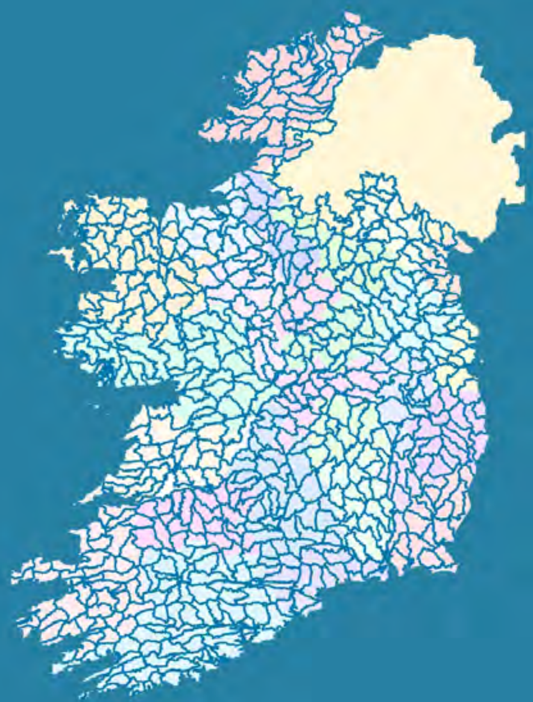
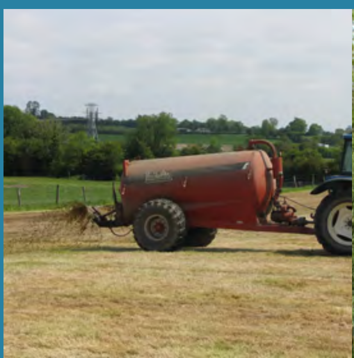



Review of potential local measures for mitigating farm impacts in catchments



Tony McNally

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About this report:

This review of potential local measures for mitigating farming impacts in catchments was prepared by Tony McNally for the EPA Catchment Science and Management Unit. It was completed in May 2017.

Note: The table of regulatory measures on page 27 has been updated to reflect the Good Agricultural Practice for Protection of Waters Regulations SI No 605 of 2017, which came into effect on 1 January 2018.

Review of potential local measures for mitigating farming impacts in catchments

The attached review and evaluation of local mitigation measures in respect of farming activities and water management was commissioned by the Catchment Science & Management Unit of the Environmental Protection Agency.

The review is intended to inform the process of catchment management planning by providing a list of potential measures for selection with some indication of their efficacy and practicality of implementation, areas suitable for use and acceptability to farmers. The important issue of cost of implementation has not been included here, but cost effectiveness is clearly a vital element of measures selection and catchment planning that must be addressed.

The measures listed are local mitigation measures; on-farm actions that may be undertaken by a single farmer. Catchment-wide actions and policy initiatives such as requirements for participation in agri-environment schemes, export of slurry from sensitive or impacted catchments, or extensive land use changes are not included.

The review focuses on nutrient control (N and P) since these are the major pressures arising from farming in Ireland. Where measures may also be effective in controlling other pollutants (sediments, pathogens or pesticides), or have other beneficial impacts (in terms of biodiversity, flood control or greenhouse gas emissions) this is captured in the review table.

A large variety of mitigation measures are available. Many are already in place, such as those in the GAP Regulations and the Rural Development Programme, and may be statutorily binding. They can be quite specific, or more broad-brush in terms of the pressure source or type that they address, and the range of environmental benefits accruing. Many measures proposed may be new and untested under specific Irish conditions or unsuited to particular bio-physical settings. The latter includes differing hydrology, hydrogeology, topography, hydrometeorology, diverse biotic receptors, sensitive ecosystems and protected areas. The need to consider these factors when choosing appropriate measures is crucial for effective mitigation of farming impacts on waters.

The 'one size fits all' approach to measures will not achieve the required environmental outcome. Therefore, the review process has tried to give an indication of pressure and source scenarios where a particular mitigation measure may apply and the range of environmental benefits that might be derived.

The literature reviewed primarily relates to agriculture (arable and pastoral), much of it directed at control of nutrient losses, or sediment as a vector for nutrient transport. However, relevant measures have also been collated from forestry and flood management sectors. The review was carried out in a relatively short period and is not an exhaustive trawl through the literature. However, it includes a number of extensive synthesis papers; inventories and major reviews of pollution control methods. The measures assessed relate primarily to Irish and UK farming, but also include European, North American and other temperate regions where measures have been considered relevant. Citations are included in the review to indicate information sources. However, the references provided is not an exhaustive list of papers reviewed but is limited to those papers that provided significant information regarding measures in relevant scenarios. In the case of synthesis reviews, these are cited rather than their original sources.

Measures have been assigned to source (24 No.), mobilisation (17 No.), pathway (18 No.) and receptor (4 No.) control stages. This continuum also reflects a priority sequence for implementation and intervention. A number of measures affect nutrient/sediment behaviour or movement at various stages along this sequence and this is indicated in the review table.

Where measures align with the GAP regulations these have been cited, although some of these GAP measures may require more stringent implementation criteria in certain sensitive or high status sites if they are to be effective e.g. extended closed periods, greater set back distances, reduced fertilizer application rates. Scenarios where GAP Regulations requirements may be inadequate to protect or restore water quality in Ireland have been previously identified, and include:

- Elevated Nitrate Concentrations on free-draining soils of the East and Southeast
- Elevated Phosphorus in karst limestone aquifers of Roscommon, Galway, Clare
- Elevated P in areas of heavy gley soils with high P content (Index 4) including Cavan, Clare, Cork, Galway, Kerry, Leitrim, Limerick, Longford, Tipperary, Monaghan and Roscommon.
- In sensitive High Status Sites with little capacity for nutrient assimilation.

Most of the measures are designed to address the more intractable problem of diffuse nutrient losses, but several are also relevant to control of point sources as indicated. The wider benefits ('Measure also Beneficial for') checked in the review are as per the source literature, although it is clear that some measures would yield additional benefits that have not been cited. Pollution swapping is also an issue for some measures and may result in negative effects in environmental quality domains other than water.

The main pathways (surface water or groundwater pathways) for which the measure is effective are indicated and whether the measure primarily applies to wet/poorly drained or dry/well drained scenarios. Drainage scenarios will depend on soil type, subsoil permeability, aquifer type, topography etc. and range from heavy impermeable gleys to karstified areas.

Effectiveness of mitigation measures has been cited as reported in papers or in reviews. However, many of the studies reported were short-term (3 years or less). Scientific rigour and study conditions also varied substantially in terms of determinands measured, soil type and conditions, vegetation and crop types, seasonality, climate, duration, scale, methodology and specific design of mitigation. Reported effectiveness therefore also varied very substantially, and values cited herein are not an exhaustive listing of results and do not represent the full range reported in the literature reviewed. Figures cited merely give an indication of representative ranges of measure performance under the study conditions.

Given the pressure on natural resources and strategies for increased agricultural output, it is essential that farmers improve environmental performance.

Climate change will exacerbate many of the problems to be confronted and farmers will also have to adapt to such challenges. Improved sustainability must be achieved by the combined and complementary effects of adaptation and mitigation measures where required. However, farmers need to be convinced of the effectiveness of measures and the value of their implementation.

Farming practices are not always based simply on commercial (or environmental) considerations. Cultural and social factors may dictate behaviour. This may result in resistance to measures uptake or modification to their design and location, even in circumstances where financial benefits may accrue. Therefore, comments on acceptability and constraints on measures uptake have been included.

Supportive measures specifically aimed at education, involvement, and advisory services are vital to promote willingness to participate and facilitate implementation of measures. Although, implementation of some measures may entail such significant losses of income that they will only be acceptable with inducements or financial compensation, or through statutory imposition, yet many of the measures offer low cost, common sense solutions to water pollution issues. Denial of cause and effect relationships, lack of confidence in outcomes of measures, and degree of environmental investedness of farmers are obstacles to implementation that must be addressed.

The last column in the review table tries to give a thumbnail outline of the salient features of individual measures. Measures dealing with similar topics are grouped in each section, and a summary of grouped measures is also provided.

It is important to note that to achieve maximum effect, appropriate measures should be applied in sequence, the 'treatment train' option. The sequence of source-mobilisation-pathway-receptor provides a priority cascade of controls that address pollution risk at the earliest possible stage, and choosing measures with multiple benefits maximises environmental gains and cost effectiveness.

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Abbreviations

Al	Aluminium
BAT	Best Available Technology
CW	Constructed Wetlands
DRP	Dissolved Reactive Phosphorus
FYM	Farmyard manure
GW	Groundwater
HNV	High Nature Value
Incidental Losses	Losses derived more directly from recently applied organic or inorganic fertilisers (cf Residual Transfers)
NI	Nitrification Inhibitor
NMP	Nutrient Management Plan
Pm	Morgan's Phosphorus
PP	Particulate Phosphorus
Residual Transfers	Losses of soil nutrient stores that were not utilised by the crop (cf. Incidental Losses)
Sed	Sediment
SMP	Soil Management Plan
STP	Soil Test Phosphorus
SW	Surface Water
TP	Total Phosphorus

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
SOURCE CONTROL MEASURES																		
S1	**Fertiliser/Slurry/Manure** Fertilizer Application Limits	y		y	y			y			y	sw gw	y	y	y	Measure is widely applied. **1-**Targets sensitive areas (NVZs) with high leaching rates that require nutrient surplus reduction. 4% reduction in N load to water reported in Sweden when N application to winter wheat and spring barley reduced by 10%. 50% reduction in P load in UK gave 20% reduction in P leaching. **13-**A 50% reduction in P2O5 fertilizer application could deliver a 20% reduction in the fertilizer component of baseline loss.	**GAP [15, 16, 20(1)] specifies amount of N and P that may be applied and requires application rates not to exceed crop requirement.**	Imposing limits on fertilizer application rates to crops aims to reduce N and P losses through leaching and runoff. Reducing residual nitrate and P in soil lowers the risk of leaching and incidental losses through surface runoff. Encourages sustainable Agriculture.
S2	**Fertiliser/Slurry/Manure** No P application to P Index 4 soils	y		y								sw	y	y	y	**2-**Soluble P loss reduced by up to 50% over the longer-term, and PP by up to 30%. **35-**The critical Pm value above which P losses in runoff increased is in the target STP agronomic optimum range i.e. (Pm=6.1–10 mg L−1) P index 3.	Requires soil testing and interpretation. High P fertilizer costs increases acceptability. **No application to grasslands of P Index 4 generally applies - GAP**	Such soils are above the agronomic optimum for crop uptake. Reduced application allows reduction in P index over time (years). **33-**P losses increase in overland flow with increasing soil test P concentration in soils. Erosional and leaching losses of P depend on soil P status.
S3	**Fertiliser/Slurry/Manure** No P application on sensitive high status sites except on basis of soil test	y		y								sw	y	y	y	**16-**P losses proportional to soil P status. High status sites believed to be sensitive to small nutrient additions.	Requires soil testing and interpretation. May result in decreased production. Evidence required through risk assessment or High Status-specific ACP.	No P application to un-enriched soils in high status catchments or sites except on basis of a soil test. GAP allows P additions of 35, 25 and 15kg/ha to PI 1, 2 and 3 soils respectively. High status sites have little capacity to absorb additional nutrients. Mandatory soil testing (3-5yrs) required to demonstrate need
S4	Fertiliser/Slurry/Manure No P application on peatland soils	y		y								sw gw	y	y	y	40- Peatland soils have limited capacity to chemically bind P	May result in decreased production.	Addition of P to peatland soils (>20% organic matter) should be prohibited unless demonstrated to have minimal potential impact. P binding capacity of such soils is low and P is readily leached.

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		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
S5	**Fertiliser/Slurry/Manure** Application determined by agronomic need	y		y	y						y	all	y	y		**12-**Over-fertiilisation with N results in more than half the additional N being at risk of leaching. **12-**Surplus of 20kg/ha N to cereals increases nitrate leaching by about 20%; under application by 20kg/ha reduces nitrate leaching by about 10-15%. **17-**Typically 50-80% of the surplus N above the recommended amount is at risk of leaching.	**Application rates listed in GAP**	Nutrient input should not exceed crop requirements. Ensures optimal uptake of nutrients and reduced availability for leaching. Supports general objective of no deterioration where status is good or high. **25-** Fields receiving N inputs in excess of the economic optimum cause a disproportionately large nitrate loss.
S6	**Fertiliser/Slurry/Manure** Application below agronomic need (nutrient mining)	y		y	y							sw gw			y	**12-**N application 10% below optimum decreases nitrate leaching by 8-12% (arable crops); 5-10% (grassland). **13-** N application 20% below recommended gives 5-10kgN/ha reduction in leaching; 50% below gives 10-15kgN/ha reduction. Halving P fertiliser application to P index 3 land reduces P loss by 20% (horticulture). **17-**Sustained reduction of 20kgN/ha would reduce potential leaching by 8kg/N/ha. **18-**First cut of silage can remove 18kgP/ha.	Productivity and cost implications. Grazing on grasslands will decrease effectiveness of the measure by recycling nutrients. Reductions in fertiliser use creates a nutrient imbalance in the field.	Where addition of fertilizer is below crop need the removal of nutrients in harvested crop gradually depletes soil nutrient levels. Reducing N application limits the quantity of residual nitrate in the field that may be leached post harvest. Depleting soil P reduces soluble P and PP losses.
S7	**Fertiliser/Slurry/Manure** Improved availability - liming	y		y	y				y			sw					Improves soil microflora and fauna thus improving structure and infiltration.	Maximising the uptake of soil nutrients through liming and pH adjustment reduces the overall fertilizer application required and reduces soil reserves at risk of loss.
S8	**Fertiliser/Slurry/Manure** Use of slow release fertilizer/Binding agents	y		y	y							sw gw	y	y		**5-**Use of rock phosphate reduced TP losses by 38% and dissolved P by 58% (New Zealand). P loss reduced by 75% using slurry at 5% solids rather than 2.5% solids. Using FYM allowed twice the P application compared to slurry with reduced P loss. Al rich water treatment sludge reduced P release from soil to SW runoff by 60-96%.		Use of low water soluble nutrients e.g. Rock phosphate, slurry with higher %dry solids, FYM, P-binding agents results in slower nutrient release in line with plant demand and improved overall efficiency of crop uptake.
S9	**Fertiliser/Slurry/Manure** Use placement technologies for manufactured fertilizer.	y		y							y	sw gw	y	y		**3-**Nitrate leaching reduced by small amount (2%); Soluble P losses reduced by up to 5%. **5-**Placement of P fertilizer might reduce P losses by 8-92%.	Can reduce application rates without impacting yield. Initial capital expenditure required. More attractive to large arable/vegetable businesses.	Precision placement of nutrients close to germinating or established crops to increase nutrient uptake and recovery. Reduces fertilizer exposure to incidental loss through surface runoff.
S10	**Fertiliser/Slurry/Manure** Use Nitrification Inhibitors	y			y						y	gw		y	y	**3-**Nitrate leaching reduced by up to 35% and N2O emissions by up to 70%. May get slight increase in ammonium and nitrite losses to water (note figures relate to New Zealand - free draining soils and longer growing season).	NIs are relatively expensive. However, some offset against reduced fertilizer applications/losses.	NIs added to manufactured fertilizers, organic manures and to grazed pastures slows release of nitrate in line with plant demand. Gives increased N efficiency and reduced leaching.

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		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
S11	**Fertiliser/Slurry/Manure** Use Clover in place of fertilizer N	y			y				y		y	gw				**3-**Nitrate leaching reduced by up to 20%. Significant decreases in N2O and ammonia emissions.	Could entail reduced stocking rates if high N rates were previously applied. Probably little uptake of measure on high N systems.	Clover fixes atmospheric N and reduces need for manufactured N fertilizer.
S12	**Fertiliser/Slurry/Manure** Batch storage/composting of solid manures	y	y		y			y			y	sw gw	y	y		**3-**Lower readily available N means leaching reduced. Collection of leachate could reduce nitrate losses by <5% and soluble P, PP by <2%. **13-**Batch storage of slurry has no effect on N or P losses. Batch storage of FYM or composting of solid manure could give 3kgN/ha/yr reduction on fields manured. No effect on P losses.	Capital costs for storage facilities. **Requirement under GAP[6] for collection and management of storage facilities for livestock manure, other organic fertilizers, soiled water or silage effluent required to prevent runoff or seepage into GW or SW.**	Store fresh solid manure for at least 90 days before spreading, or compost solid manure. If stored in field heaps site away from watercourses and drains (10m). **GAP [17] restrictions relate to periods and locations for stockpiling farmyard manure, silage bales on land.**
S13	**Fertiliser/Slurry/Manure** Nutrient Management Plans	y		y	y						y	sw gw	y	y	y	**3** - N and P losses reduced by up to 10%. **13-** N leaching reductions per year: 5kgN/ha (arable); grassland 1-5kgN/ha (dairy) and 2kgN/ha (beef). Fertiliser component of P loss reduced by 20%.	Favoured due to increasing costs of artificial fertilisers. Requires education and guidance. **GAP specifies nutrient excretion rates of livestock, nutrient content of slurries/manures, and availability in fertilisers.**	General or sensitive areas. **13-** Achieve optimum application rates; timing of application; account for all inputs; soil nutrient status and pH; accurate application; assess risk to waters.
S14	**Fertiliser/Slurry/Manure** Single nutrient or low-P compound fertilizers	y		y	y							sw	y		y	Application of compound fertilizer formulations to achieve target levels of one nutrient may result in excess application of other constituents.	Less convenient and more labour intensive. Soil testing required.	Application of single-nutrient fertilizers or low-P NPK fertilizers according to agronomic need and soil status. Reduces excess application of individual nutrients.
S15	**Fertiliser/Slurry/Manure** Improve accuracy and spread pattern of fertiliser spreaders	y			y							gw	y	y		**3-**Nitrate leaching losses reduced by up to 5%. **12-** Reduction of nitrate leaching due to under fertilisation is small compared to leaching losses due to over fertilisation.	Low cost method easily applied. Improves crop growth. **Accurate and uniform application is requirement in GAP.**	Over application of fertiliser in some areas increases N leaching while under-application reduces crop productivity. Uneven application results in variable nutrient supply and creates difficulty for NMPs.

SUMMARY

In general the fertiliser/slurry/manure measures aim to reduce nutrient application to land to the minimum amount required to meet agronomic needs (S1, S2, S5), or to below minimum requirements (S3, S4, S6) in the case of impacted catchment areas or high status areas with little capacity for adsorption of additional nutrient loads. To ensure that excess nutrient loads are not applied measures are included that maximise availability of applied nutrients through soil modifications (S7), timing of release to match crop ability to uptake (S8, S10), precision spreading or placement of fertilizers (S9, S15) or providing N through biological fixation by clover (S11). Nutrient management planning (S13) allows identification and integration of nutrient sources in a coherent approach that minimises source loads and seeks to ensure that individual nutrients are delivered in proportion to demand and existing availability (S14). Batch storage or composting of manures (S12) is primarily directed at reducing faecal pathogens loads and has a limited effect on nutrient losses. However, readily available N and total N content of stored manure can be lowered by 10-25% using this measure, and this lessens the risk of nitrate leaching loss.

Many of the nutrient source control measures listed above have been addressed in the GAP regulations and are therefore legally binding. However, some of these measures could be adapted for high status or sensitive sites, or sites where intractable nutrient problems may be encountered through voluntary or regulatory provision for selection and application in specified scenarios or locations. Application could entail attaching more stringent constraints to individual measures, such as extended time intervals for prohibited periods, or reduced application limits to address recovery timeframes, and might require incentivisation through compensatory payments e.g. as part of agri-environment schemes.

The measures are broad spectrum in that they generally apply to all nutrient types and biophysical settings. Many of them have significant implications for GHG emissions and pathogen loads to waters.

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
S16	**Crop Management** Change to Woody Perennials, Woodlands	y		y	y	y				y		sw	y			**2-**infiltration capacity increases 20 to 60 times beneath deep rooted woody perennials. Willow uses 100mm more water than grain crops per year - low leaching of Nitrate. **18-**Willow coppice shown to be effective phytoremediation system. **29-**Average nitrate concentration in drainage water from short rotation coppice was 18mg/l compared to >54mg/l from arable rotation.	May provide economic benefits.	Changing from arable or grassland to woody perennials causes dramatic changes in hydrology. Can include establishing willow coppice at base of slopes.
	SUMMARY Farm forestry is an increasingly important activity and appropriate planting of trees can offer both economic and environmental benefits. The landuse change involved results in reduced nutrient loadings, particularly if it substitutes for more intensive agriculture. Establishment of coppice woodlands in key locations also has potential to reduce nutrient and sediment loads through intercepting overland flows and enhanced infiltration. This is particularly suited to marginal lands.																	
S17	**Livestock Management** Feeds/Dietary	y		y	y						y	sw gw	y	y	y	**2-** Netherlands - P content of pig feed decreased 33% from 1973 to 1996 and resulted in a reduction in P excretion from 1.62 to 0.67 kg/pig. **3-**Nitrate losses and soluble P losses reduced by up to 10%. **13-**Crude protein reduced from 18 to 14% in dairy feed gave reduction of 2kgN/ha. **17-**Cattle excrete at least 75% of the N they ingest. **18-**Feeds contain 0.43-0.55% P. Reductions in P intake result in linear decreases in water soluble P of manure. **GAP default value 0.5%P in concentrates.**	**3** - Low to moderate uptake in dairy sector. High in pig sector. Phytase (an enzyme that aids P digestion) use in broiler industry could be increased. **5-**Useful for intensive farming units in highly vulnerable areas.	**12-**Avoid excess N or P in diet to reduce excretion. Most feeds contain more N than is required by the animal. Phase feed animals based on individual feed requirements. Lower N:P ratio in manure than crop uptake can lead to accumulation of P in soils when application is based on N requirements. Lowering P in feed or improving dietary efficiency reduces risk of P accumulation. **29-**N:P ratio for inorganic fertilisers 8:1; cattle manure 6:1; pig manure 3:1.
S18	**Livestock Management** Grazing/Stocking Rate (Also Mobilisation Measure)	y		y	y	y		y	y			sw			y	**3-**Restricting grazing to a few hours per day strongly decreased P loss in runoff. Restricted grazing during wet periods and limited plant uptake can reduce N leaching significantly. **13-**Restricted grazing (dairy) achieved 8-16kgN/ha reduction. Germany -Production of hay/silage vs grazing, combined with low emission manure spreading strongly decreased N loss. **3-**Nitrate leaching losses reduced by up to 20%, but ammonia emissions increased up to 20%. PP and soluble P and sediment reduced by up to 10%. **16-**cattle density should be maintained at <1/ha in high status catchments. **27-**Areas to which cattle had access had 57%-83% lower macroporosity, 8%- 7% higher bulk density, 27%-50% higher resistance to penetration. **28-**Under extensively managed pasture N leaching losses reduced by 69%.	Greatest benefit if grazing restrictions implemented in autumn. Most suited to dairy farms and where alternative grazing access to freely--drained land is available. Increased labour, manure management and forage production costs reduce take-up. Reduction in livestock numbers unlikely due to profitability impacts in absence of incentives/compensation. Measure may be an option in High Status catchments. Destocking to reduce grazing pressure has been achieved through Commonage Framework Plans and NPWS Farm Plans. cf. Cross Compliance re poaching.	Reduce the length of the grazing day/season. Reduce livestock density and/or grazing time in wet conditions to avoid severe poaching and compaction. Reduce the total number of livestock. Excrement can cause high P in runoff. Potential for P runoff decreases exponentially with time from grazing. Poaching reduces infiltration, plant cover, causes physical damage.

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
S19	**Livestock Management** Winter De-stocking, reduced stocking	y		y	y							sw			y		**18-**16-22% of farmers in the L. Melvin catchment gave highest preference to this measure for reducing P risk.	**18-**Adopt a summer grazing system and destock for winter to avoid slurry production. Alternatively reduce slurry production by keeping cows only and selling calves in autumn.
S20	**Livestock Management** Exclusion from rivers and streams (Mobilisation and Receptor In-Stream Measures also)	y		y	y	y		y				sw				**13-**Estimated reduction of 0-1kgN/ha averaged over farm, and 50% of soil and manure component P loss.	Most relevant to intensively stocked cattle farms. May require provision of alternative drinking water sources.	Stock-proof fencing in fields and on trackways adjoining waterways, construction of bridges for livestock crossings prevents direct addition of nutrients by urination and defaecation and also prevents trampling and bank erosion.
S21	**Livestock Management** Extensification	y		y	y	y	y	y			y	sw gw			y	**13-**Losses of Nitrate in drainage water mostly respond rapidly. Nitrate losses reduced by up to 95%. Significant reductions in soluble P leaching unlikely in short term (<10 yrs) but SW run-off is reduced in the absence of poaching (40-50% P reduction). **17-**Conversion of arable to unfertilised ungrazed grassland reduces nitrate leaching by about 90% (50-60kgN/ha down to <5kgN/ha).	Most suitable to uplands and marginal arable land and sandy/silty soils prone to erosion. Unlikely to be adopted by farmers without suitable incentives.	Converting land to extensive grassland (grazed or ungrazed) is highly effective in reducing nitrate losses. **13-**Arable reversion grassland has small losses of nitrate in drainage waters and permanent vegetation cover minimises the erosion of soil and associated P in run-off. Avoids frequent cultivations that stimulate mineralisation of organic matter. **23-**HNV farming is included here.
	SUMMARY Livestock source control measures aim to reduce nutrient loads in animal excreta and to prevent poaching of soils which results in compaction and erosional loss of both sediments and nutrients. Most animal feed formulations contain excess nutrients in comparison to dietary requirements. Balanced feed formulations that reflect plant uptake requirements, or enhanced dietary efficiency (S17) are less likely to result in soil nutrient excesses and have been successful in reducing nutrient losses. Grazing pressure can also be reduced through decreased stocking rates or strategic movement of stock from vulnerable pastures and at high risk times (S18, S19, S21). While this is an effective measure, farm scale destocking is unlikely in the absence of incentives, and relocation depends on suitable alternative pastures being available. Extensification and traditional grazing systems are effective measures for high status sensitive sites and have significant biodiversity benefits. The possibility of animal housing for extended periods may require additional slurry storage facilities and increased labour. The exclusion of livestock from waterways (S20) prevents direct deposition of nutrients in water. The extent of animal access to streams and ditches, and the resulting pressure at catchment scales can be significant.																	
S22	**Farmyard Management Measures**	y	y	y	y	y		y				sw	y	y	y	**3-**Soiled water minimization gives small reduction in nitrate losses (<1%) and P losses (<2%). **13-** 0-1kgN/ha averaged over farm; manure component of P loss reduced by 5%.	Farmyard infrastructure can be readily adapted to capture nutrients and sediments and minimize generation of soiled water. **Farmyard Inspections carried out on a risk prioritised basis promotes compliance.**	**GAP - Minimize the volume of dirty water produced in farmyard - divert clean water. Collection and storage of slurry, soiled water, farmyard manure, etc to prevent runoff or seepage to SW or GW.**

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
S23	**Soil Management Plan**	y		y	y	y						sw	y		y	**15-**SMP facilitates providing optimum conditions for crop growth, while minimising the risk of run-off and erosion.		Whole farm assessment of risk of run-off and erosion; match intended use of fields with land capability; assess soil organic matter needs; plan measures to improve structure and infiltration. Record ponding, poor growth areas, erosion events. If using plastic covers at field scale take precautions to limit run-off and erosion.
S24	**Behavioural Change**															**18-**Problems are often the result of inadequate awareness and difficulty in accessing suitable advice. **23-**The uptake or not of mitigation measures at farm level is highly dependent on improved knowledge transfer.	Agency support and accessibility of farm advisory services. The uptake or not of mitigation measures at farm level is highly dependent on improved knowledge transfer.	Education, involvement, advisory support promote willingness to participate; facilitate implementation of measures; improve relationships. Farmers become more resource efficient and environmentally friendly.

SUMMARY

Farmyard management is an effective measure to prevent pollution and is a requirement under GAP. These small point sources can have significant local impacts but can be readily resolved. Programmes of farm inspections are prioritised on a risk basis.

While nutrient management planning is well established, preparation of specific soil management plans has potential to reduce erosion and nutrient loss by capturing local knowledge to identify problem areas for bespoke solutions. Farm advisory services should provide guidance on solutions.

Behavioural change is fundamental to implementation of many of the measures cited. Farmers are often reluctant to undertake new measures even when financial incentives are provided. This may be due to lack of awareness of available solutions, lack of confidence in effectiveness of measure, lack of knowledge or expertise in measure design and implementation. Locally championed, peer-based knowledge transfer systems are preferred.

	MEASURE	NUTRIENT SOURCE/TYPE: Diffuse	Point	P	N	MEASURE ALSO BENEFICIAL FOR: Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	BIOPHYSICAL SETTING: Main pathway	Wet	Dry	Sensitive Ecos	EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
	MOBILISATION CONTROL MEASURES																	
M1	**Fertiliser/Slurry/Manure** Avoid spreading/application at high risk times	y		y	y			y			y	sw gw	y	y	y	**3-**Nitrate losses reduced by small amount (5%). Soluble P losses reduced by up to 10%. **3-**Nitrate losses could be reduced by up to 10-20%; PP and sol P reduced by up to 20-50%. **5-**Application in dry conditions can reduce P loss by 0.2kgP/ha/yr. Avoiding wet conditions reduced P losses by 30% - New Zealand. **12-**Autumn applications of slurries and manure can double nitrate leaching compared to no application. **1 -** Manure application in spring could give a N leaching reduction of 13kg/ha per 25t/ha applied (cattle manure)- Sweden. In UK spring application resulted in N reduction 0-15kg/ha. **17-** N fertiliser applied in autumn is at risk of leaching due to lack of plant uptake.	**Periods when application of fertilizer is prohibited are set out in GAP. Storage capacity for manure, organic fertilizers, soiled water and effluents from dungsteads, FYM pits or silage pits must be adequate to comply with GAP.**	Avoid applying nutrients at times when there is a high risk of run-off or leaching, and/or reduced crop uptake. **1-**Reduced N&P leaching and losses due to SW runoff through imposing closed periods (prohibited fertilisation periods) to address water-logged, flooded, frozen soils, little crop uptake. Includes periods of forecast heavy rain. Requires adequate manure collection and storage facilities to allow spreading at low risk times.
M2	**Fertiliser/Slurry/Manure** Avoiding spreading in high risk places	y		y	y						y	sw gw	y	y	y	**13-** Baseline losses of N reduced by 0-1kgN/ha/yr in UK, and manure component of P losses potentially reduced by 40%. **1-** In Sweden a ban on applying within 2m of water courses resulted in estimated 20t N and 0.5t P reduction in NVZ. **UK** - P loss reduced by 15% on sandy/clay loam. **3-**Nitrate leaching losses only reduced by 1-2%; Soluble P losses reduced by up to 2-10%.	**GAP specifies set back distances for specific scenarios and water uses.** Capital costs. Adequate storage critical. **15-** Setback of 10m from surface waters for organic manure application.	Reduce N&P leaching and losses due to SW runoff through avoiding spreading on hydrologically well connected areas e.g. flushes, direct preferential flow paths, cracked soils over drains, highly permeable soils, shallow aquifers, steep slopes and fields with high P content.
M3	**Fertiliser/Slurry/Manure** Manure Application Techniques - Soil Incorporation	y		y	y			y			y	sw gw	y	y		**1-**Reduces need for mineral fertilizer. Slurry injection reduces ammonia N losses to air to less than 5% compared to spreading. Manure incorporation reduces to less than 50% of spreading emission. Timing to meet crop needs is important. Increases yield. In Denmark incorporation of cattle manure reduced P leaching by 50%. Manure P losses down 19% on sandy loam; down 13% on clay loam. **5-**Soil injection/immediate incorporation reduced P loss by 60%.	May apply to all farms or focus on livestock farms with slurry-based systems, and above threshold livestock units in high risk areas. Especially important for liquid manures. There are economic benefits due to reduced fertiliser requirements. General public favour measure due to reduced odours. Timing important for N uptake.	Use of BAT for application to incorporate solid manure rapidly into soil and inject liquid manure. Reduces ammonia to air as N2O. Reduces P loss via surface runoff and macropore flow. Manure spreading plans or field records may be required.
M4	**Fertiliser/Slurry/Manure** Band spreading/Injection of slurry (see above Manure Application Techniques). (Also Source Reduction Measure)	y									y					**20-**Application using trailing shoe increased the NFRV from 21 to 30% in April and 12 to 22% in June. **32-**Cattle slurry applied (using traditional methods) with splashplate had an NFRV of 21% in April and 12 % in June. Application using trailing shoe equipment increased the NFRV to 30% in April and 22% in June.	Spring application of slurry often restricted by soil trafficability, especially on poorly drained soils.	**3-**Decreased ammonia losses means increased potential for nitrate leaching but manure N efficiency improved and could lead to reduced manufactured fertilizer application.

	MEASURE	NUTRIENT SOURCE/TYPE: Diffuse	Point	P	N	MEASURE ALSO BENEFICIAL FOR: Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	BIOPHYSICAL SETTING: Main pathway	Wet	Dry	Sensitive Ecos	EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
M5	**Fertiliser/Slurry/Manure** Precision Application	y		y	y							sw gw	y	y		**5-**Placement of P fertilizer might reduce P losses by 8-92%. **17-**Uneven spreading caused a 6-15% increase in nitrate leaching. Potential to reduce N leaching by 2-5kgN/ha through calibration of spreaders.		Ensuring accurate application is important for optimal plant uptake, maximising beneficial use of slurry/manure and minimizing nutrient losses.
M6	**Fertiliser/Slurry/Manure** Change from Slurry to Solid Manure Handling System	y		y	y			y				sw gw			y	**13-**Dairy and Beef manure N losses reduced 40%; manure P losses reduced 50% (sandy loam) and 25% (clay loam) reductions.	Most effective on shallow soils prone to N leaching; sloping and less permeable soils with high risk of surface run-off. High additional labour and requires adequate source of suitable bedding.	Animals kept on straw to produce a solid manure which presents less risk of nutrient and pathogen loss when spread.
M7	**Fertiliser/Slurry/Manure** Amendments (See also Measure M15 below)	y		y	y						y	sw gw			y	**31-**Alum addition to poultry litter reduced P loss, ammonia volatilisation and had negligible effect on metal release from amended soil. Aluminium chloride has been recommended as the most suitable amendment for controlling P solubility in swine and cattle slurry.	Amendments must be practical and cost effective for the farmer.	Chemical amendments can reduce nutrient solubility and mitigate leaching losses. P sorbing amendments can either be added directly to the manure before land application, spread on the ground before manure application, or incorporated into the topsoil.

SUMMARY

Measures avoiding spreading at high risk times or places (M1, M2) are core provisions of GAP and are proven to be effective in reducing nutrient losses to waters. Seasonal closed periods are established in regulations but there is substantial uncertainty relating to forecasting weather conditions that are unsuitable for spreading. High risk places are addressed in GAP through stipulating set back distances for particular scenarios. However, there can be considerable subjectivity in identifying some hydrologically connected areas e.g. areas overlying some field drains, and advisory support might prove useful. In this regard farm drainage plans (P18) and soil management plans (S23) could play key supportive roles.

Measures to incorporate or inject slurry into soils (M3, M4) ensure that loss of N through ammonia volatilisation and P through surface runoff are reduced. As much as half of plant available N can be lost through volatilisation in surface application of slurries while incorporation can reduce this by 50%. However the risk of nitrate leaching may increase. These application methods are also suitable for use in Minimal Tillage / Conservation Tillage cultivation systems (M11).

Precision spreading (M5) minimises nutrient losses by avoiding hot spots of excess application that are prone to losses and facilitates maximum crop uptake. Specialist equipment requirements mean that these methods are only likely to be cost effective on larger farm enterprises.

Changing from slurry to solid manures (M6) or the use of amendments to sequester nutrients (M7) are effective methods for reducing both N and P losses. Costs and practicalities of adopting such measures militate against their uptake.

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
M8	**Crop Management** Winter Plant Cover / Cover Crops / Catch Crops	y		y	y	y	y		y			sw gw	y	y		**1-** Average reduction in NO3 of 40kg/ha was reported in Germany. Erosion and nutrient leaching reduced by 10-15% in Finland; N loss reduced by 11-26kg/ha/yr in Denmark. Effectiveness is soil and climate dependent. **13-** Cover crops can reduce nitrate leaching by 50% compared with over winter bare soils. Straw and rough seedbed are equally effective. Reduction of 28kgN/ha/yr (arable without manure) or 44kgN/ha/yr (frequent manuring). **2-**Erosion may decrease exponentially with increasing crop cover. Possible 5% reduction in erosion if cover crops used. **3-** 30-60% reduction in nitrate leaching loss in establishment year, especially in high fertility areas. PP and sed reductions typically 20-80%. **5-** TP reduction of 63-95% in surface runoff using cover crops. **12-** Cover crops reduced nitrate leaching by ~40% compared to no over-winter cover. **17-** Cover crops can typically take up 10-60kgN/ha & were found to reduce nitrate leaching by about 50%.	**GAP specifies ploughing restrictions and requirements for green cover within 6 weeks post autumn ploughing or application of non-selective herbicide.** Requirement for high % coverage creates resistance to implementation. **13-**Autumn sowing may only be practicable on well-drained soils. Effectiveness depends on soil type, time of ploughing, plant spp., climate.	Crops/vegetation cover in winter period between main crops protects soils that would otherwise be bare. This reduces nutrient mobilisation through runoff and erosion. Cover increases infiltration, reduces run-off, strengthens topsoil resistance, protects soil surface. Establish no later than mid Sept. Late summer/autumn sowing is necessary to allow nitrate uptake. **13** Establish crop by mid-Sept at latest, or undersow spring crops. Measure includes leaving stubble of previous crop. In Italy it Includes planting shrubs.
M9	**Crop Management** Spring cultivation	y		y	y	y						sw		y		**3-** 20-50% reduction in nitrate leaching loss, especially in high fertility areas. PP and sediment loss reductions typically 20-50%. **13-** Leaching reduced by 10kgN/ha (land with no manuring) or 15kgN/ha (manure).	Applicable to cultivation prior to spring crops (maize, sugar beet, potatoes), and reseeding grass leys. **13-** Delayed cultivation on medium to heavy soils may impact on crop establishment and weed control.	Autumn cultivation results in N mineralisation at a time of little uptake. Leaves soils exposed to erosion in winter. Spring cultivation reduces nitrate leaching.
M10	**Crop Management** Crop Selection	y		y	y							sw gw	y	y		**2-** Deep rooting woody perennials can improve soil hydraulic conductivity in top 25cm by a factor of 20.		**2-**Nutrient demand, growth periods and rooting depth of crops differ and effect soil conditions and nutrient losses. Soil residual N at harvest is higher under some crops (potatoes, cauliflower). Inclusion of deep rooting crops in the rotation can improve infiltration rates.
	SUMMARY The use of green cover to minimise extent and duration of exposed bare soils (M8) significantly reduces incidental and leaching losses of nutrients. Plant cover must be established in time to allow nutrient uptake before the end of the growing season and thus removes soil nutrients through plant uptake that would otherwise be liable to loss. Cover also provides soil protection against erosion particularly in storm events which are a major cause of nutrient export to waterways. Early establishment of crops/vegetation cover after cultivation (M9) reduces soil nutrient reserves prone to leaching and protects soils. Nutrient application at times of peak plant growth in spring also ensures maximum uptake by crops. Choice of crops and rotations (M10) can affect soil structure and nutrient status and provide substantial mitigation.																	

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
M1 1	**Soil Management** Minimal Tillage / Conservation Tillage (Also Source Reduction Measure)	y		y	y	y			y	y		sw gw				**1- UK**-Leaching decreased by 0-25% compared to ploughing; nitrite loss similarly affected; (MOPS1) P and Sed losses reduced by 30-60% on clay soils and up to 90% on loamy sand. Denmark- Prohibiting soil preparation reduced N loads by approx 6.7kg/ha. Ineffective on soils with poor structure. **13-**Reduction of 2.5kgN/ha (soils without manure) and 3.5kgN/ha (with manure). 5% reduction in soil component of P loss (clay loam soils). **29-**Minimum tillage consistently associated with lower erosion (normally <1t/ha/yr). **2-**Minimum tillage decreases TP loss but may increase risk of DRP loss due to lack of soil inversion and accumulation of applied and crop residue P at the surface. May also result in P accumulation in top soil layer and increased P loss in runoff. **5-**Minimal cultivation reduces sed and P transport by up to 80%. **3-**Nitrate losses can be reduced up to 20%. PP and sed losses reduced up to 60% on medium/heavy soils and 90% on light soils.	Purchase of new machinery is an obstacle - more likely to be adopted on larger arable farms. **UK**-Well accepted and options dependent on soil type, cost, cropping type. Denmark- Organic farmers critical of re-laying prohibition and now not mandatory for them. **13-**Most commonly applied to medium to heavy soils in UK. No-till is unsuitable for light soils prone to capping. **1-** Denmark implements no-cultivation periods depending on crop and soil types. Some concerns about long term increase in soluble P; N immobilisation; increase in resistant weeds and pesticide use.	Minimum or reduced cultivation (disks or tines), direct drilling into stubble (no-till) or shallow cultivation (5-7cm without soil inversion) reduces compaction, prevents plough pan formation and improves soil structure due to higher organic matter in surface layers . Improves infiltration and water retention so reducing erosion and loss of P and sediment.
M1 2	**Soil Management** Contour ploughing	y		y		y						sw	y			**3-**Only effective on gentle or moderate slopes. PP and sed losses may be reduced 40-80%. **5-**P Loss reduction of up to 30-75%. **13-**Soil component of P loss reduced by 25-35%.	More time consuming and higher skill levels. Risk of machinery overturning on steep slopes. Also only suitable for simple slope patterns. **13-** For furrow crops (e.g. potatoes, sugar beet) harvesters only work effectively up and down slope.	Reduces risk of surface runoff in sheet and rill flow.
M1 3	**Soil Management** Leave autumn seedbeds rough	y		y		y						sw	y			**13-**Reduced soil component of P loss by 25-35%. Increased infiltration rates may increase nitrate leaching by a small amount.	**GAP requires rough surface be maintained on land ploughed 1st Dec to 15th Jan.** **13-**Most applicable to winter crops that establish well in rough seedbeds. Herbicide activity reduced in rough seedbeds. Not well suited to oilseed rape, sugar beet and reseeded grasslands.	**13-**Avoid creating a fine seedbed (powered cultivators and heavy rollers) that will slump. Encourages infiltration and reduces surface flow.

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
M14	**Soil Management** improved structure/reduced compaction	y		y		y						sw	y			**3** - Tramline disruption can reduce PP and sed losses by 30-50% on winter cereal cropped land. **5-** Absence or disrupting tramlines can reduce P losses by 72-99%. **13-**Method achieved a 25-35% reduction of soil component of P loss on tillage soils. Small increase in risk of nitrate leaching due to mineralisation where compacted soils are cultivated in autumn. 50-70% of P loss in grassland fields. **26-**tramlines up and down slope generated 46% more runoff compared to plots without tramlines on ploughed soils. This extra runoff resulted in 5 times greater sediment loss, 4 times greater TP loss . Tramlines across the slope produced the same amount of runoff, sediment and P transfer as plots without tramlines.	**13-**Cultivate in dry conditions in late summer/early autumn. Many other competing demands on farmers' time. Delay in establishing tramlines not possible where winter cereals are treated with pesticides in autumn.	**2-**Soil and subsoil compaction increases PP (and DRP) losses via surface and subsurface flow. Deep ploughing, subsoiling and shallow cultivation of tram lines reduces P losses. **13-**Cutivation of compacted soils after harvest with discs or tines increases surface roughness and infiltration. Also improves root penetration and nutrient uptake. **13-**Delay establishing tramlines until spring. Use low ground-pressure vehicles and GPS for accurate tramlines.
M15	**Soil Management** Amendments	y		y								sw	y			Addition of organic matter reduces risk of surface runoff and erosion (PP) in the long-term, but may increase risk of nutrient loss in SW. May Involve tillage and associated risks. **13-**May increase nitrate leaching through mineralisation (1-10kgN/ha). **7-**Alum most cost-effective chemical amendment, capable of greater than 90% reduction in soluble P in overlying water (agitator tests).	Must be cost effective and **compliant with GAP Regulations**. **22-**Soil pH, and not the total Al content, controls Al availability. Therefore, repeated alum treatment will not lead to an increase in Al availability. Binding capacity Alum>Fe>Lime.	Addition of lime, alum and other chemicals can reduce P mobility and losses. Addition of manure, sludge, compost to clay and silty soils to increase organic matter content, can increase infiltration, and improves microbial activity and nutrient uptake (**13**). Use of P-binding agents is effective in reducing losses but possible long-term effects (metals).

SUMMARY

A number of soil management measures relate to minimising soil disturbance and reducing compaction (M11, M14), both factors that dispose soils to erosion and reduce infiltration. Given the importance of sediment erosion in P losses, the reduction of P losses using these methods can be substantial. Mineralisation of nutrients is also reduced in minimum tillage systems resulting in reduced N leaching. Minimal tillage prevents formation of a plough pan and improves soil structure due to higher organic matter content in surface layers of soil. The lack of soil inversion and high organic matter may result in high P concentrations in surface soil prone to erosion, and may also to lead to N immobilisation.

Other soil management or cultivation measures are concerned with limiting soil erosion, especially on sloping ground (M12, M13). Ploughing across slopes (when possible) can prevent rapid runoff in preferential flow and promote infiltration.

Similar effects are produced by leaving seedbeds rough in autumn. These measures are more effective for reducing P losses but could result in slight increases in nitrate leaching.

It is possible to add chemical amendments to soils to bind P and reduce losses (M14). However, in some circumstances erosion prevention measures may be required in addition to P-binding amendments.

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
M16	**Livestock Management** Feeders/Troughs	y	y	y		y		y				sw	y	y		**3 -** Nitrate leaching reduced by small amount (<2%); PP and Soluble P and sed reduced by up to 10%. **13-**Nitrate loss reduced by 0-1kgN/ha averaged over farm.	**GAP [17(18)] specifies restrictions in relation to siting of supplementary feeders and waters, bare rock.**	**2-**Troughs and feeders provide focus points lead to nutrient hot spots, increased soil compaction, greater runoff potential and P loss. Regular moving, more frequently when soils are wet, and siting away from drains and watercourses. Construct water troughs with a firm but permeable base.
M17	**Livestock Management** Fence off rivers and streams / construct bridges (Also Receptor Measure)	y		y	y	y		y				sw	y	y		**3-**Nitrate losses decreased by <2%, PP and sol P and associated sed losses reduced by up to 5%. **5-**Livestock exclusion from streams might reduce P losses by 32-76%.	Grants available and measure in GLAS.	Stock-proof fences exclude livestock and prevents trampling of river/stream banks. Erosion and direct deposition of nutrients and pathogens when wading in streams is reduced.
	SUMMARY Livestock excreta and livestock impacts on soils can be a significant cause of nutrient mobilisation. Concentration of animals in focus areas around feeders or troughs, or along tracks results in locally high nutrient loads and significant damage to soils. Movement of feeders and provision of suitable bases around water troughs (M16) is an effective mitigation. The impacts on local water quality can be significant, and while reduction in nutrient losses may be modest, frequent replication of the problem can result in catchment wide impacts. Excluding livestock from waterways (M17) has also been included in S20, but in addition the measure prevents poaching of stream banks and the erosion of soil and nutrients that results.																	

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
	PATHWAY INTERCEPTION MEASURES																	
P1	**Buffer Strips** Fenced or Unfenced Riparian Buffers	y		y	y	y	y	y	y		y	sw	y		y	**1-**Depends on width and topography, soil type and vegetation characteristics. **2, 3, 5, 9, 15, 19-** Removal of TP/PP in 5 to 10 m buffers reported as 20-90%; sediment 56-90% (even in hilly area); N 17-81%. **21-** 1m buffers ineffective for medium/heavy soils, 6m grass buffer most common, removes sand and silt (soil erosion reduced to less than 2t/ha/yr). **28-**Finer TP enriched fraction may be passing through the buffers. **5-**Strips may become sources of soluble P. **2-**Dissolved-P retention often below 0.5kgP/ha/yr. May get release of dissolved-P up to 8kgP/ha/yr. Biomass harvesting can remove 4-15kgP/ha/yr. **3-** Nitrate losses from buffers same as ungrazed zeroN grassland (90% reduction or <5kgN/ha/yr). **9-**Natural riparian buffer zones reduced sed loss by 56%. **13-**Largely ineffective at reducing nitrate leaching. Ineffective at reducing P losses in clay soils with drains (by-pass). Buffers provide an areal pro rata benefit of taking land out of production (losses 1-5kgN/ha buffer strip). **21-** Leading edge of the buffer removes 71-97% of the sediment trapped.	Resistance due to loss of productive land, poor field areas at waters edge are ideal. Low financing under CAP a problem. Maintenance required and weed control may be an issue. Location of measure is vital. **19-**Slopes should be less than 10%. **21-**Efficacy depends on size, location, hydrology, vegetation and soil type. Compaction compromises performance. Harvesting of vegetation is the only way to remove P from buffers. Winter leaching may recharge soil P adsorption capacity. Buffers may be rendered ineffective due to field drainage (N & P) and free draining soils (N). **GAP specifies minimum set back distances in relation to certain land use practices (ploughing, fertilizer/slurry application) and water types.**	Establishing vegetated and unfertilized buffer zones alongside water courses can reduce pollutants and nutrients entering water. Soil should ideally be free-draining with good surface porosity. Permanent vegetation in buffer also reduces erosion and stabilizes banks. Reduces spray drift onto waterways. Strips should not be used for vehicle access, turning or storage. Strips need management. Width should reflect runoff characteristics - diffuse sheet versus concentrated flow. **18-**Ratio of 50:1 contributing area to buffer width is recommended. Vegetation management is critical to remove stored P. **19-**Recommended buffer zone widths 10-60m for sediment removal; 5-90 for nutrient removal. 5-20m likely to be adequate. **3-** Entry level Env Stewardship options for 2-6m strips and 10m around in-field ponds.
P2	**Buffer Strips** In-field Grass Buffer Strips / Beetle Banks	y		y	y	y	y	y			y					**3,13-**Nitrate losses similar to ungrazed, zero-N grassland i.e. <5kg/ha/yr. Typically 20-90% reduction but only pro rata to area occupied. **5,13-**Can achieve 40-80% P reduction. **6-** On a clay soil beetle banks can reduce total P and sediment losses via SW by 10-95%. **13-** Method more effective when combined with riparian buffer strips.	Not likely to be established along mid-slope contours without financial incentive . Poor patches are ideal. **13-**Particularly suited to fields with long slopes. They increase the time for field operations by about 10%. **18-**26% of farmers in L. Melvin catchment gave first preference to buffer strips for runoff interception.	**3, 13-** In-field unfertilized grass buffer strips along contours on sloping fields slows and intercepts surface runoff. **13-**Usually permanent features 2 to 6m wide.

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
P3	**Buffer Strips** Field Boundaries / Hedgerows	y		y	y	y	y		y	y		sw	y			**2-**Nitrate reduction of 50-80% observed in the surface of shallow groundwater. **3-**Nitrate losses reduced <1%. PP and sol P losses reduced up to 20%. **13-**No effect on N losses; Estimated P loss reduced by 50% on sandy loam and 10% on clay loam.	Smaller fields increase the time for field operations. Provides useful shelter for stock. **18-** 32% of farmers gave preference to hedgerows across slopes as runoff interception.	Planting of grass strips and hedgerows along contours or in natural gullies avoids surface runoff, erosion, suspended sediment and associated pollutants. Removal of nitrate by denitrification and plant uptake. Prevent drift and increase local deposition of NH3 emission. Break up the hydrological connectivity of the landscape.
P4	**Buffer Strips** Woodlands (Floodplain, Catchment, Riparian)	y		y	y	y	y		y	y	y	sw gw	y	y	y	**10-**Soil infiltration rates were up to 60 times higher where young native cross slope woodlands were present compared to heavily grazed pasture. **11-**Woodland expansion contributed to a 33% reduction in nitrate leaching in Denmark 1990-2003. **11-**Effectiveness of riparian woodland buffer strips greater on thin soils (50-90% reduction in N loadings to GW and sed loss). Little effect on deeper soils on N movement to streams. Estimated N-leaching losses from arable / grassland / woodland - 26.4/15.5/0.4 kgN/ha/yr respectively in SE England. Woodland typically 0-24 kgN/ha/yr. **18-** 5m Willow/Alder gives 16% TP removal efficiency.	Targeted financial incentives for farm woodlands/willow cultivation recommended as part of ICM. Species composition important. Alder fixes N and can promote nitrate leaching. Effectiveness of riparian woodlands as nutrient soaks depends on design, width (a key cost consideration), management, site (previous land use; depth of water table; soil type). Fast growing spp (willow/poplar) quick to establish (benefits within 3 years). Riparian and floodplain woodlands offer a greater range of multiple benefits than grass buffers. Short rotation coppice may be an attractive option but may entail N application. GAEC measures may militate against use (cf. min maintenance; encroaching unwanted veg; permanent pasture).	Riparian woodlands are typically up to 10-30m wide on both sides of the watercourse. They improve infiltration, hydraulic roughness, soil stability.

SUMMARY

A great many variations of 'buffer strip' measures have been described. Riparian buffer strips (P1, P4) can consist of grassy/herbaceous borders or treed zones along waterways or in floodplains. They may be fenced or unfenced, but either option needs to consider management. Some buffers are in-field systems (P2, P3) and when placed across drainage slopes provide effective mitigation. Width of the buffer strip is often determined by local conditions (soils and slopes) and the farmer's willingness to cede productive land. However, evidence suggests that much of the mitigation function of the strip occurs at the leading margin adjacent to the field, and strips as narrow as 1 m can be efficient in reducing sediment and nutrient losses to streams. Widths of 5 to 10m are common.

Buffer strips intercept surface flows and facilitate infiltration and nutrient uptake or binding in soils. Perennial vegetation also stabilises banks. Removal is greatest for P which may eventually accumulate to saturation level and the strip may then become a source of P. However, P losses may occur in winter months, a time when impact is reduced and therefore water quality benefits still continue. Removal of P through harvesting of vegetation is possible but use of machinery in buffers can lead to compaction and rutting that may compromise function. Some evidence suggests that deep rooted perennials in established hedgerows may reduce nitrate levels in shallow groundwater. In well drained soils or where field drains are present sub-surface drainage may by-pass buffer strips.

Where appropriate species are planted, buffer strips may have substantial biodiversity benefits.

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
P5	**Soil Management** Gateway Location	y		y		y		y				sw	y			**3-**Nitrate losses reduced by <1%. PP, sol P and sed losses reduced by up to 10%. **5-**P-losses may be reduced by up to 30%. **18-**P reduction of 7.5% possible.	Reluctance if new trackways are involved. Initial costs per gate but no further expenditure.	**2-**Gateways are high risk areas and a break in field boundaries. Locate upslope to break hydrological connectivity. Tractor rutting and animal pathways provide preferential flow paths. Resurface gateways.
P6	**Soil Management** Prevent or Loosen Compacted Soil Layers in Grassland Fields	y		y		y						sw	y			**3-**PP and sed losses typically reduced 10-50%. Little effect on nitrate but soil aeration reduces N20 emissions and ammonia emissions post slurry application reduced due to better infiltration. **5-**Disrupting tramlines with tines reduces P losses by 72-99% at field scale.	Moderate to high likelihood of uptake where soil compaction has been identified.	Loosening compacted soil layers using tynes/soil aerators/sub-soiling increases infiltration and reduces SW pathway. **10-**Prevent compaction by increasing tramline spacing , using flexible tyres, decreasing loads, correct tyre pressure.
P7	**Soil Management** Trackways	y		y		y		y				sw	y			**3-**Small reduction in nitrate (<1%). PP and sol P and sed losses reduced by <2%.	Labour and time commitment. Investment and may be difficult to find alternate routes.	Create well drained tracks with appropriate surfaces and camber to shed water. Avoid steep slopes. Maintain properly and divert drainage to grassed areas, soakaways or swales, not to bare soil, roads or watercourses. Relevant for dairy farms especially.
	SUMMARY The management of gateways and trackways (P5, P7) can prevent excessive poaching and soil damage. They are also hot spots for nutrient deposition in excreta, and erosion associated with compacted and bare soils, and preferential flow paths can cause severe localised impacts. Maintaining soil structure and porosity (P6), particularly along tramways, improves infiltration and reduces surface water flows. This measure primarily acts effectively against P losses. Improved aeration and infiltration could enhance nitrate leaching.																	
P8	**Ponds/Wetlands** Establishment/Preservation of wetlands	y	y	y	y	y	y	y	y	y	y	sw gw	y			**1-** Reductions estimated at 174-217 kg/ha/a N and 2.4-4.9 kg/ha/a P in Sweden; 130-135 kg/ha N and 20 kg/ha P in Denmark. Small constructed wetlands retain 23-42% TP; 3-15% N. Suitable sites may be scarce; effects variable; lack of planners (cf. Finland - GIS tool available). **30-**Smaller wetlands (0.03-0.4% of catchment area) could be effective if strategically located in 1st or 2nd order catchments. **2-**Efficiency of Nitrate removal depends on residence time. Artificial wetlands shown to remove 46% nitrate by mass; natural 69%.	Funding focussed on priority areas (Constructed Farm Wetlands) or designated sites (Wetlands for Biodiversity). Resistance due to loss of productive land, perceived loss of income, cost of construction and low confidence in effectiveness. Compensation too low. Guidance needed. **30-**Wetlands should be located in areas of runoff convergence.	Intercepts non-point nutrient sources and pesticides in runoff and subsurface flow, providing de-nitrification (cf discharges to enclosed coastal waters), sedimentation and assimilation. Promotes water conservation, bird habitat, game and fishing. Restores habitats lost through drainage. Located in the lowlands in headwater catchments often associated with wet meadows.

	MEASURE	NUTRIENT SOURCE/TYPE				MEASURE ALSO BENEFICIAL FOR						BIOPHYSICAL SETTING				EFFECTIVENESS OF MEASURE	ACCEPTABILITY / CONSTRAINTS	MEASURE IN BRIEF
		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
P9	**Ponds/Wetlands** Constructed Wetlands	y	y	y	y	y	y	y				sw	y			**2-**CW in small brooks showed annual P retention of 1-50gP/m2/yr. 45-75% efficiency for soil particles; 21-44% for P and 3-15% for N. **5-**Effectiveness is highly variable (design/hydraulic loading, type of runoff, soil type) ranging from 20-90% P removal to 100% increase in export in year one post construction. 5% P removal in winter; 84% in summer. **32-**Total N removal 48-80%.	Particularly applicable to intensive livestock and arable farms. Seasonality in performance - poorest in winter when export greatest. **32-**The ability of vegetation to capture nutrients in a cool temperate climate is limited. **24-**Full assessment of C and N dynamics in CWs needed to understand removal/transport to GW, SW and emissions to atmosphere. Potential for pollution swapping.	Suitable for siting at end of pipe or small ditches, streams. Should be close to problem area. May last 10-50 years before excavating.
	SUMMARY Existing or man-made natural ponds and wetlands (P8) occur at points of runoff convergence and may receive significant groundwater flows via redirected field drains or in low lying locations. They intercept diffuse nutrient loads to downstream waters through sedimentation and sorption, and denitrification. Effectiveness of nutrient retention/removal is very variable and dependent on hydraulic residence times, vegetation composition and density, and seasonal factors. In some circumstances they can become net sources of nutrients. Constructed wetlands (P9) function in a similar manner to natural ponds and wetlands. They may be of complex construction and include several basins, and often used to treat small point wastewater sources being sited at 'end of pipe' locations. Multiple wetlands at strategic locations may be required to significantly reduce nutrient losses to waterways and may be of particular benefit in intensively farmed catchments.																	
P10	**Water Management** Run-off Attenuation Features	y		y	y	y				y		sw	y			**2-**Sediment ponds at field edges removed 65-75% sediment and 25-33% TP of load entering. 12-41% P and 0-11%N reduction in flat sandy areas in Netherlands. **3-**Not effective on free draining soils. Nitrate losses may be reduced by 20%. PP and sed losses could be reduced by up to 80% from arable fields. Soluble P losses reduced up to 20%. **4-**Sed trapped by ponds ranged 0.8t/ha/yr (sandy sites); 0.3t/ha/yr (silty soils); 0.04 t/ha/yr (clay soils). TP 0.006-2kg/ha/yr, TN 0.02-7kg/ha/yr (about 1% of nutrients applied).	Measure can result in wet fields for longer periods and impaired use. Construction can be difficult and involves some loss of land.	Includes attenuation systems by constructing low earthen bunds along ditches (ponding), wider ditches with floodplain, grassed waterways and sedimentation boxes. Lowering flow rates and increasing flow pathways reduces nutrient losses through infiltration, erosion control, denitrification, adsorption. Must site in areas of runoff convergence. May be on-line or off-line.

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		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
P11	**Water Management** Ditch Maintenance & Management	y		y		y			y	y		sw	y	y		**14-**Leave a 20m buffer at the downstream end of drains to act as a silt trap. **18-**Ochre traps have good potential for P retention (4g/kg). Barriers in ditches slow flow creating temporary storage and trap sediment and associated P. **18-** Ditches reduced inorganic P load to receiving waters by 44%. **35-** Sediment retention vs slope (<2% High; 2-5% Moderate; >5% Low). Flat ditches retain sed and P - dredge to maintain retention capacity. Sloping ditches mobilise sed and P - retain vegetation. **39-**Ditch sediments can retain sol and particulate P (dry summer periods) but PP may be mobilised in rain events. Winter release of P may have less impact.	**18-**32% of farmers most favoured barriers in drainage ditches for runoff interception. **35-** Can occupy large non-productive areas - 0.45% (arable), 1.25% (grassland).	**3, 34-** Stream bed sediments influence water quality through attenuation and/or mobilisation of P. Farm ditches are a common feature with potential for P mobilisation from bed sediments. Ditch sediments may supply particulate P to the water column and downstream receiving environments during small rain events. **35-**Highest density of ditches occurs in 'P risky' areas. Consider P loss mitigation strategies according to ditch attributes including bed gradients, vegetation. Clean ditches in summer (mid-May to mid-Sept) and retain bank vegetation. Spread sediment away from banks.
P12	**Water Management** Ditches/Drains Blocking	y		y	y	y			y	y	y	sw	y		y	**10-**Upland drain blocking (grip blocking) reduced average downstream flow by one third.	Raised water table may reduce productivity and trafficability and increase risk of surface water runoff.	In-ditch barriers to block drains slows flows and encourages sed settlement and infiltration. Raising the water table in peat soils reduces peat oxidation and high ammonia concentrations in water.
P13	**Water Management** Grassed Waterways (Vegetated Ditches?)	y		y	y	y				y		sw	y				Loss of productive land and trafficability issues.	Grassed channels within fields control flows. They reduce runoff and erosion and nutrient losses. Often with constructed outlet to control discharge.
P14	**Water Management** Allow field drainage systems to deteriorate	y		y	y	y						sw gw	y		y	**3-**Nitrate leaching reduced by 10-50%. PP and sed losses typically reduced by up to 10% provided that poaching is avoided. Increase in N_2O emissions. **13-**Drainage of grasslands can result in 2-3 fold increase in nitrate leaching. Measure can achieve reduction of 10-20kgN/ha (arable) and 15-30kgN/ha (grassland). Overall 5% reduction in P loss.	Most applicable to grasslands on medium/heavy soils. Easy to implement. May result in shorter grazing season or lower stocking rates. Unlikely without financial incentive.	Ceasing management to allow drainage systems to deteriorate reduces hydrological connectivity, forces water to percolate through soil. Higher water table reduces N mineralisation. Surface runoff may increase.

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		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
P15	**Water Management** Reduced Field Drainage / backfill amendment	y		y	y							sw	y			Netherlands: 12-41% reduction in P loads to SW in sandy areas; 0-11% for N loads. Measure has no effect in drained clays and not feasible in peat areas. Newzealand - Slag in backfill gave 73% reduction in DRP; 51% TP. **12-**In a catchment with little underdrainage substantial denitrification of the order of 50% occurs.	Measure results in wet fields for longer periods and impaired use.	Tile drains transport dissolved and particulate nutrients. Reduced drain density increases pathways through soil. In wet areas this increases overland flow. Subsurface drainage lowers water table and reduces P mobilisation in P-rich surface soil, but N leaching increases. Enrich backfill with Fe/Al, lime to bind P.
P16	**Water Management** Intake Wells on Subsurface Drains.	y		y		y						sw	y			Provide sediment filtration but are a direct connection to SW. Possible use of amendments (Fe/Al, lime) to enrich backfill and reduce P mobility in sensitive areas?		Surface runoff in undulating landscape accumulates in depressions, concentrating flow and causing gully erosion. Intake wells drain hollows. Can be combined with grassed waterways.
P17	**Water Management** Permeable Reactive Barriers/De-nitrification Trench	y	y		y							gw			y	**8-** Experimental. Over 90% nitrate-N removal achieved with C sources.	Before trench can be constructed must know hydrogeology of area and source of nutrient loss. Technical and resource demanding. Sawdust has high denitrification rates due to its large surface area, but it is prone to clogging.	PRBs are low-cost sustainable and permeable materials which provide a C-rich source (e.g. Woodchip) for nitrate removal. May be placed at various depths depending on watertable height and at strategic locations e.g. along shallow GW zones in riparian zones.
P18	**Water Management** Farm Drainage Plans	y	y	y	y	y						sw gw	y			**35-** Artificially lowering the water table can also result in bypassing areas of high natural attenuation and further increase nutrient losses.		Field drainage maps and plans. Connection of field drains and directing them to low-lying wetland areas. Failure to adapt drainage design to local soil, hydrogeological or climatic conditions can result in enhanced nutrient losses from grassland fields.

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<tr><th>Diffuse</th><th>Point</th><th>P</th><th>N</th><th>Sed</th><th>Pesticides</th><th>Pathogens</th><th>Biodiversity</th><th>Flooding</th><th>GHG</th><th>Main pathway</th><th>Wet</th><th>Dry</th><th>Sensitive Ecos</th></tr>
<tr><td></td><td colspan="17">SUMMARY
Measures to manage water movement through agricultural catchments aim at decreasing hydrological connectivity through increasing pathways and reducing flow rates. Many run-off attenuation features (P10) also reduce erosion and provide opportunities for infiltration, settlement and denitrification. Existing infrastructure in the form of extensive ditch systems in many agricultural catchments provide a unique opportunity for pathway interception measures (P11, P12). Minor modifications to ditch systems and informed management options can allow the potential of ditches for retention of sediments and nutrients to be expedited. The use of grassed waterways (P13) is not common but could be considered a particular case of ditch management where retention of ditch vegetation is recommended.
Drainage of hollows in undulating landscapes (P16), particularly on clayey soils, to prevent preferential flow and erosion can reduce P losses in surface water flows.
Abandonment or reduced drainage options (P12, P14, P15) raise water tables and can result in significant increases in denitrification and reductions in nitrate leaching. Such measures would not generally be acceptable to farmers but in high status, vulnerable or marginal lands they may be considered.
Permeable reactive barriers for nitrate removal (P17) are quite experimental at field scale and require extensive expertise input in design and siting.
Farm drainage plans (P18) offer an opportunity to integrate land use and soil/topographical features in effective management of nutrient resources and protection of receiving waters in catchments. Local knowledge and expertise can be captured in such plans but they would also benefit from advisory support to ensure that natural attenuation features are retained and exploited.</td></tr>
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		Diffuse	Point	P	N	Sed	Pesticides	Pathogens	Biodiversity	Flooding	GHG	Main pathway	Wet	Dry	Sensitive Ecos			
	RECEPTOR/INSTREAM WORKS																	
R1	**Runoff Attenuation** Large woody debris (Beaver Dams) and plant debris	y		y	y	y			y	y		sw	y			**38-**Travel time of the peak of the flood was increased from 20 minutes to 35 minutes (over 1 km) where one stream spill feature was present. In an area of beaver dams, the travel time was more than doubled. Attenuation features reduce the peak discharge of floods. This may reduce bank erosion and sediment transport. Organic debris supports denitrification.	Soils may be prone to erosion due to scour around structures placed in the stream. Decomposition limits lifespan. Maintenance needs to be considered and addressed.	Provide floodwater detention ponds behind barriers constructed from 'Large Woody Debris'. Structures have sufficient height to connect the floodplain to the main channel during flood events, but are also porous enough to allow moderate floods through almost unhindered. Promotes sediment deposition.
R2	**Runoff Attenuation** Offline bunds/ In-stream Diversion Structures	y		y		y			y	y		sw	y	y			Optimum areas for storing runoff may mean loss of productive land.	Bunds intercepting flow pathways which store storm runoff and slowly release it over 6-24 hours. Slowing, storing and filtering the surface flow can attenuate the flood peak at the local scale and reduce sediment loads and PP transport. Stream can be spilled during high flows by lowering the bank beside a storage feature (in buffer zones) to roughly the height of a typical large flood event.
R3	**Invasive Alien Species Control**	y		y		y			y			sw	y	y		Control of invasive alien species and re-establishment of native vegetation prevents large areas of exposed soil in winter months and reduces the risk of erosion.		Control of riparian invasive aliens (Himalayan balsam, Japanese knotweed, Giant Hogweed)
	SUMMARY Runoff attenuation features (R1, R2) help to restore natural flow dynamics of rivers and catchments. This re-naturalisation helps to reduce flood peaks and erosion events. It also provides opportunities for enhanced infiltration and sediment settlement which reduce nutrient export. The measures are primarily aimed at flood protection and there is little evidence as to their effectiveness in mitigation of nutrient impacts on waters. Natural/native riparian vegetation consists of species mixes of annual and perennial species. This ensures vegetation cover and stable banks in all seasons that are resistant to erosion. Invasive alien species can outcompete native species and displace natural plant communities. Control of alien species (R3), which can form extensive monospecific swards that die off in winter periods to expose soils of stream banks, allows native plant communities to re-establish.																	
R4	**Livestock Management** Exclusion from rivers and streams (Also Source Reduction Measure)	y		y	y	y		y				sw				**13-**Reduction of 0-1kgN/ha averaged over farm estimated, and 50% of soil and manure component P loss.	Most relevant to intensively stocked cattle farms. May require provision of alternative drinking water sources.	Stock-proof fencing in fields and on trackways adjoining waterways, construction of bridges for livestock crossings prevent trampling and bank erosion. Prevents direct addition of nutrients by urination and defecation.

GAP Summary

	MEASURE	GAP REF.	CATEGORY
1	Take all steps to minimise soiled water produced in a farmyard.	5(1)	SOILED WATER
2	Ensure that rainwater from roofs and clean yards and water flowing from higher ground onto a farmyard is diverted without contamination to a clean water outfall and is not allowed to enter soiled yards or storage areas for soiled water. Ensure rainwater gutters and downpipes are maintained in good working condition.	5(2) (a)(b)	
3	There shall be no runoff of soiled water from farm roads to any waters from 1 January 2021	18 (20)	
4	There shall be no direct runoff of soiled waters resulting from poaching to any waters	18 (21)	
5	All slurry, soiled water, effluents, farmyard manure etc. produced in a building or yard, shall be collected and held in a manner that prevents run-off or seepage, directly or indirectly, to groundwaters or surface waters.	6(1)	COLLECTION AND HOLDING
6	The occupier of a holding shall not cause or permit slurry, soiled water, effluents, farmyard manure etc., to enter waters.	6(2)	
7	All storage facilities (including out-wintering pads, earthen-lined stores, and integrated constrcuted wetlands) for slurry, soiled water, effluents, farmyard manure etc. shall be maintained and managed in good condition.	7(1) (3)(4)	PROVISION AND MANAGEMENT OF STORAGE
8	New storage facilities shall be designed, sited, constructed, maintained and managed to prevent run-off or seepage into groundwaters or surface water, and comply with construction specifications of DAFM.	7 (2) (a)(b)	
9	The capacity of storage facilities for livestock manure and other organic fertilisers, soiled water and effluent from dungsteads, farmyard manure pits and silage pits shall be adequate to provide for storage for such a period as to comply with these Regulations and to avoid water pollution.	8 (1)(3)(4); 9; 10; 11; 12; 13; 14	CAPACITY OF STORAGE
10	An occupier shall have due regard to the storage capacity which may be required during periods of adverse weather conditions. The application to land of livestock manure or soiled water is precluded.	8 (2)	
11	The capacity of facilities for the storage of effluent produced by ensiled forage and other crops shall equal or exceed the capacity specified in Table 5 of Schedule 2, and for soiled water being shall equal or exceed the capacity required to store all soiled water likely to arise on the holding during a period of 15 days	9 (a) ©	
12	The capacity of facilities for storage of livestock manure may be less than that specified in Article 10, 11, 12 or 13, as appropriate, in the case of a holding where the occupier has a contract providing exclusive access to adequate alternative storage capacity located outside the holding, or for access to a treatment facility for livestock manure, or a contract for the transfer of the manure. Storage capacity may also be less in certain cases where deer, goats, sheep and livestock (other than diary cows) are outwintered subject to specified maximum stocking rates and other conditions.	14 (1) (2) (3) (4)	
13	The amount of fertiliser applied to promote the growth of a crop or grassland shall not exceed that specified in the Regulations.	15; 16	NUTRIENT MANAGEMENT - CROPS & GRASSLANDS
14	Chemical fertiliser shall not be applied to land within 2m of any surface waters.	17(1)	SETBACK DISTANCES
15	Organic fertiliser or soiled water shall not be applied to land within 200m of an abstraction point supplying 100m3 or more of water per day or serving 500 or more persons; 100m for schemes supplying 10m3 or more or serving 50 or more; 25m of any abstraction of water for human consumption; 20m of lake shoreline, or a turlough likely to flood; 15m of exposed cavernous or karstified limestone features; 5m of any surface water (not a lake), or 10m where slopes are >10%, or for 2 weeks preceding and following the periods specified in Schedule 4.	17(2)	
16	Alternative landspreading setback distances may be set by the Local Authority or Irish Water on the basis of technical and risk assessments and prior assessments.	17 (3)-(7)	
17	Organic fertiliser or soiled water shall not be applied to land within 10m of any surface waters where the land has an average incline greater than 10% towards the water	17 (12)	
18	Where farmyard manure is held in a field prior to landspreading it shall be held in a compact heap and shall not be placed within 250m of an abstraction point supplying 10m3 or more of water per day or serving 50 or more persons; 50m of any other abstraction source; 20m of a lake shoreline or turlough likely to flood; 50m of exposed cavernous or karstified limestone features (such as swallow-holes and collapse features); 20m of other surface waters (other than a lake).	17 (13)	
19	Farmyard manure shall not be held in a field at any time during the periods specified in Schedule 4.	17(14)	
20	Silage bales shall not be stored outside of farmyards within 20m of waters or a drinking water abstraction point in the absence of adequate facilities for the collection and storage of any effluent arising.	17(15)	
21	No cultivation shall take place within 2m of a watercourse identified on the OSI 1:10560 map except in the case of grassland establishment or the sowing of grass crops.	17(16)	
22	Supplementary feeding points shall not be located within 20m of waters and shall not be located on bare rock.	17(17)	
23	On holdings with stocking rates of 170kgs of nitrogen or more: bovines shall not be allowed ot drink directly from water from 1 January 2021; Where bovines have direct access to water, a fence at least 1.5m from the waters edge shall be installed by 1 January 2021;Livestock can be moved to isolated land parcels across a watercourse if both sides are fenced; Supplementary drinking water points must be at least 20m from watercourses by 1 January 2021.	17 (18) (19)	

	MEASURE	GAP REF.	CATEGORY
24	Livestock manure, other organic fertilisers, effluents, soiled water and chemical fertilisers shall be applied to land in as accurate and uniform a manner as is practically possible.	18(1)	MANNER OF APPLICATION
25	Organic and chemical fertilisers or soiled water shall not be applied to land in any of the following circumstances— (a) the land is waterlogged; (b) the land is flooded or likely to flood; (c) the land is snow-covered or frozen; (d) heavy rain is forecast by Met Eireann within 48 hours, or (e) the ground slopes steeply and there is a risk of water pollution having regard to factors such as surface runoff pathways, the presence of land drains, the absence of hedgerows to mitigate surface flow, soil condition and ground cover.	18(2)(3)	
26	(4) Organic fertilisers or soiled water shall not be applied to land— (a) by use of an umbilical system with an upward-facing splashplate, (b) by use of a tanker with an upward-facing splashplate, (c) by use of a sludge irrigator mounted on a tanker, or (d) from a road or passageway adjacent to the land irrespective of whether or not the road or passageway is within or outside the curtilage of the holding.	18(4)	
27	Soiled water shall not be applied to land— (a) in quantities which exceed in any period of 42 days a total quantity of 50,000 litres per hectare, or (b) by irrigation at a rate exceeding 5 mm per hour.	18(5)	
28	In an area which is identified on maps compiled by the Geological Survey of Ireland as “Extreme Vulnerability Areas on Karst Limestone Aquifers”, soiled water shall not be applied to land— (a) in quantities which exceed in any period of 42 days a total quantity of 25,000 litres per hectare, or (b) by irrigation at a rate exceeding 3 mm per hour unless the land has a consistent minimum thickness of 1m of soil and subsoil combined.	18(6)	
29	Application of fertiliser to land is prohibited during the periods specified in Schedule 4 (Closed Periods).	19(1)	CLOSED PERIODS
30	Closed periods do not apply in relation to the application to land of soiled water, or chemical fertilisers to meet the crop requirements of Autumn-planted cabbage or of crops grown under permanent cover, or fertilisers whose application rate or usage rate is less than 1kg per hectare of available nitrogen or phosphorus.	19(2)	
31	The amount of livestock manure applied in any year to land on a holding, together with that deposited to land by livestock, shall not exceed an amount containing 170 kg of nitrogen per hectare.	20(1)	APPLICATION LIMITS
32	Where arable land is ploughed between 1 July and 30 November the necessary measures shall be taken to provide for emergence, within 6 weeks of ploughing, of green cover from a sown crop. A rough surface shall be maintained prior to a crop being sown in the case of lands ploughed between 1 December and 15 January.	21(1)	CULTIVATION AND GREEN COVER
33	Where grassland is ploughed between 1 July and 15 October the necessary measures shall be taken to provide for emergence by 1 November of green cover from a sown crop.	21(2)	
34	Grassland shall not be ploughed between 16 October and 30 November.	21(3)	
35	When a non-selective herbicide is applied to arable land or to grassland in the period between 1 July and 30 November the necessary measures shall be taken to provide for the emergence within 6 weeks of the application, of green cover from a sown crop or from natural regeneration.	21(4)	
36	Where green cover is provided for in compliance with this Article, the cover shall not be removed by ploughing or by the use of a non-selective herbicide before 1 December unless a crop is sown within two weeks of its removal.	21(5)	

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