Evaluating the impacts of Nitrate Vulnerable Zones on the environment and farmers' practices: a Scottish case study[1]

ABSTRACT *Nitrate Vulnerable Zones (NVZs) have been established throughout Europe to tackle diffuse pollution. This research investigates the attitudes and practices of farmers in the River Eden catchment, within the Strathmore and Fife NVZ in eastern Scotland, and explores how these changed between 2002 and 2011. Attitudes were investigated using interviews; efficiency of nutrient use was evaluated using farm-gate nutrient budgets (NBs). Most of the 16 farmers regard NVZ regulations as burdensome and costly; however, attitudes to NVZs became more positive during the period. NBs demonstrated arable farms generate the least nitrogen (N) and phosphorus (P) surpluses, dairy the most. N efficiency improved on nine farms and declined on two; P efficiency improved on 12 farms and declined on two. Overall, the 16 farms were using 13% less N and 19% less P in 2011 compared with 2003. Water quality data demonstrates Nitrate N in the catchment's main rivers dropped between 2004 and 2011 by a mean of 15.5%, whereas mean phosphate P declined very little. Legacy P and inefficient sewerage treatment facilities may explain the latter finding. Results demonstrate that NVZ regulations, combined with economic pressures, have affected farmers' attitudes and behaviour, resulting in significant improvements in surface water quality.*

KEY WORDS: Nitrate Vulnerable Zones, farmers, attitudes, nutrient budgets, Fife, Scotland

Introduction

Diffuse pollution caused by intensive agricultural practices has long been recognized as a significant environmental issue (Hutchins 2012), and in particular the excess enrichment of surface and ground waters with nitrogen (N) and phosphorus (P). Worldwide, diffuse sources are the main polluters of waterways, not least because of the significant difficulties of regulating diffuse pollution (Doole *et al*. 2012). In 1991, the European Union (EU) took action to address this problem by introducing pollution control measures under the Nitrates Directive (91/676/EEC). The subsequent EU Water Framework Directive (WFD) of 2000 requires member states to improve the health of freshwater ecosystems and avoid eutrophication, and has identified diffuse water pollution from agriculture as a priority issue (Barber & Quinn 2012). Yet diffuse agricultural pollution remains a significant factor preventing many water bodies from achieving the WFD's objective of Good Ecological Status (Sutherland *et al*. 2010) because modern intensive agriculture is 'N-dependent but leaky' (Howden *et al*. 2013, p. 397). Under the Nitrates Directive, Nitrate Vulnerable Zones (NVZ) have been established throughout the EU in places where 'surface freshwaters…contain or could contain 50 milligrams per litre (mg l^{-1}) nitrates' (ANNEX I, A1, 91/676/EEC, 12 December 1991). Stricter management controls are enforced inside NVZs in an effort to prevent further nitrogen pollution.

Within the UK, NVZs now cover 62% of the land area of England (Environment Agency, 2011 *in* Howden *et al*. 2013), but the lower proportion of intensive agriculture in Scotland has resulted in just 14% of the land area being designated (Scottish Government 2012). Four large NVZs were established in eastern and southern Scotland in 2003, namely: (i) Moray, Aberdeenshire, Banff and Buchan; (ii) Strathmore and Fife; (iii) Lothians and the Borders; and (iv) Lower Nithsdale. These incorporate over 12,000 farms, representing nearly 25% of all agricultural holdings (Scottish Government 2012). The Action Plan for NVZs which was

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in force at the time of this study was introduced in 2009.[1] The rules specified in this Plan can be summarised as follows:

- Limits on the quantity of nitrogen (N) applied.
- Restrictions on the timing of N applications (closed periods), together with certain other restrictions on N application.
- Storage requirements for slurry, poultry manure and farmyard manure.
- Record-keeping requirements (including preparation of a Fertiliser and Manure Plan).

The Scottish Government publishes guidelines for farmers in NVZs which provide general and technical information to help farmers comply with these requirements.

The work reported here, building on an earlier study by Macgregor and Warren (2006), was carried out in the catchment of the River Eden which lies within the Strathmore and Fife NVZ (Figure 1). The catchment covers an area of approximately 320 km^2 (TRPB 1994), the majority of which (some 260 km^2) is drained by the River Eden. The River Eden itself rises in the Ochil Hills, not far from Loch Leven at around 220 metres above sea level, and the majority of the catchment is low-lying and gently undulating. Most of the agricultural land can be characterised as high quality with very fertile soils or imperfectly drained brown forest and alluvial soil types (ECN 2015). Annual rainfall over the catchment varies from approximately 1,000 mm in the upper catchment to around 600 mm at the Eden Estuary (TRPB 1994). At the river's mouth is the Eden Estuary Local Nature Reserve which is regarded as an important over-wintering site for wildfowl and waders (ECN 2015).

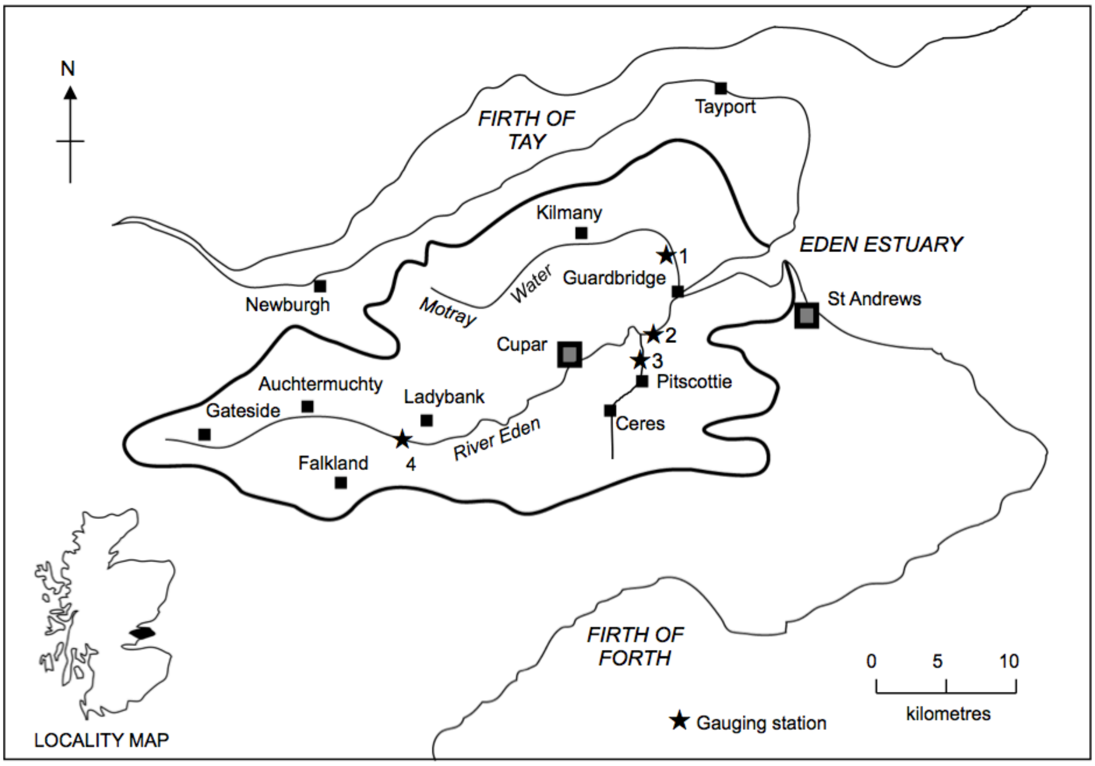

Figure 1 River Eden Catchment, Fife, Scotland

Farmers in the Strathmore and Fife NVZ have had to comply with NVZ regulations since 1st August 2003. The earlier study by Macgregor and Warren (2006) was carried out in 2002, just before the formal designation, at a time when farmers were preparing for the new regulations. In-depth interviews with a representative sample of 30 farmers explored farmers' awareness of the environmental effects of their farming practices, their perceptions of the likely impacts (financial, practical) of adhering to the regulations, and their broader attitudes to environmental legislation and to environmentally sustainable practices. Later, in June 2003, the same authors carried out farm gate nutrient budgets with 29 of these farmers (Macgregor *et al*. 2004).

Given the high-profile nature of the EU Nitrates Directive and the controversy which surrounded the creation of Scotland's NVZs, it is surprising that few other studies have been undertaken to evaluate the effectiveness of the legislation or the responses and attitudes of farmers to it. Indeed, worldwide there has been limited investigation of farmers' responses to compulsory water quality management schemes (see Barnes *et al*. 2011). Yet it is widely acknowledged that farmers' attitudes and perceptions are a critical component of policy delivery. This is because, notwithstanding the overarching bureaucratic framework of agricultural regulations, incentives and policy aspirations, what actually happens on the ground is the product of myriad decisions by individual farmers (Cope *et al*. 2011). Macgregor and Warren (2006, p. 109) portray the multi-layered edifice of agri-environmental regulations as a large, inverted triangle with farmers sitting underneath the sharp end; 'they are the actors responsible for the practical delivery of…environmental aspirations for Europe's rural areas'.

However, all too often there is a disconnection between policy design and the stakeholders who are expected to put policy into effect (Warren 2014). Policies frequently fail to take full account of the characteristics of the target audience, as research into the adoption of innovation by farmers has shown (White *et al*. 2009; Sattler & Nagel 2010). Of particular pertinence to this study are the many investigations of the mismatch between the aims of agri-environmental policies and farmers' values and motivations (Wilson 2001; Burton *et al*. 2008). Numerous barriers have been identified which impede the adoption of sustainable and/or conservation-orientated agricultural practices (Rodriguez *et al*. 2008; Moon & Cocklin 2011). A barrier that is often highlighted is the characteristics and attitudes of the farmers themselves, including a frequently noted resistance to change (Burton *et al*. 2008). Farmers' perceptions of nature, the land and conservation are typically very different from the 'conservation science' perspective which informs policy-making (Beedell & Rehman 1999; Morris 2006; Sutherland 2010). Most farmers see themselves primarily as food producers, and resist the idea, promoted through agri-environmental policies, of their becoming environmental managers (Macgregor & Warren 2006), although some evidence suggests that a pro-environmental shift in attitudes is underway in some places (Sutherland 2010).

A key conclusion from this literature is that an understanding of farmers' attitudes is important because their choices, and hence environmental outcomes, can only be explained when their attitudes are considered (Willock *et al*. 1999) and when the complex relationship between attitudes, behavioural intentions and decisions is understood (Burton 2004b; Edwards-Jones 2006). Agricultural systems are now recognised as being intricate social-ecological systems, and so the effectiveness of policies depends on a thorough understanding of the attitudes and behaviour of farmers who are the key actors (Feola & Binder 2010; Sattler & Nagel 2010). Because environmental outcomes in agricultural regions are largely determined by farmers' decisions, policy targets will only be achieved when farmers choose to adopt new practices. Self-evident as this might seem, it is striking that policy formulation has a tendency to ignore it (Burton 2004a).

As noted above, research investigating the responses of Scottish farmers to the NVZ regulations has been limited. However, following the study by Macgregor and Warren (2006), Sang and Birnie (2008), Barnes *et al*. (2009, 2011) and Blackstock *et al.* (2010) have explored farmers' behavioural responses to water quality improvement measures, including NVZs. Barnes *et al*. (2009, 2011) undertook a telephone questionnaire survey of 184 farmers across all four Scottish NVZs. They found a range of negative attitudes, including antagonism towards environmental regulations (viewed as burdensome and costly), an avoidance of responsibility for water pollution and a belief in the importance of maximising production. This conforms with other studies that have also reported negative attitudes towards water quality regulations, together with a scepticism of the underlying science and a resentment towards national or supra-national 'one-size-fits-all' rules which ignore regional variations (Macgregor & Warren 2006; Sang & Birnie 2008). However, some farmers in the Barnes *et al*. (2011) study showed an awareness of the importance of water quality issues (for both self-motivated and more altruistic reasons), a willingness to take action to protect the environment, and a commitment to the careful management of nitrogen. These more engaged farmers were dubbed 'multifunctionalists', as opposed to the 'resistors' and 'apathists'. Most farmers in all three groups, though, had made some changes to their water management practices since the NVZ designation, most commonly by fencing off livestock from watercourses and creating buffer strips.

The research reported here is a contribution to understanding the critical linkage between policy objectives and delivery, focusing on the practical and perceptual responses of farmers to one specific agri-environmental instrument, the NVZ. The research objective was to re-visit the farms surveyed in 2002 and 2003 by Macgregor and Warren (2006), interview the farmers to ascertain their current attitudes to NVZ designation, and evaluate the efficiency of their nutrient use by undertaking farm-gate nutrient budgeting. The key questions addressed by this follow-up study are:

1. Did farmers' attitudes towards environmental legislation generally and the NVZ regulations specifically alter between 2003 and 2011, and if so, how and why?
2. Were there any improvements in nutrient use (i.e. increased efficiencies)?
3. Has there been any improvement in water quality (nitrate N and phosphate P) in the major rivers of the catchment following NVZ designation?

Methods

The methods employed in this study differed for each of the questions above: data collection for Q1 involved interviews with the farmers; nutrient budgeting was employed for Q2; and, water quality data were obtained from the Scottish Environment Protection Agency (SEPA) to inform Q3.

Sampling

In Macgregor and Warren's (2006) earlier work, which began in 2002, farmers were selected using a stratified sampling procedure, which considered the location, type and size of farms in the Eden to achieve a broadly representative sample of 30 of the approximately 130 farms in the catchment. The total area covered by the sampled farms was 8,012 ha, equivalent to approximately 33% of the farming area of the catchment. The median farm size for these farms was 192 ha and while the distribution of farm types within the sample was not statistically representative, the stratification was approximately proportional to the whole farm population in the catchment. For the 2011 study (carried out in November and December), attempts were made to contact all 29 farmers who had fully participated in the earlier research. As anticipated, a number were unavailable for various reasons, but 16 farmers did agree to be interviewed and to have farm-gate nutrient budgets prepared for their farm.

SEPA uses monthly spot sampling to monitor surface water quality at over 230 gauging stations in Scotland as directed by the Nitrates Directive (Scottish Executive 2005). Nitrate N and phosphate P concentration data from four gauging stations located on three of the main rivers in the Eden catchment (see Figure 1) were provided by SEPA: two stations are located on the River Eden (SEPA Loc codes 8155 and 8175), one is on the Motray Water (SEPA Loc code 8192) and one is on a major tributary of the River Eden, the Ceres Burn (SEPA Loc code 8211). Monthly nitrate and phosphate concentration (mg l^{-1}) data from these stations were provided by SEPA for the period January 2004 to November 2011. Notwithstanding the seasonal fluctuations that can influence nitrate and phosphate concentrations in waterways, these data are regarded as sufficient indications of general water quality in these rivers for the eight-year period under consideration.

Interviews

Following Macgregor and Warren (2006), interviews were carried out using an interpretivist approach, the *general inductive method* (Thomas 2003); answers to specific questions were sought but considerable flexibility was retained in the discussions to enable exploration of unanticipated issues. Questions were therefore semi-structured, exploring respondents' perceptions of the following: compliance with NVZ regulations; cost and use of fertilisers; and adoption of technology in farming such as precision farming (GPS and computer-aided technology to support fertiliser application and distribution). Other questions explored farmers' attitudes to environmental management and their views about farming generally, e.g.

the so-called 'cost-price squeeze'. To provide further context to these questions, farmers were also asked whether they had made any major structural or operational changes to their farms since 2003 affecting the type of crops and/or livestock produced.

Farm-gate nutrient budgeting

The efficient use of nutrients (N and P) is desirable from both environmental and economic perspectives. Nutrient budgets (NBs) model and quantify the flow of inputs, outputs and losses of nutrients through the farming system; they may be regarded as a management tool that can help farmers (and others) identify losses which may allow management decisions to be made to reduce losses to a minimum (Sheaves 1999). There are two main methods of conducting NBs. The field-by-field method (e.g. AgResearch 2002) examines inputs, outputs and surpluses for all fields in the farm and then combines these to produce a whole-farm result. This method allows the farm manager to consider and target changes in management for individual fields. However, a more immediate and less 'data-hungry' method is the farm-gate method (Lanyon and Beegle 1989), which is appropriate when the focus is a catchment-scale analysis involving numerous farming enterprises. It was therefore the method employed in both phases of the work reported here.

There are necessarily a number of arithmetic constants incorporated into NB models and it may be argued that these compromise the precision of NB results; certainly, the final stated losses or surpluses must be regarded as estimates only. However, nutrient budgeting is an appropriate approach for the purpose of this study because the research does not seek to quantify absolute N and P surpluses from each farm with precision; rather, it aims to provide a spatio-temporal comparison of the *relative* pollution impacts from the farms across the geography of the catchment and over the two time periods, and the method provides consistent and reliable data for this purpose. Importantly, the same arithmetic constants were used for determining nutrient efficiency in both the 2003 and 2011 NBs.

Data variables required for the farm-gate NB estimates are presented in Table 1.

Table 1 Variables used in farm-gate nutrient budgets

Variable	Detail and description
Farm area	Sub-divided into crops, vegetables, pasture and non-productive areas.
Livestock	Accounts for all animals on the farm in the study period. Animal numbers are multiplied by their respective livestock unit (LU) value to determine overall carrying load. Manure and urea deposition is a function of total livestock units. Stock weight gains over the year are accounted for as outputs.
Milk production	Total for the year.
Wool production	Total for the year.
Livestock feeds	Accounts for all imported feedstuffs of any kind, noting the N and P values of the different feeds.
Roughage	Hay, silage or straw imported or exported from the farm.
Crops and seeds	Seeds and/or plant seedlings brought onto the farm and their weight and N and P content, plus crop yields with their respective N and P contents.
Organic manure	Farmyard manure (FYM) and/or slurry that is either imported to or exported from the farm, noting N and P levels.
Fertilisers	All mineral fertilisers used on the farm, with their respective N and P concentrations.
Legumes	Type of legume and production area
Deposition	Estimated total annual deposition of N

Results

Results are presented in three sub-sections corresponding to the three research questions, namely the data from the interviews, the data from the nutrient budgets, and the water quality data.

Interview findings

Farmers constantly adjust their enterprises for many reasons, but as business people they cannot ignore the financial bottom-line. Consequently, many framed their responses to the interview questions around fluctuations in commodity prices, perceived rising costs and lowering profits. Six main themes emerged from the interviews: compliance with NVZ regulations; cost and use of fertlilisers; adoption of precision farming technology; attitudes to environmental management; cost-price squeeze; and, farm structural/operational changes.

Compliance with NVZ regulations

As Macgregor and Warren (2006) found in the 2003 interviews, most of the concerns expressed about NVZ compliance came from farmers operating dairy and to a lesser extent mixed farming enterprises. It is notable that two of the three dairy farmers in the 2003 study were no longer dairying by 2011. Their reasons for opting out of dairying were (a) they felt it was no longer economically viable and (b) the investments necessary to make their slurry and farmyard manure (FYM) storage comply with NVZ requirements were too costly. However, the one remaining 2011 dairy farmer had opted to expand his dairy operation, investing in a new milking facility that will allow him to double the size of his herd, and he had also made the investment necessary to improve his slurry storage.

Most of the 13 non-dairy farmers thought that NVZ requirements were having some impact on production, as the following three comments exemplify:

> 'There's restrictions on applications and timing, which I do think impact on my crops – sometimes they look a bit sickly.'
> 'Some of the limits are a bit low – especially for potatoes.'
> 'For the broccoli, we can't give it the N it really needs.'

However, these farmers were clearly far less affected than the dairy producers. Other farmers also commented on the inconvenience and time involved in record keeping; in the opinion of one farmer, 'record keeping is pretty demanding. I used to spend 95% of my time on the farm and 5% in the office – now it's more like 70% on the farm and 30% in the office'.

The majority of responses concur with Barnes *et al.*'s (2009, 2011) findings that adherence to environmental regulations is regarded as burdensome and costly. However, not all the farmers interviewed in this study expressed negative views about NVZ status; indeed, five out of the 16 interviewed appeared to be quite accepting of the NVZ regulations, as illustrated by the following statements:

> 'NVZ doesn't really impact on how we grow our crops – it's fairly easy for us to stay well below the limits.'
> 'We have to be more careful about the quantities and timing but it's not affected our yields that much.'
> 'I actually thought NVZ would be more stringent but if anything it's gone the other way – I'm actually pleasantly surprised.'
> 'I don't think it's all bad – it's a tool to work with.'

One farmer expressed the view that the required record keeping was not, in fact, unduly burdensome: '…it [NVZ] is not an issue…the paperwork is just something you have to do but I don't mind too much and I do my own manure and fertiliser management plans'.

Cost and use of fertilisers

Most of the 16 farmers were quick to confirm that fertilisers were one of their more significant input costs. Many commented that the cost of fertilisers had tripled since 2003 – from around £150/tonne to over £450/tonne by 2011. This rising cost had clearly influenced farmers' thinking and even their use of fertilisers, as the following comments illustrate:

> 'It's forced me to cut back. I've been giving some fields an NPK holiday – fertilising every two years instead of every year.'
>
> 'We now use liquid fertilisers, which I find are easier to control…the last thing I want is to see it go anywhere except on the crops where it's needed.'

One farmer felt that fertiliser manufacturers had been using the higher commodity prices to exploit farmers: 'Wheat prices have gone up to over £200/tonne but the cost of fertiliser has followed; basically, the manufacturers have capitalized on the higher grain prices and have shafted us'.

Adoption of precision farming technology

Another indicator of the impact of fertiliser costs, and probably also of NVZ status, has been the rise in the use of precision farming technology since 2003. Four of the 16 farmers that took part in the 2011 study had adopted such technology since 2003. However, the switch to precision farming also involved a significant financial investment in new equipment (GPS, computers, tractors etc.), and in three of the four cases larger tractors had been introduced which also encouraged fence removal. One farmer commented, 'I now have 10 fields of about 35 acres whereas before I had 16 fields of about 20 acres'. Another said, '…now that we've got larger machines we've had to take out some fences – one field is now over 50 acres…all this is helping maintain profits but…', he added, 'I won't take out fences where there are conservation values'.

Farmers' attitudes to environmental management

Changing farmer attitudes towards environmental management is evident from a number of comments that emerged from the NVZ question (see above) but the majority of farmers (12 out of 16) also demonstrated changed attitudes in other discussion contexts. The following comments reflect not just a change in attitude but also active responses to that change:

> 'We need to respect the countryside… We're custodians and I try to remember this when I use sprays…the 'cheap and cheerful' approach just won't do any more.'
>
> 'I now know not to place a midden [FYM store] next to a ditch – that wasn't something I thought about before…I don't use sprays within five metres of a watercourse either… not that it's a NVZ concern, but I try not to use insecticides either if I can.'

Significantly, three responses suggest that NVZ status specifically had directly influenced changes in attitudes:

> 'The price of fertiliser has definitely been a factor that has forced our thinking but so has NVZ requirements.'
>
> 'I'm certainly much more aware of water quality issues than I used to be – partly because NVZ has influenced my thinking.'
>
> 'NVZ requirements have probably helped wake us up to some of the excesses of the past.'

Cost-Price Squeeze

As indicated above, fertiliser costs had risen significantly in the eight years prior to 2011 but commodity prices also went up significantly over the same period. Historically, the prices of commodities and inputs have fluctuated considerably and while it is not the intention of this paper to explore the debate surrounding agricultural terms of trade, the perceptions and views of farmers concerning a cost-price squeeze are relevant in as much as these may influence thinking about fertiliser use and management practices more generally.

The rising cost of fertilisers was discussed above but farmers also commented on the rise of other input costs, in particular, livestock feeds and fuel. For example:

> ‘Potato prices have changed enormously recently, and were very good last year, but fuel has also gone up – red diesel has gone up hugely in the last few years from about £0.25/l to nearly £0.80/l.’
>
> ‘There was a jump in cereal prices in 2008 on the back of uncertainty over supply… We were getting £85/tonne in 1997 but by 2006 it had gone up to £180/tonne…but the input costs have gone through the roof so I don’t think most farmers would be any better off.’

This last view was shared by another farmer who said:

> ‘Commodity prices have gone up quite a bit but the costs have soared…we still need every penny we can get.’

Farm structural/operational changes

There were two generic changes evident on most farms. First, all had done away with set-aside (farmland taken out of production) and all said they had done so because under the reformed Common Agricultural Policy (CAP) set-aside was no longer a requirement for receiving the single-farm payment. Since 2003 all 16 farmers had put all land that was once in set-aside back into production. As one farmer explained, ‘At one time we had as much as 30% of the farm in set-aside but then we cut back to about 10%, then 5%, finally, none at all.’ He conceded that rotational set-aside effectively meant he had fallowed his fields, which he acknowledged was probably good for soil health and regeneration. Secondly, four farmers had invested in improved technology, which for many also involved larger machinery.

As indicated above, the farmers that had introduced the greatest structural/operational changes were the dairy farmers, with two of the three 2003 dairy farmers opting out of dairying altogether. Significantly, one of the ex-dairy farmers had installed a fully automated milking facility that included a robotic milking machine. The installation of this facility had involved a very considerable investment, and the decision to get out of dairying and sell this facility perhaps testifies to the scale of the challenges facing dairy farmers. However, this farmer emphasized that his decision to get out of dairying was entirely due to the volatility of milk prices and the poor profits he was obtaining from dairying and had nothing to do with NVZ status. The other ex-dairy farmer had extended the vegetable production side of his business and was also investing in a vegetable value-adding (food processing) enterprise. He too indicated that the main reason for getting out of dairying was milk price volatility, combined with generally poor profits.

Findings from nutrient budgets

The findings from the 2003 NBs (Macgregor *et al*. 2005) have not previously been published. Consequently, these findings are first summarized before presenting the results from the 2011 NBs.

The 2003 nutrient budgets

Table 2 provides details of N and P surpluses together with their respective efficiencies for all 29 participating farms in the 2003 study.

Table 2 Farm nitrogen (N) and phosphorus (P) budgets for 29 farms in the Eden Catchment, 2003

Farm ref.	Farm type (A, M, D)[1]	Area farmed (ha)	Surplus nitrogen (kg N/ha)	N efficiency (%)	Surplus phosphorus (kg P/ha)	P efficiency (%)	Catchment pollution potential (N & P)[2]
1	M	68.8	117	21	19	25	Low
2	A	89.8	74	65	7	78	Low
3	M	323.8	118	51	10	73	High
4	M	136.0	61	71	0	99	Low
5	M	145.2	79	58	17	55	Medium
6	D	170.7	316	13	36	20	High
7	D	192.0	370	17	26	34	High
8	A	91.0	77	52	0	97	Low
9	A	340.0	51	68	6	76	Medium
10	M	498.3	97	27	14	36	Very High
11	M	266.9	138	37	-11	207	Medium
12	D	1235.0	112	43	15	55	Very High
13	M	198.3	106	62	19	66	High
14	M	280.4	58	56	8	64	High
15	A	573.5	56	63	9	65	Very High
16	M	560.0	99	36	2	84	High
17	M	365.0	111	20	17	23	High
18	M	186.2	116	41	18	45	Medium
19	A	95.4	83	48	11	57	Low
20	M	472.0	116	36	6	69	Very High
21	A	137.6	51	73	5	84	Low
22	M	119.6	120	36	4	78	Low
23	M	393.4	159	28	12	51	Very High
24	A	198.0	54	72	13	64	Medium
25	M	252.7	48	69	10	68	Medium
26	A	130.9	263	30	-3	124	Medium
27	M	428.7	83	49	3	79	High
28	A	182.4	45	82	0	101	Low
29	M	256.5	84	66	12	75	High

[1] A = Arable (crops) only; M = Mixed farming; D = Dairy

[2] Catchment pollution potential is the total farm N & P surpluses multiplied by the proportion (%) of the catchment the farm occupies. Total farm N & P surpluses categories are derived from natural breaks in the total surplus data and are as follows:

<9,999 kg N and <999 kg P:	Low
10,000 to 24,999 kg N and 1,000 to 2,999 kg P:	Medium
25,000 to 99,999 kg N and 3,000 to 9,999 kg P:	High
>100,000 kg N and >10,000 kg P:	Very High

The surplus N and P values (kg N/ha or kg P/ha) indicates how much potential diffuse pollution is emerging from the farms and consequently are indicative of the relative pollution impact that the farms are having on the watercourses of the catchment. However, the N and P efficiency (%) values may be considered more informative indicators in NBs because these show how well the farm is actually utilizing the N and P inputs. Negative values arise if the amount of N or P exported from the farm is greater than that being imported. In such cases efficiency values will be >100% (e.g. P for farms 11, 26 and 28).

Together the 29 farms showed a total surplus of 901,171 kg N for the year under consideration (beginning of November 2001 to the end of October 2002). The mean N surplus from the 29 farms was 112 kg N/ha (48% efficient). The total amount of P surplus from all farms amounted to 84,040 kg P for the year. The mean of 10 kg P/ha (71% efficient) compares favourably with the UK mean annual surplus of around 16 kg P/ha (Merrington *et al*. 2002).

It has been found in previous NB studies that the quantities of nutrients used and the relative efficiencies of their use vary according to land use i.e. types of crops – whether they are vegetable, grain and/or livestock (e.g. Domburg *et al*. 2000; Drinkwater 2005; Cherry *et al*. 2012). Table 3 summarises the data from the 2003 NBs according to farm type.

Table 3 Mean nitrogen (N) and phosphorus (P) surpluses & efficiencies for 29 farms in the Eden Catchment, 2003 according to farm type

Farm type	Surplus nitrogen (kg N/ha)	N efficiency (%)	Surplus phosphorus (kg P/ha)	P efficiency (%)
Arable (crops) only (n = 9)	83.7	61.4	5.4	82.9
Mixed farming (n = 17)	100.6	44.9	9.4	70.0
Dairy farming (n = 3)	266.0	24.7	25.6	39.7

Data from the 2003 Eden study generally support the findings from other similar studies – that arable farms generate the least N and P surpluses while dairy farms produce the most (Table 3). Dairy farming is a major source of nitrate leaching in many countries around the world (Doole *et al*. 2012). In this study, the three dairy farms contributed more than 29% of the total 901,171 kg N surplus from all 29 farms. By contrast, the nine arable farms contributed less than 15% of the total.

The 2011 nutrient budgets

Table 4 combines NB data from both the 2003 and 2011 periods and indicates which of the 16 farms have improved efficiency of N and P use.

Collectively the 16 farms showed a total surplus of 452,702 kg N for the year (December 2010 - November 2011). Unsurprisingly, this is approximately half the total surplus from the 29 farms in the 2003 study. More significantly, Table 4 demonstrates some very significant improvements in N and P efficiency between 2003 and 2011. The mean N surplus from 2011 was 95 kg N/ha (56% efficient), compared with 112 kg N/ha (48%) in 2003. At the farm level, nine farms demonstrated improved N efficiency (>5%) in 2011 compared with just two that demonstrated a decline (<5%). With P, twelve farms demonstrated improved efficiency (>5%) compared with two that demonstrated a decline (<5%).

Four farms demonstrated >21% improvement in N efficiency since 2003 (farms 5, 6, 16 and 26) but it is noteworthy that there were significant changes to two of these enterprises. Farm 6 was a dairy farm in 2003 but a mixed farm in 2011 and while farm 26 has been classed as an arable farm in both time periods, a large part of its production in 2003 was vegetables but in 2011 it was cereals only.

The total amount of phosphorus surplus in 2011 from the 16 farms amounts to 37,992 kg P for the year. The farmers involved in the 2011 study achieved an overall mean surplus of 6 kg P/ha (compared with 10 kg P/ha in 2003) and collectively the 16 farms were 110% efficient. This somewhat unusual level of P efficiency has arisen principally because one farm (farm 6) exported an extraordinarily high amount of P in the form of vegetables. Nevertheless, as Table 4 testifies, it was not unusual in 2011 for P outputs to be greater than inputs; five of the 16 farms were >100% efficient with P. The reasons why these five farmers were managing their P in this manner did not emerge during the interviews, which were carried out prior to the NBs, but it seems likely that they felt there were sufficient reserves of P stored within the soil of their farms from previous years. When the cost of fertiliser was high, they effectively 'cashed in' on that reserve.

Table 4 Farm nitrogen (N) and phosphorus (P) budgets for 16 farms in the Eden Catchment, 2003 & 2011

Farm ref.	Area farmed (ha)	Year / farm type (A, M, D)[1]		Surplus nitrogen (kg N/ha)	N efficiency (%)	N efficiency trend	Surplus phosphorus (kg P/ha)	P efficiency (%)	P efficiency trend	Catchment pollution potential (N & P)[2]
4	136.0	2003	M	61	71	↗	0	99	↑	Low
	133.6	2011	M	41	77		-12	143		Low
5	145.2	2003	M	79	58	↑	17	55	↗	Medium
	145.2	2011	M	53	72		11	69		Medium
6	170.7	2003	D	316	13	↑	36	20	↑	High
	282.0	2011	M	49	74		-19	460		Medium
7	192.0	2003	D	370	17	↗	26	34	↗	High
	178.5	2011	D	304	24		16	53		High
9	340.0	2003	A	51	68	→	6	76	↑	Medium
	301.5	2011	A	56	65		-5	135		Medium
10	498.3	2003	M	97	27	↗	14	36	↑	Very High
	403.0	2011	M	97	35		4	73		High
12	1235.0	2003	D	112	43	→	15	55	→	Very High
	968.9	2011	M	96	46		14	57		Very High
14	280.4	2003	M	58	56	→	8	64	→	High
	276.3	2011	M	70	58		10	64		High
16	560.0	2003	M	99	36	↑	2	84	↑	High
	448.5	2011	M	47	57		-1	113		Medium
20	472.0	2003	M	116	36	↗	6	69	↗	Very High
	450.0	2011	M	76	54		3	84		High
21	137.6	2003	A	51	73	→	5	84	↗	Low
	134.6	2011	A	64	69		0	98		Low
22	119.6	2003	M	120	36	↘	4	78	↑	Low
	125.6	2011	M	152	26		-4	165		Low
23	393.4	2003	M	159	28	→	12	51	↓	Very High
	364.4	2011	M	219	24		46	22		Very High
24	198.0	2003	A	54	72	↘	13	64	↗	Medium
	213.0	2011	A	108	58		11	70		Medium
25	252.7	2003	M	48	69	↗	10	68	↗	Medium
	252.6	2011	M	41	76		8	76		Medium
26	130.9	2003	A	263	30	↑	-3	124	↓	Medium
	130.0	2011	A	9	93		1	94		Low

↑ = more than 21% improvement on 2003 efficiency level: For N, n=4; for P, n = 6
↗ = 6 to 20% improvement on 2003 efficiency level: For N, n=5; for P, n = 6
→ = within 5% (+/-) of 2003 efficiency level: For N, n=5; for P, n = 2
↘ = 6 to 20% decrease on 2003 efficiency level: For N, n=2; for P, n = 0
↓ = more than 21% decrease on 2003 efficiency level: For N, n=0; for P, n = 2

[1] A = Arable (crops) only; M = Mixed farming; D = Dairy

[2] Catchment pollution potential is the total farm N & P surpluses multiplied by the proportion (%) of the catchment the farm occupies. Total farm N & P surpluses categories are derived from natural breaks in the 2003 total surplus data (Table 2) and are as follows:

<9,999 kg N and <999 kg P: Low
10,000 to 24,999 kg N and 1,000 to 2,999 kg P: Medium
25,000 to 99,999 kg N and 3,000 to 9,999 kg P: High
>100,000 kg N and >10,000 kg P: Very High

Table 5 summarizes the 2011 NB data according to farm type.

Table 5 Mean nitrogen (N) and phosphorus (P) surpluses & efficiencies for 16 farms in the Eden Catchment, 2011 according to farm type

Farm type	Surplus nitrogen (kg N/ha)	N efficiency (%)	Surplus phosphorus (kg P/ha)	P efficiency (%)
Arable (crops) only (n = 4)	59.4	71.2	2.1	99.2
Mixed farming (n = 11)	88.7	54.4	6.4	120.5
Dairy / intensive livestock (n = 1)	303.7	24.0	16.4	53.0

Comparing the data in Tables 3 and 5 reveals that nearly all the surplus values for N and P decreased significantly between 2003 and 2011. The exception is the surplus N for the dairy/intensive livestock farms (266 kg N/ha in 2003 up to 304 kg N/ha in 2011). This is because farm 12, which was a dairy farm in 2003, is by far the largest farm in the sample (1,235ha). Being such a large farm, its stocking density, compared with the other two dairy farms, was low. Consequently, the surplus N was effectively skewed down for all three farms in this group in 2003 but by 2011 there was only one farm left in the dairy group with a more typical stocking density for a dairy farm in the area and consequently a more typical but higher N surplus.

River water quality

The locations of the four gauging stations where nitrate N and phosphate P concentrations were recorded are indicated in Figure 1. Table 6 presents nitrate N and phosphate P concentrations across two sampling periods – 2004 and 2011 (2010 in the case of gauging station 3). The mean nitrate N and phosphate P concentrations for the starting year (2004) are presented along with the corresponding finishing year (2011 or 2010). Table 6 also presents the nitrate N and phosphate P trend values that emerged across the two sampling periods. These trends utilize all sampling data from all years (2004 to 2011) e.g. for gauging station 1, n=93. Linear regression reveals a statistically significant lowering trend for nitrate N at all gauging stations; however, a significant lowering trend for phosphate P appears at just one gauging station (station 2).

Table 6 Nitrate (N) & phosphate (P) concentration means and trends for selected river gauging stations in the Eden Catchment (2004 – 2011)

Gauging station (ref no.)	SEPA location code	Year	Mean nitrate N (mg l^{-1})	Mean phosphate P (mg l^{-1})	Nitrate N trend (mg l^{-1} y^{-1})	Phosphate P trend (µg l^{-1} y^{-1})
1	8192	2004 2011	10.45 (n=11) 8.14 (n=11)	0.033 (n=12) 0.030 (n=11)	-0.334	-0.009
Motray W					(n=93) (R^2=0.358) (P=<0.01)	(n=93) (R^2=0.000) (P=0.99)**
2	8175	2004 2011	6.64 (n=12) 5.66 (n=11)	0.142 (n=12) 0.078 (n=11)	-0.180	-8.430
Lower Eden					(n=95) (R^2=0.311) (P=<0.01)	(n=95) (R^2=0.072) (P=<0.01)
3	8211	2004 2010*	4.04 (n=6) 3.62 (n=12)	0.062 (n=6) 0.061 (n=12)	-0.172	-1.970
Ceres B					(n=67) (R^2=0.091) (P=<0.05)	(n=66) (R^2=0.015) (P=0.32)**
4	8155	2004 2011	7.18 (n=6) 6.11 (n=12)	0.085 (n=6) 0.071 (n=12)	-0.133	-3.208
Upper Eden					(n=78) (R^2=0.156) (P=<0.01)	(n=78) (R^2=0.026) (P=0.16)**

* 2011 data was unavailable for this gauging station
** not regarded statistically significant

The Nitrates Directive, as noted above, stipulates a maximum nitrate concentration of 50 mg l^{-1} (equivalent to 11.3 N mg l^{-1}). The Scottish Executive (2005) found that nitrate levels at sites immediately to the north of the mouth of the Motray Water in 2004 were above 40 mg l^{-1} (9.03 N mg l^{-1}). In Table 6 the mean nitrate N levels for 2004 confirm that station 1, which is on the Motray Water, was close to the upper limit; however, levels at the other three gauging stations, which are on the River Eden (stations 2 and 4) and the Ceres Burn (station 3), were well below those stipulated by NVZ status (e.g. station 4: 7.18 N mg l^{-1}, equivalent to a nitrate level of 31.80 mg l^{-1}). While these data perhaps call into question the rationale for the size and extent of the Strathmore and Fife NVZ, the River Eden and Ceres Burn are only two of several rivers within the NVZ and their nitrate N concentrations may be lower than elsewhere. Importantly, however, nitrate N levels have dropped significantly since 2004 at all four gauging stations, clearly indicating that the desired improvements in concentrations have occurred.

For the River Eden, nitrate N levels are generally slightly lower in the lower part of the catchment (gauging station 2) than in the upper catchment (station 4). The Tay River Purification Board (TRPB, 1994) previously observed higher nitrate N concentrations in the River Eden in the west (10.50 N mg l^{-1}) compared with the east (7.50 N mg l^{-1}), which spatially correlates with the locations of the less nutrient efficient dairy and more intensively stocked farms. However, it is notable that phosphate P does not reflect the same spatial pattern of nitrate N; concentrations of phosphate P in the River Eden were lowest (0.06 P mg l^{-1}) in the upper part of the catchment but rose steadily to a high of 0.24 P mg l^{-1} at the estuary. As indicated by the TRPB in 1994 the likely explanation for the phosphate P distribution is point-source inputs from sewerage treatment plants on the River Eden that combined to increase phosphate P concentrations further down river. However, the spatial difference observed by TRPB in 1994 is far less apparent in 2011. Whether this change is indicative of wider changes in agricultural land use, such as the shift away from dairying in the upper part of the catchment, or other factors cannot be determined from the data acquired in this study.

Discussion and Conclusions

Water quality data provided by the Scottish Environment Protection Agency (SEPA) for the River Eden confirms that there has been nitrate and phosphate pollution in the rivers of the catchment since before 1994 when nitrate N concentrations were 10.50 N mg l^{-1} and phosphate P concentrations were 0.06 P mg l^{-1} in the western (upper) part of the catchment (TRPB 1994). The EU's Nitrates Directive (91/676/EC) became effective for the Eden Catchment in 2003 and while phosphate is not a parameter of concern in this Directive, it must also be regarded as important if the Water Framework Directive's stated aim of returning water bodies to Good Ecological Status by 2015 is to be fulfilled in this catchment (Scottish Executive 2005).

Since 1994, water quality data provided by SEPA from a gauging station in the upper reach of the River Eden confirms that there have been significant improvements in nitrate N concentrations – down to a mean of 7.18 N mg l^{-1} (n=6) in 2004 and then reducing further in 2011 to 6.11 N mg l^{-1} (n=12). Taken together, all four gauging stations demonstrate a similar degree of nitrate N improvement; 7.48 N mg l^{-1} (n=35) in 2004 down to 5.84 N mg l^{-1} (n=46) in 2011. For phosphate P in the upper part of the catchment, the more recent data indicate a rise – from 0.06 P mg l^{-1} (TRPB, 1994) to a mean of 0.085 P mg l^{-1} (n=6) in 2004 but then back down to a mean of 0.071 P mg l^{-1} (n=12) in 2011. By way of comparison, the mean phosphate P for all four gauging stations were 0.083 P mg l^{-1} (n=36) in 2004 down to 0.060 P mg l^{-1} (n=46) in 2011, which essentially suggests phosphate P concentrations have changed very little in the surface waters of the catchment since 1994 despite the lowering P surpluses evident in the farm NBs. There are two possible explanations for the slow P response. First, P may be retained in soils and sediments of streams and rivers and the release of this 'legacy P' may take some time. Waterway P concentrations may remain largely unchanged for many years after P applications via fertlilsers have been reduced. Secondly, as the TRPB (1994) suggested 20 years ago, another possible explanation for the higher phosphate P concentrations found in the River Eden in particular is that there are other (point) sources unloading P into the River Eden. Further work would be necessary to quantify the cause/s but the sewerage treatment facilities by the River Eden at Cupar, Springfield and Bowhouse were known point-source polluters, prior to their £10 million upgrade in 2008-09.

The findings from farm-gate nutrient budgets (NBs) carried out in 2003 with Eden Catchment farmers (n=29), together with subsequent follow-up NBs in 2011 (n=16), demonstrate improvements in nutrient management for most farms that took part in both the 2003 and 2011 NB studies. Overall, the 16 participating farms demonstrated that they were using 13% less nitrogen (N) in 2011 than they were in 2003 and 19% less P. While some of these reductions arose as a result of changes in the nature of some farming enterprises (e.g. two dairy farms in 2003 changed their production emphasis to become mixed farms by 2011), most farms that had not made such radical changes also demonstrated reduced use of N and P. Importantly though, and as indicated above, water quality evidence provided by SEPA for three major rivers in the catchment supports the contention that improved on-farm nutrient management is contributing to reduced nitrate N concentrations in the catchment's waterways; furthermore, the lower nitrate N concentrations suggest that most other farms in the catchment have also improved their N management.

While there appears to be strong evidence of genuine water quality improvements in terms of nitrate N, the same cannot be said for phosphate P. The influence of legacy P should reduce in the years to come, assuming lower applications of P via fertilisers continues. Further monitoring and research is necessary to identify all sources of phosphate P to the River Eden but it was acknowledged by Scottish Water (2008) that the sewerage treatment facilities on this river needed to be upgraded to improve their nutrient removal performance. Notwithstanding the subsequent upgrade in 2008-09, it is possible that much of the phosphate P found in the River Eden emanates from these point sources rather than being of diffuse agricultural origin. This conclusion is supported by the fact that the mean phosphate P concentration in the Motray Water in 2011, which has no sewerage treatment facility, was 0.030 P mg l^{-1}, significantly lower than that found in the lower part of the River Eden (0.078 P mg l^{-1}).

Interviews carried out at the time of the 2011 NBs indicate that farmers' reductions in fertiliser use were motivated by two primary factors: the requirement to conform with NVZ regulations, and the need to reduce input costs in order to maintain profits. This second factor arose as a result of the very significant rise in the cost of manufactured fertilisers during the eight years prior to 2011; the farmers' response testifies to the power of the economic imperative, especially when coupled with legislative requirements.

Most farmers interviewed in 2011 did not express strong objections to the requirements of NVZ status and indeed, some even acknowledged that NVZ status had helped shape their attitudes towards a 'greener agenda', which they were largely supportive of. This is exemplified by the comment that 'the "cheap and cheerful" approach just won't do any more'. This contrasts with the findings of Macgregor and Warren (2006) in their 2002-03 study when the same farmers were generally antagonistic towards the then new NVZ requirements. Given the positive impact that the introduction of NVZ status appears to have had on farmer attitudes, and more importantly on water quality, we conclude that this environmental legislative instrument has largely been effective in this region.

These conclusions lend support to Sutherland's (2010) observation of a pro-environmental shift in attitudes. In that sense, applying the typology of Barnes *et al*. (2011), most of the farmers interviewed in this study could perhaps be classified as 'multifunctionalist' farmers rather than 'resistor' or 'apathist'. While this may be true for those that took part in this study, it is possible that, because these farmers volunteered their involvement, their views and management practices may be slightly skewed towards supporting sustainable farming and perhaps may not be entirely representative of the Eden's wider farming community. Nevertheless, the empirical fact remains that surface water quality in the catchment has demonstrably improved during the last decade as a result of the combined influence of economic imperatives and legislative requirements. It is questionable whether the NVZ regulations alone, without the economic driver, would have delivered such significant improvements, but they have clearly played a part in effecting both attitudinal and behavioural change.

In many parts of the UK, despite the extensive areas now designated as NVZs and the significant investment in them, nitrate concentrations in many rivers have remained 'stubbornly high' (Burt *et al*. 2011, p. 175), especially in groundwater-dominated catchments in which it may take decades for changes in land use and land management to have an appreciable impact on water quality. For example, Worrall *et al*. (2009, p. 27) report that little statistically significant improvement in water quality could be detected in 32 NVZs in England, even 15 years after designation, leading them to question the use of input management as a means of reducing nitrate pollution, and to comment that 'if NVZs cannot be shown to work, then they are a waste of money'. In a similar vein, Howden *et al*. (2013) conclude that significant improvements in freshwater quality in farming areas are unlikely without major changes in legislation and/or farm economics. By contrast, the results reported here from Fife represent an exception to this negative picture, showing that notable reductions in nitrate concentrations can sometimes be achieved over a relatively short period, and that NVZs may provide value for money in some contexts. As a caveat, it is important to note that establishing reliable trends in nitrate concentrations is difficult over periods of less than 20-30 years because shorter-term variations may reflect climatic variations rather than land management practices (Burt *et al*. 2011). Nevertheless, the data suggest that the combination of the NVZ designation and market forces is having a measurable, positive impact in north-east Fife, not only in terms of water chemistry improvements but also in terms of the 'hearts and minds' of farmers.

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Note

[1] Subsequent to this study, the Scottish Government consulted on amendments to the Action Programme for NVZs, and the strengthened regulations were introduced in 2013. See: http://www.scotland.gov.uk/Resource/0042/00422377.pdf

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