Evidence and perception of phosphorus loss risk factors in farmyards

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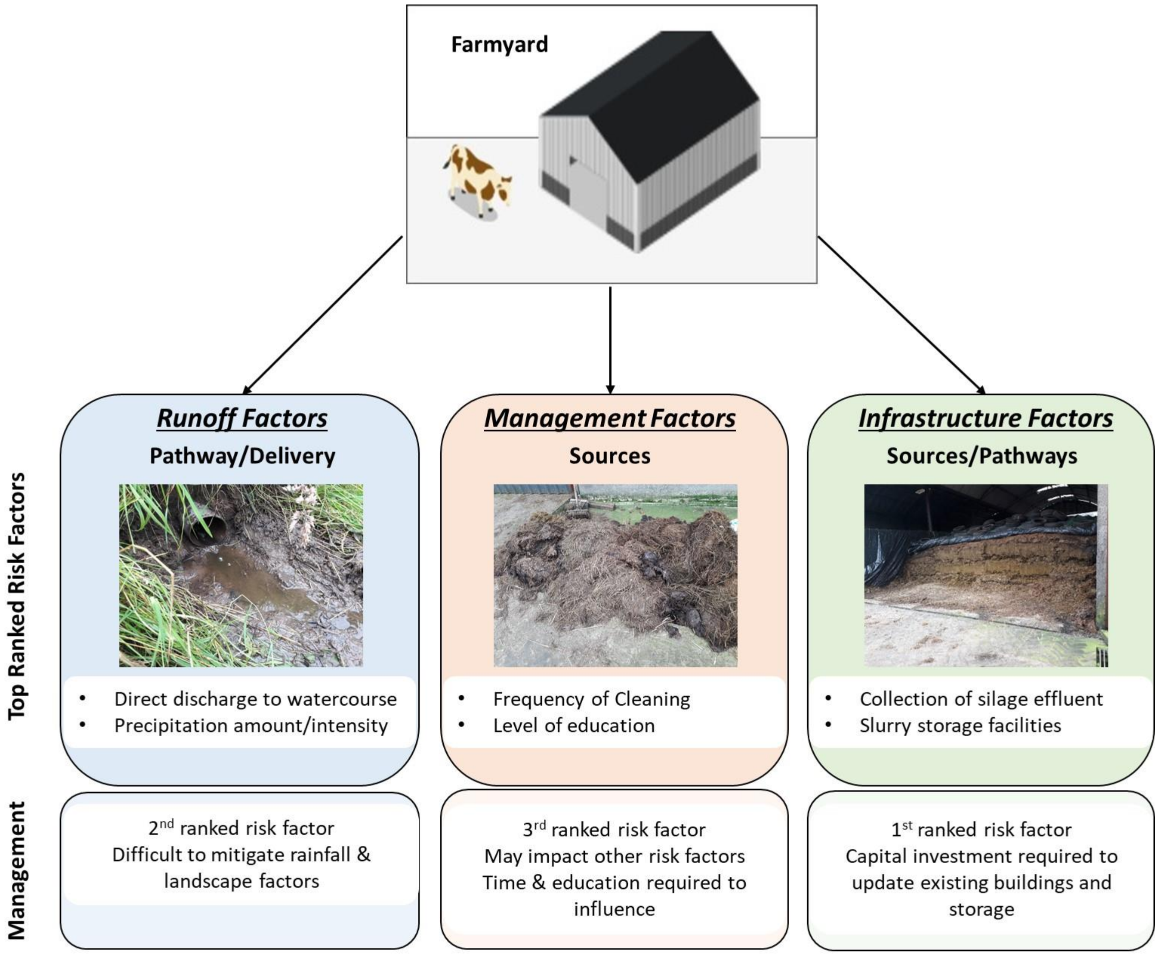
Highlights:

- Estimation of risks of P loss from farmyards were assessed by expert survey
- Runoff, management, and infrastructure factors influence farmyard P loss risks
- Silage and slurry storage are assigned the highest level of risk
- Management factors are perceived as having lowest risk
- Good consensus between researchers, policy makers and advisory regarding risks.

Keywords: farmyard, phosphorus, water quality, point source, risk

Graphical Abstract:



Abstract

Farmyards present potential point sources of phosphorus loss to watercourses, affecting their ecological quality and attainment of environmental goals. Unlike many relatively simple point sources, farmyards are complex sub-systems within the wider agricultural setting, including individual runoff, management and infrastructure factors which influence the risk (likelihood and magnitude) of phosphorus loss. Comparison across these factors is confounded by heterogeneity in farmyard design and management, however, weighting of individual factors will support estimation of the relative riskiness of farmyards. This will allow identification of appropriate mitigation measures and evaluation of cost-benefit ratios. The aim of this study is to evaluate the riskiness of runoff, management, and infrastructure factors on phosphorus loss from farmyards to water, using expert opinion and to evaluate whether those estimates are supported by the literature. A survey of research, advisory and policy stakeholders was conducted (147 respondents) in which individuals rated the importance of individual factors from 0 (having no impact) to 10 (having critical impact) on phosphorus loss from farmyards. The most highly ranked factors were within the infrastructure category, followed by runoff and finally management factors. Factors relating to silage effluent and slurry storage were assigned the greatest risk (≥8.4). Runoff factors were also high risk but may be difficult to mitigate compared to infrastructure. Management factors were rated lower by all stakeholder groups but may offer low cost options to offset more intransigent risks. High consensus was observed between stakeholder groups, with significant differences in risk ratings for only 8 out of 29 individual factors.

1. Introduction

Achieving water quality goals under the Water Framework Directive (WFD; 2000/60/EC, European Commission, 2000) requires reduction in both point and diffuse nutrient loads reaching watercourses. While source apportionment exercises (e.g. Mockler et al., 2017) indicate that long-term realisation of these goals requires reductions in nutrient loading to agricultural soils, this will be subject to significant time lags arising from hydrologic and biogeochemical factors (Schulte et al., 2010, Cassidy et al., 2017). In the immediate future, elimination of point sources is crucial to lower peak concentrations occurring during runoff events or when stream flow is too low to sufficiently dilute persistent inputs. Mitigation of point sources may be suited to one-time engineering solutions, which require capital investment but not changes in stocking rate, fertilizer use or land management.

Source apportionment models typically differentiate between non-agricultural and agricultural sources, and between land use types (SLAM – Mockler et al., 2017; PSYCHIC – Davison et al., 2008; Bowes et al., 2008 and others). However, they currently are unable to disaggregate potential sources at the farm-scale resolution at which mitigation measures are implemented. Farmyards have been identified as agricultural point sources (Moloney et al., 2019; Fish et al., 2009; Edwards et al., 2008), however, yards are not wholly analogous to other ‘simple’ point sources such as septic tanks. Rather, they involve many different contaminant types (nutrients, faecal bacteria, disinfectants, and other chemicals) and sources (livestock manures, feeds, and effluents), and farm management activities including animal handling, housing, milking, lambing/calving, feed storage etc. These activities have a strong seasonal pattern and in some instances such as milking, a diurnal routine. Often estimation of contaminant loss from farmyards does not acknowledge this complexity and assigning ‘rule-of-thumb’ values of nutrient loss from farmyards is likely to be misleading considering that there is no standardised design and that construction ages vary widely. No clear correlation between nutrient loss measurements with simple proxies such as livestock numbers exist (Brewer et al., 1999) and so estimation of loads must incorporate other characteristics of the farmyard.

The term 'soiled water' is often applied generically within UK and Irish agriculture to refer to runoff from hard surfaces without clarifying its origin, chemical composition, or clearly differentiating 'soiled' from 'clean' water. Within this paper the term is used to refer to water which has become contaminated via contact with manure, effluent, urine, fertilisers, or washings (Minogue et al., 2015). Within yards, several distinct nutrient sources have been identified in the literature. Brewer et al., (1999) defined five main sources of 'dirty/soiled water (SW)' from dairy farms; (1) bulk milk tank rooms, (2) the milking parlour pit, (3) the milking parlour livestock standing area, (4) soiled yard surfaces and (5) silage clamps. Models of contaminant transport and selection of optimal mitigation strategies require conceptual models of when, where, and how those contaminants are lost. In the case of farmyards, there is a dearth of studies which measure these individual nutrient sources and pathways under identical conditions and that differentiate the gross contribution of each of those factors within an individual farmyard. Thus, the relative riskiness (defined as the likelihood and magnitude of harm – Fish et al., 2009) of these elements cannot be compared.

In the absence of such comparison, prioritisation and cost-benefit of mitigation options cannot be evaluated. To overcome these issues Fish et al. (2009) employed a ranking exercise via expert consultation to determine the 'riskiness' of various factors as relates to faecal indicator organism (FIO) transport in agricultural settings. There are several approaches to expert elicitation designed to collate the knowledge of informed individuals by asking them to express that knowledge quantitatively in response to defined questioning (O'Hagan, 2018). Approaches may seek to revise or refine estimates through discussion and iterative processing (as per the Delphi or IDEA protocols) (Hemming et al., 2018). Alternatively, independent, quantitative assessments may be applied (as in this study and Fish et al., 2009) allowing the views of various stakeholder groups to be considered discretely. Expert judgement allows assessment of probability or of risk where empirical data may be incomplete or insufficient (Hemming et al., 2018). Oliver et al. (2009) applied the results of Fish et al (2009) as a weighting factor in a farm FIO risk assessment toolkit. While such an approach cannot replace empirical data from direct measurements, it does allow integration of knowledge from interdisciplinary sources and avoids over-reliance on direct measurements from relatively few sites. The latter issue may be particularly problematic as there is high variability in the farmyard characteristics as a whole. The consensus of experts' opinions may therefore be used to support or to guide evaluations of hazard and risk, and prioritisation of mitigation measures. Expert judgement of the relative weighting of P transport factors is incorporated in some United States P index systems (Sharpley et al., 2012), validated and calibrated against observational studies. The aim of this study is to evaluate the riskiness of runoff, management, and infrastructure factors on phosphorus loss from farmyards to water, using expert opinion.

2. Materials and Methods

In the present study, an expert elicitation approach was adapted from Fish et al. (2009) to develop and implement a survey of the level of risk posed by various factors for nutrient loss in runoff from a farmyard. The survey was composed of two elements: characterisation of the respondent (location, employment, and areas of expertise), and allocation of risk levels to factors within each of three categories: runoff, management and infrastructure (selection criteria for the risk factors is given in Table A; Supplementary Material). Runoff factors relate to the generation of overland flow and the connectivity of the farmyard to the watercourse. Management factors pertained to activities taking place within the farmyard (e.g. livestock handling, cleaning) or that may influence decision making and the functioning of the farm as a whole (e.g. participation in environmental or quality assurance schemes, age and education of the farmer, etc.). Infrastructure factors pertained to the physical characteristics of the farmyard that influence the water movement or nutrient retention (e.g.

sufficient slurry/SW storage, silage effluent collection, roofing of silage/manure bunkers etc.). Within each of the three categories, individual factors were identified based on evidence from the literature including papers which directly measured nutrient losses from farmyards, or which measured losses from individual sources within farmyards (e.g. silage, farmyard manure etc.). Participants were asked to rate the importance of each factor from 0 (having no impact) to 10 (having critical impact) on phosphorus losses to watercourses. This continuous standardised scale follows the approach of Fish *et al*. (2009), allowing respondents to weight perceived risk along a spectrum and also, to allow weightings to be incorporated into modelling exercises as per Oliver et al. (2009).

The survey was distributed using a snowball technique and was first emailed to c. 60 researchers, policymakers, regulators, advisors and inspectors and hosted on the online platform SnapSurveys. The survey was open-access so that it could be forwarded to colleagues of the recipients and to other interested individuals who had not been identified by the authors. The online platform remained active for three weeks. In addition, hard-copy versions of the survey were distributed at the Catchment Science 2019 conference in Co. Wexford, Ireland (5th - 7th November 2019) which was attended by international researchers, as well as national policy makers and advisors (https://www.teagasc.ie/news--events/news/2019/catchment-science-2019-.php). Due to the diversity of means of distribution and the encouragement to further distribute the survey it is not possible to determine a response rate.

Statistical analysis was conducted using STATA (2017) to produce summary statistics, a relative risk hierarchy, and to compare risk scores between different groups of respondents. Statistical tests were used to rank factors respondents scored as relatively higher risk within their category (Runoff, Management, or Infrastructure). For each category, the mean risk score for all factors was calculated. These were then sorted from highest (closest to 10) to lowest (closest to 0). Then, the null hypothesis that the highest two means are equal was tested, as well as the alternative hypothesis that the factor with the higher nominal mean was statistically greater than the factor with the next higher nominal mean (t-test). In the case that we fail to reject the null hypothesis the two factors are assigned the same rank. If the null hypothesis is rejected, and the alternative hypothesis shows the mean is larger, then they are assigned different ranks. This procedure is repeated until the lowest nominal mean is tested against the second lowest. In this way, a relative risk ranking is established whereby more than one factor can be considered equally 'risky' amongst themselves, but more or less risky than one or more factors. Statistical differences between how respondents with policy, research and advisory roles were also tested for. The group (policy, research or advisory) mean and 90% confidence interval was calculated. Then F-tests were used to test for any statistical differences in terms of how one group scored a risk factor compared to the other two.

3. Results

3.1 Characterisation of respondents

A total of 147 responses was received. The geographic distribution of respondents was 67% ROI, 28% NI, 3% England/Scotland/Wales and 3% other. The primary employment of respondents was 44% farm advisory (predominantly from within the ROI water quality sustainability advisory cohort), 20% local government/inspectorate, 16% research, 13% policy and 7% other. The leading areas of expertise were agricultural science (47% of respondents), water quality (47% of respondents), environmental science (47% of respondents), farming (37% of respondents), farm management (31% of respondents), catchment science (29% of respondents), regulation (25% of respondents), and soil science (33% of respondents). Hydrology, economics, geography, social science, microbiology, biodiversity and education were also reported. All but 25 respondents indicated more than one field of expertise.

3.2 Perceived levels of risk

Results of the expert survey and ranking of individual factors within the three categories are shown in Table 1 as per Fish et al. (2009), this initial layer of interrogation is used to indicate the common approximation of risk across participants and provides an insight into the perception of risk and the priorities of stakeholders. The levels of risk here are indicative rather than being wholly prescriptive, i.e. they reflect the magnitude and likelihood of impact posed by each factor, rather than specifying quantities and timings of nutrient loss. The individual factors with the highest sample means indicate that collection of silage pit effluent, slurry storage capacity, direct discharge to watercourse, condition of the silage pit and FYM storage capacity are considered the top five perceived risk factors by the participants.

Considering that factors were selected for inclusion based on existing evidence or rationale that they will have some sort of impact on nutrient loss within farmyards, it is in line with expectations that the resulting data be skewed towards the higher values in the scale. There are only two factors with a median value below 6 (Compactness of calving/lambing and Participation in off-farm employment) with the remaining 27 falling above. The standard deviation within each risk factor ranges from 1.32 to 2.44, with mean values falling close to or below the median values and ranging from 4.4 to 8.9. In most cases, less than 5% of respondents selected 'Don't Know' instead of assigning a perceived risk score to a factor, with higher rates for Quality of livestock handling facilities (7.5%), Participation in off-farm employment (8.2%), and, Compactness of calving/lambing (13.6%).

The runoff category was perceived as having the greatest control on nutrient losses, followed by infrastructure and finally, management. This ranking was consistent across employment types of respondents. No individual factors within the management category were within the top 10 ranked factors, suggesting a low prioritisation of management factors as a means to control nutrient losses, with hydrology and waste storage considered to be of greater importance.

3.3 Comparison by Primary Employment

To investigate the impact of primary employment the participants were divided into three employment groups, Farm Advisory, Research and Policy. These were compared to see if there was a statistical difference in the perceived risk scores based on employment type. A sub-sample of respondents who indicated one of the above three employment categories (n = 101) was analysed. The summarised results are presented in Table 2.

No statistical difference was found between these groups in any of the Runoff factors. However, within the Management category, the Farm Advisory group assigned lower risk scores for 'Duration of livestock housing' than Research ($F(1, 97) = 4.64$; $Prob > F = 0.034$) and Policy ($F(1, 97) = 4.56$; $Prob > F = 0.035$) groups. The mean risk score for 'Compactness of calving/lambing' was also lower in the Farm Advisory group ($F(1, 92) = 2.92$; $Prob > F = 0.09$) than Research and Policy ($F(1, 92) = 3.70$; $Prob > F = 0.058$). In many cases Infrastructure factors were given a lower risk score by the Research group than the others. The Research group scored 'Slurry storage capacity' as a lower risk factor than the Farm Advisory group (statistically significant at below the 1% level) and Policy group (statistically significant below the 5% level). A similar pattern is observed for the risk factors 'Condition of silage pit' and 'Collection of silage bale effluent'. The Research group scored both factors below Farm Advisory ($F(1, 96) = 4.25$; $Prob > F = 0.0420$ and $F(1, 98) = 6.63$; $Prob > F = 0.0115$ respectively) and Policy ($F(1, 96) = 2.81$; $Prob > F = 0.0971$ and $F(1, 98) = 4.74$; $Prob > F = 0.0318$ respectively. Researchers had a lower perceived risk of 'Area of hard standing' than Farm Advisors ($F(1, 97) = 5.87$; $Prob > F = 0.0173$) as well as 'Cracks in hard standing' ($F(1, 99) = 3.66$; $Prob > F = 0.0586$). Farm Advisory assigned a lower risk score for 'Roofing of silage pit/slurry tank/manure heap' than Policy ($F(1, 97) = 4.82$; Prob > F = 0.0305). The F-statistics and inverse probabilities that the null hypothesis of equal means can be rejected are provided in Table 2.

Table 1: Ranking of risk factors within Runoff, Management, and Infrastructure categories.

		Mean	Within Category Ranking	t-statistic Ho: diff = 0	Pr(T>t) for Ha: diff > 0	Median	Standard Deviation	"Don't Know"
Runoff Factors	Direct discharge to watercourse	8.74	1	1.626	0.053	10	2.26	1.4%
	Direct discharge to open drain/ditch	8.38	2	3.376	0.0004	9	1.88	0.7%
	Runoff from paved area to watercourse	7.53	3	0.846	0.199	8	2.38	0.0%
	Slope of farmyard to watercourse	7.30	3	0.510	0.305	8	2.20	1.4%
	Runoff from paved area to open drain/ditch	7.20	3	1.861	0.032	8	2.04	0.0%
	Distance of farmyard to watercourse	7.04	4	2.442	0.008	8	2.43	0.7%
	Number of rainfall days per year	6.35	5	0.331	0.370	7	2.23	1.4%
	Average annual rainfall	6.26	5			7	2.37	1.4%
Management Factors	Frequency of yard cleaning	7.63	1	1.396	0.082	8	2.06	2.7%
	Level of education of farmer	7.22	1	1.675	0.048	8	2.15	1.4%
	Membership of environmental schemes	6.90	2	0.119	0.452	7	2.13	2.0%
	Receipt of advisory services	6.79	2	2.548	0.006	7	2.26	4.1%
	Age of farmer	6.19	3	-0.835	0.798	6	2.41	4.1%
	Duration of livestock housing	6.12	3	1.512	0.066	7	2.44	4.1%
	Membership of quality assurance schemes	5.81	3	1.325	0.093	6	2.37	4.1%
	Receipt of basic payment	5.76	4	2.506	0.006	6	2.43	3.4%
	Participation in off-farm employment	5.02	5	2.125	0.017	5	2.52	8.2%
	Compactness of calving/lambing	4.29	6			4	2.32	13.6%
Infrastructure Factors	Collection of silage pit effluent	8.97	1	0.123	0.451	9	1.61	0.7%
	Slurry storage capacity	8.91	1	1.169	0.122	9	1.32	1.4%
	Condition of silage pit	8.71	1	2.661	0.004	9	1.51	2.0%
	FYM storage capacity	8.52	2	0.394	0.347	9	1.51	0.7%

	Soiled water storage capacity	8.44	2	3.782	0.0001	8	1.46	0.7%
	Cracks in hard standing	7.76	3	0.407	0.342	8	1.69	0.0%
	Collection of silage bale effluent	7.63	3	0.871	0.192	8	2.13	0.7%
	Roofing of silage pit/slurry tank/manure heap	7.34	3	2.041	0.021	8	1.97	1.4%
	Area of hard standing	7.32	4	0.724	0.235	7	1.76	3.4%
	Layout of farmyard	7.14	4	4.816	0	7	1.93	0.7%
	Quality of livestock handling facilities	5.86	5			6	2.34	7.5%

Table 2: Comparison of means between Farm Advisory, Research and Policy employment groups[1].

					F-test p-value		
		Farm Advisory	Research	Policy	Advisory = Research	Advisory = Policy	Research = Policy
Runoff Factors	Direct discharge to watercourse	8.83	8.65	8.74	0.7748	0.6155	0.8220
	Direct discharge to open drain/ditch	8.41	8.39	7.93	0.9755	0.4117	0.4917
	Runoff from paved area to watercourse	7.28	7.96	7.67	0.2656	0.5893	0.7255
	Runoff from paved area to open drain/ditch	7.08	7.09	7.07	0.9865	0.9851	0.9772
	Average annual rainfall	5.87	6.48	6.40	0.3090	0.4520	0.9229
	Number of rainfall days per year	6.16	6.52	6.13	0.5101	0.9688	0.6048
	Distance of farmyard to watercourse	7.16	6.96	7.67	0.7236	0.4518	0.3628
	Slope of farmyard to watercourse	7.26	7.09	7.80	0.7637	0.4198	0.3576
Management Factors	Duration of livestock housing	5.67	7.00	7.20	0.0338**	0.0353**	0.8117
	Compactness of calving/lambing	4.05	5.17	5.40	0.0907*	0.0576*	0.7853
	Receipt of advisory services	7.18	6.24	6.60	0.1153	0.3934	0.6484
	Participation in off-farm employment	4.75	5.22	5.00	0.5010	0.7383	0.8101
	Membership of environmental schemes	7.05	6.29	6.87	0.1745	0.7771	0.4392
	Membership of quality assurance schemes	5.76	5.90	6.13	0.8131	0.5900	0.7780
	Receipt of basic payment	5.79	5.52	5.73	0.6740	0.9343	0.8076
	Frequency of yard cleaning	7.68	6.91	8.00	0.1421	0.6118	0.1338
	Level of education of farmer	7.34	7.23	8.00	0.8147	0.2569	0.2527
	Age of farmer	6.33	6.41	6.60	0.8858	0.6780	0.8020
Infrastructure Factors	Area of hard standing	7.66	6.67	6.93	0.0173**	0.1241	0.6284
	Slurry storage capacity	9.13	8.14	9.13	0.0024***	0.9863	0.0223**
	FYM storage capacity	8.61	8.09	8.47	0.1277	0.7164	0.4133
	Soiled water storage capacity	8.52	8.13	8.40	0.2657	0.7658	0.5747
	Condition of silage pit	8.73	7.95	8.80	0.0420**	0.8779	0.0971*
	Collection of silage pit effluent	9.05	8.00	9.20	0.0115**	0.7463	0.0318**
	Collection of silage bale effluent	7.56	7.23	7.60	0.5427	0.9532	0.6173

[1] * indicates 0.1 > p > 0.05; ** indicates 0.05 > p > 0.01; *** indicates p < 0.01

	Layout of farmyard	7.11	6.86	7.07	0.6219	0.9411	0.7635
	Cracks in hard standing	7.88	7.13	8.00	0.0586*	0.7860	0.1048
	Roofing of silage pit/slurry tank/manure heap	6.97	7.23	8.27	0.6124	0.0305**	0.1347
	Quality of livestock handling facilities	5.50	6.17	6.13	0.3075	0.3668	0.9687

4. Discussion

The number of respondents compares well with previous studies (Fish et al., 2009) and reflects a cross-section of advisory, inspectorate, research, and policy. As indicated by their selection of disciplines, all respondents had expertise and knowledge relevant to the study topic. The high number of respondents indicating multiple fields of expertise suggests that they were qualified to comment on the interactive nature of farmyard risk factors. The results of the survey are therefore considered to reflect the general consensus within research, policy and advisory regarding the relative risk of P loss to watercourses posed by farmyards.

4.1 Validity of perceived risk

The participants prioritised silage effluent as the highest potential risk factor within the infrastructure category. This response is supported by the conclusions of Gebrehanna et al. (2014) who suggested that silage effluent may contain nutrient concentrations which exceed those of other wastewaters, such as slurry and dairy washings. However, the range in effluent P concentrations observed in the literature vary greatly, and are influenced by dry matter content at the time of ensiling, additives, forage variety etc. In summarizing the literature, Gebrehanna et al. (2014) reported mean TP content of 800 mg L^{-1} based on collation of several studies. However, the fact that silage effluent was ranked so highly in this survey may also reflect a conflation of harm to water quality posed by nutrient content and resulting from high biological oxygen demand (BOD) (± 66,000 mg L^{-1}) and low pH (± 4.3). Elevated BOD concentrations in surface water may be an indicator of point source pollution from silage sources (e.g. Hooda et al., 2000) and is inversely related to macroinvertebrate scores (Hooda et al., 2000; Friberg et al., 2010). Consequently, BOD is a priority metric for overall water quality however, the purpose of the present survey was to ascertain risks associated with nutrient (N and P) loss. The levels of actual risk in the context of nutrients may therefore be lower than reported by respondents.

The high ranking of direct or indirect discharges to the drainage network is supported by recent literature. Moloney et al. (2019) reported elevated dissolved reactive P and water soluble P concentrations in water and sediment in farmyard-connected ditches, relative to those not directly connected, with similar pattern observed in longitudinal river surveys (Harrison et al., 2019; Vero et al., 2019). The presence of direct discharge from a farmyard to surfacewater is regulated under ROI (DAFM, 2016) and NI (DAERA, 2019) agri-environmental legislation. As these are assessed under cross-compliance inspections, the presence of such point source discharges should to be rare relative to more indirect loss pathways.

Runoff from farmyards have an uncertain rainfall dependency (Edwards and Withers, 2008), and concurrently, a variable chemical composition. The moderate risk rating reported herein reflects this ambiguity, limited research, and the influence of site-specific factors.

Duration of housing and compactness of lambing/calving received relatively low estimates of risk and high level of 'Don't know' responses, reflecting their more indirect influence (if any) on nutrient losses. These factors were included as they are an indicator of the risk of nutrient loss as a result of deposition of slurry/manure, feed, and bedding to the farmyard and limit time available for tasks such as yard cleaning. Lambing and calving also often correspond to periods of high rainfall at the start of the calendar year. Their low ranking suggests that allocation of time and money to these elements are unlikely to moderate nutrient losses, although they are important to the optimal functioning of the farm as a whole.

Participation in environmental and quality assurance schemes, and indeed, receipt of basic payment, demands adherence to a baseline standard of yard maintenance and hygiene, and is subject to inspection. The literature is limited regarding the effect of participation in schemes on reductions in farm point sources. Jones et al. (2017) assessed the response of stream biological indicators in headwater stream catchments, coupled with assessment of farm practices (participation in environmental schemes) through a modelling exercises to overcome spatial differences in participation. That study suggested that moderate reductions in nutrient load resulting from participation can be expected, however, the results are likely to be spatially skewed and highly dependent on catchment-specific characteristics such as the position of mitigation options within the landscape, the extent of implementation and trade-offs with other targets.   This is reflected by the modest ranking of these factors, within the management factor category.

Age and education have been shown in various studies to have an influence on farmer's willingness to adopt measures or to participate in agri-environmental schemes (Buckley et al., 2015), which are used here as a proxy for management of yard point sources. In a study in England, Schroeder et al. (2013) identified that the direction of influence (i.e. greater or lesser willingness to participate) of age and education is inconsistent, while Buckley et al. (2015) found age (and off-farm employment) to negatively affect uptake of nutrient management practices. Two opposite hypotheses may be posed. In one scenario, older farmers may be less willing to change entrenched practices than younger farmers (Schroeder et al., 2013). In the other scenario, older farmers may exhibit greater conscientiousness and level of attention to 'housekeeping' tasks. It is not clear which is more representative of Irish and UK farmers as a whole. Age was in the lower quartile in the overall ranking in this study, suggesting that it exerts limited direct control on farmyard losses. Regarding education, Schroeder et al. (2013) found no significant influence of level of education on environmental scheme participation, although they suggest that it may reflect a greater capacity to cope with bureaucratic demands. In the present study, respondents placed education as a moderate control on losses; in other words, farmers with a greater knowledge of nutrient loss controls may be more likely to implement appropriate management strategies. This emphasises the importance of knowledge transfer efforts (receipt of advisory services also ranked highly within the management category).

Frequency of yard cleaning received the highest rank within the management category. Minogue et al. (2015) showed increased N content and BOD in dairy SW collected in tanks with more frequent scraping and washing of yards. This should not be construed as increased nutrient loss; conversely, uncaptured water flowing over these cleaned surfaces can reasonably be expected to carry less contaminants than in the absence of scraping/washing. While studies on the frequency of yard cleaning are limited, Burchill et al. (2019) similarly concluded that more frequent cleaning (either washing or scraping) limited ammonia emissions. Washing and scraping are low-cost mitigation options, requiring only time allocation and limits nutrient loss through both aquatic and gaseous pathways. Reductions in nutrient loss achieved this way may be very preferable compared to expensive infrastructural changes, stock reduction, or reduction of soil P subject to prolonged time lags. Area of the hard standing, layout of the farmyard, and quality of livestock handling facilities all received low ranking within the infrastructure category. These factors may indirectly influence the ability to effectively clean the hard standing.

4.2 Management of risk factors

Within this section we discuss potential mitigation approaches for the runoff, management and infrastructure categories While each of the 27 factors include in the survey have a potential impact we focus on those factors that were identified by respondents as of the greatest risk (risk weighting of > 7.2).

Mitigation of these risks will be as a result of policy responses in the form of regulation, financial incentive or investment, and advice. These three solutions do not align with the risk factor categories, but rather elements of all three will be required to achieve the desired mitigation on a case-by-case basis. Regulatory approaches may include prohibition of certain activities or the establishment of construction standards. Present examples of this include the ban on storage of silage bales within 10 m of a watercourse or the specification of slurry storage facilities. However, not all risk factors may be legislated. For example, factors related to the timing and amount of rainfall cannot be addressed in this way. Management and infrastructure factors could be ameliorated via financial incentives or grant aid, in the latter case. For example, changes to farmyard infrastructure has been addressed previously via the Targeted Agriculture Modernisation Schemes (TAMS) within the ROI, although this funding did not specifically aim to address runoff issues. Future iterations of this or similar schemes could be tailored to support source and pathway mitigation measures. Advisory efforts should be targeted towards changing management practices and communicating the environmental aspects of farmyard management. Considering that infrastructure and educational programs can be costed and that recommendations regarding the hourly wage for farm workers are available, cost-benefit analysis of farmyard mitigation measures could be developed based on risk ratings. Such estimates would provide a guide for policymakers as to the investment or supports required and most judicious use of available supports.

Regarding education, there is a need for tailored training in pollution prevention measures first of the advisors, and through them, the farming community. This has been addressed within the Agricultural Sustainability Support and Advisory Program in ROI (Meehan, 2019) who work within 190 Priority Areas for Action throughout the country, but expansion to the wider advisory group would improve the breadth of knowledge transfer. Buckley et al. (2015) found that contact with farm advisors and participation in advisory-led discussion groups had a highly significant positive correlation with farmer willingness to adopt best management practices.

The infrastructure category included the overall most highly ranked factors, collection of silage effluent, slurry storage capacity and condition of the silage pit. Infrastructure factors have relatively short associated time lags. Improvements to these elements will have an immediate effect in reducing loading/losses, as opposed to reduction in soil legacy P, which is associated with prolonged and uncertain decline in soil phosphorus indices (Schulte et al., 2010). As farmyards were primarily constructed for ease of animal handling or in many instances, with limited forward planning, current yard infrastructure in ROI and the UK may not be in an optimal configuration for minimising the risks of nutrient loss. Despite this, adaptation of existing infrastructure (for example, repair of damaged or old storage or hardstanding) may improve the overall function and safety of the farmyard. Addition of entirely new infrastructure such as larger slurry storage, may already be desirable in light of national farm expansion, intensification, or sustainability targets (Dept. of Agriculture, Food and the Marine, 2015, Bos et al., 2013). However, such capital investment could be prohibitively expensive in marginally profitable enterprises. In either scenario, changes or addition to yard infrastructure presents as a financial issue.

Some Runoff factors are wholly uncontrollable, e.g. average annual rainfall and number of rainfall days. Others may be difficult or impossible to influence due to fixed landscape characteristics (distance and slope to watercourse). Efforts should therefore be focussed upon those factors which can be modified. Direct discharge to watercourses could be redirected using guttering within the farmyard itself, and controlled routing of 'clean' or soiled runoff to soiled water tanks or the farmyard outlet, as appropriate. This would require first a clear understanding of what constitutes clean and soiled runoff by farmers and advisors, and secondly, a consistent classification of these in legislation. Research into the connectivity and behaviour of farm ditches showed that a low proportion of the overall ditch network is directly connected to farmyards (category 1 ditches - av. 13%) (Moloney et al., 2019). However, in highly connected systems (in which farmyard ditches are contiguous with the wider drainage network and discharge into a watercourse), a transport pathway is provided. Engineered mitigation measures to slow the flow of water and allow deposition of particulates (e.g. sediment traps, vegetated ditches – Dolinger et al., 2015) or attenuation/treatment (e.g. denitrifying bioreactors – Schipper et al., 2010) could be positioned at yard outlets in order to disrupt this pathway and reduce overall loads reaching the watercourse, without imposing upon potentially utilisable agricultural area. Maintenance of these potential solutions (e.g. by dredging accumulated sediment in traps) would be essential.

Although management factors were estimated to be a lower risk than the other categories, they may present a relatively inexpensive means to reduce nutrient loading of the yard, and hence, lower overall losses. Cleaning of the yard (scraping, hosing, sweeping, etc.) removes nutrient sources such as manure, urine, feed, or silage from areas which are vulnerable to runoff, and allows them to be safely stored in FYM or slurry storage. This is likely one of the easiest measures to implement, and moreover, is the most highly rated factor within this category. However, it may be that other indirect controls such as participation in off-farm employment will limit time available for farm management and may lead to prioritization of those duties which more directly relate to profitability. The practices and tools required to reduce loading of the yard surface are neither expensive nor complex but can only be implemented if time is available. This might be appealing compared to measures that require capital investment or that constrain production.

4.3 Concurrence between employment groups

Agreement between the three employment groups in their ranking of individual factors was high, with only 8 out 29 individual factors differing significantly. Complete consensus regarding runoff factors suggests that the strong control of hydrology on nutrient losses is well established and understood amongst stakeholder groups. Within the management category, the advisory group ranked duration of housing and calving/lambing lower than either the research or policy groups. Conceptually, a longer period of high intensity activity and animal presence in the farmyard (as opposed to in the field) could result in greater loading of the yard with manure and general untidiness. There was greater discrepancy between groups regarding factors in the infrastructure category with significant disagreement in half of the individual factors. This lack of consensus suggests that communication between these key groups is needed to establish the priorities for farmyard management.

5. Concluding Remarks

In this paper the prioritization of risk factors for P loss from farmyards based on expert understanding of three risk categories was collated and assessed. In general, there is good consensus between researchers, policy makers and farm advisory regarding the risks posed by various factors within the farmyard for P loss. Although each cohort assigned high weightings to infrastructure factors, there was a tendency for researchers to weight these factors lower than the other two cohorts. Overall, factors within the infrastructure category were most highly ranked, followed by runoff and finally management factors. Factors relating to silage effluent and slurry storage were assigned the greatest risk. Although management factors were rated as the lowest risk factor, changes to these activities may be the most practical and inexpensive to implement. Annual rainfall and number of rainfall days cannot be moderated, and infrastructural changes may be constrained by financial limitations.

This study has provided insights based on expert opinion on the risks posed by runoff, management and infrastructure factors on farmyards. However, empirical data is required to in order to quantify the contribution that losses due to these factors makes to the overall nutrient load from agricultural to waterbodies. Quantification of these losses will enable assessment of the cost effectiveness of mitigating farmyard losses in comparison to losses from other agriculture sources such a soil P and manure application.

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References

Aitken, M.N. 2003. Impact of agricultural practices and river catchment characteristics on river and bathing water quality. *Water Science and Technology*. 48(10): 217–224

Bos, J.F.F.P., Smit, A.L. and Schröder, J.J. 2013. Is agricultural intensification in The Netherlands running up to its limits? *NJAS – Wageningen Journal of Life Sciences*. 66: 65-73

Bowes, M.J., Smith, J.T., Jarvie, H.P. and Neal, C. 2008. Modelling of phosphorus inputs to rivers from diffuse and point sources. *Science of the Total Environment*. 395: 125-138

Brewer, A.J., Cumby, T.R. and Dimmock, S.J. 1999. Dirty water from dairy farms II: Treatment and disposal options. *Bioresource Technology*. 67: 161-169

Buckley, C., Howley, P. and Jordan, P., 2015. The role of differing farming motivations on the adoption of nutrient management practices. *International Journal of Agricultural Management*. 4(4): 152-162.

Burchill, W., Reville, F., Misselbrook, T.H., O'Connell, C. and Lanigan, G.J. 2019. Ammonia emissions and mitigation from a concrete yard used by cattle. *Biosystems Engineering*. 184: 181-189

Cassidy, R., Doody, D.G. and Watson, C.J. 2017. Impact of legacy soil phosphorus on losses in drainage and overland flow from grazed grassland soils. *Science of the Total Environment*. 575(1): 474-484

Davison, P.S., Withers, P.J.A., Lord, E.I., Betson, M.J. and Strömquist, J. 2008. PSYCHIC: A process-based model of phosphorus and sediment mobilisation and delivery within agricultural catchments. Part 1: Model description and parameterisation. *Journal of Hydrology*. 350(3-4): 290-302

Daxini, A., O'Donoghue, C., Ryan, M., Buckley, C., Barnes, A.P. and Daly, K. 2018. Which factors influence farmers' intentions to adopt nutrient management planning? *Journal of Environmental Management.* 224: 350-360

Department of Agriculture, Environment and Rural Affairs. 2019. Code of good agricultural practice for the prevention of pollution of water, air and soil.

Department of Agriculture, Food and the Marine. 2015. FoodWise 2025.

Department of Agriculture, Food and the Marine. 2016. Exploratory handbook for Cross Compliance Requirements.

Dollinger, J., Dagès, C., Bailly, J-S., Lagacherie, P. and Voltz, M. 2015. Managing ditches for agroecological engineering of landscape: A review. *Agronomy for Sustainable Development*. 35:999-1020

Edwards, A.C. and Hooda, P.S. 2008. Farmyard point discharges and their influence on nutrient and labile carbon dynamics in a second order stream draining through a dairy unit. *Journal of Environmental Management*. 87: 591-599

Edwards, A.C. and Withers, P.J.A. 2008. Transport and delivery of suspended solids, nitrogen and phosphorus from various sources to freshwaters in the UK. *Journal of Hydrology*. 350(3-4): 144-153

Edwards, A.C., Kay, D., McDonald, A.T., Francis, C., Watkins, J., Wilkinson, J.R. and Wyer, M.D. 2008. Farmyards, an overlooked source for highly contaminated runoff. *Journal of Environmental Management.* 87: 551-559

European Commission. 2000. Council Directive (2000/60/EC). EC Directive of the European Parliament and of the Council establishing a framework for community action in the field of water policy.

European Union. 2017. Statutory Instrument. SI 607/2017 Good agricultural practice for protection of waters regulations 2017

Fish, R., Winter, M., Oliver, D.M., Chadwick, D., Selfa, T., Heathwaite, A.L. and Hodgson, C. 2009. Unruly pathogens: eliciting values for environmental risk in the context of heterogeneous expert knowledge. *Environmental Science and Policy*. 12: 281-296

Friberg, N., Skriver, J., Larsen, S.E., Pedersen, M.L. and Buffagni, A. 2010. Stream macroinvertebrate occurrence along gradients in organic pollution and eutrophication. *Freshwater Biology*. 55: 1405-1419

Gebrehanna, M.M., Gordon, R.J., Madani, A., Vanderzaag, A.C. and Wood, J.D. 2014. Silage effluent management: A review. *Journal of Environmental Management*. 143: 113-122

Gedikoglu, H., McCann, L. and Artz, G. 2016. Off-Farm employment effects on adoption of nutrient management practices. *Agricultural and Resource Economics Review*. 40(2): 293-306

Harrison, S., McAree, C., Mulville, W. and Sullivan, T. 2019. The problem of agricultural 'diffuse' pollution: Getting to the point. *Science of the Total Environment*. 677: 700-717

Hemming, V., Burgman, M.A., Hanea, A.M., McBride, M.F. and Wintle, B.C. 2018. A practical guide to structured expert elicitation using the IDEA protocol. *Methods in Ecology and Evolution*. 9: 169-180

Hooda, P.S., Moynagh, M., Svoboda, I.F. and Miller, A. 2000. Macroinvertebrates as bioindicators of water pollution in streams draining dairy farming catchments. *Chemistry and Ecology*. 17: 17-30

Jones, J.I., Murphy, J.F., Anthony, S.G., Arnold, A., Blackburn, J.H., Duerdoth, C.P., Hawczak, A., Hughes, G.O., Pretty, J.L., Scarlett, P.M., Gooday, R.D., Zhang, Y.S., Fawcett, L.E., Simpson, D., Turner, A.W.B., Naden, P.S. and Skates, J. 2017. Do agri-environment schemes result in improved water quality? *Journal of Applied Ecology*. 54: 537-546

Lennox, S.D., Foy, R.H., Smith, R.V., Unsworth, E.F. and Smyth, D.R. 1998. A comparison of agricultural water pollution incidents in Northern Ireland with those in England and Wales. *Water Resources*. 32(3): 649-656

Martinez-Suller, L., Provolo, G., Carton, O.T., Brennan, D., Kirwan, L. and Richards, K.G. 2010. The composition of dirty water on dairy farms in Ireland. *Irish Journal of Agri-Food Research*. 49: 67-80

Meehan, N. 2019. Agricultural sustainability support and advisory programme (ASSAP). Interim report #1 2018 – 2019. December 31st 2019

Minogue, D., French, P., Bolger, T. and Murphy, P.N.C. 2015. Characterisation of dairy soiled water in a survey of 60 Irish dairy farms. *Irish Journal of Agricultural and Food Research*. 54(1): 1-16

Mockler, E., Deakin, J., Archbold, M., Gill, L., Daly, D. and Bruen, M. 2017. Sources of nitrogen and phosphorus emissions to Irish rivers and coastal waters: Estimates from a nutrient load apportionment framework. *Science of the Total Environment*. 601-602: 326-339

Moloney, T., Fenton, O. and Daly, K. 2019. Ranking connectivity risk for phosphorus loss along agricultural drainage ditches. *Science of the Total Environment*. doi.org/10.1016/j.scitotenv.2019.134556

O'Hagan, A. 2018. Expert knowledge elicitation: subjective but scientific. *The American Statistician*. 73: 69-81

Oliver, D.M., Fish, R.D., Hodgson, C.J., Heathwaite, A.L., Chadwick, D.R. and Winter, M. 2009. A cross-disciplinary toolkit to assess the risk of faecal indicator loss from grassland farm systems to surface waters. *Agriculture, Ecosystems and Environment*. 129: 401-412

Richards, S., Paterson, E., Withers, P.T.S. and Sutter, M. 2016. Septic tank discharges as multipollutant hotspots in catchments. *Science of the Total Environment*. 542: 854-863

Schipper, L.A., Robertson, W.D., Gold, A.J., Jaynes, D.B. and Cameron, S.C. 2010. Denitrifying bioreactors – An approach for reducing nitrate loads to receiving waters. *Ecological Engineering*. 36(11): 1532-1543

Schroeder, L.A., Isselstein, J., Chaplin, S. and Peel, S. 2013. Agri-environment schemes: Farmers' acceptance and perception of potential 'Payment by results' in grassland. A case-study in England. *Land Use Policy*. 32: 134-144

Schulte, R.P.O., Melland, A.R., Fenton, O., Herlihy, M., Richards, K. and Jordan, P. 2010. Modelling soil phosphorus decline: Expectations of water framework directive policies. *Environmental Science and Policy*. 13: 472-484

Sharpley, A., Beegle, D., Bolster, C., Good, L., Joern, B., Ketterings, Q., Lory, J., Mikkelsen, R., Osmond, D. and Vadas, P., 2012. Phosphorus indices: Why we need to take stock of how we are doing. Journal of Environmental Quality. 41(6): 1711-1719.

StataCorp. 2017. *Stata Statistical Software: Release 15*. College Station, TX: StataCorp LLC.

Vero, S.E., Daly, K., McDonald, N.T., Leach, S., Sherriff, S.C. and Mellander, P-E. 2019. Sources and mechanisms of low-flow river phosphorus elevations: A repeated synoptic survey approach. *Water*. 11: 1497