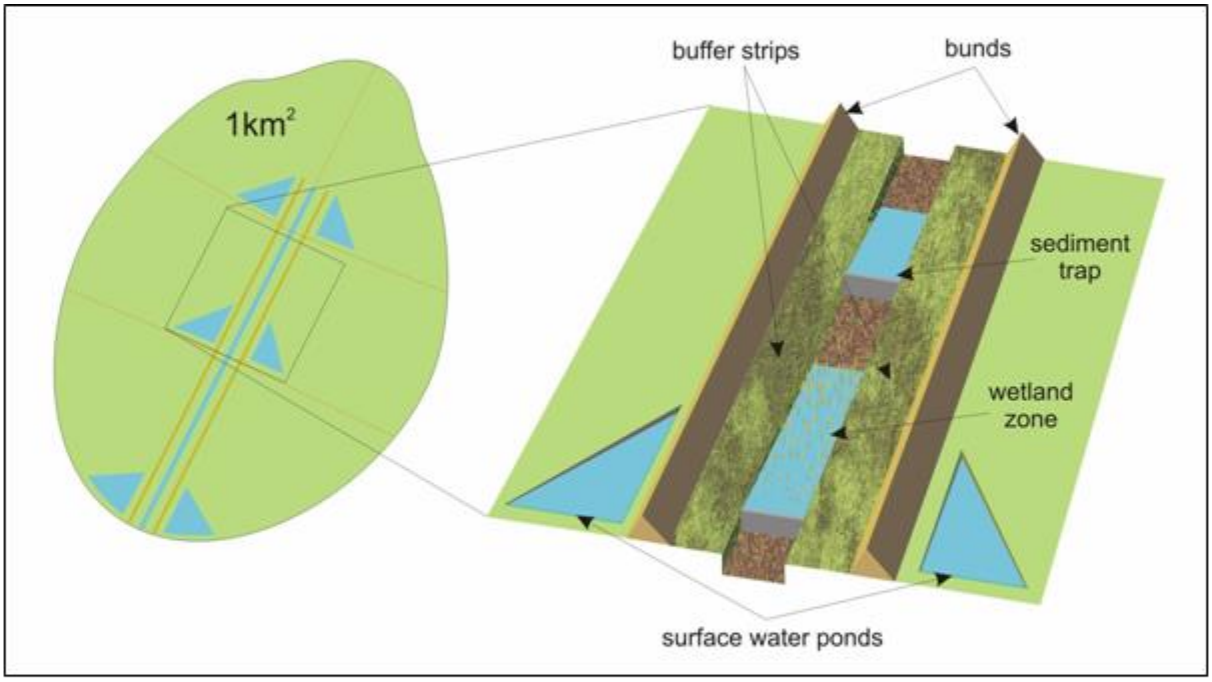

"Store, slow and filter"

The ***proactive*** approach to Farm Integrated Runoff Management (**FIRM**) plans with respect to nutrients

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Itegrated Runoff Management (FIRM) Plans

The ***proactive*** approach is committed to:-

- changing land use management in order to mitigate a range of environmental problems at demonstration farms, at full scale in partnership with stakeholders
- instrumenting and quantifying processes on small research catchments that are undergoing land use management change.
- creating multi-functional, economically viable land units by joining pollution, flooding, waste recycling and renewable energy into a common integrated funding framework.
- producing decision support tools and modelling frameworks that support catchment management and policy making.

Farm Integrated Runoff Management (FIRM) Plans are at the heart of the proactive approach. FIRM Plans are committed to the concept of the storage, slowing, filtering and infiltration of runoff on farms at source. We believe this to be practical, achievable and could easily be funded by the strategic investment of agri-environment, flood mitigation, waste recycling and renewable energy reduction subsidies. The best place to control runoff is at source and within hours of the runoff generation. These spatial and temporal windows of opportunity are not being exploited fully in environmental management.

Ponds, bunds wetlands, buffer strip have all been designed, constructed and tested at Nafferton farm in Northumberland. All features are multi-functional in order to address pollution reduction, lower flood risk, trap and recycle waste, use recycled material and create new ecological zones. FIRM plans can be achieved without damaging the profits of the farm and can funded through an imaginative, strategic mechanism that join agri-environmental, flood risk management and carbon/renewable budgets.

All the features constructed can be shown to be working to reduce pollution, store and slow runoff and to trap and recycle waste on the farm. The operational performance of the features during large storm events is still to be proven. We will not be recommending all the features listed in this report for adoption on farms, but crucially we have gained the experience to recommend a series of practical, fundable interventions that could work at the larger catchment scale and address urgent WFD needs, for example:-

- All fast and polluting flow paths can be disconnected from the channel network.
- Ponds, barriers, bunds can physically store large amounts of runoff.

- All features help to slow flow, creating ‘transient storage’.
- Wetlands are slowly de-nitrifying the runoff, but large amounts of buffering and attenuation capacity will be needed on farms.
- Sediment and nutrients can be trapped and recycled. A one-off sediment and phosphorus trap can reduce Total P by 20-60% even during storms.
- Saturated buffer strips are denitrifying the flow and they have the potential to treat large amounts of flow and act as flood retardation channels if designed appropriately.
- Ditches can be widened and can act as sediment traps, wetlands and flood retardation channels.
- FIRM plans will need farmers to adopt new sediment management plans and sediment/nutrient recovery plans. Construction and maintenance funding will be vital to the delivery of FIRM plans.

What is needed now?

A fully costed, full scale trial of the FIRM plans on a wide range of farms, working closely with farmers and farm advisors.

To test a new mode of subsidising farmers to become proactive farm runoff managers and thus solve a wide range of environmental problems.

Continued work at Nafferton to prove the performance of the features during large storm events and improve on design and operation issues.

What will FIRM Plans cost?

Costs are comparable with the budgets available from flood control projects (or possibly cheaper), agri-environment schemes and activities such as upland grip blocking. If other subsidies related to renewable energy, carbon storage, waste recycling and ecological initiatives are joined together then FIRM plans can be funded sustainably, with visible, quantifiable, multiple benefits and will address the needs of the WFD.

In order to address pollution control we feel that this would cost between **£1000/km^2/annum and £10000/km^2/annum.** This will provide drastic reduction in nutrient pollution and sediment losses in most storms.

In order to address flood control at source we estimate the costs as between **£1000/km^2/mm of runoff (rainfall depth equivalent) stored and £10000/km^2/annum/mm of runoff stored without inundating other farm land.**

Contents

1 Introduction

The ***proactive*** approach is committed to:-

- changing land use management in order to mitigate a range of environmental problems at demonstration farms, at full scale in partnership with stakeholders
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- creating multi-functional, economically viable land units by joining pollution, flooding, waste recycling and renewable energy into a common integrated funding framework.
- To producing decision support tools and modelling frameworks that support catchment management and policy making.

Farm Integrated Runoff Management (FIRM) plans are at the heart of the proactive approach. The FIRM approach is committed to the concept of the storage, slowing, filtering and infiltration of runoff on farms at source. We believe this to be practical, achievable and could easily be funded by the strategic investment of agri-environment, flood mitigation, waste recycling and renewable energy/carbon reduction subsidies. The best place to control runoff at source and within hours of the runoff generation. These are the spatial and temporal windows of opportunity that are not being fully exploited in environmental management.

A full list of current ***proactive*** projects can be found at http://www.ncl.ac.uk/iq.

The ***proactive*** approach is a dynamic philosophy geared towards intervening in the environment to improve water quality, reduce flood risk and diffuse pollution, recycle waste and introduce renewable energy generation into farming. The ***proactive*** approach includes introducing features such as temporary storage ponds, buffer strips and sediment/phosphorus stripping zones in the landscape. Full scale demonstration farm have been currently under development to prove the effectiveness of such features on working farms. Decision Support Matrices (DSMs) have been developed to communicate the results of this research to farmers and land use managers/planners, in particular the Nutrient Export Risk Matrix (NERM) and the Floods and Agriculture Risk Matrix (FARM). All the mitigation features created at the demonstration farms are either made from recycled material or are designed to trap waste that can be put back to land. Examples of waste include the reuse of ochre, which is used to trap phosphorus that is lost from the land and the use of Aquadyne, a recycled plastic material which can be used for draining land and for constructing flow control barriers. Willow, sedge and reused oak have all been sourced locally and are used to construct wetlands. Examples of trapping waste include sediment traps such as ponds and channel sedimentation zones at Nafferton Farm, phosphorus traps either attached to sediment or locked up by the ochre and wetlands that lower N loss and capture carbon.

The ***proactive*** project aims to take a balanced approach to problem solving involving researchers in a range of disciplines and stakeholders at all scales including farmers, land management planners at all scales and bodies such as the Environment Agency and Defra. We propose to apply a multi-scale toolkit for catchment management using existing tools including stakeholder workshops, research scale and catchment scale models (for example TOPCAT-NP), GIS, DSMs and policy implementation/visualisation tools (such as TopManage). Full details of the tools can be found at http://www.ncl.ac.uk/iq. Figure 1.1 reflects the role of research scale, intensive monitoring and demonstration farms to the wider environment.

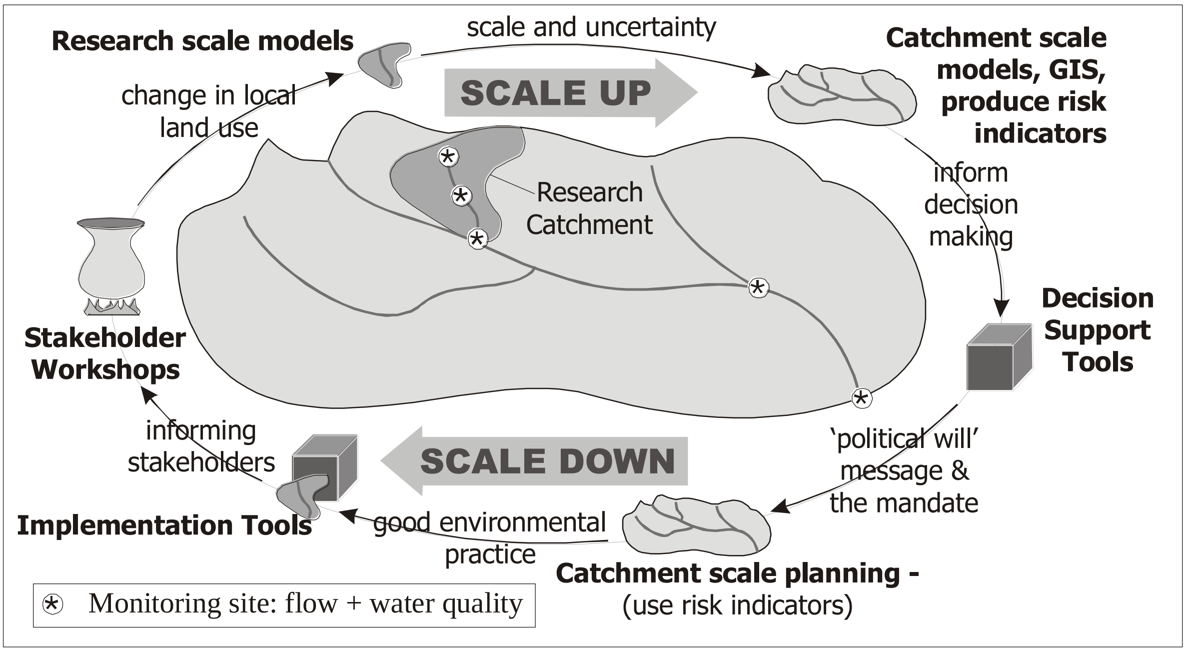

Fig 1.1 Multi-scale Framework for Catchment Management

The ***proactive*** initiative is a joint initiative with the EA. Newcastle University has invested £300,000 in infrastructure and experiments at Nafferton farm. The EA has contributed to underpinning the maintenance of this site, a second farm at Bollington Hall (near Stansted) and later work at scaling up the results within the River Eden catchment. The duration of study will be three and half years. Dr Sean Burke is a guest member of staff at Newcastle University, who commits the equivalent of 1 day per week to the ***proactive*** initiative. Since the ***proactive*** initiative commenced (September 2006) a series of ***proactive*** projects have been funded (see list). All ***proactive*** projects have a common set of goals for improving land use management.

Following the ***proactive*** approach all the experiments have used recycled materials and micro-renewable technologies. Equally, farmers are persuaded to consider any losses from the farm as waste and not as pollutants, even though farm waste poses a pollution threat downstream. Farmers are encouraged to see that renewable energy is viable (see BBC film web link http://www.ncl.ac.uk/wrgi/TOPCAT/nafferton.avi). Farmers are encouraged to trap and recycle their waste, this includes sediment and nutrients, but also farm plastics, energy and carbon. The flood risk arising from increased runoff from farms is a new concept to farmers (O'Connell et al., 2004), however farmers should be willing to help mitigate flood risk if the case for storage on farms can be funded and demonstrated. The ***proactive*** approach seeks to fund Farm Integrated Runoff Management (The FIRM approach) by paying farmers to lower pollution, lower flood risk, recycle waste and to develop renewable energy and carbon friendly features. Farmers should be paid to be ***proactive.*** This will require a fundamental change to the current agri-environmental schemes and the harmonisation and integration of subsidy schemes with flood protection initiatives and utilisation of the carbon/climate budgets on farms.

The ***proactive*** approach does not seek to replace ongoing best management practice initiatives related to cultivation, fertilisers and soil management as they are equally important to the environment. FIRM plans seek to add a large number of environmentally engineered options manage pollution and flooding. FIRM plans accept that even if best practice is being adopted by a farmer the worst case scenario is still high rainfall on a bare field with fresh application of nutrients. Hence there is need to target fast and polluting flow paths on all farms during and after storm events. This can be achieved by altering and disconnecting fast flow paths and modifying the physical and chemical flow conditions as it propagates downstream. These ideas are captured in NERM and FARM decision support matrices.

1.1 The Nafferton Farm Demonstration Site

Nafferton Farm in Northumberland (web link), can be characterised as an intensive farm that is prone to fast runoff, high nutrient loss and sediment loss. The site provides an excellent opportunity to test a range of interventions intended to trap and recycle sediments and nutrients at source. The site forms a natural 1 km^2 catchment, which can form the basis of scaling up any findings and making recommendations for larger catchments. Nafferton farm (fig 1.2, 1.3 and 1.4) is typical of mixed farms in Northumberland and similar sites across Northern England. It also has most typical farming practices and any findings from Nafferton are relevant to other farms in the UK and Europe. At the start of the ***proactive*** initiative, the BBC made a film about the work at the farm and this does give a good visual introduction the goals of the projects and the scale of the work carried out (http://www.ncl.ac.uk/wrgi/TOPCAT/nafferton.avi)

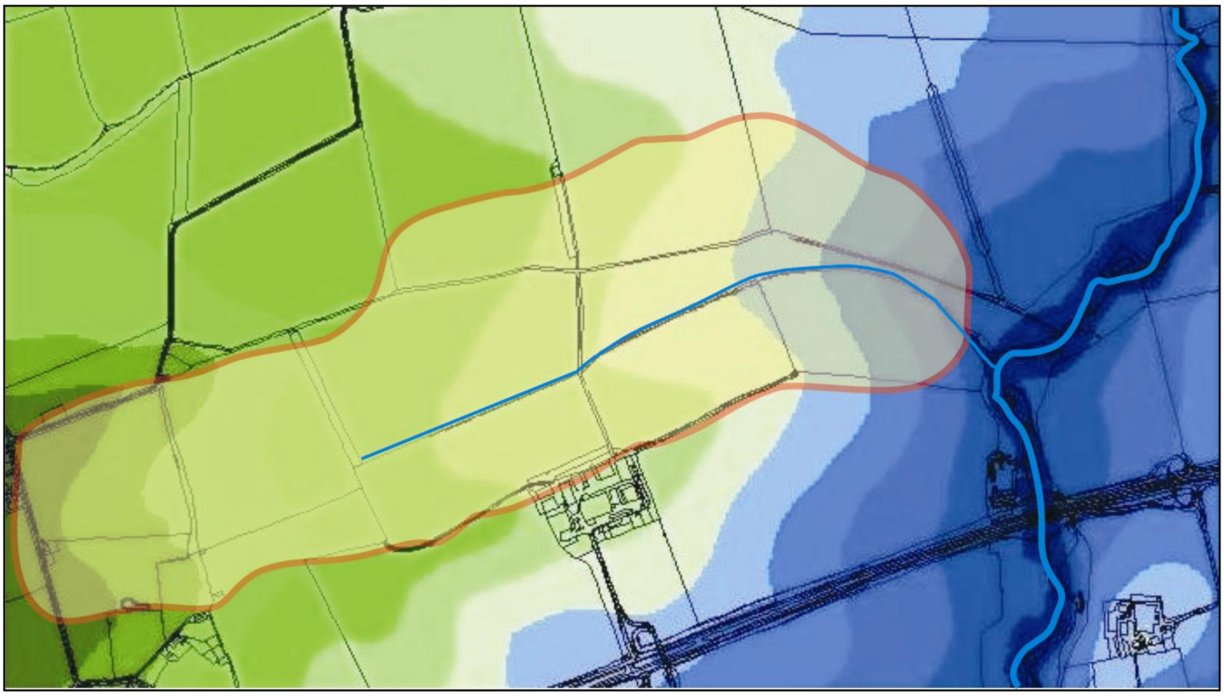

Fig 1.2 Nafferton showing a naturally draining 1km^2 catchment, which drains into the Whittle Burn.

Figure 1.3 Survey map showing position of Nafferton Farm

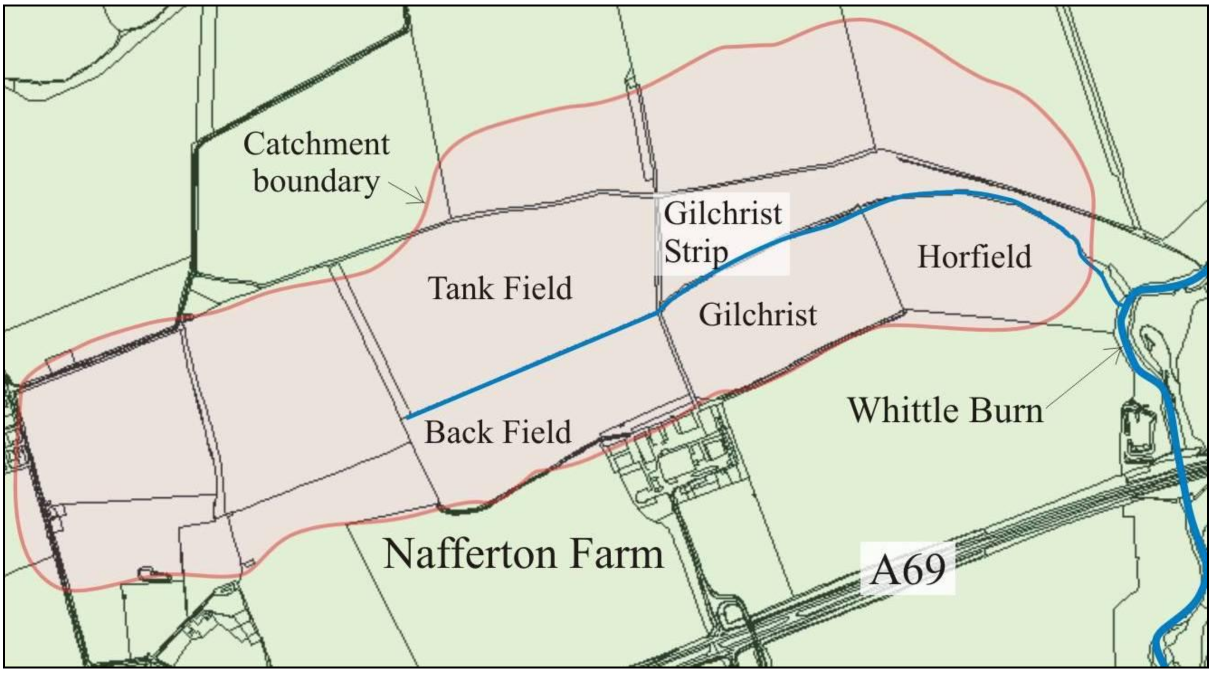

Figure 1.4 Detailed view of Nafferton Farm showing the position of the different fields, the catchment boundary and the entry point of the ditch into Whittle Burn

2 PROACTIVE interventions to improve water quality

An overview of the Proactive features and instrumentation installed at Nafferton Farm can be seen in Fig. 2.1. The rationale, management and methods of assessment are described for each feature in Sections 2.1 and 2.2.

Water quality samples are taken from four locations in the ditch and analysed immediately, on site by an autoanalyser (Fig. 2.2). Total phosphorus (TP), total dissolved phosphorus (TDP), nitrate , ammonia, pH, conductivity (EC), turbidity, and dissolved oxygen (DO) are measured using standard methods at daily time intervals and also at 4-hourly intervals during storms. Flow is also measured at two points within the ditch. A weather station is also situated on the farm.

There are two main experiments taking place on the farm. The first is to demontsrate the potential to disconnect fast flow, polluting paths from hardstandings and roads and the potential to store overland flow within fields. Essentially, the experiments demonstrate the potential to manage runoff before it enters the ditch and channel network. This is not instrumented or quantified as yet, but rather has acted as a practical visual demonstration that such interventions can play a role on the farm, without affecting the operation of the farm business.

The second experiment assumes that large amounts of polluting flow will be reaching the ditch and low order river channel network. Here we demonstrate the potential to manage the runoff before the runoff (and pollutants) exit the farm. Most farms have a network of ditches and small channels that in terms of overall length within a catchment, have a much greater potential to be managed than the larger river system. Equally, interventions in ditches and small channels have little impact on ecology, recreation or wider conservation needs. In fact, many of the ***proactive*** interventions have positive effects on the local ecology (though this has not been quantified as yet). In essence the ***proactive*** approach attempts to make the farm unit responsible for both its inputs and its outputs and thus farms can contribute actively to reducepollution, flood control and carbon budgets.

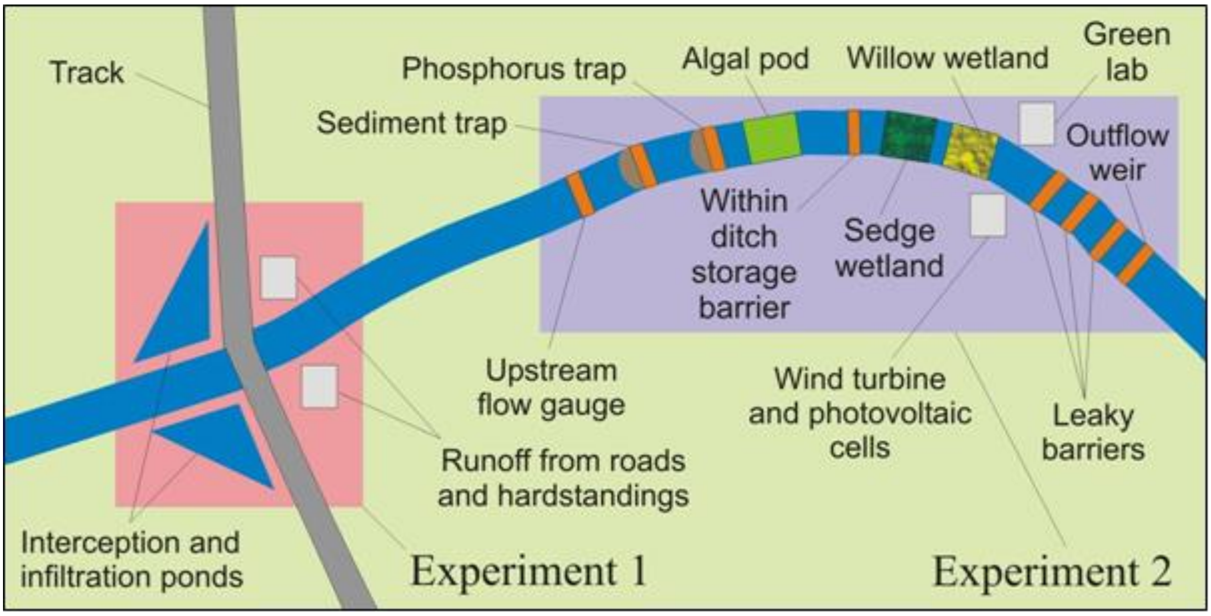

Fig. 2. 1 Overview of the PROACTIVE features and location of equipment. Sample point 1 – upstream gauge, sample point 2-below phosphorus trap, sample point 3-below sedge wetland and sample point 4 is at the Outflow Weir.

Automated Total Phosphorus analyser

Aqualab analyser for TDP analysis, Nitrate, ammonium, turbidity, EC, pH, DO & temp

Housing of analysers with reagents for analysis

Fig. 2.2 The Green Laboratory with an Autoanalyser for telemetered on-site analysis of water quality parameters. The lab is powered by a 15m micro-wind turbine and a photovoltaic array on the roof.

2. 1 Experiment 1. Interception and infiltration ponds

Before the installation of the intercepting drains and ponds the runoff from roads and hard-standings gave rise to severe waterlogged zones that in turn cause large poached areas giving rise to polluted runoff. Dairy cows traffic this road twice a day and frequently use the waterlogged field entrances, thus the road were always laden with fresh material to transport (figure 2.3).

Figure 2.3 Fast flowing, sediment laden runoff enters a field a causing a waterlogged zone with high runoff into the ditch.

Infiltration ponds were constructed using soil bunds in the corners of Tank and Back Field, at the lowest elevation, where flow would usually flow into the ditch. These features deliberately target the fastest and most polluting flow paths on the farm which is the runoff from the hard-standing, flow on the main farm track and also overland flow across the fields. Runoff from the track is intercepted by road drains (Fig 2.4a) and directed into the infiltration ponds (Fig. 2.4b).

Rationale of feature**:** to divert the runoff from the track and field into the infiltration ponds and prevent this sediment/nutrient-rich water from entering the main ditch. Slowing and storing this nutrient-rich water in the infiltration will allow the reduction of its phosphorus and nitrate loads by sedimentation and infiltration respectively. A more detailed discussion of the ponds is given in the '***Proactive*** Flood storage on farms' report.

Management of feature*:* at some point the pond will be dried down and the accumulated phosphorus-rich sediment will be recovered and returned to the land.

Assessment of feature*:* the functionality of this feature will be measured by the amount of sediment accumulated after a known period of time. The amount of phosphorus attached to the sediment and hence its potential for use as a fertiliser, will be assessed by sub-sampling the accumulated sediment prior to removal and measuring the P-content by acid digestion. The pond was designed to last 5 years, however due to the rapid build up of sediment arising from the roads and hard-standings the pond may have to be emptied sooner. Fig 2.4 (a), shows that the drain is being surcharged during larger events, this is due to unexpectedly high runoff from one field. Attempts will be made to divert the flow between the two manholes equally, but further surcharging may still occur.

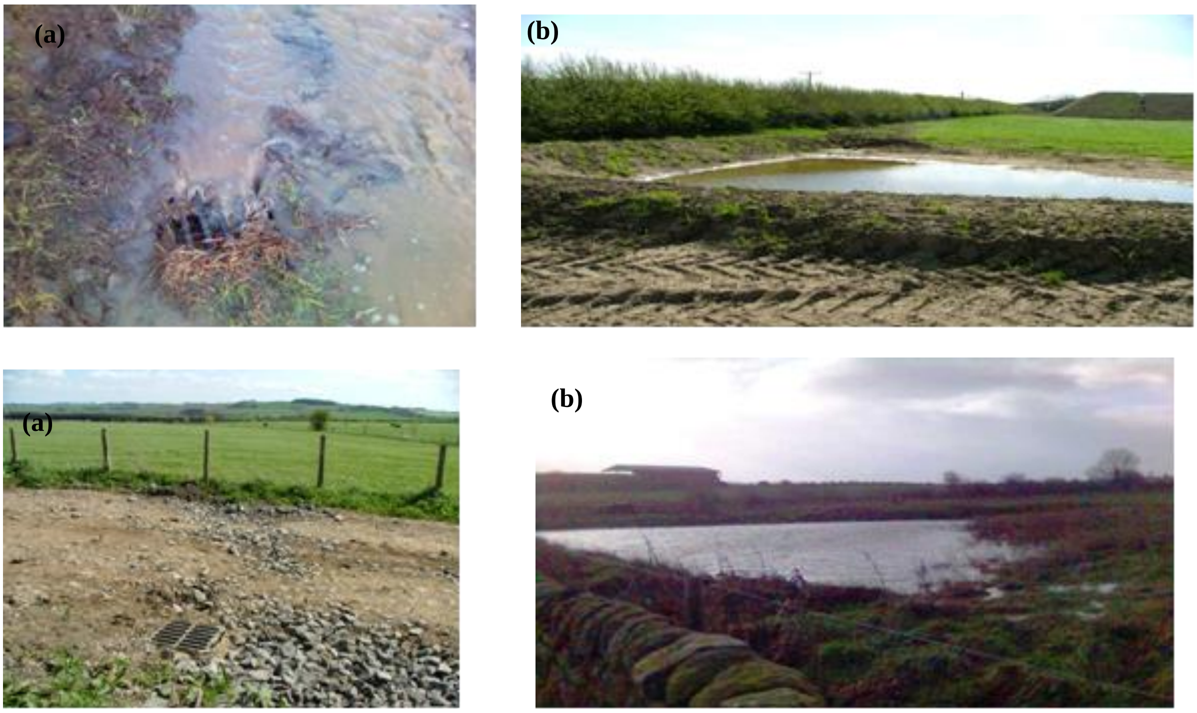

Fig. 2.4 (a) Road drains that divert road runoff into infiltration ponds; (b) infiltration ponds

2. 2 Experiment 2: Within ditch remediation and storage zone

A series of interventions have been placed within the ditch area. As a first step the farmer was reassured that no adverse effects would be caused by the construction of the features, which is still true after one and half years of installation. Most of the features were designed to test out basic design and construction hypotheses and it is not intended that all of these features will ever be implemented on farms. However, the features do give farmers and policy makers a chance to see a range of ***proactive*** interventions to store/slow/filter/infiltrate runoff. The practical knowledge gained from attempting a range of interventions has shaped later design modifications and is giving rise to the competence required to recommend similar features at other sites.

Assessment of the cumulative effect of all the features on reduction of nutrient concentrations will be assessed by comparison of water quality parameters from water samples taken from sample point 1, the water quality sampling point upstream of all remediation features and adjacent to the upper flume with water samples from water quality sample point 4 which is downstream of all features and adjacent to the v-notch weir.

2. 2. 1 Sediment Trap

At all locations along the original ditch, any zone prone to ponding would give rise to extensive sedimentation. The sediment accumulation would be reactivated and lost from the farm in the next large storm, so there was no chronic build up of sediment. This loss of sediment is undesirable for the environment but on a practical note any ***proactive*** intervention, such as a wetland or flood control barrier, would be prone to chronic sediment build up. The first response is to lower the overall sediment loss by using within field ponds (experiment 1), however there are large sediment losses from this farm. The basis of a sediment trap is to strip sediment preferentially at a site chosen by us, where the sediment can be retrieved without great difficulty.

A 5-m concrete-lined section was installed in the ditch with a barrier at the lower end of the section. The barrier, constructed from semi-permeable Aquadyne recycled plastic, allows the average flow to pass through. A line of less permeable geotextile bags situated downstream the barrier causes the ditch water to pond, which induces sedimentation conditions (Fig. 2. 5).

***Rationale of feature*:** to slow fast flowing storm runoff to allow the sediment load and the phosphorus bound to that sediment to be deposited in the concrete-lined section thereby reducing the total phosphorus concentration of this water. The concrete lined section allows easier recovery of the sediment and associated phosphorus with the aim of recycling it back to the land, protecting a valuable soil resource and reducing the need for additional P fertiliser.

***Management of feature**:* the pond will be dried down on an annual basis and the accumulated phosphorus-rich sediment will be recovered and returned to the land.

***Assessment of feature**:* the functionality of this feature will be assessed by the amount of sediment removed on an annual basis. The amount of phosphorus attached to the sediment, and hence its potential as a fertiliser, will be assessed by sub-sampling the accumulated sediment prior to removal and measuring the P-content by acid digestion.

Fig.2. 5 (a) A 5-m concrete-lined sediment trap **(b)** trap with a barrier constructed from Aquadyne, a recycled material.

2. 2. 2 Phosphorus Trap

A mine-water waste product called ochre (iron hydroxide) has been mass produced into small absorbent pellets which are capable of absorbing phosphorus (Fig. 2.6(a)). The pelletised ochre has been placed in the ditch in a series of geo-textile bags immediately downstream of the Aquadyne barrier, as seen in Fig. 2.6 (b), in the ditch to react with the water as it flows through the bags. Up to 3 tonnes of ochre will be installed to react with the runoff in high flows. The life of the feature should be several years. EPSRC have funded research into the potential reuse of ochre and its potential as a fertiliser see Heal *et al.,* 2003 and 2004.

Rationale of feature**:** to remove any dissolved phosphorus that comes into contact with the ochre by absorbing it onto/into the iron hydroxide complex and reducing the concentration of soluble phosphorus in the ditch water. This feature also acts as a fine sediment trap and so also traps the phosphorus bound to this sediment.

Management of feature*:* after several years, the ochre will become saturated with phosphorus. At this point, it will be recovered from the ditch and the P-rich ochre can be recycled back to land as a slow release fertiliser.

Assessment of feature*:* the functionality of this feature will be assessed by comparison of total phosphorus concentrations and total dissolved phosphorus concentrations at the upstream water quality sample point 1, adjacent to the upper flume, with the total phosphorus concentrations and total dissolved phosphorus concentrations from sample point 2, the water quality sample point downstream of this feature. It should be noted that this comparison will represent the overall effect of the sediment trap and phosphorus trap together.

Some detailed investigations of the phosphorus trap have been undertaken by MSc students and undergraduates in the last few years and the functionality of the phosphorus trap have been assessed. This supplementary data will be included and discussed in this report. It should be noted that the configuration of the ochre trap has been changed during the lifetime of this project, as part of the MSc projects, which have aimed to optimise the functionality of this feature by increasing contact time of ditch water with ochre. On one occasion the original feature was washed away with most of the pellets lost, hence it has been reconstructed and reinforced.

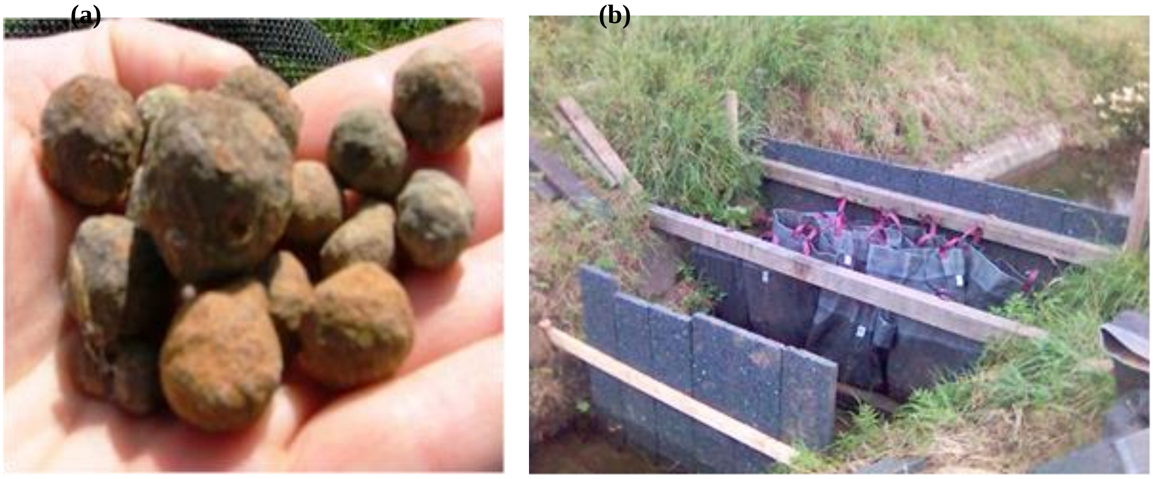

Fig. 2.6 (a) Pellets of ochre **(b)** ochre in geo-textile bags, the first line of bags act as a low permeability barrier causing the water to pond in the sediment trap. Further Ochre was later deployed between the Aquadyne barriers.

1. 2. 3 Algal Pods

Shallow streams rich in nutrients are perfect for eutrophication, however this is undesirable in larger rivers with conservation and water resource implications. One possibility therefore, is to induce eutrophication in less important ditches and channels whilst still on the farm. So the time of maximum threat in warm springtime conditions gives rise to algal blooms, which can then be harvested and the nutrient exported, thereby, protecting the locations downstream. The potential of this approach may be more beneficial to more sensitive rivers and lakes. Given the steep nature of the ditch at Nafferton, an artificial side channel was constructed. Such locations could be identified on typical farm ditches and channels and be managed to induce springtime eutrophication, however, the algal blooms themselves would require frequent harvesting. Over winter we have discovered that the features also act as excellent sediment traps.

A series of shallow tanks constructed with low cost corrugated metal sheets and reclaimed oak are assembled on the bank side of the ditch. A proportion of ditch water is fed into the upper tank via gravity and moves slowly through the tanks and is released back to the stream at the lowest tank as seen in Fig. 2. 7.

***Rationale of feature*:** to mimic a shallow ditch/river system and induce ideal primary production conditions to grow algae and utilise nutrients in the ditch water. Nutrients are removed from the system by harvesting algae at the end of the growing season with the aim of recycling it back to land as a fertiliser.

***Management of feature**:* the algal pods will need to be dried down annually to harvest algae. Further management will be necessary if the pods are not disconnected during winter storms, to recover the large amount of sediment.

Assessment of feature*:* the functionality of this feature will be assessed in the first instance visually. A photographic record of algal growth over the growing season will be kept and a qualitative assessment made.

Future assessment of this feature will be via quantification of chlorophyll ***a*** concentrations in the tanks and concentration of total phosphorus, total dissolved phosphorus and soluble phosphorus and nitrate concentrations in the ditch water before and after this feature.

Fig.2. 7 Algal pods

2. 2. 4 Within Ditch Flood Storage Barriers

Barriers across the ditch were constructed from a recycled plastic material (Aquadyne) as seen in Fig. 2.7.

Rationale of feature: to maximise any online storage/attenuation capacity within the ditch system. As the ditch is quite incised, it is perfect for the installation of within-ditch barriers. This may not be true of all ditches however; but the capability to store some flow should be possible in or around the riparian area on most small ditches and streams. The Aquadyne is freely draining so average storms will pass through the feature; however, in the more extreme events water will back up and establish a temporary pond. The barrier is deliberately placed in this position as it has an additional function of dissipating the energy in high flows and thus protecting the wetland that is immediately downstream. During large events the barrier is designed to fill up and create a temporary pond.

Management of feature: no management required. The sediment build up at this feature is being monitored and may require removal in the future.

***Assessment of feature**:* the effect of this barrier at reducing nutrient concentrations will not be assessed individually but its effects will be derived qualitatively by studying the sediment build up behind the barrier. There is still outstanding research needed to quantify the operation of these barriers during storm events.

Fig. 2.7 Aquadyne barrier immediately upstream of Sedge wetland, also as seen during a storm event.

More recently a new series of barriers were built as part of the flood storage on farms, these are referred to as leaky barriers.

2. 2. 5 Sedge Wetland

The sedge wetland was constructed by widening the ditch and back filling the earth to create a shallow bed. Aquadyne strips with willow pegs created a series of steps in the flow, thus maximising the contact of the flow with the sedge and roots. The wetland was planted with indigenous sedge from a local wetland to create a small linear wetland feature which can be seen in Fig. 2.8 . the concept is based on tertiary treatment zone from waste water treatment plants, though modification to the farm environment was needed.

***Rationale of feature*:** to increase denitrification and nutrient utilisation from the ditch water by using wetland plants such as sedges.

Management of feature: minimal removal of bank side plant material and removal of sediment from the water quality sample point downstream of this feature. The willow pegs also grow rapidly therefore they are cut once a year.

***Assessment of feature**:* the functionality of this feature is assessed by comparison of nitrate, ammonia and phosphorus concentrations from sample point 2, which is upstream of this feature and sample point 3, which is immediately downstream of this feature.

Further evidence will be provided by Edinburgh University PhD student Lena McCauley/ supervisor Dave Reay, who are currently investigating gaseous emissions in the wetland using rice chambers. A summary of these results are included in this report. Fig. 2.8 shows the sedge wetland instrumented with rice chambers by researchers at Edinburgh University.

Fig. 2. 8 Sedge wetland instrumented with rice chambers for investigation of gaseous emissions by Edinburgh University.

2. 2. 5 Willow Wetland

A series of willow hurdles have been constructed in the ditch to slow and control the flow. Willow cuttings have been planted along the bed to create a new sinuous path in the channel as shown in Fig. 2. 9. The willow soon takes root and grows very rapidly. During rainfall events the stems act as obstacles retarding the flow.

***Rationale of feature*:** is for temporary storage during high storm flows, but this feature can also remove nutrients by plant uptake from the ditch water. Nutrient removal is achieved by removal of biomass at the end of the growing season.

***Management of feature**:* the willow will require annual removal of biomass at the end of the growing season and applications of straw mulch, in the initial planting stages, until the willow crop becomes established.

***Assessment of feature**:* the effects of this feature on reduction of nutrients will be assessed by the amount of biomass removed annually.

Fig. 2. 9 Willow wetland shortly after construction and its operation during a large storm in January 2007.

2.2.6 A Saturated Buffer Strip.

Research on buffer strips and their operation can be located elsewhere, here we wish to address two main questions: what gaseous emissions arise from a saturated buffer strips and could the zone be used to further clean nutrient ditch water. Most buffer strips could be considered to be riparian ‘abandoned’ land, where there is little hydrological/ environmental engineering design related to their operation, other than a hope that it will buffer runoff from the hillslope. Buffer strips could prove to be the single largest intervention that could be funded by Defra, so it is imperative that such a large sacrifice of farmland be utilised to its maximum. Apart from benefits arising from pesticide management and the exclusion of animals from the river, buffer strips could also:-

1. strip extra nitrate from ditch flow, and
2. act as flood storage and retardation zones during larger flood events. (see Proactive... Flood Storage on Farms report).

In order to achieve these extra benefits, flow must be forced from the main channel back onto the buffer strip. The propagation, extent and magnitude of flow on the buffer strips must also be managed. Here we explore only the nutrient stripping potential (see Proactive... Flood Storage on Farms report). In Fig 2.10 a saturated zone and the gaseous emission study being carried out by Edinburgh University are shown.

***Rationale of feature*:** is to create a dedicated zone of land that is not under cultivation but is kept saturated by ditch water drawn off from the adjacent ditch. The ditch water is still relatively nutrient rich and the zone received water from the Green lab which draws water from along the ditch length, hence the seasonal flux in nitrate level is known and the approximate rate of inflow is known. The saturated zone should then denitrify the flow before the water dissipated and re-enter the ditch downstream via subsurface flow.

Management of feature*:* the buffer strip is cut once a year. The water must be kept flowing to the feature and the amount of Nitrate entering the strip must be checked. Soil moisture probes are situated to check on the soil moisture regime. An adjacent control buffer strip is also fenced off to compare the soil moisture and gaseous emissions.

Assessment of feature*:* The feature operates well and flow dissipates well. There have been discussions as to how much water should be applied and what the impact of nitrate fluctuations in the input may be causing. The test of the buffer strips operation is made only by the determination of the gases being lost.

Fig 2.10, the saturated buffer strip, showing the location of the gaseous emissions experiment

3 Results

Here we will present some key recent results from the Nafferton farm experiments. The main results and discussion can be seen in Annex 1. Experiment 1, as stated, was just a practical and visual exercise and thus the assessment of the effectiveness of the drain and ponds has only been carried out qualitatively to date. We would like to fund research into the operation of the features but other priorities have been addressed first, given limited funding. So the following results are based on the Experiment 2.

3.1 Experiment 2: Cumulative effects of ditch remediation features

As mentioned in section 2.2, the functionality of the cumulative effects of the "within-ditch remediation" features is assessed by comparing the upstream water quality with the downstream water quality using the results from the automated analyser. The water quality parameters shown and discussed in this report are total phosphorus, total dissolved phosphorus, ammonia and nitrate concentrations and also turbidity measurements.

It should be noted that the analyser carries out “quality checks” to ensure that it is operating correcting. All data that are shown to be invalid due to incorrect analyser operations have been removed.

3. 1. 1 Whole Period Assessment April 2006 - July 2007

Here all the results will be shown for the whole period and some basic assessment of the features integrated performance will be made. The later discussion of each feature will help outline the current assessment of performance. The results for this period are not conclusive for performance during storm events. The sampler draws water in sequence from the sample point 1 to 4. As the samples must be flushed between measurements that give rise to 4 hour delay between sample point 1 and 4. As the catchment can respond within a couple of hours and the peak of flow may pass the lower flume before sample 4 commences. We are now concerned that this causes an unfair comparison of feature performance. For the following section the graphs convey the patterns of pollutant loss from the farm, the seasonal nature of the storm and inter storm periods. However, the potential of the automated sampler is high and we propose to modify the sampling regime in preparation for next winter.

Fig. 3.1 shows all the valid water quality parameters measurements since the installation of the analysers in April 2006 until June 2007. Fig. 3.1 (a) shows the total dissolved phosphorus (TDP) concentrations and shows that for the majority of times, the downstream concentrations of TDP are below the upstream concentrations. Table 3, in Annex 1.1, shows that the mean concentrations over the entire sampling period at sample point 1 and 4 were 0.178 and 0.162 mg/l respectively (Collins, 2007) which represents an overall efficiency of removal of TDP of only 9%. These concentrations would both be described as “high” in the EA general quality assessment (GQA) for phosphate (EA, 2006). It can be seen on Fig. 3.1 (a) that there are occasions (circled in red) where the downstream concentrations are above the upstream concentrations, and reduce the overall performance of the within-ditch remediation of TDP concentrations. Hourly removal efficiencies for TDP range from 100% removal up to a 24-fold increase.

Fig. 3.1 (b) shows the total phosphorus (TP) concentrations and again shows that for the majority of times the downstream concentrations of TP are below or approximately the same as the upstream concentrations. Table 4, in Annex 1.1, shows that the mean concentrations of TP at sample point 1 and 4, over the entire period were 0.29 mg/l and 0.27 mg/l respectively. However, Table 4 also shows that the mean TP concentration at sample points 2 and 3 were 0.44 mg/l and

0.38 mg/l respectively. TP concentrations become elevated between sample point 1 and 2 and are then reduced by sample point 4. This is most probably due to water sampling problems experienced at sample point 2 and not by the sediment and phosphorus trap features themselves as will be demonstrated in Section 3. 2. 3. The efficiency of overall removal of TP is thus only 7% but the overall removal efficiency for TP between sample points 2 to 4 is 38%. All these mean concentrations of TP are described as “very high” by the EA GQA for phosphate (EA, 2006). Hourly removal efficiencies for TP range from 100% to a 68-fold increase

All the water quality parameter measurements shown in Fig. 3.1 (and in Annex 1) have demonstrated an overall highly variable performance with huge ranges of removal efficiency. Reasons for these huge variations will be discussed for the individual within-ditch features and also overall during storms in the following sections.

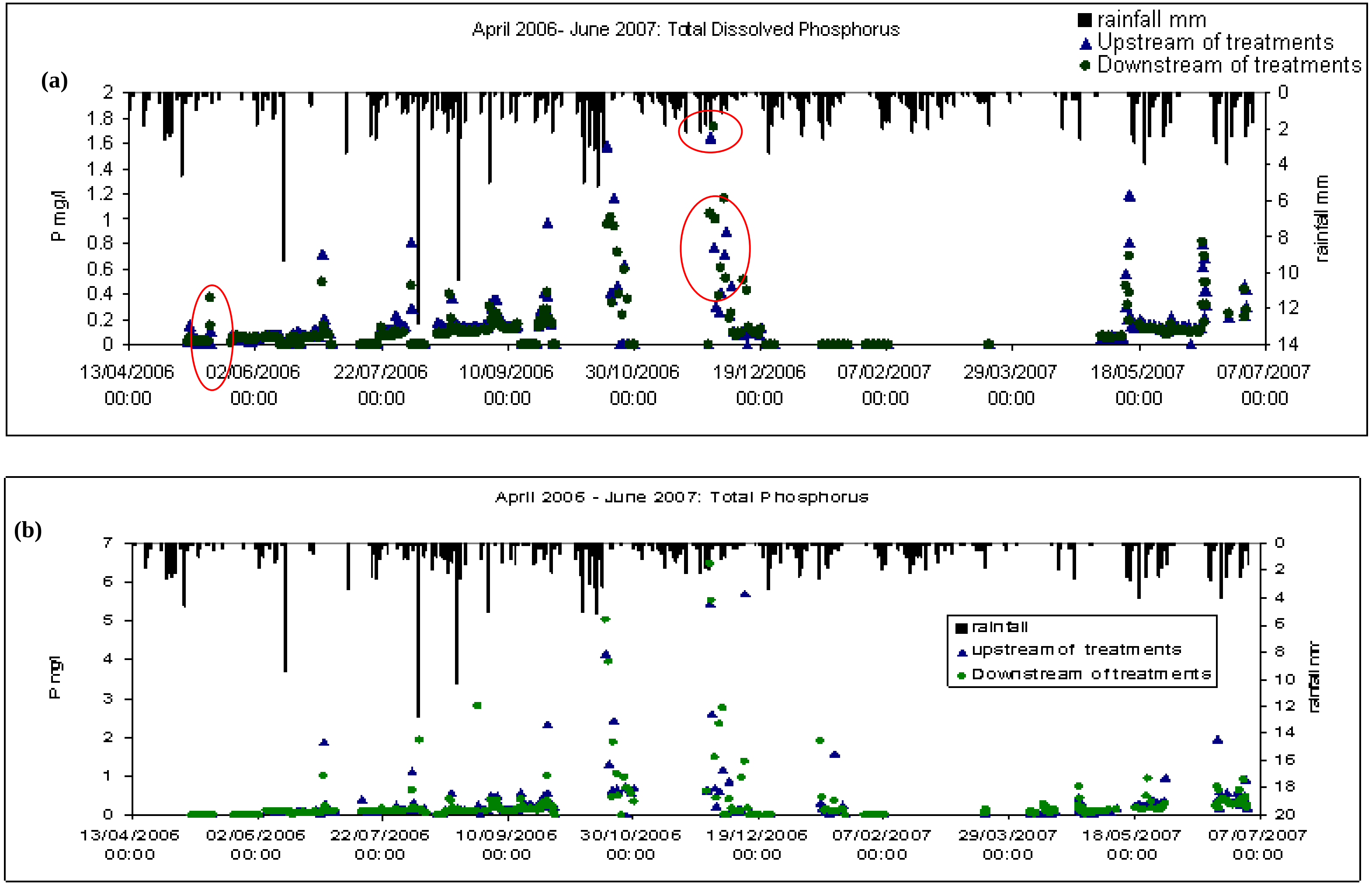

Fig. 3. 1 Water quality parameters **(a)** Total dissolved Phosphorus **(b)** Total Phosphorus from April 2006 to June 2007 at upstream and downstream locations of the within ditch remediation zone at Nafferton Farm.

3. 1. 2 Storm events April – July 2007

The ability to test storm dynamics and performance of the mitigating features is an overriding goal of the scientific studies required to back up the FIRM approach. Having largely missed the winter events we were not hopeful of collecting many storms during the current funded study period. However, following a few hot months (where the ditch exhibited extremely lows flows), a long period of storm events ensued that eventually gave rise to the equivalent of winter events. Therefore a series of scientific and technological questions were answered.

Due to difficulties in obtaining appropriate equipment, the trigger mechanism for storm sampling of water was not fully operational until late April/ May 2007. After this time, when the ditch level was above a threshold level in the upper flume, the analysers automatically switched on and took samples during the storm at four hour intervals. This has enabled the behaviour of the treatments to be evaluated during times of high nutrient export from the farm and highlighted areas in our remediation zones that either need further investigation or features that need to be modified to increase nutrient removal at this critical peak flow time.

Fig. 3.2 shows the water quality parameters during June 2007 storms and Table 3.1(in Annex1) shows the overall removal efficiency for the same water quality parameters, more are shown in Annex 1. The points of interest are:

- Nutrient concentrations are clearly increased during storms.
- Downstream concentrations are generally below upstream concentrations except during large storm peaks.
- There is good agreement between TDP and TP removal efficiency when both parameters are measured simultaneously, suggesting that the reduction in TP is mostly due to removal of soluble phosphorus at the end of June (see Table 3.1 in Annex 1)
- The removal efficiency of ammonia reduces when nitrate removal efficiency increases and vice versa.

The problem of assessing performance during storms is difficult given the time to peak of the storms and the large variation in the nutrient fluxes. Even if a synchronous sampling system is set up the time to of travel would still generate problems with comparing points over 400m apart. However, sampling events and nutrient remediation rates will continue to be addressed this winter. The mitigation features are quite small and perhaps the operation during larger storm events is much less than we expected. However the performance during inter-storm periods is consistent and conclusive. Hence, the cumulative effect of the storage/slowing/filtering/infiltration mechanisms is occurring (fig 3.2 (c) in particular). The question as to which features are most effective and how to gain knowledge of the features' operation during large events is still needed.

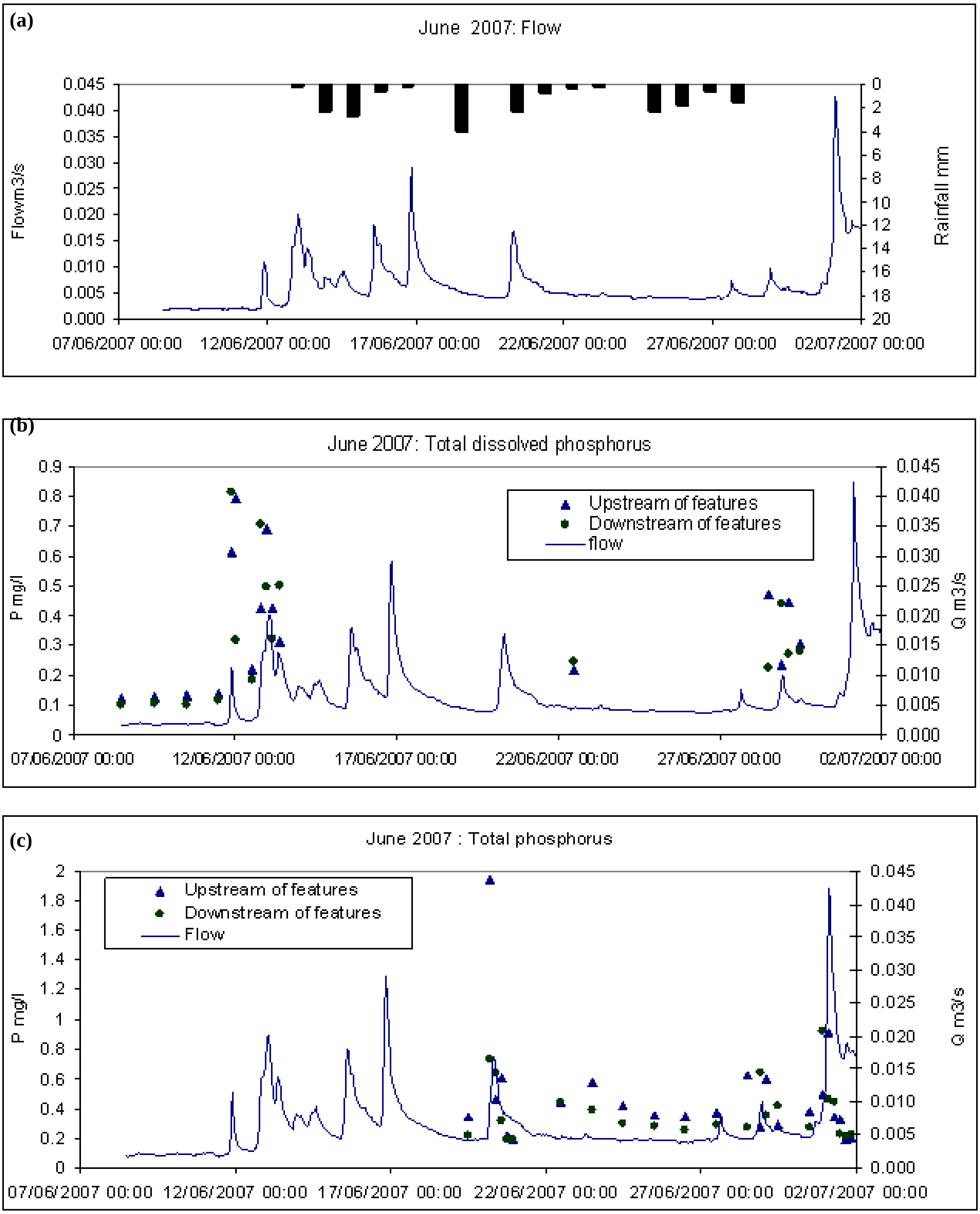

Fig. 3.2 **(a)** Flow and water quality parameters **(b)** Total dissolved Phosphorus **(c)** Total Phosphorus from June 2007 storms at upstream and downstream locations of the within-ditch remediation zone at Nafferton Farm.

3. 2 Individual within-ditch remediation features

3. 2. 1 Infiltration ponds

The amount of sediment accumulated in these infiltration ponds and the amount of phosphorus attached to it has yet to be assessed.

This quantification is scheduled for summer 2008. We would like to fully instrument these ponds and study there dynamics and efficiency as treatment zones but no funding is available at this time.

3. 2. 2 Sediment trap

The amount of sediment removed on 04 June 2007 has been estimated to be 3 m^3 when stil wet (estimated by the average depth of sediment x dimensions of concrete section). The sediment recovered can be seen in Fig.3.3. The accumulated sediment was sub-sampled prior to removal and has been air-dried for analysis in August 2007 as part of an MSc Project.

Fig. 3. 3 The visual statement, a growing mole hill of sediment after a first attempt to remove sediment before the onset of an new MSc study.

3. 2. 3 Phosphorus Trap

The ochre trap was intensively monitored during December 2006, as part of an undergraduate project where samples were taken every hour over an 8 hour period immediately upstream and downstream of the ochre trap, on four occasions. The ditch was at high flow on two of these occasions and in the usual base flow conditions at the other monitoring times. The results of this monitoring are shown in Figs.3.4 and in Annex 1. The percentage removal of the ochre P trap in Tables 3.2 and 3.3. It can be clearly seen that the P-trap is performing as intended most of the time, in all conditions, though with less TP removed during higher flows, as expected due to the lower residence time and thus contact time with the ochre. However, it can also be seen that the last three measurements taken downstream on 18th December 2006 are up to three times higher than the upstream measurements. It was noted by Nichols (2007) that this was probably caused by bankside erosion due to constant traffic caused by the sampler trying to obtain samples and may not be representative. To disregard these negative results though may be dangerous, as together with measurements at sample point 2, this could represent a pathway/source/process not previously considered and it is recommended that this should be investigated further.

Further one off studies by MSc students have also shown similar results, unfortunately their studies have often been constrained to summer low flow periods. However, a set of common results in the pilot studies have shown in a positive sense:-

- Consistent reductions in Total P between 10-60%
- Smaller reduction in Total Dissolved P
- Excellent sediment traps

And in a negative sense

- Poor contact time with the bulk of the flow
- Deterioration of the features due to sedimentation and poor choice of bags materials
- Cumulative blinding of the pellets due to a build up fine sediments

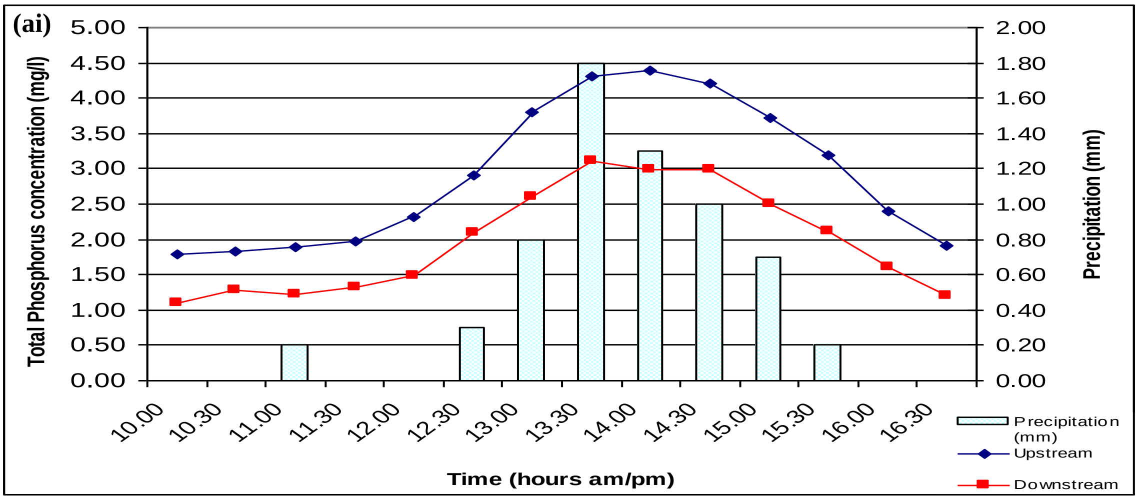

Figure 3.4 A typical TP removal pattern during a storm event

Table 3.2 Percentage of TP removed during storm 1 and 2 (Nichols. P., 2007)

Storm Event and date	Total amount of precipitation during the event (mm)	Average phosphorus removal by ochre (%)
1 (05/12/06)	6.3	31.7
2 (07/12/06)	9.9	30

Table 3.3 Percentage removal of TP during low flow on 4th and 18th Dec 2006 (Nichols, P., 2007)

Low Flow Event and date	Mean phosphorus removal by ochre (%)
1 (04/12/06)	54.9
2 (18/12/06)	26

The most recent study, taking place this year, has fully re established the ochre trap (after damage in January), see fig 3.5 again the paired sampling upstream and downstream of the sediment/ochre trap yielded 15-20% reductions. Unfortunately there was only one storm sampled when the Total P levels were high, but once again the efficiency of stripping remains constant between 12-20%, (see figure 3.6 in annex 1).

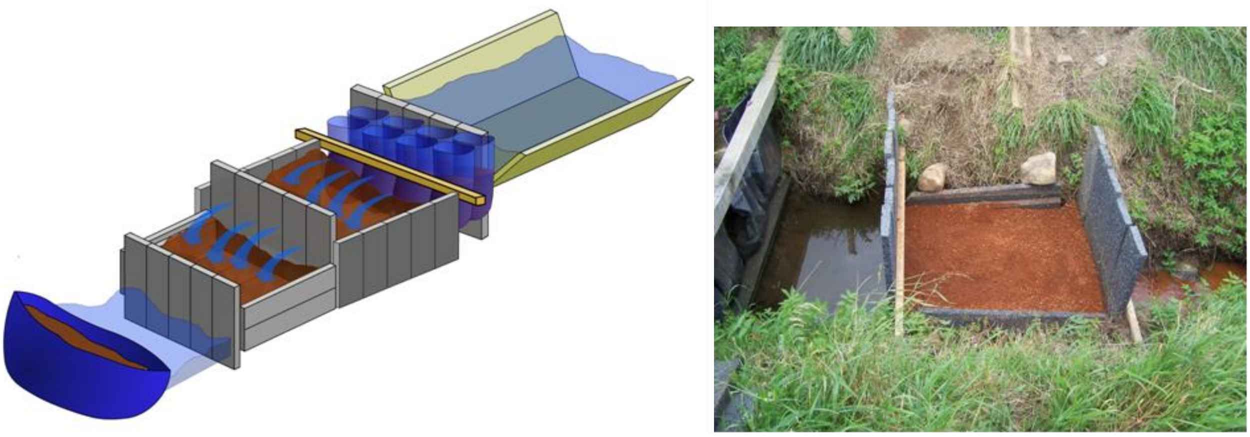

Fig 3.5 Completed ochre trap. Consists of the sediment trap upstream followed by 11 geo-textile bags, containing approximately 500kg ochre in total. Flow passes through the bags and enters a series of two ochre ‘box’ traps, containing collectively 860kg of ochre. The three Aquadyne dams ensure flow passes slowly through the traps and thus a high residence time is achieved.

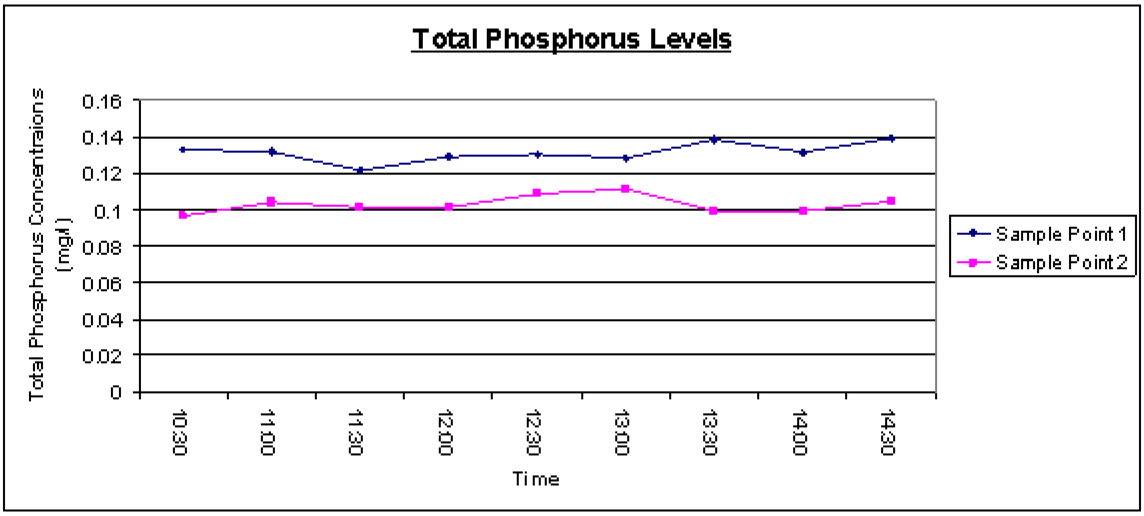

Fig 3.6 Paired upstream (sample point 1) and downstream (sample point 2) during the wetter summer period, when background Total P was higher.

Conclusions to be drawn from these one off studies, are that an effective reduction in Total P is exhibited once ample ochre is in position and the sediment trap is operational. The effectiveness of the feature may be due largely to the efficiency of sedimentation and the ability of the ochre to hold fine sediment. There is no hard evidence as yet that the ochre is performing to a high level, and ongoing work will establish this over time.

The main positive conclusion is that any slow flowing water will induce large amounts of sediment, and that this sediment can and should be recovered. Filtering water is equally effective at lowering P content. Whether or not this proves to be best achieved by ochre, Aquadyne or by the wetlands is still to be determined, but flow should be filtered. The management implications are that farmers would need to have a ditch management plan and a sediment recovery plan. This should be feasible once farmer appreciate the economic value of their lost sediment and nutrients.

3. 2. 4 Algal pods

Fig. 3.7 shows an example of the visual record that has been kept to date of the algal growth in the pods. Fig. 3.7 (a) shows the huge amount of sediment and “lost” ochre (from a very large January storm event) that had been deposited in the algal pod directly from the proportion of diverted flow from sample point 2. Again this demonstrates the huge amount of sediment transport that occurs in this ditch during winter. The pods were cleared of this sediment on 15th February 2007. Fig 3.7 (b) shows the algal growth beginning at the end of April, when temperatures were high. Fig. 372 (c) shows that the algae had changed from a free-floating thin film and become attached and denser. There is not much difference between Fig. 3.7 (c) and (d) most probably due to the unusually wet weather and fast flowing water through the ditch system resulting in turbulent flow in the algal pod.

One of the three inflow pipes was disconnected from the pod to try and reduce velocity of water moving through the pods. By then good algal growth conditions were not re-established due to the cold and wet conditions.

Behaviour of nutrients and the effects on water quality of this feature have not yet been investigated. This feature has been useful to demonstrate the high nutrient status of water leaving farms generally in the UK and the potential options for FIRM plans.

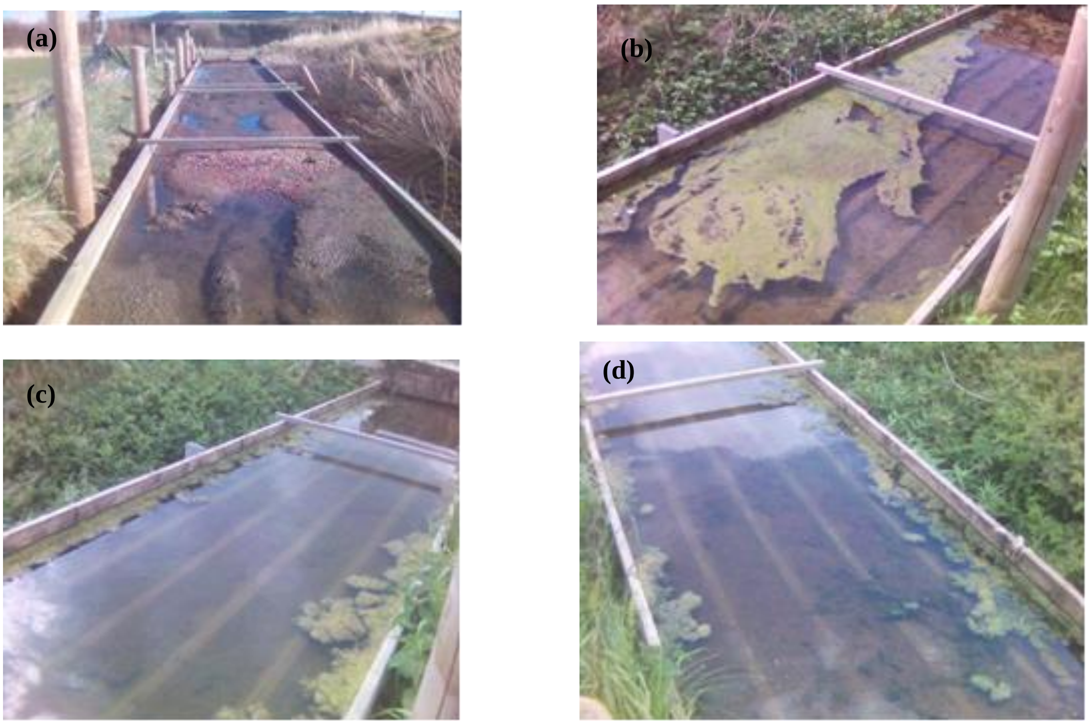

Fig. 3.7 Example of visual record of algal pods (a) 15th February 2007 (b)26th April 2007 (c) 17th may 2007 (d) 31st May 2007

3. 2. 5 The Sedge Wetland

The functionality of this feature is assessed by comparison of nitrate, ammonia and phosphorus concentration from sample point 2, which is upstream of this feature and sample point 3, which is immediately downstream of this feature.

Annex 1 shows all the nitrate, ammonium and total phosphorus concentrations upstream and downstream of the sedge wetland and demonstrates that for the most of the time, downstream concentrations are below upstream concentrations. There are a few occasions where downstream concentrations are much greater than upstream and this is reflected in the mean overall concentrations shown in Tables 2, 3 and 4 in Annex 1. The mean concentrations at sample point 2 and sample point 3 are 0.49 and 0.58 mg/l respectively for ammonium, 0.180 and 0.186 mg/l respectively for TDP and 0.44 and 0.38 mg/l respectively for TP. The mean concentrations thus suggest that the sedge wetland is increasing ammonium and nitrate concentration and reducing TP concentrations. However, maximum hourly percentage removal for nitrate, ammonium and TP range from 100 to -14%, 100 % to a 20-fold increase and 100 % to an 8-fold increase. The differences in concentrations between these sampling points, 2 and 3 are shown to be not significant, in Table 2, Annex 2 (Collins, 2007). Essentially given sampling locations and the problems of the long period between paired samples, the analyser is really sampling only the noise. The success of the one-off experiment as seen in the phosphorus trap section, may have to be repeated on a number of the remaining features if the performance of these features is to be fully proven. Evidence from the gaseous emission work is summarised in section 3.2.7

3. 2. 6 Willow wetland

The willow has grown very well over the season and as Fig 2.9 showed, it does act as a flow retardant during large events. The implication for a farm, is first the need to cut and export the willow each year, and second after a number of large storm events ‘trash’ may have built up at the upstream side of the feature which may have to be removed.

The willow was cropped in March 2007 and most of the cuttings were used to weave/build an additional barrier in the ditch to increase the flood storage capacity of this zone and so there has effectively been no removal of biomass from the ditch and thus no nutrient removal so far.

3.2.7 A Saturated Buffer Strip

The practical construction of the saturated buffer strip was not difficult, using only a small abstraction pipe from the main ditch and surplus flow from the Green laboratory and the construction of fenced of area. At this time only gaseous emissions experiments have been carried out on the buffer strip (see annex 1). The following conclusions has been contributed by Dr Dave Raey of Edinburgh University, who is studying the impacts of Nitrogen pollution swapping dynamics on farms.

In summary, the buffer strip is producing N_2, as is the control area. The positive message would be that adding Nitrate -rich water does not seem to result in huge additional N_2O emissions (based on the evidence so far).

Within the drainage channel (the sedge wetland), triplicate automatic gas flux chambers were installed in the constructed wetland area to quantify N_2O emissions and compare these to interception of dissolved nitrate. Highest N_2O emissions were associated with the lower half of the wetland and with the highest dissolved N_2O concentrations. Nitrate interception within the wetland appeared to be increasing with water temperature in the first half of 2007, with incoming nitrate loadings commonly exceeding 50mg NO_3 per litre. In summary this feature is carrying out a small but constant reduction of Nitrate, however it may be producing a disproportionate amount of N_2O emissions.

The possible future role of buffer strips on farms could be very high, we feel a careful combination of ditch flow and buffer strip management could give greatly enhanced nitrate reduction from farms. Given the small amount of N loss being gained from the wetlands and the fact that they may not work so well in winter or at high flow, we conclude that an enormous amount of extra nitrogen buffering capacity within the catchment is required. However, the implications for the ditch and buffer strip design and maintenance is also critical and is in need of urgent trialling at full scale. This trial will need to be carefully executed if it is also to achieve the goal of flood risk reduction, seas the Proactive Flood Storage on Farms report. The implications this report and the experience gained from the sedge and willow wetland trials suggest that the choice of vegetation on buffer strip should also much rougher and with high nitrogen consumption. We would like to propose urgent work is needed to test this concept now. Ideal sites are available across the Northumberland.

4 A Critique of Costs and Implementation Strategies

Here brief critique of costs is made and the likely cost of whole FIRM plan being implemented is evaluated. The cost of each feature built is shown below which reflects the full cost (though estimated) that has been incurred by the project.

Infiltration ponds, constructed by Owen Pugh, civil engineers.	£7000 each
Road drain ponds constructed by Owen Pugh, civil engineers.	£1000 each
5m concrete section in sediment trap constructed by Owen Pugh, civil engineers.	£1000
Ochre manufacture, 5 tonnes of ochre pellets	£25000
Ochre P trap	£2000
Barriers in ditches	£2000
Sedge wetland – 30 m long	£5000
Willow wetland – 30 m long	£6000
Algal Pod	£6000
Buffer strip (draw off pipe and 50 m of fence)	£500

Green lab and analyser	£70000
Renewable energy micro wind and PV array	£27000

At first viewing the interventions may seem very costly. However, there are many considerations to be taken into account

1. The costs are higher that would be expected if installed by local farmers and local agricultural engineers. All the features have been over designed and have extra built in research related components. As such the construction has incurred some extra cost. A number of the features took longer to construct as many practical lessons were being gained during the construction.
2. What is the practical cost of sediment loss, P loss and nitrate loss to the environment? If this is high, then it needs to be quantified and estimated per square kilometre of farmland so that real cost can be assigned to allow some construction of features on farms. Sediment traps and fine filters seem to be working efficiently and offer an immediate way forward.
3. How long does a feature last? How many years of subsidy can be saved by lump sum investment, say every 5 years.
4. How much will it cost to maintain the features and execute a sediment, ditch and management plan? Is it higher or lower than other pollution reduction measures in annual costs.
5. Can it be shown that sediment and nutrient capture can have economic benefits to farms if it can be effectively recovered and reused.
6. What are the multiple benefits of features that are designed for nutrient pollution management to flood risk reduction, waste recycling and carbon reduction? What about pesticide reduction and pathogen removal? All the features should contribute to a reduction in overall emissions.
7. What ecological benefits are gained from runoff management at source? Should these costs be compared with upland grip blocking expenditure?
8. How much is currently paid to farmers per square kilometre in the current agri-environment schemes?
9. Should we pay farmers to take part actively in pollution/waste reduction from farms? Independent visible evidence that features are being constructed and maintained can be done quickly by farming advisors, EA and Defra.

10. Can farmers be given incentives to manage runoff, by joining flood management funding and renewable energy/carbon funds with agri-environment funding? Can vast savings be made if multi functional feature are delivered by 1 over arching funding method of farm payment?

Overall we are asking more questions than we are answering but a case can be made that there is ample funding available within environmental scheme. Farmers would be willing to help if subsidised and FIRM plans do give a practical visible means of funding and incentives to farmers to control runoff from their land.

A possible future scenario.

A 1 km^2 square catchment on a typical farm (with field drains), with 6 fields and 500 m of ditch/channel (see fig 4.1). The FIRM plan suggests that all fast polluting flow paths should be disconnected using on the farm using ponds. In order to maximise the pollutant reduction in the ditch it will be widened and saturated zones induced. In order to maximise use of the buffer strips will be forced onto the zone to enhance nutrient stripping and attenuate flood flow. A bund and fencing (or hedgerow) on the edge of the buffer strip will stop flow from propagating onto the productive areas of the farm.

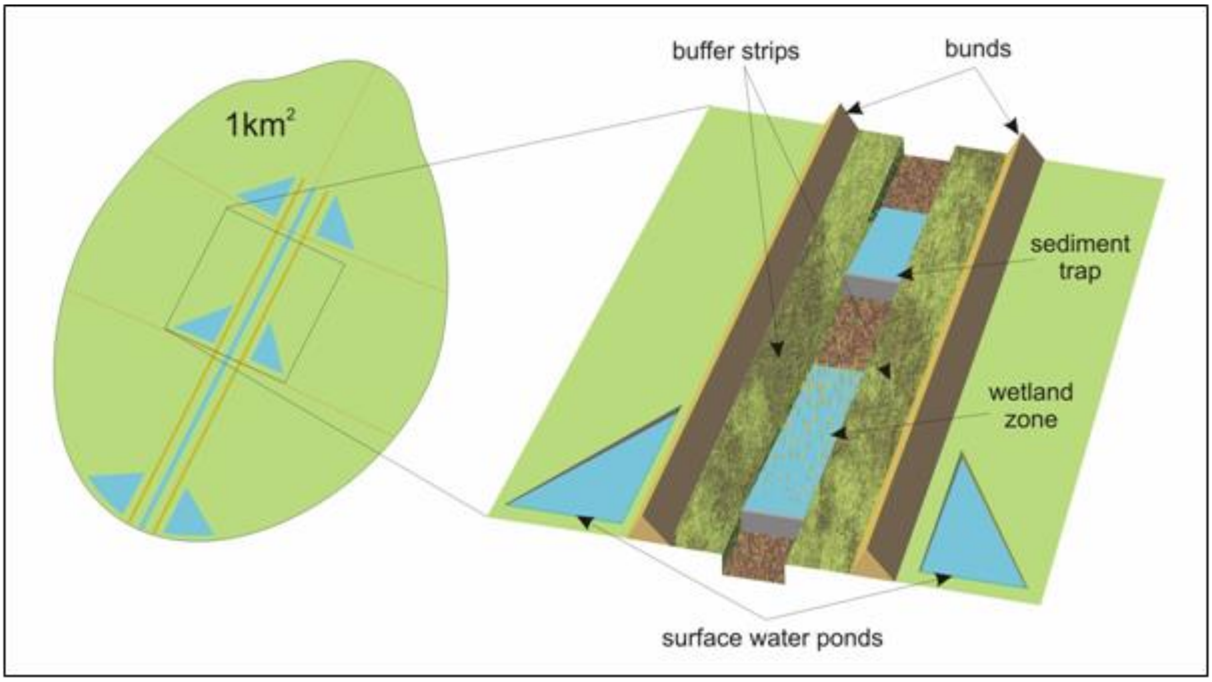

Fig 4.1 A theoretical 1km^2 catchment with a proposed FIRM plan

Features to be constructed over the life cycle of the FIRM plan:-

- 1 pond in each field, that takes all runoff from hardstanding, road and overland flow from bare fields. 6*£2000

- A 30cm high, 1km soil bund at the edge of a 6 metre buffer strip £3000
- The 6 meter buffer strip will use 1km of fencing along the top of bund (or a hedgerow) £5000
- Ditch is widened to 3 m (as at Nafferton) with zone of sedge and willow is planted. £5000
- 4 flow control barrier, 1 every 100m, which are using to slow flow and keep sedge and willow zones wet, they also force flow onto the buffer strip in storm events £5000
- 2 Sediment traps in the ditch £2000
- Maintenance payment to recover sediment and the maintenance of all features – £1000/year

Over a 5 year FIRM plan = £37000 or £7400/year/km^2

Over a 10 year FIRM plan =£42000 or £4200/year/km^2

Clearly these numbers are very rough and subject to great uncertainty. The idea here is to demonstrate the kind of economic costs/arithmetic needed to produce FIRM plans. It is almost impossible to gauge the financial benefits arising from a FIRM plan, either to the farm business or to a whole basin. Some estimate is needed of environmental benefits presented in a comparable way (e.g. per kilometre square).

If buffer strip were to not be used we would require an increased capacity in the ponds and the within ditch wetlands.

In the ***proactive*** project at Belford, a £600,000 scheme has been proposed to solve the flood problem for a catchment of 8km^2 using bunds, ponds, washlands and ditch structures. This would equate to £75000/km^2. The blocking of upland grips is also comparable in cost to the FIRM plans.

Strategic deployment of FIRM plans in areas with high pollution and flood risk or in catchments with sensitive water courses or lakes, would also be a chance to test the proactive hypothesis, to carry out full economic analysis and look at ways to keep construction costs down for a typical farm. Farmers and farm advisors would also be encouraged to deploy renewable energy schemes and use recycled waste materials. We would go further and would heavily subsidize or purchase a renewable energy system for each farm as a means of persuading farmers to join in and take a proactive part in the FIRM plan. The benefits to carbon reduction alone may be a reason to do this, but as part of an integrated plan for a farm it may have many benefits. It may be possible to get flood management subsidies to reduce carbon and carbon subsidies to reduce flood risk. The economics of paying farmers to address key environmental problems proactively should be actively pursued if the WFD is to stand any chance of achieving the 2015 targets.

5 Conclusions

The Nafferton farm study is ambitious in its goals to quantify the potential of total pollution and flow attenuation, at source. By creating this sound evidence base, the potential proactive interventions and their likely cost and viability of taking the FIRM approach can be determined.

Even though the accumulation of the solid evidence is ongoing, the work so far has shown that, for a typical intense farm:-

- Large amounts of pollution and sediment is being produced during storms (Acute losses) and between storms (chronic loss)
- The runoff generation is varied and fast and even if agri-environment schemes were taken up and the farm was operating with best practise, that large amounts of runoff would still arise and inevitable that contamination of polluted flows would occur
- Hence by targeting and modifying fast flow paths and its physical and chemical content we can address runoff related problems at source as the runoff is generated

Ponds, bunds, wetlands, buffer strips have all been designed, constructed and tested at Nafferton farm in Northumberland. All features are multi-functional and will address pollution reduction, lower flood risk, trap and recycle waste, use recycled materials and create new ecological zones. FIRM plans can be achieved without damaging the profits of the farm and could be funded through an imaginative, strategic mechanism that joins agri-environmental, flood risk management and carbon/renewable budgets together.

All the features constructed can be demonstrated to be working to reduce pollution, store and slow runoff and to trap and recycle waste on the farm. The operational performance of the features during large storm events is still to be proven. We will not be recommending all the features listed in this report be adopted on farms, but crucially we have gained the experience to recommend a series of practical, fundable interventions that could work at the larger catchment scale and address urgent WFD needs, for example:-

- All fast and polluting flow paths can be disconnected from the channel network.

- Ponds, barriers, bunds can physically store large amounts of runoff.
- All features help to slow flow, creating 'transient storage'.
- Wetlands are slowly de-nitrifying the runoff, but large amounts of buffering will capacity will be needed on farms.
- Sediment and nutrients can be trapped and recycled. A one-off sediment and phosphorus trap can reduce Total P by 20-60% even during storms.
- Saturated buffer strips are denitrifying the flow and they have the potential to treat large amounts of flow and to act as flood retardation channels if designed appropriately.
- Ditches can be widened and can act as sediment traps, wetlands and flood retardation channels.
- FIRM plans will need farmers to adopt new sediment management plans and sediment/nutrient recovery plans. Construction and maintenance funding will be vital to the delivery of FIRM plans.

The potential to store water is obvious, and we feel that each field could justify at least one pond. The pond will stop fast flow paths such as overland flow or could act to receive fast polluting runoff from hard-standings and roads.

All the features listed have some physical water storage but they also have a significant amount of transient storage. All features should be rough and all flow should be as tortuous as possible.

The impact of any slow flow or ponded water is enormous as there is a very large sediment budget on this farm, though as yet it is not quantified. The abundance of sediment means that it should be removed at strategic points within the farm and then be reused.

The issue of filtering flow is not fully resolved. The potential to use ochre or a similar material is high, but it may not ever become financially viable unless the cost of P loss and sediment is deemed to be higher and in more urgent need of removal. However the principle of filtering flow at all opportunities is an effective management strategy for Total P. Thus interception ponds and within ditch sediment traps can target coarser material and filters such as straw bails may be adequate. Wetland and overgrown ditches do filter fine sediment anyway, but the removal of course material will enhance the life of the features greatly and lower cost.

Wetlands are denitrifying the flow, but as yet there is not the buffering capacity to address the total Nitrate losses. Equally the operation of the wetland in winter and in larger storm events will require a much larger buffering capacity. Hence the need to maximise the ditch area by changing the flow dynamics, i.e. wide, with a flat bottom that spreads flow, will both improve the buffering capacity and slow flood flow.

Buffer strip could play a pivotal role in denitrification and flood control if they are designed and maintained properly. Buffer strips at this time seem to be quite wasteful, though their impact on lowering pesticide losses and excluding animals is a clear benefit. However it is hoped that these features will buffer flow from the hillslope before reaching the channel. In many cases this may be true but buffering capacity may be quickly exceeded in storm events and there may also be zones with large buffer zones that are not processing much flow. Together this means that fixed width buffer strips are likely to fail in the goal of reducing sediment and pollution levels and will not lower flood risk. We feel that if such a large commitment to taking buffer strips out of production is to occur then buffer strips should be redesigned. The proactive intervention of barriers and flow control structure should be able to force flow back onto the buffers strip. Equally, a small bund feature will be needed at the edge of buffer strips to stop larger areas of productive land being flood.

The quantification of flow and nutrient losses remains to be completed, the impact of the automated sampling system has still not been fully exploited. The problem of long time gaps between samples on such a small and rapidly responding catchment will make this difficult. By speeding sampling for key measurements (TP and Nitrate), and the abundance of data this will give we should be able to give a solid statistical basis to the FIRM approach. The data show in this report are generally favourable to supporting FIRM plans but is clearly not solid evidence as yet. The performance of the features at lower flow is more substantiated, but evlaution of performance during storm events is still needed.

One off experiments, especially those related to Total P reduction, are very supportive of the approach, and evidence that ponding water and filtering flow is a powerful management tool. However large storms will need more ponding and filtration. Hence the final FIRM plan for a theoretical full scale application, should try to maximise opportunities for ponding and filtration. Equally the buffer strip zone should provide extra treatment and flood storage capacity.

The impact of large scale FIRM plans on farms will require a very marked change in ditch management and attitude to recovering the waste. This can be achieved if the farmer values the sediment and nutrients being trapped within the features and should be motivated to recovering lost waste. However the time and energy required checking and maintaining a wide range of features will have to be tied to the farm subsidy. This will require new advice and education approaches.

What is needed now?

A fully costed, full scale trial of the FIRM plans on a wide range of farms, working closely with farmers and farm advisors.

To test a new mode of subsidising farmers to become proactive farm runoff managers and thus solve a wide range of environmental problems.

Continued work at Nafferton to prove the performance of the features during large storm events and improve on design and operation issues.

We would propose a means of scaling up the work to the River Eden, where a wide range of rainfall and runoff data is being gathered as part of the CHASM project. During the life of the CHASM project we have developed close to ties to farmers who have allowed us to instrument their land. Several of the farmers have received renewable energy schemes as part of other projects. These farmers would be willing to trial the FIRM plans as outlined.

What will FIRM Plans cost?

Costs are comparable with the budgets available to flood control projects (or possibly cheaper), agri-environment schemes and activities such as upland grip blocking. If other subsidies related to renewable energy, carbon storage, waste recycling and ecological initiatives are joined together then FIRM plans can be funded sustainably with visible, quantifiable, multiple benefits that will address the needs of the WFD.

In order to address pollution control we feel that this would cost between **£1000/km^2/annum and 10000/km^2/annum.** This will give drastic reduction in nutrient pollution and sediment losses in most storms and. This cost may fall as more full scale test are carried out. The option to deploy a FIRM plan over a longer period will also reduce cost.

In order to address flood control at source we estimate the costs as between **£1000/km^2/mm of runoff (rainfall depth equivalent) stored and 10000/km^2/annum/mm of runoff stored.** These values are taken from the Proactive Flood Storage on Farms report. The final costs are very rough in estimate. Equally, the dual benefits of the pollution and flooding problem should be costed together.

Other benefits to ecology, carbon budgets, pathogen reduction and pesticide trapping could all be added to make FIRM plans more viable.

Finally Defra and EA require a means of giving farmers incentives to change their land management whilst regulating management. Defra and EA must get value for their money. By giving farmers real, physical features to construct and maintain, then regulators will have a solid basis by which they can assess if a farmer is deploying their funds to actively reduce pollution and flood risk. We have stressed that new imaginative integrated funding sources are needed to underpin the FIRM approach. We feel that helping farmers to generate renewable energy and minimise waste on farms will encourage them to construct runoff mitigation features. A new wind turbine or some coppice woodland could help solve nutrient pollution and flooding.

References

Bowes, M.J., House,W.A., Hodgkinson,R.A., Leach,D.V. 2005. Phosphorus-discharge hysteresis during storm events along a river catchment: the River Swale, UK. Water Research, **39,** 751-762.

Carr, S., 2007.An investigation into the removal of phosphorus with the use of ochre. Newcastle University MSc. Project, Newcastle upon Tyne.

Collins, P., (2007) *Effectiveness of in-stream treatments on water quality at Nafferton Farm*. Newcastle University MSc. Project, Newcastle upon Tyne.

Environment Agency (2006) The General Quality Assessment of rivers-nutrient method. Environment Agency, Bristol.
[http://www.environment-agency.gov.uk/commondata/acrobat/nutrients.pdf]

Heal, K., Younger, P.L., Smith, K., Glendinning, S., Quinn, P., and Dobbie, K. Novel use of ochre from mine water treatment plants to redue point and diffuse phosphorus pollution. *Land Contamination and Reclamation 11, (2) pp 145-152* 2003.

Heal, K. V., Younger, P. L., Smith, K. A., Quinn, P., Glendinning, S., Aumônier, J. and Dobbie, K. E. A sustainable use of ochre from mine water treatment plants for phosphorus removal and recycling. *In: Mine Water 2004, Newcastle* 2004

O'Connell P.E., Beven K.J., Carney J.N., Clements R.O., Ewen J., Fowler H., Harris G.L., Hollis J., Morris J., O'Donnell G.M., Packman J.C. Parkin A., Quinn P.F., Rose S.C., Shepherd M., Tellier S. Review of impacts of rural land use and management on flood generation: Impact study report. Department of Environment, Food and Rural Affiars, Research and Development Technical Report FD2114/TR. Defra, Flood Management Division, London. 142pp + Appendices (219 pages). 2005.

McCauley, W. 2007 *PhD thesis* .Edinburgh University

McDiffett,W.F., Beider,A.W., Doninick,T.F., McCrea,K.D.1989. *Nutrient concentrations-stream discharge relationships during storm events in a 1st- orderstream.* Hydrobiologia, **179**, 97-102

Nichols, P., 2007. An Investigation into the phosphorus removal efficiency of an ochre filter unit during low and high flows. Newcastle University undergraduate project, Newcastle upon Tyne.

Quinn, Hewett, Jonczyk and Glennis 2007, Proactive Flood Storage on Farms. Report to the EA.

Glossary

TDP total dissolved phosphorus

TP Total phosphorus

EC Electrical conductivity

DO dissolved oxygen

pH is a scale used to describe the negative log of hydrogen ions

NTU

PO_4 is equivalent to TDP

NH_3 ammonia

q quartile