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Abatement Cost Heterogeneity and Its Impact on Tradable Nitrogen Discharge Permits

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Thiagarajah Ramilan and Frank Scrimgeour

Department of Economics, Waikato Management School, the University of Waikato, Hamilton, New Zealand
Email: ramelan@mngt.waikato.ac.nz; scrim@mngt.waikato.ac.nz

Summary

Nitrogen discharge into the Waikato River has been identified as the primary source of potential water quality degradation. Rising nitrogen levels in water are attributed to non point source pollution from agricultural activities. Pastoral farming is the predominant agricultural land use in the catchment. Increased nitrogen fertilizer use and higher stocking rates have the potential to increase the nitrogen loading into water. There is a range of best management practices and policies proposed to reduce nitrogen discharge from farming systems. Water quality trading is a policy tool that could improve the cost effectiveness of achieving environmental goals. Economic theory suggests that tradable pollution permit systems encourage polluters to reallocate pollution burdens to take advantage of any differences in marginal abatement costs. This paper develops an analytical frame work to derive nitrogen abatement costs for farms in a Waikato river sub-catchment. Policies and practices are evaluated using a bio-economic model of a typical pastoral farm in the Waikato river sub-catchment. Implications of pollution trading at the farm level are examined using programming simulation models.

Key words: Heterogeneity, Tradable discharge permits, Non point pollution, Marginal abatement cost

1. Motivation

Nutrient discharge into water bodies degrades water quality. Agricultural land use has contributed to the increased levels of nitrogen in Waikato water bodies. The contribution of pastoral agriculture to the water quality degradation has been well recognized (Parliamentary Commissioner for the Environment, 2004). The Waikato River is the longest river in New Zealand with the catchment area of about 14,250 square kilometres. Nitrogen is reported to be a significant contaminant in the Waikato River. In recent years nitrogen concentrations in the Waikato river tributaries have increased at an average of 2.5 percent per annum (Vant, 2004). Most losses of nitrogen from pasture systems are due to the leaching of nitrate. Environment Waikato, the regional council for Waikato region, says that nitrogen fertilizer use in the Waikato region has doubled within a decade. Environment Waikato's scientists believe that the nutrient influx from land use intensification and land use changes would enhance the probability of potential algal blooms in water bodies.

According to Dexcel's farm survey in 2005 average nitrogen fertilizer use in the Waikato region in a year is 123 kg N/ha. Leached nitrogen from urine and dung patches and applied fertilizer nitrogen are reported to be the major potential sources of nitrogen from cattle grazing systems (Ledgard & Menneer, 2005). Estimates of nitrogen leached from pasture, ranges from 15-115 kg N ha/yr. Nitrate leaching from the root zone is seasonal. In winter months nitrogen discharge increases due to low plant nutrient uptake as well as high drainage.

Besides supporting healthy living, water bodies contribute to aesthetic beauty, tourism and sporting opportunities. This necessitates the need for reducing non-point source pollution from agriculture. Environmental policies are used to manage the problem of non- point source pollution. Market-based approaches to environmental policy are increasingly being used to achieve water quality goals. Existence of abatement cost heterogeneity is a requirement for the success of tradable discharge permits. Linking nitrogen discharge reductions with the abatement costs is an imperative for informed decision making. Quantifying abatement costs for agricultural non-point source pollution posses a challenge. This paper develops an analytical frame work to derive heterogeneous nitrogen abatement cost of farms in a Waikato river sub-catchment.

1. 1 Study Area

In general the catchment has been considered as an appropriate spatial unit for analysis of environmental management. Integrated modelling of different policy instruments to control nitrate pollution is often based on a catchment scale (Kampas and White, 2004). The reliable estimation of pollutants at a catchment scale is a fundamental requirement to model the policy implications.

Environment Waikato has identified the establishment of nutrient targets for the Waikato river and tributaries between Lake Taupo control gates and Lake Karapiro Dam and the as a key component of future environmental policy development. The Waikato river catchment from the Lake Karapiro to Taupo control gates has been identified as one of the water bodies in the region with its highest priority for nutrient management (Brodnax, 2006; Environment Waikato, 2005 c). The sub-catchment examined in this study covers the part of the Waikato River including lakes Arapuni and Karapiro. Water quality deterioration in the sub-catchment is mainly attributed to the water quality of inflowing tributaries (Environment Waikato, 2005 b). The Lake Karapiro is being marketed as a world class events venue for water sports. Therefore water quality is a significant factor associated with recreation and development interest.

1. 2 Scale of Modelling

Many past studies, modelling farm nutrient impact focussed on a catchment/ sub-catchment scale. Since farms are the major decision making units within the catchment and respond to policy changes, our focus is on the farms within the sub-catchment. Lant et al. (2005) also stressed the difficulties arising from agricultural landscapes was that spatial units of land management (farms) are not generally at the spatial scale at which ecosystem services function. Even though water quality is produced at the watershed scale, it is on farms that actions to improve water quality need to be implemented. The proposed Waikato Regional Plan targets net improvement of overall water quality. Quantified nutrient targets will give land

owners and policy makers a much clearer idea of the required land management change rather than the term net improvement. The modelling framework proposed here intends to quantify the economic impact of changing the nutrient targets over the range of values in a spatial context.

1. 3 Best Management Practices

Strategies for reducing nitrogen discharge can be categorised into two major classes, namely source reduction and interception strategies (Ribaudo, Heimlich, Claassen, & Peters, 2001). In a pastoral farming context source reduction strategies are managing nitrogen discharges through fertilizer application, stocking rate and feeding regime. Major interception technologies are fencing of riparian margins, creation of wetlands and conservation of reserves. The management options explored are experimented within the range of New Zealand pastoral farming (Ledgard & Menneer, 2005). For instance keeping dairy animals on feed pads during late autumn and winter reduces nitrogen leaching by 50-60% (Chadwick, Ledgard, & Brown, 2002). This paper concentrates on the economics of source reduction strategies such as stand off pads, winter pads, restricted grazing during winter (Grazing off) and management of stocking rate and nitrogen fertilizer in a spatial context.

1. 4 Tradable Discharge Permits

Tradable discharge permits are one of the market based instruments used for managing water pollution. Trading provides an incentive to invest in developing abatement oriented best management practices because farmers can anticipate revenue through the sale of pollutant reduction credits (Rousseau, 2001). Tradable discharge permits render an opportunity to those affected or offended by the pollution (Swinton, 1998). Use of emission permit systems to manage water quality in Waikato river catchment raises important issues of instrument design. The development of a discharge trading is dependent upon environmental modeling of the natural system to predict the effects of trading.

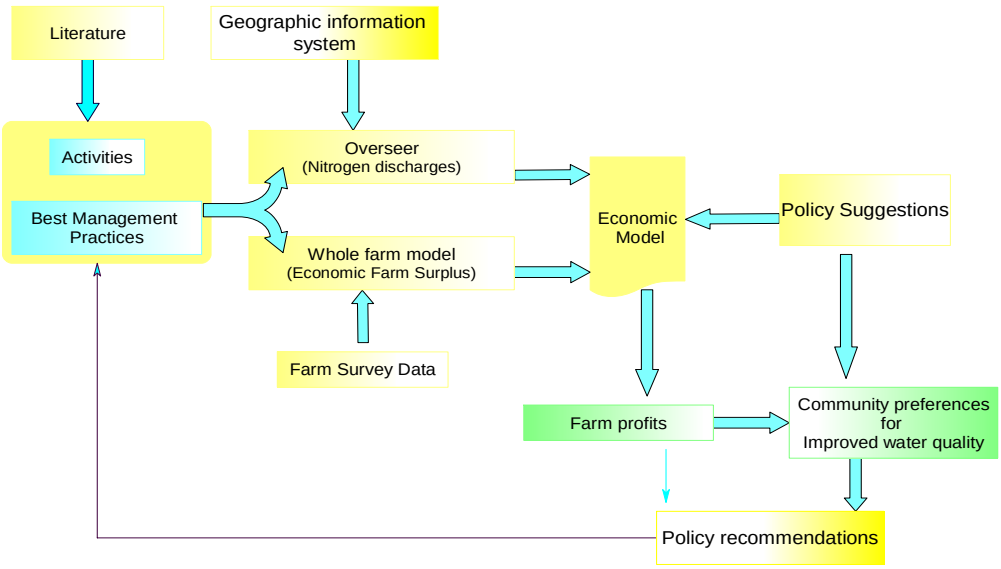
If the nitrogen problem is considered as a non uniformly mixed accumulative pollutant, an optimal control approach need to be adopted. A study by (Hart & Brady, 2002) considered nitrogen as a stock pollutant and developed an optimal control model for cost effective management. This paper develops an analytical framework to derive heterogeneous nitrogen abatement costs with in a sub-catchment. Estimates of marginal abatement cost help determine the estimates of market price of permits.

2. Analytical Framework for Modelling

The integration of the environmental and economic components provides the ability to conduct a holistic analysis of best management practices and policies proposed. In this paper dairy farming activities and associated nitrogen discharge levels were simulated under different policy scenarios to predict farmers' net return. Hypothetical representative farm types were created by integrating Dexcel's farm survey data for the Waikato region and soil physical variables which influence the nitrogen discharge. In this research intra farm heterogeneity is not considered in terms of soil physical variables. The empirical model for this analysis comprises four components. First, a Geographical Information System (GIS), a spatial analytical tool, is used to derive the catchment, identify land uses and the spatial distribution of soil physical variations. Second, a Dairy farm simulation model (Dexcel Whole Farm

Model) is used to simulate different management activities. Third, the Overseer model is used to simulate the nitrogen discharges over different management practices. Fourth, the economic model is used to optimise the management practices and quantify the cost of implementing various policies. The modelling approach is schematically illustrated in the figure 1.

Figure 1: Outline of Modelling Structure.



2. 1 Geographical Information Systems

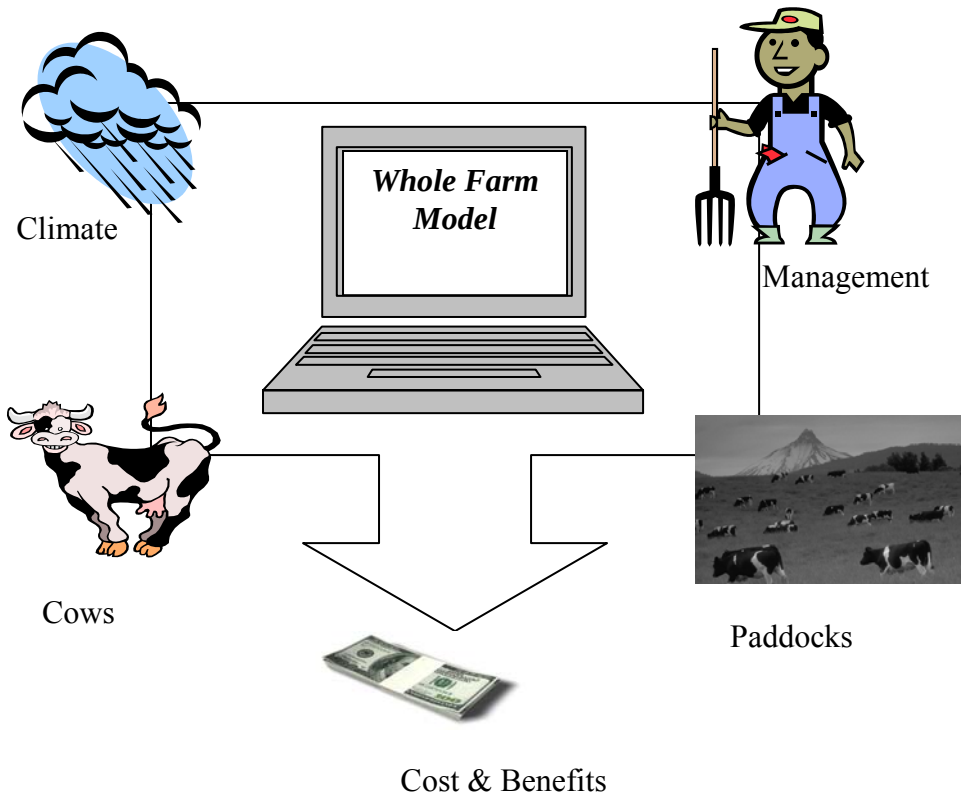
Agricultural land is heterogeneous in terms of productivity and pollution potential. Agricultural non-point source water pollution is significantly affected by spatial variation in soil, topographic, hydrologic, geologic and landscape features (Qiu & Prato, 1999). A Geographic Information System is used to represent the spatial heterogeneity in terms of differences in soil type, land slope and production systems by overlaying available data. Various data sets were combined within a GIS, such as data on farm types from Agri-quality, and soil types and slope classes from New Zealand Land Resources Inventory (NZLRI). The sub catchment of the Waikato River was derived using the River Environment Classification (REC) developed by National Institute of Water and Atmospheric Research (NIWA). The farms which fall partially within and partially outside the catchment are likely to create difficulties for administration and enforcement of policies. Further leaving the properties out of the catchment may risk the achievement of specified nutrient targets. Therefore for maximum certainty and practical workability such properties are defined as being within the catchment regardless of the precise physical location of the catchment. This is in line with the submissions for Lake Taupo (Environment Waikato, 2005 a).

2. 2 Whole- Farm Model

The whole farm model was developed by Dexcel, a major organization in New Zealand dairying research and development. It is a computer model that simulates New Zealand dairy farms. It links sub models of pasture growth and cow metabolism and is designed to simulate the complex interactions of climate, pasture, animals and

management on the farm (Figure 2). The whole farm model simulations carried out uses the McCall pasture model based on the work of (McCall & Bishop-Hurley, 2003) and the Molly cow model. A temporal dynamic nitrogen response function, derived based on the results of local scientific fertilizer studies, is incorporated into the model to simulate the nitrogen fertilizer response. The model currently does not account for the impact of cow waste on the growth of pasture. This model uses inherent soil fertility and soil moisture to differentiate soil types. According to (McCall & Bishop-Hurley, 2003), soil moisture, water holding capacity of soil horizons and soil P status are key factors which have spatial influence on pasture growth. Economic farm surpluses are generated in the economics component of the model by integrating biophysical output of the model with the Dexcel's farm survey data for the Waikato region. As far as the farms of different sizes are concerned, constant returns to scale can be assumed based on the study of (Neal, 2004). He found this to be a reasonable assumption over a wide range of farm sizes encompassing more than half of the farms surveyed in the Dexcel's economic survey.

Figure 2: Structure of the Whole Farm Model.



Adapted from Beukes, et al (2005)

2. 3 The Overseer

The diffuse nature of agricultural nitrogen pollution and the time lag before it appears in the water body, necessitates the use of a simulation model. The Overseer is a nutrient budget simulation model for decision support developed by Agresearch, New Zealand's largest Crown Research Institute for agriculture. The technical

coefficients representing nitrogen discharges into water for alternative production practices in different spatial locations were derived using the pastoral detail mode of the Overseer. The estimates of nitrogen into water are determined primarily from calculation of the amount of nitrogen inputs and outputs from farming system. In this model nitrogen discharge is calculated based on stocking rate, animal productivity (Milksolids production), slope of the land, soil type, soil nutrient status, fertilizer application and timing, feeding and effluent administration.

2. 4 Economic model

This analysis focuses on the marginal abatement costs associated with the reduction of nitrogen discharges. These estimates are derived from a set of linear programming models based on the simulated activities of whole farm model, best management practices and nitrogen discharges on a typical Waikato dairy farm. The economic model is based on linear programming. Linear programming has been widely used in catchment modeling (Atkinson & Morton, 2004; Ekman, 2005). which predicts producers' responses to alternative pollution control policies. Optimization models have the advantage of providing the solution that best achieves the specified objective and allow detail specification of farm land activities (Weersink, Jeffrey and Pannell, 2002; Brady, 2003; Taylor, 1992).

3. Conceptual Framework

Economic theory suggests that the optimum level of pollution control is at a point where the marginal cost and marginal damage of the pollution is equal. A common problem in determining the optimal pollution level is that the damage function is unknown or contentious. An alternative suggested by Griffins (1987) is to model cost effective ways of meeting an exogenous target for environmental quality.

This paper focuses on the management of nitrogen pollution discharge problem in a catchment. Heterogeneity in production can be interpreted in terms of variations in available pasture land area, stocking rate, breed type and input management strategies. Abatement cost heterogeneity is the typical prerequisite for farmers to initiate permit trading (Kampas & White, 2003). In a cost effective allocation of uniformly mixed assimilative pollutant, the marginal abatement cost is the same for each source (Tietenberg, 2006). Farms with low abatement cost may choose to abate more and trade part of their permits to high abatement cost farmers. We treat nitrogen discharges from land uses as uniformly mixed assimilative pollution. This assumption is consistent with many tradable emission permit studies (Tietenberg, 2006) and enables a static approach to analysis.

Consider a catchment that can be divided into soil types $s = 1 \ldots\ldots S$ *and land slope classes* $e = 1, \ldots\ldots E$. Number of farms $i = 1 \ldots\ldots I$. Each farm can be categorized based on combination of predominant slope and soil type. A farm is assumed to have a choice of array of activities denoted *by* K, $K = 1 \ldots\ldots K$. The symbol X_{ik} denotes the area allocated to the kth activity within the farm. Land area available within the farm is denoted by α. Thus we have $0 \leq X_{ik} \leq \alpha$. For activity k nitrogen discharge generated per ha is denoted by the z Nitrogen discharge produced by the activity is given by $Z_k X_k$. The unconstrained amount of nitrogen discharged from each farm is denoted by z_i. The total amount of nitrogen discharge in the catchment is Z. Z can be written as

$$Z = \sum_{s=1}^{S}\sum_{e=1}^{E}\sum_{i=1}^{I}\sum_{k=1}^{K} z_{isek} x_{isek}$$

In order to reduce the complexity in following equations all the subscripts are dropped except *i*. An environmental agency intends to have a targeted nitrogen discharge reduction (Z^0). A Farm's abatement cost of nitrogen can be c_i. It will depend on spatial characteristic of the farm. Aggregate abatement cost C could be lowered by assigning greater reductions to farms with lower abatement cost. In this simplistic formulation transaction and informational costs are not accounted. The reduced level of pollution on any farm is e_i, q_i is the farm returns and the unconstrained optimization of farm profit is:

$$Max = \pi(q_i, z_i)$$

The restricted profit of the individual farm in the presence of environmental regulation is described as

$$Max = \overline{\pi}[q_i, e_i)]$$

Subject to

$$\sum_{k=1}^{K} X_k \leq b$$ b - is conventional constraints such as land and labour

Minimisation of abatement cost is the maximization of restricted profit

$$\min C = \sum_{i=1}^{I} c_i = \min\left[\sum_{i=1}^{I} \pi_i(q_i, z_i) - \sum_{i=i}^{I} \overline{\pi_i}(q_i, e_i)\right]$$

Subject to

$$\sum_{i}^{I} e_i \leq Z^0$$

The profit function of each farm can be defined as:

$$\pi_i(q_i, z_i) - p_i(\overline{e}_i - e_i)$$

$\overline{e_i}$ - Allocated pollution discharge for each farm

$(\overline{e_i} - e_i)$ is the difference between utilized discharge level and allocated discharge level.

This can be a negative, positive or zero depending on the direction of trade. Pi is the permit price which can be equal to the shadow price. C can be interpreted as the differences between restricted and unrestricted farm profit. i.e the cost of abatement. Minimisation of total costs occurs when each farm's marginal abatement costs are equal or exceed, the shadow price for the pollution constraint, which is the incremental cost of one unit reduction in Z. The model assumes rational profit maximising behaviour, but farmers vary in their knowledge and objectives related to pollution control strategies. Limited borrowing capacity may also limit the adoption of best management practices to control nitrogen discharge. Extensive farm surveys can be a complementary tool to access the farmers' attitude, information barriers and institutional barriers to control non-point source pollution (Carpentier, Bosch, & Batie, 1998).

4. Empirical Modelling

The main source of nitrogen loss is animal excreta particularly urine. Fertilizer nitrogen does not lead to major direct environmental concerns, but increases the risk of losses due to an increase in urine N deposited to pasture. High nitrogen fertilizer use increases pasture growth and consequently accommodates high stocking rate. Decreasing the amount of urine –N excreted onto pasture requires reducing stocking rate and nitrogen fertilizer application concurrently (Ledgard & Menneer, 2005).Therefore the stocking rate and nitrogen fertilize application are bundled together as joint activities in the empirical model. Joint activities of various levels of fertiliser application and stocking rates are modelled using the Whole Farm Model for a typical farm of 100 ha extent.

These activities are then incorporated into a linear programming model. The linear programming model is developed using General Algebraic Modeling System (GAMS) (Rosenthal, 2006) to evaluate alternative policies for reducing nitrogen discharges in a catchment. Rather than assuming uniform effects on all farms in the watershed, the site specific impact of these policies are considered. This approach is consistent with the diffuse and spatially diverse nature of agricultural pollution in a catchment context. Dairy product prices and variable input costs of a typical Waikato dairy farm are obtained from Economic Survey of New Zealand dairy farms conducted by Dexcel. In this study abatement costs in the range of 10 to 80 percent reduction in nitrogen discharge are used to derive abatement cost curves.

Simulations are carried out using the Whole Farm Model for the following joint activities namely 180 Kg N- 3.1 SR, 130 KgN 2.5 SR. 70Kg N 1.9 SR along with the best management practices. SR and N stand for stocking rate and nitrogen fertilizer respectively. These ranges were chosen as Waikato's typical stocking rate is 2.6 cows/ha (Ministry of Agriculture and Forestry, 2005) and average level of nitrogen application is 123 kg N/ha, according to Dexcel' 2005 farm survey of Waikato farms. Joint activities are further simulated under different best management practices, namely a winter pad and grazing off. Since the Whole Farm Model does not simulate stand off pads at the moment, it is related to the standard scenario of pastoral grazing. Thus the annualised cost of a standoff pad is deducted from the cost of standard pastoral grazing activities. In bio-physical terms it is reasonable as both systems depend on paddock based grasing. The Whole farm model results in estimates of economic farm surplus.

In order to generate potential nitrogen discharges these activities are simulated with the Overseer. Spatial variation within the catchment is demonstrated using two sets of soil type and topographic combinations namely, Sedimentary/ Flat and Pumice/Easy. According to scientific literature Oslen p levels required for maximum pasture production is lower for sedimentary soils rather than pumice soils. Further nutrient retention potential is high for flat land rather than easy slope land. Thus Flat-Sedimentrary landscape can be considered as more productive than Easy-pumice landscape. Based on this, the revenue for activities for easy/ pumice soil are assumed to 5% lower than the revenue of activities for flat/sedimentary.

The costs of best management practices include both the depreciation value of capital cost feed/stand off pads and effluent disposal system and annual operating costs,

which are deducted from the whole farm model generated economic farm surplus. The lifespan of the feed pads is assumed to be 20 years.

5. Results and Discussion

5. 1 GIS Analysis

The sub-catchment derived within the broader catchment of Waikato river, identified by the Environment Waikato, using river environment classification. Maps below are generated by overlaying data bases in the Geographic Information Systems. The predominant pastoral land use in the study area is dairy farming (Figure 3). The southern end of the catchment consists of a considerable level of plantation forest**.** Waikato river and its hydro lakes Arapuni and Karapiro bifurcate the catchment. Soil groups in the New Zealand land resource inventory (NZLRI) are grouped into major soil categories namely sedimentary, volcanic, pumice, peat, recent, sands and Podzols in order to match with the soil classification adopted in the Overseer model. Soil types and slopes classes of NZLRI are grouped , with the help of Land Resource Information System Spatial Data Layers (Newsome, Wilde, & Willoughby, 2000) (Figure 4 and Figure 5).

Figure 3: Major Land Uses in the Study Area

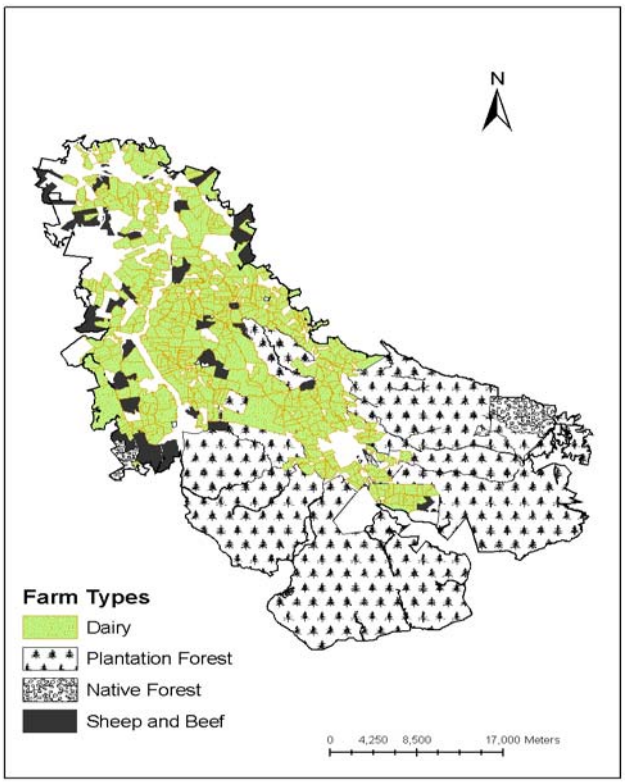


Figure 4: Major Soil Types in the Study Area

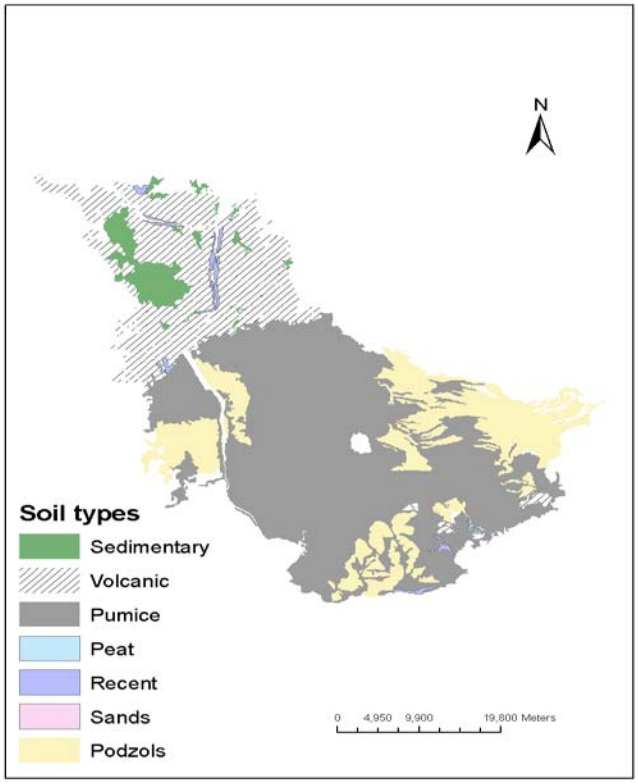
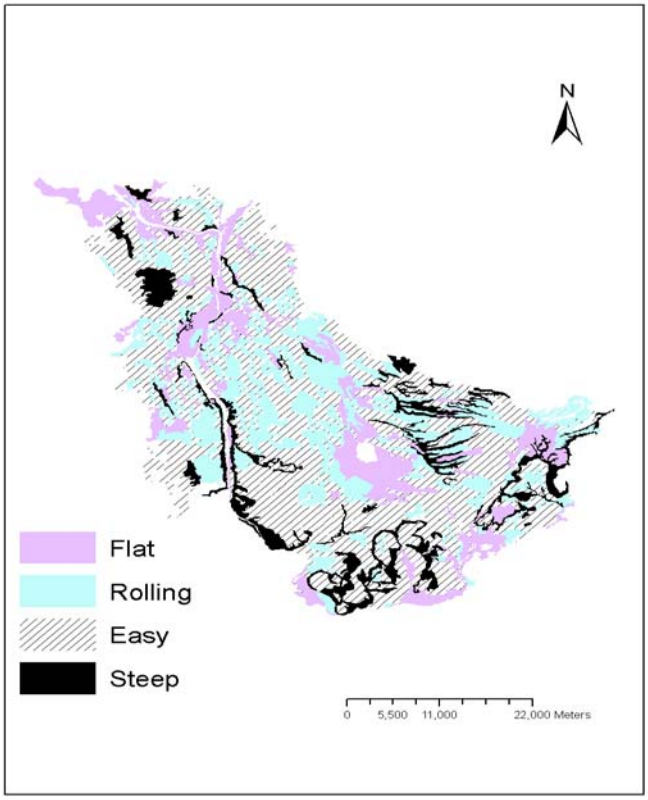


Figure 5: Topography of the Study Area



Availability of a number of trading partners is important for the success of nitrogen trading. In the presence of a low number of trading partners trading markets may fail (Crutchfield & David, 1994). This sub catchment has 370 dairy farms, 62 beef farms, 37 Sheep and beef farms, 11 sheep farms and 6 forest owners.

5. 2 Economic Analysis

An attempt has been made to estimate the costs of nutrient reduction from dairy farming activities under alternative policies in terms of best management practices. Specifically, the impact of recognising differences in spatial characteristics is explored. Spatial differences influence the effectiveness in terms of marginal abatement costs of reducing nitrogen discharge. The base case solution is generated using economic and geophysical data from the study region in the absence of nitrogen discharge restrictions. The method can be used to find the distribution of marginal abatement cost at the catchment level.

Returns from farming activities under various management practices and respective nitrogen discharges are denoted in the table 1. Farm returns are calculated based on the Whole farm model simulation. Nitrogen discharges are simulated using the Overseer. Winter pads lead to negative economic farm surplus at a lower stocking rate (1.9). Among the best management practices grazing off seems to be more profitable at high stocking rate. Stand off pads are more profitable at a lower stocking rate.

Table 1: Nitrogen Discharges and Economic Returns

Joint activity	Soil type and Slope	Standard		Best Management Practice Grazing off		Winter pad		Stand off pad	
		Net Returns	Discharge	Net Returns	Discharge	Net Returns	Discharge	Net Returns	Discharge
180 N- 3.1 SR*	Flat- Sedimentary	1286	45	1207	31	736	33	1107	35
	Easy- Pumice	1222	54	1147	28	699	48	1051	50
130N- 2.5 SR*	Flat- Sedimentary	892	33	717	23	534	25	748	26
	Easy- Pumice	847	46	681	23	507	36	710	38
70N- 1.9 SR*	Flat- Sedimentary	184	22	46	15	-ive	16	74	18
	Easy- Pumice	175	32	44	15	-ive	24	70	26

*N- Nitrogen Fertilizer, SR- Stocking rate

Results from the economic model are tabulated in tables 2, 3 and 4. Scenarios simulated are farm in Flat Sedimentary landscape with and without grazing off best management practice and farm on a Easy- Pumice landscape. Optimum activity sets are chosen by the model when the level of nitrogen discharge is parametrically restricted. The results of the economic model shed light on scenarios, which are potentially viable. Selection of more than one set of activities reveals the importance of considering intra farm variability in production and pollution parameters. Selection of same stocking rate with standard and grassing off indicates an ideal solution of practical relevance i.e. grazing off a fraction of cows would lead to an effective reduction of nitrogen discharge.

When nitrogen reduction is further constrained the extent of land under farming tends to shrink. When the land area is fixed to its full extent, profits tend to be lower still. At the 40% reduction of nitrogen discharge, 87 ha of the land 100 ha farm is stocked with 3.1 stocking rate. It paves the way for many options. The first option is to establish riparian buffers or wet lands within the farm in the most sensitive and less productive areas of the farm, which potentially reduce the nitrogen discharge from the farm by a set aside smaller than 13 ha and still be within the nitrogen discharge constraint. The second option is that farmer can diversify farm business into other enterprises with less nitrogen discharge potential like forestry or Sheep/ Beef farms. The third option can be diluting the stocking rate. That is spreading the livestock numbers for 87 ha into 100 ha. This makes the stocking rate of the farm into 2.5 animals per ha thus reducing the nitrogen discharge. Selection of activities by the model is totally based on the relative economic returns of the activities. These can vary depending on the situation. In some places stand off pads may be more economically efficient and environmentally effective rather than grazing off. In some circumstances a farmer may not be able to adopt the practice of grazing off or grazing off may relocate the problem of nitrogen discharge from one farm to other

within the catchment. Therefore a scenario without the grazing off option is simulated for a flat sedimentary landscape farm (Table 2). Therefore a farm can also be heterogeneous in adopting suitable technologies apart from heterogenity in productivity and pollution potential.

Table 2: Optimal Solutions under Different Nitrogen Restriction Scenarios (Flat-Sedimentary)

Nitrogen Reduction (%)	Nitrogen discharge Kg N/Year	Economic Farm Surplus (NZ$)	Activities (ha)	
			180N-3.1 Standard	180N-3.1 GO*
0	4500	128600	100	
10	4050	126061	68	32
20	3600	123521	36	64
30	3150	120982	4	96
40	2700	105125		87
50	2250	87605		73
60	1800	70084		58
70	1350	52562		44
80	900	35041		29

*GO- Grassing off

Table 3: Optimal Solutions under Different Nitrogen Restriction Scenarios (Flat-Sedimentary) –Without grassing Off.

Nitrogen Reduction (%)	Nitrogen discharge Kg N/Year	Economic Farm Surplus (NZ$)	Activities (ha)		
			180N-3.1 Standard	130N-2.5 Standard	180N-3.1 Stand-off Pad
0	4500	128600	100		
10	4050	120536	55	45	
20	3600	112473	10	90	
30	3150	99613			90
40	2700	85384			77
50	2250	71153			64
60	1800	56922			51
70	1350	42692			39
80	900	28461			26

Table 4: Optimal Solutions under Different Nitrogen Restriction Scenarios (Easy- Pumice)

Nitrogen Reduction (%)	Nitrogen discharge Kg N/Year	Economic Farm Surplus (NZ$)	Activities (ha)	
			180N-3.1 Standard	180N-3.1 GO*
0	5200	122200	100	
10	4680	120575	78	22
20	4160	118950	57	43
30	3640	117325	35	65
40	3120	115700	13	87
50	2600	106507		93
60	2080	85205		74
70	1560	63904		56
80	1040	42602		37

*GO- Grassing off

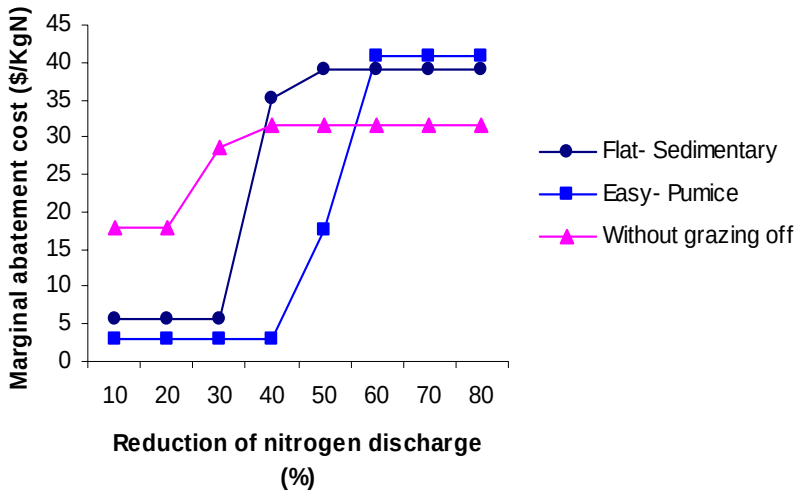
The results presented above provide the basis for the marginal abatement cost per kg of nitrogen discharge reduction as the change in returns divided by the change in discharge levels.

$$MAC = \frac{\Delta R}{\Delta D}$$

Where R is returns from farming and D is nitrogen discharge. The above formula is used to derive marginal abatement cost curve (Figure 6). Even at initial levels of abatement there is a difference in the marginal abatement cost between spatial locations. We would be able to get more precise results if geo spatial factors are properly incorporated into the whole farm model simulation. The results demonstrate that the farms with the highest discharge rates are also the farms with lowest abatement cost at the initial levels of abatement. The costs of pollution reduction are not uniform even within the same type of farms. Consistent with theory, marginal abatement costs increase when the rate of reduction in discharges increases. Relaxation of the nitrogen discharge target significantly lowers the cost of abatement. It implies substantial opportunity costs of high level of nitrogen reduction. In one or two instances at higher levels of nitrogen discharge reduction flat sedimentary lands seem to be cost effective. It should be noted 80% discharge reduction in both landscapes are not same in absolute terms as they are percentage of the initial level of discharge. The precision of the results can be improved by simulating more activities at a continuous scale. Further the objective of the economic model presented here is maximising farm profit rather than minimizing the abatement cost.

Differences in marginal abatement cost possess the potential to drive the nitrogen discharge trading. The economic incentives to trade can be increased up by stringent regulation of nitrogen discharges. The model could be used to identify geographic zones within the catchment, where nitrogen trading systems can be established.

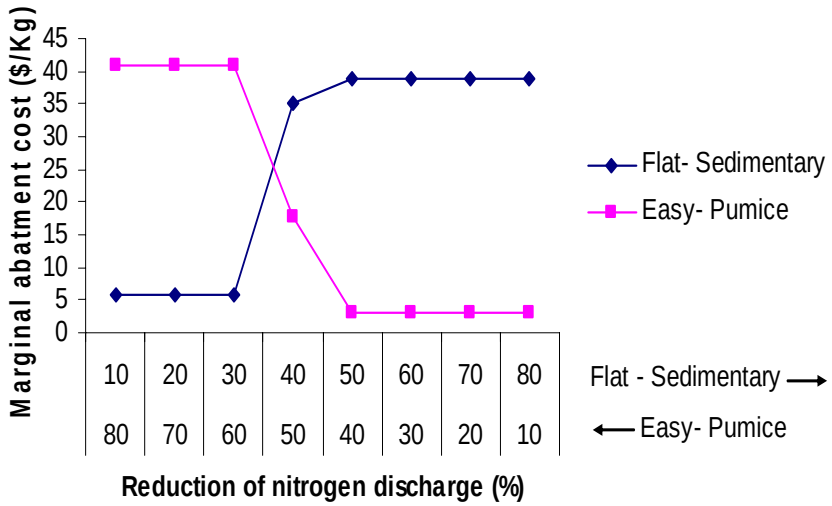
Figure 6: Marginal Abatement Cost of Different Farms



5. 3 Tradable Discharge Permits

A nitrogen source can choose to reduce its own nitrogen discharge or to pay a source with lower costs to reduce its nitrogen load. The results support the concept of nutrient trading. Under a trading scheme, sources facing higher marginal abatement cost of nutrient reduction could pay sources with lower marginal abatement costs to reduce nitrogen discharges. For instance flat-sedimentary farm can abate less than 50% of nitrogen discharge and farm with easy-pumice soil can abate more than 50% of nitrogen discharge (Figure 7).

Figure 7: Cost Effectiveness of Discharge Permit System



6. Conclusions

Designing efficient agri- environmental policies for agricultural nutrient discharge reductions requires information on the cost of reduction. This study develops an analytical framework for estimating abatement costs for nitrogen discharges and potential for trade in a Waikato river sub-catchment. The framework developed in this paper can be used to determine which areas of the catchment need to be targeted for nitrogen trading systems to be established. Exploiting the knowledge of heterogeneity across the polluting sources improves the overall efficiency of budget allocation to abatement efforts and thereby further reduce pollution damages (Farzin & Kaplan, (2004). Spatial policy modelling approach is useful to identify relatively low cost nitrogen reduction areas. It provides valuable information for farmers and policy makers. The results presented here are indicative only, and are limited by the specification of technical coefficients and price/cost relationships. If production data of the farms are known, farm level abatement costs function could be constructed. The ability to predict the abatement costs would ensure smooth functioning of nitrogen trading markets and thus may reduce the transaction costs. An environmental authority can concentrate its monitoring and activities to the areas where the pollution reduction is cost effective.

7. Implications for Future Research

Cost effective nitrogen reduction for any location in a catchment involves careful geographic and source specific selection of farms. Bio economic modeling can be used to developing this least cost strategy. The model specified here can be augmented to accommodate nitrogen transport from land parcels to the main water body. For instance, it may be more appropriate to select farms with lower marginal abatement cost of nitrogen reduction rather than at the point of discharge but at the receptors.

There are uncertainties which are scientific, mainly driven by variations in precipitation; and economic and policy (policy uncertainties involve in future policy changes, land use changes and regulatory changes. Therefore it is essential to develop stable institutions for the implementation of environmental policies. Uncertainty is particularly pronounced in evaluating nonpoint pollution, this necessitate the incorporation of stochastic elements into the model.

In line with the envisaged targets of the water quality, this type of approach needs to be coupled with research focussing on market and non-market values arising from potential water quality policy implementation. (Bennett, 2005) also stressed the importance of building a cost benefit framework into bio-economic modeling which supports the development of policies.

In designing environmental policy transaction costs are important**.** The importance of case by case evaluation of the transaction costs of various environmental policies has been stressed by (Stavins, 1995). Therefore policy choice and policy design needs to take account of transaction costs in order to increase the efficiency and sustainability of policies.

Even though site specific characteristics are incorporated into the Overseer model, they have not been fed into the Whole Farm Model. Further it is assumed that each

farm has homogeneous soil and topographical characteristics. Relaxing this assumption to allow intra farm heterogeneity may give more precise results.

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