basins to inserted (contained) filter materials (e..g. woodchip). *Ref: Ockenden et al. (2014)*

Table 4. Key criteria of the rule base for suitability of riparian management options against landscape types differing in land to surface water runoff pathways, soil wetness and water table, hillslope topography and floodplain characteristics.

Measure group	Measure	Integration with dominant runoff pathways	Integration with hillslope or floodplain form and wetness	Other rules
Baseline margin space	**Grass buffer strip**	Effective up to moderate surface runoff; Ineffective at subsurface matrix flows and artificial drainage.	Flatter floodplain receiving zone makes more effective, ineffective on steeper convex slopes.	
	Wildflower buffer	Effective up to moderate surface runoff; Ineffective at subsurface matrix flows and artificial drainage.	Flatter floodplain receiving zone makes more effective, ineffective on steeper convex slopes.	
	Wooded buffer	Moderate effectiveness at subsurface leaching interception on hillslope and floodplains due to deep roots; Ineffective at artificial drainage by itself.	Increased roughness increases surface runoff effectiveness on steeper ground.	Unsuitable for peaty floodplain or hillslope soils due to potential for carbon loss due to evapotranspiration lowering the watertable.
Surface runoff and sediment options	**Magic margins**	Effective at surface runoff and sedimentation. Ineffective at subsurface flows.	Can be used at the slope base on steeper ground. Requires moderate drainage at the slope base for infiltration, cannot be waterlogged.	May be useful in higher erosion risk situations of slope and cropping on soils that generate less runoff.
	Raised buffer: field runoff	Effective at surface runoff and sedimentation. Ineffective at subsurface flows and for freely draining soils.	Suitable to a greater range of soil wetness due to being a raised feature and outlet pipe can be engineered. May be built into moderately sloping banks.	Combine with other options for artificial drainage presence. May be useful in higher erosion risk situations of slope and cropping on soils that generate less runoff. May be used in low erosion risk situations to manage flood risk.
	Raised buffer: overbank storage	Effective at water storage and sedimentation from rising streamflow.	Suitable to a greater range of soil wetness due to being a raised feature and outlet pipe can be engineered.	Works in a catchment context to treat local and upstream runoff so may be suited to a location based on upstream and not solely local risk of runoff generation. Not suitable

				for steeply sloping banks, sited on floodplains.
	Sediment trap	Effective at surface runoff and sedimentation. Ineffective at subsurface flows and for free draining soils.	May be built into moderately sloping banks. Cannot be waterlogged or has no trapping capacity.	Mostly a measure for extreme erosion in other than poorly draining soils. Combine with other options for artificial drainage presence.
	Sediment filter fences	Effective at aggressive situations of surface runoff and sedimentation. Ineffective at subsurface flows and for free draining soils.	Useful on steeper slopes where other measures are less suitable at aggressive erosion situations.	Considered a ‘measure of last resort’ for sediment control.
Sub-surface pathway options	**Surface-, ground-water wetlands**	Good for retaining surface- and ground- water for treatment.	Only suitable for floodplain, shallow slope situations. Higher water tables required so less effective on artificially drained landscapes.	Suitable for high water table soils, especially peaty, where benefits C storage and C availability fuels denitrification.
	Tile drain-fed wetlands	Intercepts tile drainage for wetland treatment. May intercept some groundwater if capacity designed well.	Only suitable for floodplain, shallow slope situations.	May be overwhelmed if receiving a lot of surface runoff.
	Integrated buffer zones	Multiple elements: (i) tile drain interception, (ii) soil matrix flow interception in bioactive tree root treatment zone, (iii) linear pond system capable of receiving surface runoff if managed.	Only suitable for floodplain, shallow slope situations. Designed for seasonally high water tables but may usefully intercept artificial drainage on a drier floodplain situation.	Tree planting should be excluded from peat soils due to C loss risks with lowered water table.
	Denitrifying bioreactors	Intercepts artificial drainage pathways to load bioreactor with nitrogen for treatment.	Only suitable for floodplain, shallow slope situations. Requires anaerobic wet conditions and high C but both can be engineered into a wider set of situations.	May be suitable for local tile drainage on floodplains if intercepts hillslope water to ensure sufficient loading.

	Controlled drainage	Intercepts artificial drainage pathways and holds water in an artificially wetted hillslope for certain seasons.	Requires correct gentle slope and riparian profiles to maintain saturated soils on a limited cropland area temporarily.	Requires artificial drainage to extend from riparian zone up hillslope, cannot work only with local floodplain drainage limited sources
	Tile drain irrigation onto saturated soils	Irrigates tile drain water onto saturated surface soils for nitrogen treatment.	Only suitable for floodplain, shallow slope situations. Requires anaerobic wet conditions and moderate soil C levels.	
In-channel options	**Two stage channels**	Has multiple aspects of: (i) sedimentation and (ii) nitrogen processing in wet, secondary (side-benches) channel profile zones.	Requires fluctuation of river level from high to baseflow. Cannot work with high water table floodplains where stream height is maintained.	Works in a catchment context to treat local and upstream runoff so may be suited to a location based on upstream and not solely local pollution risks. Undrained wet floodplain situations are excluded. Can work with no floodplain if water table allows low stream flow.
	In ditch sediment trap, or filter	For moderate to high risk erosion areas provides sediment trapping in the channel.	Can work with a variety of slope forms and floodplain presence or not, or water tables adjacent to the channel suing different designs or trap or filter.	Works in a catchment context to treat local and upstream runoff so may be suited to a location based on upstream and not solely local erosion risks. Most suitable for high surface runoff areas. Unlikely sufficient sediment source area in freely drained landscapes.

Table 5. The suitability of the sixteen riparian management measures against the hillslope and floodplain characteristics of the model group and subgroup types. Where 0 (red) denotes unsuitable and excluded options, with 1 to 3 (yellow to green) denoting potentially suitable, suitable and highly suitable, respectively, with 4 (brown) denoting only considered for high erosion risk. *Models 1-3 are shown this page and 4-6 overpage.*

Hillslope	River connected directly to hillslope?	Floodplain characteristics	Model group and subgroup	Grass buffer strips at watercourse	Watercourse buffers with specific wildflower mixtures or altered vegetation	Wooded buffer strips at watercourse (one or both banks, continuous or scattered)	Magic margins	Raised buffer (temporary ponding of field runoff water and sediments)	Raised buffers and depressions (temporary ponding of channel water during overbank events)	Sediment traps	Edge of field sediment filter fences (temporary)	Buffer wetlands receiving surface and groundwater inputs	Tile drainage fed to a surface water constructed wetland or small semi-natural wetland area	Integrated buffer zones	Denitrifying bioreactor	Controlled drainage	Surface irrigation onto a saturated buffer zone after interruption of tile drainage	Two-stage channels	In-ditch sediment traps or filters
Freely draining soil, permeable subsoil & permeable bedrock	yes	na	1a	0	0	1	0	4	0	0	0	0	0	0	0	0	0	1	1
	no	Dry	1b	0	0	1	0	4	4	0	0	0	0	0	0	0	0	2	1
	no	Seasonally wet_undrained	1c	0	0	1	0	4	1	0	0	3	0	1	0	0	0	0	1
	no	Seasonally wet_drained	1d	0	0	1	0	1	1	0	0	1	1	3	2	0	0	1	1
	no	Peaty alluvium_undrained	1e	0	0	0	0	4	1	0	0	3	0	0	0	0	0	0	1
	no	Peaty alluvium_drained	1f	0	0	0	0	1	1	0	0	1	1	0	2	0	0	1	1
Freely draining soil, moderately permeable subsoil & slowly permeable bedrock	yes	No floodplain	2a	0	0	1	4	4	0	4	4	0	0	0	0	0	0	1	1
	no	Dry	2b	2	2	2	4	4	4	4	0	0	0	0	0	0	0	2	1
	no	Seasonally wet_undrained	2c	2	2	2	0	4	2	4	0	3	0	1	0	0	0	0	1
	no	Seasonally wet_drained	2d	1	1	1	0	2	2	1	0	1	1	3	2	0	0	1	1
	no	Peaty alluvium_undrained	2e	2	2	0	0	4	2	4	0	3	0	0	0	0	0	0	1
	no	Peaty alluvium_drained	2f	1	1	0	0	2	2	2	0	1	1	0	2	0	0	1	1
Poorly draining soil, permeable subsoil & permeable bedrock	yes	No floodplain	3a	0	0	1	3	2	0	2	4	0	0	0	0	0	0	1	1
	no	Dry	3b	2	2	2	3	2	2	4	0	0	0	0	0	0	0	2	1
	no	Seasonally wet_undrained	3c	2	2	2	0	2	2	4	0	3	0	1	0	0	0	0	1
	no	Seasonally wet_drained	3d	2	2	2	0	2	2	4	0	2	2	3	2	0	2	1	1
	no	Peaty alluvium_undrained	3e	2	2	0	0	2	2	4	0	3	0	0	0	0	0	0	1
	no	Peaty alluvium_drained	3f	2	2	0	0	2	2	4	0	2	2	0	2	0	2	1	1

Table 5. *(contd)*

Hillslope	River connected directly to hillslope?	Floodplain characteristics	Model group and subgroup	Grass buffer strips at watercourse	Watercourse buffers with specific wildflower mixtures or altered vegetation	Wooded buffer strips at watercourse (one or both banks, continuous or scattered)	Magic margins	Raised buffer (temporary ponding of field runoff water and sediments)	Raised buffers and depressions (temporary ponding of channel water during overbank events)	Sediment traps	Edge of field sediment filter fences (temporary)	Buffer wetlands receiving surface and groundwater inputs	Tile drainage fed to a surface water constructed wetland or small semi-natural wetland area	Integrated buffer zones	Denitrifying bioreactor	Controlled drainage	Surface irrigation onto a saturated buffer zone after interruption of tile drainage	Two-stage channels	In-ditch sediment traps or filters
Poorly draining soil with artificial drainage, permeable subsoil & permeable bedrock	yes	No floodplain	4a	0	0	1	2	2	0	4	4	0	0	0	0	2	0	1	1
	no	Dry	4b	1	1	1	2	2	2	4	0	0	0	1	3	1	2	2	1
	no		na																
	no	Seasonally wet_drained	4d	1	1	1	0	2	2	4	0	2	3	3	3	1	2	1	1
	no		na																
	no	Peaty alluvium_drained	4f	1	1	0	0	2	2	4	0	2	3	0	2	1	1	1	1
Poorly draining soil over slowly permeable subsoil	yes	No floodplain	5a	0	0	1	0	2	0	3	4	0	0	0	0	0	0	1	2
	no	Dry	5b	2	2	3	0	3	3	3	0	1	0	0	0	0	0	1	2
	no	Seasonally wet_undrained	5c	2	2	2	0	3	3	1	0	3	0	1	0	0	0	0	2
	no	Seasonally wet_drained	5d	2	2	2	0	2	2	4	0	2	2	3	1	0	1	1	2
	no	Peaty alluvium_undrained	5e	2	2	0	0	2	2	0	0	3	0	0	0	0	0	0	2
	no	Peaty alluvium_drained	5f	2	2	0	0	2	2	4	0	2	2	0	1	0	1	1	2
Poorly draining soil with artificial drainage over slowly permeable subsoil	yes	No floodplain	6a	0	0	1	0	2	0	2	4	0	0	0	0	2	0	1	2
	no	Dry	6b	2	2	3	0	3	3	2	0	1	3	3	1	1	2	1	2
	no		na																
	no	Seasonally wet_drained	6d	1	1	2	0	2	2	1	0	2	3	3	1	1	2	1	2
	no		na																
	no	Peaty alluvium_drained	6f	1	1	0	0	1	1	0	0	2	3	0	0	1	2	0	2

4. Example of field-scale screening between management options within the Tarland catchment

4.1. Additional risk factors

Soil erosion risk (low, moderate, or high risk) was assessed from a 50m grid map that gives the risk of a bare soil being eroded by water under intense or prolonged rainfall (Lilly and Baggaley, 2014) for the extent of the Soil Map of Scotland (partial cover) Phase 6. The susceptibility to erosion is based on soil texture and the soil's capacity to absorb rainfall combined with the slope to determine how erosive the overland flow could be with steeper slopes leading to faster runoff. Soils with mineral topsoils have been classified separately from those with organic (peaty) topsoils, while organic soils (peats) are considered to be highly erodible so are always considered to be at a high risk of erosion.

Key factors in moderating soil erosion is the amount of vegetation cover and land use, thus, information on the dominant (i.e., with higher areal coverage) crop from from the IACS database from 2007 to 2015 was used to assess land cover/use in those fields where data is available. Land cover in fields with missing IACS crop information was determined from LCM 2015 (Rowland et al., 2017). IACS crop type information for the 2007-2015 period have been previously used to calculate land use intensity (LUI) classes for each field using a method described in Cloy et al. (2021). In brief, IACS crop codes were classified into risk classes depending on whether vegetation provided complete and continuous cover of the soil to provide sufficient protection against soil erosion and on factors affecting soil compaction risk and soil aggregate instability, such as the use of heavy machinery and seed-bed preparation. In this context, grassland systems were classified as Low risk, cereals as Moderate risk and root vegetables and maize as High risk. LUI at each field for the 9-year period was assessed using a 6-class system of increasing LUI (LUI-1=Low -> LUI-6=High) using a set of rules based on the counts of years for each crop risk class (Low, Moderate and High):

- LUI-1: Rough grazing was the dominant land use in most years.
- LUI-2: Improved grassland was the dominant land use in most years.
- LUI-3: Number of years in grass was greater than number of years in cereals and no root crops grown.
- LUI-4: Number of years in cereals was greater than number of years in grass and no root crops grown.
- LUI-5: Root crops grown in at least one of the 9 years.
- LUI-6: Root crops grown for 5 years or more.

4.2. Field examples of measure suitability screening

A selection of fields with some contrasting characteristics was made from the case study areas in Figure 3 to demonstrate the potential for using the riparian context models in mitigation planning. The area of eight fields is depicted in Figure 5 and the cropping, land use intensity and soil erosion risks are in Table 6. Field D is not within the IACS annual field-level crop recording system and for this field the cropping is estimated from general national-level land cover datasets; hence demonstrating some data gaps in supporting data. The soils are all classified as mineral soils with moderate erosion risk. However, Field F has the LUI of 5, indicating that erosion susceptible root crops are present in recent rotations, and due to this we consider that this field has an increased soil erosion risk once the effect of cropping has been accounted for. Hence, measures suggested for Field F, given in Table 5 marked (in brown), are appropriate for high erosion risk situations.

Table 6 also gives the dominant riparian context models for areas adjacent to the watercourses in the fields and, using the rules in Tables 4 and 5, the resulting options for riparian mitigation measures. It can be seen that some fields have more simple contexts within the field (comprising one dominant context model), for example Field A. In contrast other fields have multiple context models and these can vary between similarities of the hillslope but absence presence of the floodplain (for example Fields B and E), or alternatively the variation at a field scale can be of a gradient of surface wetness (and therefore runoff generation) at the hillslope (for example, Fields C or H). As a result, the selection of measures varies from simple to complex (Table 6). Many measures have an asterisk denoting specific relation to site-conditions in Table 6 and for this reason we discuss the options for the specific fields.

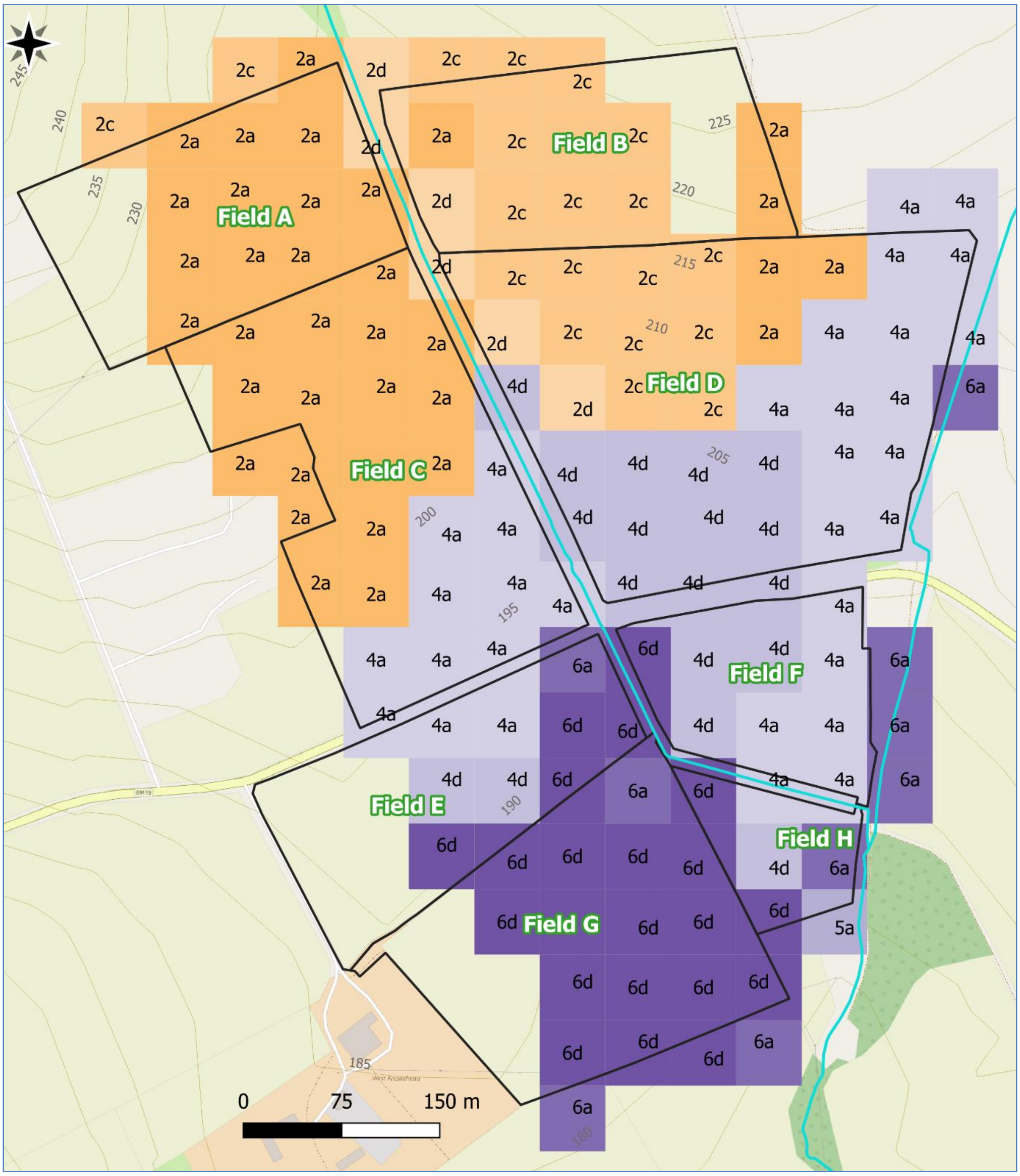


Figure 5. Example of conceptual water modelling at a 200m riparian zone for selected eight fields (Fields A-H) in Tarland. © Crown copyright and database right (2022). Labels in each 50m grid cell correspond to water model codes given in Table 2. All rights reserved. The James Hutton Institute, Ordnance Survey Licence Number 100019294.

Field A: See the example layout in Figure 6a. Dominated by free-draining hillslopes that generate some seasonal surface runoff and with only a small floodplain area and thus defined by model 2a. The risks of surface runoff are lower than other fields here but the potential measure of a wooded buffer at the bottom field corner may be a good option. The In-ditch filter potential option was discounted as the field is at the top of the ditch system with few agricultural fields upstream. The channel form may lend itself to a two-stage channel.

Field B: Dominated by freely draining hillslopes that generate some seasonal runoff but with a mixture of no floodplain and wetter floodplain areas. Hence, measures from both 2a and 2d are listed for this field with many having the asterisk symbol to denote that local survey would confirm the suitable location of measures requiring a toe-slope or floodplain slope base form to function (e.g. overbank raised buffer). Other measures such as the field runoff raised buffer have an asterisk to denote a walk-over survey would be required to inform on discrete erosion pathways necessary to place such a measure. Because of the limited extent of area 2b we suggest that end of drain measures would only have a limited floodplain source area (the rest of the hillslope is predicted as not artificially drained) and with small source areas measures for tile drains were discounted.

Field C: Floodplains are indicated to be absent and freely- to moderately- draining hillslopes run straight towards the watercourse. Magic margins, raised buffers for field runoff would be appropriate measures, with potential for wooded buffers and two-stage channels. In-ditch filters, sediment traps could be assessed whether local erosion conditions dictated these but the moderate erosion risk and spring cereals cropping suggest caution on those. If major subsurface drainage can be determined as present and located, then controlled drainage may be appropriate if nitrate is a significant issue.

Field D: Wet floodplains are indicated to be present and freely- to moderately- draining hillslopes run straight towards the watercourse. Tile drainage is likely to be a significant pollution pathway in this field and are reflected in the strongly suggested measures. Here, a complex array of options from models 2d and 4d are presented in Table 6 and these would require field survey to ascertain the severity of pressures and select further down to several key measures.

Field E: Has a small border along the stream for the field size. The field is poorly draining and whilst model 6d (with a floodplain) dominates it would require site survey to assess local conditions for measures requiring a flatter toe-slope space, such as the tile drain wetland, integrated buffer zone, raised buffer for overbank storage. If the toe of the slope was the correct angle, then tile drain irrigation onto a saturated buffer may be an option. The pressures in the field and the pollution loading and ability to locate main arterial tile drains would be needed to inform the necessity of more interventionist measures such as controlled drainage or a denitrifying bioreactor. Similarly, survey of erosion would be necessary to select and understand the necessity and location of point measures for sediment and runoff, such as the raised buffer for field runoff or sediment trap.

Field F: See the example layout in Figure 6a. The model again suggests complexity in this field with the presence of moderate to poorly drained soils with and without floodplains and the cropping suggests that artificial drainage is present. Hence, many possible measures for models 4a, 4d and 6d are presented in Table 6 to consider and field survey becomes imperative. The moderate soil inherent erosion risk class may be considered increased in risk by the presence of root crops in the rotation in recent years. Our suggested layout in Figure 6b acts on surface pathways with magic margins along one lower field edge and an example of a raised buffer (or alternatively a sediment trap) for field runoff in the field corner, if justified by survey. For subsurface pathways (subject to locating drainage by survey) an illustration of a tile drain fed wetland is given (may also be suited to an integrated buffer). We suggest that as this is the lowest of the fields in the system along the open ditch that it can be a good location for in-channel measures combating issues collectively from fields A-H. For this an in-ditch filter just prior to the confluence of the natural stream, and/or one reach of two-stage channel may be appropriate.

Field G: Has a very small border along the stream for the field size and this is an inherently poorly drained field but has some uncertainty (at the model resolution) as to whether a floodplain exists, such that site survey is required. There are various options in Table 6 that reflect this uncertainty in the spatial data. Site survey should determine if there's any major delivery point at the short stream riparian section and place discrete measures there for surface or subsurface pathways, likely something simple like a small, raised bund , sediment trap or tile drain wetland in the field bottom corner. Alternatively, it may be that survey suggests only the baseline requirement of a 2 m wide regulatory compliance buffer zone.

Field H: This small field has borders on the ditch system and the natural stream. It also has a complex mixture of moderate to poorly drained soils with and without floodplains and the cropping suggests that artificial drainage is present. Therefore, the list of measures in Table 6 is large and site survey is mandatory to establish the pressures and locate any preferred measures to discrete points of pollution delivery. A wooded buffer may be a good baseline option (especially against the natural stream) with other point measures as per the results of the survey.

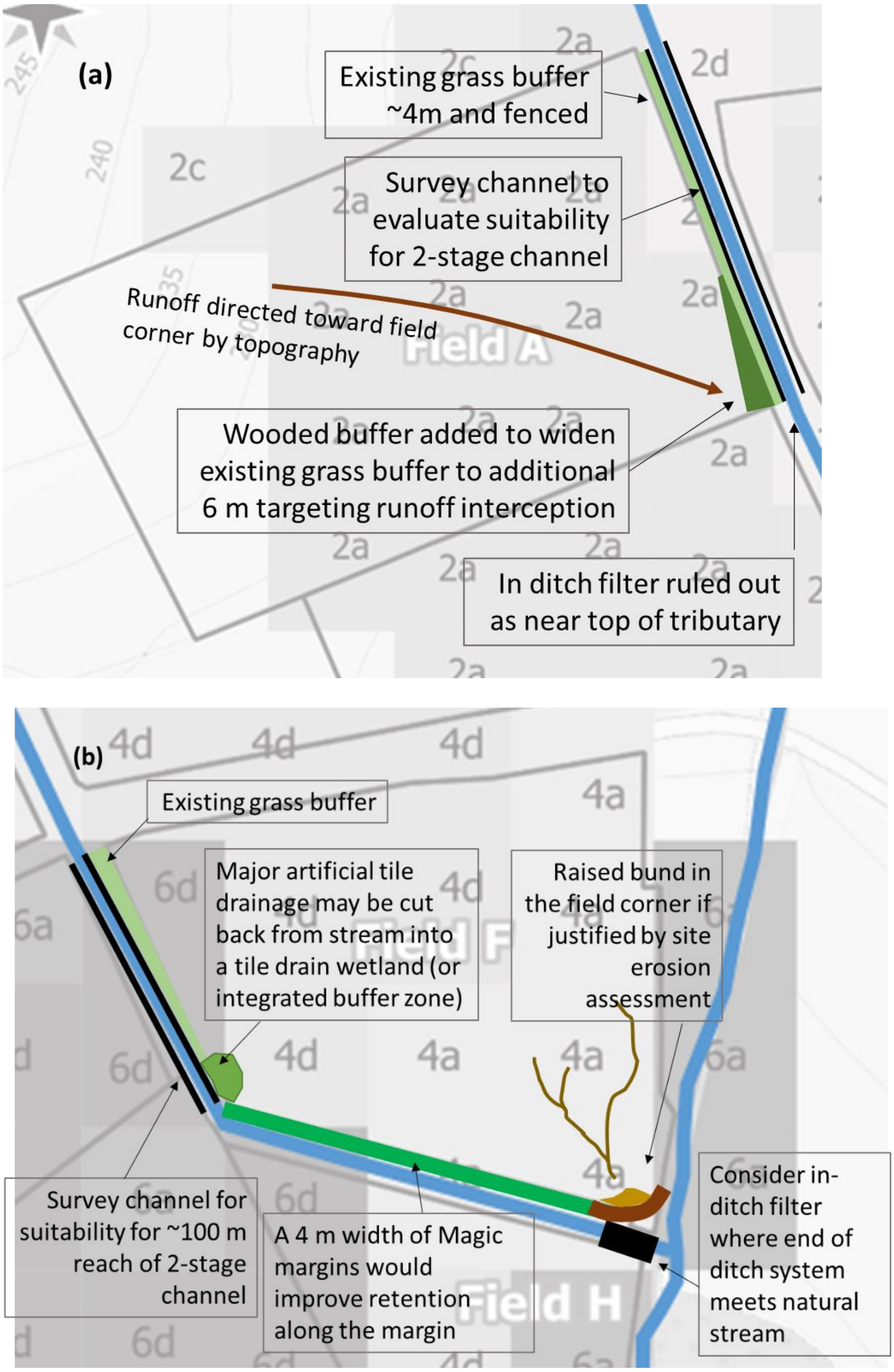
Table 6. Summary of the fields shown in Figure 5 in terms of their IACS crop type (2007-15 most frequent), calculated land use intensity, inherent erosion risk class, riparian contexts and the resulting recommendations for riparian management measures according to the rules developed here. Land cover for Field D is from LCM 2015 because of missing IACS crop information.

Fields	**Most frequent crop**	**Land use intensity (LUI)**	**Soil Erosion Risk**	Riparian models	Main landscape description	Riparian management options		
						Strong suggestions	**Suitable**	**May be considered**
A	Spring barley (*6*)	LUI-4	Moderate (mineral)	2a	Freely draining soil, no floodplain to poorly draining floodplain, likely drained			Wooded buffer; 2-stage channel; in ditch filter*
B	Spring barley (*7*)	LUI-4	Moderate (mineral)	2a, 2d	Freely draining soil, no floodplain to poorly draining floodplain, likely drained		Raised buffer: field runoff*, overbank storage*	Grass, wildflower or wooded buffer; Sediment traps; 2-stage channel; In ditch filter*
C	Spring barley (5)	LUI-4	Moderate (mineral)	2a, 4a	Freely draining hillslope to intermediate draining with artificial drainage, no floodplain		Magic margins; raised buffer: field runoff*; Controlled drainage*	Wooded buffer; Sediment traps; 2-stage channel; In ditch filter*
D	Arable & horticulture	-	Moderate (mineral)	2d, 4d	Freely draining to intermediate (with artificial drainage) hillslopes, with wet and likely artificially drained floodplain	Tile drain wetland*; integrated buffer zones; Denitrifying bioreactor*	Surface & groundwater wetlands; Raised buffer: field runoff, overbank storage	Grass, wildflower or wooded buffer; Sediment traps; 2-stage channel; In ditch filter
E	Grass under five years (*5*)	LUI-3	Moderate (mineral)	6d (minor area of 6a)	Inherently poorly draining hillslopes with artificial drainage with mostly presence of a floodplain	Tile drain wetland*; Integrated buffer zone	Wooded buffer; Raised buffer: field runoff, overbank storage*; Surface irrigation onto saturated buffer*; In-ditch filter	Grass*, wildflower* buffer; 2-stage channel; Sediment trap; Controlled drainage; Denitrifying bioreactor*

F	Grass under five years (*3*)	LUI-5	Moderate (mineral)	4a, 4d, 6d	Moderately to poorly draining hillslopes with artificial drainage and variable presence of a floodplain	Tile drain wetland*; integrated buffer zones; denitrifying bioreactor*; sediment traps*	Surface & groundwater wetlands; Raised buffer: field runoff, overbank storage*	Grass, wildflower or wooded buffer; 2-stage channel; in ditch filter
G	Grass under five years (*5*)	LUI-3	Moderate (mineral)	6a, (small area 6d)	Inherently poorly draining hillslopes with artificial drainage with variable presence of a floodplain	Tile drain wetland*; Integrated buffer zone*	Raised buffer: field runoff; Sediment trap; Controlled drainage	Wooded buffer; 2-stage channel
H	Grass under five years (*1*)	LUI-3	Moderate (mineral)	4a, 6a (small area 6d)	Moderately to poorly draining hillslopes with artificial drainage and variable presence of a floodplain	Tile drain wetland*; Integrated buffer zone*	Magic margins; Raised buffer: field runoff; Controlled drainage; In ditch filters	Wooded buffer; 2-stage channel

***Denotes measures that have strong dependencies on site aspects, or contrasts in suitability differing between contrasting riparian context models predicted to occur in the same field. These are discussed in section 4.2.**

Figure 6. Mitigation measure choices from Table 6 represented at the field scale for (a) Field A and (b) Field F.



5. Conclusions

The methodology for deriving the riparian contexts utilises well established principles in the translation of soil groupings for dominant runoff flowpaths. Building on this, the categorisation of hillslope and floodplain has been made to enable six major conceptual groups (hillslope wetness/runoff generation classes) to be further subdivided into subtypes for hillslope-floodplain combinations. A further addition within the groups and their subtypes has been rules for the presence of artificial drainage based on whether the hillslope or floodplain have a specific land use and whether soils with inherent impaired drainage and present and so have high probability of being artificially drained. Scottish soils data for the main agricultural areas are available at a geographical scale that that enables these riparian context models to be evaluated and used for field-by-field assessments within catchments (here at 50 m grid resolutions). An initial evaluation of the occurrence and distribution of the resulting 32 context models in two medium sized (<100 km^2) agricultural catchments in NE Scotland showed that all but 14 of the riparian context models were present. The characteristics of those not present were often of a free-draining alluvial floodplain, or peaty floodplains (undrained and artificially drained). Hence, each catchment had a diversity of types across the hillslope wetness and drainage classes, with and without floodplains, which justified the use of such a classification in evaluating riparian contexts at the spatial scale used.

After presenting a compilation of sixteen riparian mitigation measures for improving water quality we evaluated the integration of these with the riparian context models. Groups of the pollution mitigation methods target specific pathways, including surface and subsurface groups, with obvious linkages to the main features being drawn out in the riparian context models. A set of rules was explained for the selection of measures as being unsuitable, potentially-, to strongly- suited to the attributes of the riparian context models. Then a small area of fields exhibiting a diversity of riparian contexts was chosen from one of the case study catchments. To inform suitability where a measure was specified as only suited to a context if the erosion risk was high, then additional risk factors were assembled for the fields from spatial datasets, namely the inherent soil erosion risk and the intensity of cropping. Amongst the eight example fields there was a diversity of riparian context models even at within field-scale. Some fields comprised free draining to moderate draining soils either with floodplains absent or present within a single field; other fields had one dominant hillslope drainage class but varied in floodplain subtypes; several fields had both diversity of floodplain, or no floodplain characteristics and varying hillslopes from moderate to poorly drained. Along with this came, for some fields a clearer short-list of mitigation measures, for others the list was longer. Many of the mitigation measures required additional information that would come from field survey; in part this was for specifying the exact location and nature of the variation between context types (e.g. floodplain indicated as present vs not, or artificial drainage present vs not). The approach of short-listing mitigation measures using the riparian context models shows promise for informing catchment to farm planning scales. It is vital that this is used in conjunction with field-level surveys to make more informed decisions on the ground.

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Appendix 1. Full set of schematics for the riparian context models (refer to Table 2 for the overall key).

MODEL 1

Freely draining soil, permeable subsoil and permeable bedrock

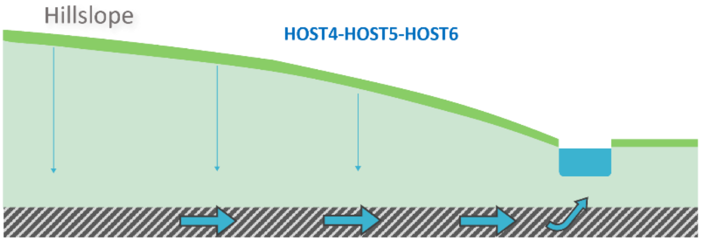
Scenario description

- Main pathways: vertical to aquifer and then horizontal towards the river in bedrock. Little surface runoff likely.
- Floodplain soils may be seasonally wet, or in some cases may be poorly draining
- Main significant issue: NO_3.

🟩	Freely draining soil
■	Poorly draining soil
□	Moderate/high permeability subsoil
▩	Intermediate and poorly draining soil with artificial drainage
▨	Permeable bedrock
🟫	Peaty topsoil on peat or alluvium
🟦	River/Stream
→	Flowpaths
⇸	Flowpaths for artificial subsurface drainage
➡	Dominant flowpaths

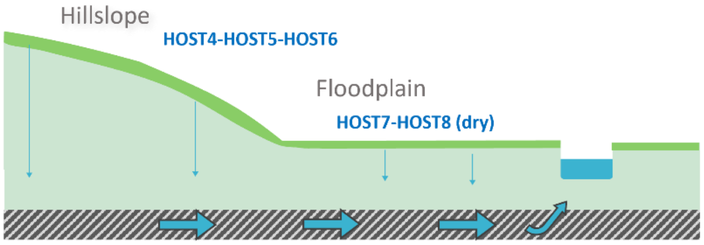
1a

River connected to hillslope, no floodplain



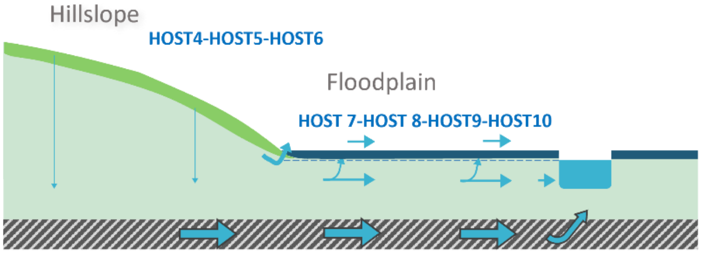
1b

Floodplain with freely draining alluvial soils



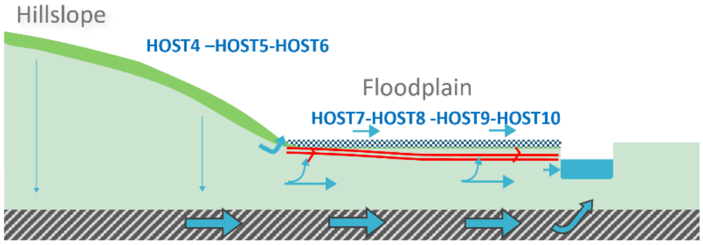
1c

Floodplain with poorly draining alluvial soil



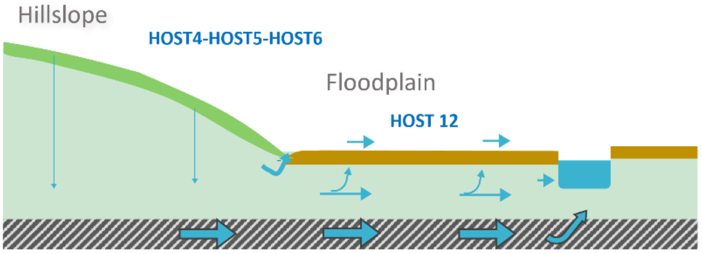
1d

Floodplain with poorly draining alluvial soil & artificial drainage



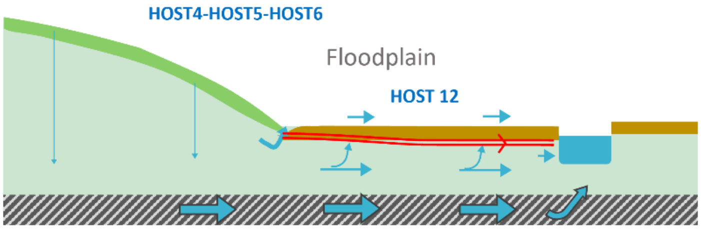
1e

Floodplain with peaty soil



1f

Floodplain with drained peaty soil



MODEL 2

Freely draining soil, moderately permeable subsoil and slowly permeable substrate

Scenario description

- Main pathways: vertical to slowly permeable substrate (rock or drift)
- Some seasonal overland flow possible, especially where soils are shallow
- Floodplain soils may be seasonally wet, or in some cases may be poorly draining
- Main significant issue: NO_3.

🟩 Freely draining soil

■ Poorly draining soil

□ Moderate/high permeability subsoil

▦ Intermediate and poorly draining soil with artificial drainage

☰ Slowly permeable substrate

🟫 Peaty topsoil on peat or alluvium

--- Slowly permeable subsoil

🟦 River/Stream

→ Flowpaths

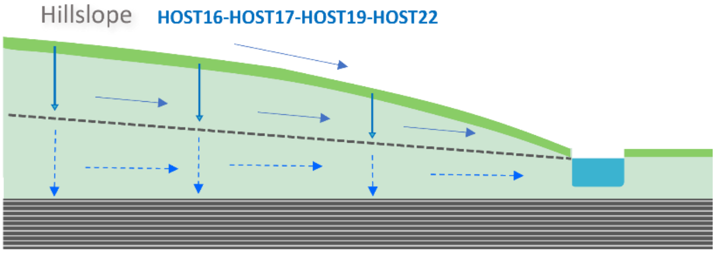
⇢ Less significant flow paths

⇉ Flowpaths for artificial subsurface drainage

⇨ Dominant flowpaths

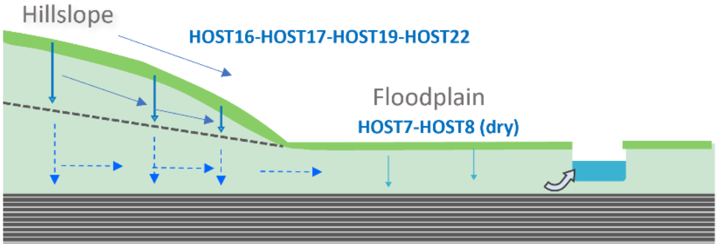
2a

River connected to hillslope, no floodplain



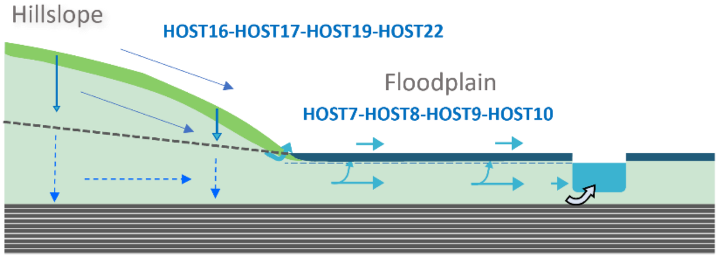
2b

Floodplain with freely draining alluvial soils



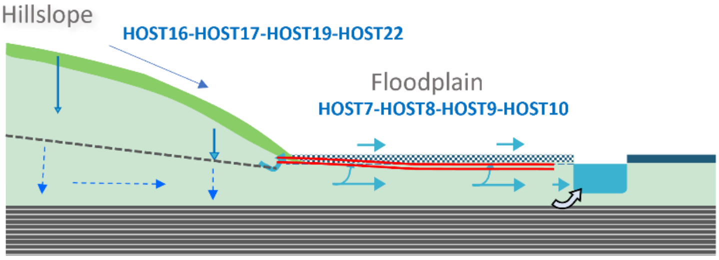
2c

Floodplain with poorly draining alluvial soil



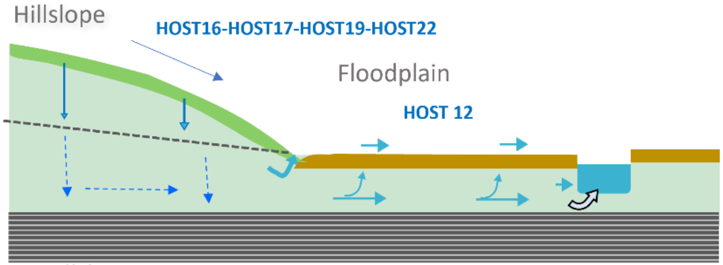
2d

Floodplain with poorly draining alluvial soil & artificial drains



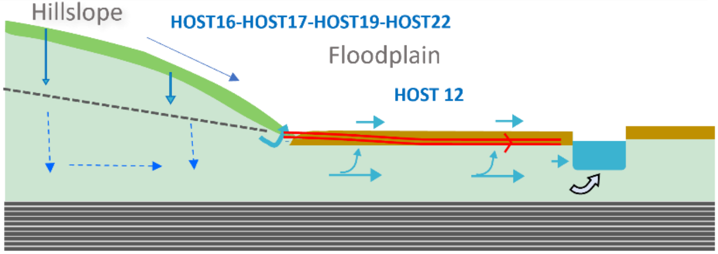
2e

Floodplain with peaty soil



2f

Floodplain with drained peaty soil



MODEL 3

Intermediate and poorly draining soil, moderately permeable subsoil and permeable substrate

Scenario description

- Main pathways: vertical to water table and then horizontal towards the river in subsoil and bedrock.
- Some seasonal overland flow likely, Floodplain soils may be seasonally wet, or in some cases may be poorly draining
- Main significant issue: NO_3.

🟩 Freely draining soil

🟦 Intermediate to poor draining soil

⬛ Poorly draining soil

⬜ Moderate/high permeability subsoil

▩ Intermediate and poorly draining soil with artificial drainage

▨ Permeable substrate

🟫 Peaty topsoil on peat or alluvium

🟦 River/Stream

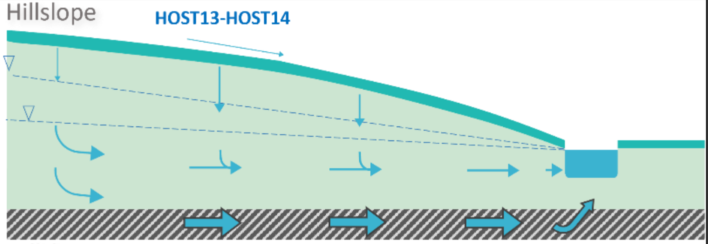
→ Flowpaths

⇉ Flowpaths for artificial subsurface drainage

➡ Dominant flowpaths

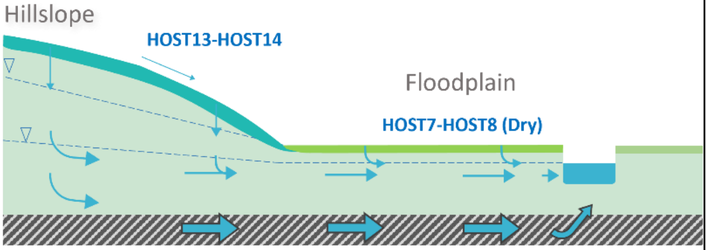
3a

River connected to hillslope, no floodplain



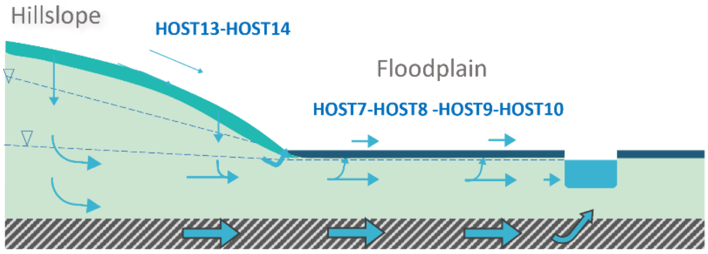
3b

Floodplain with freely draining alluvial soils



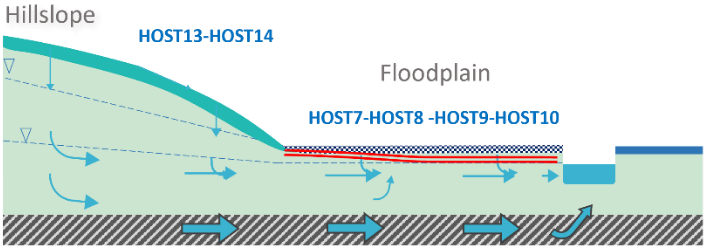
3c

Floodplain with poorly draining alluvial soil



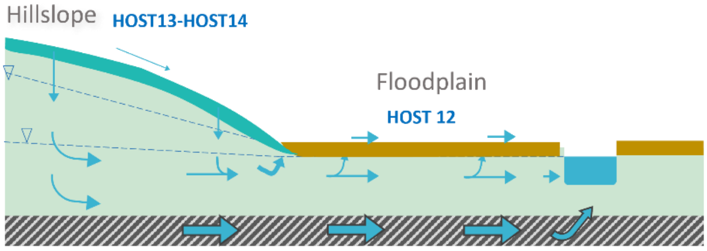
3d

Floodplain with poorly draining alluvial soil & artificial drainage



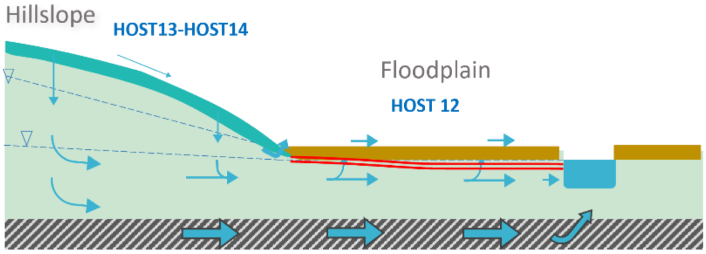
3e

Floodplain with peaty soil



3f

Floodplain with drained peaty soil



MODEL 4

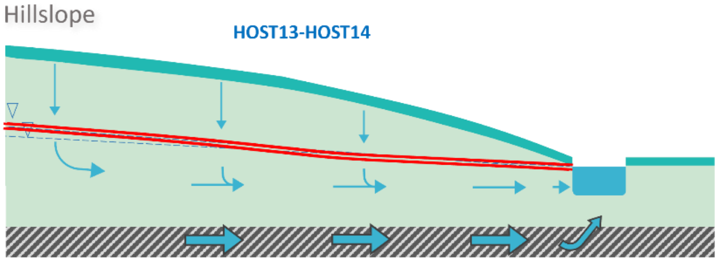
Intermediate and poorly draining soil, moderately permeable subsoil and permeable bedrock

Scenario description

- Main pathways: vertical drains and then horizontal towards the river in subsoil and bedrock. Some infiltration below drains is possible
- Some seasonal overland flow likely.
- Main significant issue: NO_3.

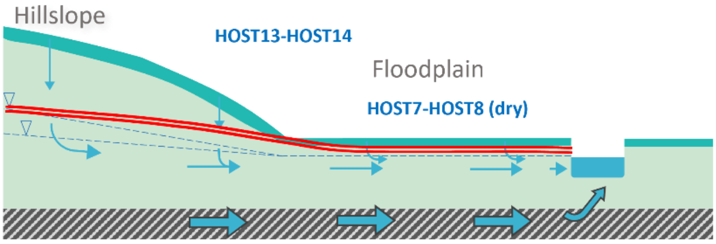
🟩	Freely draining soil
🟦	Intermediate to poor draining soil
⬜	Moderate/high permeability subsoil
▦	Intermediate and poorly draining soil with artificial drainage
▨	Permeable substrate
🟫	Peaty topsoil on peat or alluvium
🟦	River/Stream
→	Flowpaths
⇹	Flowpaths for artificial subsurface drainage
⇨	Dominant flowpaths

4a



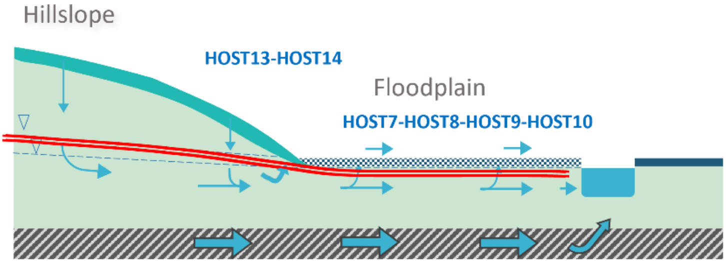
River connected to hillslope, no floodplain

4b



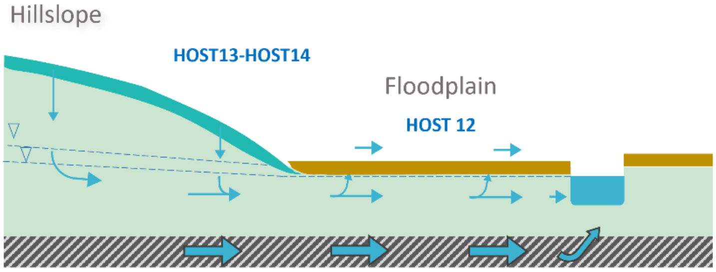
Floodplain with freely draining alluvial soils

4d



Floodplain with poorly draining soil & artificial drainage

4f



Floodplain with drained peaty soil

MODEL 5

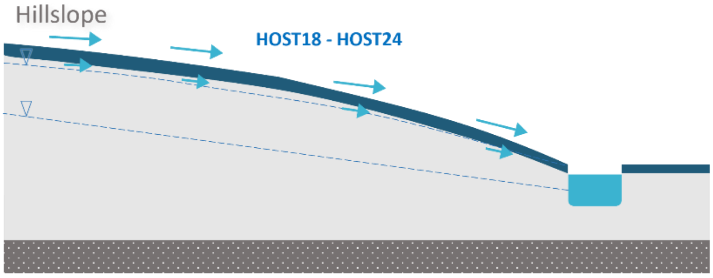
Intermediate and poorly draining soil with slowly permeable subsoil

Scenario description

- Main pathways: overland and near surface
- Vertical pathway: less significant but possible.
- Bypassing of the floodplain can occur in ditches/small watercourses
- Main significant issues: PO_4, TP and sediment.

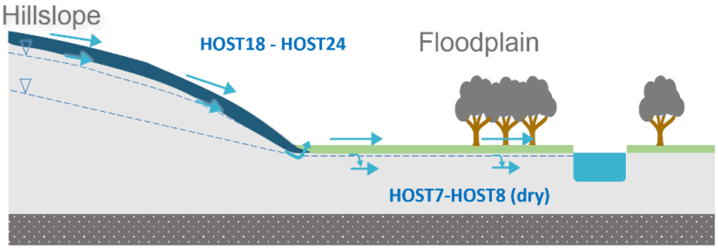
🟩	Freely draining soil
■	Poorly draining soil
▨	Intermediate and poorly draining soil with artificial drainage
□	Low permeability subsoil
▦	Bedrock
🟫	Peaty topsoil on peat or alluvium
🟦	River/Stream
→	Flowpaths
⇉	Flowpaths for artificial subsurface drainage
⇨	Dominant flowpaths

5a



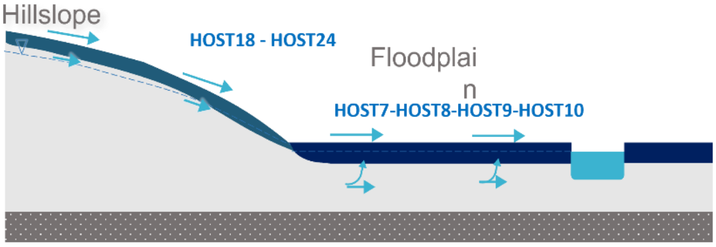
River connected to hillslope, no floodplain

5b



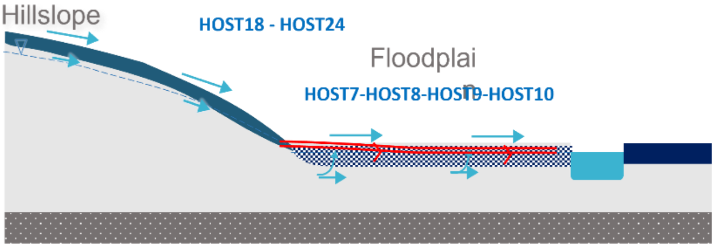
Floodplain with freely draining alluvial soils

5c



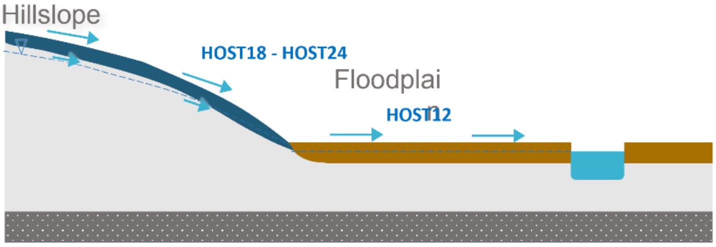
Floodplain with poorly draining alluvial soil

5d



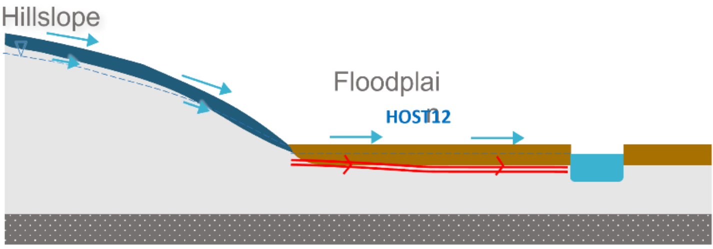
Floodplain with poorly draining soil & artificial drainage

5e



Floodplain with peaty soil

5f



Floodplain with drained peaty soil

MODEL 6

Inherently intermediate and poorly draining soils modified by artificial subsurface soil drainage overlying slowly permeable subsoil

Scenario description

- Main pathways: via drains, but times of overland and near surface flow (if drains overwhelmed and/or poor condition)
- Vertical pathway: locally to drain depth.
- Drains provide direct, rapid connection to streams
- Main significant issues: PO_4, NO_3, TP and sediment.

▩ Intermediate and poorly draining soil with artificial drainage

🟨 Intermediate and poorly draining alluvium

🟫 Peaty topsoil on peat or alluvium

⬜ Low permeability subsoil

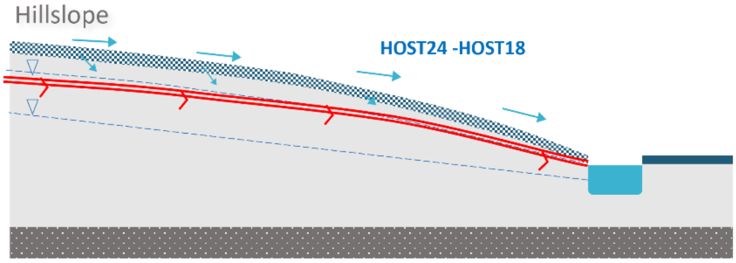
▦ Bedrock

🟦 River/Stream

→ Flowpaths

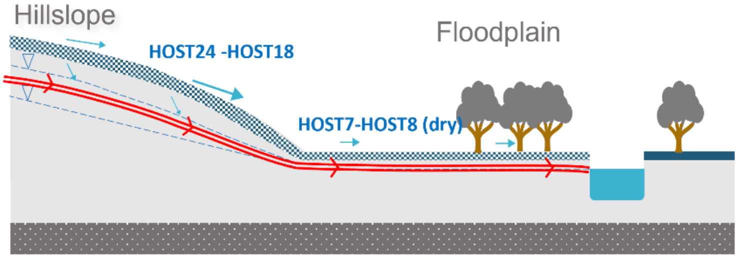
⇉ Flowpaths for artificial subsurface drainage

6a



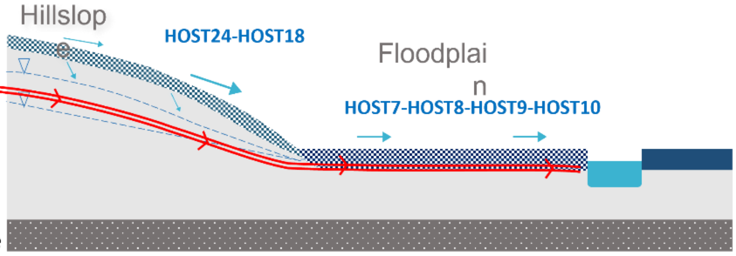
River connected to hillslope, no floodplain

6b



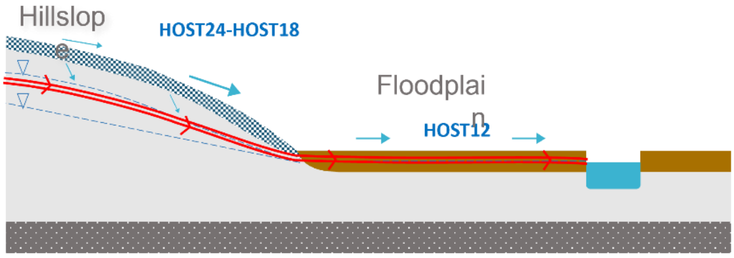
Floodplain with freely draining alluvial soils

6d



Floodplain with poorly draining soil & artificial drainage

6f



Floodplain with drained peaty soil