Environmental RTDI Programme 2000–2006

EUTROPHICATION FROM AGRICULTURAL SOURCES – Relating Catchment Characteristics to Phosphorus Concentrations in Irish Rivers

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Final Report

Prepared for the Environmental Protection Agency

by

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WATER QUALITY

The Water Quality Section of the Environmental RTDI Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in this area. The reports in this series are intended as contributions to the necessary debate on water quality and the environment.

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1 Introduction

Phosphorus (P) transport from land to water has been the focus of models at plot, field and catchment scales in an attempt to elucidate the hydrological, chemical and biological processes involved. However, under the Water Framework Directive (WFD) (Council of European Communities, 2000) there is a greater need for P models and risk assessment that use available data and can provide a predictive tool to environmental managers in support of practical solutions towards programmes of measures.

Modelling diffuse sources of P has embraced hydrological pathways and sources of P from land to water. Lemunyon and Gilbert (1993) provide a conceptual model of P transfer from soil to waterways, which incorporates widely held diffuse pollution precepts to establish a framework of key components based on field and catchment studies. In their model, Lemunyon and Gilbert (1993) recognise that water movement is the transport agent for P transfer to water whilst acknowledging the influence of soil and agronomic practices as the source compartment. This conceptual approach helps to bring recognised factors involved in P loss into balance without emphasis being placed on a single parameter.

The main objective of this research was to relate water quality data to catchment characteristics and to derive a model that describes or predicts P levels in Irish surface waters. The work carried out here collated widely used GIS data sets that describe land use, soil type, stocking densities, fertiliser P use and soil P levels. These data sets originated from a variety of sources and some are (at this time) incomplete in terms of national coverage for Ireland. In addition to the data already mentioned, the project built some additional data sets, namely, a digital terrain model to extract topographical wetness indices that might describe wet areas within a catchment, based on slope and drainage areas, and a database on soil P chemistry that describes differences in P desorption between grassland soil types. The data sets on soil type, soil P level, fertiliser P use and stocking density were initially extracted from a GIS into categories. These categories were weighted according to potential risk and then summed over each catchment to give an area-weighted index, or single variable, that describes soil type, soil P, fertiliser P and stocking density in each catchment. A more detailed explanation of how catchment indices were derived is presented in the Methods section of this report.

2 Methods

This section details the sources and types of data that were collected for the project, in addition to describing how the range of soil types were weighted against each other based on measured data on P desorption.

2.1 Water Quality

Water quality (WQ) and stream flow data were collected from large-scale catchment studies across the country, namely, the Derg–Ree Catchment Monitoring and Management System which encompassed the River Shannon System, and the Three Rivers Project, from which the Rivers Boyne and Suir data were provided for this present study. These projects provided WQ and daily mean flow (DMF) data for the years 1998–2001 and monitoring stations combined from the two projects to form an original database of 45,000 records of WQ parameters and DMF. Water quality sampling stations were selected from this database on the basis that a point source was not known to cause an influence. Downstream stations were chosen on streams and rivers where appropriate (i.e. not point source affected) and 176 stations were selected from the combined data sets. The water quality data were averaged over the 4-year monitoring period and an average for all years calculated. The P concentrations (mg/l) in surface water were expressed both as Ortho-P (unfiltered) and as flow-weighted Ortho-P (unfiltered) denoted here as Ortho-P and fwOrtho-P, respectively. The number of sub-catchments was further reduced owing to the lack of available flow data at some stations and when sub-catchments with 100% Spatial Analysis Group (SAG) soils coverage were selected for the analysis, this reduced the final number of sub-catchments to 84. Appendix A presents the list of 84 stations selected for this study and their location is shown on the map in Fig. 2.1.

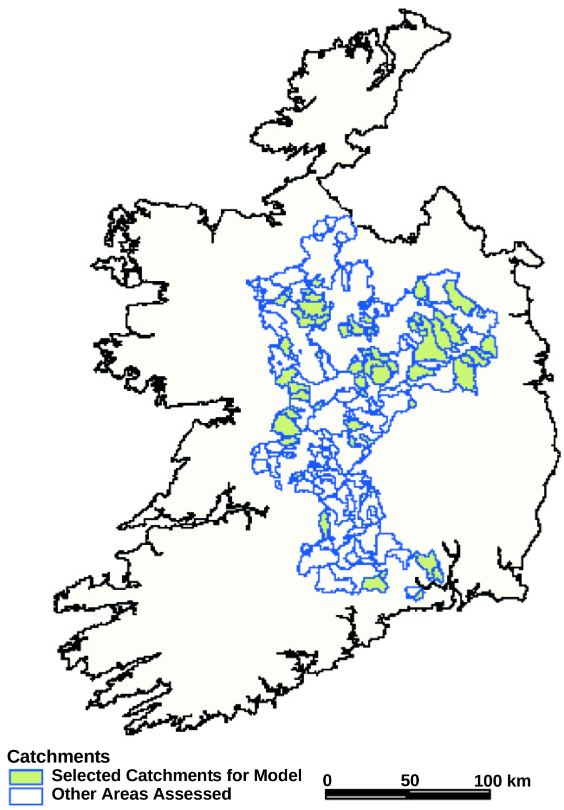

Figure 2.1. The location of sub-catchments where data were collected and those areas included in the analysis with full SAG soil coverage.

2.2 Soil Type

Soil types in the sub-catchments were described for two distinctly different purposes. Firstly, to describe the P desorption risk of soils based on differences between soils based on chemistry, and secondly, to describe the run-off risk potential of soils based on soil-survey information and topographical wetness indices derived from a digital elevation map (DEM).

The National Soil Survey in Ireland provides two data sets on soils, one with complete national coverage known as the General Soil Map of Ireland (GSM), and the other which was not completed for the whole country but exists for 13 counties (or 44% of the country). These county surveys are detailed soil surveys that provide descriptions of soil series and phases at a detailed scale, compared to the GSM (Gardiner and Radford, 1980) which maps soil associations as principal soil groups and their associated soils at a general scale. Detailed and general soil maps include great soil groups such as gleys, brown earths, grey brown podzolics, acid brown earths, peat, complexes, etc. A third soils database is currently being completed by the SAG in Teagasc, whereby soils are delineated into categories based on parent material (acidic or basic), depth (shallow, deep) and drainage (well drained, poorly drained). Soils are placed into broad categories and described as acidic mineral, basic mineral and categorised by depth and drainage classes for each. These soil-type data sets that currently exist for Ireland were utilised in this work to describe soils in terms of chemistry and run-off risk.

2.2.1 Soil phosphorus desorption risk

The differences between soil types in terms of potential risk of P loss by desorption were examined on a range of soils so that soils could be risk ranked and quantified as a variable for the model. A study of P sorption and desorption characteristics of Irish soil types was carried out over a range of soil types across six mini-catchments, and the main findings are summarised in the results section of this report. The objective of the study was to rank soil types in terms of desorption risk and to apply the risk factors to a GIS database of soils in Ireland. The Teagasc SAG, currently mapping soil classifications on a county basis for use by Irish agencies under the WFD, provided a database of soils. Broadly, this database delineates soils derived from mainly acidic and basic parent material, which coincided with the findings from the sorption and desorption studies where mineral soils displayed significant differences based on soil pH and/or catchment type (calcareous or non-calcareous). For the purposes of this project, the acidic and basic classifications of mineral soils in the SAG data were grouped into soil classes to represent non-calcareous and calcareous mineral soils. The SAG soil classifications that represented all non-calcareous and calcareous mineral soils in sub-catchments were denoted Amin and Bmin, respectively, and are presented in Table 2.1. Peat soils are represented in the SAG data and are denoted by the term Peat in this work.

2.2.2 Soil run-off risk

The GSM records 44 soil associations derived from great soil groups such as podzols, brown podzolics, brown earths, grey brown podzolics, blanket peats, gleys, basin peats, rendzinas, regosols and lithosols. Each soil association within the GSM represents a combination of great soil groups and the bulletin delineates the percentage contribution of a principal soil type and other associated soils. To describe the run-off risk potential of soil associations from the GSM, the percentage gley in each soil association was considered the delineating factor (Diamond, S., Teagasc, personal communication, 2004). Threshold levels were decided upon and soil associations divided into run-off risk categories and weighted against each other in terms of potential run-off risk. The threshold percentages and weights are presented in Table 2.2 and the weightings were derived subjectively and are not based on measured data. The percentage of each run-off risk class in each sub-catchment was extracted from a GIS. In addition, multiplying the area of each category by its assigned weight to generate an area-weighted run-off risk index (RRI) for each sub-catchment (Eqn 1) further reduced these data to a single variable, representing a soil transport factor. Figure 2.2 presents a map of the study GSM soils from the study areas categorised into run-off risk.

$$\text{SUM}(1 \times (\text{Area in RR1}) + 2 \times (\text{Area in RR2}) + 3 \times (\text{Area in RR3}) + 4 \times (\text{Area in RR4})) / \text{Total Catchment Area} \quad (1)$$

2.2.3 Topographic wetness index

Topographic Wetness Index (TWI) is a simple secondary attribute of a Digital Terrain Model (DTM) that is readily derived in a GIS. As it can identify areas which are relatively flat and have large up-slope flow contribution areas, it serves to indicate the most likely locations where saturation-excess overland flow will occur. Alone it will only provide a ‘steady state’ topographic indicator or context for the potential distribution of saturation-excess overland flow. Determination of specific saturation-excess overland flow events would also require time-variant information on antecedent soil moisture conditions, the hydrologic properties of specific soils and the duration and intensity of rainfall events.

TWI is normally computed using grid format raster data within the GIS. For each cell in the grid information on the local slope (i.e. land surface) and the up-slope contribution area (i.e. catchment area contributing flow to the cell) are integrated as:

$$\text{TWI} = \ln(As / \tan B) \quad (2)$$

where As is the contributing catchment in metres squared and B is the slope measured in degrees.

Metrics extracted from the national DTM (Preston and Mills, 2002) were used to calculate the TWI. Primary DTM derivatives on the landform slope, flow direction on the landforms and concentration of flow or flow accumulation (Jenson and Domingue, 1988) were determined using functions within the ESRI ArcView GIS with the Spatial Analyst extension.

Table 2.1. Spatial Analysis Group soil categories.

IFS soil	IFS attribute	Included great soil groups	Abbreviations for this study
Deep well-drained mineral			
Derived from mainly acidic parent materials	AminDW	Acid brown earths Brown podzolics	Amin
Derived from mainly basic parent materials	BminDW	Grey brown podzolics Brown earths (medium–high base status)	Bmin
Shallow well-drained mineral			
Derived from mainly acidic parent materials	AminSW	Lithosols Regosols	Amin
Derived from mainly basic parent materials	BminSW	Rendzinas Lithosols	Bmin
Deep poorly drained mineral			
Derived from mainly acidic parent materials	AminPD	Surface water gleys Groundwater gleys	AminPD
Derived from mainly basic parent materials	BminPD	Surface water gleys Groundwater gleys	BminPD
Poorly drained mineral soils with peaty topsoil			
Derived from mainly acidic parent materials	AminPDPT	Peaty gleys	AminPG
Derived from mainly basic parent materials	BminPDPT	Peaty gleys	BminPG
Podzolised soils with/without peaty topsoil			
Mineral podzolised soils with possible peaty topsoil and occasional iron pan layer	PodPT	Podzols Podzols (peaty)	Podzols
Peats			
Raised			
Raised bog	RsPT	Basin peats	Peat
Raised bog (cutaway/cutover)	Cut	Basin peats	Peat
Fen			
Fen peat	FenPT	Basin peats	Peat
Blanket			
Mountain	BktPt	Blanket peats	Peat
Lowland	BktPt	Blanket peats	Peat
Blanket peat (cutaway/cutover)	BktPt_cut	Blanket peats	Peat

Table 2.2. Run-off risk categories by percentage gley in GSM soil associations and assigned weights.

Run-off risk class	% Gley in soil association	Soil associations from GSM	Risk weights
RR1	5–10	16,17, 30, 31, 32, 33, 35	1
RR2	15–25	6, 8, 9, 10, 12, 13, 14, 15, 18, 19, 20, 28, 29, 34, 36, 37, 38	2
RR3	50	25	3
RR4	>75	1, 2, 4, 7, 11, 21, 22, 23, 26, 27, 39, 40, 41, 42, 43	4

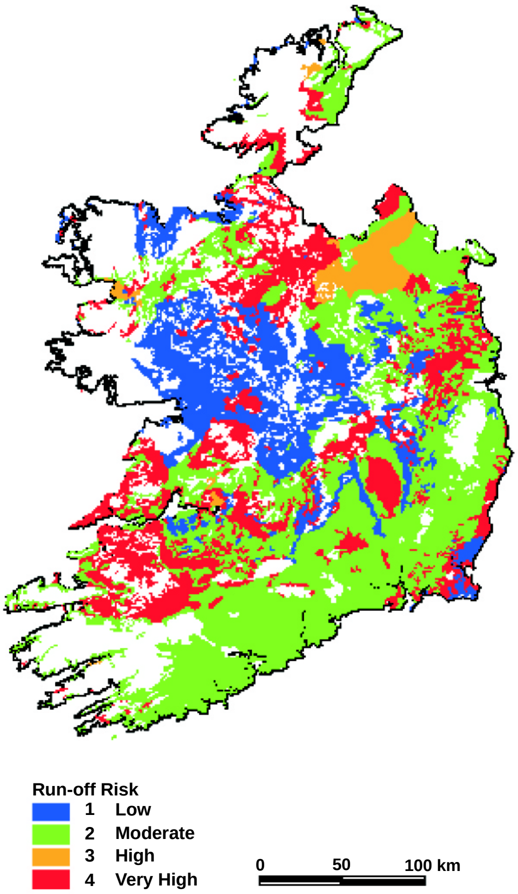

Figure 2.2. The General Soil Map of Ireland reclassified into run-off risk categories based on the percentage gley in each soil association.

In the absence of specific hydrologic information, a comparison of the TWI between different catchments serves to indicate the relative distribution of topographic conditions which may lead to saturation-excess overland flow. In this study, an arbitrary value of TWI ≥12 was determined as an appropriate threshold to indicate the relative occurrence of saturation-excess prone conditions based on topography. The condition where TWI ≥12 occurs in each of the 84 catchments and ranges in value from 4% to 63% of the catchment area. As such, it may be a reasonable indicator of the relative abundance of conditions leading to saturation-excess overland flow within the catchments.

Two statistics based on the TWI were developed:

1. the proportion of each catchment area where TWI ≥12
2. the proportion of each catchment where high run-off risk soils (RR3 and RR4) and TWI ≥12 occur in conjunction.

2.3 Land Cover

National data on land use in Ireland were provided by the EPA from a data set established by the EU on the Co-ORdination of INformation on the Environment (CORINE), from which national coverage of land-cover data is provided. The data have a minimum mapping unit of 25 ha at a 1:1,000,000 scale and provide 44 classes of land cover interpreted from satellite images recorded and updated for 2000. For the purposes of this project, the CORINE classes extracted for each sub-catchment were Improved Pasture, Unimproved Pasture, Arable, Semi-natural and Peat.

The Habitats Indicators Map produced by the SAG within Teagasc provided a second source of land-cover data for the project. Whilst the principal purpose of the Habitats Map is to indicate the distribution of habitats throughout Ireland, it provides additional classifications for grassland that are not provided by CORINE, namely, wet and dry grasslands in a peat setting (denoted here are GrassPeat). The thematic classes from the Habitats Map used in this project were Dry Grassland, Wet Grassland and GrassPeat. The SAG is generating these data on a county basis and, whilst national coverage is not yet finalised, completed counties relevant to the list of sub-catchments in this work were provided. This left some areas within sub-catchments without coverage of the selected habitat classes.

2.4 Phosphorus Loading

2.4.1 Livestock unit density and fertiliser phosphorus use

Phosphorus loading was represented by three sources of GIS data, namely, livestock unit density (LUD), fertiliser P use and soil P levels. Livestock unit density was provided by the Department of Agriculture on a district electoral division (DED) basis. These data represent the number of animals licensed that includes cattle, sheep and pigs and are based on an average of five census dates in 2003. The fertiliser use data were provided by the Central Statistics Office (CSO) and Teagasc and are based on fertiliser sales on a DED basis, and reduced to three categories. These data were reduced into categories and the area in each sub-catchment within each category was extracted. The percentage of the sub-catchment area within the categories was calculated.

Each LUD category and fertiliser P use was weighted relative to each other in terms of potential risk of P loss. In the absence of any measured data that quantify the relative risk of various stocking rates on P loss from soils and fertiliser P use, the weights used here are arbitrary. The categories and weights are presented in Tables 2.3 and 2.4 for LUD and fertiliser P data, respectively, and these were not based on measured data but on a subjective basis. Multiplying the area of each category by the assigned weight, summing over the four LUD categories, and dividing by the total sub-catchment area derived an area-weighted index for LUD. This procedure was repeated using the fertiliser P use categories to derive a similar index for each sub-catchment. An area-weighted LUD index (LUDI) and fertiliser P index (FPI) were generated using the same method presented for RRI.

2.4.2 *Soil test phosphorus level*

Creating an index, or single variable, to represent each on a catchment basis further reduced categories of LUD and fertiliser P and a similar methodology was applied to soil P data available for sub-catchments. A national GIS layer of soil test P (STP) values created for a previous modelling study (Daly *et al*., 2002) was used again in this present study. These data originated from a Teagasc database of 50,000 records of client soil test results from 1996. The data were geocoded, linking each client address to an existing GIS database of 1200 towns and villages. Although the STP data used were based on 1996 data and the geocoding method does not explicitly record the exact farm location, the database was used in this present study, despite these issues, because it remains the only national GIS data set on STP levels for Ireland. STP values were extracted for each sub-catchment area and categorised into three classes. These classes were chosen to represent some similarity to the agronomic indices used in Ireland for fertiliser P recommendations, where STP >10 mg/l is the value set at which no agronomic response to fertiliser occurs. Each class was assigned a weight relative to the risk of P loss and based on measured field data that recorded dissolved reactive P in overland flow from sites in Ireland (Daly *et al*., 2002). The categories and weights assigned to the STP database are presented in Table 2.5. An area-weighted soil P index (SPI) was generated using the same method as presented in Eqn 1 for RRI. A map of soil P categories is presented in Figure 2.3.

Table 2.3. Livestock unit density categories based on LUD/ha and assigned weights.

LUD class	LUD/ha	Risk weights
1	0–1.5	1
2	1.5–2.0	4
3	>2.0	8

Table 2.4. Fertiliser use categories based on fertiliser P use/ha and assigned weights.

Fertiliser use class	Fertiliser P use/ha	Risk weights
1	0–9	1
2	9–16	2
3	>16	10

Table 2.5. Soil test P categories based on Morgan's P values and assigned weights.

Soil test P class	Morgan's P values mg/l	Risk weights
SP1	0–6	1
SP2	6–10	4
SP3	>10	10

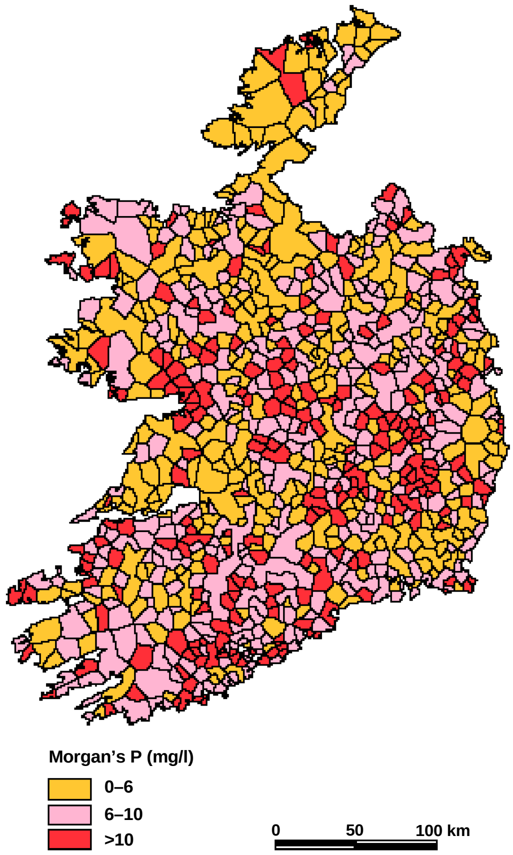

Figure 2.3. A map of Morgan's P categories on a DED basis applied to soil test P data used in Daly *et al.*, 2002.

3 Results and Discussion

3.1 Phosphorus Sorption and Desorption in Soil Types

The following results are summarised from Daly and Styles (2005) and were used to derive a desorption weighting for soils that can be applied to soil classifications from the SAG soils map. In this case, desorption weightings were based on relative rates of desorption in different soil categories.

Seventy soil samples were collected across six mini-catchments in 2001–2002, and soils ranged in properties such as %OM and pH over a range of Morgan's P values that included mineral and peat soils. Soil samples were collected and returned to Johnstown Castle laboratories for analysis using P sorption isotherms (Langmuir model) and P desorption using the iron-oxide paper strip test (FeO-P). Repeat sampling of four out of the six mini-catchments was conducted over 2004–2005 to collect mineral soils with a wider range of Morgan's P levels in an attempt to elucidate some of the findings from the earlier results.

3.1.1 Peat soils

Phosphorus sorption in peat soils did not conform to the Langmuir sorption model indicating that chemical sorption in peat soils could be inhibited by large amounts of organic matter. The lack of sorption capability in these soils indicates potential vulnerability to P loss if fertiliser and manure P is applied outside the growing season. Phosphorus desorption in these soils was significantly lower compared to the mineral soils and this was attributed to their inability to chemically bind P and build up P pools and reserves through a lack of sorption capability. Where P reserves do not exist this provides little opportunity for desorption to solution to occur and lower desorption rates from these soils, compared to mineral soils, is more likely due to lack of P storage and a build-up of P reserves that can become soluble during overland flow. For the purposes of this study, soils are risk ranked based on desorption rates over similar ranges of STP and sorption capabilities. Thus, mineral soils with high sorption capacities and desorption rates were ranked as highest risk whilst peat soils were ranked as lowest risk.

3.1.2 Mineral soils

There were statistically significant differences in P sorption among mineral soils such that non-calcareous soils had significantly higher sorption capacities and binding energies than calcareous soils. Thus, mineral soils were split into two groups, calcareous and non-calcareous, depending on pH. However, differences in desorption between these two groups only became evident at high STP values (Morgan's P).

When the desorption experiments were repeated over a wider range of Morgan's P levels, a difference in desorption was found at high soil P levels, such that desorption (FeO-P) per unit Morgan's P was significantly lower in calcareous soils than in non-calcareous soils. In the statistical analyses of the desorption data (ANCOVA), an interaction term between Morgan's P and pH proved to be significant with FeO-P, indicating that the relationship between FeO-P and Morgan's P is different for non-calcareous and calcareous soils. Visual inspection of this FeO-P–Morgan's P relationship (Fig. 3.1) indicated that it took on a different (non-linear) form in calcareous soils from the linear form displayed in non-calcareous soils. Figure 3.1 also indicates that the real difference in P desorption between non-calcareous and calcareous soils occurs at high Morgan's P levels, above those recommended by Teagasc. The data from the 2001 study were combined with the additional soil sampling data for 2004 and relationships for non-calcareous, calcareous and peat soils are plotted in Fig. 3.2. The lower R^2 values in these plots may be due to the difference in sampling dates (2001/2002 and 2004/2005); however, the differences between the three soil groups remains. In this work, non-calcareous soils displayed the highest sorption capacities and the highest desorption rates compared to calcareous mineral soils. High sorption capacities (with high Al and Fe) indicate a greater potential for P storage and build-up of P reserves, presenting a greater likelihood of P release to water at high STP levels during periods of overland flow. Gburek *et al.* (2000) suggest that most soil P losses originate from relatively small critical source areas where high soil P levels coincide with high hydrological connectivity. Data from this study showed that high Morgan's P soils from non-calcareous soils desorbed more P than high Morgan's P soils from

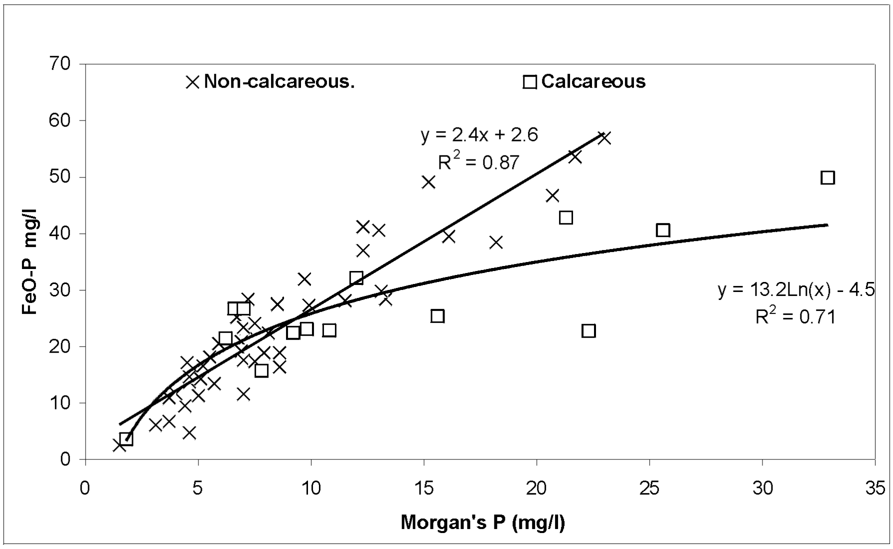

Figure 3.1. The relationship between P desorption and soil test P (Morgan's P) for non-calcareous and calcareous soils sampled in 2004/2005 from four of the original six mini-catchments in Daly and Styles (2005).

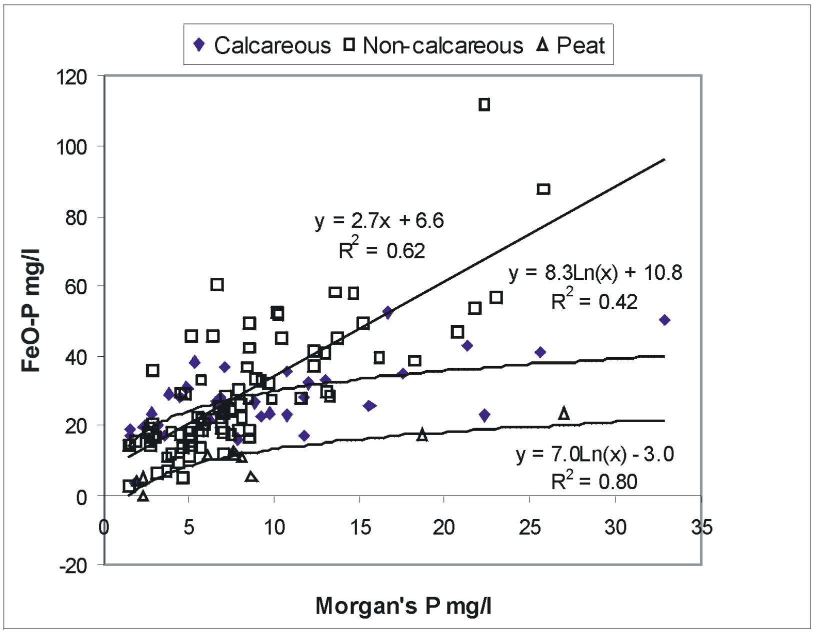

Figure 3.2. The relationship between P desorption and soil test P (Morgan's P) for calcareous, non-calcareous and peat soils.

calcareous soils, suggesting more intense critical source areas in non-calcareous soils than in calcareous soils.

The regression equations were used to predict desorption over a range of Morgan's P values (from 3 to 35 mg/l) in non-calcareous, calcareous and peat soils. Desorption in non-calcareous and calcareous soils was expressed relative to lowest desorption values in peat soils and calculated as a ratio to generate an index (average ratio over the range of Morgan's P values) that could be used to weight each soil group in terms of risk of P loss by desorption. These weights were applied to the SAG soils data and are presented in Table 3.1. A map of desorption categories applied to SAG soil classifications is presented in Figure 3.3.

Table 3.1. Phosphorus desorption categories in soils and assigned weights to SAG soils.

Soil categories	SAG categories	Risk weights
Non-calcareous mineral	Amin+AminPD	3.2
Calcareous mineral	Bmin+BminPD	1.9
Peat	Peat+Peaty gleys	1

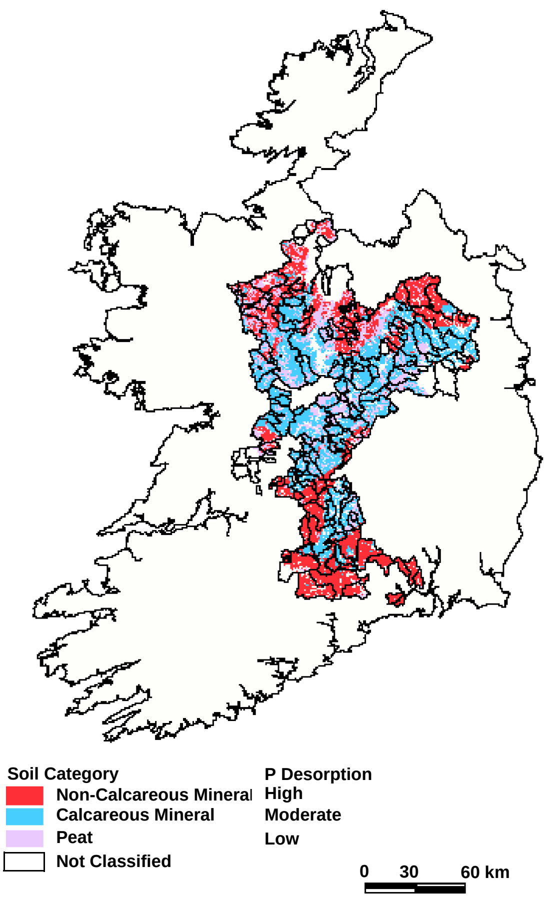

Figure 3.3. A map of phosphorus desorption categories applied to SAG soil classifications for all sub-catchment areas; sub-catchments without full SAG soil coverage are included.

3.2 Comparison of SAG Soil Categories, Detailed Soil Survey and GSM

Detailed soil-survey data on a county basis were extracted from a GIS database for the original suite of sub-catchments. Areas with full coverage of detailed soil-survey data were filtered out yielding a subset of 44 sub-catchments. The great soil groups extracted and their percentage distribution across the sub-catchments included gleys, grey brown podzolics, peats, brown earths, complexes and peat complexes. The distribution of these soil groups was compared with some of the derived indices and soil categories using other soil data sets. The percentage gley soils in sub-catchments from the detailed soil maps correlated with the RRI generated from the GSM of Ireland (r = 0.47**), indicative of some agreement with the derived risk index and soils characterised as having poor to impeded drainage. However, no significant correlation was found between percentage gley and TWI. In these data, the dominant mineral soil group appeared to be grey brown podzolics and was positively correlated with percentage areas with TWI >12 (r = 0.57***) and TWI_RR (r = 0.69***), perhaps suggesting some wet areas within this moderate to well-drained soil type. Grey brown podzolics are reported to show a proportion of limestone in the parent material and this is reflected in the high percentage of SAG mineral soils derived from basic parent material mapped for these areas. The data set of 44 sub-catchments with full detailed soil coverage was further reduced to include only sub-catchment areas that had full coverage of SAG soils. This yielded a data set of 23 sub-catchments from which a detailed soil survey and SAG soils could be compared. The poorly drained mineral soil from the SAG data (reported to include surface water and groundwater gleys) were extracted from the data and compared with percentage gley soils from the detailed soil survey. No significant correlation was found, and percentage coverage of poorly drained soils from SAG data differed substantially from those reported in the detailed soil survey, for the same areas. For example, the distribution of gley soils in sub-catchments from the detailed soil survey ranged from 0% to 37% with an average value of 12% across the data. The SAG poorly drained mineral soils derived from acidic parent material (AminPD) ranged from 0% to 27% of the sub-catchment area with an average of 2.6%. Twenty of the sub-catchments had AminPD values less than 5%, while three sub-catchments had an exceptionally high percentage of AminPD above 10%. The corresponding SAG category from basic parent material was denoted as BminPD and ranged from 0% to 8% of sub-catchment areas with an average value of 1.9%. The SAG data set appeared to underestimate the poorly drained soils categories in these areas when compared to the detailed soil-survey data. A visual comparison is shown in Fig. 3.4 which presents a comparison of the same areas with poorly drained mineral soil coverage from SAG data with gley soils from a detailed soil survey. Despite the discrepancy in poorly drained soils between these soil data sets, there was

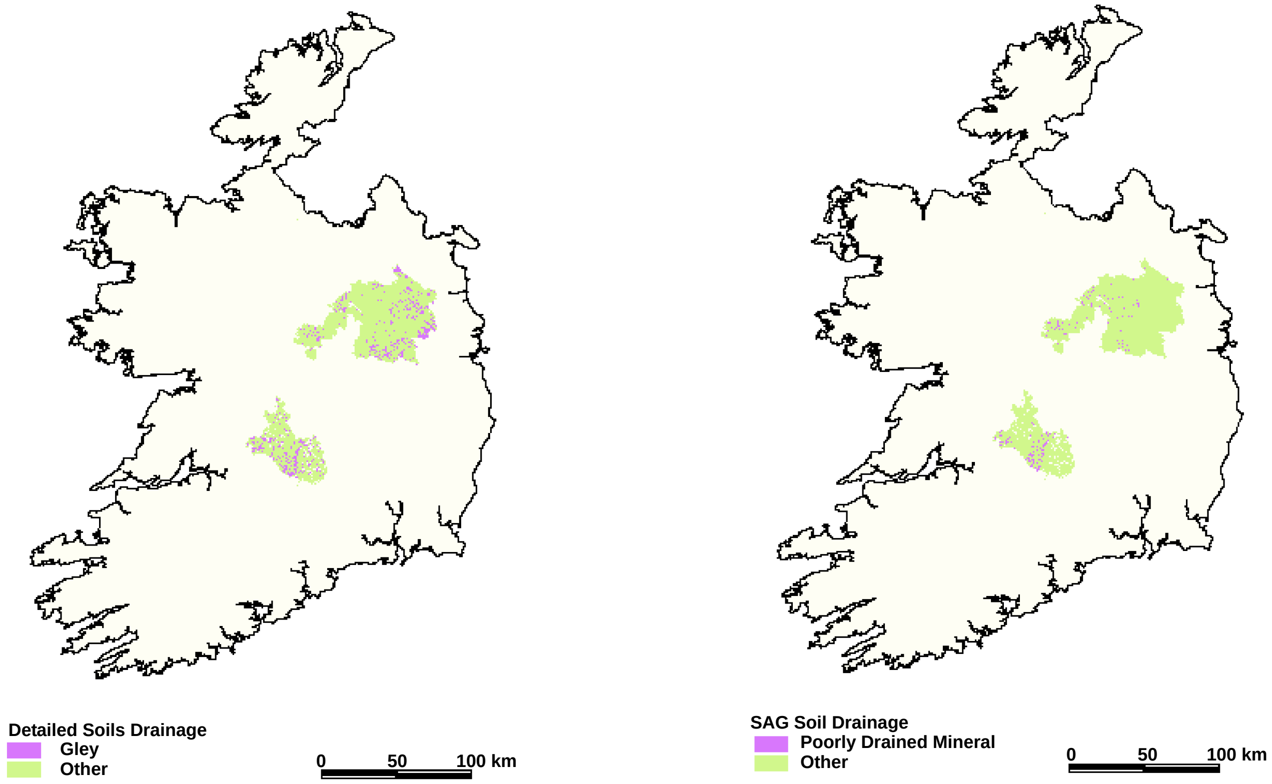

Figure 3.4. A visual comparison of gley soils mapped by the National Soil Survey (left) and poorly drained soils mapped by SAG (right) for the same areas.

good agreement between other soil groups. The soils in these data were mostly derived from limestone parent material, and the percentage sub-catchments mapped as GBP from the detailed soil survey ranged from 0% to 75% (mean 37%) similar to the Bmin category from the SAG data, which ranged from 0% to 84% of sub-catchment areas (mean 50%). The percentage of sub-catchment areas covered by both soil categories correlated positively (r = 0.84***), indicative of the good agreement in the coverage of this soil type from two separate data sources. Similarly, the Peat category from the SAG data correlated with the peat soils from the detailed soil survey of these sub-catchments (r = 0.88***) and values representing the percentage of each peat class in the sub-catchment areas, derived from a detailed soil survey (0–61%, mean 13%) and SAG (0–59%, mean 18%) were comparable.

The significantly positive correlation between RRI derived from the GSM and percentage gley from the detailed soil survey (r = 0.47**) substantiates the use of percentage gley within soil associations from the GSM as a guide towards soils that present a run-off risk based on the poor to impeded drainage characteristics of gley soils.

3.3 Relationships Between Water Quality and Catchment Characteristics Using SAG Data

The GIS data sets on land cover, soil type and P loading were extracted for each of the water quality stations that defined a sub-catchment area. The original database of selected stations contained 161 sub-catchments from which flow-weighted P values could be calculated. However, this number was further reduced when the SAG data on soils were incorporated. The SAG soils data do not as yet have full national coverage and several sub-catchments had significant areas within them without any SAG soils coverage. These sub-catchments were omitted from the following statistical analyses and only sub-catchments with 100% SAG soils coverage were accepted. This resulted in a data set of 84 sub-catchments from which correlations between fwOrtho-P and catchment characteristics (using SAG data) could be derived.

The percentage of sub-catchment mapped as acidic soil types and denoted here as Amin+AminPD correlated positively (r = 0.36***) while peat soils correlated negatively (r = –0.31**) with fwOrtho-P data. When these soils data were used to generate a P desorption index (PDI), representing desorption risk, the index was significantly positively correlated with fwOrtho-P values (r = 0.42***) and the relationship is presented in Fig. 3.5. Run-off risk was described using the GSM, by ranking

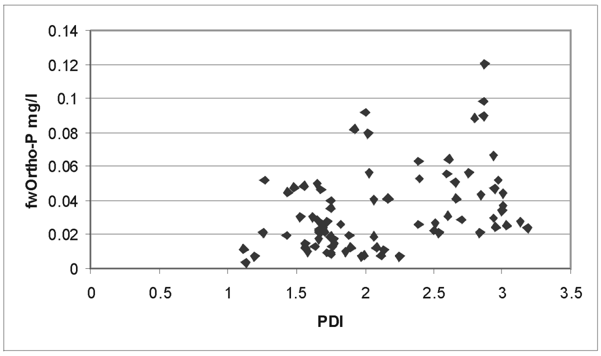

Figure 3.5. Correlation between fwOrtho-P concentrations and P desorption index (PDI) (r = 0.42*).**

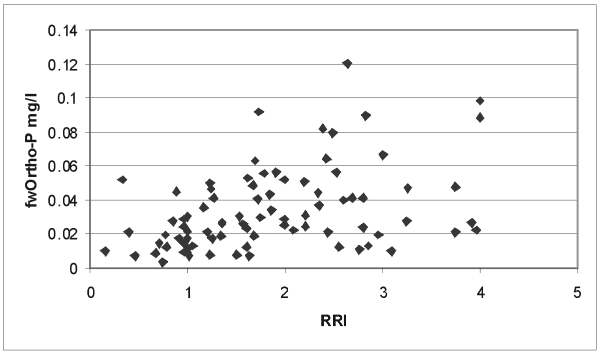

Figure 3.6. Correlation between fwOrtho-P concentrations and run-off risk index (RRI) from the GSM (r = 0.41*).**

associations of soils based on percentage gley, and the area-weighted variable generated (RRI) correlated positively (r = 0.41***) with fwOrtho-P. Figure 3.6 presents the scatter plot between these two variables.

Land-cover categories from the CORINE database extracted for each of the sub-catchments were significantly correlated with fwOrtho-P. The percentage of sub-catchments in unimproved pasture correlated positively (r = 0.53***) with fwOrtho-P (Fig. 3.7) although no significant correlation with improved pasture was found. The Unimproved Pasture category also correlated with RRI (r = 0.49***), indicating that this land-cover class is predominantly associated with wet soils (Fig. 3.8). There was also a significant correlation between Unimproved Pasture and the PDI (r = 0.47***), which is probably due to the correlation between this land-cover class and Amin+PD soils (r = 0.36***). Semi-natural areas (r = –0.32**) and Peat (r = –0.21*) areas were negatively associated with fwOrtho-P. Table 3.2 presents some summary statistics of catchment data in this data set.

STP values positively correlated with fwOrtho-P were those described by percentage area in the SP2 category, representing Morgan's P 6–10 mg/l (r = 0.32**), whilst percentage area with low P values in the SP1 category (Morgan's P 0–6 mg/l) correlated negatively with fwOrtho-P (r = –0.38***). However, percentage area with Morgan's P above agronomic values (SP3) were not significantly correlated with fwOrtho-P. The index generated from these data, SPI, was positively correlated with fwOrtho-P values (r = 0.29**). The livestock unit density and fertiliser P indices were not significantly correlated with fwOrtho-P data.

The percentage of sub-catchment areas with TWI >12 was not significantly correlated with WQ data but had a strong association with soils in the data, namely, peat soils. Percentage SAG peat soils and TWI >12 correlated positively (r = 0.29**). The CORINE Peat land-cover class

Table 3.2. Summary statistics of land-cover categories from CORINE and the Habitats Map, and percentage TWI >12 and TW >12 in selected sub-catchments (n = 84).

	fwOrtho-P mg/l	Wetgrass	Drygrass	GrassPeat	Improved Pasture	Unimproved Pasture	Arable	Semi-natural	Peat	TWI>12	TWI_RR
		%									
Min	0.004	0	0	0	1	0	0	0	0	4	0
Max	0.120	25	98	39	62	98	53	67	67	63	63
Mean	0.033	4	52	8	32	39	4	7	8	36	30
Median	0.026	2	64	6	32	39	1	4	4	37	32

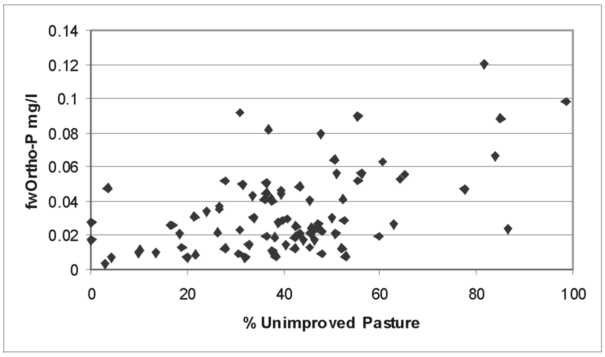

Figure 3.7. Correlation between fwOrtho-P concentrations and percentage Unimproved Pasture from CORINE land-cover data (r = 0.53*).**

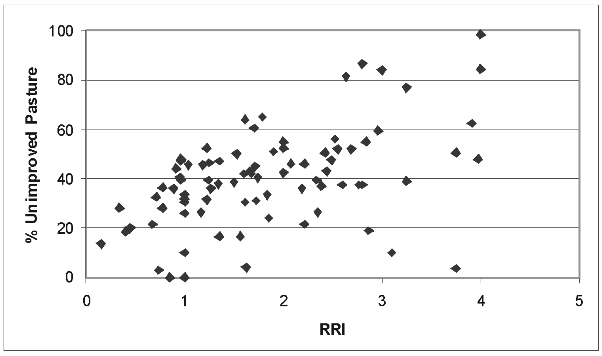

Figure 3.8. Correlation between percentage Unimproved Pasture and run-off risk index (RRI) (r = 0.49*).**

was marginally ($p = 0.06$) correlated with percentage areas with TWI >12 (r = 0.19) and this land-cover class was positively associated with the SAG peat soils (r = 0.76***), suggesting good agreement between these two data sets describing peat areas. It is unclear why there is an association between peat soils and areas with a high TWI but it could be due to the way in which TWI was derived, i.e. by locating relatively flat areas. These areas might also coincide with areas dominated by peat soils. The percentage area in run-off risk category RR4, based on a high percentage of gley soils within a soil association, correlated positively with percentage TWI >12 (r = 0.21*), indicating a weak association between topographically derived wet areas and poorly drained soils. In an attempt to isolate only mineral soils that coincide with areas with a high TWI, soils classed as RR3 and RR4 were combined to generate a variable TWI_RR, which describes the percentage sub-catchment with TWI >12 on soils that are either RR3 or RR4. However, no significant correlation with WQ was found when soil type was incorporated with TWI >12 areas.

The SAG Habitats Indicators Map included in the statistical analyses included only areas with full coverage of SAG land-cover categories and since the Habitats Indicators Map is derived from the SAG soils data, this further reduced the sample size from 84 to 64 sub-catchments. A correlation analysis using grassland categories from this database showed significant positive correlation between the percentage 'Drygrass' and fwOrtho-P (r = 0.43***) with no significant correlation between 'Wetgrass' or 'Grasspeat' and WQ data.

A backwards-stepwise regression model was computed for fwOrtho-P concentrations using all of the available catchment data, namely, the CORINE land-cover classes, desorption, run-off risk, soil P, livestock density and fertiliser P indices. The final step in the regression model retained Unimproved Pasture, Arable, SPI and PDI ($p < 0.10$ to stay in the model) that accounted for 41.4% of the variation in the fwOrtho-P data (Table 3.3). The model associates increasing fwOrtho-P concentrations with high desorbing soils, high soil P level, arable areas, and unimproved pasture. The CORINE Arable and Unimproved Pasture classes have been identified in previous Irish studies as significant variables in modelling P loss to surface waters (McGuckin *et al.*, 1999; Daly *et al.*, 2002). More recently, as part of a risk assessment methodology for diffuse pollution under the WFD, the Irish

Table 3.3. Backwards stepwise regression model of fwOrtho-P with percentage Unimproved Pasture, Arable, PDI and SPI ($p < 0.05$).

Y	Variable	Coefficient	SE coefficient	Probability	R^2
FwOrtho-P	% Unimproved Pasture	0.0005	0.0001	0.0002	0.414
	% Arable	0.0007	0.0003	0.0184	
	PDI	0.011	0.004	0.0154	
	SPI	0.003	0.001	0.0049	

EPA has derived a model predicting the probability of river waters attaining a Q value ≥4 using CORINE land-cover classes, Pasture, Arable and Urban. However, in this present study, when the pasture category was subdivided into Improved and Unimproved Pasture, the most significant and positive correlation with fwOrtho-P was found with Unimproved Pasture. Using 30 sub-catchments in Northern Ireland, McGuckin *et al.* (1999) derived P export coefficients for CORINE land-cover types and concluded that soluble P export coefficients were higher for Unimproved Pasture (0.62 kg/ha/year) compared to Improved Pasture (0.26 kg/ha/year) and attributed the difference to the undrained and compacted nature of Unimproved Pasture that encourages surface run-off. In this present study, Unimproved Pasture was the only pasture category retained in the multiple-regression model and these results concur with the undrained and compaction effects hypothesised by McGuckin *et al.* (1999) for unimproved pastures. The PDI and SPI were also retained in the multiple-regression model of fwOrtho-P and suggest a contributing effect from high desorbing soils, i.e. non-calcareous soils at high soil P levels.

3.4 A Risk Assessment Model for Sub-Catchments Based on P Desorption and Run-Off Risk (or Soil Type)

The regression modelling approach described in the previous section failed to explain a large proportion of the variability in fwOrtho-P data among 84 sub-catchments, yet identified some highly significant soil-type characteristics that were positively associated with increasing fwOrtho-P concentrations, namely, P desorption risk and run-off risk. The indices generated from these data, PDI and RRI, plotted against each other (Fig. 3.9) were positively correlated (r = 0.51***) indicating that high run-off risk may also be a characteristic of high desorption soils. However, it was apparent from the scatter plot in Fig. 3.9 that high run-off risk also exists in soils that have a low desorption index. The P desorption index was subdivided into two categories, high (PDI > 2.25) and low (PDI < 2.25), and similarly, RRI was divided into high (RRI >2) and low (RRI <2) indices. This provided the framework for four risk assessment categories that combine desorption and run-off risk presented in Fig 3.10. The objective of such an approach was to identify soils where both high desorption and run-off risk exists, and examine the WQ data to support the

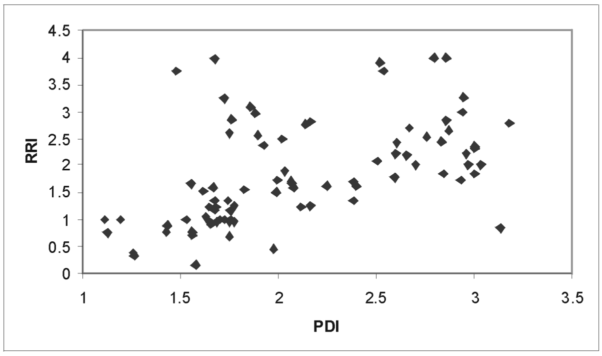

Figure 3.9. Scatter plot of run-off risk and PDI across 84 sub-catchments (r = 0.51*) divided into four risk areas based on low and high RRI by low and high PDI.**

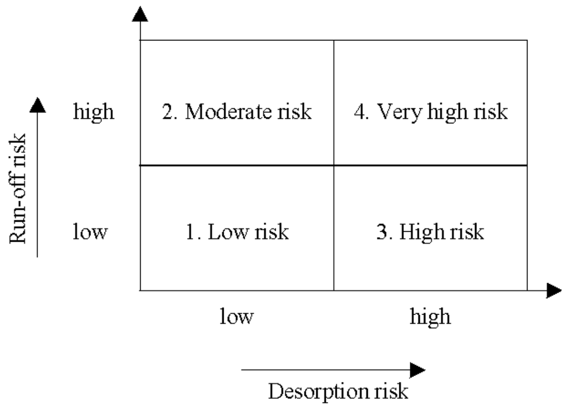

Figure 3.10. Run-off risk index (high and low) by P desorption index (high and low).

hypothesis that sub-catchments with this combination of soil characteristics (high desorption risk and high run-off risk) have highest fwOrtho-P concentrations. The scatter plot in Fig. 3.9 was divided into four quadrants to identify sub-catchments that have soils in each of the four risk categories and the fwOrtho-P data were extracted for each risk category. Analysis of variance identified significant differences in annual fwOrtho-P concentrations (F-ratio 6.4***) between the four risk categories and values are plotted in a box and whisker plot (with outliers highlighted) in Fig. 3.11 for each risk category. There was a significant trend of increasing fwOrtho-P values (r = 0.46***) as risk categories moved from 1 to 4, from 'low' to 'very high'. Water quality data were divided into winter and summer values and these data are presented for each risk class in the box and whisker plots (with outliers highlighted) for winter and summer fwOrtho-P in Figs 3.12

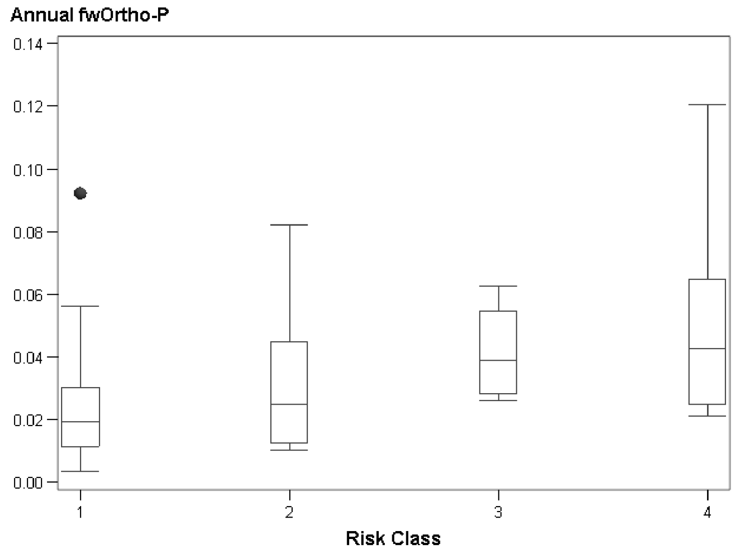

Figure 3.11. fwOrtho-P concentrations in sub-catchments that have been assigned a risk category based on PDI and RRI factors; values of fwOrtho-P in each category are significantly different and increase from 1 (low) to 4 (very high).**

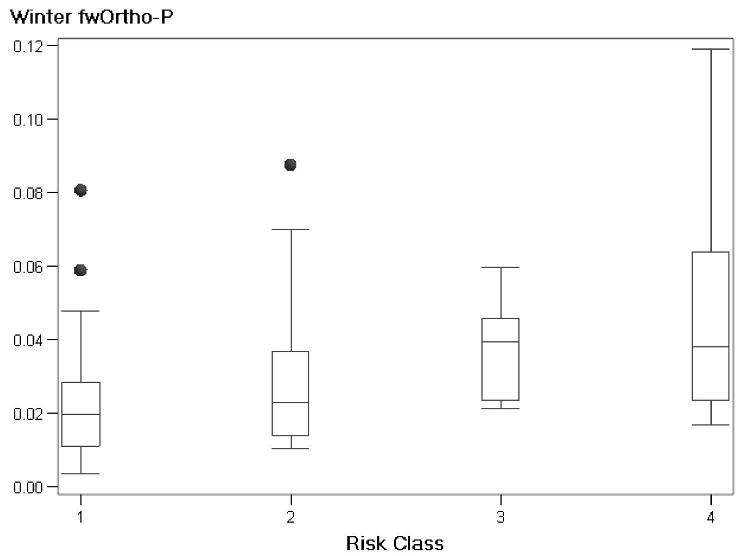

Figure 3.12. Box and whisker plot showing the distribution of winter fwOrtho-P values in each risk class.

and 3.13, respectively. Analysis of variance between risk classes for fwOrtho-P values were significantly different for winter (F-ratio 5.6**) and summer (F-ratio 5.9***) values, with highest values measured in sub-catchments in Risk 4. There were more outliers or extreme values in the summer data compared to the corresponding winter values, that may have been attributed to summer point sources, although these summer outliers were mostly from small streams within the Camlin and Inny sub-catchments that are predominantly agricultural catchments. However, highest winter fwOrtho-P values were measured in sub-catchments within Risk 4, that combined high desorption risk with high run-off risk. The fwOrtho-P data supporting the box and whisker plots are presented in Tables 3.4–3.6 for annual, winter and summer values, respectively.

The Unimproved Pasture category from CORINE also differed significantly between categories (F-ratio 10.9***) as a percentage of sub-catchments in this land-cover

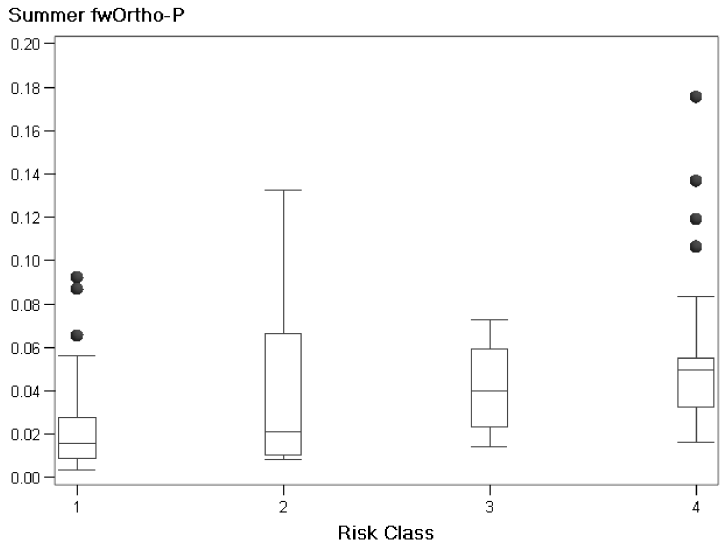

Figure 3.13. Box and whisker plot showing the distribution of summer fwOrtho-P values in each risk class.

Table 3.4. The fwOrtho-P data supporting the box and whisker plots for annual values.

Risk Class	1	2	3	4
	Annual fwOrtho-P (mg/l)			
25th percentile	0.012	0.013	0.030	0.025
75th percentile	0.030	0.048	0.056	0.065
Median	0.019	0.027	0.044	0.044
Min	0.004	0.010	0.026	0.021
Max	0.056	0.082	0.063	0.120

Table 3.5. The fwOrtho-P data supporting the box and whisker plots for winter values.

Risk Class	1	2	3	4
	Winter fwOrtho-P (mg/l)			
25th percentile	0.011	0.015	0.026	0.024
75th percentile	0.029	0.038	0.046	0.064
Median	0.020	0.024	0.040	0.038
Min	0.004	0.011	0.021	0.017
Max	0.048	0.070	0.060	0.119

Table 3.6. The fwOrtho-P data supporting the box and whisker plots for summer values.

Risk Class	1	2	3	4
	Summer fwOrtho-P (mg/l)			
25th percentile	0.009	0.010	0.023	0.033
75th percentile	0.028	0.066	0.059	0.055
Median	0.016	0.021	0.040	0.050
Min	0.003	0.008	0.014	0.016
Max	0.056	0.132	0.073	0.083

class increased as risk categories increased from 1 to 4. The Peat land-cover class from CORINE also varied significantly between risk categories (F-ratio 3.6*) with the lowest percentage of this land-cover class in the lowest risk category. The variation in Improved Pasture category from CORINE was only marginally significant (F-ratio 2.7*), suggesting a decrease in this land-cover class from risk categories 1 to 4, low to very high. The remaining catchment data did not vary significantly between risk categories (ANOVA).

A map of the 84 sub-catchments and their assigned risk category according to the combined risk of P desorption and run-off is presented in Fig. 3.14.

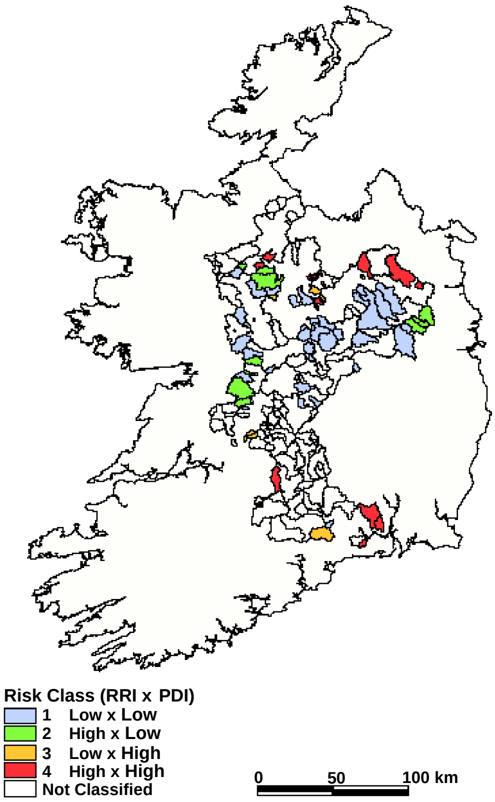

Figure 3.14. Risk categories (PDI × RRI), 1 (low) to 4 (very high), applied to the 84 sub-catchment areas used in the analysis.

4 Conclusions and Recommendations

The data analysed for this research included large volumes of GIS and water quality databases that were collated and compiled in an attempt to identify factors controlling P loss from soils and to generate a model that predicts losses in catchments. The project identified every source of soils data, land-use data and management data that currently exists in Ireland to investigate how the data might be used in a catchment modelling study. The initial statistical analysis identified soil-type variables that were significantly correlated with fwOrtho-P concentrations but failed to find any significant association between loading variables, such as livestock unity density and fertiliser P use, and fwOrtho-P concentrations. This may have been due to difficulties and inaccuracies inherent in collecting such management data where farm surveys are the basis for the data included. The management data that exist on a national scale in Ireland are not measured but recorded from fertiliser sales and farm surveys. The soil-type variables that were significantly associated with fwOrtho-P data included soil characteristics such as desorption risk and run-off risk. Most sub-catchments have a mosaic of soil groups such as brown earths, gley, grey brown podzolic, podzols and peats. To build a soil-type profile for sub-catchments, soil-type indices were generated that encapsulated and defined soils in terms of desorption risk and run-off risk, and this proved to be a useful method of dealing with large volumes of soils data extracted by GIS for multi-catchment studies such as this. The sources of soil-type data were varied and included traditional soil-survey data, based on general and detailed surveys and also the recently derived soil categories from the SAG data. These are currently being generated for the Irish EPA for use by authorities for catchment management under the WFD.

In this study, the regression model approach explained only 41% of the variability in fwOrtho-P data among 84 sub-catchments using variables that describe land use, soil type and soil P levels. Some of the unexplained variation in this model could be attributed to errors associated with the accuracy of flow measurements and the influence of smaller point sources that could not be screened out. This regression model approach could be applied to other sub-catchment areas not used in the original model, such as the 4,468 river management units identified for the WFD in Ireland. When SAG data on soil classifications are completed for the country, these data, along with CORINE and soil P data, could be extracted for each unit and the regression equation applied. This would allow for an assessment of how applicable the regression approach is to other areas of the country by providing predictive values of fwOrtho-P that can be compared against observed values.

An alternative approach was adopted and considered the critical source areas concept of areas within catchments where high P transport factors meet high P loading factors. This concept has already been highlighted in a companion study (Doody *et al*., 2006), where the author described a variable source area within a field-scale experiment as an area where soil wetness and overland flow expands as rainfall increases. These areas coupled with high STP levels would produce a critical source area for soils where high overland flow meets high soil P to produce a hotspot where losses of P are expected to be relatively high. In the present study, the critical source area concept was adapted to the soil-type variables that were correlated with fwOrtho-P, namely, desorption risk and run-off risk. In the absence of reliable P loading data, desorption was consider to be the loading factor. The laboratory experiments on desorption in soil types concluded that non-calcareous soils desorbed higher amounts of P (FeO-P) at high soil test levels, compared to calcareous and peat soils. This would indicate that if critical source areas (high soil P and high run-off risk) on non-calcareous soils exist, they would have a higher impact on water quality relative to calcareous and peat soils. This modelling concept was combined to produce the four risk categories from the scatter plot in Fig. 3.9 and shown schematically in Fig. 3.10. The water quality data confirmed that combining desorption risk with run-off risk into risk categories can indicate areas of highest and lowest risk, based on soil information alone.

In summary, the conclusions from this report are as follows:

- Soil type in catchments can be described in terms of P desorption risk and run-off risk and these risk factors can be used to define areas of low to very high risk.

- Sub-catchments with a predominance of high P desorbing soils with high run-off risk generated the highest fwOrtho-P concentrations.
- High desorbing soils with a high run-off risk could be defined as critical source areas within catchments.

The recommendations arising from this study, therefore, would include:

- More precise P management data (fertiliser P use and livestock unit density) to be incorporated into catchment modelling studies.
- A national soil P testing survey should be carried out so that this test can be used as an indicator of P use intensity and potential losses to water, in conjunction with information on soil drainage characteristics for risk assessment.
- An improved delineation of wet areas defined by topographical wetness indices derived from digital terrain models needs to be incorporated with drainage classifications from detailed soil maps.
- There is a need for a more detailed description of poorly drained soils that can be incorporated into soil-type databases and used for catchment studies on a smaller scale than the GSM might allow.
- A detailed soil survey for the remainder of the country should be completed so that soil attributes such as chemistry and hydrology can be used in catchment-based risk assessment, and programmes of measures be applied to the appropriate areas.

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Appendix A

A list of selected sub-catchments (n = 84) and their assigned risk classes, with annual, winter and summer flow-weighted Ortho-P concentrations.

Sub-catchment	Station ID	River name	Risk class	Annual fwOrtho-P	Winter fwOrtho-P mg/l	Summer fwOrtho-P
Boyne	07A01400	Athboy	1	0.056	0.059	0.087
Boyne	07B02600	Blackwater (Longwood)	1	0.048	0.048	0.054
Boyne	07B03300	Boycetown	2	0.042	0.038	0.060
Boyne	07C04190	Castlejordan	1	0.020	0.020	0.023
Boyne	07D01600	Deel (Raharney)	1	0.021	0.022	0.015
Boyne	07K02500	Knightsbrook	2	0.080	0.070	0.123
Boyne	07M03900	Moynalty	4	0.065	0.064	0.051
Boyne	07R01200	Riverstown	1	0.030	0.032	0.026
Boyne	07S01600	Skane	2	0.082	0.088	0.132
Boyne	07S02400	Stonyford	1	0.030	0.026	0.038
Boyne	07T01400	Tromman Stream	1	0.025	0.025	0.024
Boyne	07Y0190	Yellow (Blackwater)	4	0.031	0.025	0.034
Suir	16B02450	Blackwater	4	0.044	0.028	0.053
Suir	16B05100	Black Stream	1	0.092		0.092
Suir	16G01400	Glasha	1	0.007	0.006	0.008
Suir	16M021000	Multeen	4	0.037	0.038	0.055
Suir	16N01400	Nier	3	0.026	0.021	0.014
Suir	16P02500	Pollanassa	4	0.025	0.020	0.033
Suir	16S07800	Smartcastle	4	0.025	0.017	0.028
Suir	16W01400	Whelans Bridge	4	0.052		0.052
Little Brosna	25/B/12/0400	Breaghmore	1	0.007	0.007	0.007
Nenagh	25/B/34/0400	Borrisnafarney Stream	3	0.027	0.022	0.037
Kilcrow	25/C/03/0500	Cappagh (Galway)	2	0.011	0.013	0.008
Woodford	25/C/08/0100	Coos	1	0.004	0.004	0.003
Little Brosna	25/C/13/0100	Clareen Stream	1	0.008	0.008	0.006
Nenagh	25/C/24/0100	Cureeny Cross Stream	1	0.010	0.011	0.009
Brosna	25/D/14/0100	Derrycooly Stream (Upper)	1	0.007	0.008	0.004
Kilcrow	25/E/07/0700	Eskerboy	2	0.027	0.021	0.025
Brosna	25/G/01/0500	Gageborough	1	0.013	0.014	0.012
Shannon Corridor	25/G/10/0100	Grange (Tipperary)	3	0.030	0.026	0.020
Brosna	25/L/04/0200	Lemanaghan Stream	1	0.021	0.021	0.023
Kilcrow	25/L/06/0300	Lisduff (Kilcrow)	1	0.019	0.022	0.011
Brosna	25/M/01/0500	Monaghanstown	1	0.017	0.016	0.016
Shannon Corridor	25/N/03/0300	Newtown	3	0.034	0.039	0.026
Shannon Corridor	25/R/01/0300	Rapemills	1	0.014	0.013	0.015
Little Brosna	25/R/02/0150	Rock (Birr)	1	0.010	0.011	0.007
Brosna	25/T/03/0080	Tullamore	1	0.050	0.043	0.052
Woodford	25/W/01/0300	Woodford (Galway)	2	0.010	0.011	0.010
Shannon Corridor	25/Y/02/0100	Youghal (Tipperary)	3	0.044	0.040	0.052
Suck	26/A/01/0250	Ahascragh	1	0.023	0.025	0.011

Contd.

Sub-catchment	Station ID	River name	Risk class	Annual fwOrtho-P	Winter fwOrtho-P	Summer fwOrtho-P
					mg/l	
Camlin	26/A/11/0300	Aghnashannagh Stream	4	0.022	0.021	0.028
Camlin	26/A/13/0400	Aghaboy Stream	4	0.047	0.045	0.049
Suck	26/B/01/0300	Ballinure	2	0.040	0.037	0.031
Shannon Corridor	26/B/07/1000	Boor	1	0.029	0.019	0.030
Shannon Corridor	26/B/10/0500	Breensford	1	0.012	0.013	0.009
Shannon Corridor	26/B/14/0100	Ballydangan	1	0.012	0.011	0.011
Inny	26/B/24/0500	Bellsgrove	4	0.090	0.083	0.137
Roosky	26/C/02/0100	Carricknabraher	2	0.013	0.012	0.010
Suck	26/C/03/0100	Castlegar	1	0.017	0.024	0.015
Inny	26/C/05/0700	Comoge	3	0.063	0.060	0.073
Shannon Corridor	26/C/06/0120	Clooneigh	3	0.053	0.046	0.043
Camlin	26/C/20/0500	Clooncoose Stream	3	0.056	0.046	0.066
Camlin	26/C/42/0300	Currygrane Lough Stream	4	0.029	0.027	0.033
Inny	26/D/06/0400	Dungolman	1	0.027	0.029	0.017
Suck	26/D/07/0700	Derrymullan Stream	1	0.047	0.046	0.044
Camlin	26/D/20/0200	Drumnacooha Stream East	4	0.120	0.119	0.176
Camlin	26/D/21/0300	Drumnacooha Stream West	4	0.067	0.068	0.083
Camlin	26/D/22/0900	Derryharrow Stream	4	0.099	0.087	0.106
Camlin	26/F/01/0300	Fallan	1	0.041	0.035	0.056
Suck	26/F/05/0150	Francis	1	0.026	0.028	0.027
Inny	26/G/02/0150	Glore (Westmeath)	1	0.008	0.009	0.004
Shannon Corridor	26/G/06/0200	Glassan Stream	1	0.022	0.016	0.028
Suck	26/H/02/0100	Hardwood Stream	2	0.022	0.024	0.018
Suck	26/K/01/0300	Killian	1	0.036	0.038	0.023
Roosky	26/K/02/0700	Killukin	4	0.027	0.026	0.024
Camlin	26/K/14/0500	Killeenatruan Stream	4	0.089	0.086	0.119
Roosky	26/L/04/0300	Lissaphobble	1	0.019	0.020	0.013
Inny	26/L/06/0400	Lenamore Stream	4	0.051	0.050	0.044
Suck	26/L/07/0500	Laurencetown Stream	1	0.045	0.030	0.066
Shannon Corridor	26/L/12/0100	Lough Bannow Stream	1	0.052	0.081	0.023
Roosky	26/M/01/0200	Mantua	4	0.021	0.020	0.016
Inny	26/M/02/0500	Mountnugent	4	0.056	0.049	0.051
Roosky	26/O/06/0400	Owenur	2	0.019	0.022	0.009
Camlin	26/O/09/0400	Oghil Stream	4	0.041	0.044	0.051
Inny	26/R/01/0300	Rath	1	0.015	0.015	0.009
Roosky	26/S/01/0700	Scramoge	2	0.012	0.015	0.011
Suck	26/S/04/0180	Smaghraan	1	0.012	0.020	0.006
Inny	26/T/01/0300	Tagshinny Stream	4	0.021	0.019	0.033
Inny	26/T/02/0200	Tang	1	0.017	0.017	0.017
Suck	26/U/31/0100	Unknown1	2	0.048	0.034	0.072
Inny	26/U/32/0100	Unknown2	1	0.010	0.008	0.014
Shannon Corridor	26/U/33/0100	Unknown3	1	0.009	0.006	0.006
Roosky	26/W/01/0200	Woodbrook House Stream	4	0.024	0.024	0.024
Inny	26/Y/02/0250	Yellow (Castlepollard)	1	0.041	0.043	0.035